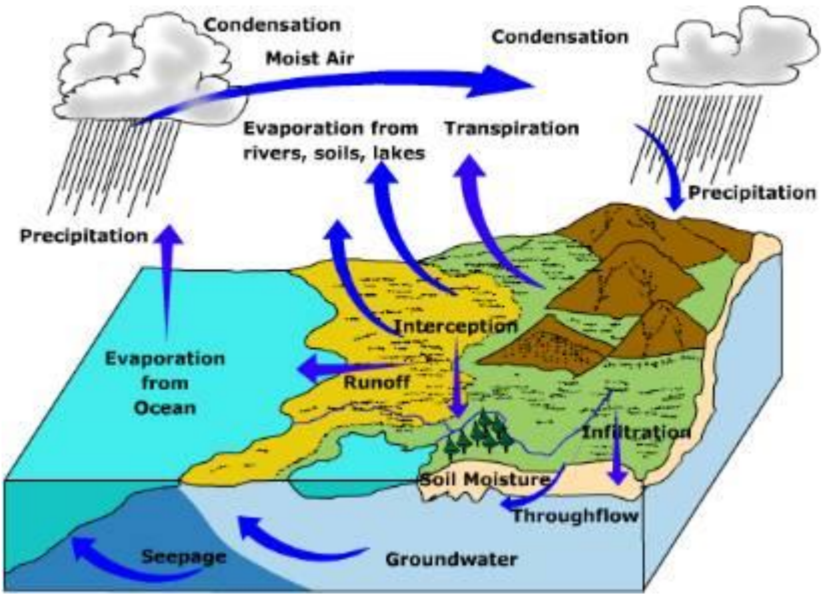
AGENDA AND AGENDA NOTES FOR THE 53rd MEETING OF THE WORKING GROUP OF NIH

16-17 MARCH, 2023
AT 1100 HRS



NATIONAL INSTITUTE OF HYDROLOGY
ROORKEE-247667

AGENDA AND AGENDA NOTES FOR THE 53rd MEETING OF THE WORKING GROUP OF NIH

AGENDA ITEMS

ITEM NO. 53.1 Opening Remarks by the Chairman

ITEM NO. 53.2 Confirmation of the minutes of 52nd meeting of the Working Group

The 52nd meeting of the Working Group was held during 12-13 April, 2022. The minutes of the meeting were circulated to all the members and invitees vide letter **No. RMOD/WG/NIH-10 dated 25 May, 2022.** No comments were received on the circulated minutes. A copy of the minutes of the 52nd Working Group is given in **Annexure-A (Page # 4).**

The Working Group may please confirm the minutes.

ITEM NO. 53.3 Action taken on the decisions/recommendations of the previous Working Group meeting

During the 52nd Working Group meeting, recommendations/suggestions were made by the Working Group members and the actions taken shall be informed by the respective Divisions during the meeting.

ITEM NO. 53.4 Presentation and discussion on the status and progress of the work programme for the year 2022-23.

The approved Work Programme of the six Divisions of the Institute for the year 2022-23 has been given in the **Annexure B** in the following order**:**

The number of studies/projects handled by each Division under different categories are given below:

	No. of Studies/Projects During the Year 2022-23					
Division	**New**		**Ongoing**		**Total**	
	Internally funded	Sponsored	Internally funded	Sponsored		Consultancy Projects
Environmental Hydrology	1	-	3	3	**7**	**2**
Ground Water Hydrology	3	1	1	7	**12**	**1**
Hydrologic Investigation	1	-	2	7	**10**	**-**
Surface Water Hydrology	9	-	2	1	**12**	**-**
Water Resources System	1	2	3	5	**11**	**-**
Research Management & Outreach	1	-	3	1	**5**	**-**
Total	**16**	**3**	**14**	**24**	**57**	**3**

During the present meeting, Division-wise progress and status of the work programme for the year 2022-23 shall be presented in detail. The Working Group may please consider the progress and status of the Work Programme for the year 2022-23.

ITEM NO. 53.5 Presentation and finalization of the work programme for the year 2023-24.

The proposed Work Programme of the six Divisions of the Institute for the year 2023-24 has been given in the **Annexure B** in the following order**:**

The number of studies/projects handled by each Division under different categories are given below:

	No. of Studies/Projects During the Year 2023-24					
Division	**New**		**Ongoing**		**Total**	
	Internally funded	Sponsored	Internally funded	Sponsored		Consultancy Projects
Environmental Hydrology	2	-	3	5	**10**	**3**
Ground Water Hydrology	3	-	3	5	**11**	**-**
Hydrologic Investigation	4	-	2	2	**8**	**-**
Surface Water Hydrology	2	-	7	1	**10**	**-**
Water Resources System	2	-	3	6	**11**	**-**
Research Management & Outreach	-	-	3	1	**4**	
Total	**13**	**-**	**21**	**20**	**54**	**3**

The work programme has been categorized into three groups; (a) Internally funded studies, (b) Sponsored projects and (c) Consultancy Projects. During the present meeting, Division-wise proposed work programme for the year 2022-23 shall be presented.

ITEM NO. 53.6: Any Other Item with Permission of the Chair.

ANNEXURE – A

MINUTES OF THE 52nd MEETING OF WORKING GROUP

MINUTES OF THE
52ND MEETING OF WORKING GROUP OF NIH
HELD AT NIH, ROORKEE, DURING 12-13 APRIL 2022

The meeting was held in hybrid mode under the Chairmanship of Dr. J V Tyagi, Director, NIH. The list of participants of the meeting is given in Annexure-I.

ITEM NO. 52.1: OPENING REMARKS BY THE CHAIRMAN

The Chairman, WG, welcomed the WG members and the Scientists of NIH. He informed that the objective of this meeting is to review the progress of 2021-22 and formulate the work program of 2022-23. The Chairman then requested the WG members to give their general observations, suggestions and remarks on the scientific activities of the Institute. These are summarized below:

S N	Member	Suggestion(s)
1.	Dr. Manoj P.Samuel	▪ Avoid duplication and redundant studies ▪ Collaboration with CWRDM ▪ Climate change impact in coastal areas ▪ Work on water footprint, Early Warning Systems ▪ Explore copyright for software
2.	Prof. A K Saraf	▪ Improve presentation skills ▪ Exhaustive literature survey needed before proposing a new study
3.	Dr. Bhishm Kumar	▪ Upload work program on NIH website ▪ Link scientists at NIH RCs through VC
4.	Dr. S. S. Grewal	▪ Focus on groundwater in Kandi areas in Punjab and Haryana
5.	Dr.Ramakar Jha	▪ Studies should be outcome based ▪ Any new study should address 'Why' and 'How', and must include literature survey ▪ Explore patents, innovations; involve water industry
6.	Dr. Sadhana Malhotra	▪ Improve presentation skills- rehearsal by presenters ▪ Bring out impact of completed studies
7.	Sh. Sudhindra Mohan Sharma	▪ Research should be society oriented/useful for society ▪ Focus of drinking water studies ▪ Strengthen outreach activities
8.	Dr. M S Rathore	▪ Time period of studies should not be too long
9.	Dr. Pawan Labhasetwar	▪ Reduce long study periods ▪ Field studies addressing water quality should have suggestions for mitigation and/or adaptation

Next, the Chairman asked the Member-Secretary to take up the agenda.

ITEM No. 52.2: CONFIRMATION OF MINUTES OF 51st MEETING OF WORKING GROUP

The 51st meeting of the Working group was held during 14-15June, 2021 in VC mode. The minutes of the meeting were circulated to all the members and invitees vide letter No. **RMOD/WG/NIH-10 dated 26 July, 2021**. The members confirmed the minutes of the 51st Working Group meeting.

ITEM No. 52.3: ACTION TAKEN ON THE DECISIONS/RECOMMENDATIONS OF THE PREVIOUS WORKING GROUP MEETING

Dr V C Goyal gave a brief account of the actions taken on the recommendations/ decisions of the 51st working group meeting.

ITEM Nos. 52.4 & 52.5: PRESENTATION AND DISCUSSION ON THE STATUS AND PROGRESS OF THE WORK PROGRAMME FOR YEAR 2021-22 AND FINALIZATION OF THE WORK PROGRAMME FOR YEAR 2022-23

The Member-Secretary requested the respective Divisional Heads to present the progress of studies carried out during 2021-22 and also to present the proposed studies for F.Y. 2022-23. Accordingly, the progress of various studies and sponsored projects, and proposal for new studies and projects during 2022-23, were presented by all Scientific Divisions during the two-day deliberations of the Working Group. The Division wise minutes of each study/project presented during the meeting are given next.

ENVIRONMENTAL HYDROLOGY DIVISION

The overview of the technical activities of Environmental Hydrology Division (EHD) was presented by Dr R.P. Pandey, Scientist 'G' & Head. The Working Group was appraised about the scientific manpower, status of completed and ongoing studies, consultancy projects, publications, technology transfer activities etc. Subsequently, the scientists of the Division were invited to present the completed studies and proposed new studies. The progress of ongoing sponsored and internal studies was reported in brief. The Comments/suggestions of Working Group members are summarized below.

Progress of Work Program for 2021-22 and Recommended Work Program for the year 2022-23

S. No.	Study	Suggestions/Comments
	Sponsored Projects	
1.	Title: Water Quality Assessment of Southwest Punjab Emphasizing Carcinogenic Contaminants and their Possible Remedial Measures Study Group: Rajesh Singh (PI), Pradeep Kumar, M. K. Sharma, Sumant Kumar Partner: Irrigation Deptt., Punjab **Duration:** 3½ Years (09/17 –3/21) Extension requested till 09/21 **Sponsored by:** NHP-PDS **Project Cost:** 65.6 Lakh Status: Completed	Progress of the study was reported and there were no specific suggestions/comments.
2.	Title: Leachate Transport Modeling for Gazipur landfill site for suggesting ameliorative measures **Study Group:** Anjali (PI), Sudhir Kumar, J.V. Tyagi, M.K. Sharma Partner: CGWB (Delhi unit) **Duration:** 3 Years (11/19 –10/22) **Sponsored by:** NHP-PDS **Project Cost:** 76.1 Lakh Status: In-progress	Progress of the study was reported and there were no suggestions/comments. The PI of this project has been transferred from EH Division to HI Division. Therefore, this study is transferred to HI Division.
3.	Title: Water Efficient Irrigation by Using SCADA System for Medium Irrigation Project	Progress of the study was reported and there were no specific suggestions/comments.

	(Mip) Shahnehar Study Group: R.P. Pandey, (PI), Jagdeesh Patra, Rajesh Singh, N. K. Bhatnagar **Duration:** 3 Years (12/17 –12/20) Extension requested till 03/22 **Project Cost:** 75.0 Lakh Status: In-progress	
4.	Title: Isotopic and geochemical approach to study vulnerable confined and unconfided drinking water aquifers in Varanasi and surrounding area Study Group: Rajesh Singh (PI), R. P. Pandey BHU, Varanasi (Lead) Other Collaborators: BARC, Mumbai, ICER, Hungary **Duration:** 3 years (07/21-07/24) **Project Cost:** Rs. 10.0 Lakh **Sponsored by:** BHU **Status:**In-progress	Progress of the study was reported and there were no specific suggestions/comments.
Internal Studies		
5.	**Title:** Water quality assessment for Haridwar District **Study Group:** R.K. Nema (PI), Rajesh Singh, J. V. Tyagi, R. P. Pandey, Pradeep Kumar **Duration:** 2 years (05/19-06/21) **Status:** Completed	• The working group member,Dr. Bhism Kumar (Ex. Scientist, NIH & IAEA) appreciated the study and its outcomes. He suggested for further investigation to find out the causes of deterioration in next study. • Sh. Prashant Rai, CGWB suggested to replace the contour maps with point maps. • Prof. A. K. Saraf, IIT Roorkee suggested to check and validate the interpolation method.
6.	**Title:** Simulation of Non-Point Source Pollution Processes in Song River **Study Group:** Pradeep Kumar (PI), J.V. Tyagi, M.K. Sharma, Rajesh Singh **Duration:**4 years (11/19-10/23) **Status:** In-progress	Progress of the study was reported and there were no specific suggestions/comments.
7.	**Title:** Development of rejuvenation plan for Hindon river system **Study Group:** M. K. Sharma (PI), Dr. Sudhir Kumar (Project Coordinator), R. P. Panday, Anupma Sharma, Anjali, Vishal Singh, Pradeep Kuamr, Nitesh Patidar, Surjeet Singh, Rajesh Singh. **Duration:**3 years (07/20 to 06/23) **Status: Closed from EH Division**	Progress of the study was reported and there were nospecific suggestions/comments. T This study has been Transferred to HI Division and merged with DST-NWO Project on River Hindon
8.	**Title:** Influence of Anthropogenic Factors on River Ganga in the stretch from Rishikesh to Haridwar **Study Team:** Rajesh Singh (PI), J.V. Tyagi, R.P. Pandey, R.K. Nema, Pradeep Kumar, M.K. Sharma	Prof. Ramakar Jha, NIT Patna suggested to consider the pollutants load in addition to their concentration for interpreting the impact.

	Duration: 2 Years (06/20 – 05/22) **Status:** In-progress	
9.	**Title:** Understanding Arsenic mobilization in groundwater of Haridwar and formulating remediation measures **Study Team:** Rajesh Singh (PI), R.K. Nema, Sumant Kumar, Pradeep Kumar, M.K. Sharma **Duration:** 3 Years (07/21 – 06/24) **Status:** In-progress	Progress of the study was reported and there were no specific suggestions/comments.
	Internal Studies (New Study)	
10.	**Title:** Characterisation of Groundwater Dynamics in Krishna-Godavari Delta using groundwater levels, Hydrochemistry, Isotopes and Emerging Contaminants **Study Group:** M. K. Sharma (PI), Suhas Khobragade, Rajesh Singh**,** Y. R. S. Rao, Collaborating Agency: CGWB, Hyderabad **Duration:**2 years (04/22 to 03/24) **Budget:** Rs. 17.60 lakh **Status:** New Study	Dr. Sharma presented the study proposal. Dr. Prashant Rai, CGWB appreciated the proposed study and suggested that this is the right time to take up this study for the benefit of society.

GROUND WATER HYDROLOGY DIVISION

Dr. M. K. Goel, Scientist 'G' & Head, GWHD, presented a brief overview, status of studies and activities carried out by the division since the 51st Working Group meeting. He gave an account of scientific personnel available in the division; ongoing and completed internal, sponsored and consultancy projects; and also the future activities planned by the division for the year 2022-23. MKG informed that one in-house R&D study and nine sponsored studies were approved for the year 2021-22.

In addition to the above studies, scientists of the division have a major role in activities of the National Hydrology Project (NHP); development of DSS (Planning and Management); development of groundwater module for "*National Hydrologic Model (NHM)*" with IIT Kharagpur; Computer Centre; External Project Management Cell; and procurement related activities. The number of research papers published in various journals, lectures delivered in various training courses and number of M.Tech./Ph.D. students guided/under guidance during the period were also reported. Three new in-house R&D studies that are planned in the year 2022-23 and two completed sponsored studies were presented. The progress of five on-going studies was also presented by the respective Principal Investigators.

A special one-hour session was dedicated to present the major outcomes of the National Mission for Sustaining Himalayan Ecosystem (NMSHE) project entitled **"Integrated Hydrological Studies for Upper Ganga Basin up to Rishikesh" which was sponsored by DST.** This project focuses on the issues of comprehensive integrated hydrological studies for upper Ganga basin up to Rishikesh and involves 11 sub-projects with different study teams. The study was completed on Sep 2021 and the final report has been completed by March 31, 2022 and the same was shared with WG members during its meeting. MKG, who worked as the Coordinator of NMSHE Project, briefly presented the work components, objectives and major achievements of all the 11 sub-projects. WG members appreciated the work done by NIH.

The details of the GWHD studies presented in the WG meet are provided in the table below.

S. No.	Project	Project Team	Duration & Status	Funding Source
Internal Studies				
1. NIH/GWH/NIH/20-22	Integrated GEE-MODFLOW based Groundwater Recharge Assessment System for Hindon River System	**Nitesh Patidar (PI)**, Gopal Krishan, Suman Gurjar	2 years (08/20 – 07/22) *Status:* ***In progress***	Internal Study
2. NIH/GWH/ NIH/22-25	Studying arsenic genesis and developing alternate water supply management strategies in Ganga basin	**Sumant Kumar (PI),** Surjeet Singh, Rajesh Singh, Gopal Krishan, M.K. Sharma, Vinay Kumar Tyagi, S.S. Rawat, Nitesh Patidar, P.K. Mishra, M.K. Goel	3 years (04/22 – 03/25) Status: **New Study**	Internal Study
3. NIH/GWH/ NIH/22-24	Conjunctive Management of Water Resources in IGNP Command	**Nitesh Patidar (PI)**, M. K. Goel, Anupma Sharma, Gopal Krishan, Surjeet Singh, Sumant Kumar, Nidhi Kalyani	2 years (04/22 – 03/24) Status: **New Study**	Internal Study
4. NIH/GWH/ NIH/22-24	Studying Groundwater Dynamics using Machine Learning and Numerical Modelling	**Nidhi Kalyani (PI)**, Anupma Sharma, Nitesh Patidar, Sumant Kumar	2 years (04/22 – 03/24) Status: **New Study**	Internal Study
Sponsored Projects				
5. NIH/GWH/ BGS/17-20	Groundwater Fluctuations and Conductivity Monitoring in Punjab - Groundwater resilience in Punjab and adaptation to future changes in climate and water resource demands (title modified by funding agency)	**Gopal Krishan (PI)**, S. Singh, C. P. Kumar (retd.), M. S. Rao BGS, UK: Dr. Dan Lapworth Dr. Alan MacDonald Dr. Daren Goody	5 years (12/17-11/22) Status**: In progress**	BGS, UK
6. NIH/GWH/ DST/ 18-20	Future Secular Changes and Remediation of Groundwater Arsenic in the Ganga River Basin - FAR GANGA	**B. Chakravorty (PI)**, Surjeet Singh (Dy. Lead), Sumant Kumar, Gopal Krishan, Suman Gurjar Other India Partners: IITR, IITKg, MCS, Patna UK Partners: Univ. of Manchester, BGS, Salford University, Univ. of Birmingham	4 years (01/18 - 12/21) Status: **Completed**	DST-Newton Bhabha-NERC-India-UK Water Quality Research Programme
7. NIH/GWH/ DST/ 18-20	Impact of Rainwater Harvesting on Groundwater Quality in India with Specific Reference to Fluoride and Micro-pollutants	**Anupma Sharma (PI)**, Sumant Kumar, Gopal Krishan, Suman Gurjar, M. K. Sharma Indian Partners: IIT Ropar, IIT Jodhpur UK Partner: Cranfield University, Water Harvest, Excellent Develop. (UK based NGO)	4 years (01/18 - 02/22) Status: **Completed**	DST-Newton Bhabha-NERC-India-UK Water Quality Research Programme

8. NIH/GWH/ DST/ 19-23	Enhancing Food and Water Security in Arid Region through Improved Understanding of Quantity, Quality and Management of Blue, Green and Grey Water	**Anupma Sharma (PI)**, Gopal Krishan, Nitesh Patidar (Lead: CAZRI Jodhpur, Partners: NIH Roorkee, IISWC Dehradun, CSWRI & CIAH, Bikaner, NIAM Jaipur)	5 years (03/19 - 02/24) Status: **In progress**	DST
9. NIH/GWH/ CCRBF/20-23	Expansion of the Indo-German Competence Centre for Riverbank Filtration – CCRBF	**Gopal Krishan** (PI & Co-coordinator)	3 years (07/20 – 06/23) Status: **In progress**	Federal Min. of Education and Research, Germany
10. NIH/GWH/ DST-SERB/21-24	Partitioning Evapotranspiration into Evaporation and Transpiration fluxes using Stable Isotopes of Oxygen and Hydrogen	**Gopal Krishan (PI)**, M.S. Rao	3 years (04/21 – 03/24) Status: **In progress**	DST-SERB

The suggestions emerged during the presentation of these studies are given below:

S. No.	Title of Project	Status and Recommendations/Suggestions
Internal Studies		
1	Integrated GEE-MODFLOW based Groundwater Recharge Assessment System for Hindon River System	Dr. Nitesh Patidar (PI) presented the objective-wise progress, results, and interface of the model developed under the study. Mr. Sudhindra Mohan Sharma asked about the model inputs, such as GW extractions and lithology and PI clarified the same. Prof. Saraf asked about the estimation of irrigation requirement in the model and PI clarified the same by explaining the LAI-based method used in the model. Prof. Ramakar Jha asked about the groundwater observation inputs in the model and PI clarified that observations are required for calibration and validation. WG members appreciated the work.
2	Studying arsenic genesis and developing alternate water supply management strategies in Ganga basin	Dr. Sumant Kumar (PI) presented the background, objectives, methodology and expected outcome of the new proposed internally funded study. The WG members appreciated and recommended to take up the study as the project outcomes would be helpful for providing safe drinking water to the community of arsenic affected areas. The WG members are of view that study area is large and hence they suggested PI to look after the resources and accordingly study area may be curtailed down, if possible. PI responded that the study area may be finalized after internal discussions. One of the WG members suggested to contact researchers working in the field of arsenic genesis and treatment. PI replied with thanks that NIH team is already in contact with few IITs.
3	Conjunctive Management of Water Resources in IGNP Command	Dr.Nitesh Patidar (PI) presented the problem statement, objectives and methodology of the new internal R&D study. WG member, Dr. Sudhir Kumar, suggested to look at an earlier study done by NIH in IGNP. WG members also suggested to review the studies done in IGNP and PI agreed on the suggestion. Dr.

		Gopal Singh Bhati appreciated the work stating that a lot of changes have happened during past 20 years in groundwater levels and cropping patterns in the area and the assessment of the current status of groundwater and water logging is needed in IGNP.
4	Studying Groundwater Dynamics using Machine Learning and Numerical Modelling	Ms. Nidhi Kalyani (PI) presented the background, objectives and methodology of the study. Prof. Ramakar Jha suggested to explore the various input layers required in the machine learning model and the PI agreed on the suggestion.
	Sponsored Projects	
5	Groundwater Fluctuations and Conductivity Monitoring in Punjab - Groundwater resilience in Punjab and adaptation to future changes in climate and water resource demands (title modified by funding agency)	Dr. Gopal Krishan (PI) presented the variation in water level in last 150 years, trend of groundwater depletion mainly due to the onset of pumping; correspondence between shallow and deep is notable; deep and shallow groundwater have similar isotopic compositions and seasonal groundwater response, highlighting the vertical connectivity of the aquifer system Dr. S.S. Grewal (Retd. Director), PAU, Ludhiana, appreciated the work and told that work should be disseminated to the policy makers. Dr. M.K. Goel replied that the work has already been presented in Punjab Vidhan Sabha. Dr. M.S. Rathore, Director CEDS, Jaipur, asked about the contribution of return flow in groundwater and effect of cropping pattern on groundwater levels to do similar study in Haryana. PI informed that component of irrigation return flow was found in groundwater but it is not quantified, for effect of cropping pattern PI replied that there was a model shown depicting the groundwater level variations due to the change in cropping pattern. Regarding the similar study in Haryana, PI replied that the NIH is already doing a PDS under NHP in Mewat region. Dr. Sudhinder Mohan Sharma, Consultant ex-nodal officer MoDWS, Indore, asked about the groundwater quality status in different aquifers. PI, informed that a plot was already shown to mark changes in salinity variations.
6	Future Secular Changes and Remediation of Groundwater Arsenic in the Ganga River Basin - FAR GANGA	Dr. Surjeet Singh (PI) presented the study in detail and reported that the study is completed and a final presentation was already made to DST. No comments were made by the WG Members.
7	Impact of Rainwater Harvesting on Groundwater Quality in India with Specific Reference to Fluoride and Micro-pollutants	Dr. Anupma Sharma (India Lead PI) presented the study approved under the India-UK DST-NERC-EPSRC Water Quality Research Programme (Newton Bhabha fund). The research objectives of the study, and the work packages were presented. Field investigations and data collection that were carried out at the fluoride affected field sites in Rajasthan, recharge attributable to rainwater harvesting structures, and the related laboratory experiments and results of chemical analysis were presented. Mobilization of fluoride under saturated conditions and fluoride release kinetics were presented using results of lysimeter and column experiments and geochemical modeling.
8	Enhancing Food and Water Security in Arid Region through Improved Understanding of Quantity, Quality and Management of Blue, Green and Grey Water	Dr. Anupma Sharma (PI from NIH) presented the DST sponsored WATER-IC project in which the lead agency is CAZRI, Jodhpur. The overall objectives of the study, and research objectives taken up by NIH were presented. Work being carried out in IGNP area in Rajasthan pertaining to estimation of groundwater recharge using water balance model and stable

		isotope analysis, as well as climate variability in the area were presented. Progress regarding field experiments to study the impacts of different irrigation schedules on a selected crop was shown. It was explained that the data generated will be used for model calibration. One of the Working Group Experts, Shri Sudhindra Mohan Sharma suggested that help from local community would further facilitate the data generation.
9	Expansion of the Indo-German Competence Centre for Riverbank Filtration – CCRBF	Dr. Gopal Krishan (PI) presented motivation for the study, development of a demonstration site, searching for new site for RBF well and progress under the project. No comments were made by WG members
10	Partitioning Evapotranspiration into Evaporation and Transpiration fluxes using Stable Isotopes of Oxygen and Hydrogen	Dr. Gopal Krishan (PI) presented the background, statement of the problem, objectives, methodology, progress and future plans of the study with main emphasis on methodology. The presentation was well appreciated. Dr. M. Samuel, Director CWRDM, asked about the methods for measuring ET and asked about use of Lysimeter. PI told that the experiments will be conducted at IIT-Kanpur and all the results will be validated and uncertainty analysis will be carried out.

RECOMMENDED WORK PROGRAM FOR THE YEAR 2022-23

S. No.	Project	Project Team	Duration & Status	Funding Source
Internal Studies				
1. NIH/GWH/ NIH/20-22	Integrated GEE-MODFLOW based Groundwater Recharge Assessment System for Hindon River System	Nitesh Patidar (PI), Gopal Krishan Anupma Sharma	2 years (08/20 – 07/22) *Status: In progress*	Internal Study
2. NIH/GWH/ NIH/22-25	Studying arsenic genesis and developing alternate water supply management strategies in Ganga basin	Sumant Kumar (PI), S. Singh, R. Singh, G. Krishan, S. S. Rawat, M.K. Sharma, N. Patidar, P. K. Mishra, M. K. Goel	3 years (04/22 – 03/25) Status: **New Study**	Internal Study
3. NIH/GWH/ NIH/22-24	Conjunctive Management of Water Resources in IGNP Command	Nitesh Patidar (PI), M. K. Goel, Anupma Sharma, Gopal Krishan, Surjeet Singh, Sumant Kumar, Nidhi Kalyani	2 years (04/22 – 03/24) Status: **New Study**	Internal Study
4. NIH/GWH/ NIH/22-24	Studying Groundwater Dynamics using Machine Learning and Numerical Modelling	Nidhi Kalyani (PI), Anupma Sharma, Nitesh Patidar, Sumant Kumar	2 years (04/22 – 03/24) Status: **New Study**	Internal Study
Sponsored Projects				
5. NIH/GWH/ BGS/17-20	Groundwater Fluctuations and Conductivity Monitoring in Punjab - Groundwater resilience in Punjab and adaptation to future changes in climate and water resource demands (title modified by funding agency)	Gopal Krishan (PI), S. Singh, C. P. Kumar (retd.), M. S. Rao *BGS, UK:* Dr. Dan Lapworth Dr. Alan MacDonald Dr. Daren Goody	5 years (12/17-11/22) *Status: In progress*	BGS, UK
6.	Assessment of Impacts of	Gopal Krishan (PI),	4 years	NHP under PDS

NIH/GWH/ PDS/17-21	Groundwater Salinity on Regional Groundwater Resources, Current and Future Situation in Mewat, Haryana – Possible Remedy and Resilience Building Measures	Surjeet Singh, C. P. Kumar (Retd.), *IIT-Roorkee:* M. L. Kansal, Brijesh Yadav *Sehgal Foundation:* Lalit Mohan Sharma	(12/17-07/22) *Status: In progress*	
7. NIH/GWH/ PDS/17-21	Ganges Aquifer Management in the Context of Monsoon Runoff Conservation for Sustainable River Ecosystem Services - A Pilot Study	Surjeet Singh (PI), C. P. Kumar, Sudhir Kumar, Suman Gurjar, Gopal Krishan	4 years (12/17-07/22) *Status: In progress*	NHP under PDS
8. NIH/GWH/ CEHM/18-22	Integrated Management of Water Resources for Quantity and Quality in Upper Yamuna Basin up to Delhi	Anupma Sharma (PI) S. K. Jain, A. Sarkar, M. K. Sharma, L. N. Thakural, Sumant Kumar, P.K. Mishra, V. Singh, N. Patidar, N. Kalyani *Partners* Haryana Irr. & WR Dept., UPGW Dept., UYRB, CWC	4 years (04/18-01/24) *Status: In progress*	Special Project under "Centre of Excellence" (NHP)
9. NIH/GWH/ DST/19-23	Enhancing Food and Water Security in Arid Region through Improved Understanding of Quantity, Quality and Management of Blue, Green and Grey Water	Anupma Sharma (PI), Gopal Krishan, Nitesh Patidar (*Lead*: CAZRI Jodhpur, *Partners*: NIH Roorkee, IISWC Dehradun, CSWRI & CIAH, Bikaner, NIAM Jaipur)	5 years (03/19 - 02/24) *Status: In progress*	DST
10. NIH/GWH/ CCRBF/20-23	Expansion of the Indo-German Competence Centre for Riverbank Filtration – CCRBF	Gopal Krishan (PI & Co-coordinator)	3 years (07/20 – 06/23) *Status: In progress*	Federal Min. of Education and Research, Germany
11. NIH/GWH/ DST-SERB/21-24	Partitioning Evapotranspiration into Evaporation and Transpiration fluxes using Stable Isotopes of Oxygen and Hydrogen	Gopal Krishan (PI), MS Rao	3 years (04/21 – 03/24) *Status: In progress*	DST-SERB
12. NIH/GWH/ APN/22	Capacity Development Program on Site Suitability Mapping for Managed Aquifer Recharge (MAR) under Varying Climatic Conditions using Remote Sensing and Machine Learning based Hydrological Modelling Tools	Nitesh Patidar (PI), S. Singh, G. Krishan *IIT Roorkee(lead)*: Basant Yadav, Ashish Pandey, R D Singh, B. J. Deka *In-kind support:* KU, Japan: Yutaka Matsuno, PNU, South Korea: Sanghyun Jeong	10 months (01/22-10/22) *Status: New Study*	Asia-Pacific Network (APN)
Consultancy Projects				
1.	Groundwater Investigations of Rana Sugars Ltd. Buttar Seviyan Area of Amritsar District, Punjab	Surjeet Singh (PI)	6 months (01/22 – 06/22) *Status: In progress*	NIT, Jalandhar (Punjab)

HYDROLOGICAL INVESTIGATIONS DIVISION

Dr Sudhir Kumar, Scientist-G and Head of the H. I. Division presented the brief details of the Division including the scientific staff strength and infrastructure. He briefly introduced about the scientific work of the Division and the various studies being carried by the Division, along with details about the publications by the Division and analytical work carried out at the Nuclear Hydrology Laboratory. He also informed about the technology transfer activities organized/proposed by the Division during 2021-22.

Table 1: Details of training Courses/Workshops organised by HI Division during April 2021-March, 2022

S. N.	Topic	Duration	Coordinator	Venue	No. of Participants
1.	Scientific data collection and processing techniques for springshed management and rejuvenation	05 Days (13-17 Dec 2021)	Dr S S Rawat	Guwahati	25
2.	Tools and techniques for springshed management	Two Days (06-07.01.2022)	Dr SS Rawat	Jammu	39
3	Stakeholder Consultation Workshop on "GRACERS Project"	March 22, 2022 (01 day)	Dr. SM Pingale	Haldia, West Bengal	50

Table 2: Details of Research Publications by HI Division during April 2021-March, 2022

Publication	Published	Accepted	Communicated	Total
Books / Book Chapter	01	-	-	01
International Journals	24	-	15	39
National Journals	02	02	01	05
International Conferences	11	02	-	13
National Conferences	02	-	-	02
Total	40	04	16	60

The progress of each individual study for the year 2021-22 and the proposal for a new study was presented by the respective P.I. of the study. A new study for springs of Tehri Garhwal district of Uttarakhand was proposed by Dr. M.S. Rao, Scientist-F. However, Chairman, working group observed that another study on springs of Tehri Garhwal district is already being undertaken by the division. So, the Chairman, working group suggested that instead of Tehri Garhwal, Dr. M.S. Rao may come up with a proposal on springs of North-East region.

The comments/actions suggested by the working group for various studies are as follows:

S. N.	Project Title	Study Team	Duration	Comments
INTERNAL STUDIES:				
1.	Assessment of impact of land use and land cover change on groundwater conditions in parts of Sabarmati river Basin, Gujarat	M. Someshwar Rao (PI) Sudhir Kumar Vipin Aggarwal	2 years (04/21– 03/23)	Dropped
2.	Integrated Hydrological	SD Khobragade (PI)	3 years	Dropped

S. N.	Project Title	Study Team	Duration	Comments
	Investigations of Renuka lake, Himachal Pradesh, for its Conservation and Management	Sudhir Kumar Hukam Singh Rajiv Gupta Vipin Agarwal Scientist from GoH.P.	(07/20-06/23)	
3.	Assessment of dissolved radon concentration in groundwater of Uttarakhand	Hukam Singh (PI), M Someshwar Rao, Soban Singh Rawat, Vipin Agarwal	1 ¾ years (04/21-12/22)	No Comments
4.	Assessment of the Possible Impact of Climate Change on Evapotranspiration for Different Climatic Regions of India	SD Khobragade (PI), Dr. Vishal Singh, Sudhir Kumar	3 years (04/22-03/25)	No Comments
SPONSORED PROJECTS:				
1.	Dating very old ground waters of deeper aquifers in Ganga Plains, India	M. Someshwar Rao (PI) Sudhir Kumar	3 Years (06/16 -12/22)	Not presented
2.	Chemical & Isotopic Characterization of Deep Aquifer Groundwater of Middle Ganga Basin	Sudhir Kumar (PI) M. Someshwar Rao Vipin Aggarwal	3 ½ year (01/18 – 06/22)	Not presented
3.	Integrated Study on groundwater dynamics in the coastal aquifers of West Bengal for sustainable groundwater management	M. Someshwar Rao (PI), Sudhir Kumar A. R. Senthil Kumar V. S. Jeyakanthan	3 ½ years (01/18-06/22)	Not presented
4.	Development of a comprehensive plan for conservation and sustainable management of Bhimtal and Naukuchiatal lakes, Uttarakhand	Suhas Khobragade (PI) Sudhir Kumar	3 years (01/18-06/22)	Not presented
5.	Groundwater Rejuvenation As Climate changE Resilience for marginalized and gender sensitive GangeS (GRACERS)	Sudhir Kumar (PI) SM Pingale	2 years (06/19 – 09/22)	Not presented
6.	Web-GIS Based Spring Inventory for Vulnerability Assessment and Hydro-Geological Investigation of Selected Springs for Sustaining Local Water Demand in Ravi Catchment of Himachal Pradesh	S S Rawat (PI) Sudhir Kumar P G Jose, Suman Gurjar, D S Bisht	4 years (08/17-09/22)	Not presented
7.	Web-enabled Inventory of Natural Water Springs of Tawi River Catchment of Jammu and Kashmir State of India for Vulnerability Analysis and Developing Adaptive Measures for Sustaining Tawi River	S S Rawat (PI) P G Jose, Suman Gurjar, D S Bisht	3 years (01/19-09-22)	No comments
8.	Changing the fate of the Hindon river by evaluating the impact of agriculture on the water balance:	Sudhir Kumar, (*Proj. Coordinator*), M. K. Sharma, (PI), Suhas	5 years (04/22-03/27)	Not presented

S. N.	Project Title	Study Team	Duration	Comments
	Developing a template for a cleaner Ganga river	Khobragade, Anjali, Vishal Singh, SM Pingale, Nitesh Patidar, Surjeet Singh.		

RECOMMENDED WORK PROGRAMME FOR THE YEAR 2022-23

S. N.	Project Title	Study Team	Duration	Status
INTERNAL STUDIES:				
1.	Assessment of dissolved radon concentration in groundwater of Uttarakhand	Hukam Singh (PI), M Someshwar Rao, Soban Singh Rawat, Vipin Agarwal	1 ¾ years (04/21-12/22)	Continuing Study
2..	Assessment of the Possible Impact of Climate Change on Evapotranspiration for Different Climatic Regions Of India	SD Khobragade (PI), Dr. Vishal Singh, Sudhir Kumar	3 years (04/22-03/25)	New Study
3.	Ascertaining the efficacy of use of State of the art technologies for spring mapping and sustainability of springs through suitable interventions	Soban Singh Rawat, (PI) Sudhir Kumar, Santosh M. Pingale, P K Mishra, D. S. Bisht, Rajesh Singh	3 years (04/22-03/25)	New Study
4.	Studies for selected springs of Tehri Garhwal region, Uttarakhand	MS Rao (PI) and Team		Chairman suggested that instead of Tehri Garhwal, a proposal on study of springs of North-East region may be formulated.
SPONSORED PROJECTS:				
1.	Dating very old ground waters of deeper aquifers in Ganga Plains, India	M. Someshwar Rao (PI) Sudhir Kumar	3 Years (06/16 - 12/22)	Continuing Study IAEA under CRP
2.	Chemical & Isotopic Characterization of Deep Aquifer Groundwater of Middle Ganga Basin	Sudhir Kumar (PI) M. Someshwar Rao Vipin Aggarwal	3 ½ year (01/18 – 06/22)	Continuing Study NHP (PDS)
3.	Integrated Study on groundwater dynamics in the coastal aquifers of West Bengal for sustainable groundwater management	M. S. Rao (PI), Sudhir Kumar A. R. Senthil Kumar V. S. Jeyakanthan	3 ½ years (01/18-06/22)	Continuing Study NHP (PDS)
4.	Development of a comprehensive plan for conservation and sustainable management of Bhimtal and Naukuchiatal lakes, Uttarakhand	Suhas Khobragade (PI) Sudhir Kumar	3 years (01/18-06/22)	Continuing Study NHP (PDS)
5.	Groundwater Rejuvenation As Climate changE Resilience for marginalized and gender sensitive GangeS (GRACERS)	Sudhir Kumar (PI) SM Pingale	2 years (06/19 – 09/22)	Continuing Study (IIT Bombay, Mumbai)

S. N.	Project Title	Study Team	Duration	Status
6.	Web-GIS Based Spring Inventory for Vulnerability Assessment and Hydro-Geological Investigation of Selected Springs for Sustaining Local Water Demand in Ravi Catchment of Himachal Pradesh	S S Rawat (PI) Sudhir Kumar P G Jose, Suman Gurjar, D S Bisht	4 Years 17/08)–0922/)	Continuing Study NHP (PDS)
7.	Web-enabled Inventory of Natural Water Springs of Tawi River Catchment of Jammu and Kashmir State of India for Vulnerability Analysis and Developing Adaptive Measures for Sustaining Tawi River	S S Rawat (PI) P G Jose, Suman Gurjar, D S Bisht	3 years (01/19-09/22)	Continuing Study (NMHS)
8.	Leachate transport modelling for Gazipur landfill site for suggesting ameliorative measures	Anjali (PI) Sudhir Kumar, J. V. Tyagi M. K. Sharma Partner: CGWB (Delhi unit)	3½ years (11/19 – 06/23)	Continuing Study NHP (PDS) Transferred from EHD
9.	Changing the fate of the Hindon river by evaluating the impact of agriculture on the water balance: Developing a template for a cleaner Ganga river	Sudhir Kumar, (Proj. Coordinator), M. K. Sharma, (PI), Suhas Khobragade, Anjali, Vishal Singh, SM Pingale, Nitesh Patidar, Surjeet Singh.	5 years (04/22-03/27)	DST

SURFACE WATER HYDROLOGY DIVISION

Dr. A.K.Lohani, Sc G & Head, Surface Water Hydrology Division presented the various activities of the division. The number of research papers published in various journals, lectures delivered in various training courses and number of M.Tech./Ph.D. students guided/under guidance during the period were also reported. The concerned PI of the study presented the progress of his/ her completed and new internal studies during the working group meeting. Sponsored studies and ongoing internal studies are not presented. The record of discussions for the respective study is given below:

Work Program for the Year 2021-22

S. N.	Title	Status and Recommendations/ Suggestions
	Completed Internal Studies	
1	Application of unified-extreme-value (UEV) distribution for flood frequency: (1) Mahi & Sabermati subzone – 3a (2) Upper Narmada -3e. **Study Group:** S.K. Singh **DOS:** April 2021 **DOC:** March 2022	**Status:** Completed Study presented.
2	Assessment of Climate Change Impact on Water Availability and Agriculture in part of Banas basin **Study Group:** Archana Sarkar, Surjeet Singh, Suman Gurjar, Sunil Gurrapu **DOS:**Nov. 2018**DOC:** March 2022	**Status:** Completed Chairman suggested to fine tune the report including rewriting the section on key messages of the study and submit the final report for review.
3	Evaluation of seasonal extreme rain events across river basins of India in 3D global temperature change scenario.	**Status:** Completed Study presented.

	Study Group: Ashwini Ranade, Archana Sarkar **DOS:**April 2018**DOC:**Sept. 2021	
4	Evaluation of the influence of low-frequency atmosphere-ocean oscillations on annual floods in the Godavari and Narmada River Basins. **Study Group:** Sunil Gurrapu, Ashwini Ranade, J.P. Patra **DOS:**Nov 2018 **DOC:**Oct. 2021	**Status:** Completed Dr. S S Grewal, inquired on how this study could be useful to an implementing agency to plan watershed management plan. The PI of the study responded saying that the relationships established in this study could be useful to estimate water availability in the watershed, which can be useful in planning a better management plan for a watershed. Dr. Ramakar Jha, NIT Patna inquired about the opposite correlations in the cane of gauges from Narmada basins. The PI of the study said that the monsoon rainfall across central India was shown to be least affected by PDO or ENSO, as studied by Krishnamurthy & Krishnamurthy, 2013. So, the opposite correlations were as expected. Dr. Jha also suggested that instead of developing linear relationships, non-linear regressions could be developed using all the indices used in this study. The PI of the study agreed with Dr. Jha and said that multi-linear or non-linear regressions may be developed based on the relationships established in this study. Dr. C T Dhanya, IIT Delhi said that statistically significant correlations between annual floods and PDO, could be misleading because many of the flow gauges were regulated along the basins. The PI of the project said that the significant correlations were also seen in the natural gauges, and the reservoir operations could also be influenced indirectly by these oscillations, i.e. on the water available in the basin. Dr. Dhanya agreed that if the correlation is significant in the natural gauges also, this can be accepted. Dr. Ashok Das, agreed with the PI of the project that the opposite correlations in the case of gauges from Narmada basin are because of the opposite relationships between monsoon rainfall and PDO in this region, as established by Krishnamurthy & Krishnamurthy, 2013. Mr. N N Rai, CWC was asking (online) about the impact of climate change on PMP in Indian watersheds, but the question was not clearly heard because of connectivity issues. The PI of the project said that the literature review on the same has been done and a status report was prepared. Dr. J V Tyagi suggested that the same report shall be shared with Mr. Rai and ask for a review of the report. Dr. J V Tyagi, suggested that the title of the

		project should be changed to show the names of the study basins, i.e. Godavari and Narmada.
Completed Sponsored Studies		
1	Hydrological modelling in Alaknanda basin and assessment of climate change impact (NMSHE) **Study Group:** A.K. Lohani, Sanjay K. Jain, Archana Sarkar, V.S. Jeyakanthan, L.N. Thakural **DOS:** April 2016 **DOC:** March 2021	**Status:** Completed Study not presented.
2	Rainfall-Runoff Modelling of Selected Basin based on LULC pattern and development of Correlation (NHP) **Study Group:** A.K. Lohani, R.K. Jaiswal, Sushant Jain; Sanjay Agarwal, Shailendra Kumar **DOS:**Oct. 2019**DOC:**April 2022	**Status:** Completed Study not presented.
Ongoing Sponsored Studies		
1	Dam break studies of Kandaleru and Pulichintala dams in Andhra Pradesh (NHP) **Study Group:** P C Nayak, Y.R.Satyaji Rao, A.K. Lohani, B. Venkatesh, A. R. S. Senthil Kumar, T. Thomas **DOS:**Sept 2019 **DOC:**April 2023	**Status:** Ongoing Study not presented.
Ongoing Internal Studies		
1	Probabilistic dam break flood wave simulation and flood risk assessment for preparation of EAP for Mahi Bajaj Sagar dam in Rajasthan **Study Group:** J.P. Patra, Rakesh Kumar, Pankaj Mani, Sunil Gurrapu **DOS:** August 2020; **DOC:** July 2022	**Status:** Ongoing Study not presented.
2	Uncertainty in rating curves and discharge estimation **Study Group:**Sanjay Kumar, L. N. Thakural, Sunil Gurrapu, N.K. Bhatnagar, J P Patra **DOS:**April 2021; **DOC:**March 2023	**Status:** Ongoing Study not presented.

RECOMMENDED WORK PROGRAMME FOR THE YEAR 2022-23

ONGOING SPONSORED STUDIES				
S. N.	**Title**	**Study Team**	**Duration**	**Status & Comments**
1	Dam break studies of Kandaleru and Pulichintala dams in Andhra Pradesh (NHP)	P C Nayak Y.R.Satyaji Rao A.K. Lohani B. Venkatesh A. R. S. Senthil Kumar T. Thomas	3 year (Sept 2019 to April 2023)	On-going
ONGOING INTERNAL STUDIES				

1	Probabilistic dam break flood wave simulation and flood risk assessment for preparation of EAP for Mahi Bajaj Sagar dam in Rajasthan.	J.P. Patra Rakesh Kumar Pankaj Mani Sunil Gurrapu	2 years (July 2020 to August 2022	On-going
2	Uncertainty in rating curves and discharge estimation	Sanjay Kumar L. N. Thakural Sunil Gurrapu N.K. Bhatnagar J P Patra	2 Years **(**April 2021 to March 2023)	On-going
NEW INTERNAL STUDIES				
1	Development of Cloud Data Based Integrated Framework to Forecast Flood for Efficient Operation of Reservoirs	Dr. A. K. Lohani Dr. R. K. Jaiswal Mr. J. P. Patra Dr. P. C. Nayak Dr. Vishal Singh	Two Years April 2022 – March 2024	No specific action Suggested
2	Application of unified-extreme-value (UEV) distribution for flood frequency: selected rivers of U.S.A.	S.K. Singh	Six month (April 2022 to Sept. 2022)	No specific action Suggested
3	Application of unified-extreme-value (UEV) distribution for flood frequency: Comparison of results using GEV distribution	S.K. Singh	Six month (Oct. 2022 to March 2023)	No specific action Suggested
4	Flood Forecasting under Changing Climate Conditions - Role of Machine Learning and Conceptual/Physical based Model	P. C. Nayak A. K. Lohani J. P. Patra Sunil Gurrapu T. Thomas Om Prakash Jatin Malhotra	3 Year (July2022 to June2025)	No specific action Suggested
5	Hydrological Study to conserve the water resources of Bikaner, Rajasthan	L. N. Thakural M. K. Shama R. K. Jaiswal J. P. Patra P. K. Mishra Nitesh Patidaar N. K. Bhatnagar Jatin Malhotra Anil Kumar Chhangani	2 Year (July2022 to June2024)	Dr. A. K Saraf, working group member, suggested to modify the name of study by substituting revival and restoration instead of conservation.
6	Review of design flood and dam break analysis of Khadakhai Dam in Odisha	J.P.Patra A. K. Lohani Pankaj Mani P. C. Nayak Sanjay Kumar	3 Year (April2022 to March2025)	No specific action Suggested
7	Climate change scenarios for Andhra Pradesh and its impact on streamflow and groundwater levels in Pennar River basin	Sunil Gurrapu Y R S Rao Nitesh Patidar R Venkat Raman	2 Year (April2022 to March2024)	Dr. C T Dhanya suggested that a separate objective should be added in this project to evaluate and reduce (optimize) the uncertainty in the projected hydrological scenarios. She

				said such analysis will be important because this project being an implementable research, the implementing agency would want to know how to handle the uncertainty. The PI of the project agreed to the same and an appropriate objective will be framed after discussing it with the other member of the team. Dr. Ramakar Jha suggested that a basic literature review should have been presented either in the proposal or during the presentation. The PI of the project informed that the objectives have been framed after discussing with the Chief Engineer of the implementing agency.
8	Investigation on occurrences of extreme rain events across Northwest Himalaya in relation to global atmospheric thermal and circulation changes	Ashwini Ranade P.K. Mishra Sunil Gurrapu	3 years (April2022 to March2025)	The committee members appreciated the importance of the study as well suggested minor modification in the title of the project.
9	Investigating gap areas, current trends and future directions of research in Climate Change Impact on Hydrology and water Resources in India through Scientometrics	Archana Sarkar Jyoti Patil Rohit Sambare Charu Pandey	1.5 Year (May2022 to Oct2023)	No specific action Suggested

Training Courses/Workshops and Research Publications Completed During 2021-22

Trainings/ Workshops Organized	**Research publications**				
	International Journals	National Journals	International Conferences	National Conferences	Chapters in books
13	3	1	7	4	2

Training Courses/Workshops and Research Publications Planned During 2022-23

Trainings/ Workshops to be Organized	**Research publications**				
	International Journals	National Journals	International Conferences	National Conferences	Chapters in books
10	2	4	5	5	2

WATER RESOURCES SYSTEMS DIVISION

Dr. Sanjay K Jain (SKJ), Sc. G and Head, presented an overview of the Division – scientific strength, the ongoing studies, sponsored & consultancy studies, technical publications and training courses organized. Thereafter, internal studies were presented by the respective PIs as given below:

<table>
<tr><th>SN</th><th>Study</th><th>Status and Recommendations/ Suggestions</th></tr>
<tr><td colspan="3">Completed Sponsored/ Internal Studies</td></tr>
<tr><td>1.</td><td>Title: Upgradation of NIH_ReSyP to .NET Platform – a Reservoir Operation Package
Team: D. Chalisgaonkar (DC); M. K. Goel
Duration: 1 year (08/20-03/22)
Funding: NIH
Status: Completed</td><td>DC presented the progress of the completed study. She informed that significant efforts have been made for the finalization of the revised version of NIH_ReSyP – 2022. All the 20 modules and their forms in .NET framework have been developed. Based on the inputs from the users, substantial improvements in the previous modeling system have been made. She informed that the following new modules have been added:
• Storage-Yield-Reliability relationship
• Instant estimation of reservoir inflow using rate of rise
• Modules added to help operator in finding actual release to be made depending on the prevalent policy.
• Instant estimation of release for flood control
• Spillway discharge rating table
• Instant spillway discharge estimation
She also informed that the help files for different modules are provided along with the software, so no separate report will be prepared and the output will be only in the form of software.</td></tr>
<tr><td>2.</td><td>Title: Real-time snow cover information system for Upper Ganga basin (Sub-project – 2).
Team: D. S. Rathore; (Now Deepa Chalisgaonkar is PI) V. S. Jeyakanthan; L. N. Thakural;
Duration: 5 years (01/16-03/21)
(Extended till Sept., 2021)
Funding: DST
Status: Completed</td><td rowspan="3">A special session of one-hour duration was allotted to briefly present the important outcomes of the eleven studies jointly conducted under National Mission for Sustaining the Himalayan Ecosystem (NMSHE). Dr. M. K. Goel, Project Coordinator, NMSHE presented the studies on behalf of all the Investigators. Dr Sanjay K Jain, Smt Deepa Chalisgaonkar, Dr M. K. Nema, and Dr. P. K. Mishra contributed during the presentation. Dr Goel informed that the study was completed by September, 2021 and the final report has been prepared. He also shared the hard copy of the report with the members.</td></tr>
<tr><td>3.</td><td>Title: Glacial Lakes & Glacial Lake Outburst Flood (GLOF) in Western Himalayan Region (Sub-project – 3).
Team: Sanjay K. Jain; A. K. Lohani; Sudhir Kumar; Praveen Thakur (IIRS)
Duration: 5 years (01/16-03/21)
(Extended till Sept., 2021)
Funding: DST
Status: Completed</td></tr>
<tr><td>4.</td><td>Title: Assessment of downstream impact of Gangotri glacier system at Dabrani and future runoff variations under climate change scenarios
(Sub-project – 4)
Team: Sanjay K. Jain; Sharad K. Jain (Retd.); P. K. Mishra; M. Arora; AP Dimri (JNU)
Duration: 5 years (01/16-03/21)
(Extended till Sept., 2021)</td></tr>
</table>

	Funding: DST **Status:** Completed	
5.	**Title:** Observation and modelling of various hydrological processes in a small watershed in Upper Ganga basin **(Sub-project – 5)** **Team:** M K Nema; Sharad K. Jain (Retd.); Sanjay K. Jain; P K Singh, P. K. Mishra; P. K. Agarwal; AP Dimri (JNU) **Duration:** 5 years (01/16-03/21) (Extended till Sept., 2021) **Funding:** DST **Status:** Completed	
6.	**Title:** Water Census and Hotspot analysis in selected villages in Upper Ganga basin **(Sub-project – 11).** **Team:** P. K. Mishra; M. K. Nema; Pradeep Kumar **Duration:** 5 years (01/16-03/21) (Extended till Sept., 2021) **Funding:** DST **Status:** Completed	
	Ongoing Sponsored/ Internal Studies	
1.	**Title:**Snow and glacier contribution and impact of climate change in Teesta river basin in Eastern Himalaya **Team:** Sanjay K. Jain; P. K. Singh; M. Arora; A. K. Lohani; Vishal Singh; **Duration:** 3 years (11/19-11/22) **Funding:** NMHS-MoEF **Status:** Ongoing	Not presented.
2.	**Title:**Assessment of seasonal variations in Hydrology and Cryosphere of upper Ganga Basin **Team:** Vishal Singh (VS); A. P. Dimri (JNU); Sanjay K. Jain **Duration:** 3 years (06/19-11/22) **Funding:**NRDMS-DST **Status:** Ongoing	Not presented.
3.	**Title:**Development of Water Accounts for the different sub-basins of Brahmaputra and Barak River Basins in the state of Meghalaya Using Water Accounting Plus (WA+) Framework. **Team:** P K Singh (PKS); P K Mishra; P K Agarwal **Duration:** 2 years (08/20-07/22) **Funding:** NHP **Status:** Ongoing	Not presented.
4.	**Title:** Development of Water Accounts for the different sub-basins in the state of Nagaland Using Water Accounting Plus (WA+) Framework. **Team:** P K Mishra (PKM); P K Singh; P K	Not presented.

	Agarwal **Duration:** 2 years (06/21-05/23) **Funding:** NHP **Status:** New	
5.	**Title:** Long term hydrological assessment for the development of water security plan into three sub-basins namely Barak, Minor rivers draining into Bangladesh and Minor rivers draining into Myanmar sub-basins in the state of Mizoram **Team:** Vishal Singh (VS); M K Nema; P K Singh; Vanlalpekhlua Sailo (SDO from Mizoram); Lalruatkima (JE from Mizoram) **Duration:** 2.5 years (06/21-05/24) **Funding:** NHP **Status:** New	Not presented.
6.	**Title:**Impacts of glacier and climate change on runoff for selected basins of Himalayan region **Team:** Vishal Singh (VS); Sanjay K. Jain (SKJ); Manohar Arora **Duration:** 2 years (08/20-07/22) **Funding:** NIH **Status:** Ongoing	VS presented the study on 'Impacts of glacier and climate change on runoff for selected basins (3 Nos) of Himalayan region'. He presented the outcome of the studies of the two catchment modelled so far. He said that the study of third catchment is under progress. The work related to impact of climate change is under progress and will be completed in next three months. He informed the work carried out for Baspa basin has already been published in Journal of Hydrology. The members asked about the validation of contribution of snow and glaciers. Dr. VS and Dr. SKJ informed that the results related to melt from snow/glacier combined have been compared with the previous works. For validation of snow and glacier melt separately. Dr. Bhism Kumar suggested to compare the results with isotope analysis based results. Chairman/Director said that the detailed analysis of isotopes for the separation of snow + glacier Q can be taken as a new study in the next phase after the submission of the present work. Dr. M K Goel informed that isotopic analysis has been carried for upper Ganga basin under NMSHE and the outcome of the study can be considered for comparison. VS noted the suggestions.
7.	**Title:**Monitoring and Hydrological Modelling of Henvel watershed in Lesser Himalaya **Team:** M K Nema; Sanjay K Jain; P K Mishra; P K Agarwal; **Duration:** 3 years (08/20-07/23) **Funding:** NIH **Status:** Ongoing	MKN presented the progress pertaining to third objective of the study, i.e., soil moisture modelling. He informed that an empirical model based on meteorological observations was already developed and presented in the previous working group meeting. In this meeting, Dr Nema explained the application of artificial intelligence (AI) in soil moisture modeling using different AI models such as MLP-ANN, DNN, SVM, MLR etc. The predicted soil moisture based on the AI model was satisfactory. The performance of the DNN model outplayed rest of the models as stated above. He further informed that a few Hybrid-AI models are also being developed and tested on the experimental catchments. The results shall be shared in the coming WG meetings. Director NIH suggested to

		run the SWAT model with the longest observed data likely to be generated with due course of time. The working group members made no specific suggestions or comments during the presentation.
8.	**Title:**Seasonal Characterization of Gangotri Glacier melt runoff and simulation of streamflow variation under different climate scenarios **Team:** M. Arora (MA); P K Mishra; Vishal Singh **Duration:** 3 years (04/18-03/22) **Funding:** NIH **Status:** Ongoing	MA presented the progress of the study. He informed the house that the data could not be collected for the ablation period of 2020 and 2021 because of Covid 19 outbreak. The progress achieved in the characterization of suspended sediment in the Gangotri Glacier melt stream was presented before the working group. It was informed that wind also plays a crucial role in the melting of glaciers and in this particular glacier the percentage of Cold katabatic and Warm anabatic wind in the years 2016-2019 is 56% and 44% respectively. HBV model was used for the simulation of streamflow. The model was calibrated for the years 2016-17 and validated for the year 2018-19. The coefficient of determination R2 for the calibration period and validation period were 0.77 and 0.71 respectively. Director NIH asked as to why SNOWMOD is not used for this analysis. In its response it was informed that SNOWMOD has been used in earlier studies but now in this study the role of aspect has also been included. However, a comparison will be made between the output of two models in future. Dr A K Saraf wanted to know the role of debris cover on the glacier melting. The results obtained from small experiments carried out earlier on the debris cover were discussed.
	New Internal/ Sponsored Studies	
1.	**Title:** Spatio-temporal Water Availability under Changing Climate and Land use Scenarios in Wainganga River Basin **Team:** M K Nema (MKN); P K Mishra; **Duration:**2 years (04/22-03/24) **Funding:** NIH **Status:** New	MKN presented proposed new study on River Wainganga with the aim to examine the basin's water resources availability and, more importantly, to estimate the influence of current and future changes in climate and land use on the basin's water balance. He informed that he has already made a visit of the study area and discussed the study with stakeholders. A few specific comments made by the WG members during the presentation are as follows: 1. The study should include the groundwater component. The proposal has been modified with an added objective and a team member from the groundwater division has been included. 2. Few changes were recommended in the listed objectives of the study, which has been incorporated. Dr M K Goel suggested to modify the second objective suitably. Dr. Nema said that the comments/suggestions will be incorporated in the study.
2.	**Title:**Monitoring and Assessment of Mountain Ecosystem and Services in North-West Himalaya (Phase-II): Monitoring and Modeling of Hydrological Processes in Glaciated and Non-Glaciated Watersheds of	SKJ presented the proposed new study which is a collaborative study with IIRS, Dehradun. He said that this project is multi institutional. He informed that the signing of MOU of the study has been already done with IIRS, Dehradun. He informed about the study

	North-West Himalaya **Team:** M K Nema; Sanjay K Jain (SKJ); Praveen Thakur (IIRS) **Duration:**3 years (04/22-03/25) **Funding:** IIRS **Status:** New	areas to be considered for the study. No specific comments were received from Working Group Members.
3.	**Title:**Hydrological Assessment of Ungauged Basins (Aghanashini, Dasanakatte, Sita Nadi, Madisala Hole, Swarna Nadi and Gurupur River Basins) of the West Flowing Rivers in the Western Ghat Region of Karnataka **Team:** P K Singh (PKS); Vishal Singh, Sanjay K Jain **Duration:**3 years (04/22-03/25) **Funding:** WRD, Karnataka **Status:** New	PKS presented the New study which is referred by WRD, Karnataka under NHP. He elaborated the objectives and informed about the involvement of the Engineers of WRD. Director asked to involve one scientist from RC, Belgavi.

RECOMMENDED WORK PROGRAMME FOR THE YEAR 2022-2023

SN	Title	Study Team	Duration	Funding (Rs. Lakhs)
Ongoing Sponsored/ Internal Studies				
1.	Snow and glacier contribution and impact of climate change in Teesta river basin in Eastern Himalaya	Sanjay K. Jain P K Singh; M. Arora A K Lohani; Vishal Singh	3 years (11/19-11/22)	NMHS-MoEF (143)
2.	Assessment of seasonal variations in Hydrology and Cryosphere of upper Ganga Basin	Vishal Singh; Sanjay K. Jain; A P Dimri (JNU)	3 years (06/19-11/22)	NRDMS-DST (23.19)
3.	Development of Water Accounts for the different sub-basins of Brahmaputra and Barak River Basins in the state of Meghalaya Using Water Accounting Plus (WA+) Framework.	P K Singh; P K Mishra; P K Agarwal	2 years (08/20-07/22)	NHP (14.50)
4.	Development of Water Accounts for the different sub-basins in the state of Nagaland Using Water Accounting Plus (WA+) Framework.	P K Mishra; P K Singh; Vishal Singh P K Agarwal	2 years (04/21-03/23)	NHP (9.00)
5.	Long term hydrological assessment for the development of water security plan into three sub-basins namely Barak, Minor rivers draining into Bangladesh and Minor rivers draining into Myanmar sub-basins in the state of Mizoram	Vishal Singh; M K Nema; P K Singh; Vanlalpekhlua Sailo (SDO from Mizoram); Lalruatkima (JE from Mizoram)	3 years (04/21-03/24)	NHP (25.00)
6.	Impacts of glacier and climate change on runoff for selected basins of Himalayan region	Vishal Singh; Sanjay K. Jain; Manohar Arora	2 years (08/20-07/22)	NIH (9.30)
7.	Monitoring and hydrological modeling of Henval watershed in Lesser Himalaya	M K Nema; Sanjay K Jain; P K Mishra; P K Agarwal	3 years (08/20-07/23)	NIH (10.22)
8.	Seasonal Characterization of Gangotri Glacier melt runoff and simulation of streamflow variation under different climate scenarios	M. Arora; P K Mishra; Vishal Singh	3 years (04/21-03/23)	NIH

New Internal/ Sponsored Studies				
1.	Spatio-temporal Water Availability under Changing Climate and Landuse Scenarios in Wainganga River Basin	M K Nema; P K Mishra	2 years (04/22-03/24)	NIH
2.	Monitoring and Assessment of Mountain Ecosystem and Services in North-West Himalaya (Phase-II): Monitoring and Modeling of Hydrological Processes in Glaciated and Non-Glaciated Watersheds of North-West Himalaya	M K Nema; Sanjay K Jain; P. K. Mishra; Praveen Thakur (IIRS)	3 years (04/22-03/25)	IIRS, Dehradun (30.91)
3.	Hydrological Assessment of Ungauged Basins (Aghanashini, Dasanakatte, Sita Nadi, Madisala Hole, Swarna Nadi and Gurupur River Basins) of the West Flowing Rivers in the Western Ghat Region of Karnataka	P K Singh; Vishal Singh; Sanjay K Jain;	3 years (04/22-03/25)	WRD, Karnataka (54.0)

DETAILS OF RESEARCH PUBLICATIONS DURING APRIL, 2021 - MARCH, 2022

Months	Division/RC/CFMS	Research studies	Research papers	Training courses	Training of personnel
1	Apr, 2021				
2	May, 2021				
3	June, 2021		2		2
4	July, 2021		2		
5	August, 2021			1	
6	September, 2021				
7	October, 2021		1		
8	November, 2021		1	1	
9	December, 2021		4		
10	January, 2022				1
11	February, 2022				
12	March, 2022	01	10	1	2
	Total	**01**	**20**	**3**	**5**

DETAILS OF TRAINING/ WORKSHOP COMPLETED

SN	Title of Training Course/Workshop	Coordinators	Duration	Venue
1.	Online training on "Hydrological Modeling using Soil and Water Assessment Tool (SWAT): Theory and Hands-on" from August 16-20, 2021, at NIH, Roorkee sponsored by National Hydrology Project (NHP) for 23 participants from 10 state governments water resources departments and 03 central implementing agencies.	Dr. M. K. Nema, Scientist 'D' Dr Vishal Singh, Scientist 'C'	5 days	Online
2.	Training on "Water Accounting Plus (WA+) for all Northeast IAs" from November 15-19, 2021, at Meghalaya, Shillong, sponsored by National Hydrology Project (NHP).	Dr P K Singh, Scientist 'D' Dr P K Mishra, Scientist 'C'	5 days	Offline
3.	Online training on "Soil and Water Assessment Tool (SWAT)" from Feb 28 to March 04, 2022, at NIH, Roorkee sponsored by Indian Council of Forestry Research and Education (ICFRE),	Dr. M. K. Nema, Scientist 'D' Dr Vishal Singh, Scientist 'C'	5 days	Online

	Dehradun.			
4.	Stakeholders' Workshop "Snow and glacier contribution and impact of climate change in Teesta river basin, eastern Himalaya" under NMHS Project at Gangtok, Sikkim on 23/02/2022	Dr. Sanjay K Jain, Scientist 'G' Dr P K Singh, Scientist 'D'	One day	Offline

RESEARCH MANAGEMENT AND OUTREACH DIVISION (RMOD)

Dr. V C Goyal, Sc. G & Head, presented an overview of the Division's activities and progress of studies during 2021-22. He also presented tables showing the studies and outreach activities proposed for the F.Y. 2022-23. Next, he invited Er. Omkar Singh, Dr. Senthil Kumar, Dr. Jyoti Patil and Er. Rohit Sambare to present the progress of studies/project as given below:

SN	Title of Project/Study, Study Team	Status and Recommendations/Suggestions
1.	Integrated assessment of water resources for sustainable use in Upper Dhasan basin in Bundelkhand Region, Central India **Team:** Dr. Jyoti P Patil (PI) Dr. T. Thomas (RC-Bhopal) Dr. Prabhash K Mishra Er. Rohit Sambhare DOS: September 2020, DOC: February 2023	The results of trend analysis, climatic indices, and WEAP model were briefly presented as those were discussed during the last WG meeting. The preliminary findings of Water Accounting + framework for Betwa basin were presented. These findings can be confirmed only after discussions with the stakeholders in the basin. The queries of the members were answered by the PI and Co-PI.
2	Establishing hydrological regime and ecohydrological functions of Jhilmil Jheel wetland (Haridwar District) Team: Er. Rohit Sambare (PI), Dr. V.C. Goyal, Dr. Suhas Khobragade, Dr. Gajendra Singh, Scientist (USAC, Dehradun), Shri N. R. Allaka DOS: Jul2020, DOC: Jun 2022 Extn. Sought upto August 2023	The HGM classification of wetland and its functional assessment using open source geospatial data has been presented. Sri S M Sharma suggested to include biodiversity component. The PI requested for extension of this study upto Aug 2023 due to his illness. The working group members agreed for extension of the study.
3	Hydrology-based scenario planning for water productivity and optimization of income from farming practices in Mewat Region, Haryana **Team:** A. R. Senthil Kumar, Omkar Singh, Rajesh Agarwal, Nageswara Rao Allaka. DOS: Jul 2020, DOC: Jun 2022 Extn. Sought upto Sep 2022	Dr S. S. Grewal suggested to consider the pattern of the crop types with respect to quality of ground water while going for the crop diversity scenario. Dr. Ramakar Jha, Professor, NIT Patna querried about the quantum of data involved in WEAP model setup. The PI infomed about the sources of data for both WEAP and LINGO model.
4.	Development of Water Security Plan for Healthcare Facilities: A Pilot Study for Swami Rama Himalayan University (SRHU-HIHT), Jolly Grant, Dehradun **Team:** Omkar Singh (PI), V.C. Goyal, Rajesh Singh (Co-PI), Jyoti Patil, Rohit Sambare, N.R. Allaka; Team from SRHU-HIHT, Dehradun DOS: Apr 2022, DOC: Mar 2024	This is a new study in collaboration with SRHU-HIHT, Dehradun. Sh. Omkar Singh (PI)presented the proposed objectives, methodology and expected outcome. Dr. Pawan Labhasetwar, Dr. Manoj Samuel and Dr. Ramakar Jha appreciated this type of study with hospitals, and suggested to take due care with Hospital Administration about any hazardous wastes in the wastewater.
5.	Innovation Centre for Eco-Prudent Wastewater	This is a sponsored project of DST (GoI) and

	Solutions (IC-EcoWS) DST (GoI), Cost: Rs. 5.1 Crore V.C. Goyal (PI), Omkar Singh, Rajesh Singh, Jyoti P. Patil, Rohit Sambare **Partners:** NIH, MNIT-Jaipur, IIT-Bombay, IRMA-Ahmedabad DOS: Apr 2019, DOC: Mar 2024	reported in the WG meeting. Hence, the progress was not presented in this meeting.

RECOMMENDED WORK PROGRAM FOR THE YEAR 2022-23

SN	Title of Project/Study	Funding	Study Team	Duration	Status
Internal Study					
1	Integrated assessment of water resources for sustainable use in Upper Dhasan basin in Bundelkhand region	NIH	Jyoti Patil (PI) T Thomas (Co-PI), P K Mishra Rohit Sambare	Sep 2020- Feb 2023	On-going
2	Establishing hydrologic regime and ecohydrological functions of Jhilmil Jheel wetland (Haridwar District, Uttarakhand)	NIH	Rohit Sambare (PI) V C Goyal (Co-PI), Suhas Khobragade, N R Allaka; Gajendra Singh-USAC, Dehradun; WI-SA, New Delhi; HESCO, Dehradun	Sep 2020- Aug 2023	On-going
3	Hydrology-based scenario planning for water productivity and optimization of income from farming practices in Mewat region, Haryana	NIH	A R Senthil Kumar (PI) Omkar Singh (Co-PI) Rajesh Agarwal, N R Allaka Scientist from KVK/Agri Univ.	Sep 2020- Aug 2022	On-going
4	Development of Water Security Plan for Healthcare Facilities: A Pilot Study for Swami Rama Himalayan University (SRHU-HIHT), Jolly Grant, Dehradun	NIH	Omkar Singh (PI) V.C. Goyal, Rajesh Singh (Co-PI), Jyoti Patil, Rohit Sambare, N.R. Allaka; Team from SRHU-HIHT, Dehradun	April 2022- Mar 2024	New Study
Sponsored Projects					
1	Innovation Centre for Eco-Prudent Wastewater Solutions (IC-EcoWS)	DST (GoI)	V.C. Goyal (PI), Omkar Singh, Rajesh Singh, Jyoti P. Patil, Rohit Sambare, Project Team, HQ (IC-EcoWS) Partners: NIH, MNIT-Jaipur, IIT-Bombay, IRMA-Anand	Apr 2019-Mar 2024	On-going

<u>Proposed Training/Webinar/Outreach Activities of RMOD (2022-23)</u>

S.N.	Outreach Activity	Tentative Date & Month	Place	Target Participants	Team
1	Brainstorming session on 'Water Security in a Changing Environment- Focus on Indian Himalayan Region (IHR)', during 16th Uttarakhand Science and Technology	June 2022	UCOST, Dehradun	Conference participants	V. C. Goyal, J P Patil, Amrendra Bhushan

	Congress				
2	5-days training on 'Life Cycle Approach for Rejuvenation of Ponds and Lakes using Nature-Based Solutions' sponsored by National Water Mission (4Nos)	April 2022 May 2022 June 2022 July 2022	Bhopal Belgaum Kakinada Roorkee	R&D Institutes/ University/ Govt. Organizations	Bhopal: T Thomas Belgavi: B Venkatesh Kakinada: YRS Rao Roorkee: J P Patil, Omkar Singh, Rohit Sambhare
3	Training on GEM	June 2022	NIH Roorkee	Admn and finance staff of NIH	A. R. Senthil kumar Omkar Singh
4	Webinar on ecohydrological functioning of wetlands	Jul 2022	NIH Roorkee	Students and researchers	Rohit Sambare V C Goyal
5	Stakeholders workshop for Upper Dhasan Basin water resources assessment	May 2022	Bhopal	CWC, CGWB, State departments (Irrigation, WRD, Agril etc)	J P Patil, T Thomas, P K Mishra, Rohit Sambhare
6	Workshop/Webinar on rejuvenation of ponds and treatment of domestic wastewater through constructed wetlands	Jul 2022	NIH Roorkee	R&D Institutes/University/Govt. Organizations	NIH: Omkar Singh, V.C. Goyal, Rajesh Singh, Digambar Singh UKCEH: Laurence Carvalho & Elliot Hurst
7	Five-day training program on "Hydrology of water bodies and their development under climatic uncertainty"	Jun/Jul 2022	NIH Roorkee	Engineers in Irrigation/PHE/SWC departments	A. R. Senthil kumar, Rohit Sambare, Santosh M Pingale, N R Allaka
8	E-course on Urban hydrology	June 2022	NIH, Roorkee NIUA, Delhi	Researchers, academicians, scholars	NIH: V C. Goyal, J. P. Patil NIUA: Victor Shinde
9	Awareness Programme for School Children	July-Sep 2022	3 Schools in Roorkee/ Nearby Roorkee	School Children	Digambar Singh, Omkar Singh, A. R. Senthil kumar, Rajesh Agarwal, N R Allaka

Other Outreach Activities:

S.N.	**Activity**
1	• Preparation of Short Video on Pond Rejuvenation & CW-NTS of Ibrahimur Masahi • River Walk of Solani River • Short video on Hydrology for People @district level • Short video on vulnerability assessment under Hydrology for People series
2	• Coordination of 75 planned Activities at HQ & RCs under Azadi Ka Amrut Mahotsav @ India 75 • Organizing activities as per mandate of Division under Azadi Ka Amrut Mahotsav @ India 75 • Compendium of NIH activities on the activities under Azadi Ka Amrut Mahotsav @ India 75
3	• Any other Outreach activity on demand/assigned

Dr. V C Goyal thanked the members for their valuable contributions during deliberations in the Working Group meeting.The meeting ended with vote of thanks to the Chair.

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ANNEXURE-I

List of Working Group Members who attended the 52nd WG meeting

1.	Dr. J V Tyagi, Director, NIH	Chairman
2.	Dr. A. K Das, IMD, New Delhi	Member
3.	Sh. Sudhindra Mohan Sharma, Ex-Nodel Officer, MoDWS, Indore	Member
4.	Sh. Prashant Rai, CGWB, Dehradun	Member
5.	Dr. Manoj P.Samuel, CWRDM, Kozhikode	Member
6.	Dr. Sadhana Malhotra, Mindspace, Dehradun	Member
7.	Prof. A K Saraf, IIT Roorkee	Member
8.	Dr. Bhishm Kumar, IAEA (Retd.), Roorkee	Member
9.	Prof. Ramakar Jha, NIT, Patna	Member
10.	Dr. S S Grewal, Chandigarh	Member
11.	Prof. Varun Joshi, GGSIPU, New Delhi	Member
12.	Prof. Danya, C.T. Assistant Professor, IIT, Delhi	Member
13.	Dr. Sushil Kumar Rohella, WIHG, Dehradun	Member
14.	Dr. R K Goyal, CAZRI, Jodhpur	Member
15.	Dr. Praveen Thakur, IIRS, Dehradun	Member
16.	Dr. P R Ojasvi, ICAR-IISWC, Dehradun	Member
17.	Dr. Manohar S. Rathore, CE &DS, Jaipur	Invitee
18.	Sh. Gopal Singh Bhatti (Retd.), Pokhran, Rajasthan	Invitee
19.	Dr. Sudhir Kumar, Sc. G & Head HI Division, NIH	Member
20.	Dr. Sanjay K. Jain, Sc. G & Head WRS Division, NIH	Member
21.	Dr. M. K. Goel, Sc. G & Head GWH Division, NIH	Member
22.	Dr. A.K. Lohani, Sc. G & Head SWH Division, NIH	Member
23.	Dr. R P Pandey, Sc.G & Head EH Division, NIH	Member
24.	Dr. V C Goyal, Sc. G & Head, RMO Division, NIH	Member-Secretary

Scientists from NIH

	EH Division		RMO Division
1	Dr. M.K. Sharma, Sc.E	18	Er. Omkar Singh, Sc.F
2	Dr. Rajesh Singh, Sc.D	19	Dr. A R Senthil Kumar, Sc.F
3	Dr. Pradeep Kumar, Sc.D	20	Dr. (Mrs.) Jyoti P. Patil, Sc.D
4	Dr. Vinay K. Tyagi, Sc.D	21	Sh. Digamber Singh, Sc.D
5	Sh. Rajesh K. Nema, Sc.B	22	Sh. Rohit Sambare, Sc.B
	GWH Division		**SWH Division**
6	Dr. Anupama Sharma, Sc.F	23	Dr. P C Nayak, Sc.F
7	Dr. Surjeet Singh, Sc.F	24	Dr. Sanjay Kumar, Sc.E
8	Dr. Sumant Kumar, Sc.D	25	Dr. Archana Sarkar, Sc.E
9	Dr. Gopal Krishan, Sc.D	26	Dr. L.N. Thakural, Sc.D
10	Sh. Nitesh Patidar, Sc.B	27	Dr. J.P. Patra, Sc.D
11	Ms. Nidhi Kalyani, Sc.B	28	Dr. Ashwini A. Ranade, Sc.D
	HI Division	29	Sh. Sunil Gurrapu, Sc.C
12	Dr. Suhas Khobragade, Sc.F		**WRS Division**
13	Dr. M.S. Rao, Sc.F	29	Smt. Deepa Chalisgaonkar, Sc. G
14	Dr. Soban S. Rawat, Sc.D	30	Dr. Manohar Arora, Sc.E
15	Dr. Santosh M Pingale, Sc.C	31	Dr. P K Singh, Sc.D
16	Sh. Hukam Singh, Sc.B	32	Dr. Manish Nema, Sc.D
17	Mrs. Anjali, Sc.B	33	Dr. P K Mishra, Sc.D
		34	Dr. Vishal Singh, Sc.C
		35	Sh. P K Agarwal, Sc.B
		36	Sh. Yatveer Singh, Sc.B

ANNEXURE – B

Division-wise Work Programme

ENVIRONMENTAL HYDROLOGY DIVISION

Scientific Manpower

S N	Name	Designation
1	Dr. R P Pandey	Scientist G & Head
2	Dr. M K Sharma	Scientist F
3	Dr. Rajesh Singh	Scientist D
4	Dr. Pradeep Kumar	Scientist D
5	Dr. Vinay Kumar Tyagi	Scientist D
6	Dr. Kalzang Chhoden	Scientist C
7	Smt. Babita Sharma	SRA
8	Smt. Bina Prasad	SRA

APPROVED WORK PROGRAMME FOR THE YEAR 2022-23

S. N.	Study	Study Team	Duration/Status
Sponsored Projects (Ongoing)			
1.	Water Efficient Irrigation by Using SCADA System For Medium Irrigation Project (MIP) Shahnehar	Dr. R. P. Pandey, (PI) Er. Jagdeesh Patra, Dr. Rajesh Singh Sh. N. K. Bhatnagar	3 Years (12/17-03/22) Further Extension till may 2023 **Project Cost**: 75 Lakh Sponsored by: NHP Status: In-progress
2.	Anaerobic Co-digestion of Thermochemically Pretreated Organic Fraction of Municipal Solid Waste and Sewage Sludge: Effect on Process Performance and Microbial Community Development	Dr. Vinay Kumar Tyagi, Sc, 'D' (PI)	5 Years (2018-2023) **Project Cost**: 106 Lakhs **Sponsored by**: DBT **Status**: In-progress
Collaborative Projects (Ongoing)			
3.	Isotopic and geochemical approach to study vulnerable confined and unconfined drinking water aquifers in Varanasi and surrounding area, India	Dr. Rajesh Singh (PI) Dr. R.P. Pandey BHU, Varanasi (Lead) Other Collaborators: BARC, Mumbai, ICER, Hungary	3 Years (07/21-06/24) **Sponsored by**: BHU **Status**: In-progress
4	Comprehensive characterization of variably processed sewage sludge in Ganga basin to classify its suitability for safe disposal	Dr. Vinay Kumar Tyagi, Sc, 'D' (Co-PI) Dr. A.A.Kazmi (PI, IITR)	02 Years (01/22-12/23) **Sponsored by**: Central Pollution Control Board (CPCB)-NMCG
5	SARASWATI 2.0 - Identifying best available technologies for decentralized wastewater treatment and resources recovery for India	Dr. Vinay Kumar Tyagi, Sc, 'D' (Co-PI) Dr. A.A.Kazmi (PI, IITR)	4 Years (03/20-02/24) **Sponsored by**: Department of Science & Technology (DST)
Internal Study (Ongoing)			
6.	Characterisation of Groundwater Dynamics in Krishna-Godavari Delta interims using groundwater levels, Hydrochemistry, Isotopes and Emerging Contaminants	Dr. M. K. Sharma, Sc. F (PI) Dr. Suhas Khobragade, Sc. 'G' Dr. Rajesh Singh, Sc. 'D'	2 Years (04/22-03-24) **Status:** In-progress
7.	Understanding Arsenic mobilization in groundwater of Haridwar and formulating remediation measures	Dr. Rajesh Singh, Sc. D (PI) Dr. R. P. Pandey, Sc. G Dr. Sumant Kumar, Sc. D, Dr. Pradeep Kumar, Sc. D Dr. M. K. Sharma, Sc. F Dr. V. K. Tyagi, Sc, D Dr. Kalzang Chhoden, Sc. C	3 Years (07/21-06/24) **Status:** In-progress
8.	Simulation of Non-Point Source Pollution Processes in Song River	Dr. Pradeep Kumar, Sc. D (PI) Dr. M.K. Sharma, Sc. F Dr. Rajesh Singh, Sc. D Er. R.K. Nema, Sc. B	4 Years (11/19-10/23) **Status:** In-progress
Internal Study (New)			
9.	Hydrological Studies for the Conservation of Rewalsar Lake	Dr. Kalzang Chhoden, Sc. C, (PI) Dr. Rajesh Singh, Sc. D Dr. R. P. Pandey, Sc. G Dr. Pradeep Kumar, Sc. D Dr. Vinay Kumar Tyagi, Sc. D	3 Years (12/22-11/25) **Status:** Proposed

		Er. Omkar Singh, Sc. G Dr. Shuhas Khobragade, Sc. G Dr. D.S. Malik, Professor, GKU, Haridwar	
10.	Comprehensive evaluation of disinfection units of STPs in Ganga basin: Occurrence and control the formation of emerging oxidation precursors	Dr. Vinay Kumar Tyagi, Sc. D (PI) Dr. Rajesh Singh, Sc. D Dr. Mukesh K. Sharma, Sc. F Dr. Pradeep Kumar, Sc. D Er. J. P. Patra, Sc. D Dr. Kalzang Chhoden, Sc. C Dr. R.P.Pandey, Sc. G	3 Years **Status:** Proposed
Consultancy Projects (Completed)			
11.	Estimation of Economic Losses in Real Terms per Hectare Basis due to Forest Fire in Uttarakhand and Madhya Pradesh	Dr. J.V. Tyagi (Lead PI) Dr. R.P. Pandey (PI) Dr. P. Kumar (Co-PI) Dr. T. Thomas Dr. L.N. Thakural Dr. P.K. Singh	2.5 Years (03/20-08/22) **Sponsored by;** ICFRE **Project Cost:** Rs. 110.33 Lakhs **Status:** Completed
12.	Site Selection for Intake Well in Alaknanda River near Srinagar for Marhi Chauras Pumping Peyjal Yojna	Dr. R.P. Pandey, Sc 'G' & PI Dr. Pradeep Kumar, Sc 'D' Dr. Rajesh Singh, Sc. 'D' Dr. Vinay Tyagi, Sc 'D'	1 Months (11/22-12/22) **Sponsored by**: Uttarakhand Peyjal Nigam **Project Cost:** Rs. 1.80 Lakh **Status:** Completed
13.	Site Selection for Intake Well in Ganga River Bharpoor Pumping Peyjal Yojna Phase-II	Dr. R.P. Pandey, Sc 'G' & PI Dr. Pradeep Kumar, Sc 'D' Dr. Rajesh Singh, Sc. 'D' Dr. Vinay Tyagi, Sc 'D'	1 Months (12/22-01/23) **Sponsored by:** Uttarakhand Peyjal Nigam **Project Cost:** Rs. 1.80 Lakh **Status:** Completed
Consultancy Projects (On-going)			
14.	Estimation of Sediment Load and GHG Emission from Reservoir of Chamera-1 Power Station, NHPC	Dr. J V Tyagi Dr. R.P. Pandey, Sc 'G' Dr. Rajesh Singh, Sc 'D' (PI) Dr. M.K. Sharma, Sc. 'F' Sh. Rakesh Goyal, Tech. Gr. I	15 Months (12/21-03/23) **Sponsored by:** Innovante Water Soluation Pvt. Ltd. Roorkee **Cost**: Rs. 3.245 Lakh **Status:** On-going
15.	Performance evaluation of Nano Catalytical Instant Water Converter (NCIWC) equipment for water and wastewater treatment	Dr. J.V. Tyagi Dr. R.P. Pandey, Sc 'G' Dr. Rajesh Singh, Sc. 'D' & PI Dr. Sumant Kumar, Sc. 'D' Dr. Vinay Tyagi, Sc. 'D' Dr. M.K. Sharma, Sc. 'F' Dr. Pradeep Kumar, Sc. 'D'	06 Months (05/22-11/22) Further Extension Requested **Sponsored by:** Envirogreen Minetech India Pvt. Ltd., Indore M.P. **Cost**: Rs. 5.90 Lakhs **Status:** On-going
Consultancy Projects (New)			
16.	Water Quality Studies for Tehri Reservoir Tehri HPP (4x250MW)	Dr. Sudhir Kumar, Director Dr. R.P. Pandey, Sc, 'G' Dr. M.K. Sharma, Sc, 'F' (PI) Dr. Pradeep Kumar, Sc, 'D' Dr. Rajesh Singh, Sc, 'D' Mrs. Babita Sharma, SRA	2 Years (02/23-01/25) **Sponsored by:** THDC, India Limited **Cost:** Rs. 6.91 Lakh **Status:** Proposed

		Mrs. Been Prasad, SRA	
17.	Technical Evaluation of Infiltration Well of Dadua-Bhandali Mineral Water Pumping Scheme on Alaknanda River for Feasible Options to Maintain the Supply	Dr. R.P. Pandey, Sc, 'G' (PI) Dr. Pradeep Kumar, Sc, 'D' Dr. Rajesh Singh, Sc, 'D' Dr. V. K. Tyagi, Sc. 'D'	02 Weeks (02/23-03/23) **Sponsored by:** Uttarakhand Peyjal Nigam **Cost:** Rs.1.62 Lakh **Status:** On-going

PUBLICATIONS

International Journal	National Journal	International Conference	National Conference	Book	Book Chapter	Total
23	-	19	02	02	08	**54**

- **International Journals (23 Nos.):**

1. Ali Mohammad Rahmani, Vinay Kumar Tyagi, Neelam Gunjyal, A. A. Kazmi, Chandra Shekhar P. Ojha, Konstantinos Moustakas (2022) Hydrothermal and thermal-alkali pretreatments of wheat straw: co-digestion, substrate solubilization, biogas yield and kinetic study. Environmental Research, 216 (1), 114436.
2. Ali Mohammad Rahmani; Vinay Kumar Tyagi; Banafsha Ahmed; A. A. Kazmi; Chandra Shekhar P. Ojha; Rajesh Singh (2022) Critical insights into anaerobic co-digestion of wheat straw with food waste and cattle manure: Synergistic effects on biogas yield and kinetic modeling. Environmental Research, 212, 113382.
3. Ankur Rajpal, Akansha Bhatia, Nilesh Tomar, A A Kazmi, Chandra Shekhar P Ojha, Vinay Kumar Tyagi (2022) Insight into a novel post-anoxic integrated biofilm process for wastewater treatment and reclamation. Journal of Water Process Engineering, 49, 102957 [IF: 5.485].
4. Anwar Khursheed; Muntjeer Ali, Faris Mohammad A. Munshi, Abdulrhman Fahmi Alali, Mohab Amin Kamal, Abdulaziz Ibrahim Almohana, Omar Alrehaili, Rubia Z. Gaur, Vinay Kumar Tyagi, Abid A. Khan, Gaurav Goel (2022) Enhanced Combined Assimilative and Bound Phosphorus Uptake in Concurrence with Nitrate Removal in Pre-Anoxic Cyclic Sequencing Batch Reactor. Environmental Technology and Innovation, 28, 102909.
5. Balasundaram, G., Vidyarthi, P.K., Gahlot, P., Arora, P., Kumar, V., Kumar, M., Kazmi, A.A., Tyagi, V.K. (2022) Energy feasibility and life cycle assessment of sludge pretreatment methods for advanced anaerobic digestion. Bioresource Technology, 357, 127345.
6. Ganesh Sude, Ankur Rajpal, Vinay Kumar Tyagi, Kapil Sharma, Pravin Kumar Mutiyar, B.K. Panday, R.P. Pandey, Absar Ahmad Kazmi (2023) Evaluation of sludge quality in Indian sewage treatment plants to develop quality control indices. Environmental Science and Pollution Research (Accepted). https://doi.org/10.1007/s11356-023-25320-1.
7. Khursheed, Anwar; Munshi, Faris Mohammad A; Almohana, Abdulaziz Ibrahim; Alali; Kamal, Mohab Amin; Alam; Shamshad, Alrehaili, Omar; Islam, Dar Tafazul; Kumar, Manish; Varjani, Sunita; Kazmi, AA, Tyagi, Vinay Kumar (2023) Resolution of Conflict of Reduced Sludge Production with EBPR by Coupling OSA to A^2/O Process in a Pilot Scale SBR. Chemosphere. 318, 137-345.
8. Kumar, A., Tripathi, V. K., Kumar, P. and Rakshit, A. (2022). Assessment of hydrologic impact on flow regime due to dam inception using IHA framework. Environmental Science and Pollution Research. [IF: 5.053]
9. Malhotra, M., Aboudi, K., Pisharody, L., Singh, A., Banu, R., Bhatia, S.K., Varjani, S., Kumar, S., González-Fernández, C., Kumar, S., Singh, R., Tyagi, Vinay Kumar (2022) Biorefinery of anaerobic digestate in a circular bioeconomy: Opportunities, challenges and perspectives. Renewable and Sustainable Energy Reviews, 166, 112642.
10. Monika Yadav, Venkatesh Balan, Sunita Varjani, Vinay Kumar Tyagi, Gaurav Chaudhary, Nidhi Pareek, Vivekanand (2022) Multidisciplinary Pretreatment Approaches to Improve the Bio-methane Production from Lignocellulosic Biomass. BioEnergy Research. [IF: 3.852].
11. Pallavi Gahlot; Vinay Kumar Tyagi, Gowtham Balasundaram; A.E. Atabani; Surinder Suthar; A.A. Kazmi; Libor Štěpanec; Dagmar Juchelková; Arvind Kumar (2022) Principles and

potential of Thermal hydrolysis of sewage sludge to enhance anaerobic digestion. Environmental Research. [IF: 8.431]

12. Pandey, RP (2021) Hydrological Drought in India – An institutionalized systemic hydrological management challenge (Case study 2). A policy-note contribution in FAO publication entitled "*A rapid review of drought risk mitigation measures – Integrated drought management*" (Author: Caroline King-Okumu; Eds: Maher Salman, FAO-UN and Daniel Tsegai, UNCCD). Rome, FAO, pp. 128-131, https://doi.org/10.4060/cb7085en.
13. Phurba Tamang, Vinay Kumar Tyagi, Neelam Gunjyal, Ali Mohammad Rahmani, Rajesh Singh, Pradeep Kumar, Banafsha Ahmed, Pooja Tyagi, Rajesh Banu, Sunita Varjani, A.A. Kazmi (2023) Free nitrous acid (FNA) pretreatment enhances biomethanation of lignocellulosic agro- waste (Wheat Straw). Energy, 264, 126249.
14. Preethi, J. Rajesh Banu, Gopalakrishnakumar, Vinay Kumar Tyagi, Amit Kumar Bajhaiya, Poornachandar Gugulothu, M. Gunasekaran (2022) Biohydrogen production from waste activated sludge through thermochemical mechanical pretreatment, Bioresource Technology, 358, 127301.
15. R. Yukesh Kannah, M. Dinesh Kumar, S. Kavitha, J. Rajesh Banu, Vinay Kumar Tyagi, P.Rajaguru, Gopalakrishnan Kumar (2022) Production and recovery of polyhydroxyalkanoates (PHA) from waste streams – A review, Bioresource Technology, 366, 128203.
16. Rajesh Banu, S. Kavitha, Yukesh Kannah Ravi, Jayakodi J, Gopalakrishnan Kumar, Vinay Kumar Tyagi and Shashi Kant Bhatia (2023) Effect of surfactant addition on disperser disintegration of water hyacinth: a new insight to overcome the inhibitory effect of lignin on methanogenesis energy and economic aspects. Sustainable Energy & Fuels. https://doi.org/10.1039/D2SE01194H.
17. Sandeep K. Malyan, Omkar Singh, Amit Kumar, Gagan Anand, Rajesh Singh, Sandeep Singh, Zhiguo Yu, Jhlasesh Kumar, Ram K. Fagodiya, Amit Kumar (2022) Greenhouse Gases Trade-Off from Ponds: An Overview of Emission Process and Their Driving Factors , https://doi.org /10.3390/w14060970.
18. Sharma, M. K., Kumar, Pradeep, Bhanot, Kunarika and Prajapati, Parul, Wadhwa, Udita, Tomar, Garima, Goyal, Rakesh, Prasad, Beena and Sharma, Babita (2022) Study of hydrochemical and geochemical characteristics and solute fluxes in Upper Ganga Basin, India, J. Asian Earth Sciences: X, https://doi.org/10.1016/j.jaesx.2022.100108 (IF: 3.374).
19. Shashi Kant Bhatia, Vishal Ahuja, Neha Chandel, Ranjit Gurav, Ravi Kant Bhatia, Muthuswamy Govarthanan, Vinay Kumar Tyagi, Vinod Kumar, Arivalagan Pugazendhi, J Rajesh Banu, Yung-Hun Yang (2022) Advances in algal biomass pretreatment and its valorisation into biochemical and bioenergy by the microbial processes. Bioresource Technology, 358, 127437 [IF: 9.642].
20. Singh S., Rawat M., Malyan S. K., Singh R., Tyagi V. K., Singh K., Kashyap S., Kumar S., Sharma M., Pandey B. K., Pandey R. P. (2023). Global distribution of pesticides in freshwater resources and their remediation approaches. Environmental Research (Accepted) (I.F.: 8.431).
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22. Vivek Narisetty, Maureen Chiebonam Okibe, K. Amulya, Esther Oreoluwa Jokodola, Frederic Coulon, Vinay Kumar Tyagi, Piet N.L. Lens, Binod Parameswaran, Vinod Kumar (2022) Technological advancements in valorization of second generation (2G) feedstocks for bio-based succinic acid production. Bioresource Technology, [IF: 9.642].
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- **National Journals: NIL**
- **International Conferences (19 nos.) :**

1. K. Singh, R. Singh, G. Pandey, 2022. Hydrogeochemistry, solute source identification, and health risk assessment of groundwater of cancer prone region in India. Water Supply (In press) https://doi.org/10.2166/ws.2022.435 (IF: 1.768).
2. S. Singh, C. Maithani, S. K. Malyan, A. Soti, N. M. Kulshreshtha, R. Singh, U. Brighu, A. B. Gupta, J. Kumar, S. Yadav, O. Singh, V. C. Goyal, 2022. Comparative performance and metagenomic analysis of deep and shallow cells of a full-scale HFCW having sequentially decreasing depths reveals vast enhancement potential. In International Conference on Biotechnology for Sustainable Bioresources and Bioeconomy (BSBB-2022) organized by the Indian Instit.
3. Balasundaram, G., Gahlot, P., Tyagi, V.K., Kazmi, A.A. (2022) "Coupled Steam explosion with anaerobic digestion to produce class A biosolids in municipal wastewater treatment plants in India: 7th India Water Week conclave,1st -5th November 2022, Greater Noida, India Oct 29-31, 2022 (ORAL, Second Prize)
4. Balasundaram, G., Gahlot, P., Tyagi, V.K., Kazmi, A.A. (2022) "Fostering solubilisation and biodegradation of sewage sludge using steam explosion pretreatment: 7th International conference on opportunities and challenges in agricultural, environmental and biosciences for global development (OCAEBGD), Oct 29-31, 2022 Goa, India (ORAL)
5. Balasundaram, G., Gahlot, P., Tyagi, V.K., Kazmi, A.A. (2022) "Investigating the effects of pilot scale thermal pretreatment facility on class A biosolids production from sewage sludge". In : 13th International symposium on southeast asian water environment , 13th-15th December 2022, Bangkok, Thailand (ORAL).
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7. Gahlot, P, Balasundaram, G, Tyagi, V.K., Kazmi, A.A. (2022) "Metagenomic analysis of sewage sludge microbiota and their potential to metabolize micropollutants". In: 13th International symposium on southeast Asian water environment, 13th-15th December 2022, Bangkok, Thailand (ORAL).
8. Gupta, A., Jain, M.K., and Pandey, R.P. Comparison between Gridded and Point Datasets for Drought Analysis in the Semi-arid Basin of Peninsular India. Abstract ID: 1057986, Paper No. H45F-07. Presented at AGU Fall Meeting, Chicago IL, USA, December 12 – 16, 2022.
9. Kalzang Chhoden, Chhavi K. Manchanda, Impact Assessment of Ponds on groundwater quality in vicinity area of District Ropar, Punjab, Challenges of Sustainability of Ground Water Resources, Proceeding in 7th India Water Week, 2022.
10. Kaptan Singh, Rajesh Singh, Govind Pandey, Sandeep Singh, Sandeep K Malyan, 2022. Scenario of Hydrochemistry, Health risk, and Solute Source in Groundwater of Bathinda District, Punjab. In India Water Week (IWW - 2022) organized by NWDA, MoJS, GOI during Nov. 01-05, 2022.
11. Kaptan Singh, Rajesh Singh, Govind Pandey, Sandeep Singh, Sandeep K Malyan, 2022. Assessment of Lead in groundwater, health risk and leaching behavior from sediments of Mansa district. In International Groundwater Conference (IGWC 2022) organized by Department of Hydrology, IIT Roorkee during Nov. 02-04, 2022.
12. Kumar, Mohit, Sharma, M. K. and Malik, D. S. (2023) Numerical groundwater flow and sulphate transport modelling in gypsum enriched aquifer of Bemetara district, Chhattisgarh state, India, Online International Conference on Environment, Water, Agriculture, Sustainability and Health (EWASH-2022): Strategizing A Greener Future & 4th Annual Meet of STE, Organized by Hindu College, University of Delhi, Delhi and Save The Environment, 12-13 January 2013, Abstract Book & Souvenir, Page 29.
13. Sandeep K Malyan, Rajesh Singh, Sandeep Singh, Arti Bhatia, 2022. Assessment of Greenhouse gas emissions from a Horizontal Subsurface Flow Constructed wetland in Roorkee, India. In India Water Week (IWW - 2022) organized by NWDA, MoJS, GOI during Nov. 01-05, 2022.

14. Sandeep Singh, Sandeep K Malyan, Kaptan Singh, Rajesh Singh, 2022. Evaluation of Metals, Pesticides, PAHs and PCBs in groundwater of Malwa Region of Punjab, India. India Water Week (IWW-2022) organized by NWDA, MoJS, GOI during Nov. 01-05, 2022.
15. Sharma, M. K., Kumar, Pradeep, Sharma, Babita, Prasad, Beena and Bhanot, Kunarika (2022) Hydrochemical behaviour, its controlling processes and importance of p(CO2) signature of meltwater of River Bhagirathi in Upper Ganga Basin, India, Paper presented in 7th India Water Week 2022, India Expo Centre, Greater Noida, 1-5 November 2022.
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19. Tyagi, V.K., Arora, P., Kapoor, A., Kazmi,A.A. (2022) "Biorefinery of Municipal Solid Waste in a Circular Bio-economy: Case study of 100 TPD Mechanical-Biological Treatment Plant" in International Conference on Biotechnology for Sustainable Bioresources and Bioeconomy (BSBB-2022) organized by Indian Institute of Technology, Guwahati, India, December 7-11, 2022.

- **National Conferences (03 Nos. Key note/Lead Paper):**

1. Pandey, R.P. and R.V. Galkate (2022) "Impact of Climate Change on Occurrence of Regional Droughts". Invited lead paper presented in "31st National Conference on Innovative Resource Management Approaches for coastal and Inland Ecosystems to Sustain Productivity" and Climate Resilience, 13-15 Oct 2022, Navsari, Organized by Agricultural University, Navsari, Gujarat.
2. Pandey, R.P. (2022). Environmental Challenges and Water Resources Management for Resilient Ecosystem in Arid Regions invited Key paper presented in National Conference on Desert Ecosystems: Status, Emerging Challenges and Perspectives, November 15-16, 2022, Jaipur.
3. Pandey R.P. (2023). Challenges on sustainability of water resources for drinking water and irrigation. Water Summit: 2023 on"Water Security in India: Challenges & Prospects". Organised jointly by the Center for Advance Water Technology and Management and Gurugram University, Manav Rachna, International Institute of Research and Studies, 24th February 2023, Faridabad, 121004 – Haryana,

- **Book Chapters (08 Nos.):**

1. Ahmed Tawfik, Vinay Kumar Tyagi and Dominique Patureau Fate of emerging contaminants in anaerobic digestate. In: Tyagi, V.K., Kaoutar, A., Eskicioglu, C. (eds) Anaerobic Digestate Management. International Water Association Publishing (IWAP). UK. Pp. 327-338, Chapter 15,ISBN: 9781789062748
2. Akansha Bhatia, Ankur Rajpal, Bhaskar Jyoti Deka, A.A. Kazmi, Vinay Kumar Tyagi (2022) Valorization of Biowaste to Biowealth Using Cellulase Enzyme During Prehydrolysis Simultaneous Saccharification and Fermentation Process. In: Enzymes in the Valorization of Waste. Ed. Pradeep Verma, CRC Press, pp. 25-37, eBook ISBN 9781003187721
3. Manojkumar Y, Sridhar Pilli, R.D. Tyagi, PuspenduBhunia, Sumanth C, Vinay Kumar Tyagi and Ashok Pandey (2022) Per- and poly-fluroalkyl substances (PFASs): An introduction. In: Sustainable Treatment Technologies for Per- and Poly-fluoroalkyl Substances. Currents

Development in Biotechnology and Bioengineering Series. Elsevier Publishing. pp.1-12, ISBN: 978-0-323-99906-9.

4. Muntjeer Ali, Sridhar Pilli, PuspenduBhunia, R.D. Tyagi, Ashok Pandey and Vinay Kumar Tyagi (2022) Occurrence, fate, and persistence of perfluorinated compounds (PFCs) in wastewater treatment systems. In: Sustainable Treatment Technologies for Per- and Poly-fluoroalkyl Substances. Currents Development in Biotechnology and Bioengineering Series. Elsevier Publishing. pp. 207-233, ISBN: 978-0-323-99906-9.
5. Pallavi Gahlot, Kaoutar Aboudi and Vinay Kumar Tyagi (2022) Effect of digestate recirculation on anaerobic digestion performance. In: Tyagi, V.K., Kaoutar, A., Eskicioglu, C. (eds) Anaerobic Digestate Management. International Water Association Publishing (IWAP). U.K. Pp. 247-259. Chapter 11, ISBN: 9781789062748
6. Pallavi Gahlot, Kaoutar Aboudi, Ahmed Tawfik and Vinay Kumar Tyagi (2022) Biochar-augmented anaerobic digestate treatment. In: Tyagi, V.K., Kaoutar, A., Eskicioglu, C. (eds) Anaerobic Digestate Management. International Water Association Publishing (IWAP). UK. Pp. 265-282, Chapter 12,ISBN: 9781789062748
7. Pandey, RP (2021) Hydrological Drought in India – An institutionalized systemic hydrological management challenge (Case study 2). A policy-note contribution in FAO publication entitled "*A rapid review of drought risk mitigation measures – Integrated drought management*" (Author: Caroline King-Okumu; Eds: Maher Salman, FAO-UN and Daniel Tsegai, UNCCD). Rome, FAO, pp. 128-131, https://doi.org/10.4060/cb7085en.
8. Sanket Dey Chowdhury, R.D. Tyagi, Sridhar Pilli, Vinay Kumar Tyagi, Ashok Pandey and PuspenduBhunia (2022) Per- and poly-fluoroalkyl substances (PFASs) in water and wastewater In: Sustainable Treatment Technologies for Per- and Poly-fluoroalkyl Substances. Currents Development in Biotechnology and Bioengineering Series. Elsevier Publishing. pp. 299-327, ISBN: 978-0-323-99906-9.

- **Books (02 Nos.):**

1. Tyagi, V.K., Aboudi, K., Eskicioglu, C. (2022) Ananerobic Digestate Management. International Water Association publishing (IWAP). pp 350 (ISBN: 9781789062)
2. Sridhar Pilli, Puspendu Bhunia, Vinay Tyagi, Rajeshwar Tyagi, Jonathan Wong, Ashok Pande (2022) Current Developments in Biotechnology and Bioengineering Sustainable Treatment Technologies for Pre- and Poly-flourakyl Substances. Elsevier (UK). pp 350 (ISBN: 9780323999069)

TRAINING COURSE/WORKSHOP ORGNIZED (04 Nos.):

SN	Topic	Duration	Place
1	Training Course titled "Hands on Advanced Instrumentations in Water Quality Analysis" under NHP (Coordinator: Dr. M. K. Sharma)	5 Days 16-20 January 2023	Roorkee
2	Training Course titled " Environmental Data Processing" under NHP(Coordinator Dr. Pradeep Kumar)	5 Days 30 January - 03 February 2023	Roorkee
3	Training Course titled " Water Quality Monitoring & Management" under NHP (Coordinators: Dr. Rajesh Singh, Dr. V. K. Tyagi and Dr. Kalzang)	5 Days 13-17 February 2023	Roorkee
Following training programme is also proposed to be organized during the 2022-23			
4	Training Course titled "Water and Wastewater Treatment" under NHP (Coordinators: Dr. V. K. Tyagi, Dr. Rajesh Singh, and Dr. Kalzang)	5 Days 20-24 March 2023	Roorkee

AWARENESS ACTIVITIES ORGANIZED (04 Nos.):

1. One-day awareness workshop on "Water Conservation & Water Security" under "Azadi Ka Amrit Mohotsav" at Arya Swaroop Arya Saraswati Vidya Mandir, Delhi Road, Roorkee on 21 April 2022.
2. One-day training workshop on Social Awareness about Water Conservation and Water Security under "Azadi Ka Amrit Mohotsav" at Government Inter college, Bhalaswagaj, Bhagwanpur Block, Roorkee Tehsil, May 19, 2022.
3. One-day training workshop on Social Awareness about Water Conservation and Water Security under "Azadi Ka Amrit Mohotsav" at Jal Vihar Colony, National Institute of Hydrology, Roorkee Tehsil, June 15, 2022.
4. One-day training workshop on Social Awareness about Water Conservation and Water Security under "Azadi Ka Amrit Mohotsav" at Methodist PG Girls Degree College, Roorkee, August 3, 2022.

PROPOSED WORK PROGRAMME FOR THE YEAR 2023-24

S. N.	Study	Study Team	Duration/Status
Sponsored Projects (Ongoing)			
1.	Water Efficient Irrigation by Using SCADA System For Medium Irrigation Project (MIP) Shahnehar	Dr. R. P. Pandey, (PI) Er. Jagdeesh Patra, Dr. Rajesh Singh Sh. N. K. Bhatnagar	3 Years (12/17-03/23) Further Extension till May 2023 **Project Cost**: 75 Lakh Sponsored by: NHP Status: In-progress
2.	Anaerobic Co-digestion of Thermochemically Pretreated Organic Fraction of Municipal Solid Waste and Sewage Sludge: Effect on Process Performance and Microbial Community Development	Dr. Vinay Kumar Tyagi, Sc, 'D' (PI)	5 Years (2018-2023) **Project Cost**: 106 Lakhs **Sponsored by**: DBT **Status**: In-progress
Collaborative Projects (Ongoing)			
3.	Isotopic and geochemical approach to study vulnerable confined and unconfined drinking water aquifers in Varanasi and surrounding area, India	Dr. Rajesh Singh (PI) Dr. R.P. Pandey BHU, Varanasi (Lead) Other Collaborators: BARC, Mumbai, ICER, Hungary	3 Years (07/21-06/24) **Sponsored by**: BHU **Status**: In-progress
4	Comprehensive characterization of variably processed sewage sludge in Ganga basin to classify its suitability for safe disposal	Dr. Vinay Kumar Tyagi, Sc, 'D' (Co-PI) Dr. A.A.Kazmi (PI, IITR)	02 Years (01/22-12/23) **Sponsored by**: Central Pollution Control Board (CPCB)-NMCG
5	SARASWATI 2.0 - Identifying best available technologies for decentralized wastewater treatment and resources recovery for India	Dr. Vinay Kumar Tyagi, Sc, 'D' (Co-PI) Dr. A.A.Kazmi (PI, IITR)	4 Years (03/20-02/24) **Sponsored by**: Department of Science & Technology (DST)
Internal Study (Ongoing)			
6.	Characterisation of Groundwater Dynamics in Krishna-Godavari Delta interims using groundwater levels, Hydrochemistry, Isotopes and Emerging Contaminants	Dr. M. K. Sharma, Sc. F (PI) Dr. Suhas Khobragade, Sc. 'G' Dr. Rajesh Singh, Sc. 'D'	2 Years (04/22-03-24) **Status:** In-progress
7.	Understanding Arsenic mobilization in groundwater of Haridwar and formulating remediation measures	Dr. Rajesh Singh, Sc. D (PI) Dr. R. P. Pandey, Sc. G Dr. Sumant Kumar, Sc. D, Dr. Pradeep Kumar, Sc. D Dr. M. K. Sharma, Sc. F Dr. V. K. Tyagi, Sc, D Dr. Kalzang Chhoden, Sc. C	3 Years (07/21-06/24) **Status:** In-progress
8.	Simulation of Non-Point Source Pollution Processes in Song River	Dr. Pradeep Kumar, Sc. D (PI) Dr. M.K. Sharma, Sc. F Dr. Rajesh Singh, Sc. D	4 Years (11/19-10/23) **Status:** In-progress
9.	Hydrological Studies for the Conservation of Rewalsar Lake	Dr. Kalzang Chhoden, Sc. C, (PI) Dr. Rajesh Singh, Sc. D Dr. R. P. Pandey, Sc. G Dr. Pradeep Kumar, Sc. D Dr. Vinay Kumar Tyagi, Sc. D Er. Omkar Singh, Sc. G Dr. Shuhas Khobragade, Sc. G Dr. D.S. Malik, Professor, GKU,	3 Years (12/22-11/25) **Status:** Proposed

		Haridwar	
10.	Comprehensive evaluation of disinfection units of STPs in Ganga basin: Occurrence and control the formation of emerging oxidation precursors	Dr. Vinay Kumar Tyagi, Sc. D (PI) Dr. Rajesh Singh, Sc. D Dr. Mukesh K. Sharma, Sc. F Dr. Pradeep Kumar, Sc. D Er. J. P. Patra, Sc. D Dr. Kalzang Chhoden, Sc. C Dr. R.P.Pandey, Sc. G	3 Years **Status:** Proposed
	Consultancy Projects (Ongoing)		
11.	Estimation of Sediment Load and GHG Emission from Reservoir of Chamera-1 Power Station, NHPC	Dr. J V Tyagi Dr. R.P. Pandey, Sc 'G' Dr. Rajesh Singh, Sc 'D' (PI) Dr. M.K. Sharma, Sc. 'F' Sh. Rakesh Goyal, Tech. Gr. I	15 Months (12/21-03/23) **Sponsored by:** Innovante Water Soluation Pvt. Ltd. Roorkee **Project Cost**: Rs. 3.245 Lakh **Status:** On-going
12.	Performance evaluation of Nano Catalytical Instant Water Converter (NCIWC) equipment for water and wastewater treatment	Dr. J.V. Tyagi Dr. R.P. Pandey, Sc 'G' Dr. Rajesh Singh, Sc. 'D' & PI Dr. Sumant Kumar, Sc. 'D' Dr. Vinay Tyagi, Sc. 'D' Dr. M.K. Sharma, Sc. 'F' Dr. Pradeep Kumar, Sc. 'D'	06 Months (05/22-11/22) Further Extension Requested **Sponsored by:** Envirogreen Minetech India Pvt. Ltd., Indore M.P. **Project Cost**: Rs. 5.90 Lakhs **Status:** On-going
13.	Water Quality Studies for Tehri Reservoir Tehri HPP (4x250MW)	Dr. Sudhir Kumar, Director Dr. R.P. Pandey, Sc, 'G' Dr. M.K. Sharma, Sc, 'F' (PI) Dr. Pradeep Kumar, Sc, 'D' Dr. Rajesh Singh, Sc, 'D' Mrs. Babita Sharma, SRA Mrs. Been Prasad, SRA	2 Years (02/23-01/25) **Sponsored by:** THDC, India Limited **Project Cost:** Rs. 6.91 Lakh **Status:** Proposed

Study – 1 (Sponsored Project)

1. **Title of the Study:** Water Efficient Irrigation by using SCADA system formedium Irrigation Project (MIP) Shahnehar
2. **Study Group:**

Project Investigator/Co-Project Investigator
Dr. R.P. Pandey, Scientist G. Er. Jagdish Prasda Patra, Scientist D Dr. Rajesh Singh, Scientist D, Sh. N. K. Bhatnagar, Scientist B
Collaborating Agency
Department of Irrigation & Public Health Engg. (I&PHE), Hydrology C&M Division, Tutikandi, Shimla-4. Himachal Pradesh

Type of study: PDS
Total Project Cost: Rs.75.0 lakh (**Funded by NHP)**
NIH Cost Allocation Rs. 18.1 lakh

Project Duration: **3-years**

Date of start: **December, 2017**

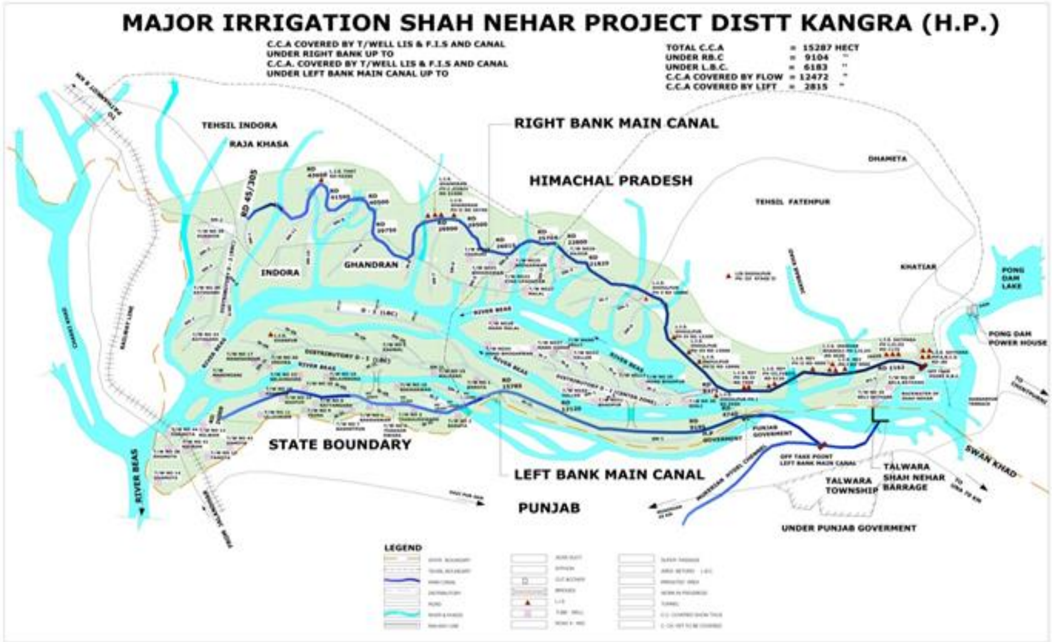
Scheduled Date of Completion: **March, 2023 (after extension)**

OBJECTIVES OF THE STUDY:
The primary objectives of this study is to **Devise a suitable approach to improve irrigation water use efficiencyin Shah Nehar Project.** The specific objectives of the study are as follows:

- To develop monitoring, supervisory control and modernize system for Agriculture Irrigation water.
- Paradigm shift in the approach from a supply-based system to a demand-based sustainable system.
- Real time monitoring of water availability at head works.
- Performance evaluation of Left Bank Canal and Right Bank Canal of MIP Shah Nehar Project.
- Identify issues that need to be addressed to improve project performance
- Suggest measures to improve water use efficiency &sustainability up to farm level
- Integrating Warabandi with SCADA system.

Study Area : <u>Shah Nehar Command Area, Himachal Pradesh</u>
Shah Nehar Irrigation Project in District Kangra, Himachal Pradesh is first Major Irrigation Project of the state amounting to Rs.143.32 crore was approved by the HP Govt to irrigate 15287 hectares of land of 93 villages situated on right and left bank of river Beas by constructing two numbers of main canals on each bank with a length of 45.30 and 25.69 km respectively. The water was fetched from outfall of Pong Dam by signing agreement between Govt. of HP and Punjab Govt. on 4/8/1983.The index map of Shah Nehar project command area is given in Figure below.

Whole of the Right bank canal enroots through the jurisdiction of Himachal Pradesh whereas about 4.0 Km of LBC out of 25.69 km falls in the state of Punjab. Out of total cost of Rs 143.32 crore the Govt. of Punjab was to share Rs 88.49 crore and remaining Rs 54.83 crore was to be borne by the Govt. of H.P. Later on due to price escalation revised DPR was prepared and approved to the tune Rs 387.17 crores at price level 2010 in 110th meeting of advisory committee of CWC. The project was included under Accelerated Irrigation Benefit Program (*AIBP*) with 90% Central Aid and balance 10% had to be shared by Govt. of Punjab and HP in the ratio of 61.74% and 38.26%.



Description of the Problem

At present the Shah Nehar project experiences improper distribution of water into the agricultural fields resulting into low yield of crops and therefore necessity of water efficient irrigation system by using SCADA. The primary objectives of the proposed study are to enhance water use efficiency, minimize water losses and to increase productivity in the command area of Shah Nehar project. The Shah Nehar project is first major Irrigation project in Himanchal Pradesh. Presently, water is being supplied to 93 villages comprise of 15287 hectares Culturable Command Area (CCA) through several outlets provided in the main canal. From each outlet the water is transported by gravity or lift scheme to each chak proposed in the command area development. The water demand of each outlet is based on the cropping pattern proposed in the respective chak. The roster of water demand is based on the warabandi schedule prepared by the Irrigation & Public Health Department in consultation with Krishi Vikas Sangh/Water User Associations.

It is proposed to quantify available water at the head-works of the canal system during cropping period, estimation of irrigation water requirement for existing cropping pattern, assessment of losses at the conveyance, distribution and application of water in the command area. The study will be helpful in identification of the potential area which requires appropriate land and water management intervention for improvement of water use efficiency. Further the study will be useful in quantifying the potential of improvement in irrigation water use efficiency in the Shah Nehar command area.

The HP IPH Department has listed the problems of irrigation water management in the Shah Neha Project based on input received from the farmers, observations made during their field visits and consultation with specialized agronomists as follows:

- ✓ Non availability of water during peak demand of crops at the tail end of command area.
- ✓ No check over theft of water from the main canals.
- ✓ Irrigation systems play vital role for sustainable agricultural development in Himachal Pradesh, but major problem of which is rather low efficiency of water use.
- ✓ No accountability due to absence of water accounting & audits.
- ✓ Poor and low consistency management of the irrigation systems efficiency.
- ✓ Lack of reliable monitoring network and supervisory control for irrigation systems.
- ✓ Non availability of effective decision making tool to improve irrigation management.
- ✓ Huge water loss due to random irrigation process.
- ✓ Lack of awareness about modern and water efficient irrigation methods.

Proposed Methodology

The purpose of the proposed study is to examine the present status of the Shah Nehar Irrigation Project water use efficiency, quantify the water losses in the main canal system & distributaries, water courses and field application. Determination of time based crop water demand and supply for existing cropping pattern and identification of irrigation system components needing water management interventions to improve water use efficiency of system and maximize the benefit from the Shah Nehar project. The work component will include the following:

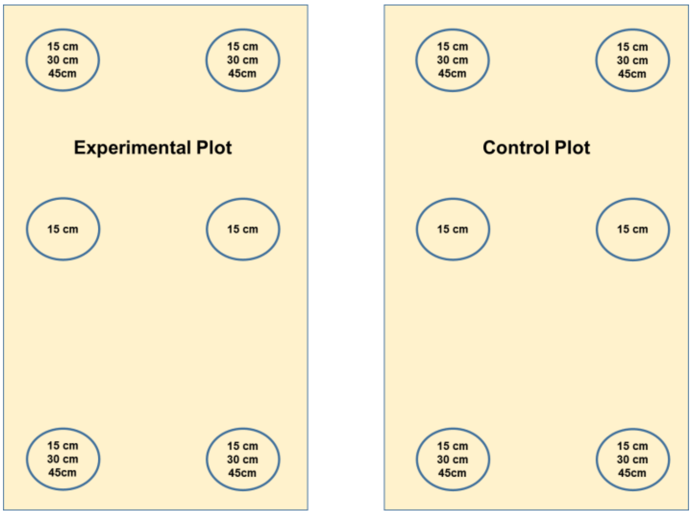
1. Monitoring of supply and distribution of water in conveyance, distributary outlets and the on form irrigation application at selected experimental sites.
2. Assessment of the real time availability of water at head works, at various outlets in the main canal and tail ends of distribution system during the Rabi, Kharif and Zaid crop period.
3. Assessment of site specific water requirement for suitable time-steps during cropping periods in different seasons
4. Devising a methodology regarding equitable distribution of water to the farmers in each crop period from head to tail reaches by using SCADA.
5. Develop a system of water supply database of quantum of water used to each beneficiary so the charges can be levied accordingly.
6. Devising a possible system of change in cropping pattern owing to real time monitoring of available water at various reaches of the canal.
7. Identification and evaluation of intervention to minimize water losses throughout the canal and distribution system, water courses and in the field application to enhance the water use efficiency.

From the data collection and analysis of the data, Water efficient Irrigation by using SCADA System will be provided so that water can be used more efficiently and hence it will increase the effectiveness of the Irrigation Project.

Progress of Work

The team NIH Scientist visited study area and conducted detailed survey of Shahnehar Project Command Area, along with Himachal Pradesh I &PHE department officials. Detailed plan for the selected experiment sites was prepared after discussion with I&PHE officials. after field survey to finalize the project modalities and work plan for the study. The pilot sites for detailed experimentation have been identified. Field investigation and instrumentation for field experimentation for the study has been finalization after meeting with the project team of the lead organization (I&PHE, Shimla) to setup monitoring schedule. The irrigation command site for SCADA implementation has been finalized.

1. The meteorological data for the assessment of present irrigation requirement has been collected from BBMB meteorological station at pong dam site.
2. The estimation of Pet and the crop water requirement for the study has been worked out.
3. The Himachal Pradesh I &PHE department has been further requested to obtain data from Kangra Agriculture College/other stations in the vicinity of the project site.
4. Base maps for the study sites have been prepared.
5. The experimental sited identified are as follows:
6. Lift Irrigation Scheme (LIS) Sthana, Terrac Sub-Division—for SCADA experimentation.
7. Selected sites/field plots in distributary-1 (D-1) command area –Badukhar Sub-Division -- for experimentation-1 in middle reaches.
8. Selected sites/field plots in distributary-2 (D-2) command area- for experimentation-2 in tail reaches.
9. Field investigations have been carried out and the layout of the experimental plots for installation of moisture sensors for measurement of crop root-zone moisture at the three sites have been prepared as follows.



S.N. (1)	Instrument/ Sensor (2)	At one Site (3)	For Three Site (4)=(3)*3
1	Moisture and temperature sensor • at 15, 30, 45 cm depth • at 15 cm depth	 8 4	 24 12
2	Flow meter (Discharge measurement)	3	9
3	Data logger/transmitter	1*	3*

10. Department of I & PHE, Shimla, Govt. of Himachal has processed for procurement of discharge & Moisture measurement sensor and installation in the field. The procurement is under process at present.
11. Installation of sensors and telemetry system for soil moisture monitoring and data transmission. (Work in progress).
12. Estimation of Irrigation requirement for different crops in the Shahnehar Command areas using meteorological data has been carried out and it will be presented in the working group meeting for comments/suggestion, if any. The summary of the estimated crop water requirement is as follows.

    Crop Water Requirement (CWR), Potential Evapotranspiration (ETo) and Irrigation scheduling in the subtropical humid region are crucial in efficient use of irrigation supply, water resources assessment, hydrology and designing the irrigation projects as the supply of water through rainfall varies in space and time. In this context, dependable monthly rainfall at 80% and 50% probability level during the period 1982-2018 has been to assess distribution of effective rainfall and the minimum expected rainfall during the crop growing period in Shahnahar command area. FAO (Food and Agriculture Organisation) CROPWAT 8.0 crop simulation model has been used to estimate reference evapotranspiration (ETo), effective rainfall, crop water and irrigation requirement and irrigation scheduling for the Rice and Wheat crop. It is found that the average annual ETo is 4.11 mm/day and varies with highest value of 6.67 mm/day in the month of June and lowest value in January (1.99 mm/day). From the observation of probability analysis at P80 and P50, it is also found that the maximum deficit can be in the order of 33.02 mm in month of July and minimum deficit of 1.32 mm rainfall in the month of November. For seasonal agricultural planning, the 80% dependable rainfall level may be considered for safer and better irrigation management planning in the study area.

Further Proposed Work Plan for next year

1. Application of field irrigation under measured and controlled conditions. (replication at three sites).
2. Quantification of irrigation water loss in different conveyance & distribution systems, field channels, and irrigation application methods.
3. To evolve irrigation scheduling (revision) considering the crops, soil moisture and prevailing climatic conditions.
4. Demonstrations and conducting workshops on OFWM practices for all the stakeholders including farmers.
5. To review the role of existing Water Use Associations (WUA) and suggest suitable
6. To extend the improved/scientific modifications for encouraging the better OFWM practices and equitable water distribution among the farmers.
7. Review of the existing Cropping patterns during different sowing seasons and suggest suitable crops for each season to enable optimum utilization of available water.

Deliverables:

1. Estimates of water availability at headwork's and irrigation water requirements for various crops a different growth stages & time period.
2. Quantification of irrigation water loss in different conveyance & distribution systems, field channels, and irrigation application methods.
3. Identification of components of irrigation system needing intervention to enhance water use efficiency.
4. Experimental assessment of SCADA based approach in the enhancement of water use efficiency.

Study - 2 (Sponsored Project)

1. **Title of the Study:** Anaerobic co-digestion of organic fraction of municipal solid waste and sewage sludge: Effect of thermal-chemical pretreatment on process performance and microbial community development

2. **Study Group:**

Project Investigator	Dr. Vinay Kumar Tyagi, Sc. 'D', EHD
Research Staff	Ms. Banafsha Ahmed, PhD Student Mr. Ali Mohammad Rahmani, PhD Student

3. **Type of Study:** Sponsored Study**,** **Budget:** Rs. 103.6 Lakhs

4. **Nature of Study:** Applied Research

5. **Date of start:** April 2018

6. **Scheduled date of completion:** June 2023

7. **Duration of the Study:** 5 Years

8. **Study Objectives**

a) Improving the efficiency of anaerobic digestion by thermo-chemical pretreatment of co-mixed substrate (OFMSW+sewage sludge)

b) To address the influence of anaerobic co-digestion and thermo-chemical pretreatment on microbial community.

9. **Statement of the Problem:**

Increasing urbanization and poor waste management practices are leading to the rapid build up of solid waste heaps in the major urban cities throughout the India. Due to lack of proper treatment techniques, the waste (organic fraction of municipal solid waste, OFMSW and sewage sludge, SS) ultimately ends up into the landfills that is the least preferred waste disposal technique. Which leads to the wastage of land resource as these areas become unfit for any other uses due to ground water pollution by leachates, soil pollution, greenhouse gas emissions (a global issue) and the odour generation.

Anaerobic co-digestion (ACoD) method is one such technique that is generally used to assimilate different waste material to improve the conventional anaerobic treatment process and recover energy rich biogas. But the opportunities are missed to maximize the recovery of biogas production from the facilities due to presence of complex organic materials in OFMSW and SS that obstruct their biotransformation of substrate i.e. rate limiting step of the process. Despite the fact that co-digestion can increase the efficiency of biogas generation these complex organic compounds are limitations of ACoD. Therefore, pretreatment (thermal-chemical) of the mixed substrate (OFMSW and SS) can be interesting option to achieve a high organic matter solubilisation, increase in acidogenic and methanogenic biodegradability, and subsequent improvement in biogas generation. Integrating pre-treatment with co-digestion of OFMSW and SS has a number of potentially positive outcomes for the anaerobic co-digestion: increased stability of the process; increased specific biogas yields and methane content of biogas produced; maximizing the substrate availability for microbial community; reduction in energy requirements during the digestion process; reduction in the operational time i.e. HRT and SRT; reduced volume of reactor will provide economic feasibility; reduced use of landfills; utilization of bio-solids (digestate) as soil conditioners; sustainable management plan for OFMSW and sewage sludge.

Limited information is available in literature about the pre-treatment of combined municipal solid waste and sewage sludge for anaerobic co-digestion process and effect on biogas production.

Hence, the primary aim of this study is to investigate the co-digestion at different waste composition and develop an energy efficient pre-treatment method for maximum biogas recovery. On other hand, according to the situation in India where a renewable energy program has been initiated in the recent past, the introduction of anaerobic digestion into urban areas seems to be a value addition. The failures of various projects are more due to technical problems, inadequate planning or inappropriate management. There is a need of research on the aspect of stakeholder's preference towards the benefits of a biomass to bioenergy project. One of the objectives of the project deals with the preference hierarchy of the various stakeholders for sustainability of a biomass project. The benefits derived from the bio-waste to bioenergy project can be classified as: (a) avoidance of danger from the burning of biomass residues. (b) creating additional job opportunities for local people. (c) transfer of technology and knowledge in renewable energy. (d) Increasing the usage of renewable energy and local content. (e) reduction of GHG emissions.

10. Methodology:

The research project has been structured in six work packages (WP):

WP 1: Waste characterization

Milestone Expect: Defining characteristics of the samples in order to adjust feeds.

WP 2: Optimization of best treatment conditions for OFMSW+Sewage sludge

Milestone Expect: Definition of best total solids percentage (%TS), best sludge combination, Optimum OFMSW to sewage sludge ratio.

WP 3: Optimization of thermo-chemical pretreatment of waste

Milestone Expect: Selection of optimum condition of thermo-chemical pretreatment

WP 4: Effect of thermo-chemical pretreatment on biogas production and microbial community development

Milestone Expect: Selection of optimum conditions of pretreatment in order to maximize the methanogenic activity and biogas production. Deep insight on the reactor functioning by microbial community study under different treatment conditions/ Identification of microbial community changes by under no-pretreatment and pretreatment conditions.

WP 5: Semi-continuous operation

Milestone Expect: Best organic loading rate and hydraulic retention time.

WP 6: Pilot scale study

Milestone Expect: Proof of upscaled process

WP 6: Results analysis, drawing conclusion and reporting

Milestone Expect: Document summary of results, National and International research publications and conferences.

11. Timeline:

Task	Description	Months									
		6	12	18	24	30	36	42	48	54	60
1	Litearture Review & Characterization of the wastes										
2	Optimization of best treatment conditions for OFMSW+Sewage sludge										
2.1	Effect of co-digestion on biogas production										
2.2	Best sludge combination with OFMSW										
2.3	Best TS percentage of substrate										
2.4	Best OFMSW:Sludge mixing ratio										
3	Optimization of thermo-chemical pretreatment										
4	Batch anaerobic co-digestion experiments on pretreated waste, microbial community analysis										
5	Semi-continuous operation (HRT & OLR)										
6	Pilot study										
7	Data analysis										
	Milestone										
	Defining characteristics of OFMSW & SS										
	Best TS percentage, best sludge combination, Optimum OFMSW to sewage sludge ratio.										
	Selection of thermo-chemical pretreatment conditions										
	Assessment of thermal-chemical pretreatment effects on microbial community & biogas production.										
	Best HRT and OLR										
	Proof of upscaled process										
	Final report, National and International research publications.										

12. Objectives and achievement during last twelve months:

S. No.	Objectives	Achievements
(i)	**Semi-continuous operation**	The semi-continuous anaerobic co-digestion (AcoD) of thermal and thermal-alkali pre-treated organic fraction of municipal solid waste (OFMSW) and sewage sludge (SS) was studied under variable hydraulic retention times (HRT) and organic loading rates (OLR). Digesters were operated under control (non-pre-treated), thermally pre-treated (125℃), and thermal-alkali pre-treated (125℃-3g/L NaOH) conditions at variable OLRs at 2.5, 4.0, 5.1 and 7.6 kgVS/m^3.d and corresponding HRTs of 30, 20, 15, and 10 days. •Thermal-alkali pre-treatment shows the best methane yield and VS removal •Highest CH_4 yield (0.445 m^3/kgVS) achieved at 15 days HRT and 5.1 kg VS.m^{-3}/d OLR •Methane composition in biogas ranged from 72-78% under steady state conditions •Highest VS removal (52%): 57 and 11% higher than control and thermal pre-treatment •> 70-80% bacterial reads: *Firmicutes*, *Bacteroidetes*, *Chloroflexi*, *Proteobacteria*, *Actinobacteria* •Key archaeal community was acetoclastic methanogens *Methanosarcina* and *Methanothrix* •Thermal- alkali pretreatment shown highest energy gain with an energy ratio of 1.25.
(ii)	**Pilot scale study**	The pilot scale digester (100 kg capacity) operation ongoing from January 2023 and will be keep operating for two different pretreatment conditions of thermal and thermal-alkali pretreatment.

13. Recommendation / Suggestion:

S. No.	Recommendation / Suggestion	Action Taken
1.	No comments	--

14. Analysis & Results:

The semi-continuous anaerobic co-digestion (AcoD) of thermal and thermal-alkali pre-treated organic fraction of municipal solid waste (OFMSW) and sewage sludge (SS) was studied under variable hydraulic retention times (HRT) and organic loading rates (OLR). Digesters were operated under control (non-pre-treated), thermally pre-treated (125℃), and thermal-alkali pre-treated (125℃-3g/L NaOH) conditions at variable OLRs at 2.5, 4.0, 5.1 and 7.6 kgVS/m^3.d and corresponding HRTs of 30, 20, 15, and 10 days. The 10 and 43% higher methane yield (0.445 m^3/kgVS) and, 11 and 57% higher VS removal (52%) was achieved for thermal-alkali pre-treated digester at 5.1 kgVS/m^3.d OLR over thermally pre-treated (0.408 m^3/kgVS, 45% VS removal) and control digesters (0.310 m^3/kgVS, 33% VS removal), respectively. Thermal and thermal-alkali digesters were failed on increasing the OLR to 7.6 kgVS/m^3.d, whereas, the control digester becomes upset at 5.1 kgVS/m^3.d OLR. Metagenomic study revealed that *Firmicutes*, *Bacteroidetes*, *Chloroflexi*, *Euryarchaeota*, *Proteobacteria*, and *Actinobacteria* were the predominant bacterial population, whereas

Methanosarcina and *Methanothrix* dominated the archaeal community. Energy balance analysis shown that thermal alkali pretreatment shown a highest positive energy balance of 114.6 MJ/ton with an energy ratio of 1.25 in comparison with thermally pretreated (81.5 MJ/ton) and control samples (-46.9 MJ/ton). Life cycle assessment (LCA) was performed to visualize the environmental impacts of anaerobic digesters treating pre-treated OFMSW

15. **End Users / Beneficiaries of the Study:** Municipal corporation

16. **Deliverables:** Technical report and research papers

17. **Major items of equipment procured:** None

18. **Lab facilities used during the study:** Bioenergy Lab, IIT Roorkee

19. **Data procured or generated during the study:** Semi-continuous operation and Pilot study related

20. **Study Benefits / Impacts:**

Municipal corporations will be the direct beneficiary, as the load of MSW handling will be lessened. Moreover, the obligation of stringent rules for the disposal of sewage sludge can be pacified as the sludge will be further used as a medium for electricity generation that can power the WWTP and the end product of digestion will be a highly stabilized end product that will not be harmful to that extent as the undigested sludge. **Industrial sector** i.e. different consultants and companies can get involved and, develop the design based on our results for better efficiency and ensure successful implementation at field scale. Moreover, a newly developed waste to energy recovery method can be circulated in the private sector and that can give green credits to the organization and it can be a stepping-stone to sustainable development. **Researchers:** Co-digestion and advanced pretreatment are emerging technologies with limited data availability on the integrated approach of both methods for organic waste treatment. The introduction of the findings of this study will benefit researchers working on municipal solid waste and sludge treatment as the option for two problematic waste management. In addition, the availability of large-scale microbial community data will aid in the development of fresh approaches involving manipulation of microbial composition and the formulation of inoculum for greater process efficiency.

21. **Involvement of end users/beneficiaries:** None

22. **Specific linkage with Institution and /or end users / beneficiaries**: Yes

23. **Shortcoming/Difficulties:** None

24. **Future Plan:**

    (i) Continuous operation study of pilot digester under variable treatment scenario

Study – 3 (Collaborative)

1. Title of the Project: Isotopic and geochemical approach to study vulnerable confined and unconfined drinking water aquifers in Varanasi and surrounding area, India

2. Project Team

Lead Investigator	Dr. S. P. Rai, Assoc. Professor, Geology Dept., BHU Varanasi
Collaborator 1	Dr. Rajesh Singh, Sc. D, EHD, NIH Roorkee
Collaborator 2	Dr. Noble Jacon, Sc. G, Hydrology Section, BARC Mumbai
Collaborator 3	Dr. Laszlo Palcsu, Sr. Researcher, ICER, Hungarian Academy of Sciences, Hungary

3. Type of Study: Internal Study, **Budget:** Rs. 10 lacs

4. Nature of Study: Applied Research

5. Date of start: July 2021

6. Scheduled date of completion: June 2024

7. Duration of the Study: 3 Years

8. Objectives

i) Identification of recharge sources and zones of aquifer system
ii) Estimation of residence time, distribution and flow velocity of groundwater
iii) Understanding interaction with aquifer and surface water bodies
iv) Understanding rock water interaction affecting the water quality and assessment of impact of anthropogenic activities on groundwater.

9. Statement of the Problem

Understanding the properties of available water resources is a key factor for sustainable watermanagement. These properties include recharge conditions of the infiltration area, safe yield ofgroundwater, transit times, direction and velocity of an accidental pollution, hydraulicconnection between aquifers, water – rock interactions affecting the water quality etc. Theseprocesses cannot be understood without the integrated approach of isotope and waterchemistry. The investigation will help to better manage the groundwater resources of the studyarea and it will be a model study for the country too.Exploitation of depleting water resources results in deterioration of water quality. Groundwatercontamination has also emerged as a serious issue that has posed serious threat to the peopleliving in the Ganga River Basin. Groundwater, which is extensively used for drinking, cookingand/or irrigation, is contaminated with arsenic in many part of the Ganga Basin and is havingsevere detrimental effects on human health. Presently, the main problem of depletion ofgroundwater in Ganga Basin is due to the unsustainable abstraction of groundwater (Rodell etal., 2009; Tiwari et al., 2009). As the groundwater level is declining, people are drilling todeeper aquifers, to meet the groundwater demand. In the arsenic affected areas, deeper aquiferhas been tapped for the extraction of groundwater to meet the drinking and other demands. Thegroundwater extracted from deeper horizons is becoming the most important fresh waterresource in Ganga River Basin. However, little is known about the deeper aquifers which arein semi-confined and to confined condition.Understanding the properties of available water resources is a key factor for sustainable water management. These properties include recharge conditions of the infiltration area, safe yield of groundwater, transit times, direction and velocity of an accidental pollution, hydraulic connection between aquifers, water – rock interactions affecting the water quality etc. These processes cannot be understood without an integrated approach of isotope and water chemistry.

Keeping in view of same, the study aims at identification of recharge sources and zones of aquifer system, understanding the surface and groundwater interactions, and the rock water interaction and anthropogenic activities affecting the groundwater quality.

10. Approved Action Plan/ Methodology:

i) Thorough review of aquifer system and water quality status of the study area.
ii) Collection and characterization of the water samples from the study area for physico-chemical, bacteriological, and isotopic parameters.
iii) Geochemical, isotopic, and statistical modeling to understand the rock-water interaction, recharge zones, surface water interactions, and anthropogenic influence.

11. Timeline (Approved):

Sr. No.	Major Activities	2021-22			2022-23				2023-24				2024-25
		Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
1.	Field Investigation and sampling plan	■											
2.	sample collection and analysis		■	■	■	■	■	■	■	■			
3.	Geochemical, isotopic, and statistical modeling					■	■	■	■	■	■	■	
7.	Publications				■	■	■	■	■	■	■	■	■
8.	Interim Report							■					
9.	Final Report											■	■

12. Objectives and achievement during last twelve months:

Sr. No.	Activity	Achievements
1.	Field Investigation and sampling plan	• The sample locations and sampling plan prepared.
2.	Sample Collection and Analysis	• Pre-monsoon (2022) samples were collected from the selected locations. • Analysis for organoleptic, major ions, coliforms, and stable isotopes in the collected samples completed and analysis of trace metals and tritium (3H) is in progress. • Based on the in-situ parameters (EC, pH and ORP) and major ion chemistry data, major hotspot sites has been identified for post monsoon sampling.
3.	Scientific Publications	• 01 research paper in international journal (under review). • 01 research paper in international journal (under submission).

13. Recommendation / Suggestion:

Sr. No.	Recommendation / Suggestion	Action Taken
1.	No specific suggestion	--

14. Analysis & Results:

Upgrading literature and data collection

- The information related to geomorphology, geology, soil chemistry and mineralogy of the study area were extracted from the published reports of CGWB, GSI and SGWB.
- Important available data such as SRTM DEM, water level data, rainfall data, and borehole data are also acquired.

Field Investigation and sampling plan

The Middle Ganga Basin is characterized by multi aquifer system and the principal aquifer systems has been classified into four major types: Aquifer I which varies from soil depth to 150 m bgl, Aquifer II - 160-240 m bgl, Aquifer III - 260-370 bgl, and Aquifer IV - 370-480 m bgl (CGWB, 2020). Based on this, the major sampling strategy was designed to collect water samples from different borehole depth following the grid sampling at 15km × 15km. It was planned to collect groundwater samples from shallow and deep wells from each grids. However due to the limited number of deeper wells (>100 m bgl) tapped by government water supply Jal-Kal and irrigation tubewells, a fewer number of water samples could be collected. Groundwater samples from different borehole depth along with coordinates were collected from the Varanasi and adjoining districts encompassing an approximate area of 20,0000 sq. km.for the Pre Monsoon season 2022 were collected (Fig. 1).

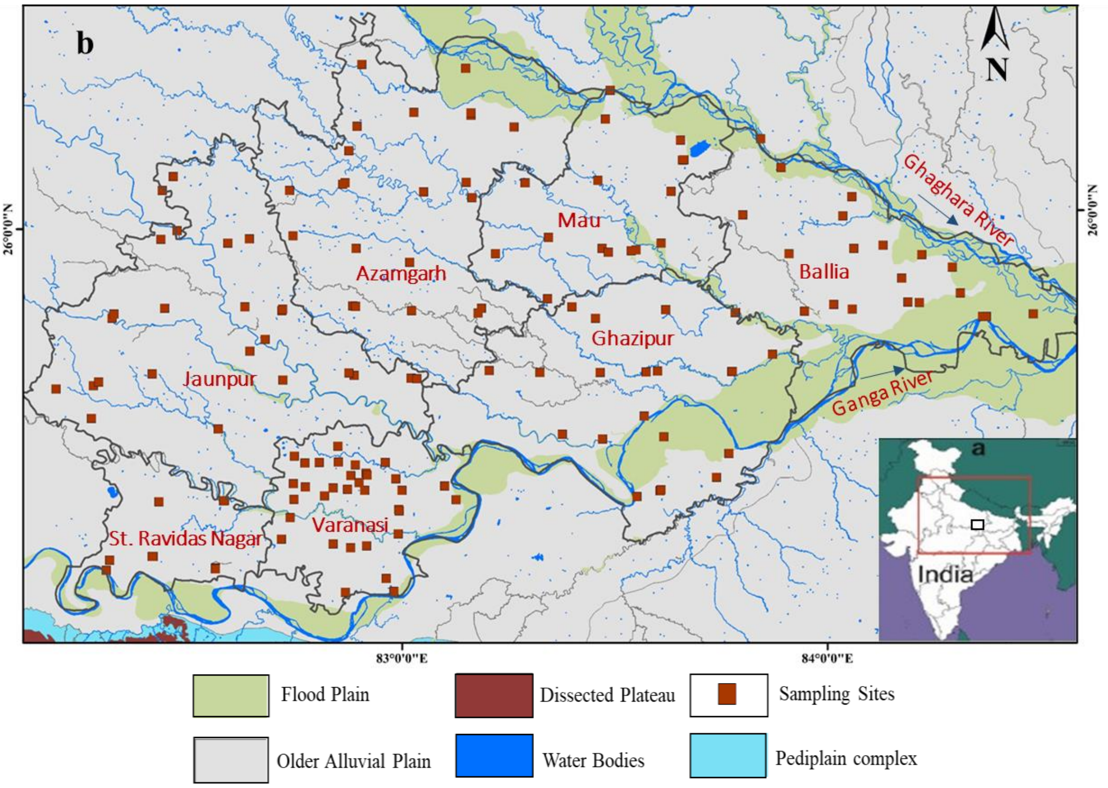


Fig. 1.(a) Ganga River Basin and black box showing study area,**(b)** the geomorphological settings of the study area, districts, major rivers along with the sampling sites.

Sampling & Analysis

- The handpumps/tubewellsof the identified locationwere continuously pumped for at least 15 minutes prior to the sampling and the water samples were collected in appropriate sampling bottles and preserved as per standard methods (APHA, 2017).The parameters such as coordinate, elevation, temperature, borehole depth, pH, ORP and EC were measured at the sampling sites.

- Alkalinity, HCO_3 and CO_3were determined titrimetrically within a day, while major ions were measured within a month after entire groundwater sampling with Ion chromatograph.

15. **End Users / Beneficiaries of the Study:** Policy makers and planners of State/Central Government Organizations

16. **Deliverables:** Technical report and research papers, GW recharge sources and aquifer zonation, SW-GW interaction, and rock-water and anthropogenic influence on water quality.

17. **Major items of equipment procured:** None

18. **Lab facilities used during the study:** Hydrogeology Laboratory (BHU),Water Quality Laboratory (NIH), Isotope Laboratory (NIH)

19. **Data procured or generated during the study:** Water quality data of the study area and anthropogenic influence on the water quality.

20. **Study Benefits / Impacts:**
    The outcome of the project would help the managers for the sustainabledevelopment and management of this scarce resource and plan for augmentation measures toensure continuous supply of water to meet the demands of the people in the region.The project will also explore the remedial measures for providing safe and clean water to the densely populated regions of the MGB.

21. **Involvement of end users/beneficiaries:** Water Resources & Environment Directorate, Varanasi and adjoining districts, CGWB Lucknow

22. **Specific linkage with Institution and /or end users / beneficiaries**: Yes

23. **Shortcoming/Difficulties:**None.

24. **Future Plan:**

- To identify the major hotspots sites based on the major and trace metals analysis.
- To conduct post-monsoon sampling for those identified hotspots to understand the monsoonal recharge.
- Geochemical and statistical modelling.

Study – 6 (Internal Study)

1. **Title of the Study:** Characterisation of Groundwater Dynamics in Krishna-Godavari Delta interims using groundwater levels, Hydrochemistry, Isotopes and Emerging Contaminants

2. **Study Group:**

Study Team		
NIH, Roorkee	**DRC, Kakinada**	**CGWB, Southern Region, Hyderabad**
Dr. M. K. Sharma, Sc. E (**PI**) Dr.SuhasKhobragade, Sc. 'G' Dr. Rajesh Singh, Sc. 'D'	Dr. Y. R. S. Rao, (PI) Sc. G & Head	Sri J. Siddhardha Kumar (PI) Sc. E & Head
Supporting Staff Mrs. Babita Sharma, SRA Mrs. Beena Prasad, RA Mr. P. R. S. Rao, PRA		

3. **Type of Study:** Internal
4. **Nature of Study:** Applied Research
5. **Date of Start:** April 2022
6. **Scheduled date of Completion:** March 2024
7. **Duration of the Study: 2** years
8. **Study Objectives**
   i) To study the groundwater level fluctuations in Krishna-Godavari Deltas
   ii) Characterisation of groundwater using Hydro-chemical and Hydrogeochemical investigation
   iii) Isotopic Characterisation of groundwater
   iv) To study the status of Emerging Contaminants in the groundwater, their sources and its impacts on human health

9. **Statement of the Problem**

Krishna and Godavari rivers are major and large rivers in Peninsula India. Water availability is more in Godavari River. Krishna delta has the water scarcity problem due to unavailability of water in Krishna River. So Andhra Pradesh government took the decision to interlinking the rivers through Polavaram canal. Flood waterfrom the Godavari River could be diverted to the paddy growing region of Rayalaseema, which often suffers from insufficient water. In order to link the two rivers a 174 km-long canal, known as the Polavaram Right Canal, was constructed and supplied with pumps that will remove excess water from the Godavari River and send it to the Krishna River. Paddy farmers in the Krishna Delta are the main beneficiary of the linking of the two rivers. Diverted water will also provide Amaravati, the planned state capital, with drinking water. The project is seen as a means to ensure the future water and food security of Andhra Pradesh.

Groundwater situation in different parts of India is diversified because of variation in geological, climatological and topographic set-up. Annual water level fluctuation of premonsoon has shown a fall in water levels for 59 % of the area, predominantly in Rayalaseema region. During post-monsoon about 90% area of the state experienced rise in annual water level fluctuation. Aquifer wise water level analysis shows that during pre-monsoon season shallowest water levels are observed in all the formations except in Intrusives. Deepest water levels are observed alluvium, Limestone and BGC. During post-monsoon season, shallowest water levels are observed in all formations except in Intrusives and Laterites. Deepest water levels are observed in Gneiss, Granite, Limestone, Quartz and Sandstone (CGWB GW Year Book 2019-20 AP).

Geo-environmental conditions have a marked influence on the groundwater quality. Hydrogeochemical studies relevant to the water quality explain the relationship of water chemistry to aquifer lithology. Such relationship would help not only to explain the origin and distribution of dissolved constituents but also to elucidate the factors controlling the groundwater chemistry. Further, groundwater quality in a region is influenced by physical and chemical parameters that are strongly affected by natural processes such as water chemistry in the recharged area, water intermixing, groundwater recharge, aquifer discharge and recharge, water flow path.

The term emerging contaminants (ECs) is generally used to refer to compounds previously not considered or known to be significant in groundwater in terms of distribution and/or concentration, which are now being more widely detected and which have the potential to cause known or suspected adverse ecological or human health effects.ECs include perfluorinated compounds (PFCs), nanomaterials, pesticides, pharmaceuticals, industrial compounds, personal care products, fragrances, water treatment by-products, flame retardants and surfactants, UV-filtersas well as caffeine and nicotine. Because of their rapidly increasing use in industry, transport, agriculture, and urbanization, these chemicals are entering the environment at increasing levels as hazardous wastes and non-biodegradable substances.

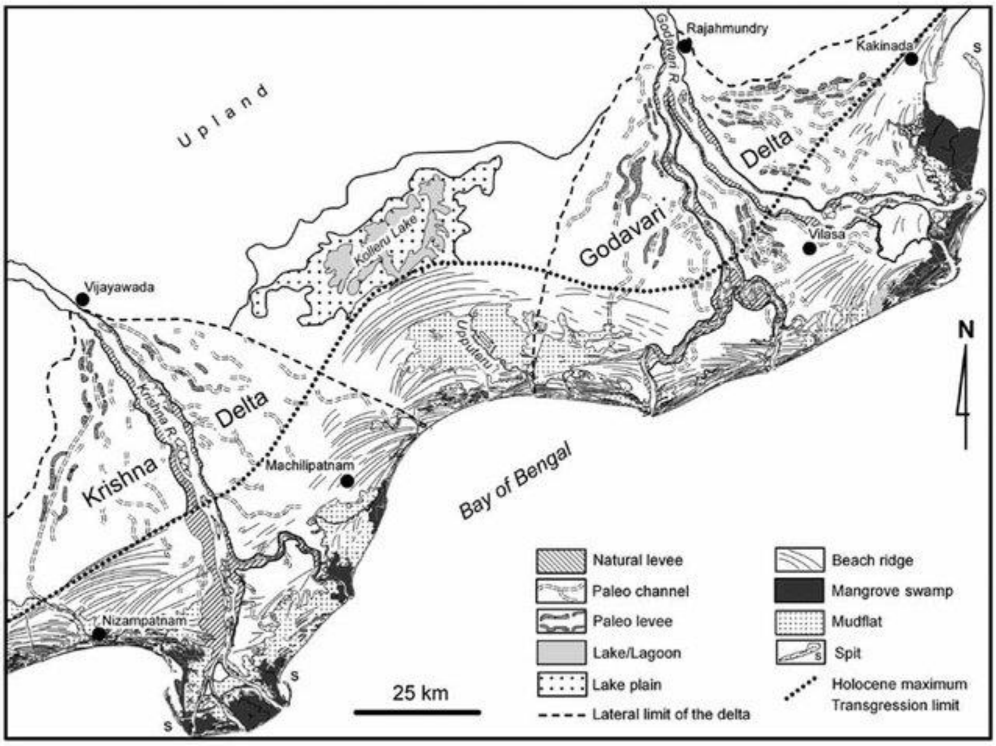


Fig. 1. Location map of Krishna Godavari deltaic region

The pathways through which these pollutants enter surfacewaters are well known and the main contributions are from effluents of wastewater treatment plants, where some residues are not removed,and from agricultural and industrial activities. Contacts and exchanges between the aquifers, rivers and sewage networks, and leaching fromagricultural fields, can cause the contamination of shallow and deepgroundwater. ECs may be a significant problem when surface and groundwaterare used for drinking water production because the conventionaldrinking water treatments, like treatment with active carbon, flocculation,and disinfection, are not specifically designed to remove these micropollutants. Traces of ECs in drinking water are actually measured and reported in only a few studies and the spatial and temporal variability of the majority of ECs in theenvironment is still poorly understood.

In view of the above, characterization of groundwater dynamics in Krishna-Godavari Deltasinterimshas been proposed using geochemical, Isotopes and emerging contamination and their sources and its impacts on human health for sustainable drinking water supply.

10. Approved Action Plan/Methodology

i) Collection of groundwater level data, lithological data, water quality data from published report, literature and from various govt. agencies.
ii) Hydrogeological characterization of the study area and establish specific linkages of groundwater quality with hydrogeology.
iii) Collection of groundwater samples from selected sources in pre-monsoon (April-May) and post-monsoon (October-November) season at identified locations.
iv) Analysis on flow and movement of groundwater.
v) Analysis for physico-chemical parameters [pH, EC, TDS, Eh, Alkalinity, Hardness, Major Cations (Na, K, Ca, Mg), Major Anions (Cl, SO_4, NO_3, HCO_3), minor elements (Fluoride, PO_4, NH_4)] metal concentrations (As, Fe, Mn, Cd, Zn, Cu, Cr, Pb, Co, Ni, Ba, Sr, V, Sc),and emerging contaminants (Pesticides, PAHs, PCBs, VOCs, BETEX, MTBE) in the collected water samples.
vi) Analysis of Stable environmental isotopes of Hydrogen and Oxygen in the collected water samples
vii) Processing of hydro-chemical data for pre- and post-monsoon seasons as per BIS and WHO standards to examine the suitability of ground water for drinking purpose.
viii) Ionic relationships will be developed and water types will be identified. Spatial distribution map will be prepared in the form of contour diagrams to identify degraded water quality zones, possible sources of pollution and specific parameters not conforming to drinking/ & irrigation water quality standards.
ix) Processing of hydro-chemical data to understand the geochemical processes controlling the chemical composition of groundwater using Scatter Plots and Gibbs Plot.
x) Soil quality monitoring for metal concentrations (Zn, Cu, Cr, Co, Ni, Ba, Sr, V, Sc) in the petroliferous regions of the study area during pre- and post-monsoon seasons.
xi) Probable impact of emerging contaminants in groundwater on human health.

11. Approved Work schedule / Timeline

S. No.	Major Activities	2022-23				2023-24			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Data collection	■	■	■	■	■	■		
2	Field surveys &Sample collection	■		■					
3	Sample Analysis		■	■	■	■	■		
4	Data Processing	■	■	■	■	■	■		
5	Interim Report				■				
6	Final Report							■	■

12. Objectives and achievement during last twelve months:

Sr. No.	Activity	Achievements
1.	Data collection	• Data collection is under progress.
2.	Field surveys &Sample collection	• Reconnaissance survey of the study area completed with identification of sampling sites. • Collection of groundwater samples from selected sources in pre-monsoon (May-June 2022) and post-monsoon (December 2022) season at identified locations has been

		completed with CGWB & RCK.
3.	Sample Analysis	• Analysis of physico-chemical parameters and metal concentrations in the groundwater water samples of pre-and post-monsoon season completed. • Analysis of emerging contaminants (Pesticides, PAHs, PCBs, VOCs, BETEX, MTBE) in the collected groundwater water samples of pre-monsoon season completed and of post-monsoon season is in progress. • Analysis of Stable environmental isotopes of Hydrogen and Oxygen in the collected groundwater samples has been completed.
4.	Data Processing	• Processing of data is under progress.

13. **Recommendation / Suggestion:**

Sr. No.	Recommendation / Suggestion	Action Taken
1.	Dr. Prashant Rai, CGWB appreciated the proposed study and suggested that this is the right time to take up this study for the benefit of society.	--

14. **Analysis & Results:**

Field surveys &Sample collection

- Reconnaissance survey of the study area completed with identification of sampling sites.
- Collection of groundwater samples from selected sources at identified locations in pre-monsoon (June 2022) and post-monsoon (December 2022) season for physico-chemical parameters, metal concentrations and emerging contaminants (Pesticides, PAHs, PCBs, VOCs, BETEX, MTBE) has been completed with CGWB & RC Kakinada.

Sample Analysis

- Analysis of physico-chemical parameters using Ion Chromatograph and metal concentrations (As, Fe, Mn, Cd, Zn, Cu, Cr, Pb, Co, Ni, Ba, Sr, V, Se, Al, Hg, U, B)using ICP-MS in the groundwater water samples of pre-and post-monsoon season completed.
- Analysis of emerging contaminants (Pesticides, PAHs, PCBs, VOCs, BETEX, MTBE) in the collected groundwater water samples of pre-monsoon season using GC-MS/MS completed and of post-monsoon season is in progress.
- Data of physico-chemical parameters, metal concentration and emerging contaminants is under processing.
- Analysis of Stable environmental isotopes of Hydrogen and Oxygen in the collected groundwater samples has been completed.

15. **End Users / Beneficiaries of the Study:** Public Health Department, AP, Ground Water Department, AP, CGWB.

16. **Deliverables:** Technical report and research papers,

17. **Major items of equipment procured:** None

18. **Lab facilities used during the study:** Water Quality Laboratory (NIH)

19. **Data procured or generated during the study:** Water quality data on Emerging Contaminants

20. **Study Benefits / Impacts:** The study will identify degraded groundwater quality zones, possible sources of pollution, understanding geochemical processes controlling the aquifer chemistry and will suggest the measures for sustainable groundwater supply for drinking purpose in the study area, therefore enable better planning and management of groundwater resources.

21. **Involvement of end users/beneficiaries: CGWB**

22. **Specific linkage with Institution and /or end users / beneficiaries**: Yes

23. **Shortcoming/Difficulties:** None.

24. **Future Plan:**

i) Processing of hydro-chemical data for pre- and post-monsoon seasons for different designated uses.
ii) Spatial distribution map will be prepared in the form of contour diagrams to identify degraded water quality zones, possible sources of pollution and specific parameters not conforming to drinking/ & irrigation water quality standards.
iii) Processing of hydro-chemical data to understand the geochemical processes controlling the chemical composition of groundwater using Scatter Plots and Gibbs Plot.
iv) Soil quality monitoring for metal concentrations (Zn, Cu, Cr, Co, Ni, Ba, Sr, V, Sc) in the petroliferous regions of the study area during pre- and post-monsoon seasons.

Study – 7 (Internal Study)

1. **Title of the Project** : Understanding Arsenic mobilization in groundwater of Haridwar and formulating remediation measures

2. **Project Team**

Project Investigator	Dr. Rajesh Singh, Sc. D, EHD
Project Co-investigator	Dr. R. P. Pandey, Sc. G & Head, EHD Dr. Sumant Kumar, Sc. D, GWHD Dr. Pradeep Kumar, Sc. D, EHD Dr. M. K. Sharma, Sc. F, EHD Dr. V. K. Tyagi, Sc, D, EHD Dr. KalzangChhoden, Sc. C, EHD

3. **Type of Study:** Internal Study, **Budget:** Rs. 30.1 lacs

4. **Nature of Study:** Applied& Basic Research

5. **Date of start:** July 2021

6. **Scheduled date of completion:** June 2024

7. **Duration of the Study:** 3 Years

8. **Objectives**
   v) To determine the mechanisms governing the As mobility, and quantify the rate and extent of these reactions in order to develop a reactive transport model to predict As mobility in groundwater, and
   vi) To design alternatives to mitigate As contamination of drinking water

9. **Statement of the Problem**

Groundwater is the most important source of domestic water in the Haridwar district and is generally free of health hazardous contaminants, however, with increasing population and intensive agricultural practices, the groundwater is getting polluted resulting in the abiotic and biotic weathering reactions of primary and authigenic minerals containing As and other trace metals. The release of previously sequestered arsenic from soils and sediments is well-recognized to result in geogenic contamination of drinking water and presents significant health risks to human and other living organisms. Our recent study on 'Water Quality Assessment of Haridwar District' indicated higher As concentration in the groundwater of Laksar and Manglaur tehsil at few locations in the range 10 to 30 µg/l. Although, the As concentration were below maximum permissible limit of 50µg/lprescribed by BIS for drinking water, it exceeded the acceptable limit of 10 µg/l. Previously, As was reported in a location near Solani river which is a monsoonal river and in the non-monsoon the flow in the river is contributed through the untreated/partially treated domestic and industrial discharge. This clearly indicates the role of pollutants entering the aquifer and initiating the secondary reaction resulting on the release of As from the aquifer sediments and requires thorough investigation before it is too late. The identification of the factors responsible for the release of the As from the sediments will help in containing the As and reducing the associated health hazard risk to consumers.

Keeping in view of same, the study aims at analyzing the groundwater and sediment samples for their As content and other parameters. Efforts will be also made to identify the factors responsible for the release of As from the sediments through batch/column experiments.

10. Approved Action Plan/ Methodology:

iv) Thorough review of abiotic and biotic geochemical mechanisms known to contribute to As mobility in aquifers and determine the groundwater constituents or parameters influencing As mobility.
v) Collection and characterization of the groundwater samples from and in the vicinity of identified locations with higher As concentration.
vi) Characterization of the aquifer sediment and As mobility in the aquifer where As was observed in exceeding the prescribed drinking water limit.
vii) Batch and column experiments for identifying the factors responsible for As mobilization.
viii) Develop a model to identify As mobility in groundwater.
ix) Design alternatives to mitigate As contamination of drinking water.

11. Timeline (Approved):

Sr. No.	Major Activities	2021-22			2022-23				2023-24				2024-25
		Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
1.	Field Investigation and sampling plan												
2.	GW sample collection and analysis												
3.	Aquifer sediments collection and characterization												
4.	Batch & column experiments												
5.	Model development for As mobility												
6.	Alternatives to mitigate As												
7.	Publications												
8.	Interim Report												
9.	Final Report												

12. Objectives and achievement during last twelve months:

Sr. No.	Activity	Achievements
1.	Field Investigation and sampling plan	• The sample locations and sampling plan prepared
2.	Sample Collection and Analysis	• Samples are collected from the selected locations. • Analysis for organoleptic, major ions, and coliforms in the collected samples completed. • Analysis of trace metals is in progress.

13. Recommendation / Suggestion:

Sr. No.	Recommendation / Suggestion	Action Taken
1.	No specific comments	--

14. **Analysis & Results:**

Field Investigation and sampling plan

- Sampling locations were selected considering the identified location with high As concentration in the groundwater.

Sampling & Analysis

- The handpumps, which are being used extensively, of the identified villages were continuously pumped for at least 15 minutes prior to the sampling and the water samples were collected in appropriate sampling bottles and preserved as per standard methods (APHA, 2017). Samples were also collected from the deep wells as per availability.
- The organoleptic parameters, major ion, and bacteriological analysis completed for all the samples following APHA's Standard Methods for the Examination of Water and Wastewater (APHA, 2017). Trace metal analysis is under progress.

15. **End Users / Beneficiaries of the Study:** Policy makers and planners of State/Central Government Organizations

16. **Deliverables:** Technical report and research papers, Factors impacting As mobilization, Model to identify As mobility, and alternatives for As mitigation.

17. **Major items of equipment procured:** Glove bag/anaerobic chamber will be procured for conducting experiments.

18. **Lab facilities used during the study:** Water Quality Laboratory (NIH)

19. **Data procured or generated during the study:** Water quality data of the study area and As mobilization mechanism

20. **Study Benefits / Impacts:**
The outcome of the project will be beneficial for the concerned departments in a sense that it will provide the information on the factors impacting As mobilization in the groundwater. The alternatives for As mitigation will be also suggested which can be implemented by concerned departments of UK government.

21. **Involvement of end users/beneficiaries:** None

22. **Specific linkage with Institution and /or end users / beneficiaries**: Yes

23. **Shortcoming/Difficulties:**None.

24. **Future Plan:**
   - Collection and analysis of GW and aquifer sediment samples.
   - Batch and column experiments.
   - Procurement of glove bag/anaerobic chamber.

Study - 8 (Internal Study)

1. **Title of the Study:** Simulation of Non-Point Source Pollution Processes in Song River

2. **Study Group:**

Project Investigator	Dr.Pradeep Kumar, Sc. ‘D’, EHD
Project Co-investigator	Dr. M. K. Sharma, Sc. ‘E’, EHD Dr. Rajesh Singh, Sc. ‘D’, EHD Er. R. K. Nema, Sc. ‘B’, EHD
Scientific Staff	Mrs. Babita Sharma, RA Mrs. Beena Prasad, RA Mr. Rakesh Goyal, Tech. Gr. I

3. **Type of Study:** Internal Study**, Budget:** Rs. 43.02 lacs
4. **Nature of Study:** Applied Research
5. **Date of start:** Nov 2019
6. **Scheduled date of completion:** Oct 2023
7. **Duration of the Study:** 4 Years

8. **Study Objectives**

(i) Assessment of the point and non-point pollutant loads
(ii) Mapping of various non-point pollution sources
(iii) Simulation of various hydrological processes in the river catchment
(iv) Simulation of non-point source pollution process for sediment, nutrients and pesticides in the river catchment

9. Statement of the Problem:

Increasing population and subsequently increasing water, food and energy demands have put tremendous pressure on the water resources. The problem is more substantiated by the increasing consumption of the products with high water footprints. The food and energy demands of rapidly increasing population have caused intense agriculture, industrialization and urbanization. This has resulted in indiscriminate discharge of municipal and industrial wastes. Municipal wastes being biodegradable produce a series of directional but predictable changes in water bodies. Industrial effluents are responsible for pollution to a lesser extent but the effects produced by them may be more serious as nature is often unable to assimilate them. Agriculture is also responsible for degrading the water quality through leaching and runoff from agricultural fields and animal husbandry units, which contain predominantly organic compounds from the use of mineral fertilizers and chemical pesticides. These pollutants ultimately contaminate aquifer system due to surface and groundwater interactions. The planning of water as a national resource is not merely a question of ensuring the availability of water in the right quantity at the right time for diverse purposes, but also ensuring the right quality for the intended use. Further, for any proper water resources planning, whether long or short term, before going into alternative plans for development, it is very essential to assess water quality problems together with hydrological analysis.

Since, point source pollution meets the river at known locations, it may be addressed by STPs or ETPs. Non-point source pollution reaches the river through the landscape after following a number of hydrologic, physical, chemical and biological processes. Hence, it is very complex to assess the causes and plan for its remediation. Very few assessments of non-point source pollution have been made in Indian rivers and they are mostly limited upto quantification of pollutant loads through the flux balance approach. Therefore, this study is being envisaged to simulate the non-point pollution process in a lower Himalayan catchment to identify the sources and causes of non-point source pollution.

10. Approved Action Plan/Methodology:

(i). Procurement of secondary data required for the analysis from various govt. agencies (discharge, sediment, other water quality parameters, soil map etc.)

(ii). Collection of water samples at monthly frequency during non-monsoon and daily frequency during monsoon season from selected locations of Song river

(iii). Collection of data on usage of fertilizers and pesticides in the Song river catchment.

(iv). Analysis of water samples for general water quality parameters, total suspended solids, nutrients and pesticides

(i). Hydrological and water quality modelling using SWAT model

11. Timeline:

S. No.	Major Activities	2019-20		2020-21				2021-22				2022-23				2023-24		
		3rd Qtr	4th Qtr	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	1st Qtr	2nd Qtr	3rd Qtr
1	Literature survey																	
2	Reconnaissance visit and sampling plan																	
3	Secondary data collection																	
4	Field surveys																	
5	Sample Collection and Analysis																	
6	SWAT Model: Preparation of database																	
7	SWAT Model: Calibration, Validation & Simulation																	
8	Interim Report																	
9	Final Report																	

12. Objectives and achievement during last twelve months:

S. No.	Objectives	Achievements
(i)	Assessment of the point and non-point pollutant loads	Three sites have been selected for the assessment of point and non-point source pollutant loads. The water quality sampling and discharge monitoring at these three sites have been carried out on weekly basis during

		the monsoon season, and monthly basis during the non-monsoon season. Further, samples have been analyzed for the water quality parameters.
(ii)	Collection of data on usage of fertilizers and pesticides in the Song river catchment	The village level surveys are being conducted for collection of data on usage of fertilizers and pesticides.
(iii)	Simulation of various hydrological processes in the river catchment	The preliminary SWAT model set-up has been completed using the secondary data sources (freely available web sources). Discharge data from CWC and soil maps from NBSS&LUP have been obtained and the same have been used for the analysis.
(iv)	Simulation of non-point source pollution process for sediment, nutrients and pesticides in the river catchment	The model set-up for simulation of non-point source pollution processes will be carried out only after the primary data of discharge and water quality is collected.

13. Recommendation / Suggestion:

S. No.	Recommendation / Suggestion	Action Taken
1.	No comments	--

14. Analysis & Results:

Three sites in the Song catchment have been selected for simulating non-point source pollution processes through the SWAT model. The first site selected is the CWC G&D site at Satyanarayana. Suswa is a major tributary of Song river and it meets Song river few kilometers upstream of Satyanarayana G&D site. So, the second site has been selected on Suswariver just before its confluence with Song river. Another site on the Song river have been selected in the upstream of the confluence of Song and Suswa rivers. These sites have been selected to isolate the point and non-point sources of pollution. Although sampling was planned to be started during monsoon season of 2021, but, due to uncertain travel restrictions caused by Corona pandemic, the same could be started from Jun 2022.

15. End Users / Beneficiaries of the Study: Deptt. of Irrigation &Deptt. of Agriculture, Uttarakhand

16. Deliverables: Technical report and research papers

17. Major items of equipment procured: None

18. Lab facilities used during the study: Water Quality Laboratory (NIH)

19. Data procured or generated during the study: Water quality data of the area

20. Study Benefits / Impacts:

The outcome of the project will be beneficial for the concerned departments in a sense that it will provide the various sources of point and non-point pollution and will suggest various scenarios for mitigating these impacts. The research outcomes from the study will be as follows:

a. Point and Non-Point pollutant loads at various locations in Song river
b. Quantum of non-point source pollution for various scenarios of fertilizers/ pesticides applications
c. Technical report and papers

21. **Involvement of end users/beneficiaries:** None

22. **Specific linkage with Institution and /or end users / beneficiaries**: Yes

23. **Shortcoming/Difficulties:**None

24. **Future Plan:**

i) Collection and analysis of samples (monthly sampling during non-monsoon and daily sampling during monsoon) from three selected sites in the Song catchment.

ii) Procurement of discharge data from CWC for the current period i.e. 2021-2023.

iii) SWAT Model calibration and validation both for flows and for water quality.

Study – 9 (Internal Study - New)

1. Title of the Project: Hydrological Studies for the Conservation of Rewalsar Lake

2. Project Team

- **Project Investigator:** Dr. Kalzang Chhoden, Sc. C, EHD
- **Project Co-investigator:** Dr. Rajesh Singh, Sc. D, EHD
  Dr. R. P. Pandey, Sc. G & Head, EHD
  Dr. Pradeep Kumar, Sc. D, EHD
  Dr. Vinay Kumar Tyagi, Sc. D, EHD
  Er. Omkar Singh, Sc. G, RMOD
  Dr. Shuhas Khobragade, Sc. G, HI
  Dr. D.S. Malik, Professor, GKU, Haridwar

In Collaboration with HPSWA, Shimla

3. Objectives

a) Identification of morphological features of the lake.
b) To understand the hydrological characteristics.
c) To identify the causes of fish mortality and eutrophication status of lake.
d) To Assess the rate of sedimentation.
e) Suggestions for remedial measures for pollution abatement
f) Mass awareness and outreach activity.

4. Present state-of-art

Lakes are one of the most important inland freshwater resources for meeting the increasing water demand. Lakes supply water for drinking, irrigation, fisheries, etc., and thus lakes have significant economic and recreational value. In Lake Ecosystem, water quality depends upon physical, chemical, and biological factors. Mainly lakes have five major problems: lowering water level, siltation, acidification, toxic contamination, and eutrophication. Phytoplankton dynamics influence the trophic level and portability of water for human use. Today surface water is most vulnerable to pollution due to its easy accessibility for disposal of pollutants and wastewaters. During the last decade, widespread deterioration in water quality of inland aquatic ecosystem systems has been reported due to the rapid development of industries, agriculture, and urban sprawl. Lakes also help in recharging groundwater and attaining water security. In view of the spatial and temporal variations in the hydrochemistry of surface waters, regular monitoring programs are required for reliable estimates of the water quality. Water quality monitoring is a helpful tool not only to evaluate the impacts of pollution sources but also to ensure efficient management of water resources and the protection of aquatic life.

Previous studies reported the effect of change in land use and seasonal variation onlake water quality. A study on Pandoh lake indicate the enrichment of nutrients in the lake water(Anshumali and Ramanathan, 2007). Kumar et al., 2019 reported hypereutrophic condition of Renuka Lake based on the Carlson's indexdue to the presence of a high concentration of nutrients. A study by Kasaya (2015) on the Rewalsar lake reported high concentrations of BOD, COD, Cl, phosphate, sulphate and very low transparency.Another study (Jindal et al., 2014) revealed the phytoplankton dynamics and water quality status of Prashar Lake. Based on the Carlson's trophic status, the lake was classified as oligotrophic with TSI values 17.085 (2008-09) and 14.57 (2009-10). Relatively less abundance of Cyanophyceae and high percentage of desmides in the lake water indicated oligotrophic status of lake. *Paenilbacillus inbetae sp*ecies a cold adapted antimicrobial producing bacteria was isolated from high altitude Suraj Taal lake by Kiran et al., 2017. Major ion chemistry of Renuka lake have been studied and it was observed that shale slate, sandstone, quartzite, and limestone rocks have contributed to the ion chemistry of lake water (Choden et al., 2022; Das and Kaur, 2001). However, the reaction of carbonate to sulphuric acid as a proton source during weathering process in the basins accounts for the high concentration of sulphate content in water. Kumar et al., 2006 and Singh et al., 2008 further reported the eutrophic conditionsof Himalayan lakes using phosphate data. The results showed

Mansar, Surinsar and Tsomoriri under eutrophic condition and Dal, Tsokar and Renuka Lake under hyper eutrophic condition. Furthermore, siltation is the another major problem in lakes due to the human and other interferences. Sedimentation is one of the main problems that reduces the depth and size of lakes. The sedimentation rate in each lake differs due to catchment lithology, slope, vegetation cover, and silt transport through inlet stream, rainfall, and wind causing differential erosion.

As per the Himachal Pradesh State Wetland Authority (HPSWA), Rewalsar lake is presently facing problems related to water quality, fish mortality, and siltation. Rewalsar wetland ecosystem is at the critical stage of deterioration mainly due to water pollution and siltation in the water body. Increasing tourism activity and human settlement around the lake create hydrological and ecological distresses. In addition to this, frequent incidents of high fish mortality in the water body due to increasing water pollution has been observed. An increase in nutrient levels in lake from the various non-point sources also leads to eutrophic conditions. Keeping this in view and as suggested by the HPSWA, a systematic and comprehensive study on the hydrological investigation of Rewalsar Lake has been proposed.

5. Study Area:

Rewalsar is a natural wetland and is located in district Mandi of Himachal Pradesh at a distance of 24 km in the southwest direction of Mandi on the Mandi-Hamirpur highway at the height of 1360 m. The lake is shaped like a square with a shoreline of about 735 m. This area falls on the confluence of "Sikandara-Dhar and 'Barkot' ranges of sub-mountainous Himalaya between latitude 31°37'30" N and E. 76°49" E longitude. The place has a series of small beautiful lakes, of which Rewalsar lake is the most beautiful and sacred. The total catchment area of Rewalsar wetland is 173 hectares. The main source of water for the Rewalsar wetland is its internal water springs. Rewalsar is an important tourist destination and also one of the most famous sacred spots for Hindus, Buddhists, and Sikhs as it is largely associated with serpent worshipping. Keeping view of its religious, cultural, and ecological importance, the Ministry of Environment & Forests, GoI has declared the Rewalsar wetland under the National Wetland Conservation Programme.

The climate of the area is sub-tropical monsoon type. The average precipitation at Rewalsar is 1690 mm and the average maximum temperature is 33° C. The minimum temperature touches the freezing point and sometime snowfall occurs in the area. Broadly, four distinct seasons namely, winter (middle of December to February), summer (March to June), monsoon (early July to the middle of September), and autumn (October to November) is observed in Rewalsar. Winter is mild in low-lying areas, whereas it snows on high mountain ranges. The spring season is warm andsunny,and the monsoon season is the wettest part of the year and is characterized by high humidity. Summers are prickly hot. The area is mostly hilly. The catchment's lithology is composed of middle Siwalik Group (Pliocene) rocks comprising predominantly of fine grained, light colored sandstone with gray siltstone, and shale inter-layered. The latter two are often thicker than the former, indicating intermittent subsiding basin condition, their more weatherable nature and intense tectonic activity; sandstone layers occasionally stand out as resistant boulder within the weathered mass. The greenish gray-siltstone often show spheroidal or elephant skin weathering which weathers to soil. Fine specks of mica are seen in the siltstone. Clayey soil is also common and is not very deep. The major, trace and rare earth element (REE) geochemistry of Rewalsar Wetland sediments supported by petrographic. Clay mineralogical studies have revealed that sediments have been derived from metamorphic source terrain. In the very vicinity of the wetland area, sandstone is seen dipping into the hill in northwest direction. The depression formed for the accumulation of water appears to have been caused by a strike slip fault that runs in the NE-SW direction. On the whole, the rocks are soft and the strata are unstable, easily lending to the forces of denudation and erosion.

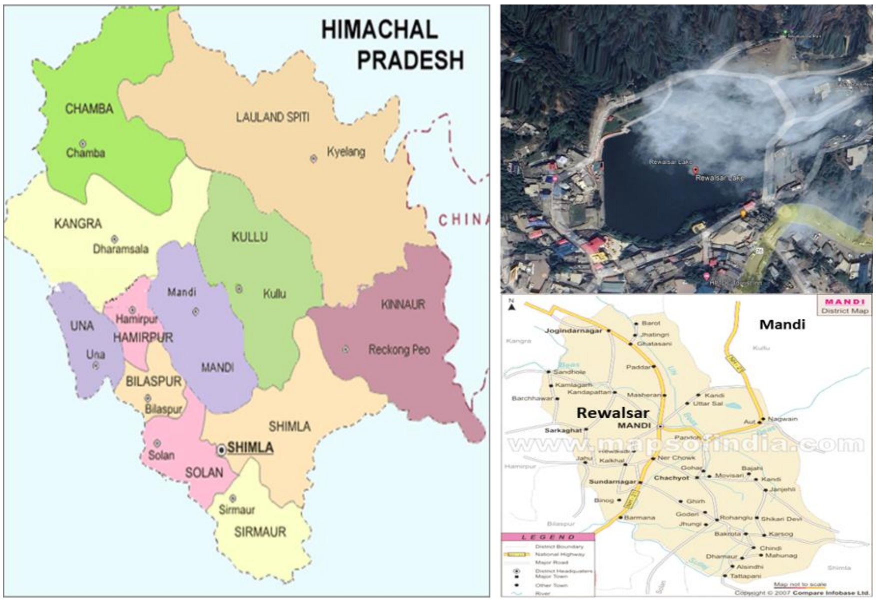


Figure: Study Area

6. Methodology:

Research objective wise detailed methodology is given below:

a) **Objective 1:** Preliminary study will be carried out to identify the physical features of lakes and sources of water in the lake considering the type of plantation, population, etc. Collection of baseline data of area related to morphological and geographical data. Sampling sites will be identified using GPS and sampling sites will be marked for further sampling and source identification of lake water. Seasonal and temporal water sample collection from the study area.

b) **Objective 2:** The water balance study of lakes will be carried out by calculating the inflow and outflow to/from the lake. The water quantity of lake will be measured by using the following equation:

$$\Delta S = Is + Iu + Pi - Qs - Qu - Ei$$

Where ΔS= Change in lake storage
Is=Surface inflow
Iu= Underground Inflow
Pi=Inflow due to direct precipitation
Qs= Surface outflow & withdrawal
Qu= Underground Outflow including seepage
Ei= lake evaporation

Table 1: Parameters to be investigated in the field

Parameters	**Instrument used**
Surface Water inflow/outflow	Discharge flow meter with data logger
Groundwater inflow/ outflow	-
Precipitation	Rain gauge with data logger
Evaporation	Pan method/ Observatory data
Depth (D)	Water level recorder
Transparency	Secchi Depth

c) Objective 3: The samples will becollection at different time intervals**.** Collected samples will be analyzed in the laboratory for physico-chemical and biological parameters (Table 2).

The accumulation of nutrients in the lake will be assessed by using the following equation:

$$\Delta N = (Sin + DRin + GWin + RDin) - (Sout + GWout)$$

Where ΔN= Change in nutrient stored in the lake
Sin=Nutrient input to lake via stream flow
DRin =Nutrient input to lake via direct runoff
GWin= Nutrient input to lake via groundwater
RDin=Nutrient input to lake via direct rainfall
Sout= Nutrient outflow from lake via lake opening, stream discharge
GWout=Nutrient outflow from lake via seepage through the beach barrier & to groundwater

Moreover, water samples will be identified for phytoplankton and chlorophyll content. The different indices will be calculated by using different equations:

i. Trophic Status Indices

Carlson's trophic status index (Carlson, 1977) has been widely used to estimate the trophic condition of water bodies. This method is based on three parameters namely Chl-a, SD and TP in a water body. Kratzer and Brezonik (1981) concluded that the total nitrogen (TN) content of the water body also impacts productivity and incorporated TN in the composite trophic status index (CTSI).

$$CTSI = \frac{TSI\ (SD) + TSI\ (Chl - a) + TSI\ (TP) + TSI\ (TN)}{4}$$

Where: TSI (SD) = 60-14.41 ln(SD)
TSI(Chl-a) =9.81 ln(Ch.-a) +30.6
TSI(TP)=14.42 ln(TP)+4.15
TSI (TN)=14.43 ln(TN)+54.45

TP and Chl-a are in µg/l, and SD transparency in meters. Based on the values of CTSI, the ponds are classified as oligotrophic, mesotrophic, eutrophic, and hypertrophic.

ii. Nygaard's algal index: Nygaard's index (1949) evaluates the productivity of water bodies based on the ratios of different algal groups. The combination of four indices is used to calculate a Compound Quotient Index (CQI)

$$Cyanophycean\ index = \frac{Cyanophyceae}{Desmidaceae}$$

$$Chlorophycean\ index = \frac{Chlorococcales}{Desmidaceae}$$

$$Bacillariohycean\ index = \frac{Centric\ diatom}{Pennate\ Diatoms}$$

$$Euglenophycean\ index = \frac{Euglenophyceae}{Cyanophyceae + Cholorococcales}$$

$$CQI = \frac{Cyanophycea + Chlorophyceae + Bacillariophyceae + Euglenophyceae}{Desmidaceae}$$

iii. **Shannon-Wiener diversity index**: Shannon-Wiener Index (H) accounts for both abundance and evenness of species present and is commonly used to characterize the species diversity in a community (Shannon and Weaver, 1964). The following equation is used to calculate the Shannon-Wiener Index:

$$H = \sum[\ (pi).ln\ ln(pi)]$$

Where pi =is the proportion of individuals of one particular species observed divided by the total number of species.

Table 2: Parameters to be analyzed in laboratory

Parameters	Instrument used
pH, EC, TDS	Sensor based Multiparameters
DO,BOD,COD	Titration method
NO3, NO2, O-PO4, SO4, NH3, Ca, Mg, Na, K, Cl	Ion chromatography
HCO3	Titration
Total Nitrogen	TKN analyzer
T-PO4, Chl a,b,c	Spectrophotometry/Sonde
Planktons density quantity	Microscope
Trace Metals	ICPMS
Pesticides	GCMS
Total organic carbon (TOC)	TOC Analyzer
TC/FC	Field test kit (Bactaslyde/Colilert)

d) **Objective 4:** Rate of sedimentation in the lake will be estimated using conventional/radiometric dating techniques.

e) **Objective 5:** Based on the result, remedial measures will be formulated to improve the water quality and quantity of lake.

f) **Objective 6:** Mass awareness activities will be carried out with the involvement of stakeholder departments.

7. Research Outcome from the Project:

a) Water quality and eutrophication status of the lake ecosystem
b) Hydrological characteristics of lake.
c) Rate of sedimentation in the lake.
d) Remedial measure for water quality improvement
e) Research papers/ report

8. Cost Estimate

a. Total cost of the project : 53,16,000
b. Source of funding : NIH internal
c. Sub head-wise abstract of the cost:

Sr. No.	Sub-Head	1st Year	2nd Year	3rd Year	Total
1	Manpower (Resource Person Jr.-2 nos)(30,000+HRA)	792000	792000	792000	2376000
2	Travelling expenditure	300000	400000	300000	1000000

3	Infrastructure / Equipment / Consumable	1500000	70000	70000	1640000
4	Experimental charges	50000	50000	50000	150000
5	Misc. Expenditure	50000	50000	50000	150000
	Grand Total	2692000	1362000	1262000	5316000

d. Justification for sub-head-wise abstract of the cost

- Travelling expenditure: For visit to the study area, attending conferences, data collection, surveys, etc.
- Equipment/Consumables: Flowmeter, Water level recorder, Rainguage, chemicals, glasswares, plastics, electrodes, etc.
- Experimental charges: Towards the analysis of samples

9. Work Schedule

a) Probable date of commencement of the project : Dec. 2022

b) Duration of the project : 3 Years

Stages of work & milestone

S.N.	Work Element/ Milestone	1st Year				2nd Year				3rd Year			
		I	II	III	IV	I	II	III	IV	I	II	III	IV
1	Literature Review and Reconnaissance survey												
2	Hiring of project staff, equipment purchasing/installation												
3	Water Mass balance assessment												
4	Assessment of water quality and eutrophication status												
5	Estimation of rate of sedimentation												
6	Remedial measures												
7	Outreach activity												
8	Interim Report/Publications												
9	Final report submission												

10. Contribution of PIs

PIs	Contribution
Dr. Kalzang Chhoden Sc. C, EHD	Water Quality, Nutrient Balancing, Eutrophication Status of Lake, Identification of Morphological Features of Lake
Dr. R.P Pandey Sc. G & Head, EHD	Water Balancing Study
Dr. Rajesh Singh Sc. D, EHD	Water Quality and Nutrient Balancing Study
Dr. Pradeep Kumar Sc. D, EHD	Hydrological Investigation and Characteristics
Dr. Vinay Kumar Tyagi Sc. D, EHD	Water Quality & Remediation Measures
Dr. Omkar Singh Sc. G (RMOD) and Dr. Suhas Khobragade Sc. G, HI	Over all Lake Expert& Sedimentation Estimation
Dr. D.S. Malik, Professor, GKU, Haridwar	Fishery Expert
HPSWA, Shimla	Mass Awareness and Outreach Activity

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Study – 10 (Internal Study)

a) Title of the Project:
"Comprehensive evaluation of disinfection units of STPs in Ganga basin: Occurrence and control the formation of emerging oxidation precursors"

b) Name and Designation of the Principal Investigator:
Dr. Vinay Kumar Tyagi, Scientist D, NIH Roorkee

c) Name and Designation of the Co-investigators:
IIT Roorkee
Dr. Bhanu P Vellanki, Professor
Dr. A. A. Kazmi, Professor

NIH Roorkee
Dr. Rajesh Singh, Scientist D
Dr. Mukesh K. Sharma, Scientist F
Dr. Pradeep Kumar, Scientist D
Er. J. P. Patra, Scientist D
Dr. Kalzang Chhoden, Scientist C
Dr. R.P.Pandey, Scientist G

d) Duration of the Project : 3 years

e) Total amount of assistance required: Rs. 7366000
(Seventy three lakhs sixty six thousands rupees)

1. ORIGIN OF THE PROPOSAL

Chlorine is one of the most common chemicals used as disinfectant globally since it possesses all satisfactory properties suitable for treating both potable and treated wastewater. The efficiency of chlorination at sewage treatment plants (STPs) with similar effluent characteristics might vary due to the presence of variable organic compounds such as saturated, unsaturated, or polycyclic compounds. In Indian STPs, the chlorine doses varies from a low concentration of 2 mg/L to as high as 10 mg/L. Thus, the nature of the treatment process affects the efficiency of chlorination and also formation of emerging oxidation precursors (EOPs). Oxidation of organic matter results in the formation of undesirable oxidation byproducts, i.e., emerging oxidation precursors (EOPs), with the highest concentration being trihalomethanes (THMs) and haloacetic acid (HAA), followed by other EOPs such as N-nitrosodimethylamine (NDMA), chloramines, etc. The principal means for controlling the formation of EOPs is to avoid the direct addition of free chlorine and proper O&M of the treatment process. Discharge of the treated water into natural water deficit water bodies, or where the flow rate is significantly less, results in a spike in EOPs concentrations. Accumulating EOPs in natural water bodies has been shown to cause serious environmental hazards even at very low concentrations. In addition, anthropogenic activities in water bodies add up the organic matter load, leading to the formation of intermediates due to the presence of free chlorine in the effluent from treatment plants. Organic compounds that comprise BOD, TOC, and COD exert chlorine demand, and other disinfectants are directly proportional. Ammonia reacts with chlorine to form chloramines. Oxidation of nitrite results in the formation of NDMA. Thus, the formation of EOPs is of great concern, and evidently, there is a need for effective technical efforts. The prime focus of the proposed study is to investigate the performance of disinfection units of various sewage treatment plants in the Ganga basin for physico-chemical and microbiological properties, tracer studies, EOPs formation, and characterization (Trihalomethanes, THM; Halo acetic acid, HAA; Nitrosodimethylamine, NDMA), and propose a technical solution to control and remove the EOPs.

2. REVIEW OF THE STATUS OF RESEARCH AND DEVELOPMENT IN THE SUBJECT

The disinfection in a water system is the process to inactivate the pathogenic microorganisms to prevent the diseases caused by them. As chlorine is effective and easily available low-cost disinfectant used in the disinfection units of many STPs for discharge into streams in most part of the world, including India. It results in the production of EOPs (Trihalomethanes (THMs), Haloacetic acids (HAAs))due to the reaction with organic matter present in wastewater, leading to unfavorable health effects like cancer induction and adverse pregnancy outcomes (Plewa and Wagner 2015).

Concerns and awareness have been raised regarding the occurrence and toxicity of these EOPs and the pressing need for their removal after the presence reported from various developed countries like America(Krasner et al., 2006), Canada, China(Feng et al., 2019) and Europeancountries(Evlampidouet al., 2020) intheir treated water(Dodds et al., 1999,Villanueva et al., 2004, Lakind et al., 2010). After consuming these EOPs in any form approximately 2-17% of cancer cases reported by the USEPA(USEPA, 2006).

In India EOPs were reported from effluent of an atomic power station in Kalpakkam, TN, India (2013-2017) in 2019(Padhi et al., 2019a). Padhi et al. 2019b,also studied the formation of EOPs during the chlorine and chorine dioxide dose on treated water. Various other researchers also identified the EOPs in drinking water treatment plants (Kumari& Gupta, 2018) and sewage water treatment plant (Tak& Kumar, 2017) from India. The EOPs formation potential in River Ganga was also reported (Naladala et al., 2018, Mishra & Dixit, 2012, Mishra & Dixit, 2013). In one of the study between 2000-2007 the higher levels of trihalomethane formation potential (THMFP) were identified in national capital Delhi (Hasan et al., 2010). Thacker et al. 2002 in their study also evaluate the EOPs in drinking water treatment plants from Mumbai in different seasons from 1995-1996 and found the concentration exceed the guideline value of 200 µg/L in post monsoon season. Basu et al. (2011) also investigated EOPs concentration and cancer risk assessment for tap water samples from water treatment plants.

The United State Environmental Protection Agency (EPA) regulate over 700 EOPs identified by various researchers. Commonly four types of THMs (Chloroform ($CHCl_3$), Bromodichloromethane ($CHCl_2Br$), Dibromochloromethane ($CHClBr_2$) and Bromoform ($CHBr_3$) and three type HAAs (Monochloro-, dichloro-, and trichloroacetic acid (MCAA, DCAA, and TCAA), Monobromo-, dibromo-, and tribromoacetic acid (MBAA, DBAA and TBAA) and Bromochloro-, bromodichloro-, and dibromochloroacetic acid (BCAA, BDCAA and DBCAA)) are identified (Tak et al.,2020).

3. PROJECT JUSTIFICATION (NEED FOR STUDY)

Humans have been exposed to the undesirable EOPs through various routes such as dermal, inhalation, and ingestion. These EOPs are designated as probable human carcinogens and are known to adversely impact the reproductive system (Nieuwenhuijsen et al., 2000; US EPA). Therefore it is important to remove the EOPs from the water before the discharge in a water body or before the release in the water distribution system.

In India very few studies taken into account to study the fate of EOPs formation in disinfection units of water/wastewater treatment systems. Few studies has been conducted on water sample collected from Ganga's barrage water treatment plant in Kanpur, India. They report that THMs concentration was within limit according to WHO guidelines(Mishra and Dixit 2012; Mishra and Dixit 2013). Kumari and Gupta (2018) studied THMs in drinking water samples of eastern India and found THMs concentration between 231 to 487 µg/L , which were very higher than the suggested limit of 80 µg/L by United State Environmental Protection Agency (USEPA).Naladala et al (2018) also reported HAA formation in ganga river.

There is inadequate information regarding EOPscharacterization in the disinfection units of STPs. A comprehensive nationwide STPs investigation program is required forEOPscharacterization based on the critical control design parameters of secondary treated wastewater. These parameters are chemical oxygen demands (COD), biochemical oxygen demand (BOD),Humics,total suspended solids (TSS), pH, alkalinity, ammonia, nitrite, nitrate and pathogens etc. Moreover, Cl_2dose,contact time, seasonal temperature alsoplay a significant role in EOPs formation.

Coagulation with alum and ferric sulphate, ozonation, adsorption through activated carbon, magnetic ion exchange, UV/ H_2O_2 and nanofiltration have all been used to remove the EOPs. These techniques have been selective in removing certain EOPs (Chaukura et al., 2020). However, integration of an advanced treatment unit after disinfection unit for EOPs removal may add further capital and operational cost in the treatment system. Therefore, it seems feasible to remove the residual organics and nitrogen precursors before biologically treated wastewater enters into the disinfection unit. In this way, formation of EOPs could be prevented. Thus, we proposed some low cost solutions of activated carbon, biochar and biological activated carbon (BAC) processes for removal of residual organics and nitrogen precursors. It will provide the new insights on the effective control onEOPs formation in disinfection units.

Based on the literature survey, it is observed that limited information is available on the characterization of EOPs in chlorinated sewage in India. Once this characterization data available from various sewage treatment plants in India, it will be easier to propose best suited control measures for EOPs formation to the Government of India. Hence, the proposed study aims to comprehensively characterize the EOPs from chlorine disinfection unitsand recommend best EOPs management options in Ganga Basin forsafe effluentdischarge into stream. The findings can be the stepping stone in the development of EOPs characterization and achieve the sustainablemanagement practices.

4. OBJECTIVES

The specific objectives of this study are:

1. To study the pathogen removal efficiency of chlorination system in full-scale sewage treatment plants.
2. To study the factors affecting chlorinationefficiency [dose, contact time, treated effluent quality, temperature, hydraulics, types of pathogens etc.,]
3. To study the formation of Emerging Oxidation Precursors (Qualitative and quantitative)in disinfection units of full-scale treatment plants.
4. To study the impact of chlorinated water discharge on water quality of receiving water body
5. To conduct pilot-scalestudies for the removal of residual organics and nitrogen precursors and control the formation of EOPs in chlorination system
6. To suggest the optimal chlorine dose w.r.t secondary treated effluent to achieve effective pathogens removal and control EOPs formation.

5. METHODOLOGY

5.1.List of Sewage treatment plants (STPs)

Twelve sewage treatment plants (STPs)representing different climates and topographies installed by the municipalities and other government bodies in various cities of Ganga basin were selected for study (Table 1). The plants use different technologies according to wastewater type, fund availability, governing body suggestions, and effluent requirements etc.

Table 1. List of the selected STPs for the study

S. No.	Name of STP	Capacity (MLD)	Technology	Wastewater	Disinfection type
1.	New Tehri, Garhwal	5	Extended Aeration	Sewage	Chlorination
2.	Kargi, Dehradun	68	SBR	Sewage + Septage	Chlorination
3.	Lakkarghat, Rishikesh	26	SBR + Filtration	Sewage	Chlorination

4.	Chorpani, Rishikesh	3.5	MBBR +Filtration Process	Sewage	Chlorination
5.	Jagjeetpur, Haridwar	27	Primary Clarifier + SBR + Filtration	Sewage	Chlorination
6.	Chandreshwar Nagar, Rishikesh	7.5	MBBR + Disk Filtration	Sewage	Chlorination
7.	IIT Roorkee	3	SBR process	Sewage	UV
8.	Coronation Pillar, Delhi	318	A_2O process	Sewage	Chlorination
10.	Indrapuram, Ghaziabad	56	SBR	Sewage+Industrial wastewater	Chlorination
11	Dinapur, Varanasi	140	Conventional Activated Sludge Process	Sewage	Chlorination
12	Goitaha STP, Varanasi	120	SBR	Sewage	UV

5.2. Performance evaluation ofdisinfection units

5.2.1. Efficiency of disinfections units

Waste water samples will be collected from various stages of STPs, i.e., raw wastewater (STP inlet), biologically treated wastewater (inlet of disinfection unit) and finally treated wastewater (disinfection unit effluent). The collected water samples will be characterized for various physical-chemical and microbiological parameters.

(v). Physical-chemical parameters: COD, BOD, DOC, bDOC, TOC, TSS, pH, alkalinity, ammonia, nitrite, nitrate, residual chlorine, humic substances

(vi). Indicator organisms and pathogens: Total Coliforms, FecalColiforms, E.Coli, Shigella, Salmonella

5.2.2. Factors affecting disinfection efficiency

The effects of various factors on disinfection efficiency (indicator microbes & pathogens removal) and EOPs formation will be studied comprehensively. Key factors will be taken into account: Disinfectant contact time, concentration/dosage of disinfectant, temperature, types of pathogens and indicator organisms, effect of water quality (suspended solids, organic matter), hydraulic retention time (HRT) of disinfection units (tracer study, designed and actual HRT verification), Cl_2 decay (Figure 1)

Fig. 1. Chlorine decay and microbial (pathogens and indicators) concentration along the chlorination disinfection units

5.2.3. Quantitative and qualitative assessment of EOPs in disinfections units and receiving water bodies

Waste water samples will be collected from inlet of disinfection unit and outlet of disinfection unit. Samples will also be collected from different points of disinfection tank. Moreover, samples will be collected from upstream and downstream of receiving water body to realize the impact of chlorinated water discharge on water quality with respect to EOPs concentration. The collected water samples will be characterized for various emerging oxidation precursors (EOPs): Trihalomethanes, THMs; Haloacetic acids, HAA; and N-Nitrosodimethylamine, NDMA)

5.3. Pilot- reactor study

Pilot scale reactor (1000 L) study will be conducted to remove the residual organics and nitrogen precursors and control the formation of EOPs in disinfection units. The low cost pollutants removal solutions of activated carbon, biochar and biological activated carbon (BAC) processes for removal of residual organics and nitrogen precursors will be studied.The effects of integration of a bio/activated carbon/ biochar filter on organic pollutants removal and EOPs formation in downstream disinfection process will be studied.

6. WORK PLAN (DURATION & ACTIVITY CHART)

S.No.	Work Element/ Milestone	1st Year				2nd Year				3rd Year			
		I	II	III	IV	I	II	III	IV	I	II	III	IV
1	Literature Review	■											
2	Hiring of project staff, equipment, purchasing/installation	■	■										
3	Performance evaluation of disinfection units in STPs		■	■	■	■	■	■	■				
4	Quantitative and qualitative assessment of EOPs formation in disinfection units		■	■	■	■	■	■	■				
5	Control of EOPs formation: Pilot reactor study									■	■	■	
6	Interim Report/Publications				■				■				
7	Final report submission												■

7. Expected outcomes(Project deliverables): Specific outcome of the study are:

1. Comprehensive evaluation of disinfection units
2. Qualitative and quantitative database onEOPs formation in disinfection units
3. Technological solution to prevent the formation of EOPs through the integration of treatment units and design modifications
4. Technical report and papers

8. Practical relevance/utility of the project

This study could be proved as one of the most economical and environmental friendlies as it requires a lesser workforce and would be a potentially very essential data record that probes deeper to the chlorine disinfection in the working STPs. Regarding the cost efficacy and operational simplicity, this project is a potential capital and O&M cost savings as it will require quite less cost for analysis and recordkeeping. Analysis part can be done by lab-sitting, but regularity and consistency in work will be required.The outcome of this research will provide useful guidelines for safe chlorine disinfectiondose and control the formation of EOPs in the Ganga Basin.

9. Agencies, which can utilize the results of the project:

Effective disinfection Cl_2 dose a most challenging task for the municipal authorities not only at the local level but also at the global level, so the benefit is not limited to a group of people, but its advantage is widespread at National as well as International scale especially for the developing communities. The findings of the proposed study will be more relevant in the Indian context. The target beneficiaries of the proposed study will be:

- National River Conservation Directorate and Ministry of Environment, Forest & Climate Change can direct the application of technology on commercial scales once proved in field conditions. Ultimately, the **Central Pollution Control Board(CPCB)**can devise standards based on this technology for the control of EOPsformation and effective disinfectant dose.
- Different Consultants and Companies can get involved and improve the design conditions for an upscaled version, better treatment efficiencies, safe and sound operation, and proper maintenance.
- Municipal corporations will be the direct beneficiaries, as effective disinfection well managed. Moreover, the obligation of stringent rules for the disposal of treated of EOPs can be pacified as the treated wastewater can be further reused or mixed with stream.
- Researchers: The record maintenance of EOPs is highly required as limited data available on the EOPs characterization in different disinfection units of sewage treatment plants across India. The introduction of the findings of this study will benefit researchers working on municipal wastewater treatment as the option for efficient management of wastewater and disinfection technologies, and conservation of our water resources.

10. Participation and promotion among public and private sector and other government ventures:

It could be achieved by writing and publication of papers in international peer-reviewed journals (e.g., Water Research, Bioresource Technology, Hazardous Material, Waste Management and Environmental Science and Technology, etc.) by presenting lectures and posters at international conferences in the field of wastewater treatment, and environmental engineering. The NIH Roorkee has an extensive network of industry contacts, which will be used in the first instance to transfer the knowledge to the Indian and International companies active in relevant industrial sectors (water sector, chemical industry, environmental industry). In further support, a one-day workshop will be organized at NIH, Roorkee by the end of this project (depends on the funds' availability or extra funds provided from funding agency), broadly announced by NIH Roorkee thanks to their massive networking implication, to the industry active in water and wastewater management sector. The results of this project will have direct significance for the management and handling of EOPs in WWTPs of India.

11. Budget Details

Full Summary of Budget (In Rs)

S. No.	Head	Ist Year	IIndYear	IIIrd Year	Total
1	Manpower a. Senior Resource Person (50000/- + HRA) b. Junior Resource Person (35000/- + HRA)	 660000 462000	 660000 462000	 660000 462000	 1980000 1386000
2	Fabricated Systems/Models	-	500000	-	500000
3	Consumables (Glassware, Chemicals, Misc.)	600000	600000	400000	1600000
4	Travel (Sample collection,Meeting & Others)	500000	500000	200000	1200000
5.	Experimental charges	200000	200000	100000	500000
6	Miscellaneous expenditure	50000	100000	50000	200000
	Grand Total	**2472000**	**3022000**	**1872000**	**7366000**

Manpower Budget Details

Designation	**1st Year**	**2nd Year**	**3rd Year**	**Total (In Rs.)**
1. Senior Resource Person (50000/- + HRA monthly) 2. Junior Resource Person (35000/- + HRA monthly)	660000 462000	660000 462000	660000 462000	1980000 1386000
Total	**1122000**	**1122000**	**1122000**	**3366000**

Justification for Manpower

One Senior Resource Person with a Ph.D. degree and one Junior Resource Person with a post-graduation degree in Environmental sciences/ Chemistry/Environmental Engineering/Chemical Engineering with research experience in the field of water and wastewater treatment and water quality analysis will be required for the extensive fieldwork, analysis work, and piloting experiments.

Consumables Cost Details

Rs. In 1st Year	**Rs. In 2nd Year**	**Rs. In 3rdYear**	**Total (In Rs.)**
600000	600000	400000	1600000

Justifications for Consumables:

Chemical such as EOPs standards, solvents (methanol, acetone, heptane, acetonitrile, and dichloromethane), glass vials, microbiological media, chemicals, and glassware will be required for the analysis of samples and remediation of EOPs.

Travel cost details

Rs. In 1st Year	**Rs. In 2nd Year**	**Rs. In 3rdYear**	**Total (In Rs.)**
500000	500000	200000	1200000

Justifications for travel
Extensive field visit for sampling at STPs. Multiple times domestic travel (Field study, Meetings and National conferences)

Experimental Charges

Rs. In 1st Year	Rs. In 2nd Year	Rs. In 3rdYear	Total (In Rs.)
200000	200000	100000	500000

Justifications for Experimental Charges
Samples shall needs to be outsources for some EOPs analysis.

12. Contribution of PIs

PIs	Contribution
Dr. Vinay Kumar Tyagi, Sc. D, EHD	Performance evaluation of disinfection units, Quantitative and qualitative assessment of EOPs formation in disinfection units, Control of EOPs formation: Pilot reactor study; suggestive measure to reduce the DBPs formation in disinfection units
Dr. R.P Pandey Sc. G & Head, EHD	Wastewater quality Balancing Study
Dr. Mukesh K. Sharma, Sc F, EHD	DBPs analysis
Dr. Rajesh Singh Sc. D, EHD	Wastewater Quality: carbon and Nutrient removalstudy
Dr. Pradeep Kumar Sc. D, EHD	Hydrological Investigation and Characteristics (Impact on water resources up- and down-stream)
Dr. J.P.Patra, Sc D,	Tracer Study, CFD modeling in disinfection tanks
Dr. KalzangChhoden Sc. C, EHD	Wastewater Quality & Remediation Measures for DBPs formation
Dr. Bhanu P Vellanki, Professor, IITR	DBPs expert, analysis of DBPs, Pilot scale study
Dr. A. A. Kazmi, Professor, IITR	BiologicalWastewater treatment Expert &residual organic carbon & nutrients removal optimization in WWTPs

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GROUND WATER HYDROLOGY DIVISION

Scientific Manpower

S N	Name	Designation
1	Dr. M K Goel	Scientist G & Head
2	Dr. Anupma Sharma	Scientist G
3	Dr. Surjeet Singh	Scientist F
4	Dr. Gopal Krishan	Scientist D
5	Sh. Nitesh Patidar	Scientist C
6	Mrs. Nidhi Kalyani	Scientist B
7	Mrs. Anju Choudhary	Scientist B
8	Sri Sanjay Mittal	PRA
9	Sri S.L. Srivastava	PRA
10	Sri Ram Chandra	SRA

APPROVED WORK PROGRAM FOR THE YEAR 2022-23

S. No.	Project	Project Team	Duration & Status	Funding Source
Internal Studies				
1. NIH/GWH/NIH/ 20-22	Integrated GEE-MODFLOW based Groundwater Recharge Assessment System for Hindon River System	Nitesh Patidar (PI), Gopal Krishan Anupma Sharma	2 years (08/20 – 07/22) *Status: **Completed***	Internal Study
2. NIH/GWH/NIH/ 22-25	Studying arsenic genesis and developing alternate water supply management strategies in Ganga basin	Sumant Kumar (PI), S. Singh, R. Singh, G. Krishan, S. S. Rawat, M.K. Sharma, N. Patidar, P. K. Mishra, M. K. Goel	3 years (04/22 – 03/25) Status: **In-progress**	Internal Study
3. NIH/GWH/NIH/ 22-24	Conjunctive Management of Water Resources in IGNP Command	Nitesh Patidar (PI), M. K. Goel, Anupma Sharma, Surjeet Singh, Gopal Krishan, Sumant Kumar, Nidhi	2 years (04/22 – 03/24) Status: **In-progress**	Internal Study
4. NIH/GWH/NIH/ 22-24	Studying Groundwater Dynamics using Machine Learning and Numerical Modelling	Nidhi Kalyani (PI), Anupma Sharma, Nitesh Patidar, Sumant Kumar	2 years (04/22 – 03/24) Status: **In-progress**	Internal Study
Sponsored Projects				
5. NIH/GWH/BGS/ 17-20	Groundwater Fluctuations and Conductivity Monitoring in Punjab - Groundwater resilience in Punjab and adaptation to future changes in climate and water resource demands (title modified by funding agency)	Gopal Krishan (PI), S. Singh, C. P. Kumar (retd.), M. S. Rao *BGS, UK:* Dr. Dan Lapworth Dr. Alan MacDonald Dr. Daren Goody	5 years (12/17-11/22) *Status: **In progress (Extended up to Nov. 2024)***	BGS, UK
6. NIH/GWH/PDS/ 17-21	Assessment of Impacts of Groundwater Salinity on Regional Groundwater Resources, Current and Future Situation in Mewat, Haryana – Possible Remedy and Resilience Building Measures	Gopal Krishan (PI), Surjeet Singh, C. P. Kumar (Retd.), *IIT-Roorkee:* M. L. Kansal, Brijesh Yadav *Sehgal Foundation:* Lalit Mohan Sharma	4 years (12/17-07/22) *Status: **Completed***	NHP under PDS
7. NIH/GWH/PDS/ 17-21	Ganges Aquifer Management in the Context of Monsoon Runoff Conservation for Sustainable River Ecosystem Services - A Pilot Study	Surjeet Singh (PI), C. P. Kumar, Sudhir Kumar, Suman Gurjar, Gopal Krishan	4 years (12/17-07/22) *Status: **Completed***	NHP under PDS
8. NIH/GWH/CEH M/18-22	Integrated Management of Water Resources for Quantity and Quality in Upper Yamuna Basin up to Delhi	Anupma Sharma (PI) S. K. Jain, A. Sarkar, M. K. Sharma, L. N. Thakural, S. Kumar, P.K. Mishra, V. Singh, N. Patidar, N. Kalyani *Partners* Haryana Irr. & WR Dept.,	4 years (04/18-01/24) *Status: **In progress***	Special Project under "Centre of Excellence" (NHP)

		UPGWD, UYRB, CWC		
9. NIH/GWH/DST/ 19-23	Enhancing Food and Water Security in Arid Region through Improved Understanding of Quantity, Quality and Management of Blue, Green and Grey Water	Anupma Sharma (PI), Gopal Krishan, Nitesh Patidar (*Lead*: CAZRI Jodhpur, *Partners*: NIH Roorkee, IISWC Dehradun, CSWRI & CIAH, Bikaner, NIAM Jaipur)	5 years (03/19 - 01/24) *Status:* ***In progress***	DST
10. NIH/GWH/CCR BF/20-23	Expansion of the Indo-German Competence Centre for Riverbank Filtration – CCRBF	Gopal Krishan (PI & Co-coordinator)	3 years (07/20 – 06/23) *Status:* ***In progress***	Federal Min. of Education and Research, Germany
11. NIH/GWH/DST-SERB/21-24	Partitioning Evapotranspiration into Evaporation and Transpiration fluxes using Stable Isotopes of Oxygen and Hydrogen	Gopal Krishan (PI), MS Rao	3 years (04/21 – 03/24) *Status:* ***In progress***	DST-SERB
12. NIH/GWH/APN/ 22	Capacity Development Program on Site Suitability Mapping for Managed Aquifer Recharge (MAR) under Varying Climatic Conditions using Remote Sensing and Machine Learning based Hydrological Modelling Tools	Nitesh Patidar (PI), S. Singh, G. Krishan *IIT Roorkee (lead)*: Basant Yadav, Ashish Pandey, R D Singh, B. J. Deka *In-kind support:* KU, Japan: Yutaka Matsuno, PNU, South Korea: Sanghyun Jeong	10 months (01/22-10/22) *Status:* ***Completed***	Asia-Pacific Network (APN)

PROPOSED WORK PROGRAMME FOR THE YEAR 2023-24

S. No.	Project	Project Team	Duration & Status	Funding Source
Internal Studies				
1. NIH/GWH/NIH/ 22-25	Studying arsenic genesis and developing alternate water supply management strategies in Ganga basin	Sumant Kumar (PI), S. Singh, R. Singh, G. Krishan, S. S. Rawat, M.K. Sharma, N. Patidar, P. K. Mishra, M. K. Goel	3 years (04/22 – 03/25) Status: **In-progress**	Internal Study
2. NIH/GWH/NIH/ 22-24	Conjunctive Management of Water Resources in IGNP Command	Nitesh Patidar (PI), M. K. Goel, Anupma Sharma, Surjeet Singh, Gopal Krishan, Sumant Kumar, Nidhi Kalyani	2 years (04/22 – 03/24) Status: **In-progress**	Internal Study
3. NIH/GWH/NIH/ 22-24	Studying Groundwater Dynamics using Machine Learning and Numerical Modelling	Nidhi Kalyani (PI), Anupma Sharma, Nitesh Patidar, Sumant Kumar	2 years (04/22 – 03/24) Status: **In-progress**	Internal Study
Sponsored Projects				
4. NIH/GWH/BGS/ 17-20	Groundwater Fluctuations and Conductivity Monitoring in Punjab - Groundwater resilience in Punjab and adaptation to future changes in climate and water resource demands (title modified by funding agency)	Gopal Krishan (PI), S. Singh, C. P. Kumar (retd.), M. S. Rao *BGS, UK:* Dr. Dan Lapworth Dr. Alan MacDonald Dr. Daren Goody	5 years (12/17-11/22) *Status:* ***In progress (Extended up to Nov. 2024)***	BGS, UK
5. NIH/GWH/CEH M/18-22	Integrated Management of Water Resources for Quantity and Quality in Upper Yamuna Basin up to Delhi	Anupma Sharma (PI) S. K. Jain, A. Sarkar, M. K. Sharma, L. N. Thakural, S. Kumar, P.K. Mishra, V. Singh, N. Patidar, N. Kalyani *Partners* HIWRD, UPGWD, UYRB, CWC	4 years (04/18-01/24) *Status:* ***In progress***	Special Project under “Centre of Excellence” (NHP)
6. NIH/GWH/DST/ 19-23	Enhancing Food and Water Security in Arid Region through Improved Understanding of Quantity, Quality and Management of Blue, Green and Grey Water	Anupma Sharma (PI), Gopal Krishan, Nitesh Patidar (*Lead*: CAZRI Jodhpur, *Partners*: NIH Roorkee, IISWC Dehradun, CSWRI & CIAH, Bikaner, NIAM Jaipur)	5 years (03/19 - 01/24) *Status:* ***In progress***	DST
7. NIH/GWH/CCR BF/20-23	Expansion of the Indo-German Competence Centre for Riverbank Filtration – CCRBF	Gopal Krishan (PI & Co-coordinator)	3 years (07/20 – 06/23) *Status:* ***In progress***	Federal Min. of Education and Research, Germany
8. NIH/GWH/DST-SERB/21-24	Partitioning Evapotranspiration into Evaporation and Transpiration fluxes using Stable Isotopes of Oxygen and Hydrogen	Gopal Krishan (PI), MS Rao	3 years (04/21 – 03/24) *Status:* ***In progress***	DST-SERB

New Internal Studies				
9. NIH/GWH/ 22-24	Hydrogeological and Isotopic investigation of groundwater in Himalayan Watershed of Kashmir, India	Gopal Krishan (PI) M.S. Rao *SKUAST-Srinagar* Rohitashv Kumar	1.5 years (09/22 – 03/24) *Status:* ***New Study***	Internal Study
10. NIH/GWH/ 23-24	Development of Archive of Soil Hydraulic Characteristics	Anju Chaudhary (PI) Nitesh Patidar, M.K. Goel, Surjeet Singh, Anupma Sharma	1 year (04/23 – 03/24) *Status:* ***New Study***	Internal Study
11. NIH/GWH/ 23-25	Enhancement and application of NIH_WISDOM	Nitesh Patidar (PI) Deepak Singh Bisht, M.K. Goel, T. Thomas, Sunil Gurrapu, Anupma Sharma, Surjeet Singh	2 years (10/23 – 09/25) *Status:* ***New Study***	Internal Study

The details of the studies are given in Annexure-I.

Trainings organized:

GWH Division organized **04** training courses.

Outreach activities since previous WG meeting:

1. Scientists published/accepted: **18** papers in int./ national journals
   17 papers in int./ national conferences
   01 edited book
   07 book chapters
2. Scientists guided/guiding thesis: **09** Ph.D
   08 M.Tech
3. Scientists conducted mass awareness activities: **01**
4. Consultancy studies completed/ ongoing: **05**
5. Scientists developed **3** Modelling Software:
   a. NIH_ReSyP
   b. PRAJAL
   c. GEE-MODFLOW

1. PROJECT REFERENCE CODE: NIH/GWH/NIH/20-22

Title of the Project: *Integrated GEE-MODFLOW based Groundwater Recharge Assessment System for Hindon River System*

Study team: PI Dr. Nitesh Patidar, Scientist-C
Co-PIs Dr. Gopal Krishan, Scientist-D
Dr. Anupma Sharma, Scientist-G

Type of study: Internal

Duration: Two years (August 2020 – July 2022)

Objectives vis-à-vis Achèvements

Objectives	Achèvements
Development of the integrated GEE-MODFLOW model to estimate groundwater recharge and to disseminate model outputs	*Completed* Integrated model, named as GEE-MODFLOW, has been developed. Various modules to download data from GEE, process and utilize in MODFLOW have been developed. A surface water module, named as Root Zone Flow (RZF) Module, to estimate infiltration, ET and percolation from the top soil layer has also been developed. MODFLOW has been integrated with RZF and GEE. A web-based interface to run and disseminate the model outputs has also been developed.
Evaluation of the estimated recharge using in-situ observations	*Completed* The integrated model has been tested against the observed groundwater heads and groundwater recharge estimates of CGWB. The model is also tested in upper Mahanadi River basin for streamflow simulation.
Assessment of the impacts of various recharge/abstraction scenarios on groundwater system of Hindon river basin	*Completed* The impacts of recharge/abstraction has been assessed using increasing groundwater pumping and hypothetically placing recharge structures.

Brief background

The excessive groundwater withdrawal led by growing water demands has resulted in rapid and widespread groundwater declines in many parts of India. To manage water resources in a sustainable manner, comprehensive understanding of groundwater system is essential. Of particular importance are the understanding of recharge processes, quantification of recharge from various sources, such as rainfall and surface water bodies, assessment of the impacts of groundwater withdrawal, and understanding the exchange of fluxes between surface and subsurface hydrological systems.

With the improved understanding of hydrological processes and recent advancements in the field of computers, many hydrological models have been developed. Although the models developed during the past decades produce useful results, a model alone may not be implemented to support decision making for groundwater management mainly due to (i) difficulties in incorporating the frequent changes in impervious surface and vegetation phenology, and (ii) no provision to disseminate the outputs to open platforms so as to support decision making. Therefore, a Groundwater Recharge Assessment System that integrates state-of-the-art hydrological models, allows to incorporate frequently available remote sensing data, data visualization and dissemination, is required for estimation of groundwater recharge and to support decision making in India. In this context, the proposed system will help assessing the replenishable groundwater, investigating impacts of various recharge/abstraction scenarios on groundwater system and analyzing the outputs on an open web-based GIS platform. The developed model is named as GEE-MODFLOW which is a part of a larger system, named as "Web-based Catchment Modelling System for Decision Making (WISDOM)". The current version of WISDOM (version: *Vadose*) has only one model – the GEE-MODFLOW, however it is envisaged that a few other models, such system model for canal commands, VIC and machine learning may also be incorporated in the next versions.

Study area

The model is tested in Hindon river basin. Hindon river originates from Saharanpur district of Uttar Pradesh and joins Yamuna river near Delhi. The basin lies between the latitudes 28°30′15″ to 30°15′12″ N and longitudes 77°20′18″ to 77°50′10″ E and has an area of ~7000 km^2. It is largely composed of Pleistocene and Quaternary alluvium represented by sand, clay and kankar. The ever-increasing groundwater abstractions to cater the agricultural needs have led to depleted groundwater levels in the area. These depletions have not only reduced the groundwater availability but also have made the groundwater more susceptible to pollution and have reduced the baseflow contribution to the streams. The alarming groundwater declines, emerging groundwater quality issues and ever-increasing water demand in the region necessitate proper planning and management of groundwater resources. This requires precise quantification of groundwater recharge, assessment of various recharge/abstraction scenarios on groundwater system and forming and implementation of water management strategies. As the groundwater is a dynamic resource which varies with the recharge and extraction, frequent assessments are needed for better planning.

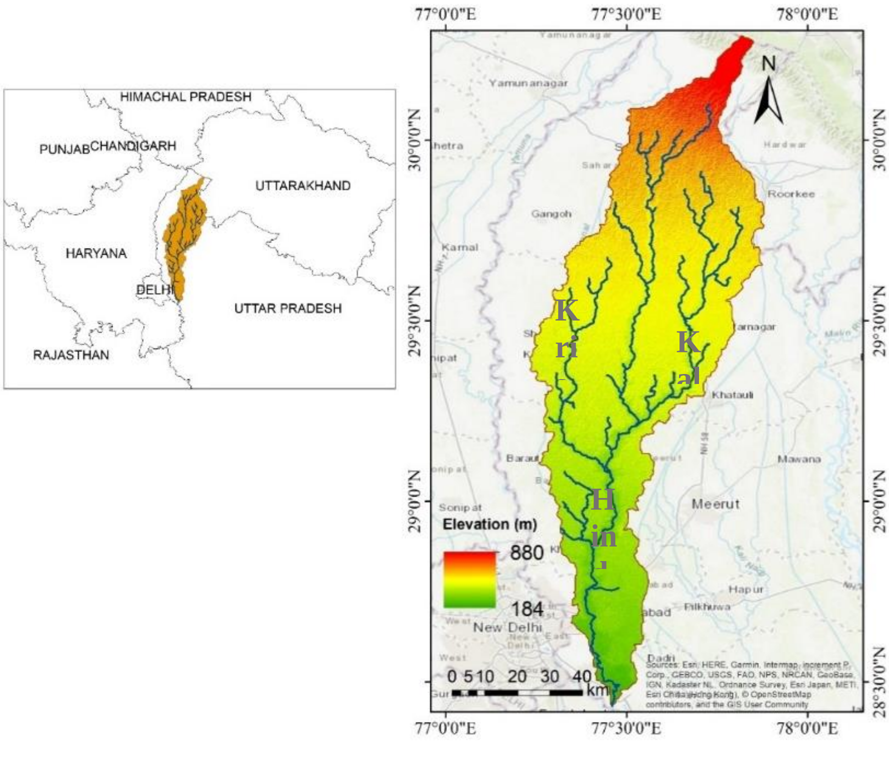
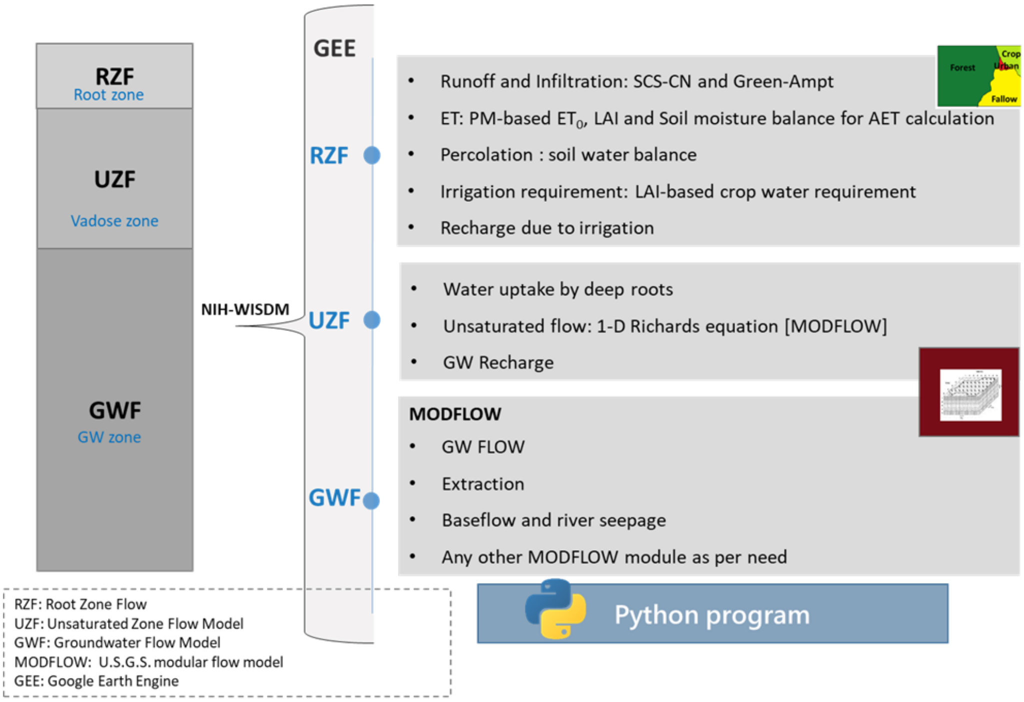


Figure – 1.1: Hindon river basin with elevation and stream network

Development of System for Integrated Modelling

Estimation of recharge requires simulation of both the surface and subsurface hydrological processes. The water that reaches to groundwater table, so called recharge, is an end result of various processes happening at surface/subsurface which are driven by various influxes, such as infiltration and irrigation, and outfluxes, such as root water uptake and soil evaporation. Therefore, in order to mimic all such processes, an integrated model is needed. The integrated model developed in this study consists of various modules which simulate surface and sub-surface processes in unsaturated and saturated zones. The model has three simulation modules, namely Root Zone Flow (RZF), Unsaturated Zone Flow (UZF), and Groundwater Flow (GWF). The processes simulated by these modules and methods used are elaborated Fig 1.2.

Figure – 1.2: Methods used in simulating surface and sub-surface hydrological variables



Root Zone Flow (RZF) Module

The RZF is developed during the present study at NIH to simulate processes in the top soil layer (say, up to 500 mm). All the processes happening at the surface and top soil layer, such as runoff, infiltration, ET from top soil layer, soil evaporation, etc., are simulated by RZF. RZF is tightly coupled with Unsaturated Flow (UZF) module to further simulate the processes in the vadose zone, such as ET from deep roots and recharge. RZF uses the well-established methods of hydrology to simulate various components, such as SCS-CN, Green-Ampt, Penman-Monteith, etc.

Unsaturated Zone Flow (UZF) Module

UZF aims at simulating the flow in unsaturated zone. In case of GEE-MODFLOW, the UZF simulates flow in the zone below the root zone (as simulated by RZF) but above the water table. UZF is a 1-D Richards Equation-based module of MODFLOW which is tightly coupled with RZF and GWF modules. The percolation from the top soil layer becomes the influx to the bottom soil layer which consists of the deep root zone and the unsaturated zone. The moisture movement in the unsaturated zone is simulated at daily time-step. Maximum transpiration from deep root as estimated by subtracting the actual transpiration occurred at the top soil layer from the maximum transpiration, becomes input to UZF. In UZF, the actual transpiration from the deeper roots is estimated considering the moisture availability at each time-step. Finally, the sum of transpiration from the top and bottom soil layers is summed to get the total transpiration.

Groundwater Flow (GWF) Module

Groundwater flow simulation is vital for simulation of recharge-pumping effects and river-aquifer interaction. In addition, integration of groundwater model helps validating the recharge by comparing groundwater head with observed heads. Results of integrated surface-groundwater model also help better decision making. WISDOM uses the very popular – modular hydrologic simulation program called MODFLOW – developed by U.S Geological Survey. MODFLOW discretizes the area of interest into several grids, control-volume units, to generate finite-difference equations. The finite-difference equations are formulated for intercell flow, boundary conditions and specified flows in terms of conductance. MODFLOW simulates groundwater flow in 3-dimensions using the Darcy's Law. The WISDOM includes six MODFLOW modules for solving various stresses and flows (Table – 1.1).

Table – 1.1: MODFLOW modules used in WISDOM

S. No.	MODFLOW Module	Description
1	DIS6	Discretization package
2	NPF6	Node Property Flow Package Pane
3	STO6	Storage Package
4	UZF	Unsaturated-Zone Flow package
5	SFR6	Stream-Flow Routing package
6	WEL6	Well package
7	GHB6	General Head Boundary package
8	CHD6	Time-Variant Specified Head package

Development of Web-based Interface

The web-based interface of the model is developed using Python programming. The system uses Python-Dash for web-interface and various Python scripts which are developed at NIH for data processing, running simulations and displaying model outputs. The system can be divided into five main components – Cloud computing, model data preparation, simulation, output visualization and dissemination. The cloud computing runs various functions on GEE's cloud and download the final data at NIH server. The data preparation module converts the GEE's data and other user uploaded data sets to desired format for modelling. The simulation module runs the RZF, UZF and GWF for integrated hydrologic simulation. The model results can be visualized in terms of maps and plots using output visualization module which can be disseminated in the form of dashboard using the WISDOM's interface.

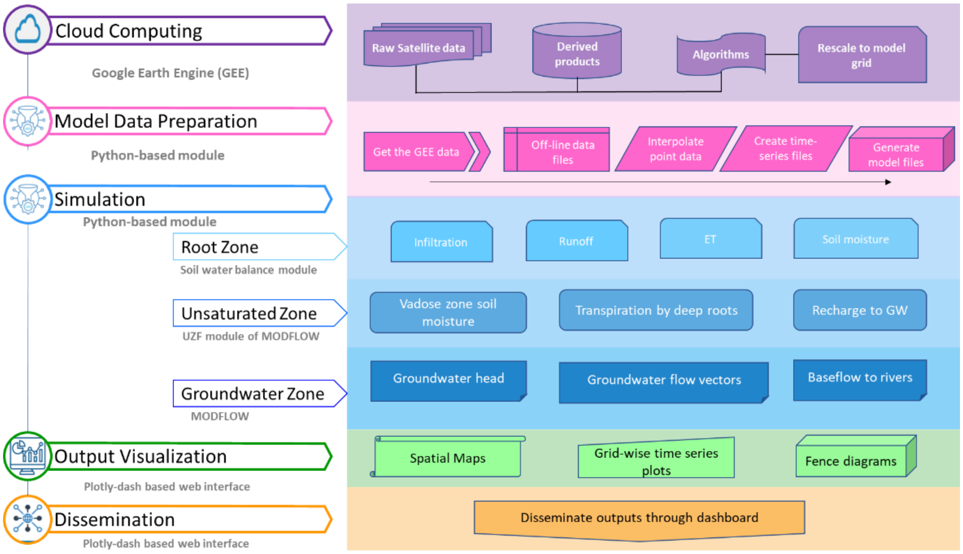


Figure – 1.3: Architecture of WISDOM

The GEE-MODFLOW can be run using the web-based interface. Interface has a workflow which guides the modeler through various file upload, parameterization and visualization steps. Once the model run is completed, a dashboard is created which shows various time-series and thematic maps with line/bar and 3D plots. This final dashboard can be published as basin dashboard for sharing model results on the internet.

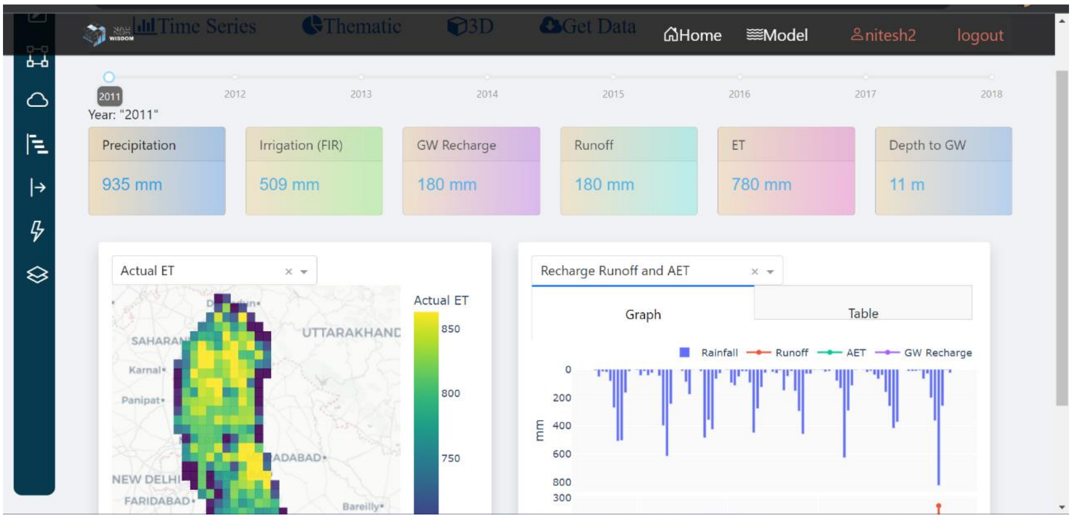


Figure – 1.4: Model output visualization dashboard of WISDOM

Model testing

The integrated GEE-MODFLOW model has been applied in Hindon river basin. Hindon basin is a part of gangetic plain and the basin boundary doesn't coincide with the groundwater divide, therefore it is difficult to assign boundary conditions in Hindon for MODFLOW. To address this, the model was applied to Ganga-Yamuna Doab region (up to Delhi) so that the boundary conditions can be assigned appropriately. The model is setup for a period of 2011 to 2018 at daily time-step. Various data sets from GEE, IMD and CGWB were used. All thematic layers, including DEM, land cover, soil, impervious surface fraction, etc., and some time series layers, such as Leaf Area Index (LAI) and vegetation fraction are retrieved from GEE using WISDOM's automated data retrieval module. Precipitation and temperature were taken from IMD. The aquifer geometry and parameters were taken from CGWB's district brochure and assessment report. To estimate the groundwater pumping from the irrigation demand (estimated by GEE-MODFLOW) proportion of irrigation demand being met from groundwater is taken from CGWB's assessment reports.

Using the web interface of the WISDOM, the GEE-MODFLOW was run from 2011 to 2018. Calibration of the model was performed by comparing simulated and observed groundwater heads at different locations. The PEST is integrated with the GEE-MODFLOW model for auto-calibration. The simulation from 2011-13 was used as calibration period and the results are validated for the period 2014-18. The comparison of the simulated and observed heads are shown in the Fig. 5. It is observed that the RMSE varies from 0.27 to 4.23 m (AMSL). The performance of model is found satisfactory in the basin for simulating groundwater levels. However, it is seen that at some locations the simulated heads deviate considerably from the observed heads, specially during the later time-steps which can be improved if more detailed aquifer data is available. The GEE-MODFLOW model is also tested in upper Mahanadi Basin (upstream of Hirakund dam) for streamflow simulation. The model simulates streamflow satisfactorily with Nash–Sutcliffe Efficiency (NSE) of 0.6.

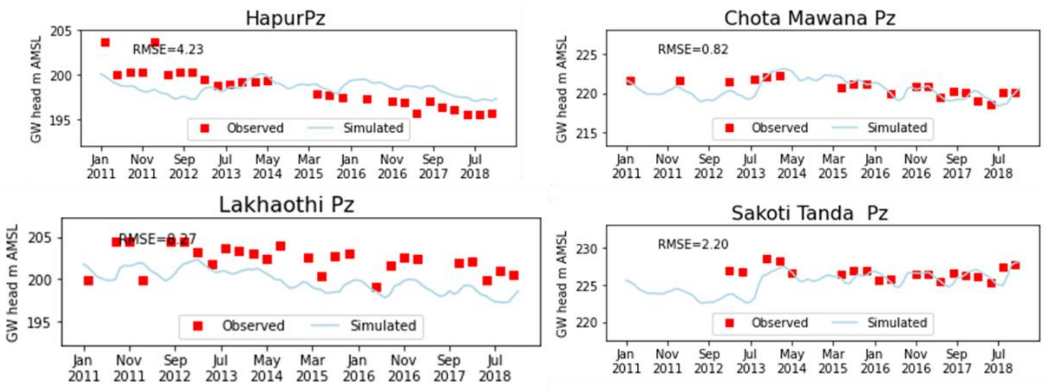


Figure – 1.5: Comparison of simulated & observed GW heads at four locations in study area

The groundwater recharge was estimated for the period 2011 to 2018 using the calibrated model. The estimated annual recharge varies from 294 mm to 425 mm (spatially averaged). The recharge is mainly governed by precipitation and irrigation in the area. The estimated recharge is compared with the district-wise assessments of CGWB. A good agreement between the estimated recharge and CGWB's assessment is observed with R^2 value of 0.6.

Conclusions

The GEE-MODFLOW model is developed to simulate surface-groundwater flow in root zone, unsaturated zone and saturated zone utilizing surface (RZF) and subsurface (MODFLOW) models. Utilizing the web-enabled interface, GEE's cloud computing, python programming and models, it reduces efforts of modelers by automating data downloading, pre-processing, post-processing and visualization which would otherwise take considerable time to accomplish using traditional tools. With its freely available easy-to-use web-interface and automated data processing, GEE-MODFLOW allows groundwater modelling without the use of any commercial GIS and MODFLOW interfaces. GEE-MODFLOW is a part of a broader system, named as WISDOM, which would also incorporate other models for canal system modelling, irrigation demand estimation, and macro-scale hydrologic modelling using VIC, in upcoming versions.

2. PROJECT REFERENCE CODE: NIH/GWH/NIH/22-25

Title of the study: *Studying arsenic genesis and developing alternate water supply management strategies in Ganga basin*

Collaborator	:	CGWB, Dehradun and NIT, Patna
Type of study	**:**	Internal
Date of start (DOS)	**:**	April, 2022
Scheduled date of completion:		March, 2025 (3 Years)
Location	**:**	Ganga basin (From Gangotri to Patna)

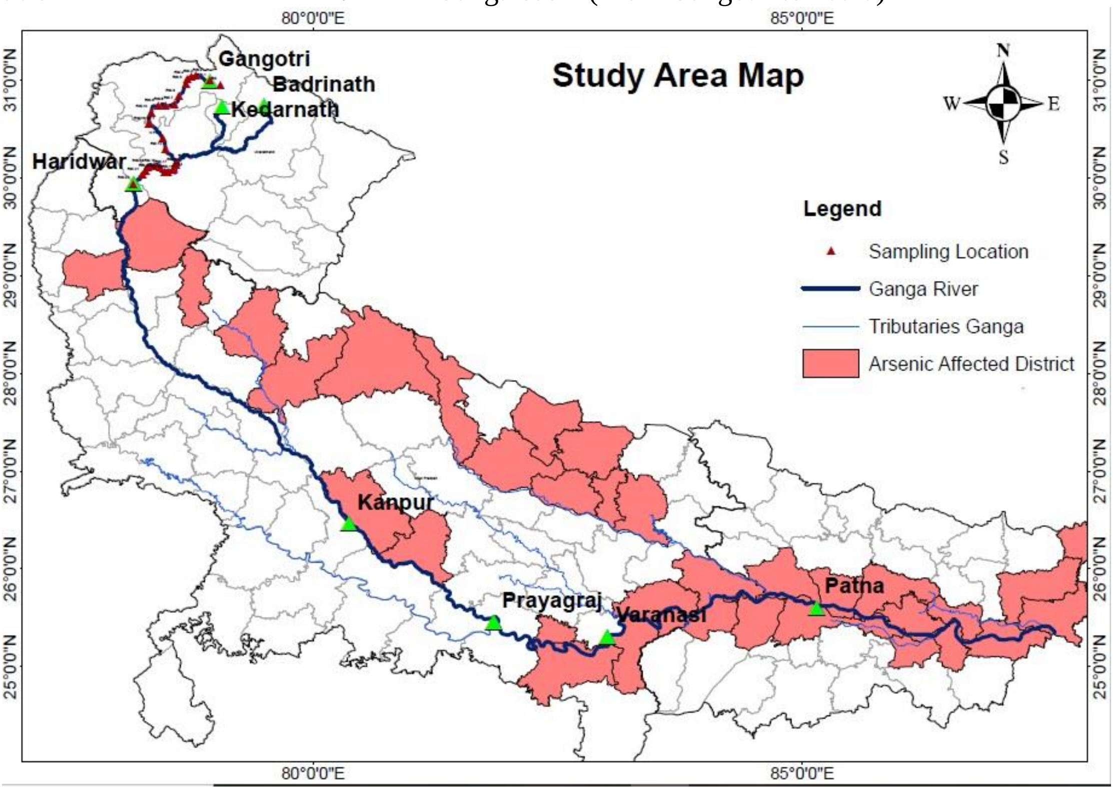


Figure – 2.1: Study Area Map

Objectives:

- Mineralogical characteristic of sediments and water chemistry in the Indian Himalayan region to detect genesis of arsenic.
- Demarcating safe aquifer for drinking water supply in arsenic affected areas.
- Performance evaluation of existing treatment units and their comparison in terms of cost, efficiency and ease of operation etc. in the central Ganga basin.
- Developing a new treatment technique with high removal efficiency in optimized cost.

Objectives vis-à-vis Achievements:

Objectives	Achievements
Mineralogical characteristic of sediments and water chemistry in the Indian Himalayan region to detect genesis of arsenic.	• Phase 1 Sampling of sediment and water completed from Gangotri to Haridwar. • Water quality (major Ions and trace metals) analysis have been completed. • Sediment Characterization: Grain Size analysis completed and XRD is in progress. • Further sampling from Haridwar onwards will be completed by March end.
Demarcating safe aquifer for drinking water supply in arsenic affected areas.	Geological Maps, Bore logs and water table maps are being obtained and prepared for further processing.
Performance evaluation of existing treatment units and their comparison in terms of cost, efficiency and ease of operation etc in the central Ganga basin.	• Questionnaire or Survey form is prepared and data will be collected from the field for further analysis and evaluation. • Data is being collected from the literature and reports available.
Developing a new treatment technique with high removal efficiency in optimized cost.	• After review and discussions, it was agreed upon that that a biochar based adsorption system will be used. • Review and selection of raw material for biochar development is under process.

Statement of the problem:

Chronic exposure to groundwater having an arsenic concentration of more than 10 μg/L leads to numerous adverse health impacts like lower intelligence quotients, type 2 diabetes, skin lesions, melanosis, keratosis, and cancer etc. Arsenic (As) contamination of water is producing the greatest impact on livelihoods in terms of public health and thus arsenic calamity in the Ganga river basin put millions of population in danger. Arsenic is a natural constituent in bedrock and soil. It usually occurs at low concentrations (average 1–2 mg/kg) in the Earth's crust, but may be concentrated in certain rock types and especially in gold and sulphide-bearing ore deposits and occurrences. Pyrite [FeS2; or arsenopyrite Fe(AsS)2] and arsenopyrite [FeAsS] are typical sulphide minerals containing As. Weathering processes of rocks and minerals appears to be a major source of arsenic found in soils. Because it accumulates due to weathering and translocation in colloid fractions, the arsenic concentration is usually higher in soils than in parent rocks. The river Ganga and its major tributaries originate from the Himalaya and carry lots of sediment and these sediments determine the chemistry of water. In the mid Holocene period, the river Ganga is likely source to transport metals from Himalaya to the plains by erosion and sedimentation. The rivers originating from the Siwalik Hills are reported to release more arsenic and heavy metals from their sediments in comparison to those major rivers originating from the Higher Himalaya. In order to study the causes of arsenic occurrence in Ganga basin and its mobilization from solid to water phase, it is planned to carry out mineralogical, geochemical and mobilization study. The significance of the study is to help in demarcating safe aquifer, improved monitoring and mitigation measures at regional level.

With the grave problems of arsenic in India, Inter-Ministerial Group (IMG) on Arsenic Mitigation was constituted on the directions of Cabinet Secretariat by erstwhile Ministry of water Resources, River Development & Ganga Rejuvenation (MoWR, RD & GR) vide order No. 11014/1/2014-GW Desk (Part-V) dated 22 Dec. 2014 under the Chairmanship of Mission Director (MD), National Water Mission (NWM). The IMG desired that National Institute of Hydrology (NIH), Roorkee should take lead role on R & D activities related to "Arsenic Mitigation" as per the areas suggested by the 'Core Committee' on "Mitigation & Remedy of Arsenic Menace in India". The DoWR, RD & GR, Govt. of India (letter no. 50013/177/2020-E.II dated 20/07/2020) advised NIH to seek funding under the subcomponent “Sponsoring and Co-coordinating research in water sector” and accordingly may submit a project proposal to INCGW. A project proposal with budgetary requirement of 1259.50 Lakhs was submitted to INCGW with detailed work component and budget of multi-institutions. Now, INCGW provided their comments/suggestions for submitting the project proposal. The NIH is under process for incorporating the comments/suggestions and the project proposal would be submitted again to INCGW for their considerations. The GWHD proposed to start working on project components pertaining to NIH under internal funding till the funds are received from INCGW considering national importance of project.

Methodology:

The study will cover the detailed hydrogeology and geochemistry of the As-contaminated aquifer of the Ganga basin. A Pre-monsoon and post-monsoon grid-wise sampling would be done in upper and middle Ganga basin to study the spatio-temporal variation of water quality parameters including arsenic. The sediment samples at different location would be collected from upper and middle Ganga basin focusing on Himalayan sediments for sediment characterization using XRD & XRF techniques. The mineralogical study would help in identifying the minerals of arsenic present in the Ganga basin.

Integrated hydrological survey of arsenic concentrations would be carried out in the Ganga basin by using field test kits and collecting preserved samples for further analyses by more precise analytical instruments in laboratory. Groundwater and surface water samples will be collected during multiple field campaigns (pre-monsoon and post-monsoon season) from both deep and shallow aquifers. In addition to that, sediment samples (from hilly and plain region along with river bed material) would be brought out to lab for further analyses. The locations of the wells will be marked using a hand-held global positioning system (GPS). Unstable parameters and indicators of the oxidation state of ground water will be measured in the field. Field measurements will include temperature, electrical conductivity (EC), pH, oxidation-reduction potential (ORP) and dissolved O_2. The measured stable value of these water quality parameters will be representative of *in-situ* conditions. Samples will be filtered in the field with disposable 0.45-micron filters and will be collected for all major anions, cations and trace elements for further laboratory level analysis. Different analytical instruments would be used for analyses of ions and metals. Performance of existing treatment technology available and which are being used in arsenic affected areas would be evaluated. The influent and effluent of treatment unit would be tested and then removal efficiencies may be ascertained. It is also planned to develop cost effective treatment units in Lab and it may be upscaled at later stage.

Analysis of Results:

In the first phase of sampling the water (surface and groundwater) and sediment samples were collected from Gangotri to Haridwar on the stretch of Ganga River. A total 25 water samples and 32 sediment samples were collected. In situ parameters like pH, EC, ORP and DO were measured on the sampling sites. The pH of the water samples of study area varies from 7.1 to 7.5 (mean 7.3) for groundwater, and 6.8 to 8.5 (mean: 7.9) for Ganga river. It is observed that the pH values are increasing as the sampling location descends from the origin towards Haridwar. The EC of the water samples varies from 206 to 393 µs/cm (mean 301 µs/cm) for groundwater, and 107 to 246 µs/cm (mean: 161 µs/cm) for Ganga river. It has been observed that the EC values are following a declining trend in the Bhagirathi river from Gangotri to Devprayag, thereafter the EC values follow an increasing trend up to Haridwar. The DO values in the river vary between 7.3 to 8.5 mg/L with an average value of 8.02 mg/L and in groundwater it varies from 2.4 to 3.5 mg/L (mean: 2.8.). The ORP of the water samples in the study area varies between 84 to 183 mv (mean 138 mv) for river water, and 27 to 125 mv (mean: 67 mv) for groundwater. The ORP values are observed to be increasing from Gangotri to Haridwar which can be due to the increase in the surface water temperature.

The water samples were analyzed for trace metals (As, Fe, Mn, Zn, Cu, Cr, Cd, Ni, Pb) using inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES, Agilant 5110 VDV). In majority of the water samples, the trace metal concentration were below the permissible level except in few instances. The concentration of Al, Fe and Mn were found to be higher than permissible limit in bulk of the samples. The As concentration in the water samples in the study area varies between ND to 14.07 µg/L with and average value of 5.9 µg/L. Out of the 22 river water samples, nine samples were having *As* concentration more than the permissible limit but were below the acceptable limit of drinking water standards. None of the groundwater samples were found to be contaminated with *As*. In groundwater samples, *Fe* concentrations were observed to be very high that might be due to the corrosion of iron pipes in the hand pumps. Further, sediment characterization and the remaining analysis of water samples are under process.

Data Requirements:

- Geological map and bore logs of various location
- Groundwater levels
- Surface water and groundwater quality etc.

Laboratory Facility used during the Study:

- Soil Water Laboratory
- Nuclear Hydrology Laboratory
- Water Quality Laboratory

Study Benefits /Impact:

A project report will be prepared highlighting the genesis of arsenic and its mobilization from solid to liquid phase. The research output and development of new technique for arsenic removal may help stakeholders for deciding the water supply management strategies in arsenic affected areas. The findings of the study will be presented in conferences/workshops and published in journals. Stakeholder (Public Health Engineering Department, Jal Nigam, Water Resources Department, Department of Drinking Water and Sanitation, Ministry of Jal Shakti etc.) engagement would be done for improving their knowledge and application of various mitigation options.

3. PROJECT REFERENCE CODE: NIH/GWH/NIH/22-24

Title of the Project: *Conjunctive Management of Water Resources in IGNP Command*

Study team:	PI	Dr. Nitesh Patidar, Scientist-C
	Co-PIs	Dr. M.K. Goel, Scientist-G
		Dr. Anupma Sharma, Scientist-G
		Dr. Surjeet Singh, Scientist-F
		Ms. Nidhi Kalyani, Scientist-B

Type of study: Internal (On-going study)

Duration: Two years (April 2022 – March 2024)

Objectives

1. Analysis of present groundwater scenario in enroute command of IGNP
2. Mapping of water-logged area in IGNP command using GW observations
3. Estimation of GW recharge from rainfall, canal and irrigation under present and future climatic scenarios
4. Conjunctive management of water resources in enroute command area of IGNP canal

S. No.	Study objectives	Achievements
1	Analysis of present groundwater scenario in enroute command of IGNP	*Under Progress* The data of groundwater levels acquired from CGWB are analyzed. Trend analysis was performed.
2	Mapping of water-logged area in IGNP command using GW observations	*Under progress* The water-logged areas are being identified using remote sensing and groundwater data.
3	Estimation of GW recharge from rainfall, canal and irrigation under present and future climatic scenarios	*To be started* The data collection for modelling is in progress.
4	Conjunctive management of water resources in enroute command area of IGNP canal	*To be started*

Background

Conjunctive management of surface water and groundwater for irrigation is recognized as an effective solution to water logging and root zone salinity. The conjunctive utilization of water resources also ensures consistent water availability for irrigation and support sustainable water management. However, despite these advantages the conjunctive management of water resources is scant in canal commands. The Indira Gandhi Nahar Pariyojana (IGNP) provides irrigation to an area of 1.963 million hectare (CCA) in Rajasthan. The project also provides domestic water supply to most of thar dessert of Rajasthan and is therefore the most important water source in the arid Rajasthan. Since the inception of the project, there has been various issues related to rising water table and increasing soil salinity. Several studies were conducted to assess the impact of canal on groundwater levels and water logging. It was observed that before the canal construction (before 1952) the depth to groundwater used to vary between 40 and 50 m. After the inception of irrigation through stage-I of IGNP groundwater level started rising. In 1972-82 the rise in groundwater level was observed to be 1.17 m/year. Later in 1995, an area of around 10% of CCA of stage-I was waterlogged and around

25% area was under critical condition (depth to GW in range 1-6 m). Such rise in groundwater level transports the salts from deeper soil layers to surface and impact the agricultural productivity in the area.

The present scenario of groundwater and mapping of water-logged area is essential in the IGNP command for effective management of land and water resources. Such analysis would help in quantifying the current potential of groundwater in conjunction with canal water to maximize the irrigation potential in command and to contain salt mobilization in root zone.

Study area

The IGNP project was initiated in the late 50’s and is situated in the districts of Sriganganagar, Hanumangarh, Bikaner, Churu, Jaiselmer, Barmer, and Jodhpur. It has a CCA of 1.963 million hectares. The project was completed in two stage, Stage-I having a 204 km long feeder which originates from Harike Barrage, Punjab, to reach Masitawali, Rajsthan, and a 189 km long main canal from Masitawali to Chattergarh in Bikaner district. Stage-II is having a 256 km long main canal from Chattergarh to Mohangarh in Jaiselmer.

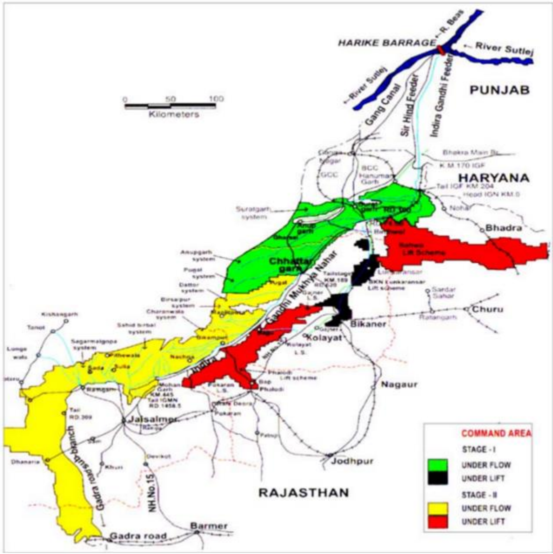


Image source: Gupta et al. (2002)

Figure - 3.1: Indira Gandhi Nahar Pariyojna (IGNP) command under stage-I and stage-II

Methodology

The assessment of the present groundwater scenario will be done utilizing the groundwater observation of Central Ground Water Board (CGWB). Trend analysis will be performed on groundwater levels to identify the trend in groundwater. The mapping of water-logged area will be performed using the groundwater data. The conjunctive management of surface water and groundwater requires an integrated simulation-optimization model. A model developed at NIH which integrated Google Earth Engine (GEE), an surface water module and MODFLOW, will be utilized for estimating recharge to groundwater. A system model was developed at NIH which will be used to simulate the demand-supply and recharge due to canal percolation and irrigation. Iterative simulation runs will be performed to optimize the groundwater extraction so as to contain the rising water level and increase irrigation intensity. The Effect of climate variability will be considered using the most recent data of climate projections.

Progress

The groundwater level data obtained from CGWB are processed for the assessment of present groundwater status in the IGNP. A python program is developed to pre-process the data, generate groundwater level maps and apply modified Mann-Kendall test. Trend analysis was performed on the groundwater data from 2001 to 2018. It is found that approximately 60% of the wells having significant rising trend in groundwater, while 16% of the wells indicate falling trend. To investigate the area under water-logged in the command, global surface water data is used which shows percentage of occurrence of water during the past ~35 years. The preliminary analysis shows two hotspots of water logging in the area, one near Suratgarh and one in the North of Jaisalmer. Further investigations to quantify the waterlogged area using time series analysis of Landsat images is in progress. The database development is in progress.

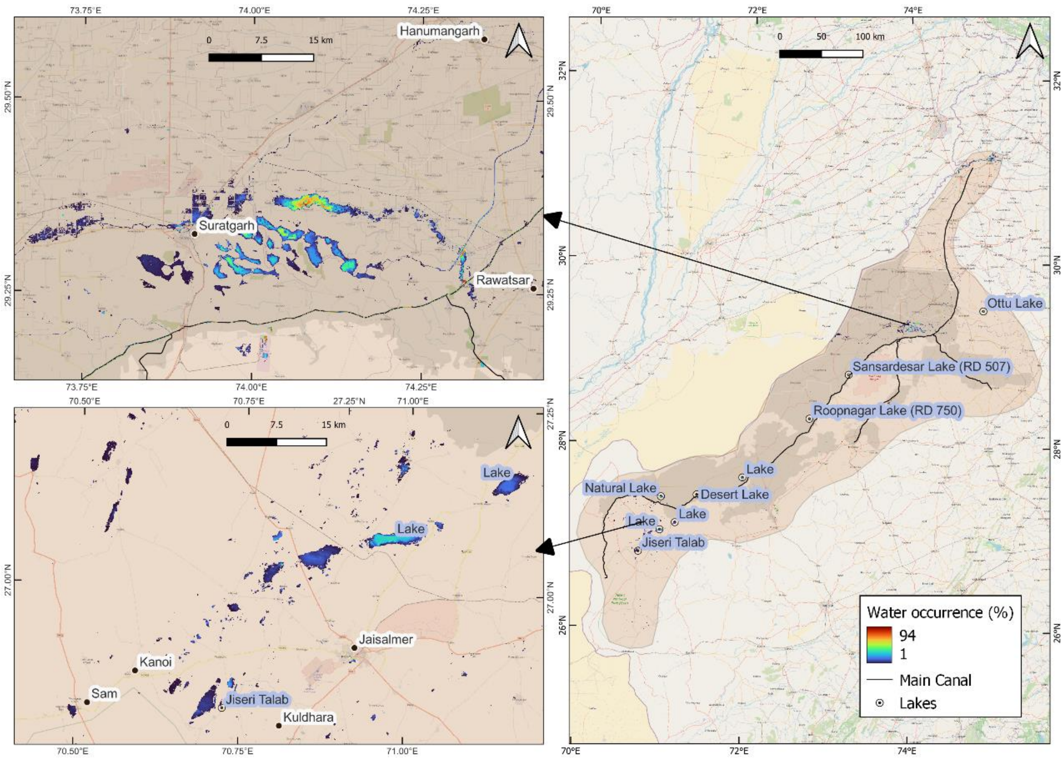


Figure - 3.2: A few patches of water-logged area identified using remote sensing data

Action plan and timeline (quarter-wise from March 2023 to Mar 2024)

Work element	Mar-Jun 2023	Jul-Oct 2023	Nov 2023-Feb 2024	Mar-Jun 2024	Jul-Oct 2024	Nov 2024-Mar 2024
GW trend analysis and mapping of water-logged area	■					
Field investigations	■	■	■			
Model simulations for quantifying GW recharge			■			
Simulation for conjunctive water management					■	■
Project report and paper						■

4. PROJECT REFERENCE CODE: NIH/GWH/NIH/22-24

Title: Study of Groundwater Dynamics using machine learning and numerical modelling

Study team:	PI	Ms. Nidhi Kalyani
	Co-PIs	Dr. Anupma Sharma
		Dr. Nitesh Patidar
		Dr. Sumant Kumar

Objectives of Study:

1. To study groundwater dynamics in Hindon subbasin of Yamuna basin using MODFLOW, recurrent neural networks and LSTM.
2. To study climate change impact on groundwater level in Hindon subbasin.
3. To compare the performance of MODFLOW, RNN and LSTM.

Methodology

MODFLOW is a physically based numerical model of groundwater flow. It uses the equation of groundwater flow to simulate groundwater dynamics. Solution of the groundwater flow equation is achieved by finite-difference method in which the groundwater flow system and simulation time are discretized into grids and stress periods, respectively. Each stress period is a period of simulation within which specified stress data are constant.

A recurrent neural network (RNN) processes sequences by iterating through the sequence elements and maintaining a state containing information relative to what it has seen so far. In effect, an RNN is a type of neural network that has an internal loop. The state of the RNN is reset between processing two different, independent sequences. What changes is that this data point is no longer processed in a single step; rather, the network internally loops over sequence elements.

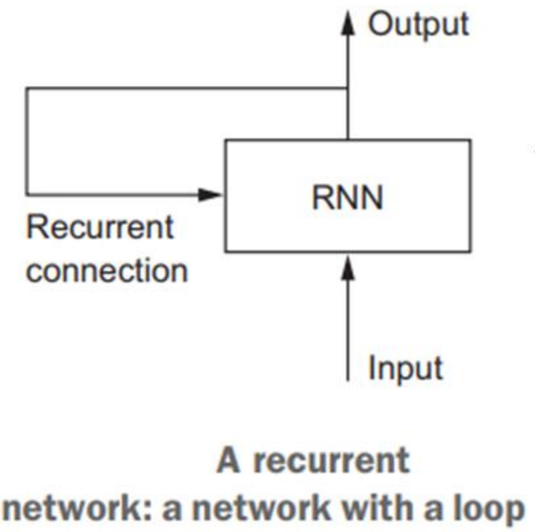
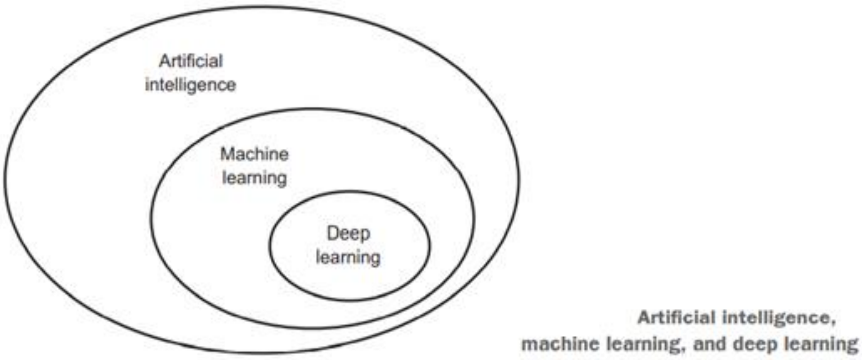


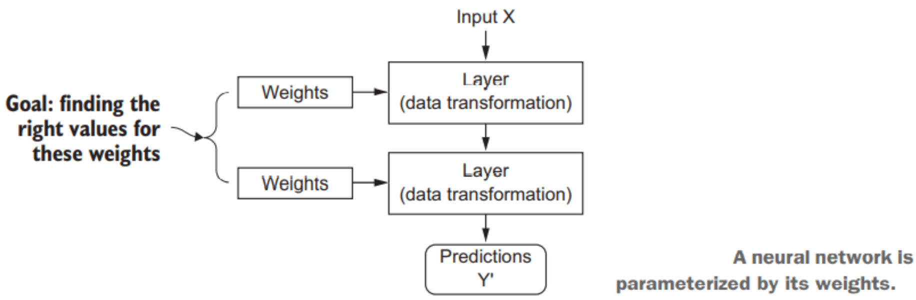
Figure – 4.1: A recurrent network with a loop

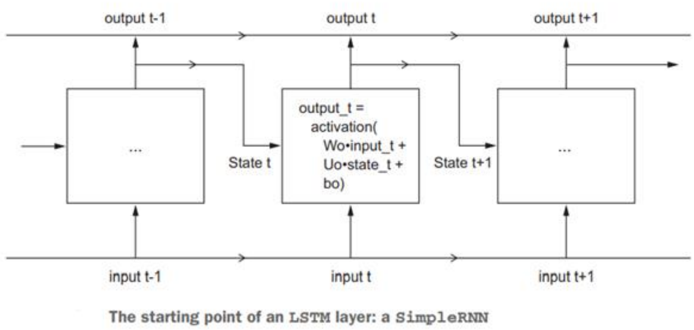
Deep Learning

Deep learning is a specific subfield of machine learning that puts an emphasis on learning successive layers of increasingly meaningful representations. How many layers contribute to a model of the data is called the depth of the model. Modern deep learning often involves tens or even hundreds of successive layers of representations and they're all learned automatically from exposure to training data. These layered representations are learned via models called neural networks, structured in layers stacked on top of each other. The model can be evaluated using three data sets: training, validation, and test. The model is trained on the training dataset and evaluated on the validation data. Once the model is ready, it can be tested on the test data.

A deep neural network has a higher level of abstraction compared to shallow neural networks. Deep neural networks are essentially recurrent neural networks. Deep neural networks do input-to-target mapping via a deep sequence of data transformations that are learned by exposure to examples.







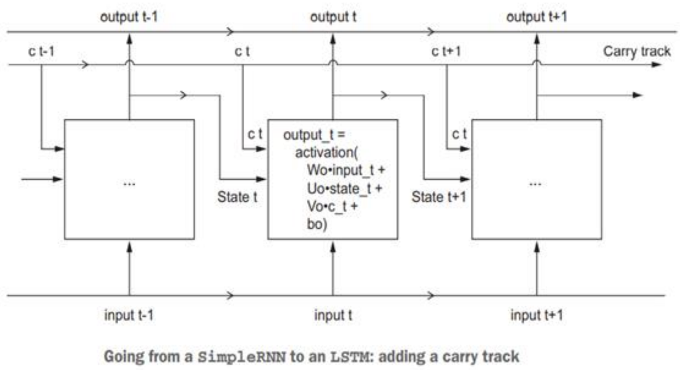
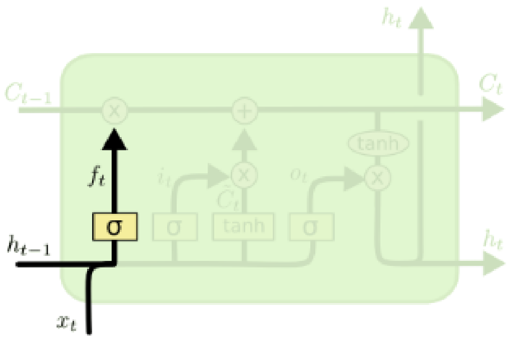
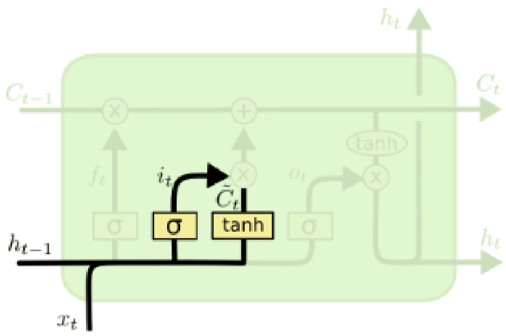


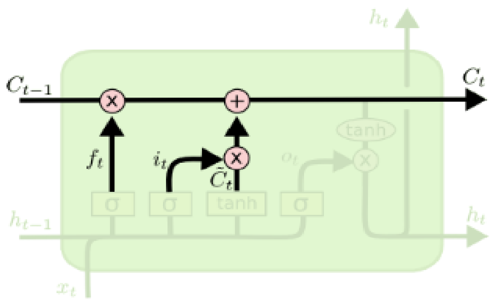
Figure – 4.2: LSTM Architecture



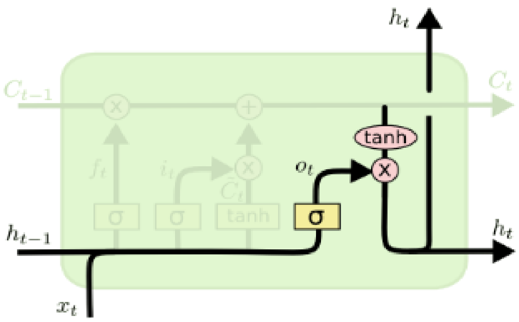
$$f_t = \sigma\left(W_f \cdot [h_{t-1}, x_t] \ + \ b_f\right)$$



$$i_t = \sigma\left(W_i \cdot [h_{t-1}, x_t] \ + \ b_i\right)$$
$$\tilde{C}_t = \tanh(W_C \cdot [h_{t-1}, x_t] \ + \ b_C)$$



$$C_t = f_t * C_{t-1} + i_t * \tilde{C}_t$$



$$o_t = \sigma\left(W_o \ [h_{t-1}, x_t] \ + \ b_o\right)$$
$$h_t = o_t * \tanh\left(C_t\right)$$

Input Layers for Groundwater Level

Precipitation
Temperature
Input Layers for Groundwater Level and Groundwater Recharge
Precipitation
Temperature
LULC
Soil Type
Ground Slope

5. PROJECT REFERENCE CODE: NIH/GWH/BGS/17-24

Title of the study : **Groundwater fluctuations and Conductivity Monitoring in Punjab- New evidence of groundwater dynamics in Punjab from high frequency groundwater level and salinity measurements**

Study Team : Dr. Gopal Krishan (PI)
Er. C.P. Kumar (co-PI) (Retired)
Dr. M.S. Rao (co-PI)
Dr. Surjeet Singh (co-PI)
BGS, UK team

Type of study : **Sponsored,** BGS, UK.
Date of start (DOS) : December 2017
Scheduled date of completion : November 2024
Location : Bist- Doab, and South-west Punjab

S. No.	Study objectives	Achievements
1	To characterise multi-year variability in groundwater level and SEC using high frequency groundwater measurements within nested shallow and deep piezometers	**Achieved** – There is certainly a trend of groundwater depletion mainly due to the onset of pumping for irrigation during the Kharif season a part of which is in the monsoon season also. So the contribution of pumping could easily far exceed the natural replenishment.
2	To collate new evidence on recharge processes, groundwater quality, groundwater residence times, and connectivity of the layered aquifer systems and surface water by repeated sampling of shallow and deep piezometers using a suite of environmental tracers	**Achieved (90%)-** Analysis carried out so far indicated that there is inter-relation between various source waters. There are some commonalities in isotope values at a certain percentile. Satluj water and canal originating have highly depleted values as compared to Beas river values Reservoir samples are highly enriched.
3	Characterise groundwater residence times and water quality in southern Punjab through detailed sampling to assess the resilience of groundwater abstraction as an adaptation strategy for continued food production.	**Achieved** (90%)– Samples were analyzed at BGS, UK for CFC and SF6, the results have been received for these parameters and data interpretation is in progress
4	Assess groundwater vulnerability to salinization from water-logging from increased surface water flows (including canal flows) through glacial melt-water and identify potential solutions for future priority research, and inform robust conceptual models of groundwater salinization in this region of India.	**Achieved (80%)-** Salinity variations are observed in the different aquifers .
5	Deliver a new groundwater data set from southern Punjab to enable comprehensive and transparent discussions of adaptation solutions to water resources in this region	Is under process
6	To prepare a status report on groundwater issues in Punjab	Report is under preparation and in addition we are working on data for new publications

Statement of the problem:

Punjab is underlain by the Indus Basin aquifer which has been rated as the second-most over stressed aquifer in the world. Among all the states of India, Punjab is drawing highest amount of groundwater resulting in its declination at an alarming rate. Bist-doab is one of the important regions of Punjab comprising of the districts of Hoshiarpur, Jalandhar, Kapurthala and SBS Nagar (fig. 1). In recent years, a large volume of groundwater reported to be extracted in Hoshiarpur and Jalandhar districts. Agriculture is dependent on groundwater irrigation and concerns exist over the sustainability of current and future exploitation of groundwater; tracer data can help quantify groundwater renewal processes. In the joint study with BGS, UK high frequency water level and conductivity data is interpreted along with the analysis of water samples for a suite of tracers. In addition to the study in Bist-Doab, the study area has been extended to south-west (SW) Punjab where increasing demand of the irrigation water led to improper surface water irrigation policies resulting in water logging problems coupled with apprehension of saline zones formation by salinity ingression towards central Punjab due to excessive groundwater pumpage. To assess the inter-connection between aquifers sampling has been planned in Faridkot, Fazilka and Muktsar districts of Punjab (fig. 1).

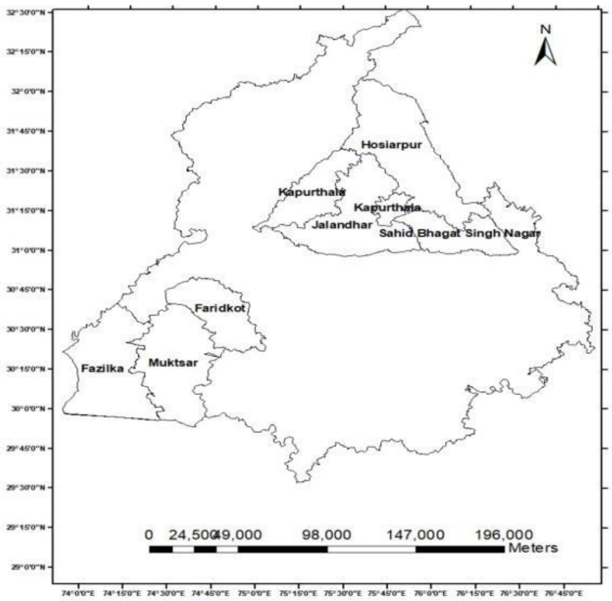


Figure – 5.1: Study area

Whether Study is a New Study/Extension of Previous Studies: Extension of previous studies

Methodology:

In this study, groundwater level and conductivity data are monitored and high resolution field based observations are collected. For this loggers were installed in Saroya, Bhogpur and Sultanpur Lodhi in the month of May, 2019 (Fig. 2). In addition to these sites water level loggers were installed in Bhogpur, Tanda and Nakodar in October, 2019 (Fig. 2). The groundwater samples were collected for analysis of CFC, SF6 (at BGS, UK) for better understanding of the aquifer systems from 10 sites (fig. 3) from the network of depth wise piezometers . Piezometers were developed in the depth range of 5 m-32 m and categorized as shallow (<10 m); intermediate 1st (10-15 m); intermediate 2nd (18-20 m) and deep (28-32m).

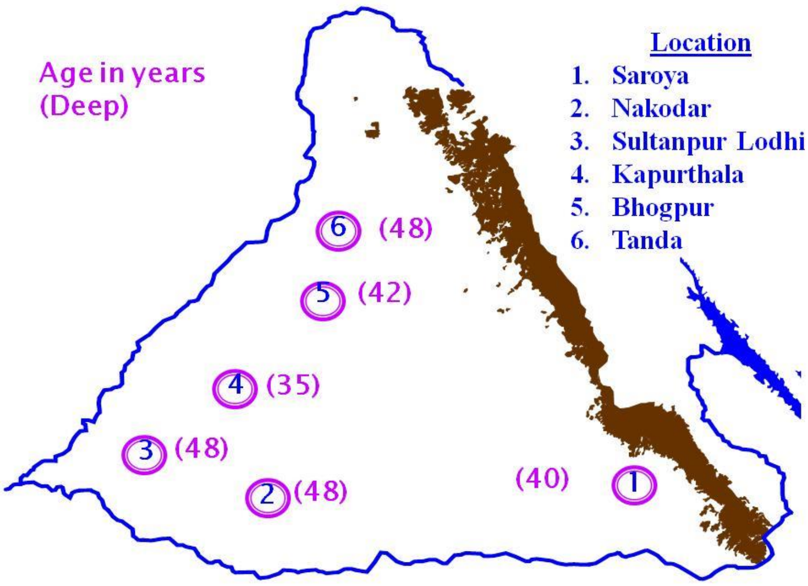


Figure – 5.2: Sites for installation of loggers in Bist Doab, Punjab

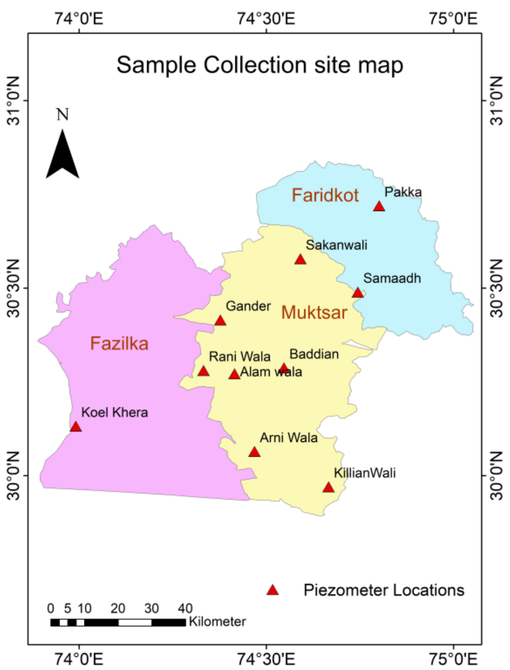


Figure – 5.3: Sites for sample collection in south-west, Punjab

Progress:

The samples at BGS has been analysed for CFC, SF6 and other heavy metals. The data analysis and interpretation is in progress. Future plan includes downloading data from water level loggers and conductivity loggers, collection of new data from state department from nearby piezometers, and data analysis work with respect to various parameters like rainfall, land use etc. to observe the seasonal and spatial variation

Bist-Doab

Average groundwater isotope values for shallow and deep groundwater sites are compared with amount weighted rainfall values and surface water end-members confirms the overall dominance of meteoric sources of groundwater recharge

Some of surface water samples show evidence of enrichment due to evaporative effects but average water isotope values for groundwaters do not show any evidence of evaporative enrichment relative to the GMWL or LMWL

Groundwater stable isotope time-series and pairwise comparisons show that there are significant differences between deep and shallow groundwater isotope signatures at the same locations suggest long-term shift in the groundwater isotope values and salinity over the last c.20 years based on based on groundwater residence time data or shallow groundwaters in this region.

SW Punjab

Salinity variations are observed in the different aquifers in terms of average electrical conductivity in deeper aquifers (30 m) is 5050 µS/cm; in aquifer tapped at depth of 5-8 m it is 4068 µS/cm while in middle aquifers 10-20 m the electrical conductivity is 2794-3006 µS/cm.

From the SF6 data, it is inferred that the piezometers tapped at the depth of 20-30 m are older (`50 years) as compared to the other aquifers (~30-45 years). The evidence is widespread CFC contamination but the SF6 is fine. Hence, best 'age' or mixing estimates come from SF6 data alone. There are varied changes such as water gets younger with the depth in some cases.

It is therefore most likely that this simultaneous change in isotope value in water samples in both deep and shallow sites is driven by changes in borehole pumping regimes that take place across the state.

Some unanswered questions are:

What is the synchronisity between deep and shallow groundwater level responses?

Do the slopes of the drawdown differ (between and within sites) – does this tell us anything about the aquifer system or just the rates of pumping or both?

Action plan:

Year	Dec. 2017 to Nov., 2024	Remark
Dec. 2017 to Nov. 2024	• Literature review on available groundwater studies including water table, water quality and other hydrogeological aspects in Punjab • Monitoring of water level and conductivity fluctuations in Bist-Doab, Punjab • Water sampling and analysis for isotopes • Prepare status report on GW issues in Punjab • Presentation of work progress in a workshop/review meeting under the project	Report preparation

6. PROJECT REFERENCE CODE: NIH/GWH/2018-21

Title of the study : *Assessment of impacts of groundwater salinity on regional groundwater resources, current and future situation in Mewat, Haryana – possible remedy and resilience building measures*

Study Team	:	Dr. Gopal Krishan (PI) Er. C.P. Kumar Dr. Surjeet Singh Dr. M.S. Rao **Haryana Irrigation Department** **Consultants -** IIT-Roorkee, Sehgal Foundation, Gurgaon
Type of study	**:**	Sponsored (NHP-PDS)
Date of start	**:**	December 2017
Date of completion	**:**	July 2022
Location	**:**	Mewat district, Haryana

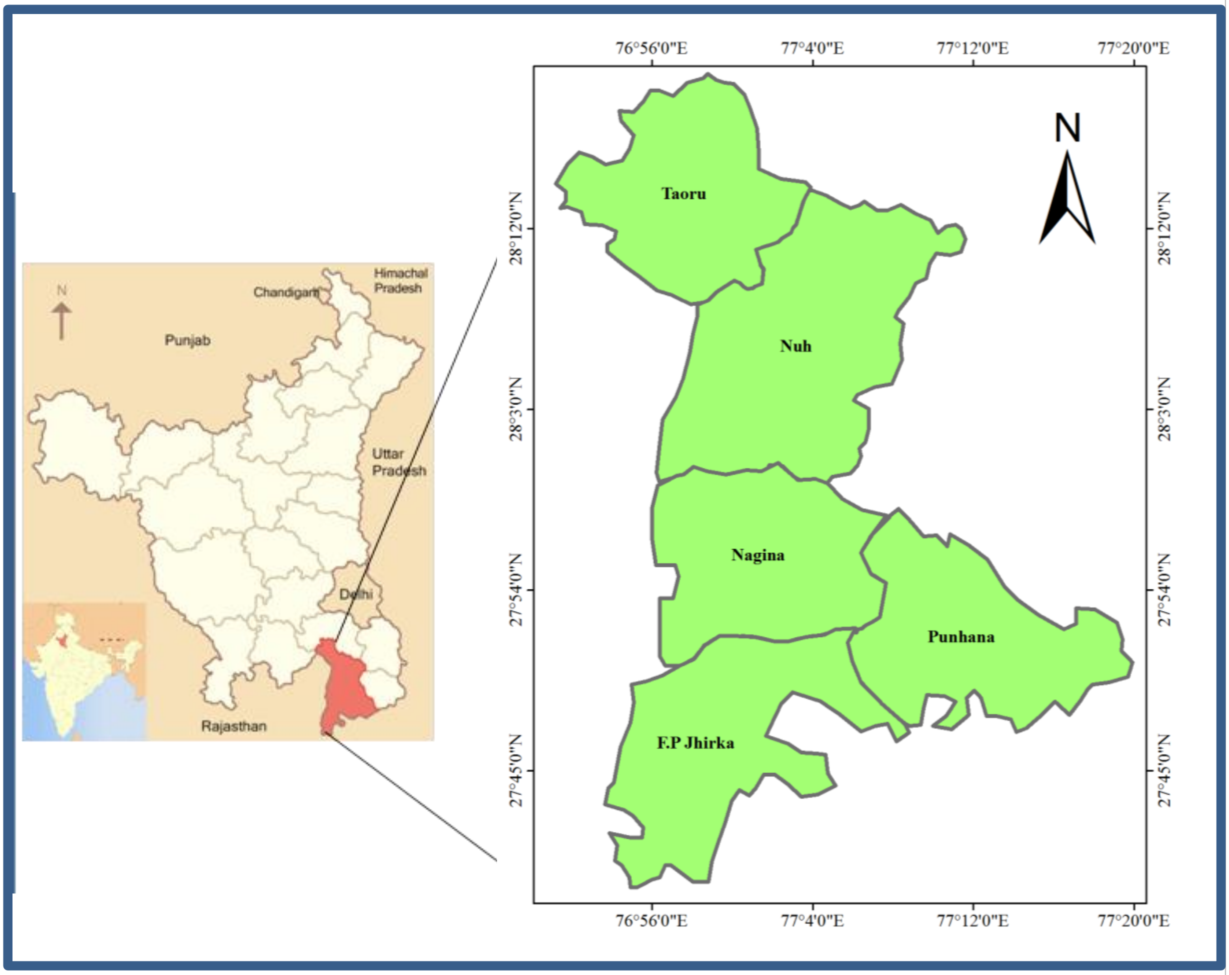
Sr. No.	Study objectives	Achievements
1	Assessment of lowering of water table (depletion in groundwater level) in the salinity impacted area using the historical data.	**Achieved** – From the available historical, it has been found that water levels have decreased in the last 40 years but the rate of declination was higher in last 2 decades.
2	Detailed qualitative analysis of the area and the aquifer depth impacted by higher salinity levels, and preparation of maps.	**Achieved –** Salinity variations maps on spatial and temporal levels have been prepared
3	To monitor influx of saline groundwater into fresh water zone	**Achieved -** Salinity variations have been found from central parts of the Mewat to the foothills of Aravali hills
4	To assess the impact of groundwater salinity on socio-economic aspects	**Achieved-S**alinity affected the socio-economic conditions of the local inhabitants to a large extent
5	To develop and demonstrate management and resilience building measures	**Achieved** -Experimental model developed and tested for development of fresh water bubble and recovery efficiency under controlled as well as field conditions.

Statement of the problem:

Groundwater salinity is a widespread problem in many productive agricultural areas in India including many districts in Haryana. Aquifer salinization gradually affects the agro-economy, livelihoods and drinking water supply in local and regional scale due to lowering of groundwater levels. Salinity is the main factor limiting the continued use of groundwater in surface water scarce area, and future reliance on groundwater is further diminished as groundwater levels decline, creating increases in salinity and in exploitation costs. A systematic groundwater development and management fulfilling the technical needs of supply-side and demand-side components can arrest the aggravation of salinity and provide sustainable solution to problem.

The proposal deals with to undertake a comprehensive study on hydrological and hydrogeological features together with chemistry and isotopic characteristics of groundwater for evaluating the causes of aquifer salinity including its aggravation and effect on agro-economy, drinking water supply and livelihoods considering the problem of Mewat district in Harayana as the pilot study areas. A few demonstrative schemes as resilience building measures towards arresting the aggravation of salinity and increase of managed aquifer recharge together with their impact assessment on overall groundwater resources are also proposed to undertake. Development of a model to predict changes in groundwater salinity as a result of aquifer recharge and extraction is another focus of the study.

Figure - 6.1: Map of Mewat district



Methodology:

This work is being accomplished in five phases as identified below:

In Phase 1, Socio-economic based survey was being carried out by Sehgal Foundation, Gurgaon to find out the impact of salinity on the socio-economic conditions of the people on the basis of some selected indicators. The findings of the study are certinly going to in initiating the development activities as coping strategies for the survival of humankind in the presence of salinity in the district of Mewat. The study proposed to employ both qualitative and quantitative method. Under the quantitative method, a well structured coded interview schedule was used. Focus Group Discussion (FGD), as a qualitative method, wasadministered to collect information on the above socio economic characteristics of the farmers.

Phase 2 of the study was to develop a hydrogeological framework of the aquifer system in Mewat district based on all existing lithologic, stratigraphic and hydrologic information collected from various agencies. The saline areas in the district are mapped.

Phase 3 include a hydro-chemical characterization (on the basis of anions, cations, physico-chemical characteristics etc.) and quantification of salinity

Phase 4 is to target the areas surrounding the drinking water wells that showed presence of salinity in Phase 2 using existing and new tube wells. Further, the water extracted from tube wells within and down gradient from the industrial areas was examined where untreated wastewater may have been disposed on the surface (e.g., in infiltration ponds) or injected into the subsurface. The main purpose of the study in Phase 3 was to identify cause/source areas using isotopes (source locations).

Phase 5 includes suggestion and development of resilience building measures. Some proposed measures are development of fresh water bubble using Aquifer Storage and recovery technique.

Findings

Socio-economic survey was carried out and it was found that the people residing in high salinity areas had to walk long distances to get the fresh water or they have to purchase it. The percentage of households purchasing drinking water is 54% which is more in the high-saline groundwater villages and it remaining 20% in the moderately saline villages and 8% in the villages that have fresh groundwater sources.

From the water level map of the study area, it is evident that water tables are deeper in the western region. The water is potable in these areas resulting in higher water withdrawals. In the eastern and southern sides of the study area, water is saline, and water tables are high. The contours of groundwater level show a natural gradient from the Aravalli hills towards the central region but due to high groundwater extraction in the foothills regions of the area, there is the apprehension of movement of water from salinity-affected areas to freshwater areas.

Salinity has been found in most of the places in the district and a notable increase in TDS values found during the period 2012 to 2016. An increase in TDS values ranging between 500-1000 mg/l in 74% area while 35% increase in area in the category of 1500-2000 mg/l TDS. In addition to the temporal increase in TDS values, seasonal variations are also observed in the groundwater for the years 2018 and 2019. About 54%, 93%, and 62% of samples were found above the maximum permissible limit of 2000 mg/L in pre-monsoon, monsoon, and post-monsoon seasons respectively. And about 8%, 7%, and 14% of samples were found within the acceptable limit of 500 mg/L in the pre-monsoon, monsoon, and post-monsoon seasons of the year 2018. About 54%, 62%, and 58% of samples were found above the maximum permissible limit of 2000 mg/L in pre-monsoon, monsoon, and post-monsoon seasons respectively. And about 8%, 0%, and 4% samples were found within the acceptable limit of 500 mg/L in the pre-monsoon, monsoon, and post-monsoon seasons of the year 2019.

For the source identifications, salinity mechanism, and residence times of groundwater, the water samples were analyzed for stable isotopes ($\delta^{18}O$ and δD) and tritium (H^3). To examine the evaporation effect on groundwater of the study area, $\delta^{18}O$ is plotted against δD. The slope of 5.64, 6.10, and 5.48 is observed for pre-monsoon, monsoon, and post-monsoon seasons, respectively. Since the regression lines are sub-parallel to Global Meteoric Water Line (GMWL) and LMWL (8.83) with slopes less than 8, it suggests the occurrence of evaporation before the infiltration of water in the unsaturated zone. It is found that salinity increases and d-excess decreases during the process of evapo-concentration in all seasons. A linear relationship between d-excess and remaining fraction was found in all three seasons in all samples. However, more scatter is found in the values of salinity and the remaining fraction in 16% of the total samples indicating seasonal variations.

It has been observed that the groundwater of the district showed an increase of 0.7g/L salinity from pre-monsoon (6.7g/L) to post-monsoon season (7.4g/L). The d-excess shows a decline of 1.6‰ in post-monsoon when compared to pre-monsoon, it decreases from 2.4‰ in pre-monsoon to 0.8‰ in post-monsoon. It was found that in the pre-monsoon season, salinity was due to mineral dissolution. However, in the monsoon and post-monsoon seasons, initial salinity also contributes to salinity.

The contribution of mineral dissolution is found by separating the salinity value of evaporation from dissolution; the results were further tested by using Tritium (^3H) to distinguish between modern groundwater (recharge occurring during the last 60 years) and pre-modern groundwater (recharge occurring >60 years). This shows that groundwater has a long residence time in high saline-affected areas. A majority of the samples show a contribution from mineral dissolution in the pre-monsoon season, with a slight decrease in monsoon and post-monsoon seasons. There is wide variation in tritium activities which may be due to discontinuous water flow or poor connectivity between aquifers.

Similar observations to isotope analysis were found using Principal Component Analysis (PCA), KMO and Bartlett's tests were found valid for both the years 2018 & 2019, and PCA is found suitable for the study area. Three principal components were selected based on the Eigen value which explains 79.58% and 85.08% of total variation in the year 2018 and 2019 respectively. The first Principal component (PC-1) is identified with salinity is governed by rock-water interactions and agricultural return flow. The second Principal component (PC-2) with alkalinity and the third Principal component (PC-3) described the pollution.

A laboratory experimentation followed by ASR setup at site Karhera, Mewat district, Haryana to inject fresh water into a saline aquifer with the help of an inlet tank. Recovery efficiency (RE) ranged from 28 to 71.69 % with an average of 57.32 %. In such situation, where there is no surface water source, this recovery rate is very much advantageous. Final report of the study submitted.

7. PROJECT REFERENCE CODE: NIH/GWH/PDS/17-21

Title of the study: *Ganges Aquifer Management in the Context of Monsoon Runoff Conservation for Sustainable River Ecosystem Services - A Pilot Study*

Type of study : Sponsored by NHP under PDS
Date of start (DOS) : December 2017
Scheduled date of completion : July 2022 (Four Years)
Location : Sot River Catchment (Uttar Pradesh)

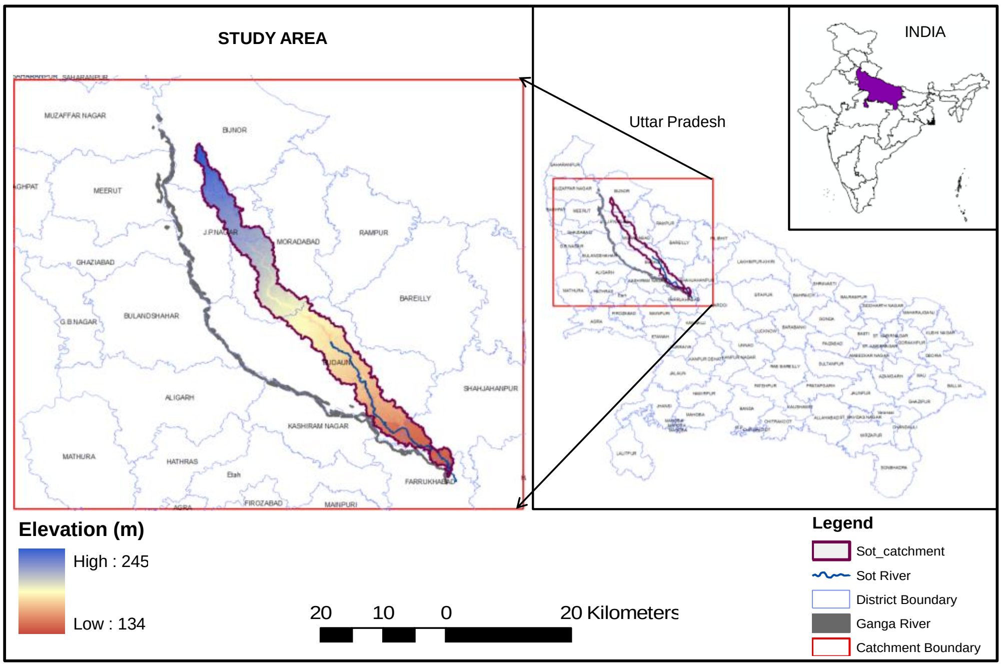


Figure – 7.1: Study site

Study objectives:

- Hydro-geological characterization of the area.
- Analysis of meteorological and hydrological variables *vis-a-vis* cessation of river flows during lean season.
- Estimation of surface water and groundwater availability.
- Analysis of stream-aquifer interaction.
- Aquifer management measures for enhancing river flow during lean season.

Statement of the problem:

Declining groundwater levels, diminishing river flows, turning perennial rivers into ephemeral rivers, and impact of climate change are posing extreme scarcity of water availability in many tributaries of the Ganga river. Such phenomena are not only affecting the water resources but also the livelihood of farmers and the river ecosystem.

The study area comprises of the catchment of Sot river, a tributary of the Ganga river. The river flows in between the Ganga and the Ramganga river. Though both these rivers have good water potential, the Sot river is drying-up in recent years after monsoon season, and its catchment faces acute water problem and many hydrological problems, including extra-deep groundwater levels, recurrent droughts, soil erosion and desertification in some of the areas. The catchment area falls in districts of JP Nagar, Moradabad, Budaun, Shahjahanpur and Farrukhabad. The region suffers from extended droughts, depleted water resources, declining groundwater levels, and uncontrolled developmental activities. These factors coupled with the threat of the impending climate change may lead to an aggravation of the crop losses and desertification process in the area. The Sot river, earlier used to be perennial, has now become seasonal river. Under this background, it was felt necessary to investigate the river-aquifer interactions and dynamics to identify causes of drying of river and suggest measures for rejuvenation.

Methodology:

- Delineation of aquifers using litholog/ borelog data by developing fence diagram, cross-sections, profiles and 3D model in the Rockworks software.
- Time series analysis by synchronizing various temporal data (rainfall and groundwater) to study the variation in river flows and the cessation of river flows during the lean seasons of various years.
- Parametric and non-parametric trend analysis using Mann-Kendall and Sen-Slope Estimator, and change detection using Pettit technique on the hydro-meteorological variables to find the declining trends in river flows, groundwater levels and rainfall during both monsoon and non-monsoon seasons in various years.
- Estimation of surface water availability from river flow data using flow-duration curve and groundwater availability using GEC-2015 methodology.
- Vulnerability analysis using SAHP/DRASTIC approach.
- Catchment water balance using mass balance approach.
- Integrated surface water and groundwater modelling for river-aquifer interactions and future scenarios for river flows during lean seasons.
- Isotopic analysis to verify the reaches of recharge/discharge zones to/from the river.
- Development of a management plan for the enhancement of water resources both surface and underground.

Objectives vis-à-vis Achievements:

Objectives	Achievements
Hydro-geological characterization of the area.	Completed
Analysis of meteorological and hydrological variables *vis-a-vis* cessation of river flows during lean season.	Completed
Estimation of surface water and groundwater availability.	Completed
Analysis of stream-aquifer interaction.	Completed
Aquifer management measures for enhancing river flow during lean season.	Completed

Analysis of Results:

The study is envisaged on the river and groundwater flow interactions and dynamics to answer the questions on drying of Sot river. To carry out the study, existing catchment information, literature survey, meteorological, hydrological and geo-hydrological investigations, and groundwater data acquisition are essential. Review of literature related to the study was completed. The study area comprises of 3,027 sq.km of Uttar Pradesh. The elevation of the catchment varies from 138 to 245 m above mean sea level. Various thematic maps such as catchment boundary, catchment location, DEM, drainage, slope, soil, sub-basin, district/tehsil/road network, grid and land use have been prepared. Daily river flow data was collected and processed to analyze variations of river flow along with rainfall variation. Changes in land use and meteorological variables were also completed. Lithology data was processed and geological sections and fence diagram are prepared. Infiltration and hydraulic conductivity tests were conducted at 48 locations in the entire Sot river catchment for which infiltration and conductivity values were computed and infiltration equations were fitted. Disturbed and undisturbed soil samples were also collected from the same 48 locations of the catchment for the determination of soil properties.

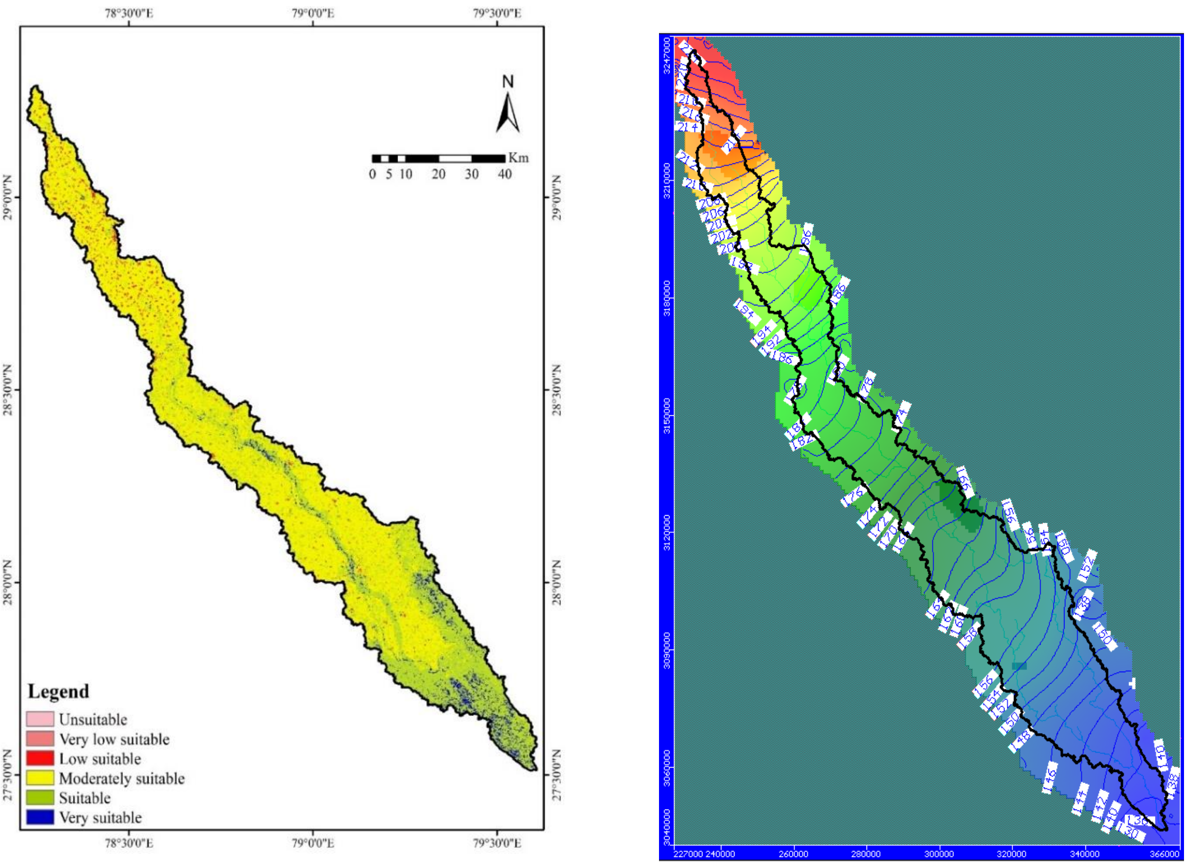
Groundwater modelling was done using the Visual MODFLOW software to model the four-layer groundwater system and assess impacts of groundwater recharge interventions in the catchment.

The data for the period from 2009 to 2018 were used. The model was calibrated for the period 2009 to 2014 and validated for the period 2014 to 2018. This calibrated and validated model was then used for assessing the impact of groundwater recharge structures in the catchment.

To implement the groundwater recharge structures in the Sot catchment, potential zones for groundwater recharge were identified. Eleven thematic layers, namely ground elevation, LULC, surface slope, soil, geology, geomorphology, drainage density, recharge, depth to aquifer, depth to groundwater and groundwater fluctuation, were used for identifying these zones. Saaty’s Analytic Hierarchy Process (AHP) was used to finalize the consistent weights of various thematic layers. The groundwater potential zones were delineated into six classes viz. unsuitable, very low suitable, low suitable, moderately suitable, suitable and very suitable, using the Prajal tool. The maximum area was found under the moderately suitable condition followed by suitable and very suitable condition. The zones were used to implement the groundwater recharge structures in the catchment.

Finally, few scenarios on groundwater recharge structures are suggested in the Sot catchment for augmentation of groundwater so as to contribute to river in the form of base flow. Three types of recharge structures are suggested depending on the local conditions. These structures include check dams, percolation tanks and recharge shafts. Eight check dams are suggested mainly in the upper part of the catchment. Seven percolation tanks are distributed in the catchment wherever thickness of surface soil is less. Seven recharge shafts are suggested where upper unconfined aquifer is deeper and separated by thick aquitard layer. The impact of these structures is presented with and without these recharge interventions in the form of change in groundwater level profiles. It is seen that the groundwater levels show rise in water table profiles after implementation of the recharge interventions. The water table profiles show rise during the period of recharge and decline during the period of no recharge. It is also observed that in general the water table profiles show rising trend after the recharge interventions. Similar structures can be implemented at other feasible locations (falling under the suitable and moderate suitable zones).

The condition of the Sot river is already very much deteriorated in past few decades and lot of sediment and mud is deposited in the river course. Because of this, capacity of river is reduced a lot. Also due to deposition of mud on the river bed, water exchange capacity between river and groundwater is reduced considerably. Developmental activities and land use changes have also impacted the runoff and groundwater recharge conditions in the river catchment. Considering all these aspects, various measures are suggested for rejuvenation of the Sot river. The final report was submitted to the PDS Cell and the report is under review.



***(a)* Groundwater potential zones,** **(b) Spatial variation of groundwater table**

Adopters of Results of Study: CGWB; Agric. Deptt., GWD and IWRD, Govt. of U.P.

List of Deliverables: Reports; Research papers; Training Workshops.

Laboratory Facility used during the Study:

- Centre of Excellence for Advanced Groundwater Research
- Soil Water Laboratory
- Nuclear Hydrology Laboratory
- Water Quality Laboratory

Data Procured/ Generated during the Study:

- Toposheets, DEM, Meteorological data, Soil information, Groundwater Levels, Landuse, River flows, Lithologs.

Study Benefits /Impact:

- Surface water and ground water availability.
- Scenarios on augmentation of groundwater in the catchment.
- Groundwater recharge measures.
- Measures for revival of river.

8. PROJECT REFERENCE CODE: NIH/GWH/PDS/18-24

Title of the study: *Integrated Management of Water Resources for Quantity and Quality in Upper Yamuna Basin up to Delhi*

Type of study: Special Study under Centre of Excellence in Hydrological Modelling (NHP)

Date of start: April 2018

Duration of study: Six years

Location Map:

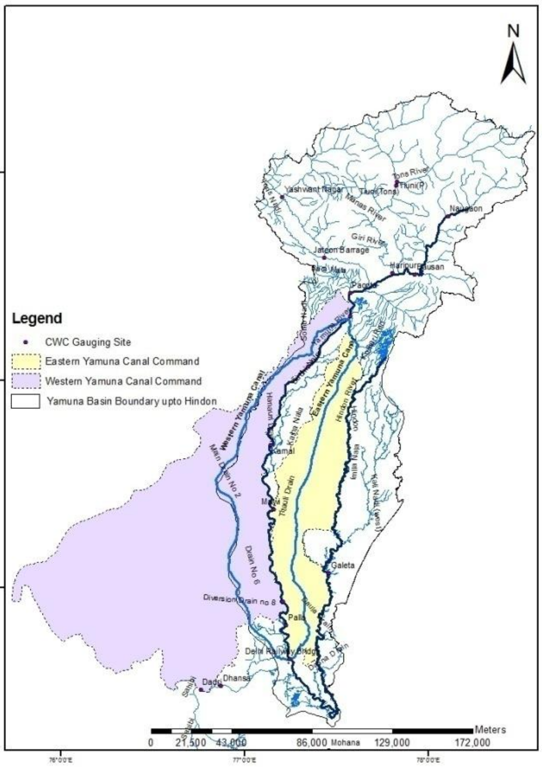


Figure - 8.1: Study area showing the Upper Yamuna Basin and command of EYC and WYC

Study objectives:

1. Application and performance evaluation of selected hydrological models for the simulation of the surface water, groundwater, and water quality
2. Quantification of the contribution of snow and glacier melt to surface water resources through snowmelt runoff modelling for the Tons river
3. Assessment of changes in baseflow contribution to river Yamuna.
4. Assessment of present and future water availability under alternate scenarios of climate change
5. Integrated water allocation planning based on present and future scenario of water availability for (i) Eastern Yamuna Canal Command, (ii) Western Yamuna Canal Command
6. Formulation of adaptation measures in the context of climate change
7. Flood frequency analysis and flood plain mapping of river Yamuna
8. Assessment of anthropogenic activities on water quality
9. Numerical modelling of groundwater recharge dynamics and impact of climate variability on renewable groundwater resources

10. Roll out of technical know-how through training workshops for partner organizations

Objectives vis-à-vis Achievements:

Objectives	Achievements/ Activities
Application and performance evaluation of selected hydrological models for the simulation of the surface water, groundwater, and water quality	Application of hydrological models completed for SWAT, HEC-RAS, VIC, QUAL2K. Application ongoing for MODFLOW. Includes data collection from various agencies, field visits, data processing and analysis. In addition, equipment purchased under project.
Quantification of the contribution of snow and glacier melt to surface water resources through snowmelt runoff modelling for the Tons river	Data processing and work on snowmelt runoff model SWAT for Himalayan portion (incl. Tons).
Assessment of changes in baseflow contribution to river Yamuna	Assessment of changes in baseflow contribution to river Yamuna completed.
Assessment of present and future water availability under alternate scenarios of climate change	Extracted data for study area, data processing, prepared maps for climate change indicators
Integrated water allocation planning based on present and future scenario of water availability for (i) Eastern Yamuna Canal Command, (ii) Western Yamuna Canal Command	In progress using MODFLOW for Yamuna-Hindon Interbasin. Groundwater related data collected for Eastern Yamuna Canal Command. Completed application of WA+ tool using satellite measurements for the study area.
Formulation of adaptation measures in the context of climate change	To be taken up.
Flood frequency analysis and flood plain mapping of river Yamuna	River cross-section survey completed. Flood frequency analyses completed. Flood plain mapping for selected reach.
Assessment of anthropogenic activities on water quality	Field visits undertaken and data collected from central/ state agencies. Assessment of surface water quality of Yamuna river completed. Groundwater samples collected from different locations and analyzed.
Numerical modelling of groundwater recharge dynamics and impact of climate variability on renewable gw resources	Modeling using GIS based WetSpass distributed model. Field and lab experiments for soil parameters for selected sites completed.
Roll out of technical know-how through training workshops for partner organizations	One online training course organized for 24 officers of UP Ground Water Department.

Deliverables:

1. Application of various models pertaining to surface water hydrology, groundwater hydrology, basin planning and their inter-comparison in respect of UYB;
2. Evaluation of the impact of climate change, land use change and population growth on the water resources in UYB;
3. Evaluation of impact of climate variability on renewable groundwater resources;
4. Training Workshops for State Department officials of UP and Haryana.

9. PROJECT REFERENCE CODE: NIH/GWH/DST/19-23

Title of the study : *Enhancing Food and Water Security in Arid Region through Improved Understanding of Quantity, Quality and Management of Blue, Green and Grey Water*

Type of study (sponsored/consultancy/referred/internal): Sponsored by DST

Nature of study: Applied research

Duration: 02/2019 to 01/2024

Lead agency and project partners:

CAZRI Jodhpur (Lead agency),
NIH Roorkee,
IISWC Dehradun,
CSWRI Bikaner,
CIAH Bikaner,
NIAM Jaipur

Aims

- Enhancing water productivity at farming system as well as its components level
- Analyzing future demand and supply of water at regional and sub-regional level
- To develop improved methods for reusing industrial effluents in agriculture
- Capacity building of stakeholders in enhancing water productivity and developing policy guidelines

Objectives

I. To enhance water productivity in farming systems/regional level (Jodhpur, Jaisalmer, Barmer and Bikaner)
II. To develop improved methods for reusing industrial effluents in agriculture
III. To analyze future demand and supply of water at regional and sub-regional level (Jodhpur, Jaisalmer, Barmer and Bikaner)
IV. To develop policy guidelines and capacity building of stakeholders

Objectives vis-à-vis Achievements:

Objectives	Achievements/ Activities
Enhancing water productivity at farming system as well as its components level	Field experiments undertaken with CAZRI to study the impacts of different irrigation schedules on the water balance components. Numerical modeling to study various irrigation management scenarios. Database buildup for WA+ tool to process spatial information on water depletion and net withdrawal using satellite measurements in respect of study area. Equipment purchase completed.
Analyzing future demand and supply of water at regional and sub-regional level	To be taken up with project partners
To develop improved methods for reusing industrial effluents in agriculture	Work by project partners
Capacity building of stakeholders in enhancing water productivity and developing policy guidelines	To be taken up with project partners

Lab Facility used during the Study:

- Centre of Excellence for Advanced Groundwater Research
- Soil and Water Laboratory
- Water Quality Laboratory

Deliverables & Beneficiaries: Beneficiaries will include farming communities in arid regions of Rajasthan. Deliverables include research papers, reports, software, manuals, brochures, flyers, users' interaction workshops.

10. PROJECT REFERENCE CODE: NIH/GWH/BMBF/20-23

Title of the study:	*Expansion of the Indo-German Competence Centre for Riverbank Filtration – CCRBF*
Name of PI and members:	NIH, Roorkee, India Dr. Gopal Krishan (PI and co-coordinator) **University of Applied Sciences Dresden (HTW Dresden/HTWD), Germany** Prof. T. Grischek (Project Leader) Dr. C Sandhu (Project Coordinator)
Type of study:	**Sponsored,** Federal Ministry of Education and Research, Germany (BMBF)
Date of start (DOS):	**01** July 2020 (**Approval received in Feb, 22 Ministry of Jal Shakti & DEA**)
Scheduled date of completion:	**30** June 2023; extension requested upto December 31, 2023 on no cost basis
Location:	Agra, Uttar Pradesh and Phillaur, Punjab

S. No.	Objectives	Achievements
1	Determination of the upper limit for removal of "emerging pollutants" by RBF	**80%** – Past data has been collected and plotted
2	Investigate the inclusion of RBF as a "smart water infrastructure concept" within the "Smart City" project of the city of Agra	**60%-** RBF technique has been proposed as an master plan for the nation and is being conceptualized for selected sites including one at Agra
3	Synthesis of information for inclusion in the RBF Master Plan and guidelines	**60%-** Literature on RBF techniques used in India has been collected from various sources

Background

The floodplain of the Yamuna river between the National Capital Region of Delhi and the city of Agra (located approximately 200 km south of Delhi) is one of the most densely populated urban and rural regions in India (COI, 2011). Large quantities of untreated to partially treated domestic and industrial wastewater are discharged into the Yamuna between these two cities resulting in a critical river water quality (Agarwal and Trivedi, 1995; CSE, 2002; Seth and Babu, 2007). Despite the Yamuna's poor water quality, the river is a major source of raw water for domestic purposes for towns and cities located by it, including Agra city and for irrigation in the rural and semi-urban areas (GONCTD, 2013). After direct pumping from the river, the water is conventionally treated. However most of these conventional drinking water treatment plants are technically unable to remove the high concentrations of micro-biological, organic and inorganic parameters present in the river water thereby either resulting in deliberate interruptions in drinking water production or in widespread consumer dissatisfaction due to noticeable and unacceptable organoleptic quality of the supplied water (CSE, 2002; Sandhu et al., 2011). Furthermore, there is a widespread perception amongst the consumers that the water supplied in the taps is unsafe for consumption without prior treatment at the household level. That is why many households typically use reverse osmosis filters. There are also many areas that are not connected to the piped water supply. These areas have to rely either on groundwater (vertical wells, handpumps) or water delivered in tankers that is expensive and is not affordable by many people.

By using wells installed on the banks of flowing rivers, river bank filtration (RBF) combines the advantage of easy access to large volumes of induced surface water (SW) with the benefit of an improvement in water quality due to natural treatment processes occurring during aquifer passage. Field investigations at various locations across India including in Uttarakhand and the Yamuna floodplain (Delhi and Mathura) have confirmed that there is a large potential to use RBF as an alternative to directly abstracted SW for drinking water production, primarily because it provides an ecosystem service by effectively removing pathogens and turbidity even in monsoon (Sandhu et al. 2011, 2016).

Proposed solution, technological intervention and demonstration up to 2018

In light of the previously described background and scientific investigations conducted on RBF at locations in Uttarakhand, NCR Delhi and other parts of India within the framework of the Saph Pani project (2011 – 2014) accompanied with construction of pilot RBF schemes in Uttarakhand, NIH was motivated to demonstrate RBF technology at six sites across India, including Agra, that have diverse environmental conditions within the project Peya Jal Suraksha (PJS, 2015–2018) funded by the Ministry of Jal Shakti (NIH, 2019). Consequently, the site in Agra was first investigated with standard geophysical, geotechnical and water quality investigations. Accordingly, the site was found feasible for the construction of a vertical exploratory well. The well was constructed on the riverbank in the premises of the Agra waterworks at Jeevani Mandi in February 2018. Due to the scheduled termination of PJS in 2018, only one water sample could be analysed during development of the well in 02/2018. Further investigations, including geohydraulic measurements (water levels monitored for at least one hydrological year) and water quality, could not be conducted. So it was not possible to evaluate the purification efficiency of the RBF system at Jeevani Mandi, because the system only became operational when the PJS project concluded.

Nevertheless, water quality investigations conducted at an existing high capacity horizontal RBF well in Mathura by collaborators from IIT Roorkee in 2007/2008 and subsequently by NIH Roorkee, HTW Dresden and TU Dresden at the same RBF well in Mathura and Yamuna river and near-bank groundwater from 2013 onwards in Agra and Mathura within the framework of the Saph Pani project and Indo-German Competence Centre for Riverbank Filtration (MoU NIH & HTWD, 2011) showed a high potential for RBF as a pre-treatment step for drinking water production. The main advantages of RBF in Agra-Mathura region are an improvement of organoleptic parameters (taste, odor and aesthetic appearance) and a substantial lowering of concentrations of organic compounds including dissolved organic carbon (DOC), turbidity and pathogens and a low risk of formation of disinfection by-products. The main positive observation is that while river water DOC concentrations are high and show a large seasonal fluctuation of around 9 mg/L (3 mg/L in monsoon – 12 mg/L in non-monsoon), the concentration of DOC in the RBF wells was found to be substantially lower at 3 mg/L and 6 mg/L in monsoon and non-monsoon respectively. Removal of total and fecal coliform of 1.3–1.7 and 2.3–3.2 log_{10} units respectively was observed at the high capacity RBF well in Mathura. Thus RBF can serve as an important pre-treatment step and provide cost-savings for post-treatment.

Validation, demonstration and exploitation of RBF technological intervention post 2018

With the impending conclusion of project PJS in 2018, NIH and HTWD endeavored to exploit the infrastructure created in PJS (pumping well), in a new collaborative project. The rationale for this is given below. None of the following were possible to investigate in the predecessor project PJS:

1. Validation of RBF process:
    a. Possibility to investigate the upper limit of the purification capacity for RBF w.r.t. organic micropollutants and pathogens because the Yamuna river is one of the most polluted rivers worldwide

b. Comparison of RBF water quality with directly abstracted and conventionally treated surface water treated at the same location
c. Investigation of the effects of aquifer anisotropy (hydraulic conductivity changes in vertical/z-direction due to intermittent low and high conductivity layers) because the subsurface stratification found in the Yamuna floodplain in Agra is similar to many locations in the Ganga-Yamuna basin
d. Estimation of the portion of bank filtrate in pumped water from well and travel time of bank filtrate from river to well

2. Demonstration of RBF scheme:
   a. Development of existing well into a demonstration site for RBF to show how a RBF site should be made and to display the benefits of RBF
   b. Creation of infrastructure to monitor the RBF site by construction of at least 1 monitoring well
   c. Demonstration of the purification capacity of RBF for conditions typical of extremely polluted rivers with complex subsurface geology

3. Exploitation of above by:
   a. Development of a science-based masterplan for RBF water supply in India using above scientific results
   b. Revision of existing guidelines on RBF into a second edition that will incorporate scientific / technical experiences of above
   c. Investigate the inclusion of RBF as a "smart water infrastructure concept" within the "Smart City" project of the city of Agra

Whether Study is a New Study/Extension of Previous Studies: New study

Methodology:

NIH has already established the abstraction well infrastructure at the site at Agra in PJS project (2015-2018) including vertical borewell with submersible pump, provision of electricity supply to pump and construction of pump house. Samples will be collected from river, RBF exploratory well, adjoining drainages and groundwater to assess the removal of emerging pollutants and pathogens. So the main focus of this project will cover validation, demonstration and exploitation aspects (discussed above), especially:

- Determination of the upper limit of removal of "emerging pollutants" by RBF
- Equipping the site with water quality monitoring infrastructure
- To equip site with promotional/information materials on research done at site

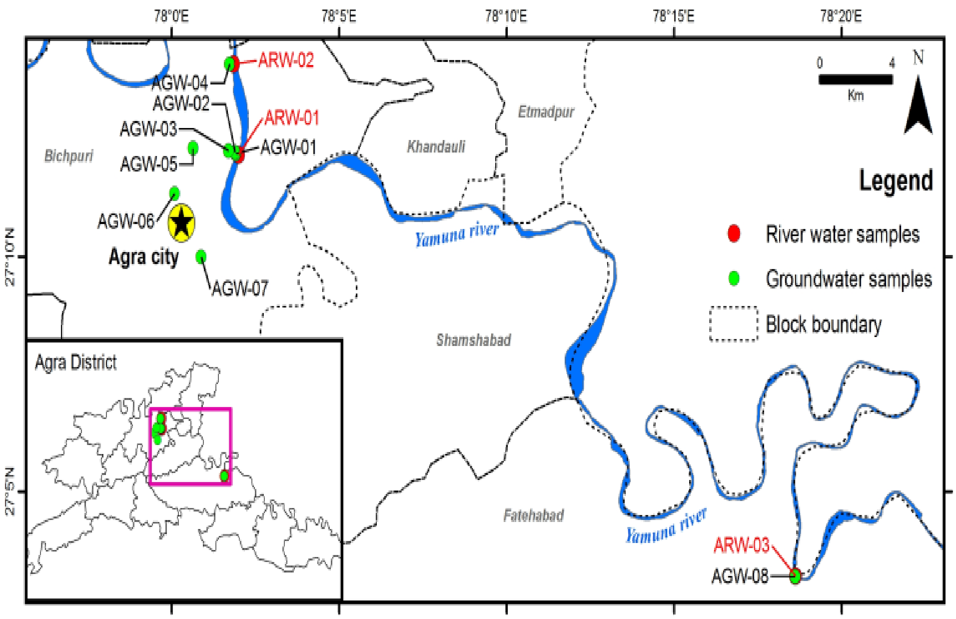


Figure – 10.1: Study site

Progress

1. Work package/WP 1: Strengthening of network/collaboration

a. Completion of administrative formalities by signing Cooperation Agreement with 7 other Indian partners and 7 German partners in CCRBF consortium (total 15 partners).
b. Obtaining permission from Ministry of Jal Shakti and Department of Economic Affairs, Govt. of India, for NIH to be a partner of CCRBF consortium and to participate in CCRBF project activities.
c. Signing of Transfer Contract with HTWD (CCRBF project coordinator) to receive funds from the funding agency BMBF, Govt. of Germany.
d. Application to MoJS to extend the existing MoU between NIH and HTWD on "Indo-German Competence Centre for Riverbank Filtration" (IGCCRBF) for third phase from 2021 to 2026. Extension of MOU granted for 5-year period 01.06.2021 to 31.05.2026 wide MoJS letter dated 11.10.2021
e. Participation in 4 project/consortium meetings (online due to Covid-19 pandemic) on 21 July 2020, 03 February 2021, 08 July 2021 and 14 July 2022
f. Participation in online CONNECT programme meeting organized by BMBF on 18 November 2021 and 06 October 2022

2. WP2: Development of RBF demonstration site Agra

Due to the Covid-19 pandemic, especially the critical second wave from March to May 2021 and subsequent monsoon season, it was only possible to commence field work in Agra from October 2021

a. Scientific-technical support to CCRBF German partners HTWD & TUD for field investigations in Agra, liaison with stakeholder UP JAL Nigam (Oct. 2021 – Nov. 2022)
b. Collection and analyses of water samples for Oxygen-18 and Deuterium isotope
c. Co-supervision and scientific and logistic support to collaborative master thesis of:

J. Nainan (2022) Synthesis of complex hydrogeological conditions for riverbank filtration in Agra and Guwahati, India. Master Thesis, TU Dresden, Institute of Groundwater Management; HTW Dresden, Division of Water Sciences; NIH Roorkee, Groundwater Hydrology Division & BBEC Kokrajhar, Dept. of Civil Engineering.

d. Field work comprising water sampling for ions, heavy metals, dissolved organic carbon and organic micropollutants, shallow drilling with auger/tripod to determine groundwater level at site
e. Review and synthesis of literature and preparation of project reports

The key conclusions from the work in Agra are:

a. 20,000 persons of economically weaker sections of society solely receive water from RBF exploratory well. Therefore the well has a high social importance
b. Seepage of bank filtrate through silty fine sand layers possible
c. Portion of bank filtrate in exploratory well can be due to better hydraulic connection of river and aquifer upstream
d. Post-treatment of ammonium required for exploratory well water, otherwise good water quality of exploratory well

Inclusion of new project site by Sutlej river in Punjab

Additionally, and with reference to the progress report of CCRBF for the year 2021-2022, a potential RBF site in village Gagdhagara, near Talwan town by the Sutlej river in Punjab has been included in the project. This is in tune with the World Bank report (2020) on "Managing Rural Drinking Water Quality in Punjab", wherein the following have been recommended:

i. Establishment of RBF systems in Punjab as a safe long-term solution
ii. And systematic inventory of existing sites and exploration of new sites for development of RBF systems along major rivers

Thereby cooperation with an additional stakeholder, namely the Department of Drinking Water Supply and Sanitation, Govt. of Punjab, has also been initiated.

Consequently, the quality of the Sutlej river water and groundwater from a vertical well used for rural water supply and located ~200 m from the riverbank in Gagdhagara, were investigated within the CCRBF project in June 2022 with the following key results and conclusions:

a. current investigations in Gagdhagara by NIH & German partners HTWD and TUD reaffirm recommendations of World Bank report (2022, points i & ii above).
b. inorganic water quality of well within IS 10500 limits for drinking water
c. little to no removal of atrazine and carbamazepine during subsurface passage indicates river-aquifer hydraulic connection
d. potential for RBF at existing site exists, however further geohydraulic investigations and water quality monitoring needed
e. good example of RBF as a sustainable source in Jal Jeevan Mission

3. WP3 to WP5: Guideline for RBF in India (WP3), Education & Training (WP4) and RBF masterplan (WP5)

Results from WP2 are being synthesized into these WPs and accordingly disseminated/exploited.

4. WP6: Dissemination and exploitation of results

NIH contributed/disseminated for the period 01 July 2020 to 31 December 2022 as follows (details in annexure II):

- 11 conference presentations (annexure II, s.no. 1 to 11)
- 2 ad hoc/workshop presentations, including at a meeting with Ministry of Jal Shakti, New Delhi and Department of Water Supply and Sanitation, Govt. of Punjab, Chandigarh (annexure II, s.no. 12 & 13)
- 1 brainstorming session organized by Uttarakhand State Council for Science & Technology (UCOST), Dehradun, 31.07.2021 (annexure II, s.no. 14)
- 2 peer-reviewed book chapters published (annexure II)
- 7 conference abstracts included in proceedings, 1 article in India's leading water industry publication "Everything About Water"

Action plan:

The project has been delayed due to the Covid-19 pandemic. Accordingly, the CCRBF project coordinator HTW Dresden (HTWD) submitted an application to the funding organization (BMBF) for project extension up to at least 31 December 2023 and if possible up to 31 March 2024 on a costneutral basis. According to DLR, the project management agency of BMBF, extension up to 31.12.2023 can be granted in principle. For this HTWD is presently preparing a detailed application for project extension.

Period	**July 2020 to June, 2023** (Annexure 1)	Remark
July 2020 to June 2023	Monitoring of the site regularly Establishing the site with monitoring infrastructure Project works as listed in section "Validation, demonstration and exploitation of RBF technological intervention post 2018" Preparation of revised RBF guidelines and masterplan on RBF for India Prepare a status report Participation of NIH in 3rd International Riverbank Filtration Conference in Dresden from 13.– 15.06.2023 Participation of NIH in CCRBF project meeting in Dresden on 16.06.2023	Report preparation as per Annexure 1 and dissemination activities as per Annexure 2
01 July 2023 to 31 March 2024	Field work and water sampling during monsoon season Preparation of input for RBF guidelines and masterplan Organisation of a final project conference in February 2024 (subject to project extension)	Subject to project extension

Strategic linkages for further work and follow-up

- Discussions with GiZ representative at the 5th India-EU Water Forum, New Delhi, 27 Oct. 2022, for advancement of activities on RBF in India. Further discussion planned.
- Discussions with representative of Haryana Water Resources Authority at Internal Ground Water Conference, Roorkee, 02. – 04.11.2022 for advancement of activities on RBF in Haryana. Further discussion planned.
- Discussions with Department of Water Supply & Sanitation, Govt. of Punjab for advancement of activities on RBF in Punjab. Further discussion planned.

Study Benefits /Impact:

- The result will be the creation of a road map within framework of RBF masterplan to increase contribution of RBF to total drinking water supply from currently less than 1% to at least 5% by 2030.
- Strengthening Indo-German/European scientific collaboration on managed aquifer recharge/RBF
- The project has a high socio-economic relevance for the underprivileged households living in Jeevani Mandi area of Agra because before implementation of the action they had no access to safe drinking water and after implementation of action they have access to safe drinking water.
- informing and collating experiences/knowledge; capacity development and strengthening competence on MAR/RBF.
- evaluating existing work bases and sharing or making them known within the network synergies with other Indo-European projects (e.g. DST–EU-Horizon2020 funded projects).

Specific linkages with Institutions:

- German partners: HTWD, TZWD, TUD, FHP, AUT, AKUT, GiZ (to be intensified)
- Indian partners: UJS, BHU, CSIR-CMERI, BBEC, AU, IITM, TERI, UPJN

Future plan

- Use of synergies from the competence-pool of RBF/CW/MAR through training and thematic cooperation between partners and stake holders
- Possible extension of CCRBF project up to 31 March 2024.

11. PROJECT REFERENCE CODE: NIH/GWH/*DST-SERB/2021-24*

Title of the study : *Partitioning Evapotranspiration into Evaporation and Transpiration fluxes using Stable Isotopes of Oxygen and Hydrogen*

Name of PI and members : NIH, Roorkee, India
Dr. Gopal Krishan (PI)
Dr. M.S. Rao (co-PI)
IIT-Kanpur
Dr. Shivam Tripathi (PI)
Dr. Richa Ojha (Co-PI)
Dr. Rajesh Srivastava (Co-PI)
Dr. Saumen Guha (Co-PI)

Type of study : **Sponsored,** DST-SERB

Date of start (DOS) : April 2021

Scheduled date of completion : March 2024

Location : NIH Roorkee and IIT-Kanpur

S. No.	Study objectives	Achievements
1	Estimate evapo-transpiration (ET) flux at a study site in Kanpur	**80%** – Experiments has been set up at IIT Kanpur after the standardization of methodology at NIH
2	Partition ET flux into soil evaporation (E) and plant transpiration (T) fluxes, and investigate ➢ diurnal fluctuations in the fluxes; ➢ variations in the fluxes during a cropping season; differences in the fluxes between two cropping seasons, namely Rabi (wheat) and Kharif (rice);	**50%-** Experiments have been conducted for one wheat and two rice seasons. The data are being analysed to estimate components of ET fluxes.
3	Quantify uncertainties in the estimates of E, T and ET fluxes	**60%-** Experiments to finalize the methodology are in progress

Statement of the problem:

Agriculture is the single largest user of freshwater in India. A significant portion of the applied irrigation water eventually evapotranspires. The transpiration (T) component of the evapotranspiration (ET) is associated with crop productivity, while the undesirable soil evaporation (E) component represents losses. The knowledge of the relative magnitudes of E and T fluxes is therefore essential for designing efficient irrigation techniques and understanding energy and moisture transfer in the soil-plant atmosphere continuum. In this direction, the institute has developed methodologies for collection of air moisture samples, soil evaporation and evapotranspiration samples, transpiration samples. Wherever possible, instruments are designed and fabricated inhouse to suit the local conditions and give reliable data at a low cost. For experimentation in the field, two sites are selected in Kanpur to study ET partitioning at plot and field scales. The sites are instrumented for measuring ET fluxes using hydrometric and isotopic methods.

Whether Study is a New/Extension of Previous Studies: Extension of previous study

Progress

As part of the project, the following work has been completed at the NIH-Roorkee to date:

1. **Collection of Atmospheric moisture samples**

We used the cone-condensation technique to collect atmospheric moisture samples. Using the 8 screws provided, the aluminium cone was positioned so that the tip of the cone was directly just above the bottle and the moisture droplets condensing on the surface of the cone fell directly onto the bottle.

2. **Collection of Plant transpiration samples**

Water is dispersed into the atmosphere via the stomata and can be collected using transpiration bags. Plant transpiration samples were collected using transpiration bags.

S.No.	Common Name	Scientific Name
1	Ashoka tree	Saraca asoca
2	Indian laurel	Terminalia elliptica
3	Jamun tree	Syzygium cumini
4	False Ashoka Tree	Polyalthia longifolia

3. **Model development to collect Soil evaporation samples**

Our current model for collecting soil evaporation samples is made of a clear Acrylic Sheet and lists the following features:

I. Experiment set up made of transparent Acrylic Sheet (5 mm thickness) with dimensions 75*75*60 cm.
II. Air compressor for suction and trapping evaporated vapors in the glass tube (where these vapors can be condensed). The compressor is connected to a rotameter and nozzle valve to control the suction and trap process.
III. The mixture of Liquid nitrogen and acetone for condensing vapors.
IV. Wireless Bluetooth data logger and sensor to know humidity and temperature variations inside and outside the experimental setup.

An air compressor was used to suction and trap the vapors in the glass tube (where these vapors were condensed). The suction process occurred at a rate ranging from 3 lt/min to 5 lt/min. The volume of the sample collected was found proportional to the suction rate.

4. **Collection of Rainwater samples**

A Standard non-recording rain gauge prescribed by the IMD (Symon's rain gauge) was used to collect the rainwater samples. The gauge consisted of a funnel with a sharp-edged rim of 127 mm diameter, a cylindrical body, a receiver with a narrow neck and handle, and a splayed base that was fixed in the ground. The rain falling into the funnel was collected in the receiver kept inside the body and measured using a special measure glass which was graduated in mm. The gauge was fixed on a concrete foundation of size 60 cm x 60 cm x 60 cm which was sunk into the ground. The rainwater samples were also used to develop the LMWL for the region.

5. **Collection of Groundwater samples**

Standing water within a bore is exposed to atmospheric conditions and can undergo changes to its physical and chemical characteristics and is not representative of the water in the aquifer.

Unless aquifer quality is known to be vertically uniform, samples collected may include a mixture of groundwater entering the borehole using the open or screened casing methodology and can be considered to produce a composite sample or one of approximately average composition.

We observed a large isotopic variability in the atmospheric moisture ($\delta^{18}O$ = -5.25‰ to -28.59‰; δD = 1.68‰ to -127.01‰), which is most likely due to seasonal variations in the source of atmospheric moisture. The isotope values in rain samples ranged from $\delta^{18}O$ = -5.52‰ to -11.21‰; δD = -30.75‰ to -86.74‰, while groundwater samples showed the least variations ($\delta^{18}O$ = -7.14‰ to -7.40; δD = -50.04‰ to -52.28‰) in their isotopic values. The observed enriched isotopic values of transpiration samples may be explained by isotopic enrichment controlling factors such as relative humidity, temperature, and the internal and external ambient environment of the leaf. With further investigation, the data collected in this study can be useful for understanding the factors responsible for seasonal variability in isotopic values of evapo-transpired moisture.

Work done at IIT Kanpur

Experiments are being conducted at two sites, one inside IIT Kanpur and the other 15 km north of IIT Kanpur at Bithoor. Instruments are installed at both the sites to measure hydro-meteorological parameters, and the soil properties of the sites are characterized. Two sets of experiments have been performed for the Kharif season (rice; 2021-22 and 2022-23 cropping seasons) and one set for Rabi season (wheat; 2022-23 cropping season). Experiments for the second Rabi season are in progress.

A locally developed late sown wheat variety K7903 (Halana) and a locally popular hybrid rice variety DuPont Pioneer (PHB 71) are used in the experiments. Weighing-type mini-lysimeters are designed and installed at both the sites to measure E and ET fluxes. In addition, sensors have been deployed to measure temperature, relative humidity, rainfall, and wind speed & direction.

We have compared various soil and plant water extraction techniques, namely, rotatory vacuum evaporator, azeotropic distillation, displacement fluid centrifugation, and cryogenic vacuum distillation, and have standardized protocols for each technique. Further, for each experiment set, we have collected samples of soil, plant, irrigation water, river water and atmospheric water for multiple days during the cropping season for isotopic analysis. For estimating interception losses, we have used catch-cans and tipping bucket rain gauges. We have also developed a method to collect stem flow by using a centrifuge tube wrapped around the wheat stem.

Action plan:

Period	**April 2021 to March, 2024** (Annexure 1)	Remark
April 2021 to March 2024	Installation of instruments Collection of waters samples, isotope analysis Data analysis and uncertainty quantification Data dissemination and report writing	Report preparation

Study Benefits /Impact:

1. Diurnal, inter- and intra- cropping seasonal variations in soil evaporation (E), plant transpiration (T) and evapotranspiration (ET) fluxes at the study sites.
2. A methodology to quantify uncertainty in ET partitioning. In addition, the results obtained and methodology developed during the proposed project will be useful for - (a) validating process based hydrological models that estimate E and T fluxes separately, and (b) improving irrigation efficiency by developing agricultural practices that reduce soil evaporation losses.

12. PROJECT REFERENCE CODE: NIH/GWH/ APN/22

Title of the study: *Capacity Development Program on Site Suitability Mapping for Managed Aquifer Recharge (MAR) under Varying Climatic Conditions using Remote Sensing and Machine Learning based Hydrological Modelling Tools*

Name of PI and members	**NIH, Roorkee (**Partner organization**)** Nitesh Patidar (PI), Surjeet Singh, Gopal Krishan, ***IIT Roorkee*** (Lead organization); *KU*, *Japan* (In-kind support); *PNU*, *South Korea*:
Type of study	**Sponsored,** Asia-Pacific Network (APN)
Date of start (DOS)	01 Jan 2022
Date of completion	31 Dec 2022
Status	**Completed**

Objectives vis-à-vis Achievements

S. No.	Study objectives	Achievements
1	Disseminate knowledge on MAR, climate variability, and emerging planning tools and techniques. This would primarily be aimed at forming a necessary base in the trainees to understand various groundwater processes, groundwater-climate interactions, and sustainable MAR planning	*Completed* A five-day training was conducted on-line jointly by NIH and IIT Roorkee during 06-10 June, 2022, on "Approaches for Management of Groundwater Quantity and Quality with special focus on MAR".
2	Develop and disseminate an integrated approach, considering quantity and quality, for site suitability mapping for MAR under changing climate to support effective MAR planning in the identified Indian hot-spots. The integrated approach will utilize remote sensing and machine learning-based hydrological modeling tools	*Completed* A web-portal and a web-based tool, named G-MCDA, was developed and being hosted at http://prajal.org/ . A training was conducted jointly by IIT Roorkee and NIH Roorkee during Nov 21-24, 2022.
3	Evaluating the MAR projects using available field observations and hydrological models	*Completed* A one-day workshop was conducted jointly by IIT Roorkee and NIH Roorkee on Nov 25, 2022.

Background

In the states with inadequate surface water supplies and low rainfall, the major part of irrigation water is provided using the groundwater source. Under the threat of climate change, groundwater resources, therefore work as a cushion against climate variability. Managed aquifer recharge (MAR) has already been accepted as a reliable approach for groundwater recharge, however, the implications of such recharged water on groundwater quality are still not well understood. Nevertheless, to tackle the twin hazards, alarming decline in groundwater levels, and consequent deterioration of groundwater quality, artificial recharge has now been widely propagated in India. Central Ground Water Board (CGWB) in 2013 proposed the master plan for artificial recharge to groundwater in different states. Recently, a more detailed master plan for artificial recharge to groundwater (2020) is proposed identifying the total area for artificial recharge of 11.23 lakh sq. km.

However, this large-scale recharge project can only succeed if the implications of MAR on environment and health at the local, regional and global scale are well understood. Global knowledge sharing and capacity building at the local scale would make sure that the MAR projects are well planned and have the potential to tackle challenges in MAR development, operation, and management.

Trainings and workshops conducted

The capacity building trainings and workshops attempted to address various issues relating to the MAR development, operation, and management at the local and regional scale. The site suitability mapping using Multi-Criteria Decision Analysis (MCDA), Google Earth Engine, machine learning, and hydrological models were demonstrated during the program which would help the scientists, policymakers and other relevant stakeholders in addressing the issues of water quantity/quality and climatic variability. The developed science-based knowledge platform (praJal) along with lectures and hands-on manuals will help various stakeholders (civil society and policymakers) in addressing the issues of MAR design, sustainable operation strategy and management at regional and global level as well. Two trainings and one workshop were conducted during this program jointly with IIT Roorkee. A total of ~55 officers from 7 different states were trained during the program.

PraJal and G-MCDA

A web-portal (PraJal) and web-based tool (G-MCDA) was developed for site suitability mapping for Managed aquifer recharge. The developed websites consist various information on upcoming trainings, videos lectures and manuals. The G-MCDA, which also hosted on PraJal, is an integration of Google Earth Engine (GEE), Multi-criteria Decision Analysis (MCDA), python and web, which allows quick site suitability mapping for MAR. G-MCDA can be accessed free of cost using the URL “http://prajal.org/”.

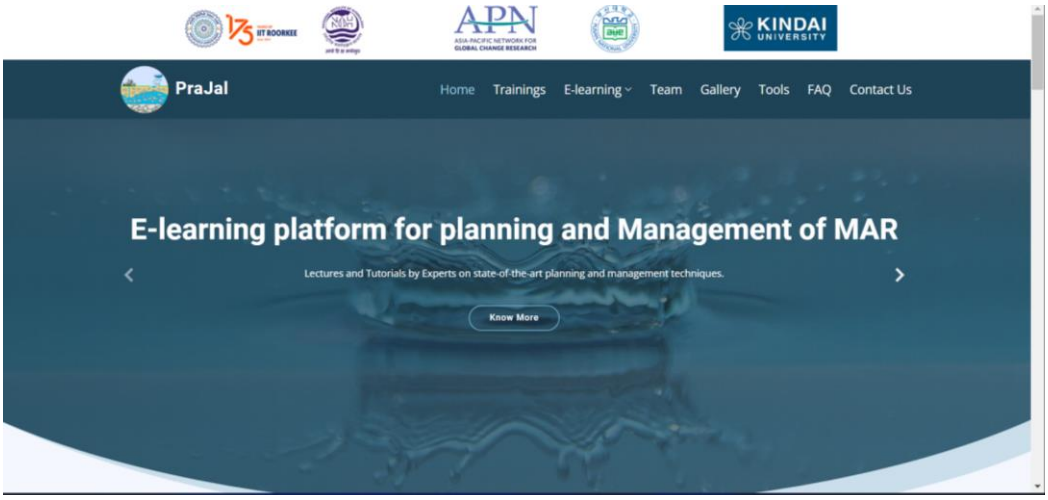


Figure – 12.1: PraJal – web-portal developed during the study (http://prajal.org/)

13. PROJECT REFERENCE CODE: NIH/GWH/ 22-24

Title of the study : *Hydrogeological and Isotopic investigation of groundwater in Himalayan Watershed of Kashmir, India*

Name of PI and members :

NIH, Roorkee, India
Dr. Gopal Krishan (PI)
Dr. M.S. Rao (co-PI)

SKUAST-Srinagar
Prof. Rohitashv Kumar (co-PI)

Type of study : **Internal**

Date of start (DOS) : **September** 2022

Scheduled date of completion : **March** 2024

Location : **Kashmir**

S. No.	Study objectives	Achievements
1	To assess surface and groundwater quality using hydrogeochemical analysis	**10%** – Sampling sites are finalized
2	To characterize isotopic signatures in groundwater and surface water	**20%-** First set of samples collected and analysed
3	Delineation of the groundwater recharge zones and spring-water quality assessment	In progress

Statement of the problem:

One of the main tributaries of the river Jhelum, the Doodhganga stream provides a vital source of drinking water and irrigation for the people of Budgam and Srinagar. Any contamination near recharge areas can lead to degradation of water quality in areas of discharge (streams and springs). Therefore, monitoring the water quality is a crucial issue for the sustainable management of water resources. Keeping in mind these concerns, it is important to delineate the potential recharge sites in order to prevent or at least reduce future contamination. Stable Water isotopes - hydrogen (δ^2H) and oxygen ($\delta^{18}O$) in conjunction with conventional hydrogeology and hydrogeochemistry have been shown to be effective tools for solving many critical hydrological problems (Clark and Fritz 1997; Bhat and Jeelani, 2015). Therefore, the mountain watershed of the Doodhganga River is selected for the research in this study. Combining field investigation and indoor analysis, this study will analyze the hydrogen and oxygen isotopes and hydrochemical characteristics of surface water and groundwater in the basin using environmental isotope and hydrochemical techniques. This study would discuss the effect of altitude on hydrogen and oxygen isotopes and the interaction between surface water and groundwater in the mountainous watershed of the Doodhganga River. This is of great significance for enhancing the understanding of the water cycle in mountain basins and understanding the interaction and transformation relationship between surface water and groundwater for the rational utilization and effective protection of water resources in mountainous areas, as well as preventing and controlling water pollution. This study also provides a theoretical basis for the study of the water cycle in the basin under changing environments.

Study area

Doodhganga literally means stream of milk and implies that the stream once carried water as pure as milk and as holy as the Ganges. Doodhganga catchment of Kashmir Valley located in the northern part of India between 33° 42′ to 34°50′ N and 74°24′to 74°54′ E, covers an area of 655 km². It is one of the left bank tributaries of the river Jhelum, originating on the eastern slopes of the Pir Panjal mountain range below the Tatakuti peak which is at an altitude of 4,500 m a.s.l (Hussain and Pandit 2011a, b). The topography of the watershed is varied and exhibits altitudinal extremes of 1,548–4,634 m a.m.s.l (Romshoo and Rashid 2012). The upper reaches of the catchment that is usually snow covered and has extremely steep slopes of more than 70 %, followed by comparatively lesser steep slopes of 60–70 % which reflect the different aspects of mainly the Karewa formations in the middle parts of the watershed. The downstream watershed area have very gentle slope of 0–1 % (Hussain and Pandit 2011a, b).

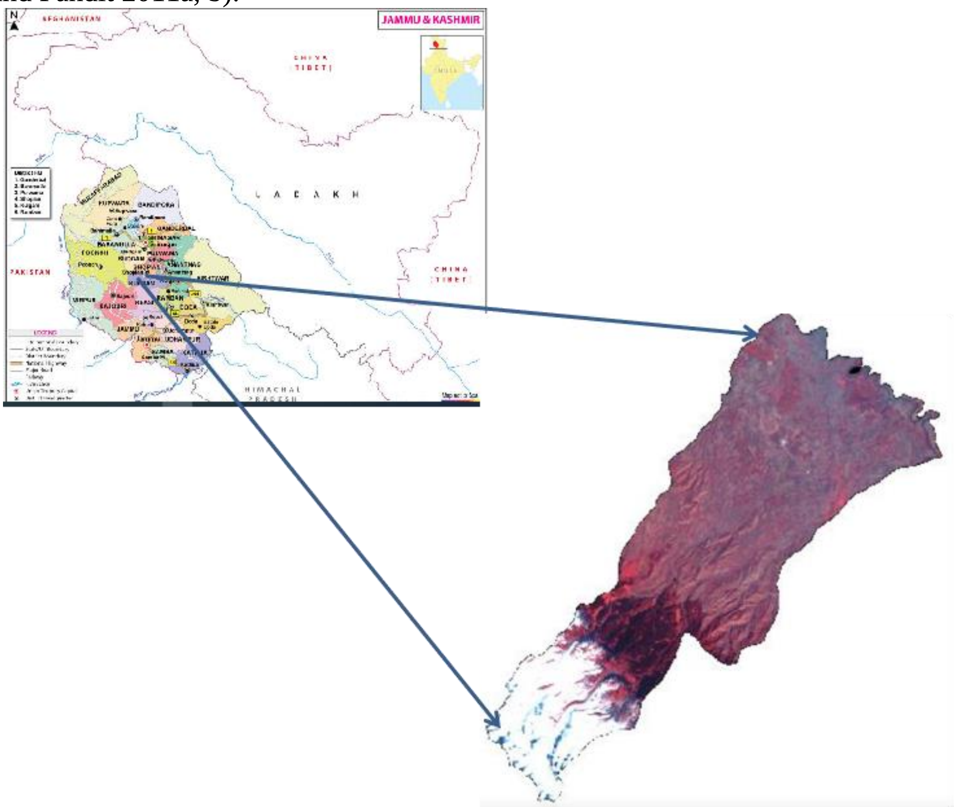


Figure – 13.1: Doodhganga Watershed

Whether Study is a New Study/Extension of Previous Studies: New study

Methodology:
Preliminary Work:

Base map of the study area will be digitized from the survey of India toposheet using ArcGIS 10.2 software or delineating the area using HecGeoHMS in ArcGIS platform. Precise locations of sampling points will be determined in the field and the exact longitudes and latitudes of the sampling points will be imported using a GIS platform.

Objective 1: To assess surface and groundwater quality using hydro-geochemical analysis.
Fieldwork, and collection of surface and groundwater water samples for the analysis of physio-chemical parameters and isotopic analysis will be carried out. Physical parameters (temperature, pH, total dissolved solids, and electrical conductivity) will be measured and recorded in-situ using portable instruments. Determination of major ions and trace elements

Objective 2: To characterize isotopic signatures in groundwater and surface water to delineate the sources of groundwater recharge using isotopic signatures. Stable Water isotopes - hydrogen (δ^2H) and oxygen ($\delta^{18}O$) will be analyzed

Objective 3: Delineation of the groundwater recharge zones and groundwater contamination sites / Or Assessment of groundwater contamination risk mapping.
Sources of Groundwater Recharge: The values of $\delta^{18}O$ and δ^2H measurements of precipitation and groundwater will be assessed to identify the recharge areas of groundwater. The area can be identified by measuring ^2H and ^{18}O concentrations and correlating them to the altitude at which precipitation could have infiltrated the ground.

Groundwater Contamination source assessment: The spatial variability of Hydro-geochemical and isotope values will be carried out in GIS software using geospatial analysis tool and the hotspots of aquifer contamination will be identified.

Progress

The sampling sites are identified (fig. 2) and samples are analysed for isotopes analysis

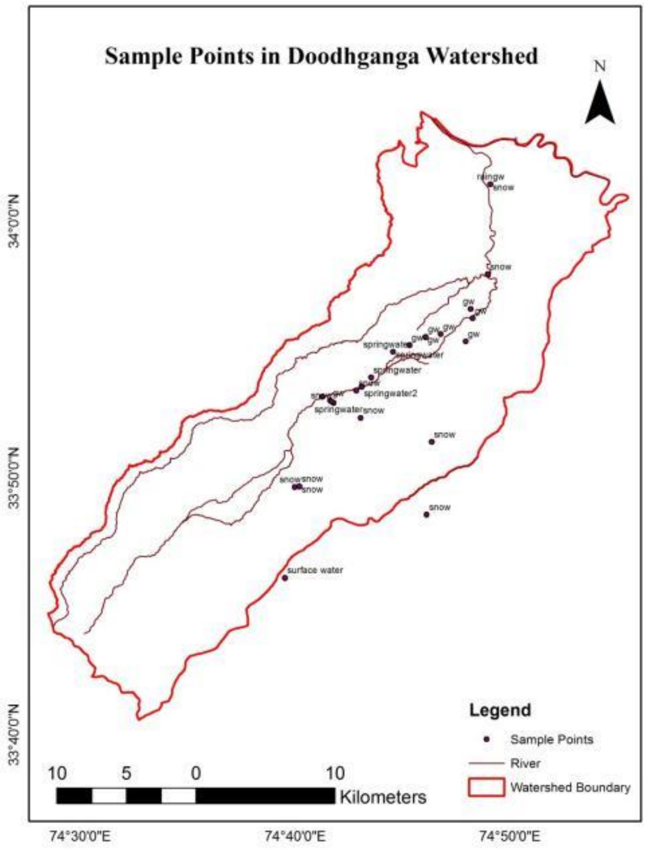


Figure - 13.2: Sampling sites

Action plan:

Period	September 2022 to March, 2024	Remark
September 2022 to March 2023	Collection of waters samples Analysis of the samples Data analysis and interpretation Report writing and publication	Report preparation as per Annexure 1

Study Benefits /Impact:

- Isotope characterization of water resources in the study area
- Source identification
- Surface water-groundwater interactions
- Water quality assessment
- Reports and publications

NEW STUDIES

14. PROJECT REFERENCE CODE: NIH/GWH/NIH/23-24

Title of the Project: *Development of Archive of Soil Hydraulic Characteristics*

Study team:	PI	Ms. Anju Chaudhary, Scientist-B
	Co-PIs	Dr. Nitesh Patidar, Scientist-C
		Dr. M.K. Goel, Scientist-G
		Dr. Surjeet Singh, Scientist-F
		Dr. Anupma Sharma, Scientist-G

Type of study: Internal
Duration: One year (April 2023 – March 2024)

Background

Soil Hydraulic Properties, such as soil texture, hydraulic conductivity and soil moisture retention curve etc. are important inputs to various hydrologic analysis and modelling. Soil Water Laboratory of NIH has been conducting such investigations in various parts of India under various R&D studies funded by NIH and external agencies. Scientist of NIH and staff of Soil Water Lab make considerable efforts to collect soil samples from the field and conduct various investigations in the lab to derive soil hydraulic properties. A total of ~3,330 soil samples have been tested since 2011 which provide abundant data for various hydrologic analysis. The analysis includes soil texture identification with measurement of sand, clay and silt fractions, analysis on pressure plate apparatus to derive soil moisture at different suction pressures for soil moisture characteristic curve, analysis of soil organic contents, estimation of soil hydraulic conductivity, etc. Such data are although very useful for hydrologic modelling, these are rarely available.

It is envisaged that such soil test results conducted in past historical period (with a buffer gap of 4 years for reporting/publication by the project team), if published through a GIS-portal on NIH website, could help researchers and planners in their analysis towards better water management. In this context, it is planned to develop an Archive of Soil Hydraulic Characteristics to store the soil-test results in digital format and disseminate them through a GIS portal.

Objectives

The prime objective of the study is to develop a web-based system to store and disseminate soil hydraulic characteristics analyzed in Soil Water Lab of NIH. The specific objectives of the study are as follows:

I. Development of archive of soil hydraulic characteristics. The results of soil analyses performed during the past years (2011-2022) will be digitized in a standardized format to append in the archive.
II. Development of a web-based GIS-dashboard to publish the soil hydraulic characteristics.
III. Development of an automated system to store the results of soil hydraulic analysis to be performed in future in the archive and publish them on the portal.

Methodology

Digitization

The soil test results in Soil Water Lab used to be stored in the form of printed/hand written sheets. These data are to be converted to digital format in order to process, store in the archive and publish on the portal. A format for each soil hydraulic characteristic will be decided and the same will be followed while converting the data from hard copies to digital sheets.

Development of archive
To store results of all the analysis performed in the past and to be performed in the future, a archive will be developed. The archive will store all data in the desired format for further processing for GIS analysis.

Development of GIS-dashboard
To publish the data stored in the archive, a GIS-dashboard will be developed. Python programming with HTML and CSS will be used to develop the web-based GIS-dashboard. The dashboard will fetch the data from the archive and will display it on the dashboard in the form of interactive maps, plots and tables.

Development of automated system
An automated system is to be developed for processing and storing the results of soil analysis to be performed in the future. This will enable automated data insertion to the archive and allow automated publishing after the analysis completes the assigned lock-in period (say four years). This system will be developed in Python which will communicate with the soil archive and the dashboard.

Action plan and timeline (quarter-wise from April 2023 to Mar 2024)

Work element	**Apr-Jul 2023**	**Aug-Nov 2023**	**Dec 2023-Mar 2024**
Digitization of data for archive			
Development of GIS-dashboard			
Development of automated system			
Project report and research paper			

15. PROJECT REFERENCE CODE: NIH/GWH/NIH/23-25

Title of the Project: Enhancement and application of *NIH_WISDOM*

Study team:	PI	Dr. Nitesh Patidar, Scientist-C
	Co-PIs	Dr. Deepak Singh Bisht, Scientist-C Dr. M.K. Goel, Scientist-G Dr. T. Thomas, Scientist-F Dr. Sunil Gurrapu, Scientist-D Dr. Anupma Sharma, Scientist-G Dr. Surjeet Singh, Scientist-F

Type of study: Internal

Duration: two years (Oct 2023 – Sep 2025)

Background

The excessive groundwater withdrawal led by growing water demands has resulted in rapid and widespread groundwater declines in many parts of India. To manage water resources in a sustainable manner, comprehensive understanding of groundwater system is essential. Of particular importance are the understanding of recharge processes, quantification of recharge from various sources, such as rainfall and surface water bodies, assessment of the impacts of groundwater withdrawal, and understanding the exchange of fluxes between surface and subsurface hydrological systems.

Web-based Integrated catchment modelling System for Decision Making (WISDOM) is developed recently at NIH. For integrated hydrologic modelling a model, named "GEE-MODFLOW" is developed as a part of WISDOM for groundwater recharge estimation. Estimation of recharge requires simulation of both the surface and subsurface hydrological processes. The water that reaches to groundwater table, so called recharge, is an end result of various processes happening at surface/subsurface which are driven by various influxes, such as infiltration and irrigation, and outfluxes, such as root water uptake and soil evaporation. Therefore, in order to mimic all such processes, an integrated model is needed. The integrated GEE-MODFLOW model consists of various modules which simulate surface and sub-surface processes in unsaturated and saturated zones. The model has three simulation modules, namely Root Zone Flow (RZF), Unsaturated Zone Flow (UZF), and Groundwater Flow (GWF). During the development, the GEE-MODFLOW was tested in the Hindon river basin for groundwater recharge estimation. However, to ensure its applicability in other areas, a detailed testing and validation is required. Therefore, it is planned to test the GEE-MODFLOW model in other basins.

The current version of WISDOM has mainly two models, the RZF (developed at NIH) and MODFLOW (developed by USGS) which was developed to estimate groundwater recharge, although it estimates all other hydrological components, such as runoff, ET, soil moisture and streamflow. WISDOM have several advantages, such as easy-to-use and free access through web-browser. To extent its capability to model surface hydrology using state-of-the-art models, such Variable Infiltration Capacity (VIC) model, integration of a surface hydrologic model with MODFLOW is proposed. Further, inclusion of tools, like map creator, trend analysis, etc., would further enhance the utility of NIH_WISDOM.

Objectives

The main objective of the study is to enhance and test the NIH_WISDOM for integrated modelling. The specific objectives of the study are as follows:

I. Integration of surface hydrologic model in NIH_WISDOM

II. Development of tools for hydrologic analysis such as, map creator, trend analysis, etc.
III. Testing of developed models by comparing simulated groundwater recharge with CGWB's assessments in an alluvium aquifer.
IV. Application of NIH_WISDOM in a hard-rock area by developing equivalent porous media model.

Study area

Two basins/inter-basins will be identified for testing the GEE-MODFLOW model. An alluvium aquifer will be identified based on data availability, possibly in the Gangatic plain. Similarly, one basin/sub-basin will be identified in a hard-rock region where both the groundwater and streamflow data are available to test the model.

Methodology

The VIC model will be integrated with the MODFLOW model for integrated modelling. An interface for the integrated VIC-MODFLOW model will be developed and included in the NIH_WISDOM. The tools, such as map creator and trend analysis, will also be integrated in WISDOM using Python programs.

The NIH_WISDOM will be applied to an alluvium and a hard-rock area for estimating various hydrologic components, such as recharge, runoff, ET, streamflow, etc. In the hard-rock area, an equivalent porous media model will be developed by calibrating the GEE-MODFLOW/VIC-MODFLOW with the observed groundwater head. The simulated groundwater head, groundwater recharge and streamflow will be compared with observed data as procured by CGWB and CWC.

Action plan and timeline (quarter-wise from Oct 2023 to Sep 2025)

Work element	**Oct 2023-Jan 2024**	**Feb-May 2024**	**Jun-Sep 2024**	**Oct 2024-Jan 2025**	**Feb-May 2025**	**Jun-Sep 2025**
Development of VIC-MODFLOW						
Development of tools, such as map creator and trend analysis						
Application of WISDOM in alluvium aquifer						
Application of WISDOM in hard-rock aquifer						
Project report and research paper						

HYDROLOGICAL INVESTIGATION DIVISION

Scientific Manpower

S N	Name	Designation
1	Dr. S D Khobragade	Scientist G & Head
2	Dr. M S Rao	Scientist F
3	Dr. Soban S. Rawat	Scientist D
4	Dr. Santosh M. Pingale	Scientist D
5	Mrs. Anjali Bhagwat	Scientist C
6	Sri Rajeev Gupta	Scientist B
7	Sri V K Agarwal	PRA
8	Sri Vishal Gupta	SRA

APPROVED WORK PROGRAMME FOR 2022-23

S. N.	Project Title	Study Team	Duration	Status
INTERNAL STUDIES:				
1.	Assessment of dissolved radon concentration in groundwater of Uttarakhand	**Hukam Singh (PI),** M Someshwar Rao, Soban Singh Rawat, Vipin Agarwal	1 ¾ years (04/21-12/22)	Completed Study
2..	Assessment of the Possible Impact of Climate Change on Evapotranspiration for Different Climatic Regions Of India	**SD Khobragade (PI),** Dr. Vishal Singh, Sudhir Kumar	3 years (04/22-03/25)	On-Going Study
3.	Ascertaining the efficacy of use of State of the art technologies for spring mapping and sustainability of springs through suitable interventions	**Soban Singh Rawat, (PI)** Sudhir Kumar, Santosh M. Pingale, P K Mishra, D. S. Bisht, Rajesh Singh	3 years (04/22-03/25)	On-Going Study
SPONSORED PROJECTS:				
1.	Dating very old ground waters of deeper aquifers in Ganga Plains, India	**M. Someshwar Rao (PI)** Sudhir Kumar	3 Years (06/16 - 12/22)	Continuing Study IAEA under CRP
2.	Chemical & Isotopic Characterization of Deep Aquifer Groundwater of Middle Ganga Basin	**Sudhir Kumar (PI)** M. Someshwar Rao Vipin Aggarwal	3 ½ year (01/18 – 06/22)	Continuing Study NHP (PDS)
3.	Integrated Study on groundwater dynamics in the coastal aquifers of West Bengal for sustainable groundwater management	**M. S. Rao (PI),** Sudhir Kumar A. R. Senthil Kumar V. S. Jeyakanthan	3 ½year)01/ 18– 06/22(	Continuing Study NHP (PDS)
4.	Development of a comprehensive plan for conservation and sustainable management of Bhimtal and Naukuchiatal lakes, Uttarakhand	**Suhas Khobragade** (PI) Sudhir Kumar	3 Years)01/ 18– 06/22(	Continuing Study NHP (PDS)
5.	Groundwater Rejuvenation As Climate changE Resilience for marginalized and gender sensitive GangeS (GRACERS)	**Sudhir Kumar (PI)** SM Pingale	2 years (06/19 – 09/22)	Continuing Study (IIT Bombay, Mumbai)
6.	Web-GIS Based Spring Inventory for Vulnerability Assessment and Hydro-Geological Investigation of Selected Springs for Sustaining Local Water Demand in Ravi Catchment of Himachal Pradesh	**S S Rawat (PI)** Sudhir Kumar P G Jose, Suman Gurjar, D S Bisht	4 Years)08/17 – 09/22)	Continuing Study NHP (PDS)
7.	Web-enabled Inventory of Natural Water Springs of Tawi River Catchment of Jammu and Kashmir State of India for Vulnerability	**S S Rawat (PI)** P G Jose, Suman Gurjar, D S Bisht	3 Years)01/ 19– 09/22(	Continuing Study (NMHS)

S. N.	Project Title	Study Team	Duration	Status
	Analysis and Developing Adaptive Measures for Sustaining Tawi River			
8.	Leachate transport modelling for Gazipur landfill site for suggesting ameliorative measures	**Anjali (PI)** Sudhir Kumar, J. V. Tyagi M. K. Sharma Partner: CGWB (Delhi unit)	3½ years (11/19 – 06/23)	Continuing Study NHP (PDS) Transferred from EHD
9.	Changing the fate of the Hindon river by evaluating the impact of agriculture on the water balance: Developing a template for a cleaner Ganga river	**Sudhir Kumar,** (Proj. Coordinator), M. K. Sharma, (PI), Suhas Khobragade, Anjali, Vishal Singh, SM Pingale, Nitesh Patidar, Surjeet Singh.	5 Years)04/22 – 03/27(	DST

PROPOSED WORK PROGRAMME FOR THE YEAR 2023-24

S. N.	Project Title	Study Team	Duration	Status
INTERNAL STUDIES:				
1.	Assessment of the Possible Impact of Climate Change on Evapotranspiration for Different Climatic Regions Of India	**S.D.Khobragade (PI),** Dr. Vishal Singh, Sudhir Kumar	3 years (04/22-03/25)	**Continuing Study**
2.	Ascertaining the efficacy of use of State of the art technologies for spring mapping and sustainability of springs through suitable interventions	**Soban Singh Rawat, (PI)** Sudhir Kumar, Santosh M. Pingale, P K Mishra, D. S. Bisht, Rajesh Singh	3 years (04/22-03/25)	**Continuing Study**
3	Developing a Stable Isotopic Analysis System for analyzing the dissolved Nitrates in water	**M. S. Rao(PI)** Vishal Gupta	1 and ½ years (04/23-09/24)	**New Study**
4	Geo-Hydro-Chemical and Isotopic Aspects of Occurrence of Springs: A case study from the major settlement areas of Bhagirathi basin, Uttarakhand, India	**Dr. Soban Singh** Rawat, (PI) S. D. Khobragade M K Sharma, M S Rao, S.M. Pingale P. K. Mishra	3 years (04/23-03/26)	**New Study**
5	Feasibility of Open Sources Data for the Estimation of Runoff and Water Storage Capacity for Rainwater Harvesting Strategies	**S.M. Pingale(PI)** Soban Singh Rawat, S. D. Khobragade Rajeev Gupta	2 Years (04/23-03/25)	**New Study**
6	Sedimentation and Water Quality Studies of Phulahar Lake, Pilibhit (U.P.)	**Rajeev Gupta (PI)** S. D. Khobragade S.M. Pingale	2 Years (04/23-03/25)	**New Study**
SPONSORED PROJECTS:				
1.	Leachate transport modelling for Gazipur landfill site for suggesting ameliorative measures	**Anjali (PI)** Sudhir Kumar, J. V. Tyagi M. K. Sharma Partner: CGWB (Delhi unit)	3½ years (11/19 – 06/23)	Continuing Study NHP (PDS) Transferred from EHD
2.	Changing the fate of the Hindon river by evaluating the impact of agriculture on the water balance: Developing a template for a cleaner Ganga river	**Sudhir Kumar,** (Proj. Coordinator), M. K. Sharma, (PI), Suhas Khobragade, Anjali, Vishal Singh, SM Pingale, Nitesh Patidar, Surjeet Singh.	5 Years)04/22 – 03/27(	DST

ITEM NO. 53.2 ACTIONS TAKEN ON THE ADVICE / DECISIONS OF THE 52nd MEETING

The specific action taken on the advice/decision of the 51st meeting of Working Group of NIH are as follows:

SN	Project	Comments/ suggestions	Action Taken
INSTITUTE FUNDED R & D STUDIES			
1	Assessment of impact of land use and land cover change on groundwater conditions in parts of Sabarmati river Basin, Gujarat	Dropped	-
2	Integrated Hydrological Investigations of Renuka lake, Himachal Pradesh, for its Conservation and Management	Dropped	-
3	Assessment of dissolved radon concentration in groundwater of Uttarakhand	No Comments	-
4	Assessment of the Possible Impact of Climate Change on Evapotranspiration for Different Climatic Regions of India	No Comments	-
SPONSORED PROJECTS			
1.	Dating very old ground waters of deeper aquifers in Ganga Plains, India	No comments (Study was not presented)	--
2.	Chemical & Isotopic Characterization of Deep Aquifer Groundwater of Middle Ganga Basin	No comments (Study was not presented)	--
3.	Integrated Study on groundwater dynamics in the coastal aquifers of West Bengal for sustainable groundwater management	No comments (Study was not presented)	--
4.	Development of a comprehensive plan for conservation and sustainable management of Bhimtal and Naukuchiatal lakes, Uttarakhand	No comments (Study was not presented)	--
5.	Groundwater Rejuvenation As Climate changE Resilience for marginalized and gender sensitive GangeS (GRACERS)	No comments (Study was not presented)	--
6.	Web-GIS Based Spring Inventory for Vulnerability Assessment and Hydro-Geological Investigation of Selected Springs for Sustaining Local Water Demand in Ravi Catchment of Himachal Pradesh	No comments (Study was not presented)	--
7.	Web-enabled Inventory of Natural Water Springs of Tawi River Catchment of Jammu and Kashmir State of India for Vulnerability Analysis and Developing Adaptive Measures for Sustaining Tawi River	No comments	--
8.	Leachate transport modelling for Gazipur landfill site for suggesting ameliorative measures	No comments (Study was not presented)	
9.	Changing the fate of the Hindon river by evaluating the impact of agriculture on the water balance: Developing a template for a cleaner Ganga river	No comments (Study was not presented)	--

ITEM NO. 52.3 PROGRESS OF THE WORK PROGRAM OF THE DIVISION FOR THE YEAR 2022-23

As per the approved work program, the status of studies carried out in HI Division during 2022-23 is given below:

Type of study/Project	Completed during 2022-23	To continue in 2023-24	Total
Internal R & D Studies	01	02	03
Sponsored Projects	07	02	09
Total	08	04	12

Details of training Courses/Workshops organised by the Division during 2022-23

S. N.	Topic	Duration	Coordinator	Venue	No. of Participants
1	Scientific Data Collection and Processing Techniques for Springshed Management and Rejuvenation	19-22.12.2022	Dr. S. M. Pingale & Dr. S. S. Rawat	Irrigation Reserch Institute (IRI), Roorkee, Uttarakhand	24
2	Springshed Management	13-15.12.2022	Dr. S. S. Rawat	DoLR, Kohima, Nagaland	47
3	Scientific Data Collection and Techniques for Springshed Management and Rejuvenation	06-09.09.2022	Dr. S. S. Rawat	NEHARI, Guwahati	28
4	Tools and Techniques for Springshed Management	03.09.2022	Dr. S. S. Rawat	Govt Degree College, Udhampur. Jammu & Kashmir	80
5	Groundwater contaminant transport monitoring & modelling	23 to 27.05.2022		Online Under NHP – PDS - 19	40
6	Stakeholder Meeting Under DST-NWO Hindon Project	One Day on 15th Feburary,2023	Ms. Anjali,	c-Ganga office, New Delhi.	10

Details of samples analysed by the Division Laboratories during 2022-23:

S.N.	Parameter analysed	No. of samples
1.	δ^2H on DI-IRMS	4372
2.	$\delta^{18}O$ on DI-IRMS / CF-IRMS	3997
3.	Tritium	260
4.	WQ samples on IC	1465

Details of Research Publications by the Division during 2022-23

Research Publication	Published	Accepted	Communicated
Books/Book Chapter	-	-	-

International Journals	5	-	-
National Journals	-	-	-
International Conferences	2	-	-
National Conferences	2	-	-

Details of major instruments purchased by the Division & its labs during 2022-23

S.N.	Name of Instrument	Qty.	Cost (Rs.)
1	Multi-channel Gamma Ray Spectrometer with HPgE Detector –	01 No.	Rs. 60,37 Lakhs-

The progress of the various studies undertaken during 2022-23 is given below:

A. Internally Funded R & D Studies

1. PROJECT REFERENCE CODE: NIH/HID/R&D/2022/2

Study Title: **Ascertaining the Efficacy of Use of State of the Art Technologies for Spring Mapping and Sustainability of Springs through Suitable Interventions**

Study Team: S S Rawat (P.I.), Sudhir Kumar, Santosh M. Pingale, P K Mishra, D. S. Bisht and Rajesh Singh
Collaborating agencies: Central Ground Water Board (CGWB)
Type of Study: Internal
Duration of Study: 03 Years (July 2022 to June2025)

Study Area: The present study is being carried out for Bilangana and Pratapnagar CD blocks of Tehri Garhwal district and Ukhimath CD block of Rudraprayag district of Uttarakhand state of India

Objectives:

1. To physically validate the springs identified by SOI using state of the art technologies in Bilangana and Pratapnagar CD blocks of Tehri Garhwal district and Ukhimath CD block of Rudraprayag district,
2. To create web-based spring database & its regular updation,
3. To conduct water quality analysis of the surveyed springs to understand the qualitative status of the springs in the area,
4. To identify the vulnerable springs which needs to be revived, and
5. To develop the capacity of local stakeholders and implementing agencies for effective development and management of springshed programme

Progress:

1. Five Survey of India (SoI) toposheets have been digitalized and 75 springs have been identified (Fig. 1).
2. Different base maps such as Digital Elevation Map (DEM), Drainage Network, Topomaps etc has been prepared digital form for planning the survey of the springs emerging in Bhilangana block of Tehri Garhwal district.
3. A field visit was performed by the project team on 14-15.02.2023. Six springs have been geotagged, performed measurements of onsite physical parameters of springs, filled samples for detailed water quality and isotopic analysis.

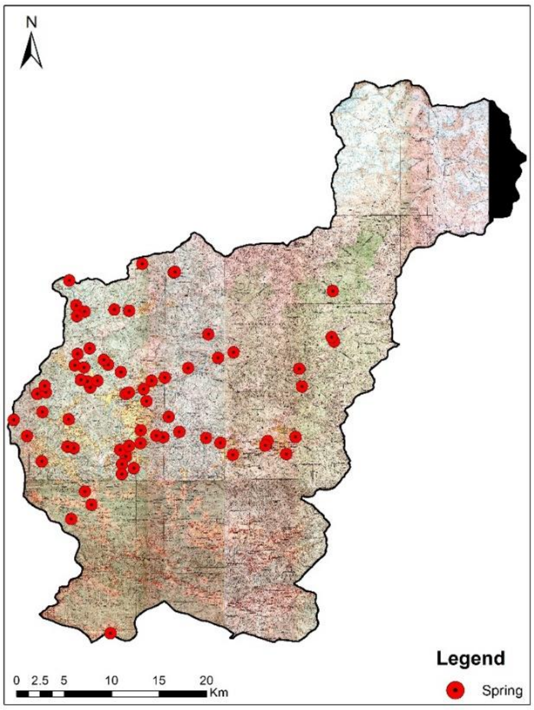


Fig. 1: Map of the Bhilanagana block of Tehri Garhwal district of Uttarakhand showing the Spring locations digitalized from SOI topo-sheets.

2. PROJECT REFERENCE CODE: NIH/HID/R&D/2022/1

Study Title:	**Assessment of the Possible Impact of Climate Change on Evapotranspiration for Different Climatic Regions of India**
Study Team:	SD Khobragade (PI), Dr. Vishal Singh, Scientist-C, Dr. Sudhir Kumar, Sc-G;
Type of Study:	Institute Funded R & D Study
Duration:	3 years
Date of Start:	April, 2022
Date of Completion:	March, 2025
Budget:	10 Lakh

Statement of Problem:

Evapotranspiration is one of the key components of the hydrologic cycle. Precipitation which falls on the land is subjected to evaporation and evapotranspiration before it reaches back to the oceans, causing a significant loss of the available water. Increasing scarcity of water due to increased ET losses may lead to difficulties in meeting the various demands of the growing population and its development needs. Most of the water bodies in the warm tropical regions undergo heavy evaporation losses. As per the CWC (2006) report, average annual evaporation loss from reservoirs/water bodies in India is about 27,000 MCM. As such, any change in evapotranspiration is likely to significantly affect the global hydrologic as well as energy cycle (IPCC, 2013). Being a cause of significant water loss, evapotranspiration plays a major role in determining the stream flow regime. Therefore, understanding the impact of temperature rise or climate change on evapotranspiration is essential for a proper understanding of the impact of climate change on the hydrological regime of the stream and water availability in the basin or water body. It shall provide a proper assessment of how much more or less water shall be available and, if less water is available, then how much additional water shall be required to meet the various demands. Unfortunately, not many studies have been reported on assessment of impact of climate change on evaporation and Evapotranspiration, more so for India.

Objectives:

The major objectives of the proposed study are: ·

i) To assess the present ET regime of some selected climatic regions of India
ii) To assess the impact of rising temperature on various hydro-meteorological parameters used for ET assessment
iii) To predict and compare the possible impact of climate change on ET regimes of the selected climatic regions of India

Study Area

The study is proposed to be carried out for different climatic regions of India. About five areas are to be identified to represent different climatic regions.

Brief Methodology

i) The present average ET rates for selected climatic regions of India shall be estimated from the present hydro-meteorological data of last few decades, using the Penman-Monteith model
ii) All temperature dependent hydro-meteorological paramours shall be identified.
iii) Projected climatic data variables such as minimum and maximum temperature from the latest GCMs developed under CMIP6 project shall be obtained to analyze the impact of climate change on ET factors.
iv) For this purpose, the evaluation of four best GCMs with SSP245 and SSP585 scenarios
v) (total eight scenarios) will be done for selected climatic regions and then the bias

correction and spatial downscaling of the GCM variables will be performed for selected climatic regions of India.

vi) The downscaled and bias corrected GCM variables shall be used as input to the Penman-Monteith model and future changes in ET rates will be estimated by performing probabilistic linear and non-linear trends analysis (e.g. Quantile regression, Q-Q plots, and CDF).

vii) The present and projected ET rates shall be compared to assess the impact of climate change on ET variability (in terms of magnitude of change) for different regions.

viii) The present and predicted rates of different climatic regions shall be compared and factors responsible variation shall be identified

The progress of the study shall be discussed during the WG meeting.

3. PROJECT REFERENCE CODE: NIH/HID/R&D/2021/2

Study Title:	**ASSESSMENT OF DISSOLVED RADON CONCENTRATION IN GROUNDWATER OF UTTARAKHAND**
Study team:	Hukam Singh (PI), M Someshwar Rao, Soban Singh Rawat, Vipin Agarwal
Collaborating agencies:	CGWB, Dehradun
Type of Study:	MoU with CGWB
Funding Agency:	Internal Funding
Budget:	Rs. 4.00 Lakh
Duration:	One Year Nine Months (April 2021 to December 2022)

Objectives:

Mapping the spatial distribution of radon levels in groundwater in Uttarakhand.

Study Area:

The study has been carried out for Haridwar and Dehradun districts of Uttarakhand.

Methodology:

In order to study the radon contamination in the study area at different locations, groundwater samples for pre and post monsoon seasons have been collected for in-situ radon measurement for studying the spatial and temporal variation of radon concentration.

Progress of Work/Results and Analysis:

Samples have been collected from 29 locations in the Haridwar and Dehradun districts of Uttarakhand. These samples have been analyzed in the Institute Lab. The study has been completed and draft final report has been submitted. The results and inferences shall be presented in the working group meeting. results will be presented in the WG meeting.

B. Sponsored Projects

1. PROJECT REFERENCE CODE: NIH-26_2017_62

Study Title **Chemical & Isotopic Characterization of Deep Aquifer Groundwater of Middle Ganga Basin**

Project Team: Dr Sudhir Kumar (PI)
Dr M Someshwar Rao (Co-PI)
Sh. Vipin Agrawal
Sh. Vishal Gupta

Budget: 55.40 Lakhs **(PDS: NIH)**

Project Duration: Jan 2018-Jan 2023

Statement of the problem

Uttar Pradesh is one of the most populous states in the country. The population of the state in the last two decades has increased from 16.62 crores to 23.5 crores. Agriculture is the largest source of economy in the state. Approximately 68.7% of the land is used for cultivation. The volume of food grain production in the state in the last two decades has increased from 42.75 MT (2001) to 54.64 MT (2019). To keep pace with the growing population and food production the water demand in the state is steeply increasing. In the case of groundwater resources, in the year 2000, the groundwater exploitation was 54.31% which increased to 73.78% in 2013. The state supplies 13 billion liters of water every day under drinking water schemes. Along with urbanization, solid and liquid waste is also increasing. The state generates more than 19.2 million tons per day of municipal solid waste, of this, only 5.2 million tons get treated. Untreated waste is contaminating the environment including water resources directly or indirectly. As a result, the freshwater resource is shrinking both due to excessive use and quality deterioration. Further, climate change is disrupting the rainfall pattern which is also aggravating the water demand. Keeping these aspects into consideration, the present project is taken up with the objective to assess the availability of freshwater resources and to identify the possible solutions to augment it for its sustainability. The specific objectives of the project are:

i. Long-term change in groundwater conditions
ii. Identification of groundwater recharge sources
iii. Water quality of deep & shallow groundwater
iv. Measures for the sustainability of groundwater resource

Study area:
The study area includes 27 districts of Uttar Pradesh (UP), India, enclosed between the river Ganga in the south, and the rivers Sharda and Ghaghara in the north, and covers 95,100 km^2 geographical area.

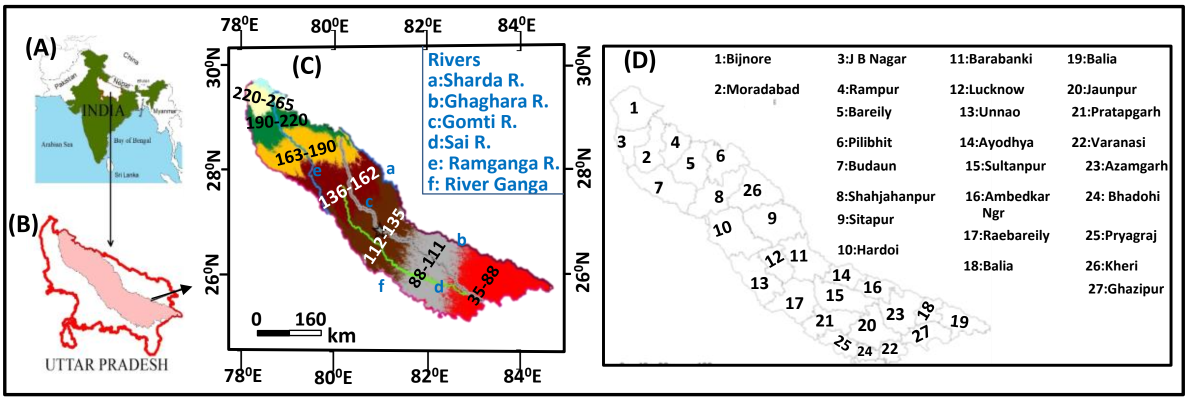


Fig: Study area. A:Location of Uttar Pradesh (UP) in India. (B) Study area in UP (C) DEM and major rivers in the study area (D) District administrative boundary and the district names in the study area.

Methodology: To understand the genesis of water quality, its evolution, and its hazards, multi-depth groundwater samples were collected, measured for the major ions and heavy metals, and analyzed using various hydro-statistical methods. To estimate the groundwater's annual turnover time and the groundwater's source of recharge, the stable isotopic composition, and environmental tritium in the groundwater were measured and analyzed by examining the spatial variation pattern. To investigate the climate change in the study area and its impact on the water resource, decadal-scale rainfall, temperature, and groundwater level data were downloaded and analyzed to decipher long-term trends in groundwater level, temperature (minimum, maximum, and average) patterns, rainfall, and drought indexing. Further, a correlation was examined between groundwater level and the climate parameters (rainfall and temperature). Finally, for the augmentation of groundwater resources, potential groundwater recharge zones were mapped, and the locations for artificial recharge measures were identified. The overall scheme of analysis is shown in the figure below:

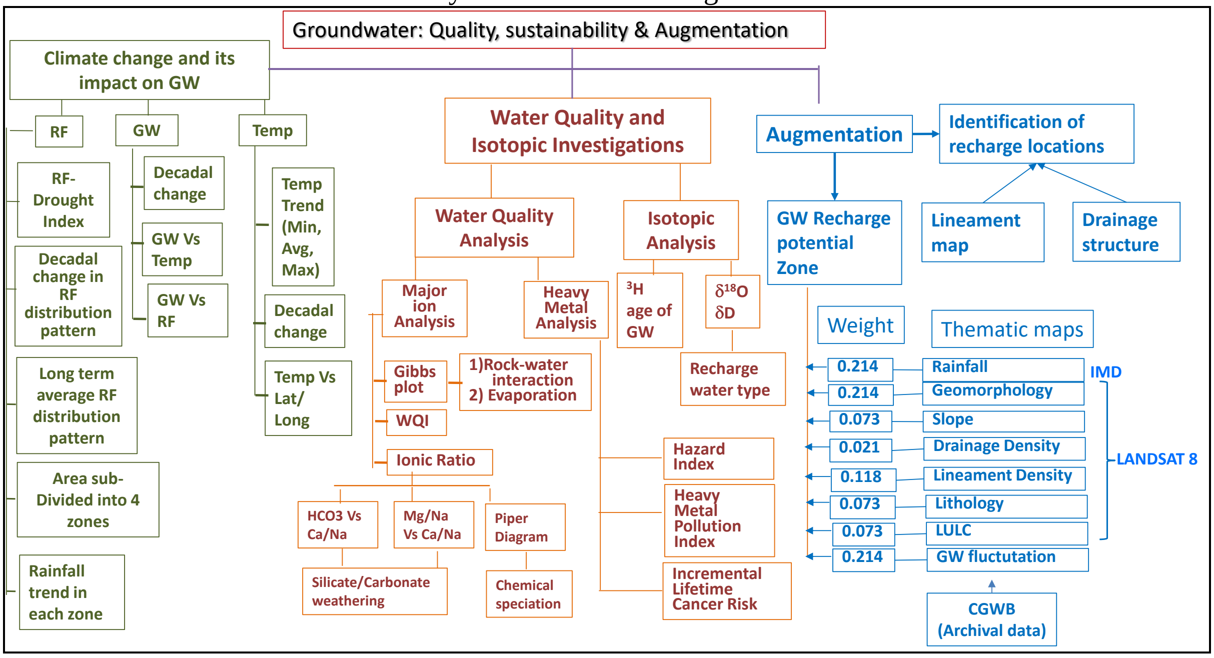


Fig: Flow chart of the project planning and the work elements

Results:

Groundwater Quality Analysis:

Hydro-chemical speciation: The Piper plot shows, 85% of groundwater (shallow and deep) is of Ca^{2+} -Mg^{2+} -HCO_3^- type and Ca^{2+} - HCO_3^- type, and the remaining groundwater is Ca^{2+}-Mg^{2+} -Cl^-, and Na^+ -K^+ –HCO_3^- type. Further, the ionic ratio plot between Mg/Na and Ca/Na indicated that >90% of deep groundwater and about 70% of shallow groundwater is formed from carbonate weathering.

Relationship of water composition and aquifer lithological characteristics: The Gibbs plot shows that 80% of groundwater is evolved through rock-water interaction and the remaining 20% through evaporation or a combination of rock-water and evaporation process.

Groundwater suitability for irrigation: Wilcox's diagram, Permeability Index, and Magnesium Hazard estimations show that more than 90% of groundwater falls in the good to excellent category for irrigation use.

Groundwater suitability for drinking needs: Analysis of groundwater for Water Quality Index (WQI) has shown that 74% area (~71,084 km^2) is of excellent quality, while very poor to unsuitable quality is distributed in small pockets in the North and southwest regions covering an area of 2795 km^2.

Correlation between water quality parameters: Water quality parameters have shown a high positive correlation (>0.78) between Na^{2+} & SO_4^{2-}, Cl^- & Na^+, Cl^- & Mg^{+2}, NO_3^- & Cl^-, δ^{18}**O &** δD, and Mg^{+2} & Na^+. The poor water quality for drinking is mainly due to fluoride in groundwater.

Heavy Metal Pollution Index: Based on the heavy metal pollution index (HPI) it is inferred that 10% of the area (~9590 km^2) is affected by heavy metal contamination, mainly due to the dissolved Al, Mn, and Fe in groundwater. The cancerous risk (*Incremental Lifetime Cancer Risk*) from heavy metals contamination is less than the critical limit of 10^{-4} for both adults and children.

Climate change in the study area:

Drought & Wet Cycles: The climate change in the study area into normal/drought/wet patterns over the past three decades (1991-2020) is analyzed using Rainfall Anomaly Index (RAI) and the Rainfall Deviation Percentage (D%)

From the distribution of extreme RAI values, it is concluded that the south-eastern region is vulnerable to frequent draughts and wet periods, the north-western region is vulnerable to extreme wet (rainfall) years, and the central region is fairly normal for wet years but prone to moderate draughts.

The spatial distribution map of deviation percentage (D%) from normal precipitation also provided a pattern similar to that observed from RAI. A striking feature that is seen in the D% distribution map is the deficient rainfall region that is distributed over a 50-km width along the river Ganga. This region has received deficient rain spells for more than 7 years during 1991-2020.

For further examining the change in the rainfall pattern, a comparative distribution map of the decadal average rainfall distribution pattern is prepared for the periods 1991–2000, 2001–2010, and 2011–2020. The map in general shows higher rainfall in the northwest region compared to the southeast region. But, more importantly, it shows a major dry period that spread over a large region in the south-eastern zone during 2001–2010. In 2011–20, this area that was covered under the dry zone decreased in its spatial coverage and appeared in the west-central region.

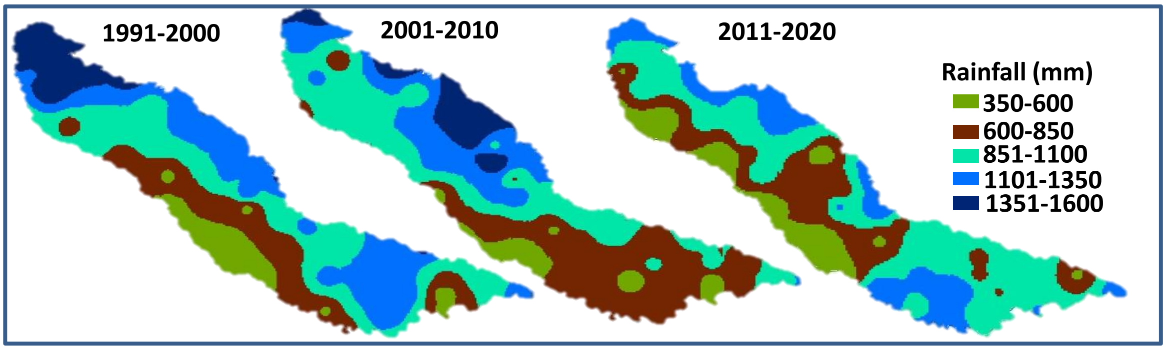
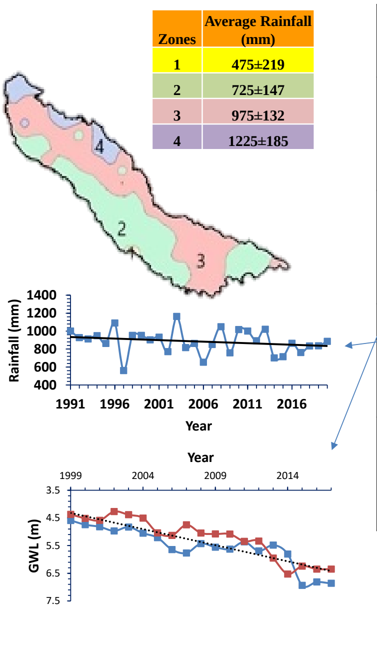


Fig: Decadal average rainfall distribution pattern for the periods 1991-2000, 2001-2010 and 2011-2020

In order to examine temporal variation of rainfall, the rainfall distribution pattern for 3 decades average is prepared and is divided into 4 zones. For each of these zones, rainfall trends and groundwater level trends (pre- and post-monsoon) have been analyzed. In most of the zones, it is observed that independent of the rainfall trend, whether increasing (zone 2), decreasing (zone 3) or being constant (zone 4), the pre- and post-monsoon groundwater level trend always showed a falling trend. Thus, it is clear from the study that the groundwater in the study area is constantly depleting almost the entire study area.



Zone	Rainfall (in % normal (PN)) vs time Year: 1991-2020	Post-monsoon GW level Vs Time Year: 1998 to 2018	Pre-monsoon GW level vs time Year: 1998 to 2018
1	$RF_{(in\ PN)}$ =0.779$Year_{(xxxx)}$-1461 Trend: Increasing In 1991: 89 %Normal In 2020:111 %Normal Sen's Slope: 2.1	$GWL_{(in\ m)}$ =-0.01$Year_{(xxxx)}$ +26.72 Trend: Rising In 1998: 4.7 m BGL In 2018: 4.5 m BGL	$GWL_{(in\ m)}$ = 0.029$Year_{(xxxx)}$-52.36 Trend: Falling In 1998: 4.78 m BGL In 2018: 5.36 m BGL
2	$RF_{(in\ PN)}$ =0.215$Year_{(xxxx)}$-331 Trend: Increasing RF in 1991: 96 %Normal RF in 2020: 103 %Normal Sen's Slope: 0.5	$GWL_{(in\ m)}$ =0.135$Year_{(xxxx)}$ -265.5 Trend: Falling In 1998: 4.23 m BGL In 2018: 6.9 m BGL	$GWL_{(in\ m)}$ =0.127$Year_{(xxxx)}$ -248.6 Trend: Falling In 1998: 4.36 m BGL In 2018: 6.9 m BGL
3	$RF_{(in\ PN)}$ =0.215$Year_{(xxxx)}$-331 Trend: Decreasing RF in 1991:105 %Normal RF in 2020:94 %Normal Sen's Slope: -0.5	$GWL_{(in\ m)}$ =0.123$Year_{(xxxx)}$ -241.1 Trend: Falling In 1998: 3.9 m BGL In 2018: 6.33 m BGL	$GWL_{(in\ m)}$ =0.11$Year_{(xxxx)}$ -216.1 Trend: Falling In 1998: 4.51 m BGL In 2018: 6.7 m BGL
4	$RF_{(in\ PN)}$ =0.215$Year_{(xxxx)}$-331 Trend: No change RF in 1991: 193.5 %Normal RF in 2020: 194.2 %Normal Sen's Slope: 0.4	$GWL_{(in\ m)}$ =0.14$Year_{(xxxx)}$ -275.0 Trend: Falling In 1998: 4.3 m BGL In 2018: 7.1 m BGL	$GWL_{(in\ m)}$ =0.105$Year_{(xxxx)}$ -204.62 Trend: Falling In 1998: 4.57 m BGL In 2018: 6.7 m BGL

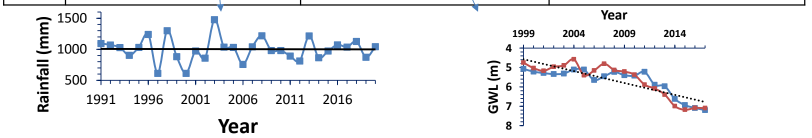


Fig: Long-term trend of rainfall and groundwater level in the study area. On the basis of long-term rainfall (1991-2020), the study area is divided into 4 zones (Low (475±219 mm), Moderate (725±147 mm), High (975±132 mm), and Very High (1225±185 mm). Trend equations for rainfall and groundwater level (pre- and post-monsoon) in each of this zone are shown in the table. For illustration, data plots for rainfall and post-monsoon period for zone no. 3 & 4 are shown.

It is known that the global temperature is rising at the decadal scale, and also that the temperature has a direct influence on the rainfall, and evapotranspiration. Considering this, the decadal temperature pattern of the study area is analyzed. The long-term average temperature distribution pattern increase of temperature increases along the NW-SE direction. At the decadal scale, the temperature minimum is rising at the rate of 0.16^{0}C/decade whereas, the temperature maximum is decreasing at the rate of 0.04^{0}C/decade. Since the spatial distribution pattern of average temperature shows a systematic geographical variation, equations were developed for the estimation of minimum and maximum temperature using geographical coordinates, and these are given below:

$$T_{min} = 35.28 - 0.38xLat-0.078xLong$$
$$T_{max}=78.41-0.95xLat-0.26xLong$$

Isotopic Analysis:
The isotopic composition of groundwater (at shallow and deep depths) in the study area is observed to get enriched in its isotopic composition constantly with the progressive distance away from the foot-hill zone of the Shiwalik range. This is similar to the general observation of depleting rainfall isotopic composition with the progressive rainout process as the clouds move towards mountains from the moisture source region. On this basis, it is inferred that local rainfall is the major source for groundwater (shallow and deep depths) of this region. This enrichment in isotopic composition stopped just before the central region (Lucknow district) from where onward depletion in the isotopic composition of groundwater (shallow and deep depths) started indicating the additional source of groundwater recharge of depleted isotopic composition. The study area, which extends beyond the central region (Lucknow district) to the southeast tail end, is covered by a dense network of canals that carry the water of depleted isotopic composition. Thus, isotopic composition indicated the canal as the major source (in addition to the rainwater) of recharge to the groundwater in the southeast zone of the study area.

It is further seen that the isotopic composition of the shallow aquifer in general shows more fluctuations than that of the deep aquifer. Such large fluctuations in the isotopic composition suggest that the shallow aquifer is getting recharged at multiple locations along its pathways by the water of different isotopic compositions arising from different water sources, such as highly depleted water (canal water), moderately enriched water (rainwater), and highly enriched water (municipal wastewater), etc. To a lesser extent, the deeper aquifer also exhibited such fluctuations, indicating its interaction with the overlying aquifer. This indicates that the deep aquifers of the region are of the semi-confined type, and the shallow aquifers are semi-confined to unconfined in nature. This conclusion was further confirmed through EC analysis and groundwater dating. The intercomparison EC of shallow and deep aquifers also exhibited a similar pattern to that of the isotopic pattern of shallow and deep aquifers. The tritium-based median age of the shallow aquifer groundwater was observed to be 23 years, and that for the deep aquifer, ~30 years. Through multi-technique investigations, it is concluded that from Shiwalik foot-hills to the central part of the study area (Lucknow district) rainfall is the major source of recharge to groundwater, and beyond this, canal water is also equally important contributing recharge source to the groundwater. The shallow groundwater is of the semi-confined to unconfined type and, hence, is getting recharged from different surface water sources along its pathway in addition to the rainfall as the major source. The deep groundwater is of the semiconfined type and is receiving recharge from the overlying aquifer in most of the study area.

Potential Groundwater Recharge Zones:

The groundwater recharge potential zone of the study area is mapped by integrating 8 thematic maps (rainfall, geomorphology, slope, drainage density, lineament density, lithology, LULC, and groundwater fluctuation) using the Analytical Hierarchical Process. The potential recharge zone map prepared using this method shows high groundwater potential in the NW-N region and poor potential in the SE-S region. With respect to population, the NW-N zone has a low population, whereas the SE-S zone is highly populated. Therefore, the SE-S zone is highly vulnerable to groundwater availability and needs suitable management measures for groundwater augmentation. Overall, 12% of the area is covered by the high potential groundwater recharge zone, 29% of the area is covered by the moderate potential zone, and 58% of the area is covered by the low potential groundwater recharge zone.

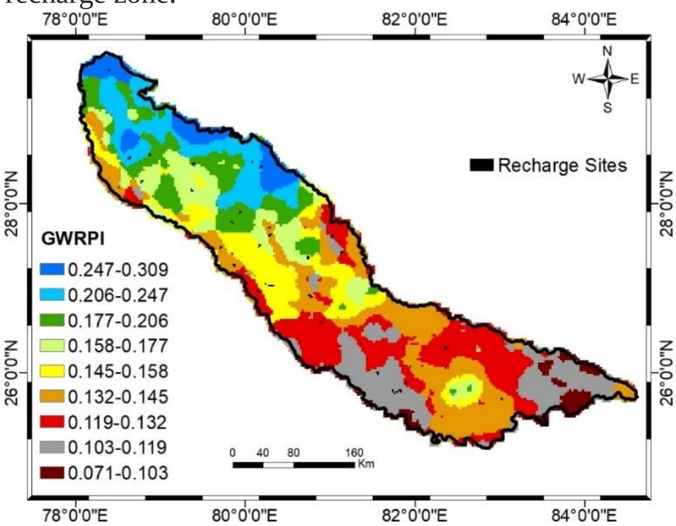


Fig: Spatial distribution of Groundwater Recharge Potential Index (GWRPI) and the identified recharge sites in the study area. The map is prepared by integrating 8 thematic maps using the AHP method of analysis. The area can be categorized into three categories of Groundwater Recharge Potential Zones (GWRPZ) as High GWRPZ: for GWRPI >0.2, Moderate GWRPZ: for GWRPI in the range 0.14 to 0.2, and Low GWRPZ: for GWRPI <0.2.

Outcome:

- Analysis of rainfall data has shown that the part of the region covered under 50 km width along the river Ganga is susceptible to frequent droughts, the southeastern zone of the study area is vulnerable to both drought and wet rainfalls, and the northeastern zone is vulnerable to extreme rainfall events. Rainfall Anomaly Index and Deviation percentage (D%) although use different equations and parameters to analyze the rainfall data, provided the same results.
- Since the rainfall and temperature contours systematically increase/decrease along the SE-NW direction, the average variation of these climate parameters were expressed using the mathematical equation in terms of local geographical coordinates.

- Long-term average annual minimum temperature is observed to rising at the rate of 0.018^0C per year. But no such change is observed for the annual average maximum temperature.
- Groundwater in the entire study area is depleting at the rate of 10 cm annually.
- Water quality analysis has shown the quality of groundwater good for drinking needs in 75% of the area and good for irrigation needs in 90% of the area.
- The major source of recharge to groundwater is rainfall in the upper (northwest) half zone and the combination of canal and rainfall in the lower (southeast) half zone
- High fluctuating water quality of shallow groundwater is due to its semi-continuous recharge from surface water sources all along its flow path whereas, such sharp fluctuations are not observed in the deep aquifer as it is getting recharged at a low rate from the overlying aquifer. Thus, the deeper aquifers of the study area are semi-confined in nature and are vulnerable to contamination to a certain extent due to possible contamination from the recharge from the overlying aquifers.
- For groundwater augmentation purposes, 92 locations for artificial recharge sites were identified.
- Since the report is based on field data the outcome of the report can be used in protecting the groundwater resources from contamination, and its augmentation using suitable recharge measures at the suggested sites. The report is useful to field agencies as well as to researchers working in similar fields in other geographical areas.

2. **PROJECT CODE: NHP-NIH-22_2017_38**

Study Title	**Integrated Study on Groundwater Dynamics in the Coastal Aquifers of West Bengal for Sustainable Groundwater Management**
Study Team:	Dr Sudhir Kumar (PI) Dr M Someshwar Rao (Co-PI) Sh Vipin Agrawal Sh Vishal Gupta
Budget:	55.40 Lakhs (NIH PDS)
Project Duration:	Jan 2018-Jan 2023

Statement of the problem

The deltaic fan of West Bengal resulted from the active sedimentation by sediment deposition by the distributaries of the river Ganga at the region of their discharge into the Bay of Bengal. In the tidally active deltaic zone, these distributaries bring seawater to inland areas during high tides and discharge freshwater from the inland rivers to the sea during low tides. The deltaic zone is hydro geologically an active zone due to the active process of sedimentation, moderation of the river morphological conditions due to developments of barrages constructions, diversions on the upstream zones, infrastructural developments on the river waterways, construction of coastal bunds and groynes, land reclamation for cultivation purposes, changing land use pattern to accommodate the urban sprawl, industrial expansion, power plants, harbors and ports, flood control measures, etc. These changes are modifying seawater-groundwater interaction conditions, increasing groundwater withdrawals, and also increasing the pollution of freshwater resources in the deltaic region. Keeping these aspects into consideration, the present project is taken up with the objective to assess the availability of freshwater resources and to identify the possible solutions to augment it for its sustainability. The specific objectives of the project are:

i. Identification of groundwater recharge sources
ii. Water quality of deep & shallow groundwater
iii. Vulnerability of groundwater due to salinity
iv. Groundwater management

Study Area:

The coastal deltaic zone of West Bengal has been distributed among the five coastal districts of Howrah, North 24 Paragana, South 24 Paragana, Purba Medinipur, and Paschim Medinipur; and Kolkata Municipal Corporation (KMC), covering a total area of 26,500 km^2 (**Fig 1**). The area is drained by eight rivers (Subarnarekha, Pichhabani, Rasulpur, Haldia, Rupnarayan, Hugli, Kulti, and Ichhamati), in addition to tidal streams and canals of the region. The three watersheds Rupnarayan, Haldia, and Kulti together constitute 52% of the study area.

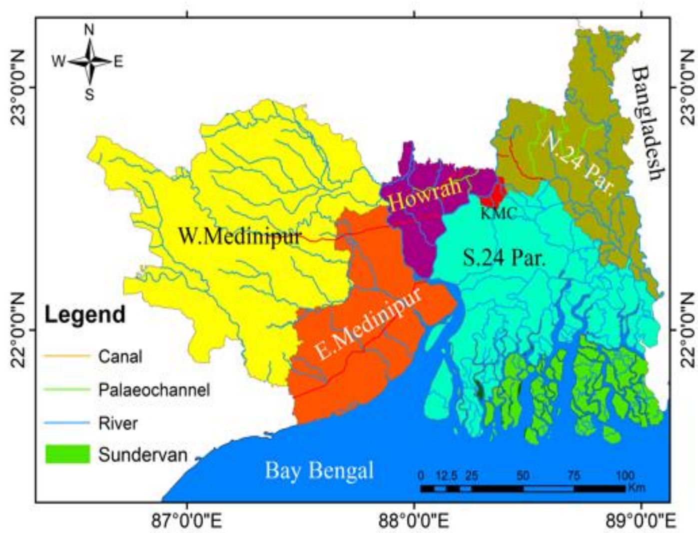


Fig 1: The study area that constitutes the five coastal districts (i)West Medinipur, (ii) East Medinipur, (iii) North 24 Parganas, (iv) South 24 Parganas and (v) Howrah, and KMC (the Kolkata Muncipal Corporation)

Methodology:

The methodology of the study involves the assessment of hydrologically vulnerable zones of the study area and the causative factors for the vulnerability, identification of the source of recharge to groundwater, and management measures for groundwater augmentation and sustainability. To assess the impact of rainfall variability on water resources, rainfall data for the past 26 years is collated and analyzed. In order to examine the impact of guiding parameters causing the change in the groundwater condition, decadal changes in the groundwater pattern are examined. Since fulfilling the demand for drinking water is the ultimate priority in the water sector, the population growth and its distribution pattern in the study area are evaluated. Also, since water contamination is directly linked with human health, and the use of contaminated and saline water in irrigation can reduce agricultural yields, the water quality of the study area is assessed with respect to the drinking water and irrigation water quality norms. Since the area is located along the coastline, degradation of soil and water due to salinization are the basic problems in this area. The major drivers for the salinization are sea-level rise and saline water inflows inland through tidal waves. In the present study, the rate of increase of sea level and the tidally-influenced inland area is mapped. For the purpose of augmentation and management measures, the sources of recharge to the groundwater are identified using isotopic methods, and the potential groundwater recharge zones are identified using remote sensing and GIS methods. The overall scheme of analysis is shown in Fig 2.

Results –

a) Long-term rainfall and groundwater level pattern:

The analysis of the past 26 years (1993–2018) of the rainfall and groundwater level data has shown that during this period, the study area received an annual average rainfall of 1728.4 mm. The driest year during this 26-year period was 2012 (rainfall of 905.64 mm), and the wettest rainy years were 1999 and 2014 when 2089.7 mm of rainfall occurred. Excluding these extreme (dry and wet) years, the average rainfall for the 26-year period is estimated as 1740±165 mm. The region experienced a major fluctuation in the rainfall pattern during 2008-2013 (Fig 3). During 2007-2012, the rainfall steadily decreased from 2008 mm and reached 905.6 mm and then rapidly increased and reached 1969 mm in 2013. That is an overall change of more than 100% between 2012 and 2013. The spatial distribution pattern of rainfall, in general shows, a high rainfall zone distributed over South 24 Pargana and East Medinipur, and a low rainfall zone distributed over the north-western parts of the study area.

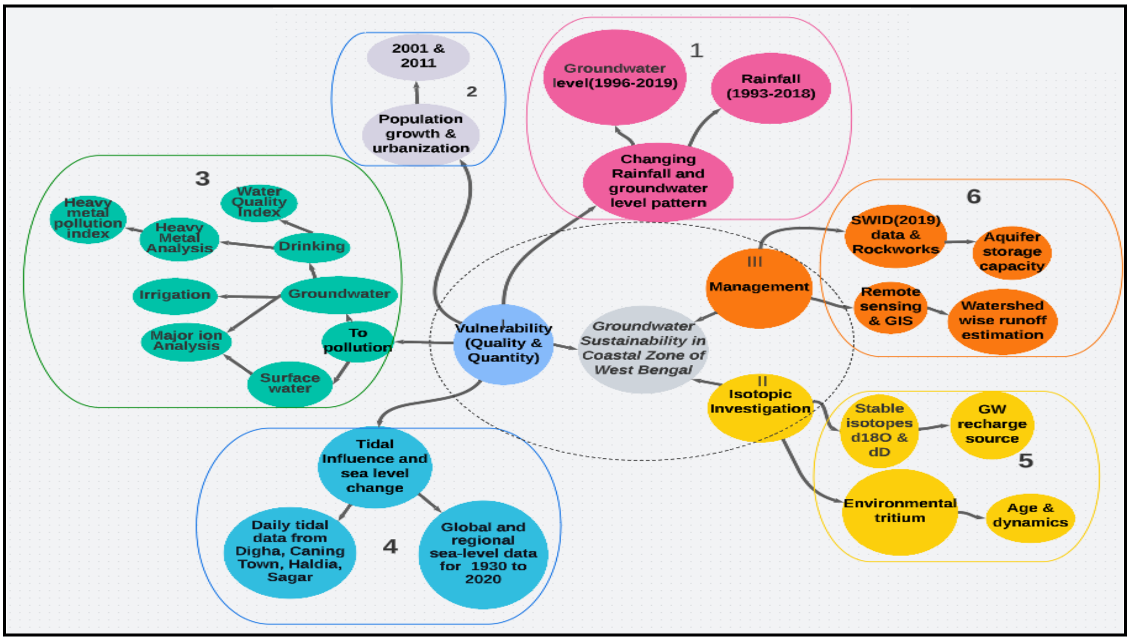


Fig 2: Scheme of project planning and its work elements

The groundwater level in the study area exhibited a general pattern of the declining level at the rate of 0.34 m/year with a broad snag structure during the period from 2007 to 2010 and a major trough in 2013. However, no such trend in the rainfall pattern is observed. The continuous depletion in groundwater level is an alarming condition, as the falling of water level below a critical limit may cause a reversal of the hydraulic gradient leading to the accelerated intrusion of seawater making it difficult to freshen the groundwater resource thereafter. Thus, the area is susceptible to seawater intrusion if the falling groundwater levels are not brought to an end.

b) Population: -

With the increase in population, the demand for clean water also increases. To examine the increasing demand with the growing population, the population density distribution of the region is analyzed using census data of the years 2001 and 2011. The average population density of the study area in West Bengal is 1,269 persons per sq. km (census 2011). During the period from 2001-11 population density increased mainly in the northern portion of the South 24 Pargana district and in the western parts of the Howrah district. Therefore, in the near future, the demand for drinking water may increase substantially in this part of the study area, which is difficult to substantiate for the supply of potable water, as this part of the study area falls under the tidal-influenced zone, and the groundwater is vulnerable to salinization if it is overdrawn.

c) River-water Quality:

Saline water influx through tidal inflows, inundation of low-lying areas during storms, evaporation of flood water leading to soil salinization, and infiltration of saline water or leaching of salts through the infiltrating water during monsoon periods causing groundwater salinization are the common hydrological features and the hydrological issues of the coastal zone. Since tidal water is the major cause of salinization of soil and water (groundwater), the change in the salinity of tidal water in the last decade is examined using the data of the West Bengal Pollution Control Board (WB PCB, Govt of West Bengal).

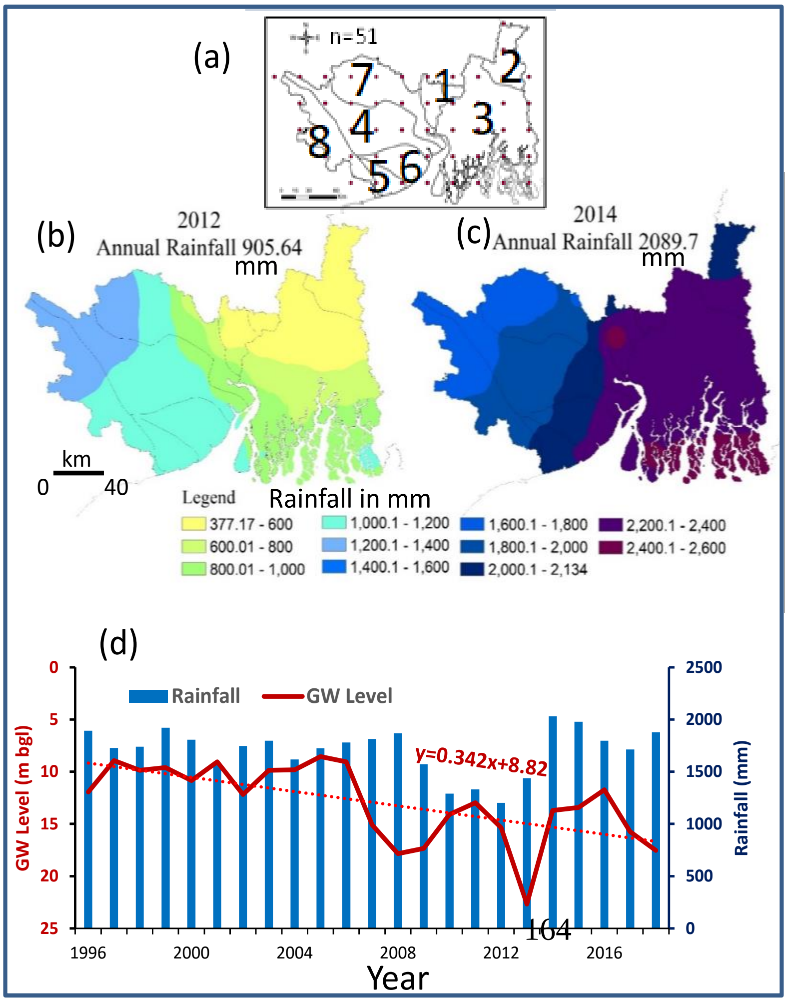


Fig 3: Rainfall and groundwater level in the study area. (a) Grid point map of rainfall data along with 8 numbers of watersheds numbered as: 1 - Damodar & Saraswati, 2- Jamuna Ichhamati,3- Tidal Streams,4 - Kasai-Haldi,5- Pichhabani,6 –Rasulpur,7 – Rupnarayan, 8- Subarnarekha.
(b) & (c) Rainfall shows the distribution pattern for the driest year 2012 and the wettest year 2014. (d) Comparison of rainfall and groundwater levels for the period from 1996 to 2018. For preparing the rainfall bar chart two years of moving average data is used.

The plot of salinity change with time indicated a general pattern of decrease in the salinity in almost all the streams. A few streams anomalously showed an abrupt increase in the salinity in the year 2016, and thereafter followed a general trend of decrease in the salinity. Depending upon the initial salinity values (in the year 2011), over the decade period, the salinity of these tidal streams decreased by 5-66 % of their initial value. Thus, the data shows a decrease in seawater inflows in these tidal streams and thereby freshening of these streams. New storage structures in the upstream region may also contribute to increasing water availability and maintaining the minimum flow requirements in the streams, thereby improving the water resources of the region.

d) Daily tides and long-term changes in sea level:

The average global sea level is rising at a constant rate of approximately 3.4 mm per year, which is primarily controlled by climate forcing. The rise of sea level causes the permanent submergence of coastal land. In contrast to this, the tidal waves operate on the time scale of the semi-diurnal, diurnal, and synodic cycles of the moon. The tidal wave amplitudes (difference between low and high tide) can vary over a range from a few centimeters to several meters, and the magnitude of this depends on the gravitational forces of the sun and moon, local geomorphic features, and coastline geometry. Depending upon the tidal wave height and the local geomorphology, the tides can bring seawater several kilometers into the interior of the inland through its tidal creeks and streams. (Figure 4)

In the present study, the daily tidal data is collected from four sites: Digha, Caning Town, Haldia, and Sagar, and for analysing the long-term sea-level rise, the sea-level data for the period 1930–2020 is collected from four locations (Haldia, Sagar, Garden Reach, and Hiron (Bangladesh)) from the public domain site (psmsl.org).

The average tidal wave in the study area is observed to have fluctuated (difference between minimum and maximum water level) in the range of 5 meters. The tidal trend is observed to be diurnal, following the cycle of the lunar phases. The inflow of marine water into inland areas due to the tidal effect has covered a maximum length of 120 km from the sea coast and covered an entire North and South 24 Pargana districts, Howrah district, and a major portion of the East Medinipur district.

The sea level trend exhibited the highest increase in the sea level at the Garden Reach site, with a maximum rise of 500 mm during 1972–1978, and an average sea level rise of 4.23 mm/yr during the period 1932-2018. At all the other sites, the rise in sea level from 1970 to 2020 was at a rate of 2.7 mm per year**.**

Since the tidal waves are affecting more than 60% of the study area, the impact of tides on soil salinization and groundwater salinization appears to be more effective than that getting caused due to due sea level rise. Therefore, measures to control the tidal wave effect on the salinization of soil and water need to be taken on a priority basis.

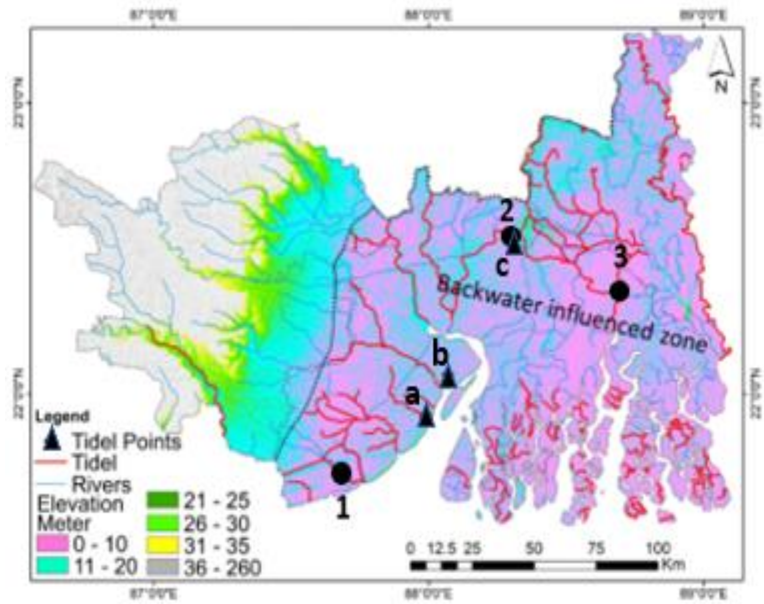


Figure 4: Influence zone of backwater shown in red colour lines with elevation less than 10m. Tidal data was collected from three sites: a-Pichhabani River, Contai, East Medinipur;, and, b- Hoogli (Ganga) river, Bichali Ghat, Howrah**, c-** Matla river, Canning Town, South 24 Pargana.

1,2 and 3 are the location points of samples collected for water quality and isotopic investigation

e) Groundwater Quality:
For groundwater suitability for drinking and irrigation purposes, 400 samples of groundwater quality data (the data of this study plus the data published by CGWB) were analyzed for EC, pH, major-ions (Na^+, Ca^{2+}, Mg^{+2}, K^+, SO_4^{2-}, Cl^-, NO_3, HCO_3^-), and heavy metal (Al, Mn, As, Pb, Fe, Cu, and Zn) concentrations. The results of this analysis are summarized below.

EC: **I**n shallow aquifers (depth <100m), EC was found maximum in the central region of the study area with an average EC of 3400 µS/cm. In deep aquifers, higher salinity was found in small pockets in the eastern and southern parts of the study area with an average EC of 4400 µS/cm. Higher EC in groundwater observed at a few locations may be due recharge of saline water from the backwater channels at these locations.

Water Quality Suitability for Drinking Needs: For the purpose of drinking water suitability, groundwater was analyzed using the water quality index (WQI) using the water quality parameters pH, Cl^-, SO_4^{2-}, NO_3^-, Na^+, K^+, Ca^{2+}, and Mg^{2+}. On the basis of WQI, it is observed that groundwater quality is excellent in 30% area, good quality in 35%, poor quality in 25% area, very poor in 7% area, and unsuitable in 3% area. In general, the groundwater quality of West Medinipur district is of excellent quality and very poor to unsuitable in the East Medinipur district
.

Water Quality Suitability for Irrigation: 42 % area has excellent quality groundwater for irrigation i.e. West Medinipur & South of N Pargana .13 % area is covered with good quality groundwater which can be used for irrigation with appropriate management. 15% of the area is under doubtful i.e. unsatisfactory for most of the crops. 30 % of the area is lying mostly in the Central and Southern regions (coastal zones) of the study area was found unsuitable for irrigation for all crops.

Heavy Metal Concentration: Heavy metal analysis indicated, 70 % of the study area was contaminated by at least one heavy metal among the analyzed heavy metals (Al, As, Mn, Cu, Fe, Cr, Pb, and Zn). Moreover, arsenic was found above the permissible limit of 10µg/l (WHO) in 50 % (~11250 km^2) of the study area, distributed mainly in three districts: North 24 Pargana, South 24 Pargana, and East Medinipur. Also, East Medinipur is the district having the highest population growth rate per year i.e. 3.36 % (from the 2001-2011 censuses). Thus the study area appears to be highly vulnerable to anthropogenic pollution.

f) Isotopic characterization of Surface water and Groundwater of the study area:
For chemical and isotopic analysis of channel water, water samples were collected from three locations and analyzed for EC and stable isotopic composition. The data range and the values for the characteristic equations are detailed in **Table 1.**

Table 1: Isotopic data of stream waters and groundwater yielded the following characteristic isotopic lines:

	Sampling location	Water type	Sampling period	Isotopic equation
Surface water	Hooghly River at Bichali Ghat, Metiabruz, Kolkata, Municipal Corp.	Fresh surface-water (FSW) EC <500 µS/cm	Feb-Apr, 2022	$\delta D=8.9x\delta^{18}O+15$
	1) Pichaboni River at Contai Purba Medinipur 2) Matla River at Canning, South 24 Paragnas	Saline surface-water (SSW) EC>25,000 µS/cm	Apr-May, 2022	$\delta D =6.05x\delta^{18}O-2.0$
	Sea (Bay of Bengal) water at Digha Sea Beach	EC =50,400 µS/cm	May 2022	$\delta D = +0.33$

Groundwater	Uniformly collected with in the study area	EC= 368 - 2250µS/cm	2019-2021	$\delta D_1=6.7x\delta^{18}O +3.9$ $\delta D_2=4.9x\delta^{18}O -5.47$ $\delta D_3=5.2x\delta^{18}O -6$

The characteristic isotopic line for SSW passes from the point (0,-2) (and not from 0,0) indicating a combined effect from mixing with seawater and evaporation. The evaporation might be due to the low flows in these streams in the presence of backwater during high tides. The two isotopic lines (FSW and SSW) intersect at (-6.1‰, -38.9‰). The most depleted point on the SSW line has an EC of 28,800 µS/cm and isotopic composition of (-2.71, -19.33). Applying the end-member isotopic mixing model, the first point on the mixing line appears to be contaminated by 55% of seawater.

For analyzing the groundwater for the identification of the recharge sources and the cause for the salinity enrichment, the isotopic data of groundwater, GMWL, and SSW points are plotted in a $\delta^{18}O$ vs. δD cross plot.

The evaporation lines 1, 3, and 4 intersect the GMWL at (-4.65 ‰, -27.18 ‰), (-5‰, -30‰), (-5.79‰, -36.32‰) respectively, indicating the isotopic composition of the original water, and it can also be inferred from these isotopic compositions that these waters (groundwater) are of continental origin with no contamination from seawater. The isotopic characteristic of seawater-surface water interaction line (δD_2) intersects the evaporation lines δD_3 & δD_4 at (-3.11‰, -20.86‰) and (-4.87‰, -31.52‰). These intersection points indicate the common isotopic composition of backwater channel water and the recharging groundwater.

Since these intersection points lie on the evaporation line, this implies that the backwater channels contain surface water that is partially evaporated.

To summarize thus, groundwater is formed from meteoric water and is subjected to different extents of evaporation before infiltration. In the presence of backwater pressure from seawater inflow through the backwater channels, the discharge flow rate in the backwater is slow, and thereby these are subjected to evaporation, as evidenced by the characteristic isotopic evaporation lines 1, 3, and 4. The partially evaporated water in the backwater channels interacts with seawater, gets mixed, and finally discharges into the sea (Bay of Bengal).

For groundwater age dating, shallow and deep groundwater samples from the districts of East Medinipur, Howrah, North & South 24 Parganas were collected and analyzed for environmental tritium. **The age distribution plot for deep aquifer shows the average groundwater is about 30 years with the component break-up as 43% in the age range 26-37 years, 47% in the age range 15-25 years, 8% with age >38 years, and remaining 2% is the groundwater of recent origin (<15years). Since** the groundwater is old to get dated by the tritium age dating technique, for a better age estimation other dating techniques such as ^{39}Ar, ^{14}C, ^{81}Kr, etc., may be used.

g) Aquifer mapping and groundwater management measures:

To assess the aquifer volume in each of the watersheds, isopach maps of the aquifers at depth ranges of 0 -100 m and 0 -200 m were prepared. This is accomplished by summing the thickness of all the aquifer zones in a tube-well starta-chart that fall within the desired depth range (0-100 meter, and 0-200 meter). Thus, the total aquifer thickness within these two depth ranges for each strata chart of the study area is estimated. Using this data, a contour map that represents aquifer thickness in the top 100 m and 200 m of the subsurface zone of the entire study area is prepared. The areas enclosed in the contour were then integrated to estimate the total thickness of the aquifer in the watershed falling in the top 100m and 200m sub-surface zones. The total aquifer volume at 100 m and 200 m depths is then computed by multiplying the integrated aquifer thickness with the watershed area. The groundwater storage capacity is then computed by multiplying the aquifer volume by the specific yield. On this basis, the groundwater volume computed was found to be highest in the tidal stream zone.

h) Runoff estimation:

For estimating the runoff, SCS-CN method is used. The LULC map was prepared using the SENTINEL 2 data, the soil map was prepared using NBSS & LUP data, and is then classified into hydrological soil groups, and for rainfall, the data for the past 26 years period (1993-2018) was collected from IMD, Govt. of India. The SCS runoff curve number for AMC II (average conditions) of the study area is estimated at 75. The estimated curve number is validated using rainfall-runoff data. The estimated runoff for the watersheds of the study area is summarized in the table. The estimated runoff data is useful for flood risk management, landscape planning, and artificial recharge measures.

Table 2. Annual average runoff in percentage of the annual rainfall in different watersheds of the study area

Sr no.*	Districts	Watersheds	Annual Average Rainfall (mm)	Annual Average Surface Runoff from rainfall (%)
1	**Howrah**	**Damodar & Saraswati**	**1699.28**	**52.53**
2	**North 24 Parganas**	**Jamuna Ichhamati**	**1595.75**	**35.72**
3	**North 24 and South Parganas**	**Tidal Streams**	**1785.31**	**31.8**
4	**Purba and Paschim Medinipur**	**Kasai-Haldi**	**1737.72**	**44.57**
5		**Pichhabani**	**1890.24**	**30.64**
6		**Rasulpur**	**1871.29**	**28.83**
7		**Rupnarayan**	**1651.94**	**47.03**
8		**Subarnarekha**	**1747.43**	**43.47**

(* Serial no of the watersheds is the same as mentioned in fig. 3a)

Conclusions:

The following conclusions are drawn from the present study:

1. The spatial pattern of rainfall shows higher rainfall near the coast. This general pattern is observed to deviate during extreme rainfall events. In the last three decades, 2012 was the driest year, and 1999 and 2014 were the wettest years.
2. Groundwater in the study area is depleting at a rate of 0.34m/year.
3. In 45 percent of the study area, groundwater is polluted with arsenic.
4. 70 percent of the groundwater in the study area is contaminated by at least one of the analysed heavy metals (Al, As, Mn, Cu, Fe, Cr, Pb, and Zn).
5. The sea level has risen at a rate of 2.7mm per year over the last 50 years (1970-2020).
6. The seawater inflow through tidal waves covers more than 60% of the study area. This includes the districts of North and South 24 Parganas, Howrah, and East Medinipur.
7. The decadal trend of water quality has shown a trend of decreasing salinity in the tidal streams.
8. Analysis of groundwater quality for drinking needs shows groundwater to be excellent in 30% of the area, good in 35% of the area, poor in 25% of the area, very poor in 7% of the area, and unsuitable in 3% of the area.
9. The highest growth in urbanization is taking place in the eastern parts, which are vulnerable to salinization due to the intense network of tidal streams.
10. Watershed-wise, run-off, in decreasing order is:

11. In 90% of the study area, groundwater quality is good to excellent for irrigation needs.
12. Isotopic data from the analysed groundwater revealed that 90% of the samples were meteoric in origin and were not contaminated by seawater.
13. The groundwater in the study area is moderately old (~30 years).
14. Considering the expansion of the built-up area in the eastern part of the study area and also looking at the vulnerability of this zone to groundwater salinization, prioritizing the identification of groundwater zones vulnerable to salinization from tidal streams is suggested.
15. Considering the highest rate of groundwater depletion in the northwestern part of the study area (highlands of the West Medinipur district), this zone may be demarcated and investigated in detail for artificial recharge measures.

3. PROJECT REFERENCE CODE: NIH/HID/NHP/2018-21/1

Study title:	**Development of A Comprehensive Plan for Conservation and Sustainable Management of Bhimtal and Naukuchiatal Lakes, Uttarakhand**
Study Team:	S.D. Khobragade (PI), Sudhir Kumar, and team from IRI, Roorkee
Collaborating agency:	IRI, Roorkee (Lead Organization for NHP PDS)
Type of Study:	PDS under NHP
Duration:	3 years (extended to five years)
Date of Start:	January, 2018
Date of Completion:	December, 2022
Budget:	36 Lakh (NIH Componenet))

Statement of Problem:

The lake region of Kumaun Himalaya is known for its biodiversity and socio-economic value. The catchment areas of the Bhimtal and Naukuchiyatal lakes is are hot spots of biodiversity with about 500 species of resident and migratory birds, 20 species of mammals, over 525 species of butterflies and over 11,000 species of moths, beetles, bugs and other insects. Both Bhimtal and Naukuchiatal lakes have traditionally been used as primary sources of drinking and irrigation water for their regions. However, anthropogenic disturbances in the lake catchment over the last few decades, are leafing to problems such as heavy sedimentation. etc. As such, the lakes need a comprehensive conservation plan. The lakes have been identified for conservation under the National Lake Conservation Plan (NLCP) of the Government of India. However, conservation plan for any lake needs proper understanding of the hydrology of the lake ecosystem. Many studies have been reported on the Bhimtal and Naukuchiatal lakes on water quality, ecology and sedimentation but there are no reported hydrological studies. The lakes are owned by the Irrigation department, Uttarakhand who want to conserve the lakes.

Objectives:

i) To assess the seasonal water availability of the lakes and assess its adequacy in meeting future demands
ii) To assess the water quality of the lakes and possible causes of its degradation
iii) To estimate sedimentation rate and expected life of the lake
iv) To suggest a comprehensive conservation and sustainable management plan for the lakes

Brief Methodology

i) Field surveys and field investigations
ii) Bathymetric survey
iii) Collection, processing and analysis of the available data
iv) Generation of additional required data.
v) Preparation of base maps and morphometric characterization
vi) Sample collection and laboratory analysis
vii) Data interpretation and analysis
viii) Assessment of Water balance components, water quality status, sedimentation rates, isotopic characterization

Study Area

Bhimtal is largest lake of all the lakes of Kumaun lesser Himalayan lakes. The lake is situated at 29° 21' N and 79° 34' E at an altitude of 1345 m, amsl. The surface area of the lake is about 0.46 km^2, maximum depth is about 24.7 m and storage capacity is about 5.27 Mm^3. Naukuchiatal is deepest of all the lakes of Kumaun lesser Himalaya. It is situated at 29° 19' N and 79° 35' E at an altitude of about 1320 m, amsl. The surface area of the lake is about 0.30 km^2, the maximum depth is about 42.7 m and storage capacity is about 5.17 Mm^3.and perimeter of the lake is about 3.13 km. The maximum length is about 983 m and maximum width is about 693 m. Both the lakes are significant in terms of drinking water, irrigation requirements, fisheries, recreation and aesthetic values. Due to the various anthropogenic activities (intensive construction and increase in population), the lake and their respective catchments are suffering from various environmental problems, particularly since two decades. The study area is a sub-tropical climate region, with maximum temperature of 32°C during summer (May and June) and minimum temperature below 0°C during winter. The average annual rainfall of the study area is about 1600 mm.

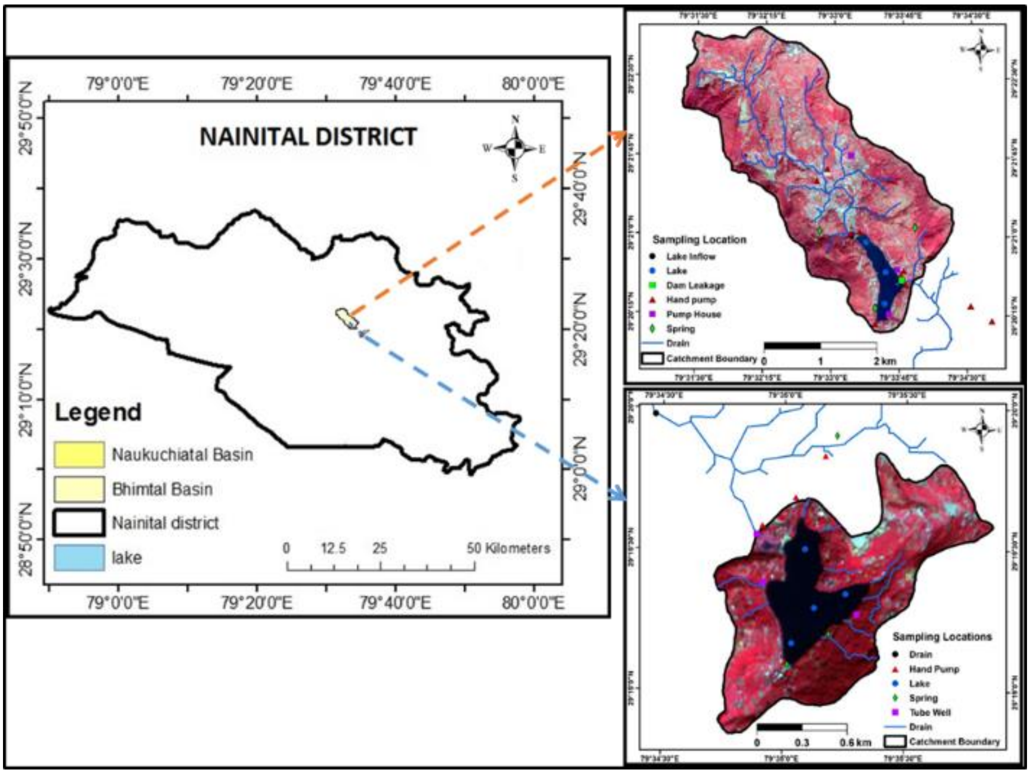


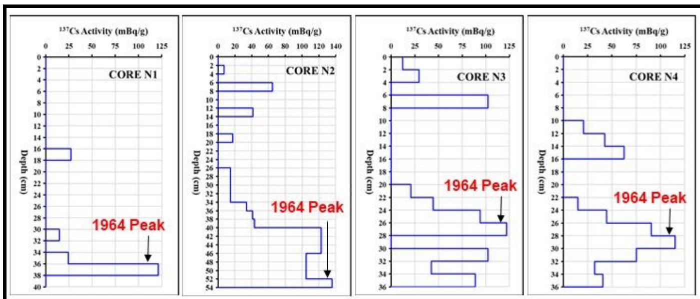
Figure 1: Study area map of Bhimtal and Naukuchiatal lakes

Progress:
The study has been completed and the final presentation was made during the recent review meeting of the NHP-PDS held at Delhi during February 2022. The draft final report is under preparation and is likely to be submitted by March, 2023.

Important Results

- The catchment to lake surface area ratio is 5.3 for Naukuchiyatal lake, while it is 23.5 for Bhimtal lake indicating different areal water loads although the capacities of the lake are more or less similar (approx. 5.0 MCM)
- The agricultural area has reduced significantly from 40% to 29% for Bhimtal lake catchment and from 48% to 32% for Naukuchiatal lake catchment during the period of 2002 to 2018
- Forest cover has marginally decreased in Bhimtal lake and increased in Naukuchiyatal lake during the period of 2002 - 18.
- The built-up area has increased from 5% to 16% for Bhimtal lake catchment and 3% to 9% for Naukuchiatal lake catchment during the period of 2002 - 18.
- The decrease in forest cover and an increase in the built up area is indicative of the urbanization place in Bhimtal lake catchment. This is likely to increase surface runoff and peak flow. They are also expected to decrease the infiltration of water to the ground water hampering the underground inflow of water to the lake.
- There is an increasing trend in rainfall and rainy days for the area

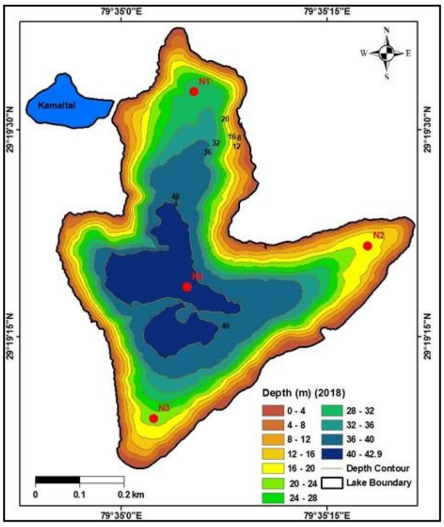
- In Bhimtal lake, the mean water level showed a declining trend during 2004-2014, however, after 2014 this decline has significantly reduced. In case of Naukuchiyatal lake, decline in water levels is observed during the last few years.
- Both the lakes have significant subsurface or ground water inflows. However, monthly water availability in Bhimtal lake is influenced by different factors in different months. Although same is true for Naukuchiyatal lake also, rainfall determines the change in lake storage to a greater extent.
- Total monthly evaporation losses from the Bhimtal and Naukuchiatal lakes are insignificant relative to the change in storage. They vary in the range of 0.01 MCM to 0.06 MCM for Bhimtal lake and 0.01 MCM to 0.05 MCM for Naukuchiatal lake.
- Significant sediment deposition has taken place in both the lakes. The maximum depth of the lake has reduced to 24.7 m in 2018 compared to 25.0 m in 2002 for Bhimtal Lake. The maximum depth has reduced from 42.7 m in 2018 to 45.0 m in 2002 for Naukuchiatal Lake.
- During the period of 2002 to 2018 the major sediment deposition in the Bhimtal lake has been observed along the NW part of the lake while for Naukuchiatal lake most sedimentation has been observed in central part of the lake. In both lakes most of the sediments have been deposited in the range of 0 to 1 m.
- Bhimtal lake shows significant depth wise variation in water quality parameters due to stratification. Naukuchiatal lake water is well mixed due to installation of aeration pump and hence no stratification is observed.
- Water quality has been observed to be fairly good for both the lakes. The water quality has been found to be particularly excellent for irrigation for which the lake waters are being used presently.
- For Bhimtal lake, among the major cations, Ca^{+} and Mg^{+} dominate over Na^{+}, K^{+} and NH_4^{+}, and among the major anions, HCO_3^{-} dominates followed by SO_4^{-}, Cl^{-}, NO_3^{-}, F^{-}
- For Naukuchiatal lake, among the major cations, Ca^{+} and Mg^{+} dominate over Na^{+}, K^{+} and NH_4^{+}, and among the major anions HCO_3^{-} dominates followed by NO_3^{-}, Cl^{-}, SO_4^{-} and F^{-}
- The water chemistry is dominated by Ca^{+}, Mg^{+} and HCO_3^{-}, an indication of a carbonate lithology source for the water composition for both lakes



Core ID	Area (m^2)	Rate (cm/y)	Rate (m/y)	Error	Accu. Area (m^3)
N1	62618.19	0.64	0.0064	0.0003	399.46
N2	61369.97	0.91	0.0091	0.0005	560.79
N3	57006.37	0.47	0.0047	0.0002	265.37
N4	118212.90	0.50	0.0050	0.0004	591.06
				Total	1816.69
			Avg. Rate (m/y)		0.0061 ± 0.0003

Area (m^2)	Volume (m^3)	Mean Depth (m)	Mean Sedi. Rate (m)	Life-Post 1964 (y)
299010	5245359	17.54 ± 1.24	0.0061 ± 0.0003	2887 ± 265

SEDIMENTATION RATE & USEFUL LIFE OF THE LAKE NAUKUCHIATAL



Recommendations

No serious environmental or hydrological issues (except sedimentation) have bee observed for both the lakes. However, for the purpose of sustainable management of the lakes, some measures are suggested as follows:

- Efforts should be made to ensure minimum sediment flow to the lake though lake catmint treatment. Construction debris should strictly not be allowed to flow with the runoff water. The inflow drain of Bhimtal lake may be provided with mesh at the outlet, so as to prevent the entry of bed load and construction debris in the lake.
- In order to minimise silt entry into the lake check dams in series in both the major nallah and minor valleys may be constructed.
- Due to steep slopes, and increasing concrete cover, runoff is likely to reach the lakes with a short travel time. In case of heavy rains, this may lead to significant filling of lake calling for opening of the sluice gates. Efforts should, therefore, be made to provide opportunity for more recharge of groundwater by increasing travel time of runoff water, through increase of forest cover or by adopting some structural measures, if feasible.
- The drainage line of Bhimtal lake carrying runoff from the catchment may be regularly cleaned so as to allow smooth flow of water to the lake.
- Further increase in built up area or concretization of the lake catchment surface may be avoided. Any existing illegal concrete surface/structure may be removed and natural recharge may be allowed. If concretization of the surface in the catchment is must, it should be ensured that it has enough perforations so as to allow recharge of ground water.
- A detailed study on the hydro-geological and recharge characteristic may be undertaken including aquifer mapping of the springs. The study should include identification of recharge areas of the springs in the lake catchment which bring water to the lake through drain or overland flow and all efforts be made to ensure that recharge areas of the springs do not get disturbed due to urbanization.
- On an average continuous leakage of 432 m^3/d lake water has been observed from the dam of Bhimtal lake. Immediate action may be taken to prevent the leakage to avoid further possible damage to the dam.
- Although hotspots for biodiversity, the potential of the lakes for tourism has not been fully explored. Eco-tourism may be developed for both the lakes and resources generated from tourism activity may be utilized for management of the lake.
- Although, currently the water quality of lake is not a concern, however regular monitoring of lake water quality to track changes in ecological health is suggested.
- Regular removal of tree branches and dead plant material from lake shores.
- Engage local stakeholders and community groups in lake management efforts to increase public awareness.
- The data availability scenario for both the lakes is not very encouraging. Regular monitoring of various physical, hydrological, meteorological, water quality, biological, and ecological parameters is strongly recommended for the lake.
- Some leakage is observed from sluice gate of Bhimtal lake which needs to be controlled/monitored.
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4. PROJECT REFERENCE CODE: NIH-21_2017_31

Study Title:	**Web GIS Based Spring Inventory for Vulnerability Assessment and Hydro-Geological Investigation of Selected Springs for Sustaining Local Water Demand in Ravi Catchment of Himachal Pradesh**
Study Team:	S S Rawat (P.I.), Sudhir Kumar, P G Jose, Suman Gurjar, and D S Bisht
Collaborating agencies:	Himachal Pradesh Jal Shakti Vibhag
Type of Study:	Sponsored (under NHP-PDS)
Funding Agency:	World Bank
Budget:	Rs. 69.00 lakh
Duration of Study:	04 Years (August 2017 to December 2022)

Study Area: Ravi River catchment of Himachal Pradesh having an area of about 5400 sq. km is the area selected for this study. Hilly part of the Ravi River catchment completely falls in hill Chamba district and almost entire Chamba district drains into Ravi River. Geographically, Chamba is the second largest district of the Himachal Pradesh and significant part of the district is under scheduled tribes (highest ST population in the state). Topographically catchment having very rugged terrain and elevation varies from 467 m to 5872 m, amsl. All four agro-climatic zone of the state found only in this district i.e. Shivalik hill zone (350-650 amsl), Mid zone (650-1800 amsl), High hill zone (1800-2200 amsl), Cold dry zone (>2200 amsl, snowfall).

Objectives:

- Creation of web-enabled database of the springs emerging in the catchment based on extensive inventory of physical and hydro-chemical characteristics.
- Mapping of vulnerable springs using hot-spot analysis.
- Hydrogeological investigation of some selected springs, which are vulnerable and having high societal importance for identification of their spring-shed area and potential.
- To suggest adaptive strategies for selected hot-spot springs for spring sanctuary development to sustain the local water demand.
- To build capacity among the local stakeholders through creating para-hydrogeologists for conserving and managing the springs.

Statement of the Problem:

About 85% of the total water demand of Himachal Pradesh State is from the rural areas that are largely dependent on traditional water resources. However, as per the survey report of HP State Council for Science, Technology and Environment 70% sources were not in proper working condition and going to dry up in near future. In Chamba district, less than 1% sources were found working well, while more than 99% were in poor condition. Keeping in view of the importance of traditional water resources in sustaining the water demand of the state, a Purpose Driven Study (PDS) was taken under National Hydrology Project (NHP) for investigations of the springs of Ravi River Catchment of Himachal Pradesh.

Brief Methodology:

- Conducting the Survey using handheld GPS
- Preparation of GIS layers and Base line data collection
- Development of Web-GIS Information System using open source technologies such as Geo-Server, Post-GIS, HTML, Java etc.
- Identify the vulnerable springs through Hot-spot analysis
- Identification of recharge area using the integration of Hydro-geo-chemical and isotopic analysis.

Results and Analysis:

- Total 971 springs have been geotagged, surveyed and detailed information on various characteristic of spring were collected.
- Samples for water quality analysis for all surveyed springs were collected and analysis in water quality lab at WHRC, Jammu. Total 14 water quality parameters viz. pH, EC, Ca^{+2}, NO_3^{+}, SO_4^{-}, F^{-}, SiO_2, K^{+}, Fe, Na^{+}, Cl^{-}, HCO_3^{-}, CO_3^{-2} and alkalinity were quantified.
- Web-GIS based portal named, ISHVAR (**I**nformation **S**ystem of **H**imalayan springs for **V**ulnerability **A**ssessment and **R**ejuvenation) having the information of 971 surveyed springs on 35+ parameters have been created with all supporting GIS layers and geotagged spring photographs (Fig. 1). All springs data are also available in the form of infographics for easy to understand.

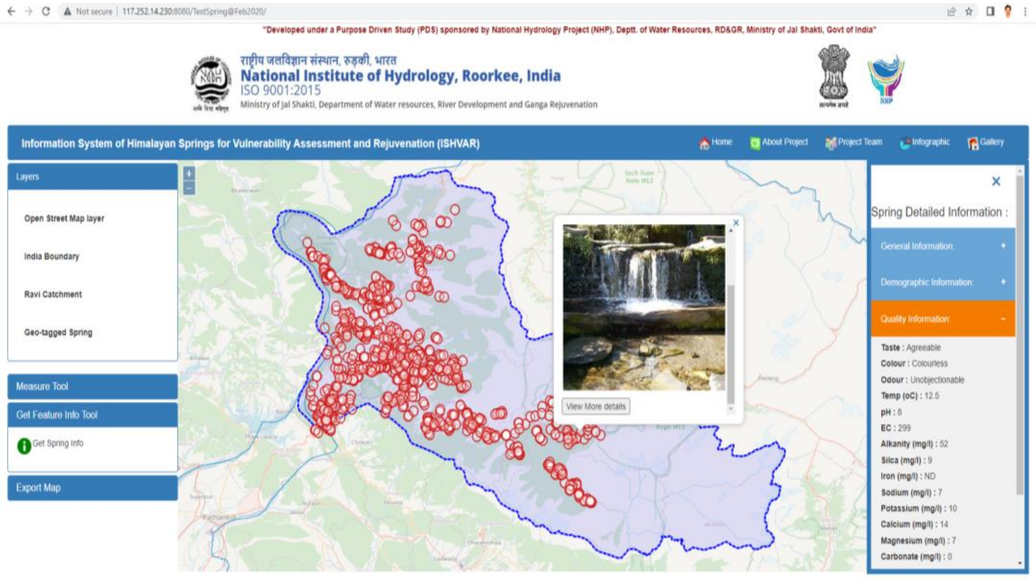


Fig. 1: Developed GIS based Web-Portal (ISHVAR) under NHP-PDS.

- One year daily Rainfall at 07 different locations (Sherpur, Dherog, Sahu, Mahela, Gera, Holi and Bharmaur) of the catchment was observed and rainfall samples for isotopic analysis were collected.
- Daily discharge of selected 05 springs located at different locations of the catchment were observed and isotopic samples of spring water were taken and anlayzed.
- Local geological mapping of 05 springs have been performed and cross-section have been developed.
- Various Physicochemical water quality parameters of selected 05 springs at pre & post monsoon were collected and analysed
- Recharge area of selected springs were demarcated based on the inputs derived from Geological mapping, Hydro-chemical and Isotopic analysis. (Fig 4). Once the recharge area identified suitable recharge measures can be constructed in the recharge area for augmentation of spring discharge.

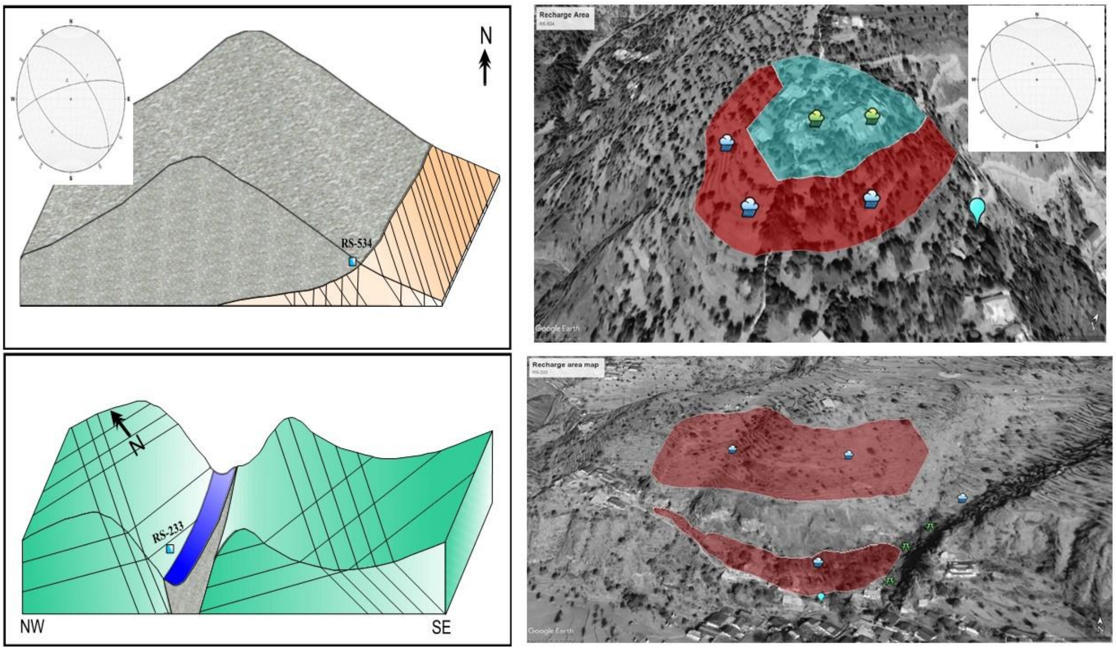


Fig. 2: Developed geological cross-sections and identification of recharge area of selected springs of Ravi river catchment.

Conclusions:

A comprehensive digital Spring map of Ravi River catchment was developed in the form of a Web-GIS based portal wherein detailed information of most of the springs emerging in Ravi River catchment are available. Out of 971 surveyed springs, 231 springs were found vulnerable and to be needed urgent treatment for their rejuvenations. Methodology for rejuvenation of sprins of Ravi river catchment have been developed based on the integrated analysis (Hydro-geo-chemical & Isotopic) of 05 springs located in different parts of the Ravi river catchment. Such developed methodology can be extended for all 231 identified vulnerable springs in the catchment for augmentation of the discharge of Ravi river, particularly during the lean season of the year. To disseminate the outcome of the project 01 training course and 01 Stakeholder workshop in were conducted during the project duration.

5. PROJECT REFERENCE CODE: SP/38/2019-22/RCJ

Study Title: **Web-Enabled Inventory of Natural Water Springs of Tawi River Catchment of Jammu and Kashmir State of India for Vulnerability Analysis and Developing Adaptive Measures for Sustaining Tawi River**

Study Team: S S Rawat (P.I.), P G Jose, Suman Gurjar, and D S Bisht
Collaborating agencies: Dept. of Soil and Water Conservation, Govt. of Jammu & Kashmir
Type of Study: Sponsored (under NMHS)
Funding Agency: Ministry of Environment, Forest & Climate Change, Govt. of India
Budget: Rs. 38.04 lakh
Duration of Study: 03 Years (January 2019 to September 2022)

Study Area:
The present study is focused on the Tawi River Catchment (Fig. 1). Tawi River is a major river that flows from Jammu division of Jammu and Kashmir and drain about 2168 km^2 up to Jammu region. Tawi River, also called the lifeline of the two major district (Jammu and Udhampur) of Jammu region, is the left bank tributary of river Chenab originating from the lapse of Kali Kundi spring area southwest of Bhadarwah in Doda district. The length of River from its originating point to Jammu is about 150 km. The Tawi River has a very high social impact as it is the only major source of water for drinking, agricultural and industrial needs, and it serves to the almost 20% population of the whole J&K state.

Objectives:
- Creation of GIS based web-enabled database of the springs emerging in Tawi River catchment based on extensive inventory of physical and hydro-chemical characteristics.
- Identification of vulnerable springs using hot-spot analysis.
- Hydro-geological investigation of some selected springs, which are vulnerable and having high societal importance for identification of their spring-shed area and potential.
- To suggest adaptive strategies for selected hot-spot springs for spring sanctuary development to sustain the local water demand.
- To build capacity among the local stakeholders through creating para-hydrogeologists.

Statement of the Problem:
As per SOI toposheets more than 350 major springs are emerging from Tawi catchment and are responsible for maintaining the base flow of the River, which also is important for sustaining the artificial lake and Tawi Riverfront Development Project, which are under construction. There is hardly any water flowing in River Tawi during lean season and the people of the area face acute shortage of water impacting their very livelihoods. In view of cultural, social and hydrological importance of Tawi catchment and lack of base data on springs, the proposed project has immense significance for the sustainable water resource management in the catchment wherein revival of drying springs will play a vital role.

Brief Methodology:
- Conducting the Survey using mobile app
- Preparation of GIS layers and Base line data collection
- Development of Web-GIS Information System using open source technologies such as Geo-Server, Post-GIS, HTML, Java etc.
- Identify the vulnerable springs through Hot-spot analysis
- Identification of recharge area using the integration of Hydro-geo-chemical and isotopic analysis.

Results and Analysis:
- Total 469 springs have identified in Tawi river catchment up to Jammu (2168 sq. km). A total

of 47 parameters have been recorded in the field which cover all the general, spatial, social and demographic factors related to the spring.

- Web-GIS based portal named, ISHVAR (**I**nformation **S**ystem of **H**imalayan springs for **V**ulnerability **A**ssessment and **R**ejuvenation) having the information of 469 surveyed springs on 47 parameters have been created with all supporting GIS layers and geotagged spring photographs (Fig. 2). All springs data are also available in the form of infographics for easy to understand.
- One year daily Rainfall at 07 different locations (Sherpur, Dherog, Sahu, Mahela, Gera, Holi and Bharmaur) of the catchment was observed and rainfall samples for isotopic analysis were collected.

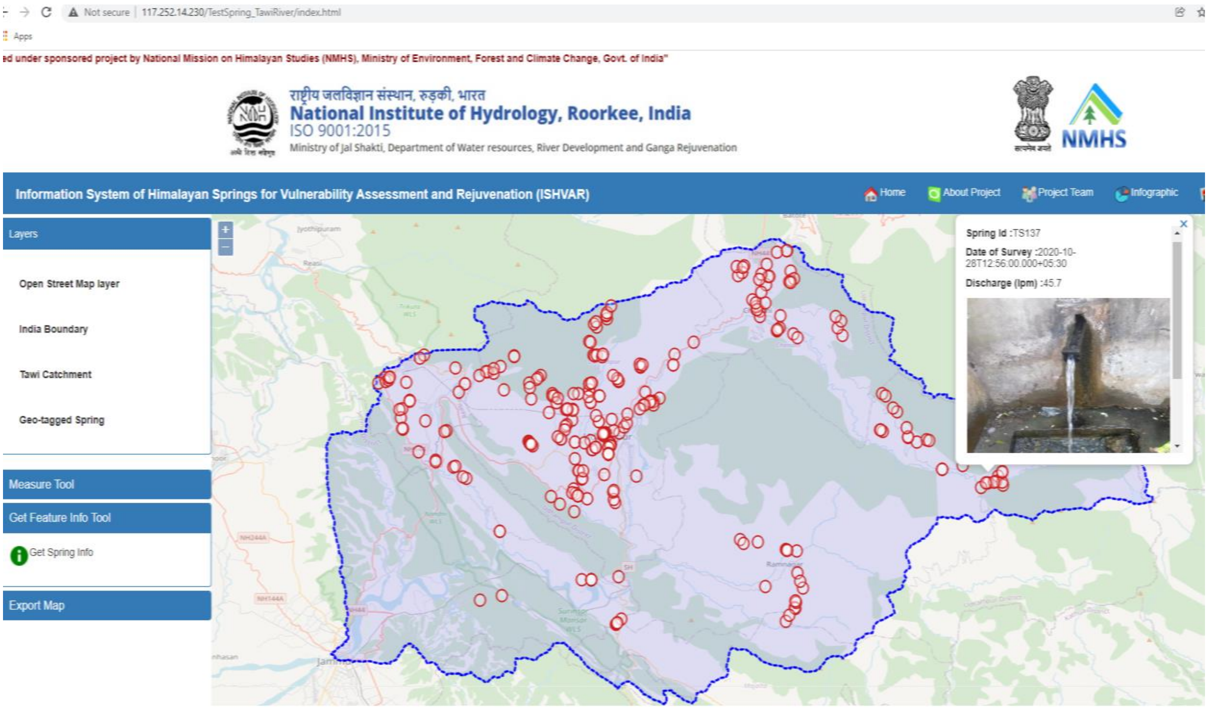


Fig. 2: Web-GIS based spring portal for Tawi catchment of Jammu & Kashmir.

- Daily rainfall for one year at Seven raingauge stations i.e. Jammu (282 m, amsl), Udhampur (750 m, amsl), Pangara Jagir (766 m amsl) Chennani (1210 m, amsl), Jagir (1488 m amsl) and Mantalai (1650 m, amsl) was recorded and rainfall samples for isotopic analysis were collected.
- Daily discharge of selected 05 springs located at different locations of the catchment were observed and isotopic samples of spring water were taken and analysed.
- Local geological mapping of 05 springs have been performed and cross-section have been developed (Fig. 2).

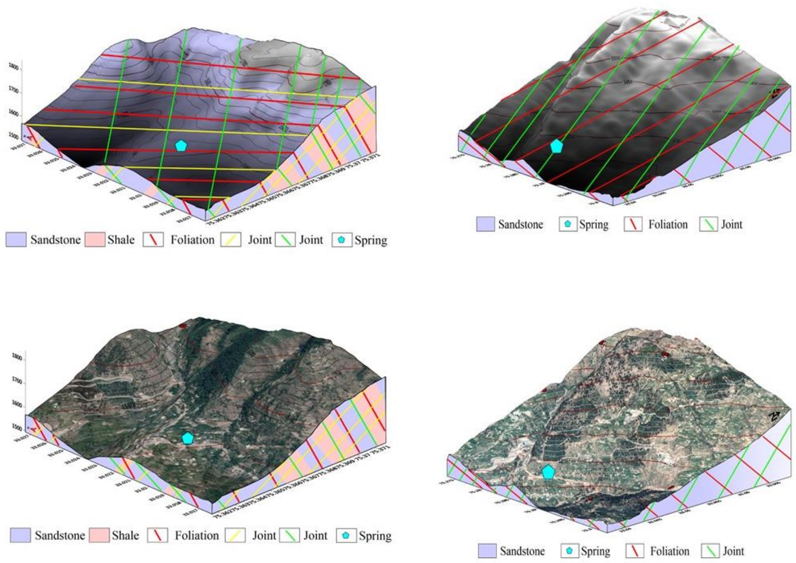


Fig. 2: Geological cross-sections developed for selected springs of Tawi river catchment.

- Various Physicochemical water quality parameters of selected 05 springs at pre & post monsoon were collected and analysed
- Recharge area of selected springs were demarcated based on the inputs derived from Geological mapping, Hydro-chemical and Isotopic analysis (Fig 3). Once the recharge area identified suitable recharge measures can be constructed in the recharge area for augmentation of spring discharge.

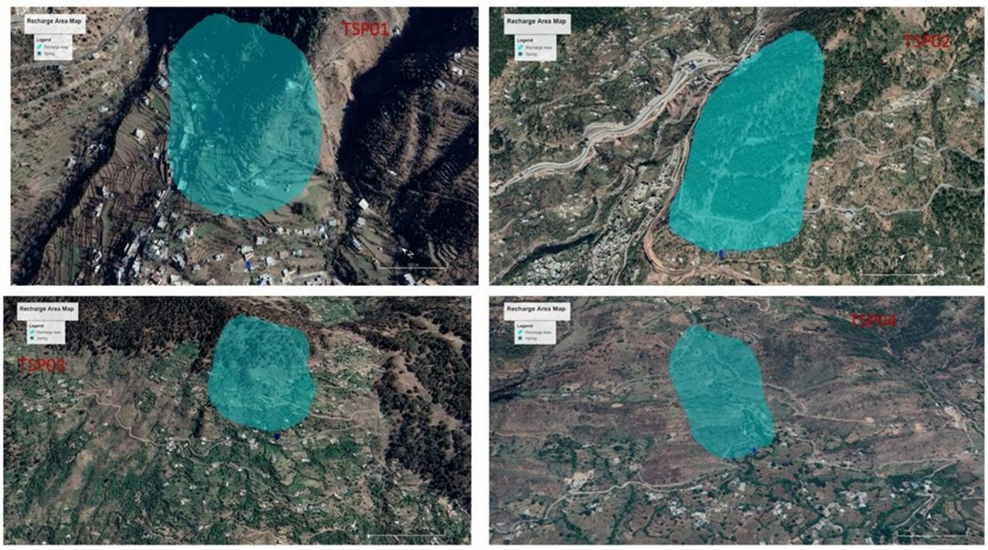


Fig. 3: Recharge area demarcated for selected springs of Tawi catchment.

Conclusions:

Spring web-portal for Tawi catchment of UT of Jammu & Kashmir having the information of 469 surveyed springs on 47 parameters have been created with all supporting GIS layers and geotagged spring photographs (Fig 2). For collecting the data for creating spring inventory a survey form covering questionnaire to various parameters related to the springs has been created in KoBo tool box. This app has capability to utilize the camera and GPS of the mobile to geotag a springs. Out of 469 surveyed springs, 51 springs were found highly vulnerable and to be needed urgent treatment for their rejuvenations. While 419 springs were found Moderately Vulnerable and to be needed periodic supervision. Methodology for rejuvenation of springs of Tawi river catchment have been developed based on the integrated analysis (Hydro-geo-chemical & Isotopic) of 05 springs located in different parts of the Tawi river catchment. Such developed methodology can be extended for all 51 identified highly vulnerable springs in the catchment to maintain the sufficient water flow in the river particularly non-monsoon season. To disseminate the outcome of the project 02 training courses on 'Tools and Techniques for Springshed Management' and 01 Special lecture on “Application of Isotopes in Hydrology” were conducted in which more than 100 participants from Tawi river catchment have been trained.

6. Study Title: **Leachate Transport Modeling for Gazipur landfill site for suggesting ameliorative measures**

Study Group: Er. Anjali, Scientist C, HID
Dr. Sudhir Kumar, Scientist G & Director NIH
Dr. J. V. Tyagi, Scientist G (Superannuated)
Dr. M. K. Sharma, Scientist F, EHD
Type of Study: Sponsored project by NHP (PDS), Budget: Rs 76,10,000/-
Nature of Study: Applied Research
Date of start: 1 November, 2019
Scheduled date of completion: 31 May, 2023
Duration of the Study: 3 Years (+7month extension)

Objectives:

i) Understanding of hydrodynamics of groundwater flow in the study area.
ii) Chemical characterization of Leachate.
iii) Isotopic characterization of leachate and its variation due to recharge and extraction of groundwater.
iv) Assessment of Micro-plastic and metals (Hg, Ni, Co) in landfill leachate.
v) Modelling of leachate migration pattern in groundwater in space and time.
vi) Suggesting ameliorative measures for contaminant plume migration.
vii) Dissemination of knowledge and findings to stakeholders through manuals, leaflets, booklets and workshops/training programs.

Statement of the Problem:

The growth in population, urbanization and industrialization has led to the increase in the generation of solid waste all over the world. It is believed that the rate of waste generation is an index of socio-economic development and an economic prosperity of a country. This is evident from the fact that the rate of waste generation is more prominent in the developing countries where there is an increased rate of unplanned urbanization of the cities.

In India, the total Indian urban population amounts to approximately 377 million (Census of India 2011). The cities which have more than 100,000 populations contribute to more than 72 percent of the total municipal solid waste. The growth rate of population in urban India is much higher than that in rural India. The Census figures also show Delhi to be the most urbanised State in India. Since waste generated by the city depends on its population and per capita income, it is estimated that the quantity of Municipal Solid Waste (MSW) would reach 17,000 – 25,000 MT/day by 2021 (Talyan et al.,2007).

For solid waste management in Delhi, twenty landfill sites were identified and developed since 1975, and of which 15 have already been closed and two were suspended. At present only three landfill sites are in operation. They are namely, Bhalaswa catering the needs of northern part of Delhi, Okhala in the southern part and Gazipur in the eastern part of Delhi.

The dumping of waste in these non-engineered landfill sites contributes to percolation of leachate in the groundwater. These percolating liquids have high concentration of hazardous chemicals. The harmful constituents of leachate then move along the groundwater in the surrounding region rendering it unfit for human consumption and pose various health risk.

The various attempts made so far to model leachate movement suffer from a common problem that no surety can be established as to whether the pollution is result of leachate or any other source is contributing towards groundwater deterioration in that region. The current study focuses on modeling of leachate movement through groundwater and apportionment of leachate which has not been attempted so far.

Approved Action Plan/Methodology:

i) Literature review on chemical and isotopic characterization of leachate, groundwater contaminant transport modeling etc.
ii) Field survey of the region and groundwater sampling – using standard protocols.

iii) Characterization of leachate using EPA methods- TCLP (method no.- 1310) & column study (method no.- 1312).
iv) Collection of groundwater levels to ascertain the flow direction.
v) Identification of groundwater recharge and discharge areas.
vi) Collection of groundwater samples on bi-monthly basis at identified locations.
vii) Analyzing the physico-chemical parameters: pH, EC, DO, COD, TOC, Major anions, cations, and trace metals (Fe, Mn, Zn, Pb, Cd, Cr, Radium etc).
viii) Analysing the stable isotopic characteristics of leachate and groundwater at various identified locations.
ix) Analysing the groundwater samples and leachate for micro-plastic.
x) Processing of hydro-chemical and isotopic data on bi-monthly basis.
xi) Modeling the leachate migration from the landfill to groundwater table. The model will be developed for one dimensional vertical transport of contaminants through unsaturated zone.
xii) Modeling of leachate plume movement in groundwater will be performed using MT3D MODFLOW and HELP. The leachate transport model will be calibrated based on chemical and isotopic data.
xiii) Suggesting ameliorative measure for containment of contaminant plume based on groundwater modeling.

10. Timeline:

S. No.	Activities	YEAR 1				YEAR 2				YEAR 3			
1.	Hiring of manpower & training												
2.	Purchase of equipment & consumables												
3.	Upgrading literature and data collection												
4.	Delineation of villages and finalization of sampling location												
5.	Collection and analysis of samples												
6.	Statistical analysis of data and Carcinogenicity test												
7.	Contaminant remediation												
8.	Training & capacity building												
9.	Scientific publications												
10.	Final technical report												

Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
1st Year	Literature survey	Field investigation, data collection and literature survey	Groundwater sampling and data processing	Groundwater sampling and analysis, estimation of flow parameters, and interim report

2nd Year	Groundwater sampling and analysis, and leachate characterization	Groundwater sampling and analysis, plume characterization and model conceptualization	Groundwater sampling and analysis, model conceptualization, training and workshop	Groundwater sampling and analysis, development of mathematical model, and interim report
3rdYear	Development of mathematical model	Computational runs with the developed model and identification of vulnerable areas and hot spots	Computational runs with the developed model and identification of vulnerable areas and hot spots	Finding ameliorative measures, training, workshop and report writing

12. Objectives and achievement during last six months:

S. No.	Activity	Achievements
1.	Field Investigation and sampling plan	• Groundwater sample collection from 130 grids from the vicinity of landfill. • Leachate Samples taken from the landfill.
2.	Decolourization of samples	• Samples colour removal was undertaken • Reasons for coloured samples was identified. • Field applicability of chemical treatment assessed.
3.	Literature survey	• Literature on Microplastics, leachate characterization and isotopes in landfill was extensively surveyed.

Analysis & Results:

- Field Survey was undertaken for selecting sites for Leachate sampling.
- For understanding the basic characteristics of leachate, preliminary samples were collected in order to find out the suitability of various experiments and to identify the procedures need to be followed in future.
- The physico-chemical, metal contents and isotopic parameters of Leachate was identified.
- The physico-chemical, metal contents and isotopic parameters of Groundwater in the study arae identified.
- Presence of microplastics in leachate samples detected.
- Modelling movement of contaminant within the landfill.
- Source Identification with statistical analysis.
- Training of Groundwater Monitoring and Modelling.

Future Plan:

- Field Visits will be planned and sample collection will be undertaken.
- Groundwater Modelling and Contaminant Transport
- Modelling microplastic movement in soil and Groundwater
- Source Apportionment

7.	**Study Title:**	**Changing the fate of the Hindon river by evaluating the impact of agriculture on the water balance: Developing a template for a cleaner Ganga river**

Study Team:	Dr. Sudhir Kumar, (Project Coordinator), Dr. M. K. Sharma, (Principal Investigator), Dr. Suhas Khobragade, Ms. Anjali, Dr. Vishal Singh, Dr. SM Pingale.
Collaborating agencies:	IIT Kanpur
Type of Study:	Sponsored by DST (under DST-NOW call)
Funding Agency:	Department of Science and Technology, GoI
Budget:	Rs. 240 lakh
Duration of Study:	05 Years **(**April 2022 to March 2027)

Objectives

This research aims at providing scientific understanding on the hydrological functioning and the impact of agricultural water management of the Hindon subbasin of the Ganges river. Three areas of research are distinguished:

1) Integrated water systems analysis to understand the spatio-temporal relations between surface water and groundwater quantity and quality, and the impact of human activities and climate characteristics by setting up a monitoring network.
2) Interventions to improve agricultural water management and reduce negative impacts on water quantity and quality.
3) Develop recommendations for improvements in Hindon basin water quantity and quality, food production and economic revenues.

Statement of the Problem

River Hindon, an important tributary of river Yamuna flowing through the districts of Western Uttar Pradesh, is subjected to varying degree of pollution caused by numerous untreated and/or partially treated waste inputs of municipal and industrial effluents. The toxic pollutants from these wastes will ultimately reach the ground water and enter in the food chain posing a threat to human health because of their carcinogenic nature. The pollution matrix in some stretches of the river becomes so complicated that anaerobic and septic condition prevails during the lean period due to discharge of effluents to the river from various industries and municipal areas. Though a large number of studies, to understand the pollution aspects of river Hindon, have been carried out by different workers (Verma and Mathur, 1971; Verma and Dalela, 1975; Verma et al., 1980; Patel et al., 1985; Singhal et al., 1987; Joshi et al., 1987; Seth, 1991; Seth and Singhal, 1994; Khare, 1994; Kumar, 1994; Lokesh, 1996; Jain, 1996, 2000; Kumar, 1997; Jain and Ali, 2000; Jain and Ram, 1997a, 1997b; Jain and Sharma, 2001a, 2002, 2006; Jain et al., 1997, 1998a, 1998b, 2002, 2003, 2004a, 2004b, 2005, 2007; Sharma, 2001; Sharma et al., 2009a, 2009b), but no comprehensive and holistic plan for rejuvenation of river has been attempted. This requires monitoring of water resources and pollutants within the river basin through data collection, modeling of river water and groundwater interaction and interpretation. Further hydrological study of the basin is important to understand the surface and groundwater interaction. Water Balance in Hindon River Basin will provide water allocation for different sectors for better water management in the basin. Reach-wise recharge augmentation plan may be implemented by identification of affluent and effluent sections in the river.

Approved Action Plan/Methodology

i) Literature review and collection of data from published reports and papers.
ii) Procurement of secondary data required for the analysis from various govt. agencies (discharge, rainfall, landuse/landcover, lithology, ground water level, aquifer parameters, sediment concentration, other water quality parameters, soil map etc.)
iii) Monitoring of water quality of River Hindon monthly basis for one year
iv) Study the relationships between different hydrological parameters

v) An inventory of pollution sources contributing to the River will be prepared from the collected information and Major Contaminant zones will be identified.
vi) Identification of affluent and effluent sections of River Hindon.
vii) Water Balance of Hindon River Basin using SWAT-MODFLOW model
viii) Reach-wise Recharge augmentation plan will be suggested

11. Work schedule / Timeline

Year	Month	Consortium Activity	NIH action plan
2022-23	Apr - Jun, 2022	Preparatory activities like approvals etc.	• Hiring of Project staff • Meetings with IIT K for formulating plans for field Visits • Forwarding request to state govt. for data • Literature Review
	Jul - Sep, 2022	Start of the project Kick of Meeting Hiring of Staff, PhD Creation of Advisory Board	• Administrative Approval for Equipment • Kick off Meeting and formal introduction of the members involved, role and responsibilities allocation. • Combined field visit of IIT K and NIH for G&D site and piezo-site locations.
	Oct - Dec, 2022	• Designing Observational Network • Identification of farms, urban and industry locations	• Installation of Piezometers and G&D sites • Inventory of pollution sources • Survey for morphometric analysis of river Hindon • Health, Agricultural and drinking issues identification.
	Jan - Mar 2023	Stakeholders Identification Installation of Base network and bathymetry Measurement	• Creation of Pollution Inventory • Stakeholders Identification • Groundwater level trend analaysis • Water quality over years inventory
Year-2 2023-24	Apr - Jun, 2023	Field investigations	• Soil, Groundwater and river water quality sample collection and analysis
	Jul - Sep, 2023	Data preparation for IHE-FEWS	• Contribute to FEWS data platform
	Oct - Dec, 2023	• Stakeholders Meeting • Field investigations	• Stakeholders Meeting • River discharge and water quality, • Groundwater levels and water quality
	Jan - Mar 2024	Report writing	• Preparation of Interim report • Scientific paper writing
Year-3 2024-25	Apr - Jun, 2024	Data collection	• Groundwater and river water quality sample collection and analysis
	Jul - Sep, 2024	Groundwater Investigation	• Recharge Estimation for Hindon river Basin • Estimation of Parameters for

			Groundwater Model Development.
	Oct - Dec, 2024	Mid- Project stakeholders meetings	• Stakeholders Meeting
	Jan - Mar 2025	Data interpretation and Report writing	• Preparation of Interim report • Scientific paper writing
Year-4 2025-26	Apr - Jun, 2025	Data collection	Groundwater and river water quality sample collection
	Jul - Sep, 2025	Sample analysis	Groundwater and river water analysis
	Oct - Dec, 2025	Scientific Advisory Board Meetings	Final Groundwater-surface water interaction Model
	Jan - Mar 2026	Stakeholders Workshop Result sharing and analysis	Effluent and affluent zone identification. And integration of individual developed models
Year-5 2026-27	Apr - Jun, 2026	Development of GW Model	Development of GW Model
	Jul - Sep, 2026	Calibration and Validation of the model	Calibration and Validation of the model
	Oct - Dec, 2026	Data analysis and interpretation	Suggestions and measures for Hindon rejuvenation
	Jan – Mar, 2027	Advisory Board Meetings for project finalization	Working on finalization of results with Dutch Partners.

13. Analysis & Results:

- Purchase of Equipment and Services Completed.
- Collection of 158 groundwater Samples
- Collection of River Water samples for water quality analysis.
- Three field Visits to river Hindon
- One workshop for aligning the thoughts and expectation. Held at New Delhi, During 15th Feb,2023.

14. Future Course of work

- Installation of Soil-moisture Probes.
- Piezometer Construction and Installation
- Construction of Various G&D sites.
- Field Investigation and sample collection.

ITEM NO. 52.3 PROPOSED WORK PROGRAM OF THE DIVISION FOR THE YEAR 2023-24

Apart from the 02 Internally Funded R & D studies and 02 Sponsored Projects that shall continue during 23-24 from the work programme of 2022-23, following 04 New Studies are being proposed for the work programme of 2023-24:

<u>New Studies for 2023-24:</u>

1. PROJECT REFERENCE CODE: NIH/HID/R&D/2023/1

Study Title:	**Developing a Stable Isotopic Analysis System for analyzing the dissolved Nitrates in water**
Study Team:	Dr M Someshwar Rao, Sc. 'F' Mr Vishal Gupta, SRA
Duration:	**One and half years (April, 2023-September, 2014)**
Funding:	**NIH Funds**

Background:

Tracing the source of nitrate in nitrate-contaminated groundwater is a major concern in groundwater pollution studies. Sources that can contribute to nitrate contamination, include leaching and runoff from agricultural fields, urban wastewater, sewage, animal manure, septic tanks, landfills, etc. Isotopic analysis of NO_3^- is one of the most popular techniques used for tracing the source of nitrate in water. The analysis involves the measurement of the $\delta^{15}N$ and $\delta^{18}O$ composition of dissolved nitrate in water. The measured nitrogen isotopes are expressed using the following delta scale:

$$\delta^{15}N\,[‰] = \left[\frac{{}^{15}N/{}^{14}N_{sample}}{{}^{15}N/{}^{14}N_{reference}} - 1 \right] \text{X } 1000$$

and

$$\delta^{18}O[‰] = \left[\frac{{}^{18}O/{}^{16}O_{sample}}{{}^{18}O/{}^{16}O_{reference}} - 1 \right] \text{X } 1000$$

The $N_{reference}$ can be, atmospheric N_2 ($\delta^{15}N_{air}=0$), IAEA-N-1 ($\delta^{15}N$ = +0.43 ‰), IAEA-N-2 ($\delta^{15}N$ =+20.32 ‰), etc.. The oxygen isotope ratios are reported relative to the Vienna Standard Mean Ocean Water (VSMOW)

In addition to $\delta^{15}N$ of NO_3, nitrogen isotope can also be measured for NH_4, dissolved organic nitrogen (DON) or particulate organic nitrogen (PON).

The major concern involved in the isotopic analysis of nitrates is to avoid any interconversion between NH_4^+, NO_3^-, DON, and PON and any fractionation during the conversion of the desired compound to its respective gas (N_2 or N_2O) for $\delta^{15}N$ analysis and to the gas CO_2 or CO or N_2O for $\delta^{18}O$ analysis.

The specific objectives of the present project are:

- To prepare a manual on SOP for sample collection, the analytical procedure for $\delta^{15}N$ and $\delta^{18}O$ analysis of nitrates in water, and data interpretation
- To develop a state-of-the-art system for isotopic analysis of nitrates in water
- Application of stable isotopes of nitrates for tracing the source of nitrate using a case study

Budget: Rs 15.0 lakhs

Budget Components	Amount in Lakhs
Manpower (1 year) Project Associate: Rs 31,000/-+HRA Semi-skilled (Daily wage)	 4.06 1.56
Purchase of instrumental parts, water sampling units, accessories, and their assembly	8.25
Miscellaneous	1.13
Total	15.0

Justification:

Project Associate (1 no.) The development of a system for nitrate analysis involves the requirement of expert support for the following needs:

i) A microbiologist to help in developing a system for preparing and growing *P. chlororaphis, aurofeciens*, and isolation of pure culture, quantitative analysis for measurement of microbial growth,

ii) A chemist to help in developing a system for converting the dissolved nitrates to Ag_2O to $AgNO_3$ using the (cation-anion exchange resin) column chromatography technique.

Daily wage (Semi-Skilled): For general support in lab-work

Time Line:

Work components	1st Qr	2nd Qr	3rd Qr	4th Qr	5th Qr	6th Qr
Preparing the manual on SOP for sample collection procedure, the analytical procedure for $\delta^{15}N$ and $\delta^{18}O$ analysis of nitrates in water, and data interpretation	✓	✓				
Appointment of staff	✓	✓				
Procurement of instrumental parts (domestic and imported items), chemicals, glassware, and isotopic standards from IAEA, Vienna		✓	✓			
System development and calibration			✓	✓	✓	
Case study				✓	✓	✓
Final report						✓

2.. PROJECT REFERENCE CODE: NIH/HID/R&D/2023/2

Study Title: **Geo-Hydro-Chemical and Isotopic Aspects of Occurrence of Springs: A case study from the major settlement areas of Bhagirathi basin, Uttarakhand, India**

Thrust Area under XII five-year plan: Sustainable water systems management: Adaptation of hydro-system to climate change

Study Team: Dr. Soban Singh Rawat, Scientist ‘E’ (PI)
Dr. Suhas Khobragade, Scientist ‘G’, and Head, HID
Dr. M K Sharma, Scientist ‘F’, EHD
Dr M S Rao, Scientist ‘F’, HID
Dr. Santosh M. Pingale, Scientist ‘D’, HID
Dr. P K Mishra, Scientist ‘D’, WRS

Type of Study: Internal funding (New Study)

Duration: **3 years (April 2023 to March, 2026)**

Objectives

The present study will be carried out with the following objectives:

i) To characterize the identified springs based on their hydro-chemical and isotopic characteristics,
ii) To understand the geological control and its impact on the occurrence of springs,
iii) To carry out the vulnerability analysis of springs in the study area, and
iv) To identify the major recharge sources of springs through isotopic analysis.

Study area

The present study will be carried out from New Tehri to Harshil, Uttarakhand along the River Bhagirathi, a tributary of mighty River Ganga. The study will be focused in an area of about 2 km on both sides of the river, considering the major settlements region. Geologically, the area consists of rocks of lesser Himalaya and central crystallines, separated by the main central thrust near Sainj (20 kms from Uttarkashi town along Uttarkashi-Gangotri Road). Lesser Himalayan part comprises of Quartzite, limestone, Slates, Schistosh-Quartzites and Epidiorites and the central Crystallines constituted by Gneisses, Schists, amphibolites and Migmatites. The area encompasses several major tectonic lineaments such as North Almora Thrust, Vaikrita thrust, Munsiari thrust.

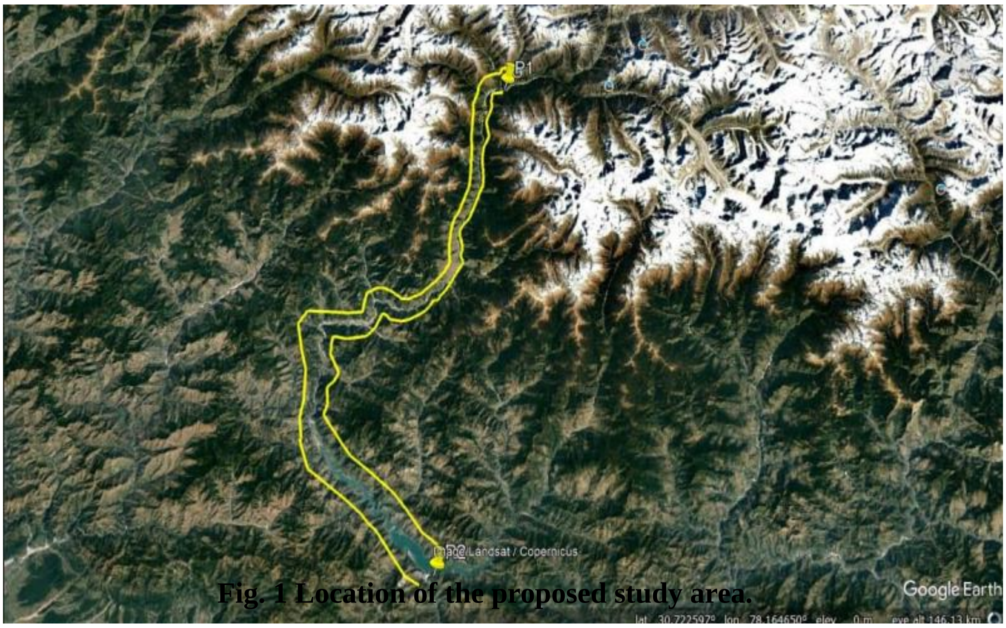


Fig. 1 Location of the proposed study area.

Present state-of-art

The accessibility to potable water has become a challenge and is receiving attention of many researchers across the globe. The quality and quantity of safe drinking water has been impeded owing to population growth, climatic changes, urbanization, and disposal of industrial and agro-chemical wastes to water resources either directly or indirectly (FAO 2011a, b; WWAP 2012, 2015). In Indian Himalayan region, springs form the major sources of potable and irrigation water for rural households. Majority of the Himalayan Rivers have their origin in form of springs which maintain base flow of the rivers in non-rainy seasons. Nearly 50% of the perennial springs have dried up or became seasonal in recent decades (NITI Aayog, 2018). Almost 60% of the springs in IHR have shown a noticeable decline in discharge of seasonal springs (Negi and Joshi, 2004). This drastic decline in discharge is mainly attributed to human activities (urbanization, population pressure, deforestation and landuse changes) and natural factors (enhanced rainfall intensity, decreased temporal spread of monsoonal rain and reduction in winter precipitation). Besides decline in discharge, water quality of springs is also deteriorating due to changing landuse pattern and inappropriate sanitation practices. Owing to the spring's importance for livelihood, socio-economy and ecology, Government of India has given emphasis on mapping, monitoring, rejuvenation, and restoration of springs in the vicinity of Himalaya.

Valdiya and Bartarya (1989, 1991) suggested that overgrazing, change in landuse land cover, deforestation and road cutting has considerably reduced the springs discharge in Gaula river catchment. Such large-scale mapping of springsheds, long term monitoring data of discharge and water quality are required for planning the development strategies for sustainable development in other areas also. Climatic variability and Geochemical characteristics of spring water in Kashmir valley has been studied by Jeelani et al., 2011. The results suggest carbonate and silicate weathering as dominant rock weathering processes followed by multiple hydrochemical facies due to water-rock interaction. The water is undersaturated with calcite and dolomite and the springs are recharged by regional streams. Lone et al., 2021 worked on the water quality of freshwater Himalayan springs in South Kashmir using multivariate statistical analysis and observed a combined effect of lithological and anthropogenic activities on water quality.

Several studies that have been carried out on spring water are mostly focused on qualitative analysis. However, the occurrence of springs in any region is controlled by the regional geology and topography, presence of lineaments such as faults, fractures, joints etc. Additionally, the presence of lineaments also plays an important role in the development of secondary porosity and permeability in hard rock terrain. The dip direction of rocks, faults and fractures determine the flow direction of water in springsheds. Such studies focusing the genesis of springs in relation to regional geology and structural features are lacking in Himalayan region. Therefore, the present study will focus on the genesis of springs and their variability along the major structural features in addition to identification the ionic sources and quality assessment of spring water.

Methodology

Field Work

- Identification of springs across the Bhagirathi river from Tehri to Harsil in a buffer zone of 02 km both side of the river.
- In-situ measurement of the physio-chemical parameters (pH, temperature, Dissolved oxygen, Oxidation Reduction Potential, and electrical conductivity) in water using portable measuring kits.
- Collection of water samples from springs in pre-monsoon and post monsoon seasons for the analyses of water for major ions, trace metals and stable isotopes in the laboratory.
- Measurement of discharge of some selected springs.
- Collection of necessary hydrological and climatic data from various Government and private organizations.

Laboratory Work

- Measurement of major ions including fluoride, chloride, sulphate, phosphate, nitrate, sodium, potassium, ammonium, magnesium, and calcium using Ion Chromatograph.
- Trace elements including iron, copper, cobalt, nickel, arsenic, manganese, zinc, chromium, beryllium, and lithium will be measured using IC-PMS.
- Analysis of stable isotopes of oxygen ($\delta^{18}O$) and hydrogen (δD) using IRMS.
- Preparation of geology, structure, and spring location and LULC maps using previous published records, data collected during field survey and high-resolution satellite imageries. Springs will be characterize based on the information collected during field survey and lab analysis. Vulnerable springs will be identified based on the collected parameters. Potential zone for recharge will be identified based on the various analysis to maintain the discharge of selected vulnerable springs.

Sl. No.	Activity	1st Year				2nd Year				3rd Year			
1	Desk preparation												
2	Survey of Springs												
	Chemical and isotopic analysis of spring water												
3	Identification of Vulnerable Spring												
4	Identification of geological structure of the area and their field verification (Lineament, Fault, fractures etc.)												
5	Development of various GIS layers and digital database of the study area												
6	Rainfall and Spring discharge measurements												
7	Identification of possible recharge zones in the study area												
8	Synthesis of report												

Final Outcome

The present research will be helpful to provide a database of the hydrogeochemical conditions of the area and can be summarized in the following possible outcomes:

- Preparation of inventory for the presence of springs in the proposed study area.

- Identification of the role of chemical/physical weathering and anthropogenic activities on the chemical characteristics of water in the catchment area.
- Determination of the suitability of water used for drinking purposes.
- Suggestion for possible remedial measures for improving the water quality and discharge of springs in the area if required.

Budget estimates

a. The total cost of the project (03 Years duration): **Rs 34.90 lakh**
b. Source of funding: Internal funding from NIH
c. Sub Head wise abstract of the cost:

S. No.	**Head**	**Amount (Rs)**
1	Salary (01 Resource Person (Junior) @25000/month and 01 Highly skilled daily wager @ 20000/month for entire project duration)	16,20,000
2	Travelling expenditure	8,00,000
3	Infrastructure/Equipment	1,70,000
4	Consumables (Chemicals and plastic wares)	6,50,000
5	Capacity building (Workshop for stakeholders)	1,00,000
5	Contingency	1,50,000
Total		**34,90,000**

3. PROJECT REFERENCE CODE: NIH/HID/R&D/2023/3

Study Title:: **Feasibility of Open Sources Data for the Estimation of Runoff and Water Storage Capacity for Rainwater Harvesting Strategies**

Thrust Area under XII five-year plan: Sustainable water systems management: Adaptation of hydro-system to climate change

Project team: Santosh M. Pingale (PI), Soban Singh Rawat, S.D. Khobragade, Rajeev Gupta

Type of Study: Internal R&D study

Duration: 2 years

Date of Start: 1st April, 2023

Date of Completion: 31st March, 2025

Budget: Rs. 18.88 Lakh

Statement of the Problem

The ultimate aim of this study is to understand the complexity of the different resolutions data on surface runoff and water storage capacity estimation of the rain water harvesting structures in the catchments. This study will do quantitative & volumetric assessment of runoff and water storage capacity in the water harvesting structures such as check dams. The outcome will be useful for making effective for Rainwater Harvesting Strategies. This quantification and volumetric assessment is more important for accurate estimates and understanding the magnitude of runoff and storage capacity of the rainwater harvesting structures in the catchment. Therefore, this study will be useful for local community, policy makers, Engineers and administration for appropriate management and adopting suitable measures in making rainwater harvesting strategies in the catchments.

Objectives

General objective

The general objective of the present study is to assess the feasibility of open sources data for the estimation of runoff and water storage capacity for the rain water harvesting strategies.

Specific objectives:

The present study will be carried out with the following objectives:

6. To estimate the surface runoff in the catchments using different sources of data.
7. To develop Intensity-Duration-Frequency (IDF) curves for different return periods of rainfall and flow duration curves for sustainability analysis of the streamflow.
8. Estimation of water storage capacity of the water harvesting structures by different sources of topographic data.
9. Quantification & volumetric assessment of runoff and water storage capacity for Rainwater Harvesting Strategies

Study area

The present study will be carried out for the selected structures and catchments considering Plain and Hilly terrain of Uttarakhand State.

Methodology

The proposed methodology has been described here:

a. The catchments will be selected where water harvesting structures are already available for its quantitative & volumetric assessment.
b. Two catchments will be selected, which represents the plain and hilly terrain for the present study.
c. The surface runoff (Peak rate and total volume) will be estimated by using Rational method and SCS curve number method.
d. These will be estimated using different sources of topographic data while other datasets will be taken same.

e. The Intensity-Duration-Frequency (IDF) curves for different return periods of rainfall and flow duration curves for sustainability analysis of the streamflow will be developed for safe design of rainwater harvesting structures.
f. The water storage capacity of the water harvesting structures will be estimated by different sources of topographic data and different hydrological modelling tools.
g. Also, quantification & volumetric assessment of runoff and water storage capacity will be carried out for making Rainwater Harvesting Strategies in the catchments.
h. Finally, suitable recommendations and appropriate sources of data will be quantified for making rainwater harvesting strategies in the catchments.

Research outcome from the project

- ✓The quantification and volumetric assessment of different sources and scale of topographical data on surface runoff estimation in terms of total volume and peak rate of runoff estimations.
- ✓Also, the accurate quantification and volumetric assessment of water storage capacity of the water harvesting structures based on different sources and scale of topographical data.
- ✓Development of IDF curves, which can be used in the safe design of hydrologic, hydraulic, and water resource systems; and flow duration curves, which can be used for estimation of dependable flows for water availability and distribution planning in the catchment area.
- ✓The outcome and procedures of estimates will be useful for Policy Makers, Engineers and Planners and various stakeholders for soil and water conservation activities in the different catchment areas.

Budget estimates

a. The total cost of the project: **Rs. 18.88 Lakh**
b. Source of funding: Internal funding
c. Sub Headwise abstract of the cost

Table 1 Tentative estimates of the Project

S.N.	Sub-head	Justification	Year 1 (2023-24)	Year 2 (2024-25)	Total (Rs)
1	Manpower	1 Project Associate-I (INR 31000+HRA per month) for field assistance, data collection & analysis	4,05,480	4,05,480	8,10,960
2	Fieldwork/ Travel	Includes taxi hire charges, accommodation, DA, Porter & labour charges etc.	4,03,000	4,03,000	8,06,000
3	Contingency		50,000	50,000	1,00,000
	TOTAL		**8,58,480**	**8,58,480**	**17,16,960**
	Overhead	**10%**	85,848	85,848	1,71,696
Grand Total			**9,44,328**	**9,44,328**	**18,88,656**

d. Details of Budget components

Justification for Sub-head-wise abstract of the cost

Salary: Full time **Project Associate-I** (@Rs 31,000/month+HRA for two years) for field assistance, data collection & analysis at the selected project sites.

Travel: Extensive field work would be essential for topographic and geophysical survey, data collection, monitoring of sites and ground truth survey in the study area

SN	Travel	No. of persons	Total
1	DA	5	2,50,000
2	Accommodation	5	2,40,000
3	Porter	2	96,000
4	POL/Taxi	Lump sum	2,00,000
5	Contingency		50,000
		Total	**8,06,000**

Note: Calculated for 10 days of field work in 2 years

Equipment: The required data will be procured from IMD, NRSA and other State government agencies. In addition, Automatic Water Level recorder (02) and other instruments have been planned to utilize for carrying out detailed study from the HI Division.

Work Schedule:

a. Probable date of commencement of the project: April, 2023
b. Duration of the project:02 Years
c. Stages of work and milestone:

S.N.	**Work Element**	**1st Year**				**2nd Year**			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Site Selection & literature review								
2	Data collection (e.g. hydro-meteorological data, satellite imageries)								
3	Creation of GIS data base of selected sites/catchments								
4	Field data collection and survey of selected sites and catchments								
5	Collection and analysis of field data								
6	Surface runoff estimation by different sources of topographic data								
7	Development of IDF and FD curves								
8	Storage capacity estimation of water harvesting structures by different sources of topographic data								
9	Quantification & Volumetric Assessment for Rainwater Harvesting Strategies								
10	Report writing								
11	Dissemination of results/Scaling out plan								

4. PROJECT REFERENCE CODE: NIH/HID/R&D/2023/3

Study Title:	**Sedimentation and Water Quality Studies of Phulahar Lake, Pilibhit (U.P.)**
Project team:	Rajeev Gupta, Sc-B (PI), Dr. S D Khobragade, Scientist-G Dr. S M Pingale, Scientist-D
Type of Study:	Institute Funded R & D Study
Duration:	**2 years**
Date of Start:	01st April, 2023
Date of Completion:	31th March, 2025
Budget:	**15.00 Lakh**

Background and Statement of Problem:

The discharge in Gomti river has reduced significantly in recent years due to reduced outflow from Phulhar lake which is its source. The State Govt want to conserve and rejuvenate the Phulahar lake for which notification has also been issued. It has decided to carry out joint studies on Phulahar lake by few organizations. It has approached and requested NIH for conducting the Bathymetric studies of the lake. Further, there are around 26 different type of Tortoise present in the Phulahar Lake. The State Govt wants to protect these tortoises for which it is interested in water quality studies of the lake.

Objectives:

i) To determine the bathymetry of the lake
ii) To estimate sedimentation rate and expected life of the Lake
iii) To assess the environmental health of the Lake through assessment of its water quality

Study Area

The Phulahar lake is located 3 km east of the Pilibhit Town in Uttar Pradesh at an elevation of 185 m. It is the source of the Gomti river. Around 26 different type of Tortoise are known to be present in the Phulahar Lake. The state administration is developing a Tortoise conservation and research centre at nearby lake area.

Justification for the study

The present study has been proposed keeping in view the requirement and request of the state government of Uttar Pradesh.

Methodology

(i) Bathymetric survey of the lake
(ii) Collection of sediment cores and its analysis for Cs-137 activity
(iii) Field surveys
(iv) Sample collection and laboratory analysis for water quality assessment

Research outcome/Deliverable from the project

i) Comprehensive Project Report including all data, maps, information, analysis and results.
ii) Research Publications

Beneficiary/End User

The findings of the study would be used by the State Administration for development and conservation of the lake

Budget: 15.00 Lakh

The details of the budget are as follows:

S.N.	Budget Head	Total Amount Rs (lakh)
1	Remuneration/Emoluments for other staff (Highly skilled worker/field assistsnst) for 24 months	5.0
2	Travelling Expenditure(about 10 visits)	4.0
3	Experimental Charges/Field Work/Consumables	4.0
4	Contingency	2.0
	Total	**15.0**

Details of the Budget :

Remuneration:

of the 2 part time field Assistants @ 10000/- per person per month for 24 months = 4.80 say **500000.00**

Travelling Expenses :

S N	Travel	Amount
1.	Travel Expenses including DA, Accommodation	200000.00
2.	Taxi Hiring Charges	200000.00
	Total	400000.00

Field Work/Consumables:

S.N	Field Work / Consumables	Amount
1.	Consumables like water sample bottles, chemicals, Battery, ziplock bags, stationery items etc	200000.00
2.	Field work expenses like labour, boating, Portar Charges	100000.00
3.	Misc Charges	100000.00
	Total	400000.00

Work Plan/Activity Chart:
As given in activity schedule below. :

ACTIVITY SCHEDULE

SN	Activity	Year- I				Year- II			
		1	2	3	4	1	2	3	4
1.0	**PREPARATORY WORK**								
1.1	Recconasance survey & finalization of various sampling locations	√							
1.2	Collection & Review of all available data/information	√	√						
1.3	Preparation of basic maps of lake and catchment	√	√						
2.0	**FIELD WORK**								
2.2	Collection of water samples for water quality analysis	√	√	√	√	√	√		
2.4	Collection of sediment cores			√					
2.7	Bathymetric Survey of lake			√					
3.0	**LABORATORY ANALYSIS**								

3.1	Analysis of samples for Water Quality		√	√	√	√	√	√	
3.3	Dating of sediment samples				√	√	√		
4.0	**DATA INTERPRETATION & ANALYSIS**								
4.1	Processing of bathymetric data				√	√	√		
4.2	Development of depth-area-capacity curve for the lake						√		
4.3	To estimate sedimentation rate of the lake						√		
4.11	To assess the water quality of the lake			√		√		√	
4.12	Assessment of suitability of lake water for various uses								
5.0	**PREPERATION OF REPORT**								
5.1	Preparation of Draft Report				√				
5.2	Preparation of Final Project Report								√

SURFACE WATER HYDROLOGY DIVISION

Scientific Manpower

S N	Name	Designation
1	Dr. A K Lohani	Scientist G & Head
2	Dr. S K Singh	Scientist F
3	Dr. P C Nayak	Scientist F
4	Dr. Sanjay Kumar	Scientist F
5	Dr. Archana Sarkar	Scientist F
6	Dr. L N Thakural	Scientist D
7	Er. J P Patra	Scientist D
8	Dr. Ashwini A. Ranade	Scientist D
9	Sri N K Bhatnagar	Scientist B
10	Sri Om Prakash	Scientist B

APPROVED WORK PROGRAM FOR THE YEAR 2022-23

COMPLETED STUDIES (SPONSORED)			
S. No. & Ref. Code	**Title**	**Study Team**	**Duration**
1. NIH/SWHD/19-23	Dam break studies of Kandaleru and Pulichintala dams in Andhra Pradesh (NHP)	P C Nayak Y.R.Satyaji Rao A.K. Lohani B. Venkatesh A. R. S. Senthil Kumar T. Thomas	3 year (Sept 2019 to Nov 2022) Completed

ONGOING STUDIES (SPONSORED)			
S. No. & Ref. Code	**Title**	**Study Team**	**Duration**
1. NIH/SWHD/20-23 MoE-STARS/STARS-1/743	Operational coastal flood management through short-to-medium range (real-time) flood vulnerability mapping in the Brahmani-Baitarani River Basin integrating human and climate induced impacts (Funded under STARS by MHRD, GoI)	B. Sahoo, (PI, IIT-Kgp) R. V. Kale, (Co-PI)	03 years (July, 2020 – June, 2023) *(To be transferred from WHRC Jammu to SWHD NIH Roorkee*)

COMPLETED STUDIES (INTERNAL)			
S. No. & Ref. Code	**Title**	**Study Team**	**Duration**
1.NIH/SWHD/20-22	Probabilistic dam break flood wave simulation and flood risk assessment for preparation of EAP for Mahi Bajaj Sagar dam in Rajasthan.	J.P. Patra Pankaj Mani A.K. Lohani Sunil Gurrapu Rakesh Kumar	2 years (July 2020 to August 2022) Completed, Draft report prepared
2.NIH/SWHD/21-23	Uncertainty in rating curves and discharge estimation	Sanjay Kumar L. N. Thakural Sunil Gurrapu N.K. Bhatnagar J P Patra	2 Years (April 2021 to March 2023) Completed
3.NIH/SWHD/22-22	Application of unified-extreme-value (UEV) distribution for flood frequency: selected rivers of U.S.A	S.K. Singh	Six month (April 2022 to Sept. 2022) Extension up to 31March2023
4.NIH/SWHD/22-23	Application of unified-extreme-value (UEV) distribution for flood frequency: Comparison of results using GEV distribution	S.K. Singh	Six month (Oct. 2022 to March 2023)

ONGOING STUDIES (INTERNAL)			
S. No. & Ref. Code	**Title**	**Study Team**	**Duration**
1.NIH/SWHD/22-24	Development of Cloud Data Based Integrated Framework to Forecast Flood for Efficient Operation of Reservoirs	A. K. Lohani R. K. Jaiswal J.P. Patra P. C. Nayak Vishal Singh	Two Years April 2022 – March 2024
2.NIH/SWHD/22-24	Flood Forecasting under Changing Climate Conditions - Role of Machine Learning and Conceptual/Physical based Model	P. C. Nayak A. K. Lohani J. P. Patra Sunil Gurrapu T. Thomas Om Prakash Jatin Malhotra	3 Year (July 2022 to June 2025)
3.NIH/SWHD/22-25	Hydrological Study to conserve the water resources of Bikaner, Rajasthan	L. N. Thakural M. K. Shama R. K. Jaiswal J. P. Patra P. K. Mishra Nitesh Patidaar N. K. Bhatnagar Jatin Malhotra Anil Kumar Chhangani	2 Year (July 2022 to June 2024)
4.NIH/SWHD/22-24	Review of design flood and dam break analysis of Khadakhai Dam in Odisha	J.P.Patra A. K. Lohani Pankaj Mani P. C. Nayak Sanjay Kumar Jatin Malhotra	3 Year (April 2022 to March 2025)
5.NIH/SWHD/22-25	Investigation on occurrences of seasonal extremes across Northwest Himalaya in relation to global atmospheric thermal and circulation changes	Ashwini Ranade P.K. Mishra Sunil Gurrapu	3 years (April 2022 to March 2025)
6.NIH/SWHD/22-23	Investigating gap areas, current trends and future directions of research in Climate Change Impact on Hydrology and water Resources in India through Scientometrics	Archana Sarkar Jyoti Patil Rohit Sambare Charu Pandey	1.5 Year (May 2022 to Oct 2023)
7.NIH/SWHD/21-24	Investigation of hydrodynamic approach of flood inundation mapping along with assessment of changes in river planforms using a cloud-based Google Earth Engine (GEE) computing platform in data-scarce Western Himalayan River basin	R. V. Kale A. K. Lohani J. P. Patra D. Khurana	03 Years (September 2021-October 2024)

PROPOSED WORK PROGRAMME OF SWHD FOR THE YEAR 2023-24

ONGOING STUDIES (SPONSORED)			
S. No. & Ref. Code	**Title**	**Study Team**	**Duration**
1. NIH/SWHD/20-23 MoE-STARS/STARS-1/743	Operational coastal flood management through short-to-medium range (real-time) flood vulnerability mapping in the Brahmani-Baitarani River Basin integrating human and climate induced impacts (Funded under STARS by MHRD, GoI)	B. Sahoo, (PI, IIT-Kgp) R. V. Kale, (Co-PI)	03 years (July, 2020 – June, 2023) *(To be transferred from WHRC Jammu to SWHD NIH Roorkee*)

ONGOING STUDIES (INTERNAL)			
S. No. & Ref. Code	**Title**	**Study Team**	**Duration**
1.NIH/SWHD/22-24	Development of Cloud Data Based Integrated Framework to Forecast Flood for Efficient Operation of Reservoirs	A. K. Lohani R. K. Jaiswal J.P. Patra P. C. Nayak Vishal Singh	Two Years April 2022 – March 2024
2.NIH/SWHD/22-24	Flood Forecasting under Changing Climate Conditions - Role of Machine Learning and Conceptual/Physical based Model	P. C. Nayak A. K. Lohani J. P. Patra Sunil Gurrapu T. Thomas Om Prakash Jatin Malhotra	3 Year (July 2022 to June 2025)
3.NIH/SWHD/22-25	Hydrological Study to conserve the water resources of Bikaner, Rajasthan	L. N. Thakural M. K. Shama R. K. Jaiswal J. P. Patra P. K. Mishra Nitesh Patidaar N. K. Bhatnagar Jatin Malhotra Anil Kumar Chhangani	2 Year (July 2022 to June 2024)
4.NIH/SWHD/22-24	Review of design flood and dam break analysis of Khadakhai Dam in Odisha	J.P.Patra A. K. Lohani Pankaj Mani P. C. Nayak Sanjay Kumar	3 Year (April 2022 to March 2025)
5.NIH/SWHD/22-25	Investigation on occurrences of seasonal extremes across Northwest Himalaya in relation to global atmospheric thermal and circulation changes	Ashwini Ranade P.K. Mishra Sunil Gurrapu	3 years (April 2022 to March 2025)
6.NIH/SWHD/22-23	Investigating gap areas, current trends and future directions of research in Climate Change Impact on Hydrology and water Resources in India through Scientometrics	Archana Sarkar Jyoti Patil Rohit Sambare Charu Pandey	1.5 Year (May 2022 to Oct 2023)

7.NIH/SWHD/21-24	Investigation of hydrodynamic approach of flood inundation mapping along with assessment of changes in river planforms using a cloud-based Google Earth Engine (GEE) computing platform in data-scarce Western Himalayan River basin	R. V. Kale A. K. Lohani J. P. Patra D. Khurana	03 Years (September 2021-October 2024)

NEW STUDIES (INTERNAL)			
S. No. & Ref. Code	**Title**	**Study Team**	**Duration**
1.NIH/SWHD/23-25	Estimation of confidence intervals of index flow duration curves	Sanjay Kumar, Sunil Gurrapu L. N. Thakural J. P Patra	02 Years (April 2023 to March 2025)
2. NIH/SWHD/23-24	Hydraulic force-inversion equation for exact modeling of hydraulic jumps in rectangular channels	Sushil K. Singh	One Year (April 2023 to March 2024)

COMPLETED STUDIES (SPONSORED)

1. PROJECT REFERENCE CODE: NIH/SWHD/19-23

Project Title: Dam break studies of Kandaleru and Pulichintala dams in Andhra Pradesh

Principal Investigator	: P C Nayak, Y.R.Satyaji Rao, A.K. Lohani, B. Venkatesh, A. R. S. Senthil Kumar, T. Thomas
Budget and Funding	: Rs. 55.6 lakhs
Period	: 3 year (Sept 2019 to Nov 2022)
Funding Agency	: NHP
Status	: Completed

Objectives:

- Dam break analysis of Kandaleru and Pulichintala dam using HEC-RAS. The study includes the sensitivity analysis for dam breach parameters.
- Computation of flood hydrograph and water level at different cross-sections.
- Assessment of flood inundation extent and water depth at different places in the downstream of dam.

Overall progress of the Study:

The Pulichintala Dam is a distinguished dam situated in Guntur district of Andhra Pradesh state. It is a Concrete dam constructed on Krishna river. The dam has a height of 42.24 m and length of 2922 m. The latitude and longitude of this dam are $16^0 46' 14''$N and $80^0 03' 33''$ E respectively. Kandaleru reservoir is mainly fed by a link canal from the Somasila dam. The Telugu Ganga project also provides irrigation water in Andhra Pradesh. It is an earthen dam of 10 km length and falls between latitude $14^0$16’57.26 N” and longitude of $79^0$36’28.70 E”. The river cross-section for upto a distance of 85 km for Pulichintala and 10 km for Kandaleru was used in the study. For Pulichintala dam the generated peak hydrograph is 121368.90 m^3/s and 59,209.70m^3/sec for Kandaleru. Sensitivity analysis is performed for breach width, breach formation time, PMF change and for roughness coefficient by varying with pre-defined percent change. Based on the study, a flood inundation map is prepared for both the dams. The inundated area for Pulichintala dam is 1980.984 sq.km. which would affect population about 2,170,385 and for Kandaleru dam is 45.68 sq.km affecting a population of about 8,826. The probable population affected in the downstream of Pulichintala dam break is about 2,170,385 and for Kandaleru dam break is about 8,826.

The figures showed below gives the inundation map to the downstream of dam location and hydrograph plot for different places. Fig1 and 2 shows the result of Pulichintala dam and Fig 3 and 4 shows the result of Kandaleru dam.

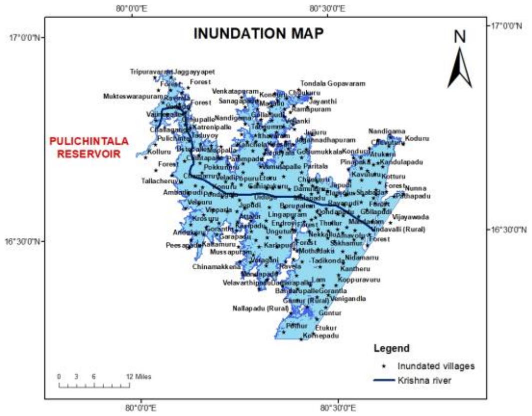


Fig1: Inundation map of Pulichintala dam barrage

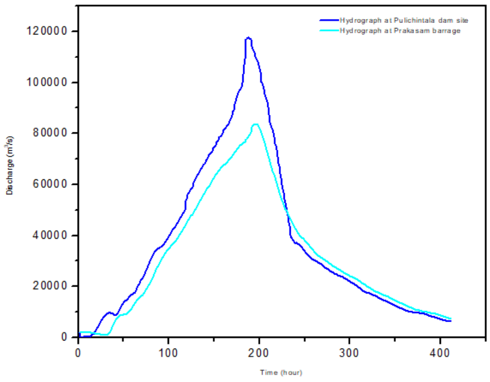


Fig2: Hydrograph at dam and Prakasam

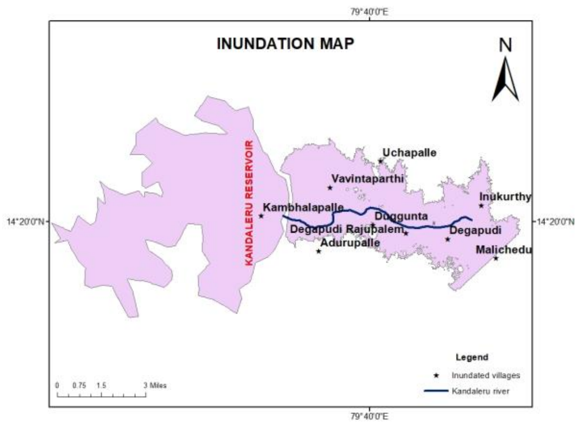


Fig3: Inundation map of Kandaleru dam

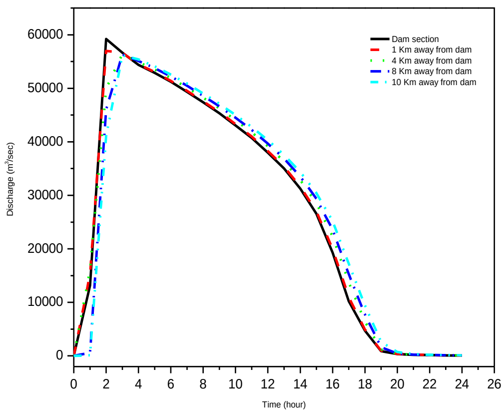


Fig4: Hydrograph at dam and different location

Objective vis-a-vis Achievement

As mentioned in the objectives, dam break analysis using HEC-RAS model has been carried for Kandaleru and Pulichintala dam. Flow hydrograph has been generated at different location downstream of the dam up 10 km. and 85 km for Kandaleru and Pulichintala dam respectively Sensitivity analysis has been carried out for breach widths, changing breach formation time, changing roughness coefficient.

Progress since last meeting

The study has been completed and draft report submitted.

ONGOING STUDIES (SPONSORED)

1. Project Code: MoE-STARS/STARS-1/743

Title of the Project:	Operational coastal flood management through short-to-medium range (real-time) flood vulnerability mapping in the Brahmani-Baitarani River Basin integrating human and climate-induced impacts
Project Team:	B. Sahoo, (PI, IIT-Kgp) R. V. Kale, (Co-PI, NIH Roorkee)
Collaborating agency	IIT Kharagpur
Type of Study	Sponsored by MoE under STARS Project
Duration	4 years
Date of Start	July 2020
Date of Completion	June 2024
Budget	56 Lakh (IIT KgP)

Statement of Problem

The inter-state Brahmani-Baitarani river basin is the second largest in Odisha which has undergone rapid industrialization and mining activities with the issues of flood havocs during monsoon season and reduced low flows during non-monsoon periods. This coastal river basin of the Bay of Bengal is flood prone due to its flat low-lying topography with flash floods, highly meandering dendritic drainage pattern, backwater effects from sea-surges, climate induced extreme precipitation and tropical cyclone, sea level rise, subjective reservoir operation, increased upstream river flux due to rapid urbanization, shifting cultivation practices, and floodplain encroachment reducing the river carrying capacity. Therefore, to aid for operational flood disaster management, this study proposes to develop a short-to-medium-range flood forecasting system accounting for all the aforementioned factors for an accurate real-time flood vulnerability mapping of the coastal Brahmani-Baitarani river basin. This method involves mapping of the delta region taking into account compound effect of rainfall, storm surge and upstream discharge.

Objectives:

a) Assessment of historical flood inundation and sedimentation scenarios in the study area through field survey, secondary data, and remote sensing approaches
b) Detection of historical changes in land use and river cross-sections due to sedimentation and anthropogenic activities using survey data and satellite imageries
c) Forecasting of inflows into and releases from the Rengali/Mandira reservoirs in real-time up to 10-days lead-time accounting for the effects of urbanization, paddy land use, and river sedimentation
d) Forecasting the tidal effect / sea-surges at the river-ocean confluence in the Bay of Bengal
e) Simulation of real-time 2-D flood inundation mapping in the deltaic river basin considering upstream streamflow forecasts, stream-aquifer exchange fluxes, and downstream tidal /sea-surge forecasts up to 10-days lead time.
f) Development of flood vulnerability maps in real-time (up to 10-days advance) for operational flood management using UNESCO-IHE guidelines

Brief Methodology

This study can be separated into four major categories viz., Land-surface process modeling, reservoir modeling, coastal flood plain dynamics, and ocean melding. In land-surface modeling SWAT Pothole model will be used with an error correction sub model to improve the streamflow forecast for future time period with different lead periods. Then streamflow information will be used in the reservoir operation modeling to reduce the flood peak and hydropower generation. Further the simulated release from the reservoir will be used for flood mapping in the delta region of the Brahmani-

Baitarani River basin by accounting the tidal surge generated using ADCIRC+SWAN. The vulnerability map will be generated for different lead-time taking into account the UNESCO-IHE guidelines.

Study Area

The study area consists of the Brahmani and Baitarani River basins (Figure –1), extends over the states of Odisha, Jharkhand and Chhattisgarh having an area of 51,822 km^2 which is nearly 1.7% of the total geographical area of the country with a maximum length and width of 403 km and 193 km. It lies between 83°55' to 87°3' East longitudes and 20°28' to 23°38' North latitudes. The basin is bounded by the Chhotanagpur Plateau on the north, by the ridge separating it from Mahanadi basin on the west and the south, and by the Bay of Bengal on the east. The Brahmani sub basin covers 39,033 km^2 and has a long sausage shape.

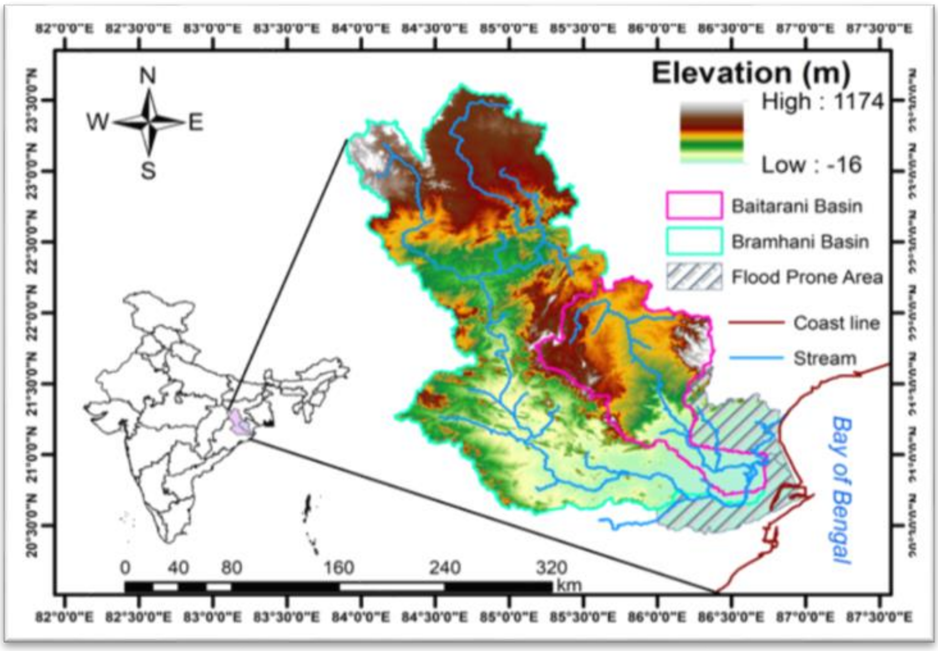


Figure –1. Elevation map of the Brahmani and Baitarani River basins.

The Baitarani sub-basin extends over 12,789 km^2 and is roughly circular in shape. The Brahmani, known as South Koel in its upper reaches, rises near Nagri village in Ranchi district of Jharkhand at an elevation of about 600 m. The river has a total length of 799 km. In its tail reach, the river is known as Maipura. The Baitarani River rises near Dumuria village in the hill ranges of Kendujhar district of Odisha at an elevation of about 900 m and has a length of about 355 km. The river is known as Dhamra in its lower reaches. The important tributaries of Brahmani joining it from left are the Karo, and the Sankh whereas the Tikra joins from the right. The main tributaries of Baitarani joining from the left are the Salandi and the Matai. Brahmani and Baitarani form a common delta area before outfalling into the Bay of Bengal. The major part of the basin is covered with agricultural land accounting to 52.04% of the total area and 2.95% of the basin is covered by water bodies. The basin spreads over 16 parliamentary constituencies (2009) comprising 10 of Odisha, 4 of Jharkhand, and 2 of Chhattisgarh.

Action Plan

Milestone/ Activity	July-Dec 2020	Jan-Jun 2021	July-Dec 2021	Jan-Jun 2022	July-Dec 2022	Jan-Jun 2023	July-Dec 2023	Jan-Jun 2024
Objective-1								
Objective-2								

Objective-3								
Objective-4								
Objective-5								
Objective-6								

Achievements vis-à-vis Objectives

Objectives	Achievements
Assessment of historical flood inundation and sedimentation scenarios in study area through field survey, secondary data, & remote sensing approach	Completed
Detection of historical changes in land use and river cross-sections due to sedimentation and anthropogenic activities using survey and satellite data	Completed
Forecasting of inflows into and releases from the Rengali/Mandira reservoirs in real-time up to 10-days lead-time accounting for the effects of urbanization, paddy land use, and river sedimentation	completed
Forecasting the tidal effect / sea-surges at the river-ocean confluence in the Bay of Bengal	Completed
Simulation of real-time 2-D flood inundation mapping in the deltaic river basin considering upstream streamflow forecasts, stream-aquifer exchange fluxes, and downstream tidal /sea-surge forecasts up to 10-days lead time.	In-progress
Development of flood vulnerability maps in real-time (up to 10-days advance) for operational flood management using UNESCO-IHE guidelines	

Progress of work

Objective (a)

Task #1: Collection and analysis of historical flood data over the Brahmani-Baitarani delta

- One SRF has been posted
- Secondary data collection and remote sensing data procurement is completed

Task #2: Procurement and analysis of meteorological data and satellite imageries

- In order to assess the flooding due to extreme monsoon-precipitation, daily data at all available rain gauge stations as well as event-scale sub-hourly precipitation data are procured from 8 meteorological stations. For the flood mapping of historical events, the LISS-III and LISS-IV, SAR data for selected historical flood event has been procured from NRSC. The input data required for modelling for all the main revisors in Brahmani- Baitarani river system has been collected and processed. Further, the radar data available for the coastal area will be collected. Some of the other required data has been already procured/collected from respective government agencies.

Task #3: Preparation of Flood Maps of recent flood events

Satellite imageries were processed to determine the flood-affected areas during the recent floods in the basin. For this, the events of May 2021, July 2017, and July 2015 were chosen based on the availability of Sentinel satellite imageries. The results of the satellite image-based flood inundation mapping are presented in **Table –1** in the form of total inundated area and inundated crop area.

Table 1 Selected historical flood events in the Brahmani and Baitarani basin delta

Date	Total inundated area (km^2)	Crop area inundated (km^2)
15 July 2016	1054.8	719.6
25 July 2017	1471.8	819.1

25-26 May 2021	136.0	27.2

Concluding Remarks of Objective #a: It is evident that there is a frequent occurrence of floods in the coastal region of Brahmani and Baitarani Basin. In the last 5 years, three major floods have occurred in the coastal plains creating major damages to the property and life. Flood event occurred in the month of July in 2016 inundated nearly 1054 Km^2 of landmass including cropland of 719 km^2. After a gap of 1 year, another major flood took place affecting a total landmass of 1471 km^2 including cropland of 819 km^2. Recently in May, 2021 the flood was caused due to cyclone 'Yaas', inundating 136 km^2.

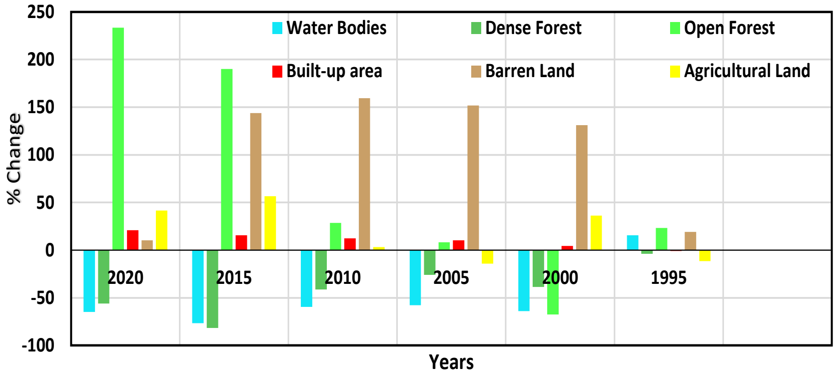
Objective (b)

Task #1:

- The CartoDEM with10 m resolution has been procured from NRSC.
- Work on historical change in river cross sections is going on.

Task #2: Preparation of Land Use and Land Cover Map

Anthropogenic activities have substantially changed natural landscapes, especially in regions that are extremely affected by population growth and climate change such as the Eastern part of India. Understanding the patterns of land-use and land-cover (LULC) change is important for efficient environmental management, including effective water management practice. Using remote sensing techniques and geographic information systems (GIS), this study focused on changes in LULC patterns of Brahmani and Baitarani River Basins for over 30 years. Multi-temporal satellite imageries of the Landsat series were used to map LULC changes. The LULC map is divided into 6 classes, i.e. Water bodies, Dense forest, Open forest, Built-up area, Barren land, and Agricultural land. Further, the soil map of the study area has been generated.



Concluding Remarks from Objective #b: Brahmani and Baitarani Basin have undergone major LULC changes. The dense forest has decreased up to 56% and the open forest has increased significantly up to 200%. Human interference can be seen clearly as the built-up area has increased substantially to 15%. Agricultural and barren lands have also experienced substantial changes of up to 150% and 50%, respectively.

Objective (c)

Flood forecasting plays a significant role in managing coastal flooding. In this study flood forecasting model is developed taking bias corrected Numerical weather prediction model forcings. The streamflow was simulated for using the SWAT model and a error forecasting sub-model was implemented to minimize the error. Streamflow forecast simulated by SWAT Pothole model is updated using an error correction model taking error time-series, i.e., $\varphi(t)$, $\varphi(t-1)$, ……, $\varphi(t-d)$ as input, which is obtained during the SWATP calibration phase; where $\varphi(t)$ is the simulated error between the observed (Q_{obs}) and SWATP estimated (Q_{sim}) discharge at any time, t, calculated as $\varphi(t) = Q_{obs}(t) - Q_{sim}(t)$. Where, d is the effectively correlated time lag obtained by auto-correlation function analysis of the error time series. The error-correction (forecasting) models are enlisted as: i) AutoRegressive (ARu); ii) AutoRegressive Moving Average with eXogenous inputs (ARMAXu), iii)

Wavelet-based neural network (WNNu); iv) Dynamic wavelet-based Non-linear AutoRessive with eXogenous inputs (WNARXu)

Concluding Remarks from Objective #c: Using an error forecasting model to minimize the random error helped to improve the streamflow forecast at different lead-time. The NSE improved and falls in the range of 0.84 to 0.75 for a lead day of 1 to 5, respectively.

Objective (d)

Cyclones that make landfall on India's east coast are likely to cause inland floods and need real-time surge warnings to ensure minimum damage. The state-of-the-art numerical-wave models are often used for simulating such wind-driven events in the ocean. The work attempts to explore the effectiveness of a tightly coupled ADCIRC-SWAN model to compute water surface elevations as a combined effect of wind, astronomical tides, and waves. For the computation of storm tide, the coupled ADCIRC-SWAN model has been run for two simulations namely SIM1 and SIM2. The surge-wave model is calibrated for tropical Cyclone Fani (SIM1), which made its landfall on 3rd May 2019. Another Cyclone Yaas (SIM2), which hit the Bay of Bengal on 24th May 2021, is used to validate the model. As there are not many tide-gauge stations in the study region, the Dhamra tide gauge, located near the banks of Brahmani is considered for validation purposes. The computed water levels are compared with the measured tide gauge levels.

Concluding Remarks from Objective #d: The coupled model produced a Nash-Sutcliffe Efficiency (NSE) coefficient of 0.85 during the SIM1 run and 0.83 during the SIM2 run which shows good robustness of the tightly coupled model in predicting ocean water surface elevations i.e., tides and surges.

Objective (e)

#HEC-RAS 2D model simulation

The trials are initially carried out to map flood inundation in the BBD (Brahmani-Baitarani Delta) during the Yaas cyclone, which made landfall to the north of Dhamra port as a result of storm tide, upstream discharge, and precipitation. At BBD mouth, the ADCIRC-SWAN estimated temporal tide values serve as a downstream boundary condition. The HEC-RAS model has been set-up of BBD using Copernicus DEM with 30 metres resolution. The perimeter of the 2D flow area is defined along the boundary of the BBD. Computational points are generated with a grid spacing of 90 meters. The model based on 2D diffusive wave equation is run for the same period in which the ADCIRC-SWAN model has been executed. The results of the flood inundation simulation in BBD are presented in Figure 5.7.

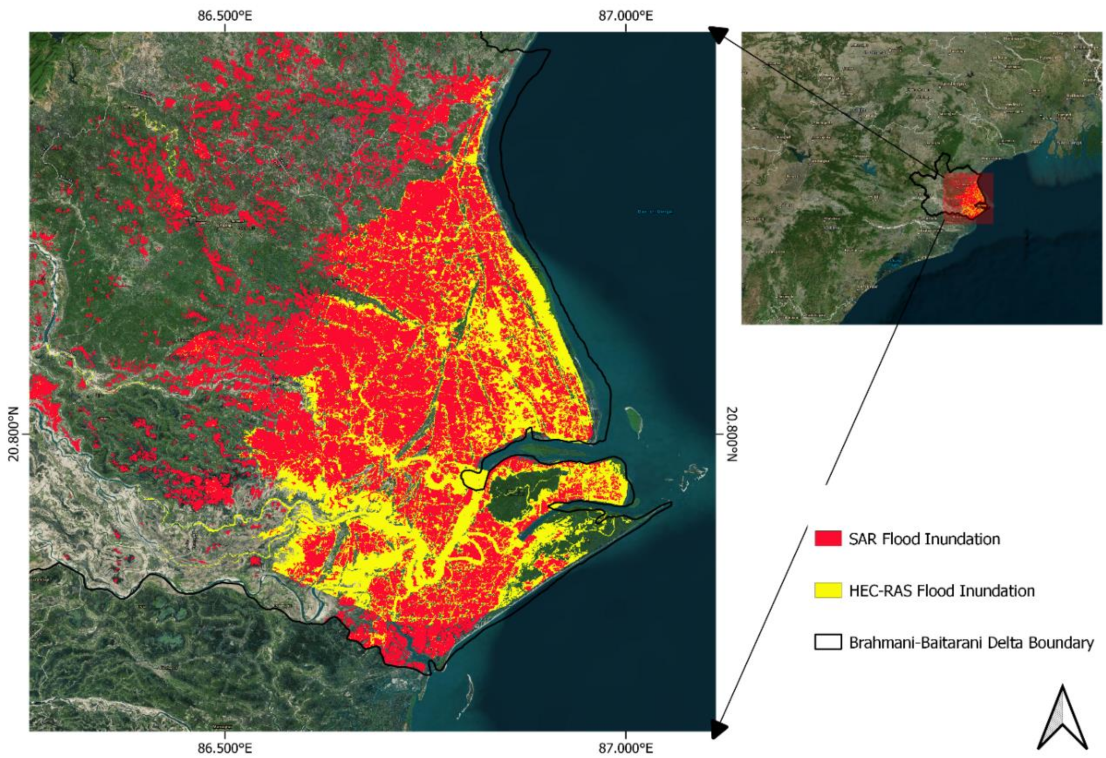


Figure 2. Flood inundation map of BBD generated based on HEC-RAS 2D simulation and SAR (Sentinel-1) extracted inundation extent.

Concluding Remarks from Objective #e: The flood inundation extent at BBD by HEC-RAS 2D model is shows an overall accuracy of 81.6% and Cohen's Kappa Coefficient of 0.63 as compared to those extracted from SAR satellite data.

Future Plan

- Simulation of real-time 2D flood inundation maps in the deltaic basin considering upstream streamflow forecasts with stream-aquifer exchange fluxes and downstream tidal/sea-surge forecasts up to 10-days lead-time:

- Development of flood vulnerability maps in real-time (up to 10-days advance) for operational flood management considering the guidelines of the UNESCO-IHE . The best combination of the models, adaptable to data-scarce situations, would be chosen through rigorous testing for developing the maps in real-time.

COMPLETED STUDIES (INTERNAL)

1. PROJECT REFERENCE CODE: NIH/SWHD/20-22

1. Title of the study
   Probabilistic dam break flood wave simulation and flood risk assessment for preparation of EAP for Mahi Bajaj Sagar dam in Rajasthan.
2. Study group:
   a. Project Investigator: J.P.Patra, Sc. – D, SWHD
   b. Project Co-Investigator: Pankaj Mani, Sc. – F, CFMS Patna
      A.K. Lohani, Sc. – G & Head SWHD
      Sunil Gurrapu, Sc. – C, SWHD
      Rakesh Kumar, Ex-Sc. – G & Head SWHD
3. Duration of study: 2 Years (Aug 2020 to Jul 2022) : Completed
4. Type of study: Internal.
5. Location map

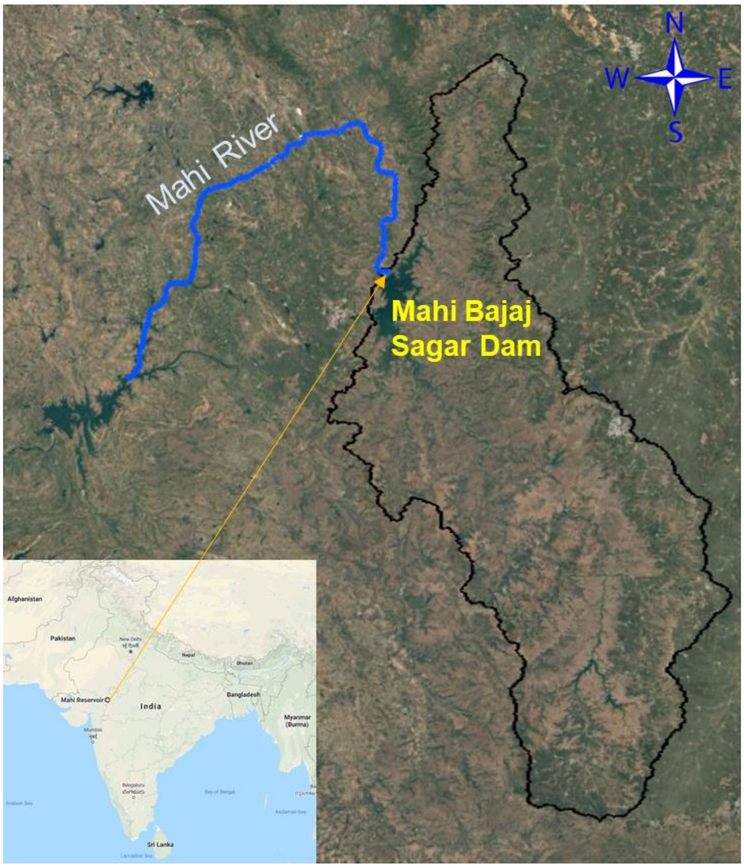


Figure 1: Location map of the study area

6. **Study Objectives**
   a. Estimation of probabilistic dam breach outflow hydrograph.
   b. Preparation of Exceedance Probability Inundation (EPI) Maps.
   c. Comparison outflow hydrographs due to level pool and dynamic routing of flows through the reservoir.
   d. Flood hazard and flood risk assessment due to Mahi Bajaj Sagar dam breach.

7. **Statement of the problem**
   Dams have played a key role in fostering rapid and sustained agricultural and rural growth and development in India. Over the last fifty years, India has invested substantially in dams and related infrastructure. In India about 5254 large dams have been completed and another 447 under construction (NRLD 2017). However, failure of these structures may lead to

catastrophic losses. In India there are 36 reported failures cases so far. The first such failure was recorded in Madhya Pradesh during 1917 when the Tigra Dam failed due to overtopping. The worst dam disaster was the failure of Machu dam (Gujarat) in 1979 in which about 2000 people have died. With increasing number of dams becoming older and older, the likelihood of dam failures in India is expected to be an ascending path. Considering these aspects India has undertaken the Dam Rehabilitation and Improvement Project (DRIP) to improve the safety and operational performance of selected existing dams in the territory of the participating states. Emergency Action Plan and flood inundation mas for the Dam are under preparation.

Dam breach modelling is a key component to a well-rounded and robust dam safety program. Various researcher and guidelines recommended combination of breach parameters. However, instead of mapping a large zone with equal probability of occurrence (either “in” or “out” of the flooding zone), modelling a full range of breach scenarios – from partial to complete, correlating the downstream impacts with a likelihood or probability of an area actually flooding would be of practical importance for dam owners. This risk-based approach arms decision makers with a probability based analysis map, would help them to visualize and prioritize actions in areas that are more likely to flood first. Such analysis would lead to smarter emergency action planning, allowing first responders and other agencies to stage critical resources such as disaster response team in key places to allow for systematic evacuation.

A flood hazard is an indication of the possible source of danger due to flooding. It, however, does not imply any risk unless persons or objects that are vulnerable to damage are exposed to it. The various hazards to be mapped include themes like the flood inundation areas, water depths and velocities, and arrival times of flood waves. Various guidelines and recommendations have been prepared under the DRIP for classifying hazard to people, vehicle, buildings etc. Moreover, combined flood hazard maps can be developed from the relationships of flood depth and velocity. Traditionally, floodplain management in India is dominated by the hazard-based method. The severity of the risks is directly proportional to the significance of the impacts of flooding i.e., the consequences of flooding. Limiting the flood hazards and reducing the degree of vulnerability to the flood impacts (such as proneness to water and velocity damage) may significantly reduce the consequences of flooding. Better management of future flood risk aims at reducing potential losses.

8. Approved action plan and timeline

S.N.	Work Element	1st Year				2nd Year			
1	Collection of basic data, topography, cross-section, satellite images, thematic maps etc.	■	■				■		
2	1-D level pool dam breach model setup.		■	■	■				
3	Quantification difference between level pool routing and full unsteady flow routing.				■	■			
4	Generation of probabilistic breach parameters		■	■		■			
5	Estimation of probabilistic dam breach outflow hydrograph.				■	■	■		
6	Preparation of Exceedance Probability Inundation (EPI) Maps.						■	■	
7	Combined general flood hazard classification and preparation of Flood Hazard Maps.							■	■
8	Risk identification.								■

S.N.	Work Element	1st Year				2nd Year			
9	Estimation of Population at risk and potential loss of life.								■
10	Workshop/ Training.							■	
11	Report.				■				■

9. **Role of team members**

S. N.	Role / Action	Member/(s)
1	Collection of basic data, topography, cross-section, satellite images, thematic maps etc.	JPP, PM, TRS
2	Compilation and analysis of data, satellite images	JPP, PM
3	1-D level pool dam breach model setup	JPP, PM
4	Quantification difference between level pool routing and full unsteady flow routing.	JPP, PM, AK
5	Generation of probabilistic breach parameters	JPP, RK, SG
6	Estimation of probabilistic dam breach outflow hydrograph	JPP, RK, SG
7	Preparation of Exceedance Probability Inundation (EPI) Maps.	PM, JPP, SG
8	Combined general flood hazard classification and preparation of Flood Hazard Maps.	JPP,PM
9	Risk identification, estimation of Population at risk and potential loss of life.	JPP,PM, SG, RK
10	Report	JPP,PM, SG, TRS

JPP = J. P. Patra, RK = Rakesh Kumar, AK = A. K. Lohani, PM = Pankaj Mani, SG = Sunil Gurrapu, TRS =T. R. Sapra

10. **Brief Methodology**

Dam breach models are commonly used to predict outflow hydrographs of potentially failing dams and are key ingredients for evaluating flood risk. The standard practice deterministic approach with assumption of various breach parameters viz. breach size, shape, formation time etc. Such approaches are generally conservative and there is no communication of risk and uncertainty. In this study, it is proposed to apply a dam breach modelling framework to improve the reliability of hydrograph predictions. The EP will be determined by using Monte Carlo simulation technique: (i) Realization: “A Single Modelled Event in a Probabilistic Simulation”, (ii) For each Realization, randomly sample uncertain input parameters (breach parameters) about pre-defined probability distributions, (iii) Run a large number of Realizations (10,000?) – large enough to demonstrate convergence of statistical moments (mean, variance, skewness, kurtosis, (iv) sort the results and select percentiles = EP discharges. Finally, routing of the chosen EP hydrograph downstream to determine its associated inundation and damages using a hydrodynamic model (HRC-RAS). This would help to answer-given a dam failure, what is the probability of any discrete location being in the flood zone?

The storage reservoir area upstream of the dam is modelled as storage area i.e. level pool routing through the lake. However, full unsteady flow routing through the reservoir pool can be carried out in 1-D with cross-sections or with bathymetry in 2-D. In general, full unsteady flow routing (1D or 2D) would be more accurate for both with and without breach scenario. However, availability of cross-section / bathymetry data in the reservoir area is often problematic. In this study the difference between level pool routing and full unsteady flow routing through the Mahi Bajaj Sagar dam reservoir will be estimated for peak flow and routed outflow hydrograph. Classified flood hazard vulnerability maps will be developed from the relationships of flood depth and velocity for various categories viz. Generally safe for vehicles, people and buildings; Unsafe for small vehicles; Unsafe for vehicles, children and the elderly; Unsafe for vehicles and people; Unsafe for vehicles and people, all buildings vulnerable to structural damage, some less robust buildings subject to failure; Unsafe for vehicles and people, all building types considered vulnerable to failure. Risk analysis has brought a paradigm shift that has allowed advancement in the evaluation and management of flood risks, which may affect people, the environment, and human development

11. **Results achieved with progress/present status**

The salient features of Mahi Banswara project is obtained from the project authority and literatures. The contour map for the reservoir spread area is obtained from Gujarat Engineering Research Institute (GERI). The river cross-section at some of the locations are collected and openly available DEM for the area is also collected. The dam break analysis of Mahi Bajaj Sagar dam projects has been carried out to estimate the breach outflow from the reservoir storage. The reservoir is assumed to be at MWL and breach parameters are estimated based on the physical characteristics of dam and its construction material. The breach parameters have been estimated using regression equations and has been verified for their upper and lower bound from table suggested by Federal Agency guidelines. The breach in dam is considered when the inflow in Mahi Bajaj Sagar raises the reservoir level above the MWL of RL 281.5 m. The computed breach parameters from various methods are summarized in Table 1. The Mahi dam being earth rock fill dam, a trapezoidal breach section with is considered. The maximum water level for MBS dam is RL 281.5 m. The length of the earthen portion of the dam is 2627.07 m. The time of failure computed by Xu and Zhang is excessively high. At the start of breach, the reservoir is considered at FRL (RL 281.5 m) and the breach continues till water in reservoir lowers down to minimum reservoir level. The resulting dam breach flood hydrograph is shown in Figure 2.

Table 1: Description of breach parameters.

SN	Method	Average Breach width (m)	Time of failure (hour)	Side slope of breach section
1	MacDonald	461	4.96	0.5
2	Froehlich (1995)	307	10.75	0.9
3	Froehlich (2008)	280	8.87	0.7
4	Von Thun & Gillete	106	0.78	0.5
5	Xu & Zhang	174	12.97	0.5

The recently developed guideline in DRIP, advocate for use of the equations given by Froehlich (2016) for estimation of breach parameters. However, it has also associated uncertainty in estimation of various parameters viz. breach width (B), side slope, formation time etc. More over these parameters are also limited by the design section of dam. The outflow hydrograph with breach parameters at different statistical level in a deterministic approach are shown in Figure 2. It is evident that there is large variation in the estimated values of peak flood using various methods.

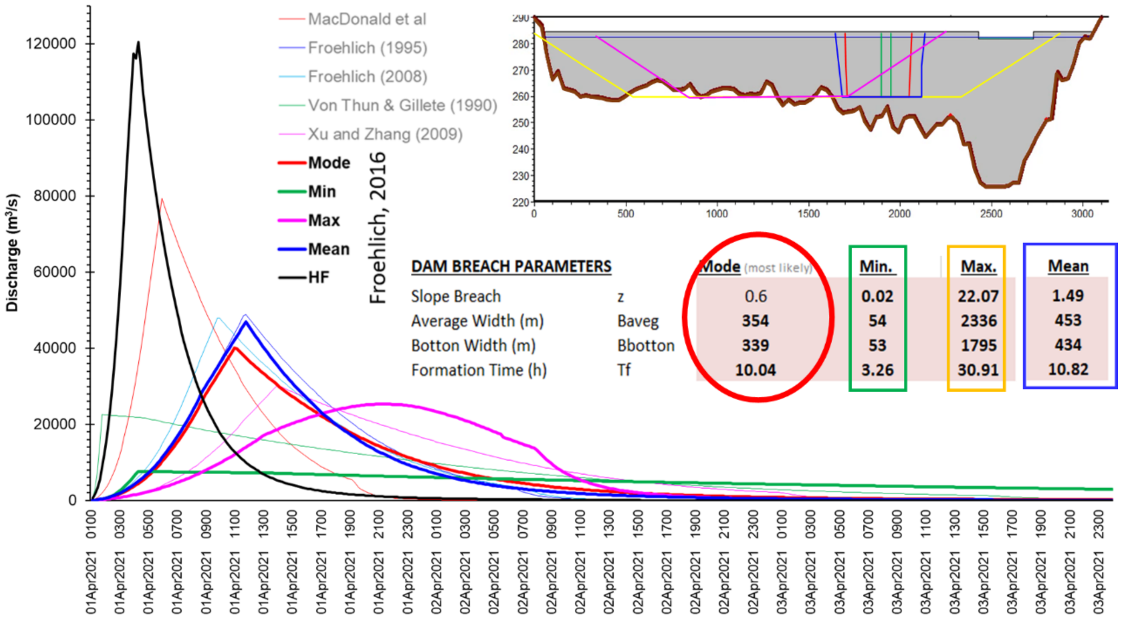


Figure 2: Dam breach flood hydrographs

However, such approaches are generally conservative and there is no communication of risk and uncertainty. In this study it is proposed to apply a dam breach modelling framework to improve the reliability of hydrograph predictions. The Exceedance Probability (EP) of hydrograph is determined by using Monte Carlo simulation technique, where each breach parameter is randomly sampled about pre-defined probability distributions. This require a large number of realizations to demonstrate convergence of statistical moments (mean, variance, skewness, kurtosis) as shown in Figure 3. It may be notes that with 50,000 realizations is quite adequate for this case (Figure 4). The estimated peak discharge at 1% , 5%, 10% and 50% EP are 74100 m^3/s, 61183 m^3/s, 55221 m^3/s and 37612 m^3/s respectively. The Map showing different hazard vulnerability classes due to PMF is shown in Figure 5.

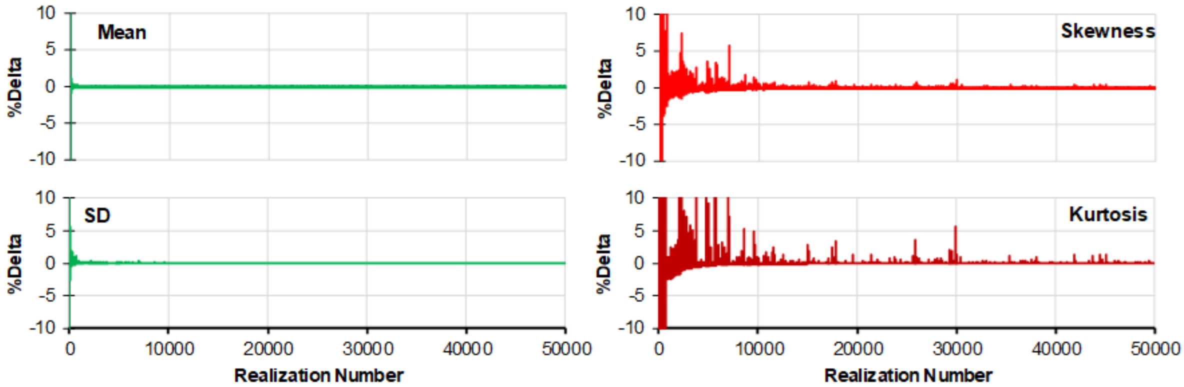


Figure 3: convergence of statistical moments

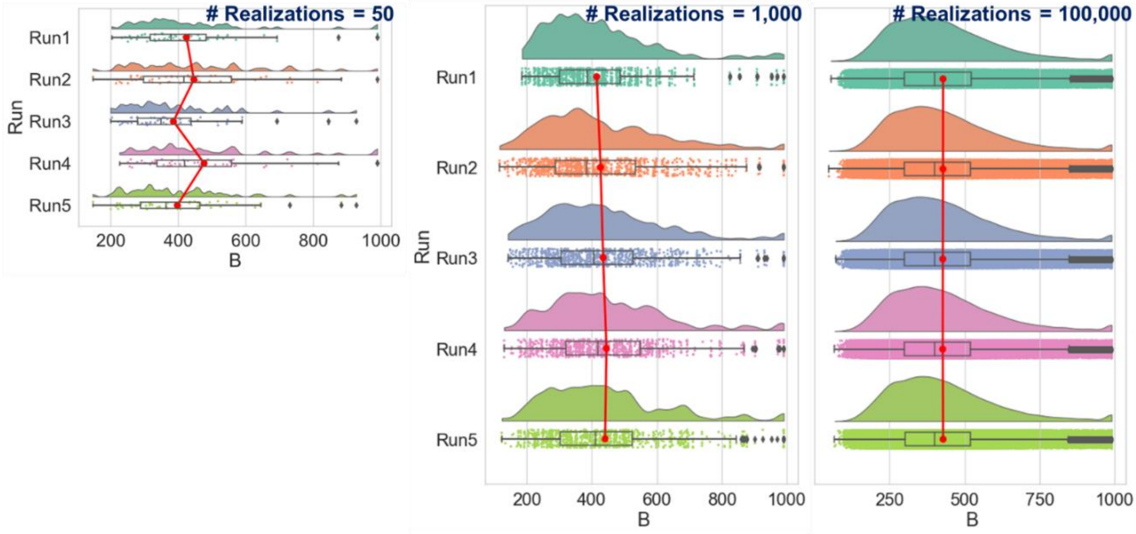


Figure 4: Distribution breach bottom width for different size of realizations.

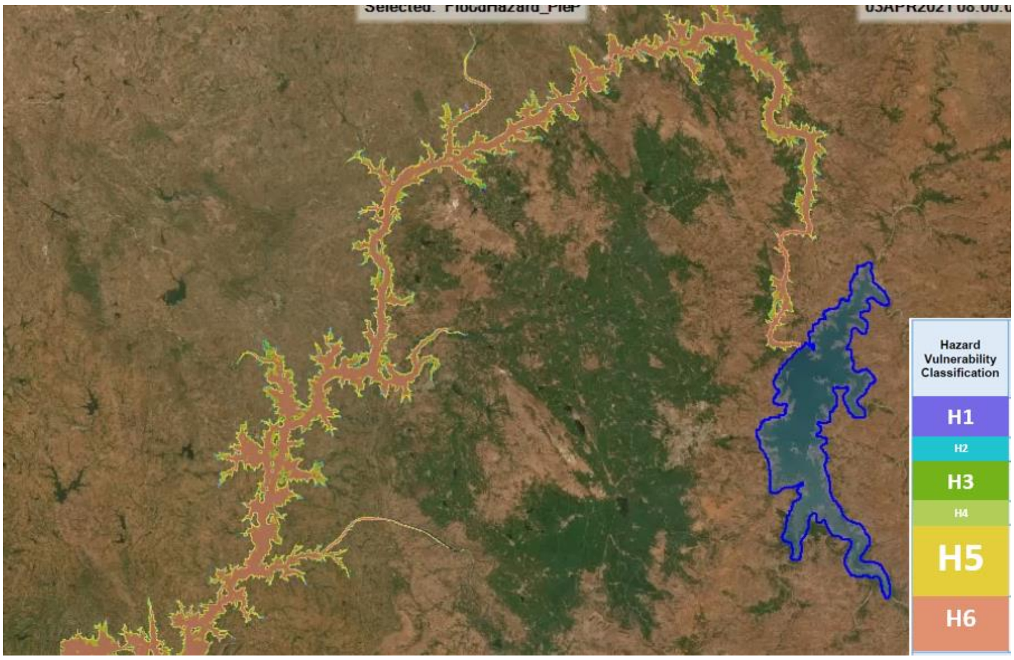


Figure 5: Map showing different Hazard Vulnerability classes

The exceedance probability of simulated peak discharge from dam breach is shown in Figure 6 (b). The estimated peak discharge at 1%, 5%, 10% and 50% EP are 74100 m^3/s, 61183 m^3/s, 55221 m^3/s and 37612 m^3/s respectively. It may be observed that the there is no significant difference in the peak discharge among 1000, 10000 and 50000 realizations up to 10% EP. Moreover at 1% EP there is no significant difference in the peak discharge among 10000 and 50000 realizations. The dam breach flood hydrograph for different Exceedance probability are shown in Figure 6 (c). It may be noted that though there is large variation in peak breach outflow at different EP, the time of peak identical for most of the EP. The EPI maps at different EP is shown in Figure 6(a). The estimated inundation area at 1%, 10% and 50% EP are 967 km^2, 874 km^2, and 706 km^2 respectively. Though the peak of dam breach flood is at 1% EP is about two times to that of 50% EP, the corresponding increase in flood inundation area is about 37%. The estimated population at risk at 1%, 10% and 50% EP are 391807, 349926 and 270768 respectively. The EPI maps as shown in Figure 6(a) will be more useful in risk informed decision making process by further analysis of flood hazard and population at risk.

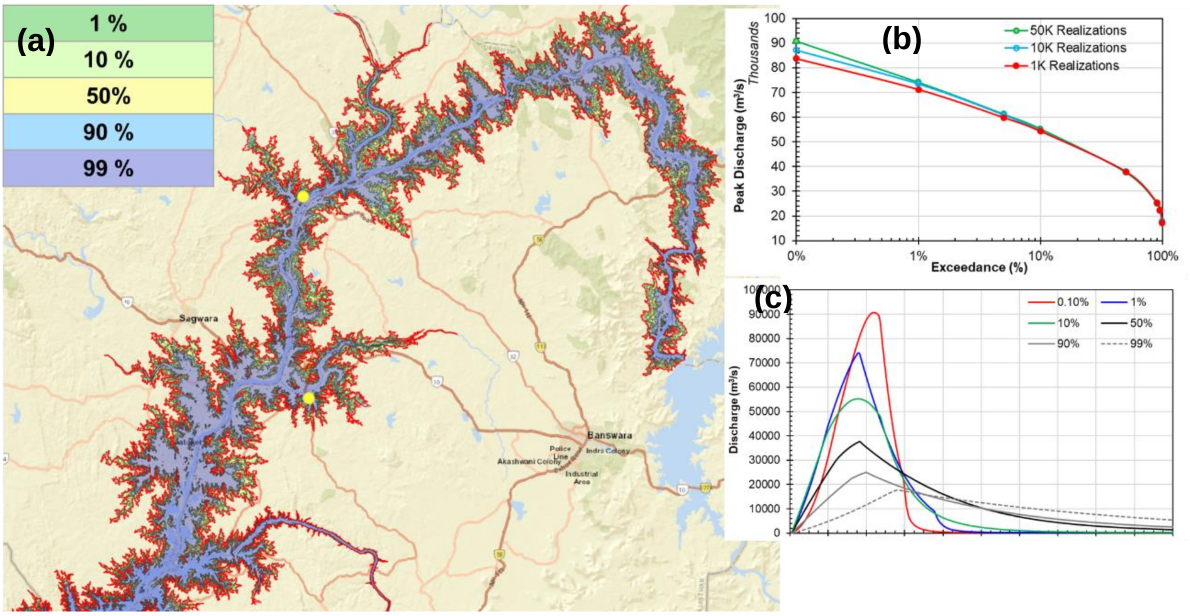


Figure 6: Probabilistic dam breach flood inundation. (a) Exceedance probability inundation maps, (b) Exceedance probability of peak breach outflow, (c) dam breach flood hydrograph at different Exceedance probability.

12. Conclusions

This study uses Froehlich's (2016) dam breach parameter equations and a dam breach modelling framework using HEC-RAS to improve the reliability of breach hydrograph prediction of Mahi Bajaj Sagar Dam. The MBS dam being earth rock fill dam, a trapezoidal breach section is considered. Initially the outflow hydrograph with breach parameters at different statistical level in a deterministic approach is estimated. It is evident that there is large variation in the estimated values of peak discharge at different statistical level of breach parameters. In probabilistic approach each breach parameter is randomly sampled about pre-defined probability distribution up to 100000 realization and breach flood hydrograph for each realization is generated using a truncated model of MBS dam in HEC-RAS. The skewness and kurtosis of % deviation in peak breach outflow has not converged up to 10000 realizations and convergence of statistical moments are found to be adequate for 50000 realizations. The estimated peak discharge at 1%, 5%, 10% and 50% EP are estimated as 74100 m^3/s, 61183 m^3/s, 55221 m^3/s and 37612 m^3/s respectively. No significant difference in the peak discharge is observed among 1000, 10000 and 50000 realizations up to 10% EP. Further, even at 1% EP there is no significant difference in the peak discharge between 10000 and 50000 realizations. Large variation in peak breach outflow is observed at different EP. However, the time of peak discharge is identical for most of the EP. The EPI maps are prepared using HEC-RAS results. The inundation area at 1%, 10% and 50% EP are estimated to be 967 km^2, 874 km^2, and 706 km^2 respectively. Though the peak of dam breach flood is at 1% EP is about two times to that of 50% EP, the corresponding increase in flood inundation area is about 37%. The EPI maps will be more useful in risk informed decision making process by further analysis of flood hazard and population at risk. The results of this study aid our understating of dam breach flood simulation uncertainties and increased understanding of probabilistic dam breach modelling. Utilizing such approach, areas with the highest risk of flooding could be prioritized for evacuation and better emergency action plan can be prepared to increase public safety and minimize losses during critical situations.

13. Action taken on comments of previous working group meeting

There were no specific comments.

14. List of deliverables

- Exceedance Probability Inundation (EPI) maps for Mahi Bajaj Sagar dam breach condition.

- Quantification of difference between level pool routing and full unsteady flow routing through the Mahi Bajaj Sagar dam reservoir.
- Maps showing depth, velocity, time of flood arrival, vulnerability due to large controlled release and dam break of Mahi Bajaj Sagar dam.
- Capacity building for assessing and mapping risks associated with dams.

COMPLETED STUDIES (INTERNAL)

2. PROJECT REFERENCE CODE: NIH/SWHD/NIH/21-23

1. **Title of Study:** **Uncertainty in rating curves and discharge estimation**

2. **Study Group:** Sanjay Kumar, Sc-E, PI
L. N. Thakural Sc-D, Co-PI
Sunil Gurrapu Sc C, Co-PI
J. P Patra Sc 'D' Co-PI
N. K. Bhatnagar Sc 'B' Co-PI

3. **Study Period:** **Two Years (**April 2021 to March 2023)

4. **Objectives of the Study:** The objectives of the study are:
   1. To estimate uncertainty in stage discharge relationship.
   2. To estimate uncertainty in river discharge estimation.

5. Statement of the Problem:

The uncertainty in the river discharge measurement and estimation is caused by different sources of errors. These mainly includes uncertainty in (a) observations of river stage and discharge used to parameterize the rating curve, (b) presence of unsteady flow conditions, and (c) interpolation and extrapolation errors of the rating curves. The study will provide a framework for analyzing and quantifying the uncertainty in the (i) river flow data (ii) stage-discharge relationship The study also examines various hydraulic factors controlling the flow at a cross section in the river and provides an understanding of independent variables that describes relations among stage, discharge and other parameters.

6. Methodology:

Statistical methods/tools and the procedures described in various ISO documents (GUM, HUG) will be used for the estimation of river discharge uncertainties. The uncertainty in discharge measurement (assuming velocity area method) will be quantified as per the ISO 748 which provides the magnitude of these errors at 95% confidence level. The GUM defines the law of propagation of errors for combining uncertainties from several sources and HUG described it for different types of mathematical expressions generally used in hydrometry. This is illustrated by considering the quantity Q as a function of several measured quantities x, y, z . The error δQ in Q due to errors δx, δy, δz.… in x, y, z…., respectively, is given by

$$\delta Q = \frac{\partial Q}{\partial x}\delta x + \frac{\partial Q}{\partial y}\delta y + \frac{\partial Q}{\partial z}\delta z + \cdots$$

The uncertainty of a discharge measurement determined from a stage-discharge rating function (as opposed to a gauged discharge which is determined from a current meter) is evaluated using statistical equations based on law of propagation of errors described above. Let X_{rd} be the uncertainty in the recorded discharge, the above error equation is then modified for uncertainty in discharge computation using stage-discharge relationship as

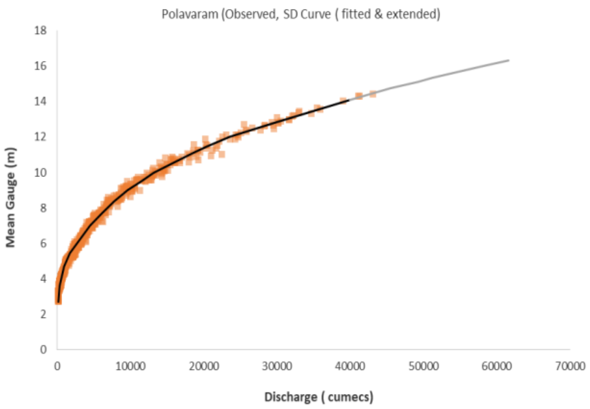
$$X_{rd}=\pm(X_{\alpha}{}^{2} + \beta^{2}X^{2}\ H)^{1/2}$$

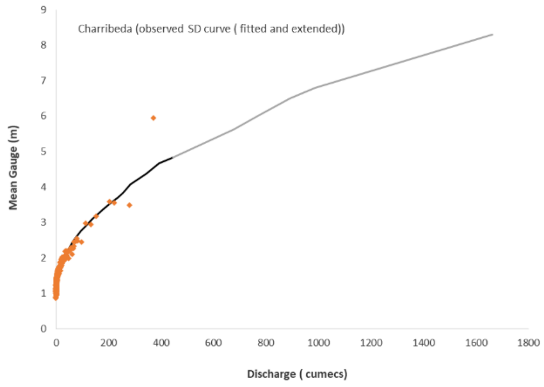
In practice, X_{α} is the standard error of the mean relation ($S_{mr)}$ and XH_{h0} is the standard error of measured gauge. The stage discharge relationship, being a line of best fit provides a better estimate of discharge than any of the individual observations, but the position of the line is also subject to uncertainty, expressed as the Standard error of the mean relationship (S_{mr})

$S_{mr} = S_e\sqrt{\frac{1}{n}+\frac{(P_i-\bar{P})^2}{S_P^2}}$ & $CI_{95\%}$ $=\pm tS_{mr}$ where t student t value at 95% probability; P_i= ln(hi +a); S^2_P=variance of P; $CI_{95\%}$=95% confidence interval.

7. Analysis and Results:

Observed and estimated discharge data of several gauging sites in the lower Godavari basin (subzone 1f) has been collected from CWC. The observed stage and discharge data of these sites has been used to determine the stage-discharge(SD) relationships and their variation. The quantification of the deviation of observed discharge from SD curve (fitted) provides a measure of uncertainty of the SD relationship





The stage-discharge relationships for various sites has been shown graphically and uncertainty in the Stage-Discharge relationship is quantified. The total uncertainty in the discharge estimation has been quantified by combing uncertainty as described in HUG. The results show that uncertainty in computed discharge at low and higher stages is more as compared to discharge computed in the medium range of stages.

8. End users/beneficiaries of the Study: Central and State government departments, academicians, BIS etc.

9. Deliverables: Report/Manual, Publications

COMPLETED STUDIES (INTERNAL)

3. PROJECT REFERENCE CODE: NIH/SWHD/NIH/22-22

Title of Study: Application of unified-extreme-value (UEV) distribution for flood frequency: selected rivers of U.S.A.

Study group	Sushil K. Singh**,** Scientist F
Date of start of study	01 April 2022
Duration and scheduled	Six months
Date of completion of study	30 September 2022
Type of study	Internal (without/no funding)

Objectives of study

This study is undertaken as an extension of the prior approved projects "*Generalization and parameter estimation of GEV distribution for flood analysis: Specific application on Indian data-*2016" and "*Application of unified extreme value distribution for flood frequency to different subzone-basins of India-*2018," to practically demonstrate the wider applicability of the proposed GUEV distributrion.

To illustrate and demonstrate the practical application of previously developed generalized GUEV (unified extreme-value) distribution for analyzing the flood frequency of peak flows in basins falling under different subzones of India. The internal studies (without/no funding) completed for different subzones are:

1. Mahanadi subzone-3d – "Singh, S. K. (2017-18). *Generalization and parameter estimation of UEV distribution for flood analysis: Specific application on Indian data*." [This report considers Mahanadi sunzone-3d]
2. Krishna & Pennar subzone-3h – "Singh, S. K. (2018-19). *Application of unified-extreme-value distribution for flood frequency: Krishna & Pennar subzone-3h*."
3. Narmada & Tapi subzone-3c – "Singh, S. K. (2019-20). *Application of unified-extreme-value (UEV) distribution for flood frequency: Narmada & Tapi subzone-3c*."
4. LowerGodavari-3f – "Singh, S. K. (2020-21). *Application of unified-extreme-value (UEV) distribution for flood frequency: Upper Godavari-3e*."
5. Lower Narmada & Tapi subzone-3b – "Singh, S. K. (2020-21). *Application of unified-extreme-value (UEV) distribution for flood frequency: Lower Narmada & Tapi subzone-3b*."
6. Mahi & Sabermati subzone 3a – "Singh, S. K. (2021-22). *Application of unified-extreme-value (UEV) distribution for flood frequency:* (1) Mahi & Sabermati subzone 3a."
7. Mahi & Sabermati subzone 3a – "Singh, S. K. (2021-22). *Application of unified-extreme-value (UEV) distribution for flood frequency:* (2) Upper Godavari subzone 3e."

The current year study is intended for the rivers of U.S.A. to practically assess the wider applicability of the proposed GUEV distribution

Statement of problem and brief methodology

In an earlier report, the innovative model of UEV distribution for analyzing extreme events has been developed by the author, which is a true mathematical unification of the three extreme value (EV-1, EV-2, and EV-3) distributions and better substitutes the GEV (generalized extreme-value distribution), is intended to be applied to the peak flows observed in the basins falling under two above mentioned subzones of zone-3 of India. Also, proposed therein to quantify the deterministic confidence limit and interval applicable for predicting the flood peaks.

Adopters of the results of study and their feedback

Practitioners, field engineers, and academic personals.

Deliverables

Research report detailing the application for flood frequency analysis of peakflows and research papers in International Journals with illustrative application on the published international data and the Indian data available/collected at NIH.

COMPLETED STUDIES (INTERNAL)

4. PROJECT REFERENCE CODE: NIH/SWHD/NIH/22-23

Title of Study: Application of unified-extreme-value (UEV) distribution for flood frequency: Comparison of results using GEV distribution.

Study group	Sushil K. Singh**,** Scientist F
Date of start of study	01 October 2022
Duration and scheduled	Six months
Date of completion of study	31 March 2023
Type of study	Internal (without/no funding)

Statement of problem and brief methodology

In this report, the comparison of results using GEV distribution and that using the proposed GUEV distribution is intended, for a couple of Indian subzones**.**

Adopters of the results of study and their feedback

Practitioners, field engineers, and academic personals.

Deliverables

Research report detailing the application for flood frequency analysis of peakflows and research papers in International Journals with illustrative application on the published international data and the Indian data available/collected at NIH.

ONGOING STUDIES (INTERNAL)

1. PROJECT REFERENCE CODE: NIH/SWHD/NIH/22-24

2. Title of the Project

Development of Cloud Data Based Integrated Framework to Forecast Flood for Efficient Flood Management

2. Project Coordinator:	Dr. A. K. Lohani, Sc-G (PI), NIH Roorkee Dr. R. K. Jaiswal, Sc-E (PI), NIH, CIHRC, Bhopal
Project Investigator(s)	Dr. J.P. Patra, Sc-E (Co-PI) Dr. P. C. Nayak, Sc-F (Co-PI) Dr. Vishal Singh, Sc-D (Co-PI)

3. Objectives

- To analyse rainfall and runoff for selected reservoirs
- To carry out water balance of reservoirs for computation of runoff
- To develop rainfall-runoff model for the catchment of reservoirs
- To develop integrated framework for real time flood forecasting using cloud based climatic data for early warning and efficient flood management
- To develop hydrodynamic model for assessment of flood impact downstream of dam

4. Present state-of-art

Flooding is an overflowing of water onto land that is normally dry. floods can happen during heavy rains, when ocean waves come on shore, when snow melts too fast, or when dams or levees break. flooding may happen with only a few inches of water, or it may cover a house to the rooftop. Floods are catastrophic events that cause damage to lives and properties. Due to the impact of climate change, high intensity rainfalls are being observed in the most part of world and India. These extreme precipitations may cause unprecedented runoffs and resulting in higher floods in the catchment. The recent change in climate pattern and land use in the catchment further aggravate the situation especially downstream of dams and reservoirs. The old formulae used to compute routed flood and flood protection works need to be evaluated and reformulated under changing climate situations.

Generally, regression based equations are commonly used for flood forecasting at reservoirs. In this method, water levels in the upstream and future forecast conditions from IMD are used to determine inflow in the reservoirs and according operation of gates are made during flood season. Nowadays, several sources of forecast data for climate variables on grid levels are available which can be used in well calibrated rainfall-runoff model to determine possible inflows to the reservoir through an integrated system. The gathered knowledge of future inflows can be used for efficient reservoir operation and assessment of downstream flood and issue appropriate preparedness for evacuation in the event of high flood. In the present study, Tawa dam of Madhya Pradesh, Ravi Shankar Sagar dam from Chhattisgarh, Dharoi dam from Gujarat and Beesalpur dam from Rajasthan in India.

5. Methodology

Methodology for the automation of the forecasting model is presented in Figure-1. The GIS database of Tawa dam catchment consisting of topography, land use, soil, drainage, downstream structures etc. has been created. This GIS database works as base information for modeling the rainfall-runoff processes. Further a rainfall-runoff models has been developed to assess the production of water from catchment under given hydrological conditions. In the study, HEC-HMS rainfall-runoff model on a daily basis has been developed for Tawa reservoir catchments. Calibration and validation results of the model are presented in Figure 2,3 and 4. The developed model will be able to accommodate future forecast climate data for the forecast of runoff with acceptable accuracy.

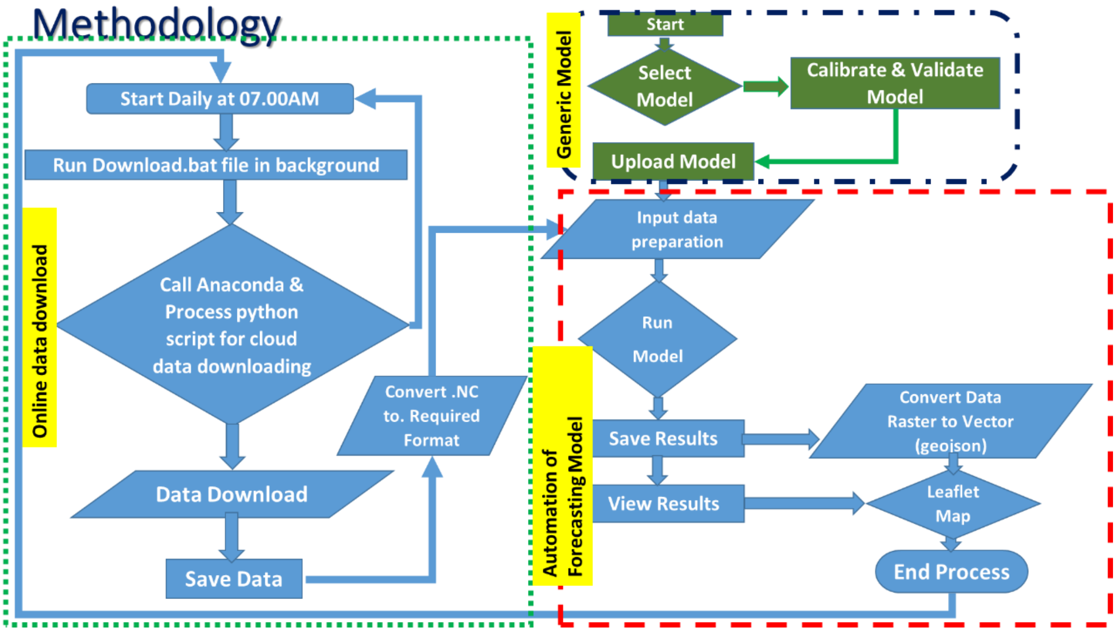


Figure-1: Methodology of Flood Forecasting System

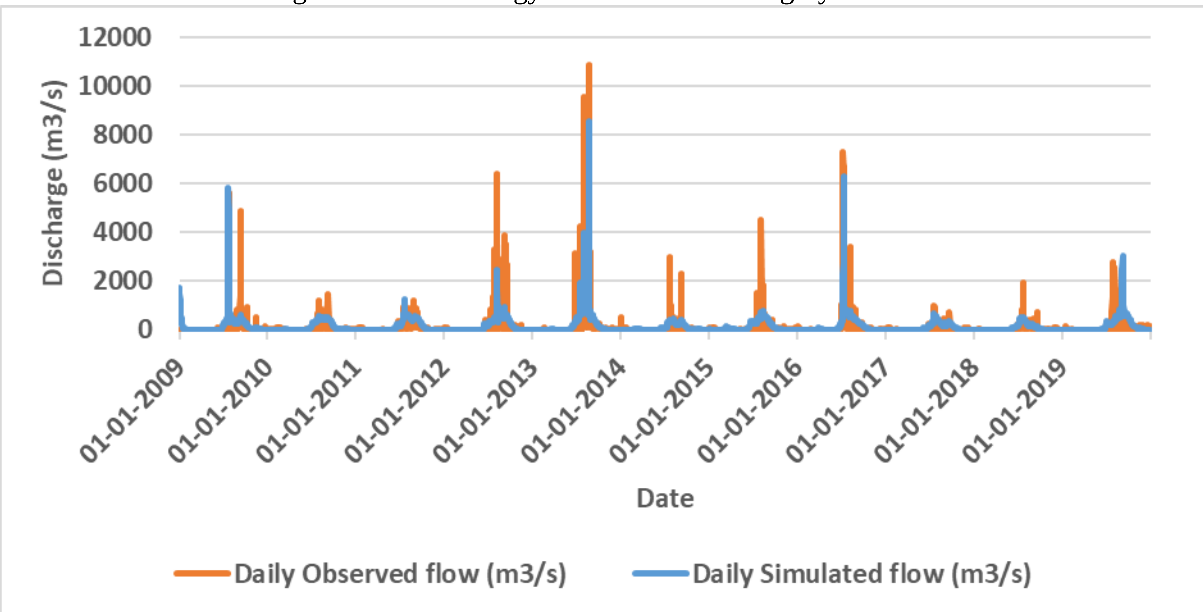


Figure-2: Calibration and validation of Tawa reservoir inflow

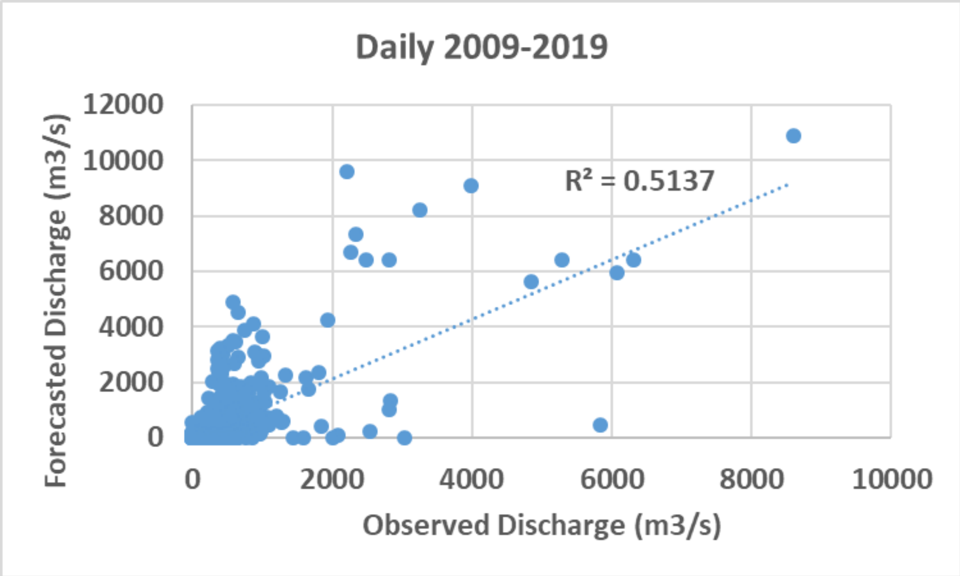


Figure-3: Scatter plot of observed and computed Tawa reservoir inflow (2009-2019)

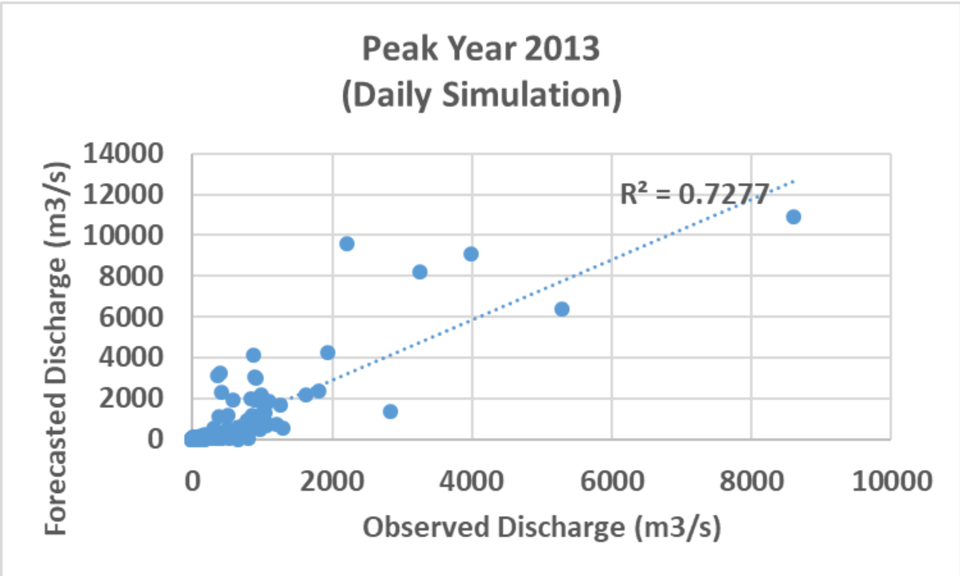


Figure-4: Scatter plot of observed and computed Tawa reservoir inflow (Peak flow 2013)

6. Research outcome from the project

The catastrophic events are more and more common in all over the world and India. The proposed integrated system for forecasting reservoir inflows will be useful to water resource Departments of respective states for efficient reservoir operation and issue emergency warning well in advance to evacuate the people. The general public will be benefitted by getting timely information in the event of catastrophic flood situation.

ONGOING STUDIES (INTERNAL)

2. PROJECT REFERENCE CODE: NIH/SWHD/NIH/22-24

Title of the Study: Flood Forecasting under Changing Climate Conditions - Role of Machine Learning and Conceptual/Physical based Model

Study Group: PI :P. C. Nayak, A. K. Lohani, J. P. Patra, Sunil Gurrapu, T. Thomas, Om Prakash, Jatin Malhotra

Type of Study: Internal Study

Nature of Study: Basic and Applied Research

Date of Start: July 2022

Scheduled date of Completion: June 2025

Duration of the Study: 3 years

Study Objectives

- Develop a deep neural network-based hydrologic model to predict the long-lead-time flood forecasting
- Comparison between conceptual/distributed model with deep neural network to improve the flood forecasting
- The performance of the proposed model will be tested for Baitarani basin in Odisha state
- To predict the long leand time flood forecasting under changing climatic conditions, *i.e.*, include the GCM models output for future predictions

In the whole world one of the most common disasters is flood. Changing climatic conditions impact the river flow, which creates the flood conditions in all over the world. Flood often causes human loss, economic loss etc, so for that reason flood forecasting study is very important in today's scenario. Flood forecasting can help the water agencies to prepare advance disaster management map. Flood forecasting tools can be divided into conceptual models, physical models, and black box models. Here, flood forecasting technique is used for Baitarani basin of India. The Baitarani river rises in the hill ranges of Keonjghar district of Orissa at an elevation of about 900m and has length of about 355km. The Baitarani basin extends over 12,789 km^2 and is roughly circular in shape. The main tributaries of Baitarni joining from left are the Salandi and the Matai. Two gauge stations Anandpur and Champua are considered for analysis in the Baitarani basin using Long Short Term Memory (LSTM) technique. Latitude and longitude of Anandpur and Champua are 21^{o}12', 86^o 07' and 22^o 03' and 85^{o}39' respectively.

Artificial Neural Network (ANN) models offer great forecasting skills for predicting long-term hydrological variables. ANNs are the most widely used Machine Learning (ML) method due to their accuracy, high fault tolerance and powerful parallel processing in dealing with complex flood functions especially where datasets are not complete. The most successful and widely used Recurrent Neural Network (RNNs) is the Long Short Term Memory (LSTM) network. LSTM model has been calibrated and validated for two gauging sites namely Champua and Anandpur Rainfall, water level, and discharge data from 1991 to 2021 is used for flood forecasting in which 70% data used for training set and 30% is used for testing set. 0.25 daily gridded rainfall data is downloaded from IMD website and water level, discharge data is provided by CWC, India for about 30years (1991-2021).
Table1 summarizes the performance indices for both of the gauging sites with the 1 day and 2day lead time. Flow Duration Curve is shown in Fig1 and 2 for the calibration of Anandpur and Champua site with 1day lead time.

Table1: Performance indices

Gauging site performance indices		Champua (1-day)	Champua (2-day)	Anandpur (1-day)	Anandpur (2-day)
Correlation	Calibration	0.97	0.94	0.96	0.96
	Validation	0.95	0.91	0.05	0.94
Efficiency	Calibration	90.30	75.14	88.94	83.61
	Validation	87.14	60.08	88.92	80.89
RMSE	Calibration	20.29	25.22	130.09	158.40
	Validation	25.67	32.59	118.38	155.52
R^2	Calibration	0.95	0.94	0.95	0.96
	Validation	0.96	0.95	0.96	0.95

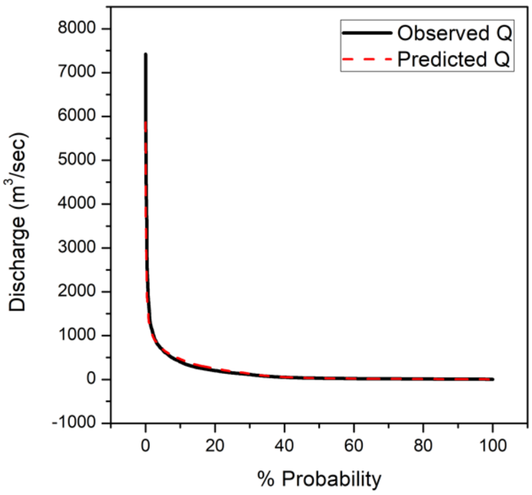


Fig1: Flow Duration Curve at Anandpur

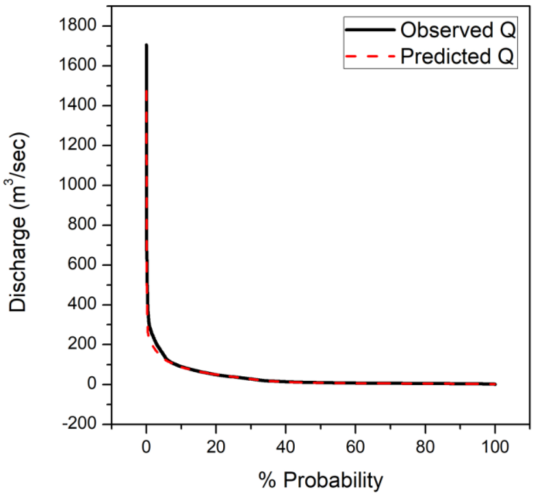


Fig2: Flow Duration Curve at Champua

Objective vis-a-vis Achievement

As mentioned in the objectives, preliminary investigation has been conducted to forecast flood for Champua and Anandpur gauging site for 1day and 2 day lead.

Progress since last meeting

The required hydrological has been collected from Odisha Water Resources Department and CWC, Bhubaneswar. Analysis is under progress

Future work for the next year: Flood forecasting using conceptual/physics based model is under progress

ONGOING STUDIES (INTERNAL)

3. PROJECT REFERENCE CODE: NIH/SWHD/NIH/22-24

1. **Title of the Project**: Hydrological Study for revival and restoration of traditional water bodies in Bikaner, Rajasthan

2. **Project team:**

a. Project Coordinator — Dr. A. K. Lohni, SC-G

b. PI Project Investigator(s) — Dr. L. N. Thakural, Sc-D, Lead PI
Dr. M. K. Shama,Sc-E
Dr. Rahul Kumar Jaiswal, Sc-E
Sh. J. P. Patra, Sc-D
Dr. P. K. Mishra, Dc-D
Dr. Nitesh Patidaar, Sc-B
Sh. N. K. Bhatnagar, Sc-B,
Sh. Jatin Malhotra, SRA,

c. PI from Partner Organisation:
Dr. Anil Kumar Chhangani, Professor
Department of Environmental Science,
Maharaja Ganga Singh University,
Bikaner

3. **Present state-of-art**

Small traditional waterbodies including ponds and tanks are the most important water sources especially in rural areas. These waterbodies are increasingly recognized for their role in meeting rural water needs, aquifer recharge, providing livelihood opportunity, maintaining ecological balance and ecosystem services (Biggs et al., 2016). Small waterbodies are playing vital role in socio-cultural, economic and environmental development. Often, tanks and ponds support rural livelihoods of the marginalized community in rural, urban, coastal and tribal areas. There are about 5,00,000 tanks in India and mostly situated in semi-arid parts of India. As per 5th Census of Minor Irrigation Schemes Report, in surface flow schemes, tanks/ ponds have largest share of 41% followed by reservoir (14%) and temporary diversions (10%). These tanks help in capturing the runoff during monsoon and providing water for irrigation and other multiple uses for the community. However, continued unsustainable exploitation, increasing negligence and lack of conservation and urban growth resulting in huge adverse impact on these small waterbodies. In the last few decades, waterbodies have been under continuous and unrelenting stress, caused primarily by rapid urbanisation and unplanned growth. Encroachment of these waterbodies, often, identified as one of the causes of urban floods. Further, these waterbodies are being polluted by untreated effluents and sewage (Bindu and Mohamed (2016); Matto, 2019). Waterbodies are the lifeline for human existence and always the backbone of water resource sustainability in any urban area. They are going to disappear around the world. Solid waste dumping, industrial pollution, sewage pollution, encroachments, commercial fish farming and other practices are the main causes of this situation. Urbanization and industrialization have increased the intensity of pollution to such an extent that waterbodies' self-healing capacities are no longer enough to counter these multiple onslaughts. Flood mitigation, groundwater recharge, biodiversity enhancement, industrial development and water security are just a few of the benefits that waterbodies provide to a city. It is time their role is properly evaluated in the urban economy and effective actions are initiated for their rejuvenation. Bikaner city has a number of water bodies since ancient time, which has been disappeared due to ignorance and non-maintenance of these water bodies.Bikaner city will be studied followed by broad recommendations on site-specific approaches for revival and restoration.

4. Objectives:

a) To prepare inventory of water bodies in Bikaner and to understand the role of the water bodies in the human survival, livestock and livelihood sustainable and in biodiversity conservation.
b) Long-term spatio-temporal analysis of rainfall, temperature and meteorological variables.
c) Landuse land cover (LULC) change detection in the study area and selection of pilot water bodies (ponds).
d) Trend analysis of groundwater levels and assessment of recharge to groundwater in Bikaner district
e) Surface water availability analysis of pilot water bodies.
f) Identification of various issues both quantitative and water quality assessment of pilot water bodies.
g) To understand the socio-economical role of the water bodies to meet the daily requirement of community for water and other natural resources in and around water body.
h) To understand the existing governance and management practices of water bodies by the local community or any other authorities.
i) Suggesting ameliorative measures to restore water quality of water bodies and daptive and mitigation measures for rejuvenation and sustenance of water bodies.

5. Present state-of-art

Small traditional waterbodies including ponds and tanks are the most important water sources especially in rural areas. These waterbodies are increasingly recognized for their role in meeting rural water needs, aquifer recharge, providing livelihood opportunity, maintaining ecological balance and ecosystem services (Biggs et al., 2016). Small waterbodies are playing vital role in socio-cultural, economic and environmental development. Often, tanks and ponds support rural livelihoods of the marginalized community in rural, urban, coastal and tribal areas. There are about 5,00,000 tanks in India and mostly situated in semi-arid parts of India. As per 5th Census of Minor Irrigation Schemes Report, in surface flow schemes, tanks/ ponds have largest share of 41% followed by reservoir (14%) and temporary diversions (10%). These tanks help in capturing the runoff during monsoon and providing water for irrigation and other multiple uses for the community. However, continued unsustainable exploitation, increasing negligence and lack of conservation and urban growth resulting in huge adverse impact on these small waterbodies. In the last few decades, waterbodies have been under continuous and unrelenting stress, caused primarily by rapid urbanisation and unplanned growth. Encroachment of these waterbodies, often, identified as one of the causes of urban floods. Further, these waterbodies are being polluted by untreated effluents and sewage (Bindu and Mohamed (2016); Matto, 2019). Waterbodies are the lifeline for human existence and always the backbone of water resource sustainability in any urban area. They are going to disappear around the world. Solid waste dumping, industrial pollution, sewage pollution, encroachments, commercial fish farming and other practices are the main causes of this situation. Urbanization and industrialization have increased the intensity of pollution to such an extent that waterbodies' self-healing capacities are no longer enough to counter these multiple onslaughts. Flood mitigation, groundwater recharge, biodiversity enhancement, industrial development and water security are just a few of the benefits that waterbodies provide to a city. It is time their role is properly evaluated in the urban economy and effective actions are initiated for their rejuvenation. Bikaner city has a number of water bodies since ancient time, which has been disappeared due to ignorance and non-maintenance of these water bodies. Bikaner city will be studied followed by broad recommendations on site-specific approaches for revival and restoration.

6. Methodology:

- Present GW Scenario and trend analysis
- Estimation of GW recharge
- Trend analysis using statistical approach
- Assessment of Land use/Land Cover and its impact on runoff characteristics in the catchments of Waterbodies

- Assessment of Soil Loss from the catchments
- Surface water availability analysis
- Water Quality Assessment from water bodies
- Site-specific approaches for revival and restoration
- True repositories of biodiversity

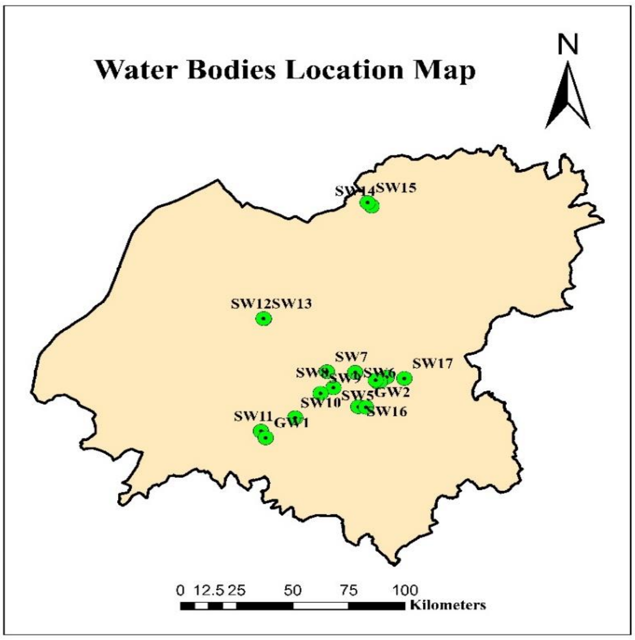
7. Research outcome from the project:

The outcome of the study will help in the revival and restoration of ponds in Bikaner. bodies.

8. Progress:

The water bodies in Bikaner were identified and mapped. The catchment area of selected water bodies located in both urban and rural areas has been delineated using a digital elevation model (Cartosat DEM) with a spatial resolution of 30 m in the GIS environment. The Lanuse/Landcover for the study area has also been prepared using Landsat 8 imagery for the year 2020. The daily gridded IMD data of rainfall (0.25°x0.25°), maximum temperature, and minimum temperature (1°x1°) for the period 1951-2020 were downloaded. The daily data were processed and converted to a monthly scale. Homogeneity Tests for rainfall, maximum temperature, and minimum temperature series were performed to detect the change point using four widely used tests namely the Pettitt test, standard normal homogeneity test (SNHT), Buishand range test, and von Neumann ratio test on an annual and seasonal time scale. Moreover, non-parametric approaches (Mann Kendall and Sen slope of Estimator) were employed to detect and quantify trends in these variables. A reconnaissance survey and collection of water samples of the 15 water bodies including the water bodies referred by the Ministry of Jal Shakti has been carried out during the field visit of Bikaner. Some parameters like pH and electrical conductance were measured on the spot by means of portable meters (HACH, USA). For other parameters, samples were preserved by adding an appropriate reagent and brought to the laboratory in sampling kits maintained at 4^{o}C for detailed chemical analysis. The analysis of physico-chemical parameters DO, BOD, COD was performed as per standard methods (APHA, 2017). Major Cations (Na, K, Ca, Mg), Major Anions (HCO_3, Cl, SO_4, NO_3), Minor Ions (F, PO_4) were analyzed using Ion Chromatograph. Ionic balance was calculated, the error in the ionic balance for majority of the samples was within 5%. The location map of the sampling sites is shown in Fig.1

Fig. 1. Map showing locations of sampling sites



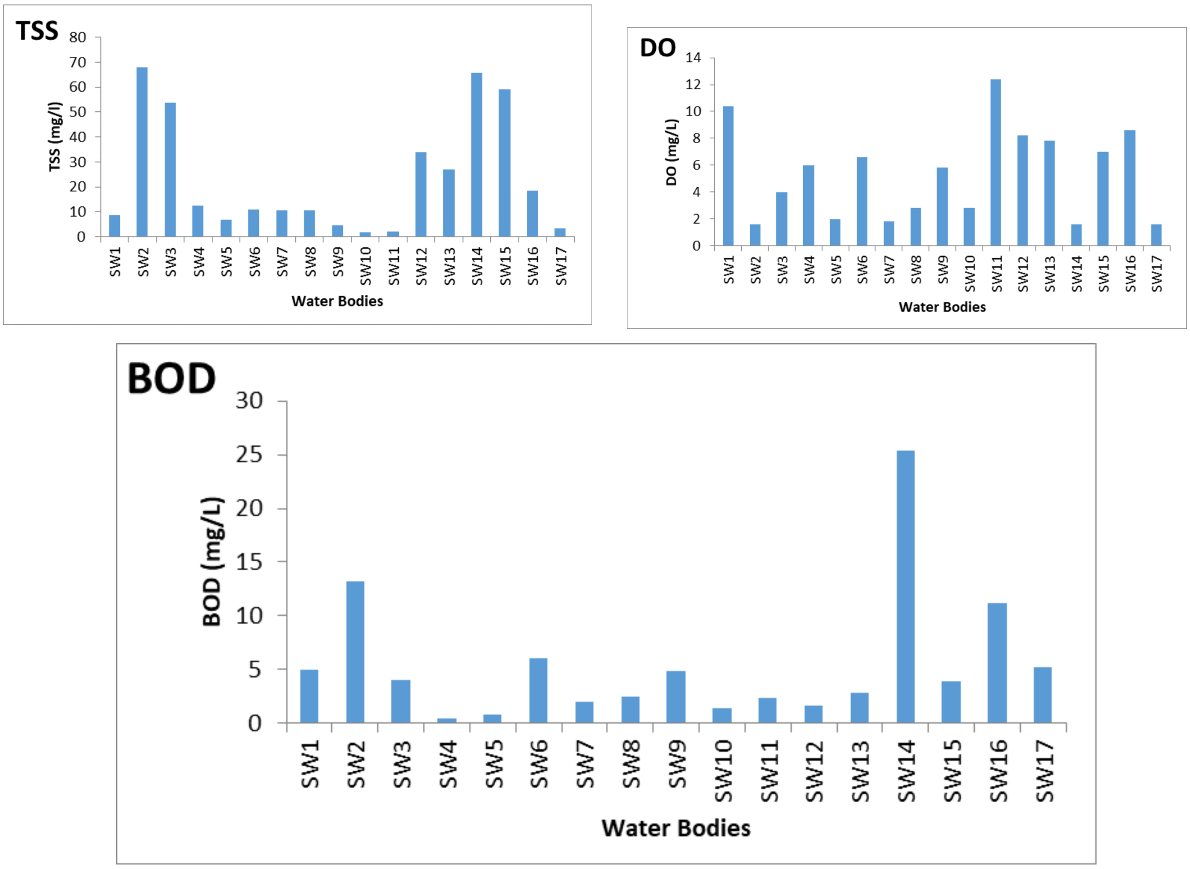


Fig 2: water samples for TSS and Demand parameters (DO, BOD)

Soil investigation was performed in the urban and rural areas of the Bikaner district. Soil samples from seven different locations were collected and analyzed in the Soil Water Lab of NIH for deriving soil texture and soil moisture characteristic curves. It was observed that the texture is mainly sandy in the area with more than 50% sand proportion at all locations. An infiltration test was performed in the field using a double ring infiltrometer at four locations. The infiltration rate varies approximately from 16 to 20 mm/hr in the study area. The groundwater status and trends were also carried out for the detection of trends in groundwater level utilizing groundwater level data acquired from CGWB. The results reveal that a rising trend (in 43% wells) is observed towards the IGNP canal, while the groundwater is falling in the Southern parts (in 21% wells) and approximately 35% of wells show a no-trend in groundwater levels of the Bikaner district for the period 2001-2020.

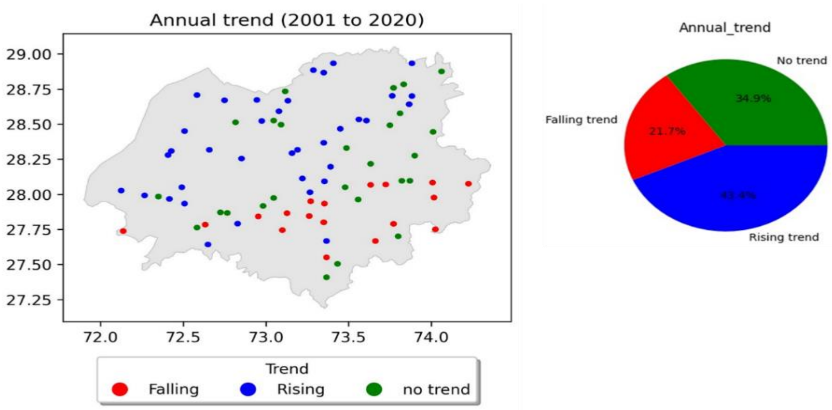


Fig. 3. Trend in groundwater levels in the Bikaner district

ONGOING STUDIES (INTERNAL)

4. PROJECT REFERENCE CODE: NIH/SWHD/NIH/22-25

1. Title of the Project
   Review of design flood and dam break analysis of Khadakhai Dam in Odisha.

2. Project team:
   a. Project Investigator: J.P.Patra, Sc. – D, SWHD
   b. Project Co-Investigator: A. K. Lohani,, Sc. – G & Head SWHD
      Pankaj Mani, Sc. – F, CFMS Patna
      P. C. Nayak, Sc. – F, SWHD
      Sanjay Kumar, Sc. – F, SWHD
      Jatin Malhotra, SRA
   c. WRD Odisha: Tapas Pattanaik, Damsaftey
      Tareni Sen Dhala, CE & BM Subarnarekha

3. Duration of the Study: 3 years (April 2022 to March 2025) : Ongoing
4. Type of Study: Internal Study
5. Location Map

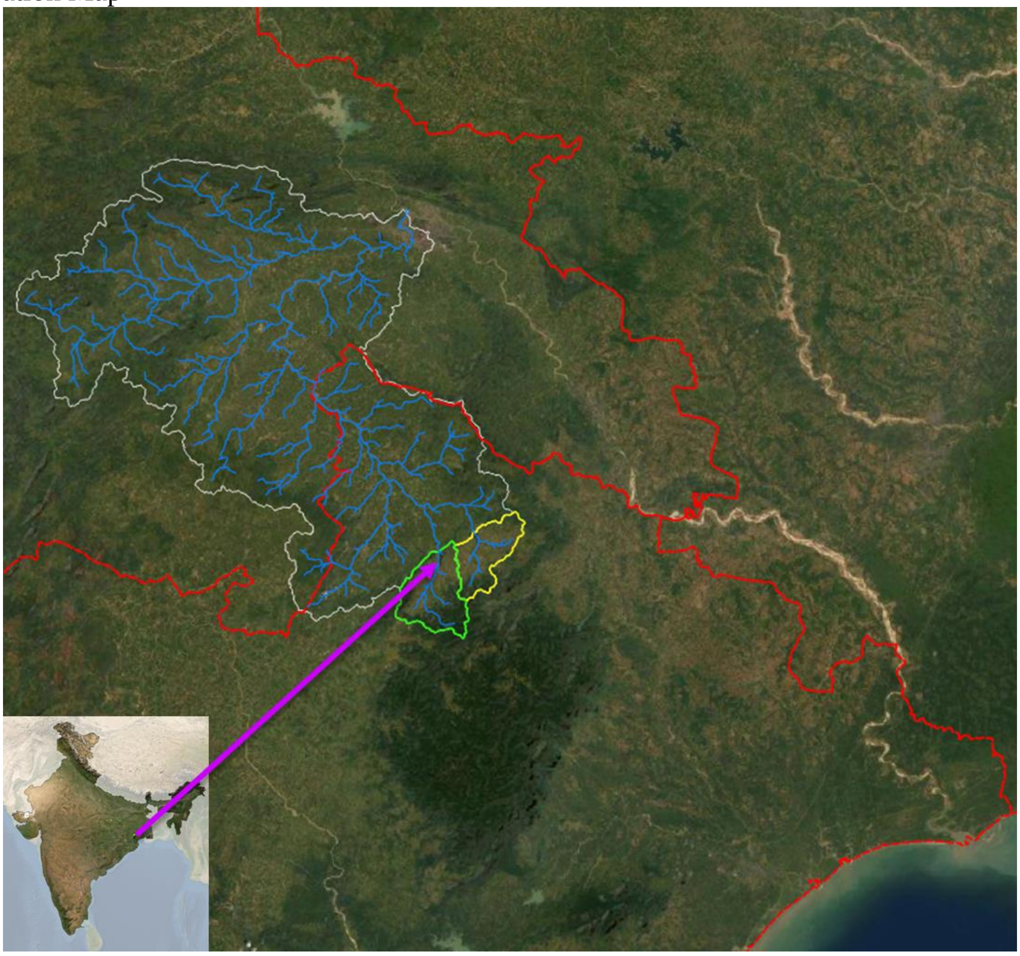


Figure 1: Location map of the study area

6. **Objectives**

   a. To estimate design flood for the Khadakhai Dam.
   b. To analyses uncertainty associated with estimation of design floods in view of future

climate projections.

c. To review and improvement of Khadakhai Dam operation rule curve.
d. To prepare dam breach flood inundation maps for various scenarios.
e. To access sensitivity of the flood inundation maps due to uncertainty in estimate of design flood, breach parameters and reservoir sedimentation.

7. **Statement of the problem**

The Khadakhai Dam is an earthen dam of 365.4 m length build across Khadakhai river in 1981. The maximum height above foundation of the dam is 37 m. It has been constructed on two ends of hills i.e., Bhitarmda hill and Karanjharan hill end points. The reservoir is known as Suleipat reservoir, created mainly for irrigation purpose. In April 2012, Ministry of Water Resources, River Development & Ganga Rejuvenation through Central Water Commission with an objective to improve safety and operational performance of selected dams started the Dam Rehabilitation and Improvement Project (DRIP) with World Bank assistance. Design flood review and preparation of EAP are two important activity in DRIP. The older dams are designed with limited data and atmospheric realities of that period. Now, as those realities shift dramatically with the climate crisis, and need to be relooked. A dam operator has to manage the water release and storage cycle in such a manner that at the end of the monsoon period, its reservoir is at its full capacity. The storage and release schedule of a dam is governed by a rule curve. However, these rule curves are based on monsoon patterns of a time when such patterns were far more predictable, and less disrupted by climate change than they are today. Dam breach modelling is a key component to a well-rounded and robust dam safety program. Various researcher and guidelines recommended combination of breach parameters. The parameters are highly sensitive to peak flood and resulting flood inundation extent. This is further increased with uncertainty in design flood, reservoir operation policy, reservoir sedimentation etc. These needs to be addressed systematically while developing flood inundation map and EAP.

8. **Approved action plan and timeline**

S.N.	Work Element	1st Year				2nd Year				3rd Year			
12	Collection of basic data, topography, cross-section, satellite images, thematic maps etc.	■	■				■						
13	HEC-HMS model setup, review & estimate design flood		■	■	■								
14	Uncertainty analysis for design floods with future climate projections.				■	■	■						
15	Analysis of operation rule curve								■	■			■
16	HEC RAS model setup for dam beach modelling			■	■								
17	Dam breach flood inundation modelling and combined general flood hazard classification							■	■			■	
18	Review and analysis of reservoir sedimentation and updating of EAC table									■	■		
19	Sensitivity of the flood inundation maps.									■	■	■	
20	Workshop/ Training.			■				■				■	
21	Report.				■				■				■

9. **Brief Methodology**

It is proposed to develop a rainfall runoff model using HEC-HMS for estimating design flood hydrographs at the dam site. Design flood will be estimated using the recently developed PMP atlas. Further, the future climate projections (INCC), non-stationarity in the rainfall/

discharge pattern along with LULC changes will be analysed for assessing uncertainty in the design flood estimates. Based on the estimates of design flood it is proposed to evaluate and improve the existing rule curve in DSS (PM) platform. The dam break analysis will be carried out using HEC RAS. Sensitivity analysis will performed to access sensitivity of the flood inundation maps due to uncertainty in uncertainty in design flood, reservoir operation policy, reservoir sedimentation etc.

10. **Results achieved with progress/present status**

The salient features of Khadakhai dam is obtained from the project authority and literatures. The physiographic parameters of the river catchment at dam site have been estimated by GIS processing of STRM DEM. The catchment area map of the project comprising of elevation band, drainage/ catchment area at dam site is shown in Figure 2. The Synthetic Unit Hydrograph is developed using these catchment characteristics and relationships provided in flood estimation report for Lower ganga plains subzone-1g (CWC, 1994). The manual on estimation of design flood analysed time distribution pattern of storms in the area for which adequate self-recoding rain-gauge data are available. In the manual, depth duration analyses of maximum rainfall depths for standard duration of 6, 12, 18, 24, 36, 48 hours etc., were obtained for each of the storms and expressed as percentage of the total storm depth. Enveloping percentages are then obtained and applied to adjust the design rainfall based on observational data. In absence of hourly rainfall data it is recommended to apply a factor of 1.15 to convert 1-day maximum rainfall to 24-h maximum rainfall. The 24 hour rainfall is divided in to incremental hourly rainfall according to time distribution provided in the CWC report. To obtain the critical sequence of rainfall the largest of increments is placed against the peak of UH, then the next largest against the next UH ordinate and so on until all rainfall increments get arranged. Then the sequence is reversed to get the critical sequence for all spells. In case of 24-h duration rainfall the first and second 12 h blocks are interchanged to get critical situation. The design loss rate is subtracted from the hourly rainfall to obtain effective rainfall hyetograph and then direct runoff hydrograph is estimated by convoluting this effective rainfall with SUH. Finally, the base flow is added to obtain design flood hydrograph. The HEC HMS model has also been prepared with IMD gridded rainfall data as input. The HEC RAS model for Dam break modelling is being prepared.

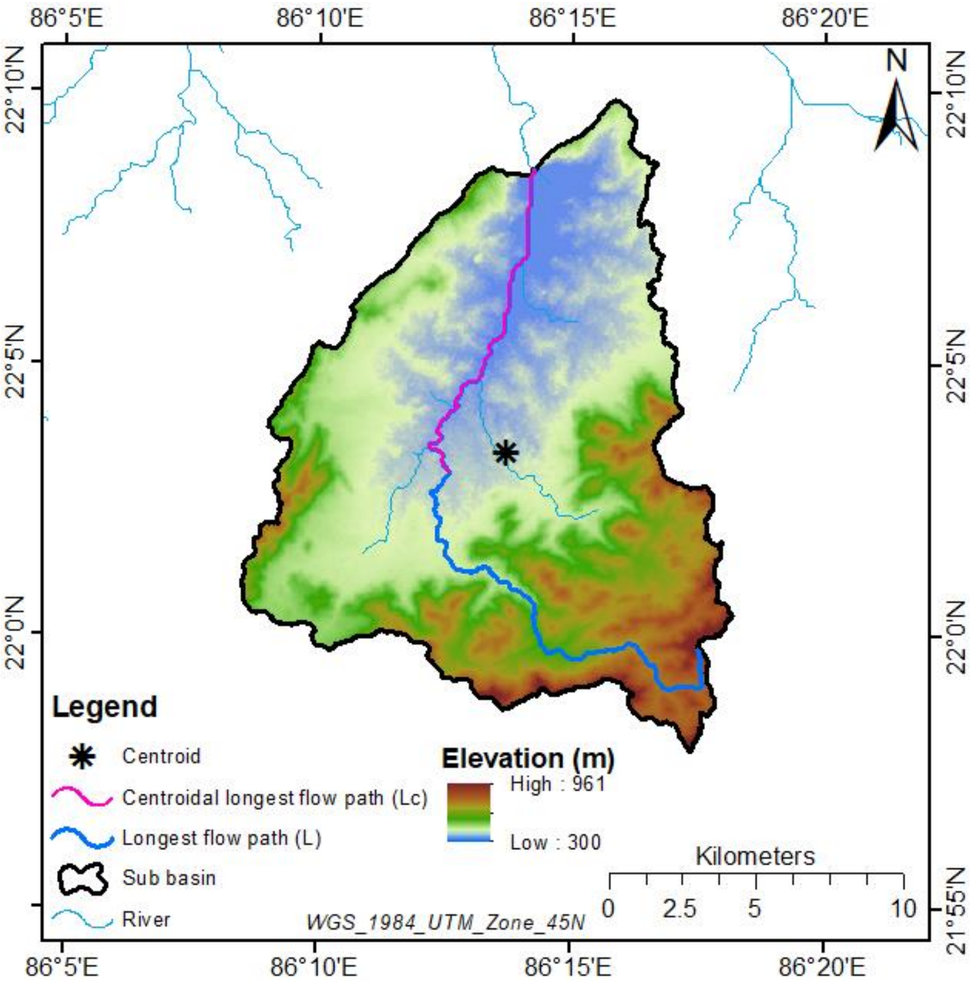


Figure 2: Catchment area map for Khadakhai dam.

11. **Research outcome of the project**
    - Revised design flood for the Khadakhai Dam.
    - Flood inundation maps along with depth, velocity, time of flood arrival, combined flood hazard due to large controlled release and dam break of Khadakhai Dam.
    - Capacity building in line with DRIP.
    - Application of DSS (PM) developed under NHP

12. **End Users/Beneficiaries of the study:**
    Department of Water Resources, Govt. of Odisha

ONGOING STUDIES (INTERNAL)

5. PROJECT REFERENCE CODE: NIH/SWD/NIH/22-25

Title of the Project: Investigation on occurrences of seasonal extremes across Northwest Himalaya in relation to global atmospheric thermal and circulation changes

Thrust area under XIIth Plan: Impact of climate change on water resources and hydrology of extreme

Project team:	Dr. Ashwini Ranade, Scientist 'D' (PI) Dr. P.K. Mishra, Scientist 'D' (Co-PI) Dr. Sunil Gurrapu, Scientist 'D' (Co-PI)
Type of Study:	Internal
Status:	New Study
Duration:	3 years
Date of Start:	1 April 2022
Scheduled date of completion:	31st Mar 2025

Objectives:

- To document broad features and unique characteristics of the large-scale and isolated heavy rainstorms/snowstorms across Northwest Himalaya. *(Completed)*
- To generate in-depth information about the location, shape, size, and intensity of the various rain-producing weather systems that are formed over the northwest Himalaya during different seasons of a year. *(Ongoing)*
- To investigate the relationship among global atmospheric thermal structure and general and monsoonal circulation features and seasonal extremes over the NW Himalaya. *(Ongoing)*
- To study the nature of mid/upper tropospheric tropical-extratropical interactions and different thermo-hydrodynamical processes causing isolated heavier rain/snow storms. (*Ongoing)*

1. Statement of the problem:

Heavy rain events over the northwest Himalayan region are becoming ferocious in recent years causing catastrophic disasters. Colloquially termed as the cloudburst has a potential to downpour over a smaller region in very short duration. International disaster database (http://www.emdat.be) has reported the substantial increase in the extreme rain events over the western Himalayas in recent 30-40 years. It is one of the most studied but less understood phenomena so far. Under the influence of highly complex terrain and tropical-extratropical interactive atmosphere, the northwest part of Himalaya becomes more prone to such types of extreme events, especially during the monsoon season. There is a widespread belief that, in a recent global warming period, due to the intensification of the hydrological cycle, extreme rain events are increasing (Senior et al. 2002, IPCC 2007). The sixth assessment report (IPCC, 2021) projected that, extreme rainfall are projected to be intensifies by 7% for each additional 1 ºC due to acceleration of hydrological cycle in warmer climate across the globe and become more frequent mostly in Africa and Asia. Since 2010, about 17 noticeable extreme events have been observed over Indian Himalayan region of Leh, Uttarakhand, Jammu and Kashmir and Himachal Pradesh, about 5 over subtropical Pakistan and 2 each over Nepal and China. Studies shows that, multiple visualizable factors operated in accord to produce extreme weather/rain events across subtropical Asia. Unprecedented interactions between deep westerly trough and cross-equatorial Indian Ocean south-westerlies as well as Pacific easterlies results in evolution of large and intense monsoon trough extending from Philippine through Indus basin. Arabian sea and Bay of Bengal provides the excessive moisture and numerous synoptic scales, mesoscale and microscale weather systems are evolved and interconnected in the anomalous monsoon trough along with topographical features results in increase in the severity of the events. Formation and intensification of troughs in the temperate westerlies is a short period phenomenon. Therefore, condensation and intense rainfall in subtropical mountainous terrain that involving confluence and convergence of huge airmasses of contrasting characteristics are short lived

In this study, we propose a detailed systematic analysis of various heavy rainstorm events over northwest Himalaya during winter, pre-monsoon, monsoon and post-monsoon seasons of a year on case by case basis by using the available station (hourly) and gridded (daily) rainfall observations and reanalysis atmospheric parameters (temperature, pressure, geopotential height, precipitable water, wind, absolute vorticity, cloud cover, vertical velocity, freezing level, OLR etc.)

2. Dataset used:

- Rainfall Data: Gridded rainfall products from IMD; hourly rainfall data of selected stations across NW Himalaya
- NCEP-CFSR dataset (2.5 degree): Temperature, geopotential height and wind at 12 isobaric levels, PPW, MSLP, OLR, Freezing level, lapse rate
- ERA-5 Reanalysis (0.25 deg): Divergence at all levels, Vertical Velocity, Vorticity, CAPE, Low, medium, high and total cloud cover, moisture convergence.

3. Analysis and Results

3.1 Annual and seasonal rainfall characteristics of NW Himalaya

Daily rainfall data of the three states (Uttarakhand, Himachal Pradesh and Jammu and Kashmir) are area-averaged in order to get Northwest Himalaya (NWH) daily rainfall data for the study period. The annual and seasonal (JJAS, OND, JF and MAM) rainfall are calculated from daily NWH rainfall data. The mean annual rainfall during 1951-2021 of NWH is 1267.1mm (±165.7) and monsoon rainfall 754.9mm (±131.1). During non-monsoon period, the mean rainfall during OND season is 98.2mm (±62.1), JF is 168.0mm (±60.3) and during MAM it is 246.1mm (±79.8). The spatial distribution of mean annual and seasonal rainfall across the NWH region shows large spatial variation across NWH states. The mean annual rainfall spatially varies from 713.4 to 2723.4 mm, JF rainfall from 55.2 to 320mm, MAM varies from 58.9 to 431.9mm, JJAS from 217.9 to 2164.5 mm and OND varies from 43.9 to 170.7 mm. The maximum annual rainfall spatially varies between 1281.4 to 4668.8 mm while that of JF: 155.4-2311 mm; MAM: 244.9-15.4mm; JJAS: 453.8-4090mm and OND: 240.3-1101.5mm (Fig 1)

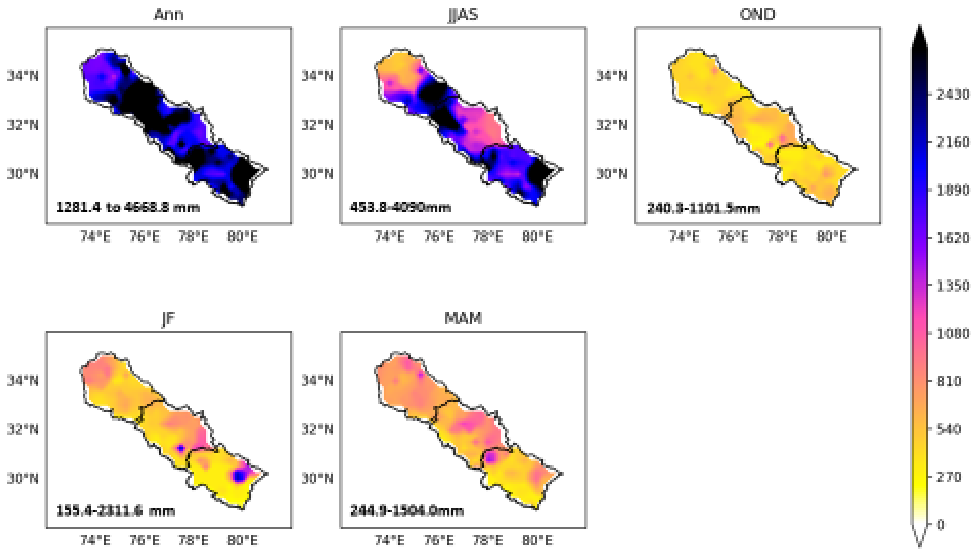


Fig1. Spatial distribution of annual and seasonal maximum rainfall during 1951-2021.

Inter-annual variations in area-averages annual and seasonal rainfall are studied using Mann-Kendall test for its trend detection. Visual examination as well as the statistical test does not show the existence of any long-term trend in NWH annual and seasonal rainfall during 1951-2021. However, in recent years (2001-2020) OND rainfall shows a significant decrease (-25.10%, significant at 5% level) compare to the preceding 51 years (1951-2000) record. JJAS rainfall shows 3.4% increase, JF: -2.9%

decrease, MAM: -8% decrease and annual: -2.3% decrease in recent 20 years but all are not statistically significant.

3.2 Identification and characteristics of Large-scale Long-period EREs

The 1-to 10-day duration large-scale extreme rain events (EREs) are intended to quantify the severity of persisting intense rains over a particular area. In order to understand the variability of intensity of EREs of different durations, 1- to 10-day extreme rain events for each year during 1951-2021 concerning rainfall intensity and areal extent are identified over NWH. On daily basis each 0.25º sq grid is identified under wet condition if actual rainfall exceeds the daily mean monsoon rainfall (DMMR) of the particular grid. The DMMR is the daily mean rainfall during normal monsoon period over the grid. On the 0.25º grid scale, the DMMR varies between less than 2mm/day to more than 18mm/day across NWH. With DMMR as the threshold for the separation of wet grids, area averaged rainfall is calculated to identify large-scale long-period extremes.

The rainfall intensity (RI) of 1- to 10-day extreme is the annual maximum daily mean rainfall calculated for 1- to 10-day durations and the rainfall amount (RA) of 1- to 10-day extreme refers to annual maximum cumulative rainfall for the duration 1- to 10-days. The procedure has been applied for each year of the period 1951–2020 to get the sequence of extreme rain events concerning rainfall intensity (ERE-RI) for 1–day to 10-days durations. Based upon the number of grids under wet condition percentage area of NWH under wet condition is identified on daily scale. Extreme rain events concerning areal extent (ERE-AE) are identified as the annual maximum area under wet condition.

Climatological characteristics of 1- to 10-day large-scale extreme rain events concerning RI/RA and AE are given in table 1. Normally the mean RI decreases from 58.04mm (±20.77) per day for day-1 ERE to 25.93mm (±3.41) per day for 10-day EREs. While the rainfall amount increases form 58.04 mm (±20.77) to 259.28mm (±34.10) day for 1- to 10-day extremes respectively. The highest observed RI 1-day ERE was 146.51mm/day during 1968 and that of 10-day was 366.28mm/day during 1969. The areal extent of ERE-AE varies decreases from 17.3% for 1-day ERE-AE to 10.38% for 10-day ERE-AE. The standard deviation in the areal extent is about 1% for all EREs.

The distribution of cumulative rainfall intensity (highest observed, mean plus 2sd {standard deviation}, mean plus 1sd, mean minus 1sd, mean minus 2sd, mean minus 2sd. and lowest observed values; y-axis) for 1- to 25-day increases following a second-degree polynomial law with the duration (x-axis) (Fig2). The standard deviation (SD) which is the absolute major of variability increases linearly with the increase in mean maximum rainfall amount.

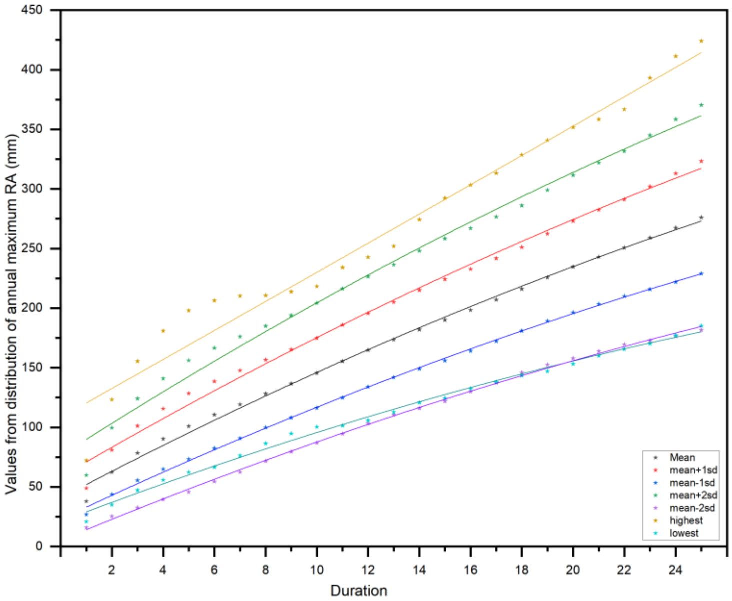


Fig2. Relationship between cumulative rainfall intensity and duration of 1- to 25-day Large-scale EREs

Inter-annual variations in rainfall intensity and areal extent of area-averaged 1- to 10-day EREs are studied using Mann-Kendall test. Results shows that, RA/RI of large-scale 1- to 5-ay ERE does not show any significant change tested using to Mann-Kendall test. Inter-annual variations of RA/RI of 1- to 10-day extremes are homogenous and random. In recent 20 years, RA/RI of 1-day ERE has been increased by 7.75% (statistically not significant) compare to preceding 51 years. No significant change is observed in RA/RI of 2-to 10-day ERE in recent 20 years. Areal Extent (%age) of large-scale 1-day ERE shows significant increasing trend (5% level) tested using to Mann-Kendall test. However, inter-annual variations of RA of 2- to 10-day extremes are homogenous and random. In recent 20 years, AE of 1-day ERE has been significantly (1% level) increased by 4.64% compare to preceding 51 years. No significant change is observed in RA/RI of more than 2- to 10-day ERE in recent 20 years.

3.3 Identification and characteristics of Isolated Spatio-temporal Long-period EREs

Small-scale isolated extreme rain events exhibit large inter-annual spatial variability. To understand characteristics of these extremes an elaborate analysis of temporal and spatial variability of 0.25 deg grid scale EREs of 1- to 10-day duration has been carried out. The annual maximum rainfall series on grid scale for one day has been prepared during 1951-2021 by selecting year-wise highest rainfall amount for a particular grid. Similarly annual maximum rainfall series for 2 to 10-day duration are also prepared.

The mean rainfall of 1-day ERE spatially varies from 50.3mm to 168.9mm across NWH states. For 10-day ERE, the RI (RA) varies from 12.1mm/day (121.23mm) to 52.8 mm/day (528.15mm). The spatial variation of highest experienced RI during the study period shows that, the 1-day ERE most extreme rainfall varies between 106mm and 762.9mm, while for 10-day most extreme ERE, the rainfall intensity varies between 26.3mm/day to 142.3mm/day. The highest rainfall amount of 10-day ERE observed to vary spatially from 263mm to 1422 mm. Most of the severe extreme rain events are observed to be occurred in Himachal Pradesh and Uttaranchal states (Fig3.)

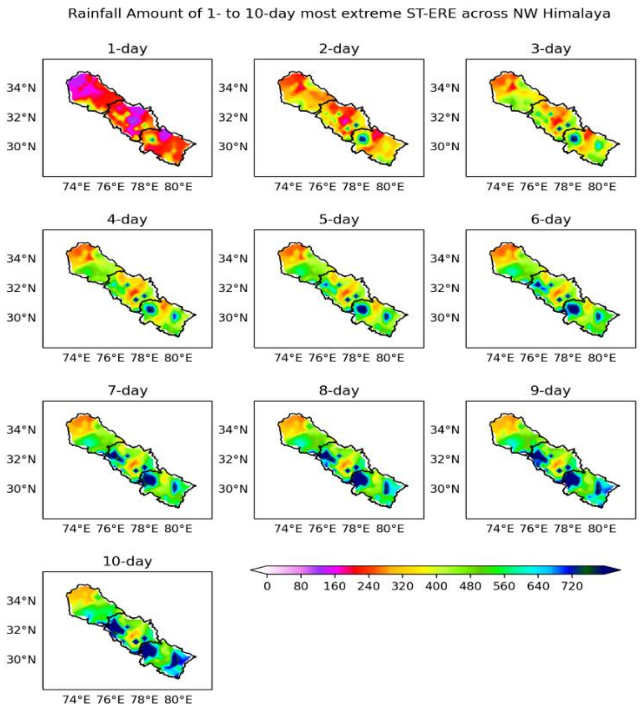


Fig.3 Spatial Distribution of Rainfall amount of the most extreme ST-ERE of 1- to 10-day duration during 1951-2021

3.4 Important Results:

1. The mean annual rainfall during 1951-2021 of NWH is 1267.1mm (±165.7) and monsoon rainfall 754.9mm (±131.1). No significant trend is observed is annual and monsoonal rainfall

of NWH. The series are homogenous and random. However during recent 20 years (2002-2021), OND rainfall has decreased significantly by 25% compare to preceding 51 years (1951-2001).

2. Spatial distribution of annual maximum rainfall is highly variable. It varies between 1281.4 to 4668.8 mm while that of monsoon rainfall varies between 453.8-4090mm across the NWH states.

3. No significant long-term trend is observed in RA/RI of large-scale ERE-RI for 1 to 10-day duration EREs. However Areal Extent of large-scale 1-day ERE-AE shows statistically significant increasing trend.
4. In recent 20 years, RA/RI of 1-day ERE has been increased by 7.75% (statistically not significant), While AE of ERE-AE of 1-day duration has been increased significantly by 4.6% compare to preceding 51 years. No significant change is observed in RI/RA and AE of 2-to 10-day EREs in recent 20 years.
5. Increase in seven selected values from distribution of rainfall amount of 1- to 25-day EREs follow second-degree polynomial with increase in duration. The standard deviation which is the absolute major variability increases linearly with mean maximum rainfall amount.
6. The rainfall amount of 1-day isolated ST-ERE spatially varies from 50.3mm to 168.9mm. The cumulative rainfall of 10-day ST-ERE spatially varies from 121.2mm to 528.2 mm across NWH.
7. The highest experienced rainfall amount of 1-day isolated ST-ERE varies across NWH from 106mm and 762.9mm. The highest experienced RI of 10-day ST-ERE varies from 263.2mm to 1422.9mm
8. Most of the 1- to 3-day EREs are observed to be occurred below 3000m elevation across NWH states.

Deliverables

1. Provides in-depth information about the large-scale long-period and isolated spatio-temporal EREs. over the northwest Himalaya during different seasons of a year. T
2. Detailed understanding about the large-scale circulation dynamics, tropical-extratropical interaction mechanisms at different levels of the atmosphere, thermodynamical processes and the role of orography in the evolution and genesis of heavy rainstorms over Northern Himalaya.
3. The results are helpful for the assessment and prediction of the rainstorms over northwest Himalaya well in advance.

Adopters of the results of the study and their feedback: Weather analysist, water resources sectors

Major items of equipment procured: None

Lab facilities during the study: None

Specific linkages with Institutions/beneficiaries: None

Shortcomings/Difficulties: Shortage of manpower

ONGOING STUDIES (INTERNAL)

6. PROJECT REFERENCE CODE: NIH/SWD/NIH/22-23

Title of the Study

Investigating gap areas, current trends and future directions of research in Climate Change Impact on Hydrology and water Resources in India through Scientometrics

Study Team	Dr. Archana Sarkar, Sc F, SWHD (PI) Dr Jyoti Patil, Sc D, NIH New Delhi office (Co-PI) Mr. Rohit Sambare, Sc C, RMOD (Co-I) Mrs Charu Pandey, A.L.I.O., Library (Co-I)

Type of Study	Internal		
Date of Start	1 May 2022	Scheduled date of completion	31 Oct 2023

Study Objectives:

- To study and analyze the growth and direction of research in the field of climate change impacts on hydrology and water resources in India during 1992-2021
- Identification of gap areas and emerging areas in the research on climate change impact on hydrology and water resources to address the water security issues in India
- Evaluation of research productivity of institutions engaged in research on climate change impact on hydrology and water resources in India through scientometrics
- Dissemination of study findings through workshop/training course, scientific documentation and other outreach means.

Background

Scientometrics is considered a powerful tool of tracing the development of a given scientific field, thereby revealing the gap areas and emerging research problems, and evaluation of scientific contributions and research productivity of research community, institutions, regions, countries, etc. As technological advancements occur, there is a paradigm shift in the working trends in any field. So it is recommended to look for emerging trends and propose new developments when the current trends of any research domain are studied. Bibilometric analysis and scientometric mapping can show the change in mindset of researchers by studying the research works over a time period. Also by identifying the research questions in the water sector today, one can have insight into the future of research in the field. As Boyack et al. (2005) stated that a correctly constructed science map help to understand the inputs, associations, flows and output of science and technology: “Just like in physical world, maps help us to understand our environment- where we are, what is around us and the relationships between neighbouring things”. In recent years, scientometrics has come to play a major role in the measurement and evaluation of research performance.

Potential climate change and its unfavourable impacts on hydrologic systems pose a threat to water resources throughout the world. As per the latest report of IPCC (AR6) released in August 2021, it is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred. The scale of recent changes across the climate system as a whole and the present state of many aspects of the climate system are unprecedented over many centuries to many thousands of years. Evidence of observed changes in extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and, in particular, their attribution to human influence, has strengthened since AR5. Many changes in the climate system become larger in direct relation to increasing global warming. They include increases in the frequency and intensity of hot extremes, marine heatwaves, and heavy precipitation, agricultural and ecological droughts in some regions, and proportion of intense tropical cyclones, as well as reductions in Arctic sea ice, snow cover and permafrost.

The effect of climate change on hydrology in tropical Asia has many facets. The Himalayas, which act as a mountain barrier on the earth, where polar, tropical and Mediterranean influences interact, play an important role in maintaining and controlling the monsoon system over the Asian continent. In the Himalayas, the storage of precipitation in the form of snow and ice (in glaciers) over a long period provides a large water reservoir that regulates annual water distribution. As a populous, tropical developing country, India faces a bigger challenge in coping with the consequences of Climate Change than most other countries. It is now clear that enhanced climate variability and climate change due to continued emission of greenhouse gases in the Earth's atmosphere will alter the key characteristics of summer monsoon rainfall and could significantly impact water supply and demand throughout the Indian subcontinent. Continued global warming is projected to further intensify the global water cycle, including its variability, and the severity of wet and dry events. Natural drivers and internal variability will modulate human-caused changes, especially at regional scales and in the near term, with little effect on centennial global warming. These modulations are important to consider in planning for the full range of possible changes. There is a strong need to reconnect climate science and policy development with the local context to generate relevant knowledge supporting future climate change adaptation and disaster risk reduction strategies on a local to national to international level. The ability to undertake policy action requires information, knowledge, tools, and skills.

Statement of the problem

Many researchers/academicians/policy makers in India have studied and published various aspects of climate change impact on hydrology vis-à-vis water resources and policy implications. However, such studies have been carried out in isolation focusing on specific region/river basin and specific aspect of climate change impact (floods/droughts/water availability/etc). As such, a scientometric analysis of research on climate change impact on hydrology and water resources by Indian scientists has not yet been carried out. The proposed study is expected to highlight the gap areas, emerging trends, and potential opportunities in taking forward the research on climate change impact on hydrology and water resources, which is gaining momentum in view of the looming water scarcity. The study will provide an insight into the dynamics of research on climate change impact on hydrology and water resources and also provide a roadmap to the policy planners in India to address the Sustainable Development Goals (SDG).

Approved Action plan and timeline

S. No.	Work Element	First Year				Second Year	
		Q1	Q2	Q3	Q4	Q1	Q2
1	Identification of computational tools						
2	Identification of search strings relevant to research on climate change impact on hydrology and water resources in India						
3	Data collection from various sources						
4	Bibliometric analysis using bibliographic databases						
5	Manual analysis by searching and analyzing data from websites						
6	Scientometric mapping						
7	Interpretation of bibliometric analysis						
8	Preparation of research publications, outreach material, and synthesis report						

Progress

Objectives	Achievements
May 2022- Jan 2023	
Identification of computational tools	Completed
Identification of search strings relevant to research on climate change impact on hydrology and water resources in India	Being refined from time to time
Data collection from various sources	In progress
Bibliometric analysis using bibliographic databases	In progress
Manual analysis by searching and analyzing data from websites	Yet to start
Scientometric mapping	Initiated

Analysis and Results

The Scopus cited research database (1992-2021) by Indian authors in for the 'Hydrology' and 'Climate Change' keywords was collected from Library of Indian Institute of Technology (IIT), Roorkee. The 31 years Scopus database includes research papers, book chapters, conference papers, review articles, books, editorials, short surveys, and conference proceedings. The collected data were processed and analyzed in R-biblioshiny package to extract the preliminary results related to hydrology- climate change research in India.
The main information of the collected data includes the authors contribution to the research articles (single authored, multi- authored, authors per document, Co-authors per documents etc.). The average citations per documents and collaboration index of the research was also highlighted in the main information.
The other results of preliminary analysis of Hydrology-Climate Change (CC) database includes most cited documents, most relevant documents, word cloud and thematic evolution. The Word Cloud result showed that research in the hydrology along with climate change are mainly focused on climate models, water supply, hydrological modelling, water resources, environmental monitoring, rainfall, runoff, rivers, evapotranspiration and hydrological response etc.
The thematic evolution observed in the research database from 1992 to 2021 shows that in the recent database, the research is not limited to studying the parameters or impact of climate change on hydrology, monsoon patterns and groundwater but impact on humans and environment were evolved in research.
Another important finding is about the most relevant sources of research information as shown in the figure below. Other graphs, tables and word cloud figures would be presented during the working group.

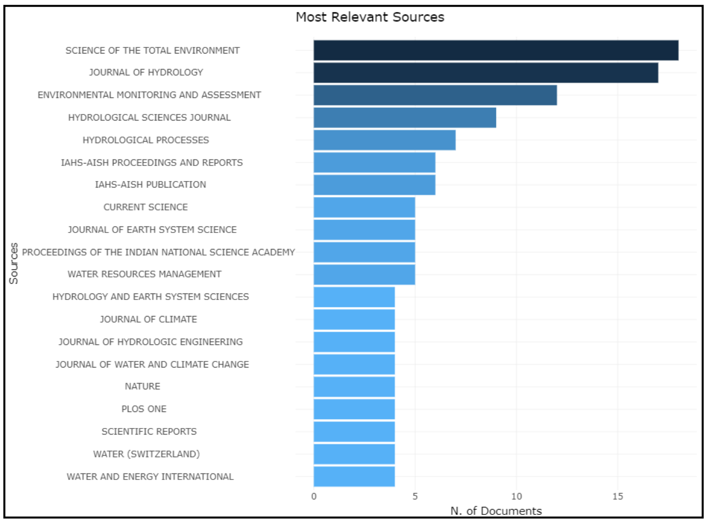


Figure: Most relevant sources

Deliverables
Research papers, synthesis report, policy brief

End users/beneficiaries of the study
Research Organisations, Academic Institutes, Central and State Government Agencies, Policy Makers, NGOs.

Future Plan
As per the approved/proposed action plan.

ONGOING STUDIES (INTERNAL)

7. PROJECT REFERENCE CODE: NIH/SWD/NIH/21-24

Title of the Project:	Investigation of hydrodynamic approach of flood inundation mapping along with assessment of changes in river planforms using a cloud-based Google Earth Engine (GEE) computing platform in data-scarce Western Himalayan River basin
Project Team:	Dr. R. V. Kale, Sc. D, SWHD, NIH Roorkee (PI) Er. D. Khurana, SRA, WHRC NIH Jammu (Co-PI)
Collaborating agency	
Type of Study	Internal Project (NIH)
Duration	3 years
Date of Start	September 2021
Date of Completion	October 2024
Budget	Rs. 90,000/-

Statement of Problem

The water-related disasters particularly flood hazard is on rise all over the world particularly in the western Himalayan region in its frequency, magnitude and damage caused to property and society. Therefore, there is very high societal demand to cope with flood hazards and incurred damages. Usually, in conditions of scarce data availability, a preliminary and cost-effective floodplain delineation can be carried out using procedures that relay on the analysis of geomorphic features (Manfreda et al., 2014). The worldwide conducted studies have shown that geomorphic behaviour and form of rivers across the world have changed strongly compared to a century ago due to land cover change and/or infrastructure construction (Schwenk et al., 2017). These changes to river planform and geomorphic dynamics have caused, and continue to cause, ecological, hydrological and environmental impacts. These river changes can be attributed to processes occurring over multiple timescales. As observed changes in geomorphic dynamics in rivers are strongly timescale-dependent, limiting a geomorphic study to a single timescale can cause biased observations in channel dynamics, with long-term measurements leading to underestimations of the total change occurring over shorter timescales (Harvey and Gooseff, 2015; Donovan and Belmont, 2019). With recent technological advancements, access to Google Earth Engine (GEE), a cloud-based computing platform for planetary-scale geospatial analyses offers access to petabytes worth of remotely sensed Earth observation data (e.g., multi-spectral satellite imagery) (Gorelick et al., 2017), enabling meaningful geomorphological analyses at higher spatial resolutions, over greater spatial extents and at finer temporal resolutions than ever before. Relevant to flood risk management, recent applications of GEE include the integration of Synthetic Aperture Radar (SAR) imagery with optical satellite imagery (e.g., Landsat collections) for event scale flood detection and monitoring (e.g., DeVries et al., 2020).

A considerable number of studies have demonstrated the use of the one- and two-dimensional (1D and 2D) numerical models to delineate floodplains, which allow an accurate representation of river hydraulics and floodplain inundation dynamics. Simplified 2D models have a solid advantage by being computationally significantly more efficient than, for instance, fully 2D models based on the complete St Venant equation (Néelz and Pender 2013). Previous research study by Néelz and Pender (2013) clearly indicates that for the representation of flood extent all 2D packages perform comparably (those which solve full shallow water equations and those, which neglect/simplify certain terms). For the data-scarce areas and flashy river basin, hydrological and inundation models play a critical role on flood simulations, planning of an emergency flood disaster risk management activity, planning of long-term flood control counter measures and risk assessment (Chao et al., 2019, Yu et al., 2018).

Taking into account all the issue discussed in above section, the present study likely to attempt to utilize power of a cloud-based GEE to analyses the planforms changes. Further, this study attempts to evaluate the predictive capabilities of two-dimensional Rainfall-Runoff-Inundation (RRI) model and its comparison with HEC-RAS/HEC-HMS model results in development of flood inundation mapping.

Objectives

a) To use a cloud-based Google Earth Engine (GEE) computing platform to systematically identify inter-annual changes in river planform morphology
b) Interpret changes in channel conveyance that are relevant for flood risk assessment
c) To evaluate predictive capabilities of Rainfall-Runoff-Inundation (RRI) model in development of flood inundation map
d) To carry out comparison of the RRI model-based flood inundation maps with those obtained by using HEC-RAS and HEC-HMS models.

Brief Methodology

The methodology followed to achieve the objectives of the study is briefly presented as follows:

a) To investigate spatial differences in river planform, the rivers will be classified into number of reaches defined by their physiographic setting and valley gradient
b) Google Earth Engine will be used to extract information on river planform morphology from multitemporal, multi-spectral satellite imagery. Landsat surface reflectance products (Landsat 5 Thematic Mapper, Landsat 7 Enhanced Thematic Mapper and Landsat 8 Operational Land Imager) and sentinel data products (Sentinel-1 SAR GRD and Sentinel-2 MSI) will be used as the primary source of satellite imagery available from 1988 onwards and other imagery data may be used in the investigation.
c) Various indices particularly Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI) and or Automated Water Extraction Index (AWEI) and other suitable approaches will be used to achieve active channel mapping at multi-temporal scale.
d) Numerous automated and semiautomated tools in python or MATLAB programming languages for planform analysis exist, with the outputs from GEE ready to be used to derive planform statistics and quantify change. These tools will be used to derive planform statistics and quantify the changes.
e) The Rainfall-Runoff-Inundation (RRI), a two-dimensional coupled hydrological and inundation model, which include three key components: a rainfall-runoff model, a river routing model, and a flood inundation model will be used develop the flood inundation map for the selected high flood events in the study as well as for 10-, 50- and 100-year return year flood at gauging site based on standard frequency analysis and unit hydrograph techniques.
f) Further, the flood inundation results for the study area by RRI model will be compared with those obtained by the application of the HEC-RAS and HEC-HMS model.

Study area

The River Tawi, which passes through the heart of the Jammu city, is an important tributary of the Chenab River in the Western Himalayan region. Tawi river originates from the lap of Kailash Kund glacier and adjoining area southwest of Bhadarwah in Doda district of the Union Territory of Jammu and Kashmir, India. The catchment area of the Tawi river basin is bounded by latitude 32° 35' 20''-33° 6' 6'' N and longitude 74° 29' 8''-75° 40' 54'' E which varies between 239 and 4331 m. The total catchment area up to its confluence with the Chenab river is around 2964 km. The basin shape in the upper part is elongated while broad in the lower part. The catchment of Tawi river up to Indian border is about 2745 km^2 falls mostly within the districts of Jammu and Udhampur of J&K state. Location of the Tawi catchment is shown in Fig. 1. The average height of the catchment is about 2200 m above mean sea level (msl). Being a mountainous river Tawi has more than 2000 numbers of tributaries and sub-tributaries. However, there are nine numbers of predominant tributaries of the river Tawi. The Tawi River is comprised of streams of 1-6 orders.

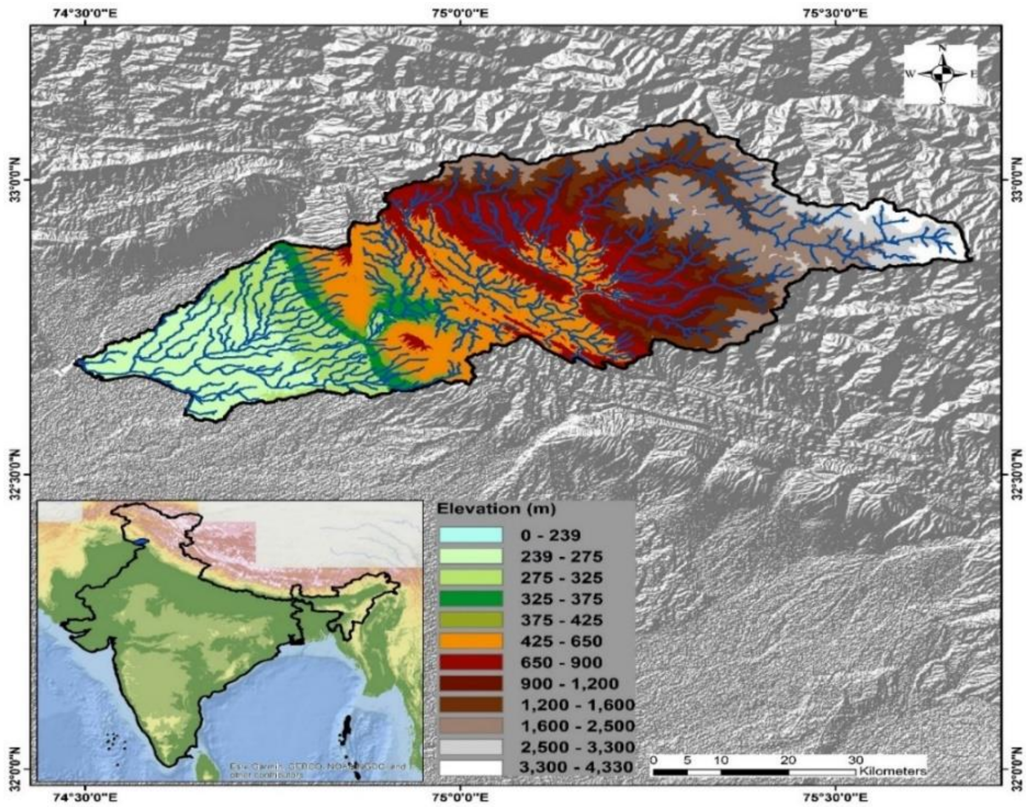


Figure – 1: Location map of Tawi river basin.

Action Plan

Stages of work and milestone:

Work Element	1st Year				2nd year				3rd year			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Literature Review and detailed formulation of research approach	■	■										
Procurement/Collection of available hydro-meteorological data, river cross-section, gauge/discharge data, rating curve, satellite images, thematic maps. Collection of GCP and flood water mark data through field work (if condition permits) etc	■	■	■	■	■	■	■	■	■	■		
Development of codes in GEE	■	■	■	■	■							
Analysis of fluvial geomorphometric Planform results				■	■	■	■	■	■	■		
RRI model set-up for study area			■	■	■	■	■	■	■			
Comparison with HEC-RAS/HEC-HMS model results							■	■	■	■	■	
Results analysis							■	■	■	■	■	
Assessment of flood inundation under current and future changing climate			■	■			■	■			■	■
Report writing	1st interim report				2nd interim report				Final report			

Achievements vis-à-vis Objectives

Objectives	Achievements
To use a cloud-based Google Earth Engine (GEE) computing platform to systematically identify inter-annual changes in river planform morphology	In-Progress
Interpret changes in channel conveyance that are relevant for flood risk assessment	In-Progress
To evaluate predictive capabilities of Rainfall-Runoff-Inundation (RRI) model in development of flood inundation map	In-Progress
To carry out comparison of the RRI model-based flood inundation maps with those obtained by using HEC-RAS and HEC-HMS models.	In-Progress

Progress of work

Objective (a)

Literature Review and detailed formulation of research approach

A through literature of the review has been carried out to formulate the research approach in the present study. These changes to river planform and geomorphic dynamics have caused, and continue to cause, ecological, hydrological and environmental impacts. These river changes can be attributed to processes occurring over multiple timescales. As observed changes in geomorphic dynamics in rivers are strongly timescale-dependent, limiting a geomorphic study to a single timescale can cause biased observations in channel dynamics, with long-term measurements leading to underestimations of the total change occurring over shorter timescales (Harvey and Gooseff, 2015; Donovan and Belmont, 2019). The changes in the Tawi planform during 1988 to 2022 based on the composite Landsat data is shown in Figure 2. It has been observed that significant changes in the planform of the Tawi river has been observed in the lower reaches downstream of the Sidhara gauging site as observed from following Figure 2. The further work is under progress to extract the planforms for various time scale from sentinel-1 and sentinel-2 images using proposed water masking filters.

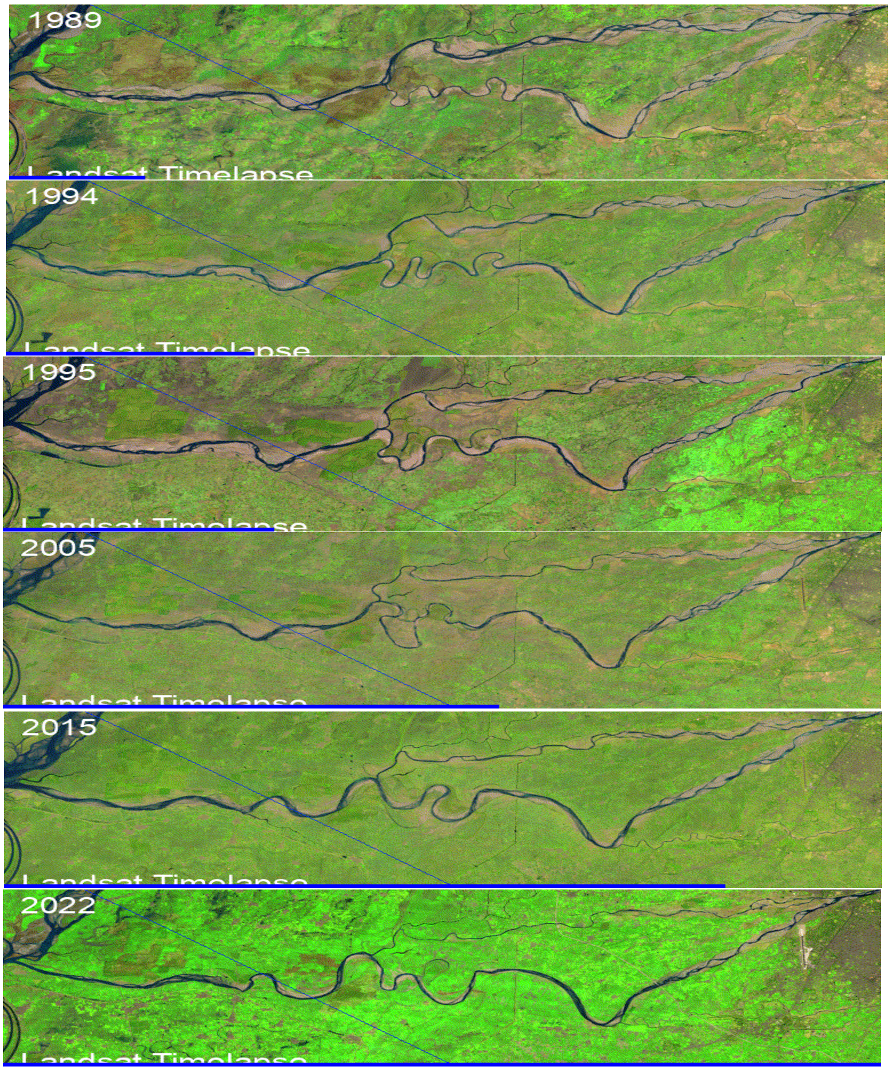


Figure 2: Observed changes in the Lower Tawi river planform during 1988 to 2022.

Most of the required available hydro-meteorological data, river cross-section, gauge/discharge data, rating curve, satellite images, thematic maps are collected.

The programming codes in GEE required to be improved and tested to achieve the results.

Objective (b)

Extracting the active river channel within Google Earth Engine (GEE): The programming code within Google Earth Engine (GEE) was used extract active river channel masks from Landsat 5, 7 and 8 satellite imagery. Three main processing steps: (i) cloud masking and temporal compositing; (ii) active river channel classification; and, (iii) cleaning and image export. The preliminary results achieved are shown in Figure 3. Similarly, the active river channel masks for various time-scales will be extracted for period 1988-2023.

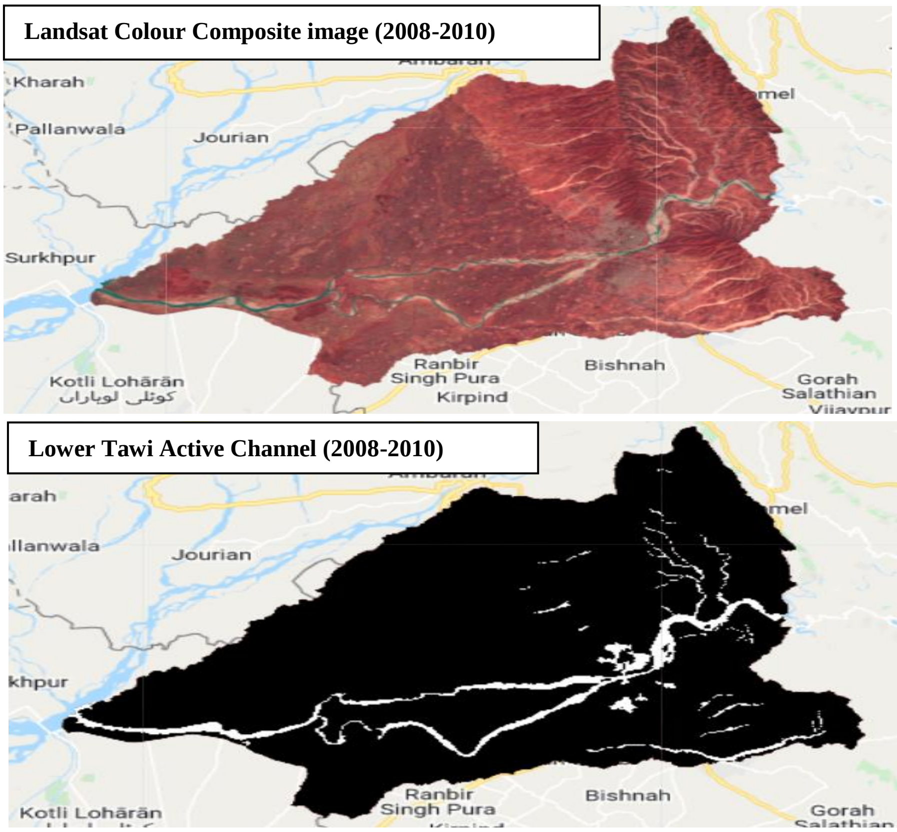


Figure 3. Extracted active lower Tawi river channel mask from a series of Landsat satellite images in Google Earth Engine

Objective (c)

The setting up the 2D Rainfall Runoff Inundation model is under progress. The primary results will be discussed in the working group meeting.

Future Plan

- Further development of codes in GEE to accomplish objectives (a) and (b)
- Analysis of fluvial geomorphometric Planform results
- RRI model set-up and calibration and validation for study area
- Writing up of interim report

NEW STUDIES (INTERNAL)

1. PROJECT REFERENCE CODE: NIH/SWHD/NIH/23-25

1. Title of Study: Estimation of confidence intervals of index flow duration curves

2. Study Group:
Sanjay Kumar, Sc-F, PI
Sunil Gurrapu Sc-D, Co-PI
L. N. Thakural Sc D, Co-PI
J. P Patra Sc 'D' Co-P

3. Study Period: **Two Years (**April 2023 to March 2025)

4. Objectives of the Study: The objectives of the study are:

- To develop Annual Flow Duration Curves (AFDC) and index flow duration curve.
- To estimate the confidence intervals (90%, 95% & 99%) of index flow duration curves.

5. Statement of the Problem:

A flow duration curve (FDC) illustrates the relationship between magnitude and frequency of daily, weekly, monthly (or some other time period) streamflow, providing an estimate of the percentage of time a given streamflow was equaled or exceeded. FDC provides a graphical view of overall historical variability associated with stream flow in a river and thus have been used to solve problems in water resources engineering such as hydropower planning, water quality management, flood control, river and reservoir sedimentation etc.

An FDC is the complement of the cumulative distribution function (cdf) of daily streamflow and their interpretation depends on the particular period of records on which they are based. However, if one considers N individual FDCs, each corresponding to one of the individual N years of record, then one may treat those N annual FDCs in the same way as one treats a series of annual maximum and annual minimum stream flows. This annual based interpretation enables confidence intervals and recurrence intervals to be associated with FDCs in a nonparametric framework.

6. Methodology:

A nonparametric framework based on annual flow duration curve (AFDC) and index flow duration curve will be used for estimation of the confidence intervals (CIs) of AFDCs. Considering that the quantile x_p are values of a variables *X*(discharge) having exceedance probability *P* then FDC can be described simply as a plot of x_p verses *P*, where *P* can be computed as complement of the distribution function *F* of *X* such that

$$P = 1-F(X \leq x_p)$$

To estimate index flow duration curve and CIs, the FDC are developed on annual base by considering *N* annual FDCs, each corresponding to one of the *N* years of the data. For daily data each curve is a sequence of $n=365$ values X_i with $i=1 \ldots n$ arranged in ascending order $X_{1:n} \leq X_{2:n} \ldots . X_{n:n}$, where $X_{i:n}$ is the i^{th} order statistics.

AFDCs summarizes the distribution functions of the *n* order statistics $X_{i:n}$ from annual minima $X_{1:n}$ to annual maxima $X_{n:n}$. Considering the average of the *N* values available for each $X_{i:n}$, a average AFDC, which represent a typical year wherein the interpretation is not affected by abnormal observations during the period of records. Moreover, other percentile as well as the average can be taken into account to provide α percentile of AFDCs which can be used for estimating CIs for the average.

7. Data Requirements:

Daily discharge data. Data sources would be from field organization (CWC or State Water Resources Department) and related literature.

8. Action Plan and Timeline:

S.N.	Major Activities	1st Year		2nd Year	
1	Literature review				
2	Development of annual flow duration curves (AFDC)				
3	Development of index Flow Duration Curve (Interim Report - 1)				
4	Development of a framework for estimation of CI for AFDCs.				
5	Estimation of CI for annual flow duration curves at various sites in in the region1f (Final Report).				

9. End users/beneficiaries of the Study: Central and State government departments, academicians, BIS etc.

10. Deliverables: Report/Manual, Publications

NEW STUDIES (INTERNAL)

2. PROJECT REFERENCE CODE: NIH/SWHD/NIH/23-24

1. **Title of Study:** Hydraulic force-inversion equation for exact modeling of hydraulic jumps in rectangular channels
2. **Study group** Sushil K. Singh, Scientist F
3. **Study Period:** **One Year (**April 2023 to March 2024)

4. Objectives of study

Deriving a new closed form analytical inversion equation of nondimensional hydraulic force for channel flow with implicitly accounting the nonuniform velocity, nonhydrostatic pressure distribution over flow depth, bed friction, and turbulence. In view to very closely simulate the classical experimental data on hydraulic jump, and make it useful and handy to field engineers, practitioners and academicians.

5. Statement of problem and brief methodology

New method for the analytical solution (single term) of the three degree (cubic) equation.

6. Adopters of the results of study and their feedback

Practitioners, field engineers, and academicians.

7. Deliverables

Research report detailing the analytical inversion of hydraulic force equation and its application in exact modeling of the hydraulic jumps in rectangular channels. Publication of research papers in SCI Journals.

WATER RESOURCES SYSTEM DIVISION

Scientific Manpower

S N	Name	Designation
1	Dr. Sanjay K Jain	Scientist G & Head
2	Dr. Manohar Arora	Scientist F
3	Dr. P K Singh	Scientist D
4	Dr. Manish Nema	Scientist D
5	Dr. P K Mishra	Scientist D
6	Dr. Vishal Singh	Scientist D
7	Dr. Sunil Gurrapu	Scientist D
8	Sh. Jatin Malhotra	PRA

APPROVED WORK PROGRAMME FOR THE YEAR 2022-2023

SN	Title	Study Team	Duration	Funding (Rs. Lakhs)
Completed Sponsored/ Internal Studies				
1.	Developments of Water Accounts for Subarnarekha Basin Using Water Accounting Plus (WA+) Framework	P. K. Singh; P. K. Mishra; M. K. Goel; Suman Gurjar	2 years (12/18-12/20)	NIH
2.	Real time flood modelling using HEC-RTS modelling framework	Vishal Singh; A. K. Lohani	2 years (12/18-12/20)	NIH
Ongoing Sponsored/ Internal Studies				
1.	Development of a project website and hydrological database in Upper Ganga Basin **(Sub-project – 1)**	M. K. Goel; M. Arora; A. K. Lohani; D. S. Rathore; D. Chalisgaonkar; A. R. S. Kumar; S. Singh; P. Mani; A. Sarkar; M. K. Nema; P. K. Mishra	5 years (01/16-03/21) (Likely to be extended till Sept., 2021)	DST (52.15)
2.	Real-time snow cover information system for Upper Ganga basin **(Sub-project – 2)**	D. S. Rathore; (Now Deepa Chalisgaonkar is PI) V. S. Jeyakanthan; L. N. Thakural;	5 years (01/16-03/21) (Likely to be extended till Sept., 2021)	DST (48.83)
3.	Glacial Lakes & Glacial Lake Outburst Flood (GLOF) in Western Himalayan Region **(Sub-project – 3)**	Sanjay K. Jain; A. K. Lohani; Sudhir Kumar; Praveen Thakur (IIRS)	5 years (01/16-03/21) (Likely to be extended till Sept., 2021)	DST (36.79)
4.	Assessment of downstream impact of Gangotri glacier system at Dabrani and future runoff variations under climate change scenarios **(Sub-project – 4)**	~~Renoj J.Thayyen;~~ Sanjay K. Jain; Sharad K. Jain (Retd.) P. K. Mishra; M. Arora; AP Dimri (JNU)	5 years (01/16-03/21) (Likely to be extended till Sept., 2021)	DST 80.4 (NIH) + 73.2 (JNU)
5.	Observation and modelling of various hydrological processes in a small watershed in Upper Ganga basin **(Sub-project – 5)**	M K Nema; Sharad K. Jain (Retd.); ~~Renoj J.Thayyen;~~ Sanjay K. Jain; P K Singh, P. K. Mishra; P. K. Agarwal AP Dimri (JNU)	5 years (01/16-03/21) (Likely to be extended till Sept., 2021)	DST (54.07)
6.	Water Census and Hotspot analysis in selected villages in Upper Ganga basin **(Sub-project – 11)**	P. K. Mishra; M. K. Nema; ~~Renoj J. Thayyen;~~ Pradeep Kumar	5 years (01/16-03/21) (Likely to be extended till Sept., 2021)	DST (90.99)
7.	Investigating Water Stress using Hydro-meteorological and Remote Sensing data	D. S. Rathore; (Now L. N. Thakural is PI); Sanjay Kumar; B. Venkatesh M. K. Jose; T. Chandramohan	3 years 2017-2020 (Recommended for extension up to June, 2021)	PDS under NHP (50.23 Lakh)

8.	Snow and glacier contribution and impact of climate change in Teesta river basin in Eastern Himalaya	Sanjay K. Jain P. K. Singh; M. Arora ~~Renoj J. Thayyen;~~ A. K. Lohani; Vishal Singh;	3 years (11/19-11/22)	NMHS-MoEF (143 Lakh)
9.	Assessment of seasonal variations in Hydrology and Cryosphere of upper Ganga Basin	~~Renoj J. Thayyen~~ A. P. Dimri (JNU) Sanjay K. Jain Vishal Singh	3 years (06/19-11/22)	NRDMS-DST (23.19 Lakh)
10.	Permafrost mapping and characterization of Ladakh Region	~~Renoj J. Thayyen;~~ A. P. Dimri (JNU) will lead now; G. Jeelani (KU); V. Agnihotri (GBPNI)	3 years (11/19-11/22)	NMHS-MoEF (197.48 Lakh)
11.	Development of Water Accounts for the different sub-basins of Brahmaputra and Barak River Basins in the state of Meghalaya Using Water Accounting Plus (WA+) Framework.	P K Singh; P K Mishra; P K Agarwal	2 years (08/20-07/22)	NHP (14.50 Lakh)
12.	Seasonal Characterization of Gangotri Glacier melt runoff and simulation of streamflow variation under different climate scenarios	M. Arora P K Mishra Vishal Singh	3 years (04/18-03/21) (Extended for 12 months)	NIH
13.	Impacts of glacier and climate change on runoff for selected basins of Himalayan region	Vishal Singh; Sanjay K. Jain; Manohar Arora	2 years (08/20-07/22)	NIH (9.30 Lakh)
14.	Henval Experimental Watershed: Observations and modelling (Phase II)	M K Nema; Sanjay K Jain; ~~Renoj J. Thayyen;~~ P K Mishra; P K Agarwal	3 years (08/20-07/23)	NIH (10.22 Lakh)
15.	Upgradation of NIH_ReSyP to .NET Platform– a Reservoir Operation Package	D. Chalisgaonkar M. K. Goel	1 year (08/20-07/21)	NIH
New Internal/ Sponsored Studies				
1.	Development of Water Accounts for the different sub-basins in the state of Nagaland Using Water Accounting Plus (WA+) Framework.	P K Mishra; P K Singh; P K Agarwal	2 years (04/21-03/23)	NHP (9.00 Lakh)
2.	Long term hydrological assessment for the development of water security plan into three sub-basins namely Barak, Minor rivers draining into Bangladesh and Minor rivers draining into Myanmar sub-basins in the state of Mizoram	Vishal Singh; M K Nema; P K Singh; Vanlalpekhlua Sailo (SDO from Mizoram); Lalruatkima (JE from Mizoram)	3 years (04/21-03/24)	NHP (25.00 Lakh)
3.	Monitoring of Hydrological Processes in Glaciated and Non Glaciated Watersheds of North-West Himalaya	M K Nema; Sanjay K Jain; Manohar Arora; Vishal Singh; Praveen Thakur (IIRS)	3 years (04/21-03/24)	IIRS (Total 701.37 Lakh)

PROPOSED WORK PROGRAMME FOR THE YEAR 2023-2024

SN	Title	Study Team	Duration	Funding (Rs. Lakhs)
Completed Sponsored/ Internal Studies				
1.	Seasonal Characterization of Gangotri Glacier melt runoff and simulation of streamflow variation under different climate scenarios	M. Arora; P K Mishra; Vishal Singh	3 years (04/21-03/23)	NIH
2.	Impacts of glacier and climate change on runoff for selected basins of Himalayan region	Vishal Singh; Sanjay K. Jain; Manohar Arora	2 years (08/20-07/22)	NIH (9.30)
3.	Assessment of seasonal variations in Hydrology and Cryosphere of upper Ganga Basin	Vishal Singh; Sanjay K. Jain; A P Dimri (JNU	3 years (06/19-12/22)	NRDMS-DST (23.19)
Ongoing Sponsored/ Internal Studies				
1.	Snow and glacier contribution and impact of climate change in Teesta river basin in Eastern Himalaya	Sanjay K. Jain P K Singh; M. Arora; A K Lohani; Vishal Singh	3 years (11/19-11/22) Extended up to 03/23	NMHS-MoEF (143)
2.	Development of Water Accounts for the different sub-basins of Brahmaputra and Barak River Basins in the state of Meghalaya Using Water Accounting Plus (WA+) Framework.	P K Singh; P K Mishra;	2 years (08/20-07/22) Extended up to 03/23	NHP (14.50)
3.	Development of Water Accounts for the different sub-basins in the state of Nagaland Using Water Accounting Plus (WA+) Framework.	P K Mishra; P K Singh; Vishal Singh; P K Agarwal	2 years (04/21-06/23)	NHP (9.00)
4.	Long term hydrological assessment for the development of water security plan into three sub-basins namely Barak, Minor rivers draining into Bangladesh and Minor rivers draining into Myanmar sub-basins in the state of Mizoram	Vishal Singh; M K Nema; P K Singh; Vanlalpekhlua Sailo (SDO from Mizoram); Lalruatkima (JE from Mizoram)	3 years (04/21-03/24)	NHP (25.00)
5.	Monitoring and hydrological modeling of Henval watershed in Lesser Himalaya	M K Nema; Sanjay K Jain; P K Mishra;	3 years (08/20-07/23)	NIH (10.22)
6.	Spatio-temporal Water Availability under Changing Climate and Landuse Scenarios in Wainganga River Basin	M K Nema; P K Mishra; Rahul Jaiswal	2 years (04/22-03/24)	NIH (9.72)
7.	Monitoring and Assessment of Mountain Ecosystem and Services in North-West Himalaya (Phase-II): Monitoring and Modeling of Hydrological Processes in Glaciated and Non-Glaciated Watersheds of North-West Himalaya	M K Nema; Sanjay K Jain; P. K. Mishra; Praveen Thakur (IIRS)	3 years (04/22-03/25)	IIRS (30.91)
8.	Hydrological Assessment of Ungauged Basins (Aghanashini, Dasanakatte, Sita Nadi, Madisala Hole, Swarna Nadi and Gurupur River Basins) of the West Flowing Rivers in the Western Ghat Region of Karnataka	P K Singh; Vishal Singh; Sanjay K Jain; Abhilash R.	3 years (04/22-03/25)	NHP (54.0)
9.	Climate change scenarios for Andhra	Sunil Gurrapu; Nitesh Patidar;	2 years (04/22-03/24)	NIH

	Pradesh and its impact on streamflow and groundwater levels in Pennar River basin	YRS Rao; R Venkata Raman; TVNAR Kumar		
New Internal/ Sponsored Studies				
1.	Monitoring and Modelling of Gangotri (Bhojwasa) watershed under different Climate Scenarios	P K Mishra; Vishal Singh; Sunil Gurrapu; Jatin Malhotra	3 years (04/23-03/26)	NIH (60.0)
2.	Glacier recurrence survey, Instrumentation and Modeling to study the Batal Glacier in part of Western Himalaya, India	Vishal Singh; P K Mishra; Sunil Gurrapu; Sanjay K Jain; Manohar Arora Jatin Malhotra	5 years (04/23-03/28)	NIH (71.0)

<u>**COMPLETED STUDIES**</u>
<u>**INTERNAL RESEARCH PROJECT: NIH/WRS/2021-23/01**</u>

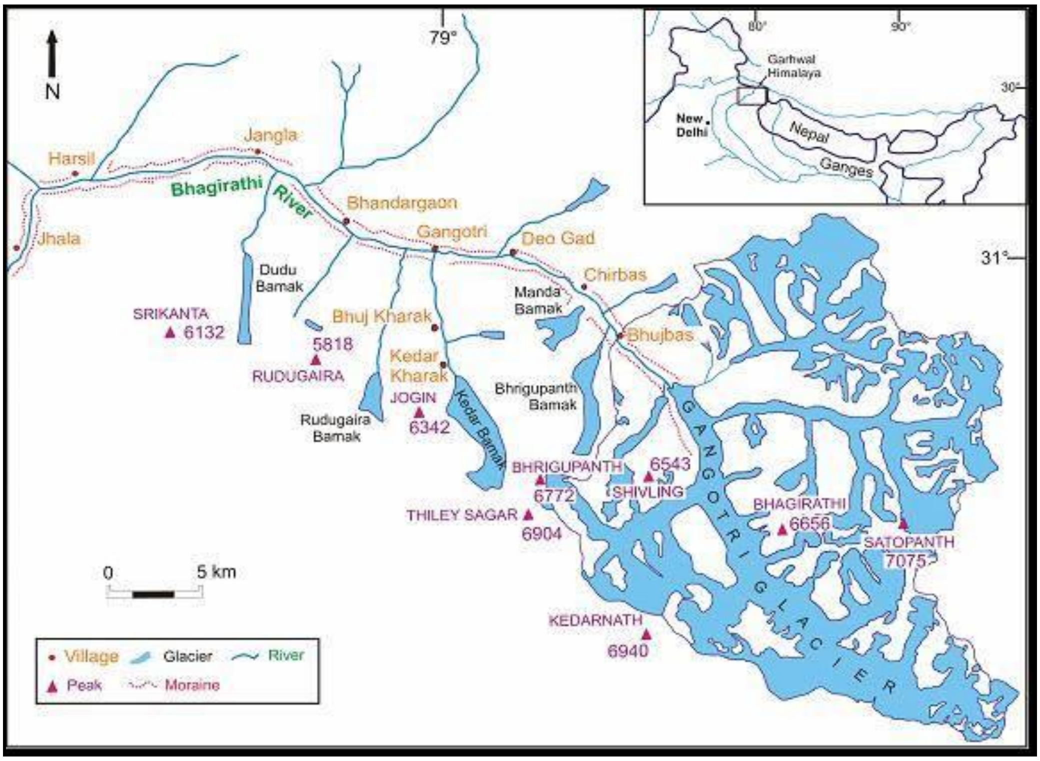
1. Title of the Study: Seasonal Characterization of Gangotri Glacier melt runoff and simulation of streamflow variation under different climate scenarios.

2. Study Group: Dr. Manohar Arora, Scientist 'F'
Dr. P K Mishra, Scientist 'D'
Dr. Vishal Singh, Scientist 'D'

3. Type of Study: Internal Project

Date of start: 01.04.2018
Scheduled date of completion: 31.03.2023

4. Location Map:



5. Objectives: The objective of this study includes:

- Continuous observations of meteorological, hydrological and suspended sediment data for the melt season to determine monthly and seasonal specific water and sediment yield from the study glacier.
- Seasonal characterization of the glacier melt.
- Estimation of suspended sediment yield from the Glacier.
- Modeling the catchment runoff variation under different climatic scenarios.

6. Statement of the problem:

The study involves collection and analysis of hydro-meteorological and discharge data of the glacier site. The second step is to use a snow melt model for streamflow generation and identification of different runoff components. The third step is to simulate catchment runoff variation under different scenarios.

7. Action Plan

Year	May to October	November to April	Remark
All Years	Field investigations & Data Collection	Data analysis	Report preparation after three years

6. Objectives vis-à-vis Achèvements

Objectives	Achèvements
Continuous monitoring of meteorological and hydrological data for monthly and seasonal specific water yield and its variability from the year to year	The field investigations for ablation season of May 22 was started in May 22 and ended in the first week of October 22. The data collected has been processed. Based on the three years (2018, 2019 and 2022), the average monthly discharge computed for May, June, July, August and September are 26.1,58, 99.7, 99.5 and 51.9 m^3/s respectively. The average monthly volume of water flowing from the gauging site are 54.8,146.3, 267.1, 266.6 and 134.6 MCM for June, July, August and September are, respectively. In terms of volume, the total melt water from the Gangotri Glacier for the ablation period 2018, 2019 and 2022 was estimated to be 862.5, 745.5 and 945.4 MCM. Results indicate that respective date of peak volume discharge was found to be in July for the ablation period 2018, 2019 and 2022.
Characterization of Suspended sediment in the Gangotri Glacier Melt Stream	Particle size analysis was carried out from the samples collected. Mean monthly suspended sediment concentration for May, June, July, August and September during the study period was 536.7,1289.6, 2464.3, 1318.8 and 592.4 ppm, respectively. Maximum daily mean suspended sediment concentrations observed in May, June, July, August and September were 1355, 5194, 18749, 3506 and 1569 ppm, respectively. For the entire melt season, the mean daily suspended sediment concentration was computed to be 1348 ppm.
Seasonal Distribution of Cold Katabatic and Warm Anabatic Wind.	The percentage of Cold katabatic and Warm anabatic wind in the years 2016-2019 is 56% and 44% respectively.
Simulation of Streamflow for the Gangotri Glacier Melt Stream.	HBV model was used for the calibration of streamflow. The model was calibrated for the years 2016-17 and is to be validated year 2022. Different functionalities, such as an automatic calibration using a genetic algorithm or a Monte Carlo approach, as well as the possibility to perform batch runs with predefined model parameters make the HBV model interesting especially for estimating streamflow.

COMPLETED STUDIES
INTERNAL RESEARCH PROJECT: NIH/WRS/2020-22/02

1. Title: Impacts of Glacier and Climate Change on Runoff for Selected Basins of Himalayan Region

2. Project Team:

Dr Vishal Singh, Scientist 'D'
Dr Sanjay K Jain, Scientist 'G'
Dr Manohar Arora, Scientist 'F'

3. Project Duration: 02 Years (08/20 – 07/22)

4. Objectives

1. To apply a data assimilation technique and bias correction methods for constructing more accurate high resolution gridded (i.e. approximately at 0.05º×0.05º) hydro-meteorological data sets (e.g. precipitation) over the selected river basins.
2. To develop a novel Integrated approach for snowmelt and glacier melt runoff modeling by incorporating SWAT and SPHY hydrological models with special emphasis on uncertainty estimation utilizing real time remote sensing and hydro-observation datasets.
3. To study the impact of snow and glacier changes on the runoff.
4. To analyze the impact of climate change and the long-term (21st century) variability in snow and glacier melt runoff utilizing latest CMIP6 GCMs datasets.

5. Present state-of-art

A limited number of studies have been carried out related to the separation of snow and glacier melt contributions, especially in the Himalayan region under glacier and climate changing conditions. The computation of snowmelt induced runoff from the glaciered catchment has always been a key hydrological issue, especially over high mountainous regions like Himalaya. Climate change studies resulted that around 1ºC temperature has been increased in Himalayan regions, which have been identified as one of the most vulnerable glaciated regions to climate change. The conservation of Himalayan freshwater reserves is necessary for the design and management of hydropower plants, supply of drinking water, agricultural management practices and flash flood risk assessment. This study has been proposed to carry out a research analysis over Himalayas to assess the impact of glacier and climate change in the long-term time frame (e.g. 21st century). For snow and glacier modelling, a novel approach based on snow-glacier hydrological model such as SPHY will be incorporated. SPHY model is a grid-based model and uses multiple thematic and meteorological datasets. In this study, we will use a temperature index model utilizing variable degree-day factors (uses separate factor for snow, clean ice glacier and debris glacier) in SPHY at each grid scale for analyzing snow and glacier melt runoff, especially designed for the Himalayan conditions. No such variable degree-days factors have not been applied for each grid. For climate change analysis, latest CMIP5/CMIP6 GCMs coupled with SWAT model will be utilized. SWAT model has been widely utilized in the simulation and projection of various hydro-meteorological components.

6. Methodology: In the present study four Himalayan river basins such as Baspa, Parbati, Lachung and Subanshiri will be taken up.

6.1 Data assimilation and bias correction

For meteorological datasets, a high resolution gridded daily precipitation and temperature dataset (12.5º×12.5º) were constructed for the historical time by assimilating IMD, IMDAA, TRMM and CHIRP datasets as per their availability. The bias correction has been done using advanced bias correction methods viz. Quantile mapping and Linear scaling etc.

6.2 Integrated Hydrologic Modelling:

For the modeling of snowmelt and glacier melt, a gridded and fully distributed model SPHY and a semi-distributed model SWAT have been utilized. The calibration and validation of modeling outcomes have been done utilizing the observed datasets at different gauges.

6.3 Snow and Glacier runoff changes

For snow-covered areas (SCAs) and glacier mapping, MODIS, LISS 3, LISS 4, and Sentinel satellite sensors data have been utilized. For snow cover extraction Normalized Difference Snow Index (NDSI) based on cloud removal technique has been performed as previously used by various researchers. For the computation of snow and glacier melt a variable degree day factors based Temperature index model was applied in SPHY model. The long-term changes in snow and glacier melt runoff have been assessed with respect to glacier changes and climate utilizing glacier datasets and climate model datasets. For this purpose, different times (temporal) glacier maps have been derived and the changes in glacier area for each of the selected river basin has been computed.

6.4 Validation of Satellite-based Snow Covers with SPHY model derive Snow Covers and Model calibration

Various satellite-sensor based remote sensing products MODIS based SCA has been used to validate the SPHY derived snow covers.

7. Objective wise results and conclusions

Objectives	Works completed	Achievement
To apply a data assimilation technique and bias correction methods for constructing more accurate high resolution gridded (i.e. approximately at 12.5º×12.5º) hydro-meteorological data sets (e.g. precipitation & temperature) over the selected river basins viz. Baspa river, Upper Ganga river and Upper Teesta river.	For the meteorological data analysis and modeling of snow-glacier melt runoff, the IMDAA re-analysis datasets and CHIRPS datasets were utilized. The Bias corrections using Quantile Mapping has been performed. For the analysis, the daily precipitation, minimum and maximum temperature datasets were utilized. IMD gridded datasets have been considered as the observed and reference datasets for the bias correction of CHIRPS and IMDAA-reanalysis datasets.	100%
To develop a novel Integrated approach for snowmelt and glacier melt runoff modeling by incorporating SWAT/SPHY hydrological models with special emphasis on uncertainty estimation utilizing real time remote sensing and hydro-observation datasets.	For the long-term hydrological assessment, the SPHY and SWAT models have been utilized. For the Baspa and Upper Ganga, SPHY model has been setup and For Teesta the SPHY and SWAT both models were setup. The model calibration and validation have been performed using the observation datasets (gauge Q) and real time satellite derived snow covers (MODIS snow cover data). For the uncertainty and sensitivity analysis, number of modeling parameters are optimized for each slected river basin and then final model simulation was performed. For the separation of snowmelt Q and gacier melt Q from the total discharge, the SPHY model was performed which uses the elevation band criteria to separate the glacier and non-glacier parts. The strength of the glacier melt induced runoff computation has been evaluated with reference to observed discharge at different gauges in all selected river basins, which showed a reliable agreement between modeled and observed runoff, in most of gauges (R^2>0.7).	100%
To study the impact of snow and glacier changes on the runoff.	For analyzing the effect of glacier changes on runoff, the temporal glacier maps for each selected river basin has been computed and the computation of different runoff components such as snowmelt runoff (Q), glacier melt Q,	100%

	baseflow Q and rainfall Q w.r.t. different times glacier maps highlighting area based changes have been computed. To see the behavior of runoff for different glacier sized watersheds, the three basins have been divided into a number of watersheds. In Baspa four watersheds while for Ganga and Teesta basins, six watersheds have finally selected depending on quantum of glacier. As per the decadal computation of glacier melt scenarios for all river basins viz. Baspa (i.e. 2003-2010 and 2011-2018), Ganga (1986-1995, 1996-2005, 2006-2015, and 2011-2020) and Teesta (1996-2010 and 2006-2020), observations showed that watersheds having large glaciers, the melt runoff has increased, while in cases of the watersheds having small glaciers, the melt runoff has decreased due to reduced glacier cover. In case of Baspa basin, glacier melt runoff has decreased by 5% while for Ganga and Teesta basins it has increased by 1%. Similarly, for Baspa basin, snowmelt runoff has increased by 6% and for Ganga and Teesta it has decreased by 3%.	
To analyze the impact of climate change and the long-term (21st century) variability in snow and glacier melt runoff utilizing latest CMIP6 GCMs datasets.	For the analysis of climate change, the two best fit CMIP6 climate models with two SSP scenarios viz. SSP245 and SSP585 have been selected and the long-term changes in snow cover and snowmelt and glacier melt runoff have been computed. Based on the CMIP6 model based assessment of lng-term changes in snow cover areas over Ganga river basin, a significant reduction in the snowfall during December to March has been observed, which may be caused due to the increment in temperature that disturbs the ration of precipitation versus snowfall. Due to significant changes in glaciers areas and rise in temperature, a significant increase in snowmelt+glacier melt runoff has been observed, especially in Baspa and Teesta river basin.	100%

COMPLETED STUDIES
SPONSORED RESEARCH PROJECT: NIH/WRS/2019-22/03

1. **Thrust Area under XII five Year Plan**: Himalayan Cryosphere and Climate Change

2. **Project Team:**
   Dr. Vishal Singh, Scientist 'D'
   Dr. Sanjay K. Jain, Scientist 'G'
   Collaborator: Dr. A. P. Dimri, Professor, SES, JNU, New Delhi

3. **Title of the Project:** Assessment of seasonal variations in Hydrology and Cryosphere of upper Ganga Basin

4. **Objectives:**
   a. Hydrological run-off modeling using GRACE satellite observations.
   b. Estimation of solid and liquid precipitation using land surface and air temperature based approach.
   c. Estimation of snow mass change and snow water equivalent (SWE) in snow season using GRACE satellite data and compared with remote sensing data.
   d. Seasonal soil moisture fluctuations with emphasis to ISM (JJAS) and IWM (DJM)

5. **Study Area**

The Ganga river originates from the Gangotri glacier in the Himalayas at an elevation of about 7138 m above the mean sea level (m.s.l.). At its source, the river is called Bhagirathi. It decends down to the valley up to Devprayag where it is joined by the Alaknanda river. Alkananda originates from the twin glaciers namely the Bhagirath Kharak and Satopanth. After the confluence its confluence with Alaknanda, the combined river is called Ganga. The river continuous to flow in the downstream section and cascades along the valley for distance of approximately 130 km and after cutting through the Siwalik range of Hills, it emerges into plains at Rishikesh in Uttarakhand. The total area of Upper Ganga basin upto Rishikesh is around 21762 km2 and the elevation varies from 325 m to 7800 m. Soils of this region do not from a compact block and differ valley to valley and slope to slope according to different ecological and environmental conditions. Soils of upper Bhagirathi and Alaknanda are of mixed origin such as glacial and fluvio-glacial. In the lower hilly region, soils mostly comprise forest soils and hill soils. The soil in this region is very thin and all exposed slopes are susceptible to severe erosion and to gullying. Landslides are very frequent in the region. The bed region of river is rocky up to 40 km downstream of Rishikesh.

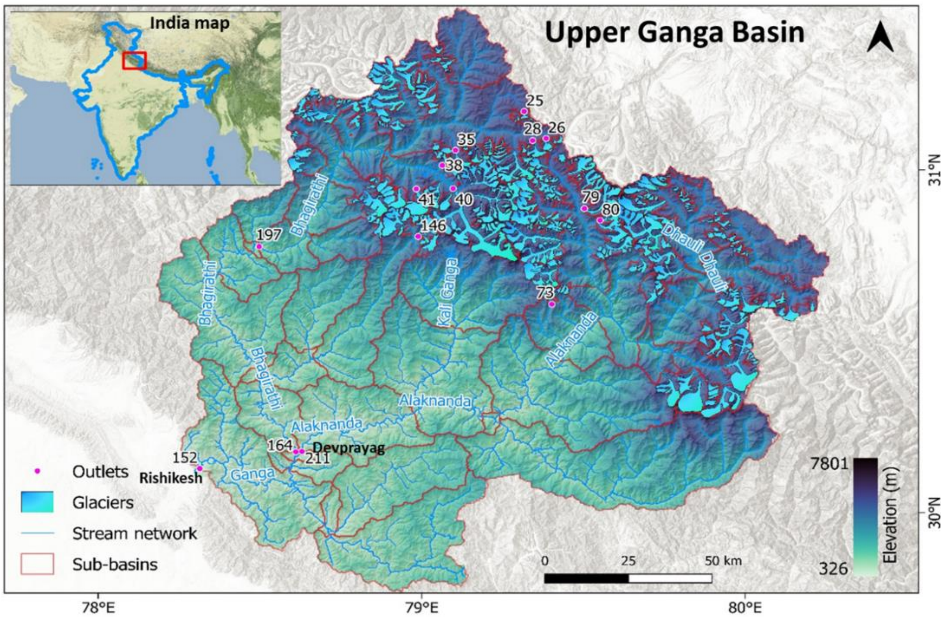


Figure 1: Showing the study area map i.e. Upper Ganga Basin (up to Rishikesh) with delineated subbasins (221 nos.) or stations.

6. **Research Outcome from the project:** A) Development of expertise in GRACE –TWS data analysis and manpower development B) Regional assessment of snow water equivalent/ glacier change assessment through the monthly variation of TWS.

7. **Cost Estimate:**

Total cost of the project:	Rs. 23.19 lakhs
Source of funding:	NRDMS-DST

8. Methodology

For spatio-temporal analysis of snow-glacier melt and separation of snow melt and glacier melt from the total flow, the SPHY model developed by Future Research Water Group Netherlands (Terink et al., 2015) has been setup in four different decadal scenarios (DSs) viz. 1986-1995 (i.e. DS1), 1996-2005 (i.e. DS1), 2006-2015 (i.e. DS1) and 2011-2020 (i.e. DS1) with respect to different times glacier maps viz. 1990, 2000, 2010 and 2020, respectively. The SPHY model has scripted in Python programming, which utilizes the PCRASTER module as the dynamic modeling framework to compute various water balance processes. In this research study, the spatial resolution of the model was set at 250 m^2 grid scale and performed all the simulation at this grid scale and then aggregated at watershed and/or outlets as shown in the workflow diagram (Figure 2).

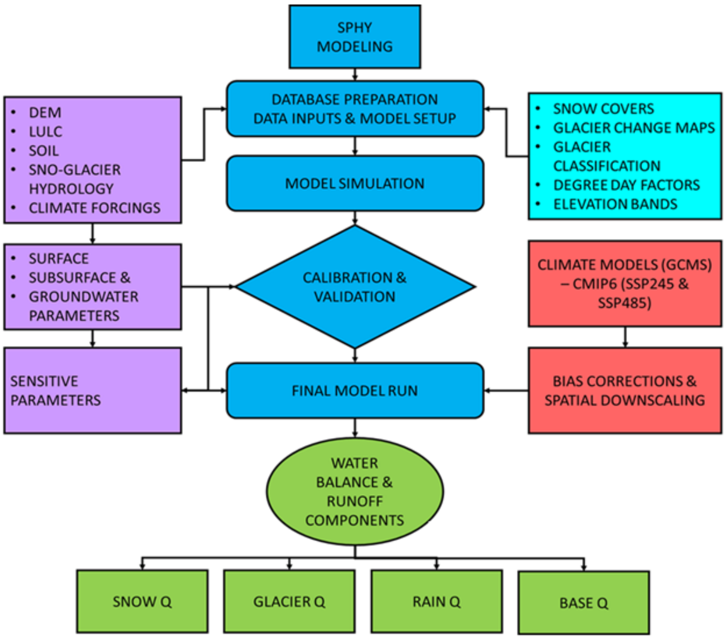


Figure 2: Workflow of SPHY model for the computation of hydrological components.

9. Main Observations

1. TWSA represents a part of hydrological processes over the river basins and IHR. In the IHR, over northwest India and Pakistan, the western disturbances (WDs) are the primary weather system responsible for winter precipitation (Dimri, 2006).
2. Monsoon dominates precipitation in GRB and BRB with a mean of 32.77cm and 32.19cm respectively. Mean TWS reduces across the basins during winter.
3. A contrary change in the mean TWS is observed in north IRB which experiences an increase in TWS, while a decrease is observed in southeast.
4. The main contribution of storage is from monsoon precipitation than other seasonal sources. Seasonally significant decreasing trends of TWS are observed in the IHR with 99 percent confidence interval.
5. Most of the areas of three basins experience a decreasing trend. GRB among the IHR basins is dominantly showing the most decreasing trends in all the seasons.
6. Interestingly, most negative trend for TWS in GRB is observed during monsoon at the rate of 6.16 ($*10^{-2}$ cm/year) with a standard deviation of 1.8 over the study period

10. Concluding Remarks

In this study, the changes in glacier areas have been computed in different times and their impact on melt runoff including snow and glacier melt runoff have been analyzed separately. For the assessment of melt runoff, SPHY model has been significantly utilized and the separation of snowmelt runoff and glacier melt runoff from the total discharge has been done at different locations. We find that the contribution from glacier melt runoff has been increased, while a noticeable decrease was observed in snowmelt runoff due to computed changes in the glacier areas and well as changes in the meteorological conditions. The contribution of runoff from rainfall has been increased in the basin. Overall, we find that the glacier areas have been reduced around 5% from 1990 to 2020 and around 98.8 km^2 glacier area have been lost. Though, this change is not so steep, but if the warming continues, the rate of change may be enhanced and this condition can be critical to small size glaciers, especially which are situated at lower altitudes. The accelerated rate of change of glaciers may enhance the uncertainty in the contribution of different runoff components. Overall, the present study observations give a more detailed insight into glacier area changes and their impacts on glacier melt, snow melt and other runoff components at subbasin scale.

In this study, seasonal Snow Water Equivalent is measured by amalgamating the simulation result of SPHY-model and GRACE monthly observations. The GRACE data is significantly downscaled from

100 km resolution scale to 25 km scales utilizing the Machine Learning algorithms. Random Forest regressor algorithm performed well in predicting the downscaled GRACE result. The downscaled GRACE at 25 km scale is able to capture the local scale variability and hence, found useful for the computation of TWSA and SWE in the Upper Ganga Basin. The variations in GRACE terrestrial water storage data is of great importance in studying the changes of snow water equivalent in the study area. The GRACE data is well compared with the MODIS derived SCA and other hydro-meteorological components and a significant relationship has been established. The downscaled GRACE data is found useful for exploring cryospheric components and well tested at the Upper Ganga Basin. GRACE+SPHY coupled methodology is helpful in understanding the seasonal snow-glacier changes while working at a sub-basin scale in the cold regions where the observed data is limited. However, the monthly temporal resolution of GRACE limits the estimation on daily basis and hence it is only useful for estimating SWE on a seasonal scale. Similar approach can be utilized in other Himalayan river basins to analyze the effects of glacier changes on melt runoff.

As per the observations obtained from the present study work, which is well performed over the Upper Ganga Basin, the GRACE+SPHY coupled methodology can be applied in other basins such as Satluj and Baspa river basins (part of Indus basin, western Himalaya) and Teesta river basin (part of Brahmaputra basin, eastern Himalaya) to understand the seasonal as well as long-term snow-glacier changes at a smaller scale in the cold regions where the observed data is limited. The next major step will be the downscaling of GRACE at much smaller scales such as 10 km and 5 km over the western and eastern Himalayan river basins, on a Daily Time step. The integration of local scale hydro-meteorological variables, WRF model datasets and integration of Machine learning and Data Assimilation techniques utilizing open data sources can be effectively utilized to downscale the high resolution GRACE datasets. This research work can be further extended over the other Himalayan river basins covering eastern and western Himalayan river basins so that the existing cryopsheric variability can be better understood.

ONGOING STUDIES
SPONSORED RESEARCH PROJECT: NIH/WRS/2019-22/01

1. Title - Snow and glacier contribution and impact of climate change in Teesta basin in Eastern Himalaya

2. Study Team

NIH Roorkee:

Dr. Sanjay K Jain, Scientist 'G'
Dr. P K Singh, Scientist 'D'
Dr. Manohar Arora, Scientist 'F'
Dr. A K Lohani, Scientist 'G'
Dr. Vishal Singh, Scientist 'D'

JNU, New Delhi:

Dr. A P Dimri, Professor

CAU Sikkim:

Dr. S R Yadav, Assistant Professor (SWCE)

IITM Pune

Dr. (Mrs) Nayana Deshpande, Scientist D

3. Objectives

The proposed project will adopt an inter-disciplinary approach to address the following objectives, in particular for the Teesta basin within the eastern Himalayas:
The objectives of this study are:

- Assessment of recent changes in snow, glacier, rainfall and its impact on the hydrology of the Teesta basin through Hydrologic modelling.
- To understand the influence of glacier size, debris cover, topographic (i.e., altitude, aspect, and slope) and climatic variables on recent glacier changes?
- Sediment transfer characteristics of Teesta River at selected sites and identification of major drivers.
- Assessing climate change in the basin and future scenarios and resultant hydrological responses
- To understand and simulate the magnitude of the GLOF hazard of glacial lakes formed due to glacier recession using MIKE-II breach modeling.
- Identification of key change indicators for water resources of the region and their impact on local communities
- To develop a comprehensive and interactive web-enabled database repository of the hydro-met database and modelling spatial outputs with basic GIS functionalities.

4. Sponsored by NMHS, MOEF & CC

5. Project Cost Rs. 143 Lakhs

6. Methodology

In the present study, modelling of snow/glacier melt runoff, sediment sampling and modelling, climate change studies, impact of climate change and glacier lake outburst flood are proposed to achieve the objectives.

- Snow/glacier melt runoff modelling will be done using SNOWMOD and VIC models. Landuse/landcover, snow/glacier maps etc. will be prepared for the study basin using standard RS and GIS techniques. Hydro-meteorological data will be collected from different sources such as CWC, IMD, NHPC and state agencies.

- Sediment yield modelling and assessment will be done using Delivery Ratio and GIS coupled empirical models, SWAT model and conceptual SCS-CN based sediment yield models.
- Many methods have been developed for generating climate scenarios for the assessment of hydrologic impacts of climate change, which include downscaled general circulation model (GCM) simulations. Data and knowledge generated will be used to implement a sub-grid scale parameter scheme for Regional Climate Model using RegCM4 model with sub-grid parameterization and refined future projections for climatic variables.
- The satellite data along with field investigations will be used to assess glaciers and glacial lakes. MIKE 11 model will be used for GLOF simulations.
- A comprehensive web enabled database repository will be developed based on information from the field data collection and modelling results.

7. Time-Line and Activities

	Activities	1st Year		2nd Year		3rd year	
NIH	Hiring Manpower	■					
	Procurement of the instruments	■	■				
	Data collection and database preparation		■	■	■		
	Model data need and requirement by other PIs			■	■	■	
	Model simulations and sensitivity analysis			■	■	■	
	Study of impact of climate change			■	■	■	
	Sediment studies				■	■	
	GLOF studies			■	■	■	■
	Development of a comprehensive and interactive web-enabled database repository			■	■	■	■
	Workshops/Trainings				■	■	■
	Report writing					■	■
CAU	Hiring Manpower	■					
	Procurement &installation of Met. stations	■	■	■			
	Data collection and Data synthesis		■	■	■	■	
	Sediment studies			■	■	■	■
	Report writing						
JNU & IITM	Hiring of manpower	■					
	Climate modelling work		■	■	■	■	
	Report writing					■	■

8. Progress till-the-Date

Spatial Process in Hydrology (SPHY) model has been used for the overall water balance computation and then the separation of all main runoff (Q) components (e.g. snow melt runoff, glacier melt runoff, base flow and rain induced runoff) for Teesta river basin. However, the main emphasis is given to the glacier melt and snowmelt runoff computations. In the upstream point at Chungthang, the contributions from different runoff components are recorded as 47% from rain induced runoff, 25% from glacier melt runoff, 23% from snowmelt runoff and 5% from baseflow. At outlet (Teesta lower dam IV), the contributions from different runoff components are recorded as 78% from rain induced runoff, 10% from glacier melt runoff, 9% from snowmelt runoff and 3% from baseflow. We also applied SWAT model and found that the snow and glacier melt runoff contributes about 16% to the average annual flow of the Teesta lower dam IV of the Teesta river basin. Soil erosion modelling using RUSLE shows that the area under extremely severe erosion category in Teesta basin is 38.17%, 39.52% and 41.81%, respectively due to CHIRPS, IMDAA and TRMM datasets. Similarly, the area under very severe erosion is found to be 8.18%, 7.81% and 9.23% and under severe erosion as 11.62%, 10.91% and 11.17%, respectively due to CHIRPS, IMDAA and TRMM datasets. Finally, the future assessment of the soil erosion has been done by using the best performing CMIP6 models for the study region, i.e., EC-Earth3 and BCC-CSM2-MR for two Shared Socioeconomic Pathways (SSPs), i.e., SSP245 and SSP585 for Near Future (2021-2050), Mid Future (2051-2080) and Far Future (2081-2100). The results show that there is an increase in the percent (%) area susceptible under extremely severe erosion in Near Future, Mid Future and Far Future under EC-Earth3 (~64%) and BCC-CSM2-MR (~48%) models with respect to SSP245 and SSP585 projection scenarios as compared to the historical period (2000-2019). The glacial lake inventory was done for the years 1990, 2000, 2010, and 2020 and we found 25 most vulnerable lakes (based on several weighted geometric and geomorphic characteristics), out of which 10 lakes are with the highest GLOF threats. These lakes are largely located near the major snowline and great Himalayan water divide in Sikkim's north-eastern region. Keeping in view these findings, these lakes should be monitored on a regular basis.

ONGOING STUDIES
SPONSORED RESEARCH PROJECT: NIH/WRS/2020-22/02

1. **Title:** Development of Water Accounts for the different sub-basins of Brahmaputra and Barak River Basins in the state of Meghalaya Using Water Accounting Plus (WA+) Framework.
2. **Project Team:**
   Dr P. K. Singh, Scientist 'D'
   Dr P. K. Mishra, Scientist 'D'
3. **Project Duration: 02 Years (08/20 – 07/22) ***Extended till 03/23
4. **Objectives**

The major objective of this study is to apply newly developed WA+ framework for sub-basins of Brahmaputra and Barak basins in the state of Meghalaya.

a) To develop water accounts for the study basins/sub-basins.
b) To estimate ET consumption patterns and beneficial and non-beneficial water consumptions.
c) To develop accounts for agricultural services (i.e., land productivity and water productivity).
d) To prepare the detailed WA+ report for study basins/sub-basins.
e) To impart training on WA+ to the state officials of Water Resources, Agricultural and other related Depts.

5. **Present state-of-the-art**

Water accounting (WA) can provide a coherent and consistent solution to the spatial & temporal assessment of WP and the allocation of water across various competing sectors to avert the looming water crisis. WA also considers the consumption of water and the benefits and services - including ecosystem services - that result from that consumption, including the return flow of non-consumed water. Various efforts have been made by United Nations (UN), Food and Agricultural Organisation (FAO), International Water Management Institute (IWMI) and the Australian government to develop standard WA frameworks. FAO's global information system on water and agriculture (AQUASTAT) is an important source of data, however, it does not distinguish between consumptive use and non-consumptive use. The System of Environmental Economic Accounting for Water (SEEA-WATER) of the United Nations Statistics Division (UNSD) (UN, 2012) requires a variety of data from numerous sources, which are unlikely to be available at many times (Dimova et al., 2014; Perry, 2012). It does not distinguish between the green and blue water resources (Falkenmark and Rockstr¨om, 2006; Rockstr¨om and Gordon, 2001). The Australian Water Accounting Standard (AWAS) developed by the Water Accounting Standards Board (WASB) of the Australian Bureau of Meteorology (BOM) accounts for water withdrawals rather than consumptive use. However, AWAS does not provide any information on rainfed systems and natural evapotranspiration (ET) processes.

The International Water Management Institute (IWMI) developed a WA procedure (Molden, 1997) with the aim of tracking water depletion rather than withdrawals to avoid errors when neglecting recycling, and to account for ET. The IWMI WA framework has been applied by IWMI in many irrigation system studies (e.g., Bhakra system in India (Molden, 1997); Zhanghe Irrigation System in China (Dong et al., 2004)) and at the national scale (e.g., India: Amarasinghe et al., 2007; SriLanka: Bastiaanssen and Chandrapala, 2003). However, only a few countries have adopted these WA mechanisms usually due to the lack of data needed to implement these approaches.

6. **Methodology**

The Water Accounting Plus (WA+) Framework is based on open access remote sensing data -in conjunction with open access GIS data and hydrological model output. WA+ communicates information on water storage, flows and fluxes for a variety of land use systems using eight intuitive fact sheets, tables and maps that are designed to be understood by people with technical and non-technical backgrounds alike.

The WA+ framework is developed by IHE-Delft in partnership with IWMI, FAO, and the World

Water Assessment Program (WWAP). WA+ is based on a mass water balance approach (at the pixel level) and uses Budyko theory (Budyko, 1974) (Figure 1) and WATERPIX model (IHE, 2016) for this purpose. The basis of this water balance approach is that outflow from a certain area of interest (e.g., river basin) are explicitly related to the net inflow and depletion through a measurable ET processes.

WA+ framework classifies land use land cover (LULC) in to 80 classes. These 80 LULC classes are further grouped under four main Water Management Classes (WMC), i.e., Protected Land Use (PLU), Utilized Land Use (ULU), Modified Land Use (MLU), and Managed Water Use (MWU) (Figure 2). WA+ framework uses the Budyko theory (Budyko, 1974) for measurable ET separation in to ETgreen and ETblue. The Budyko theory is based on the coupling of (a) Water Balance approach and (b) Energy Balance approach. The water balance is performed individually for green and blue pixels, respectively.

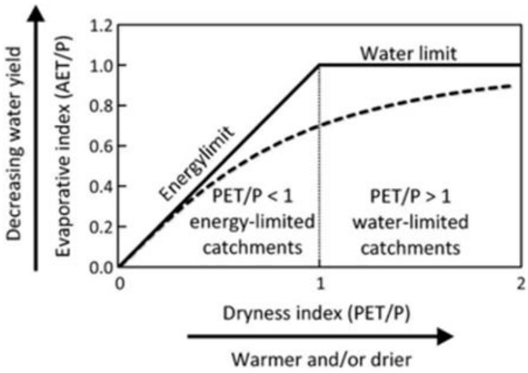


Figure 1: Budyko Framework **Figure 2: WA+ Based WMC**

6.1 Study Area and Major Input Data

The state of Meghalaya is the north eastern part of India and is bounded in the north and east by Assam plains and in the south and west by Bangladesh plains. In the north, it is bounded by Kamrup and Goalpara districts of Assam and on the east by Karbi Anglong and North Cachar. The southern border is the international border with Bangladesh which is about 496 km long. Meghalaya is located between 25º01’51.58” N to 26º07’10.31” N latitude and 89º49’10” E to 92º48’04” E longitude with altitude ranging from 50 to 1966 meters. The State covers geographical area 22,429 km^2. Figure 3 shows the basin map of the Meghalaya state.

The WA+ framework makes use of open source remote sensing data in an effort to maintain a high level of transparency. Remote sensing is a reliable and objective source of data. Data products from the National Aeronautics and Space Administration (NASA) and European Space Agency (ESA) are provided free of charge for all users regardless of nationality or intended application. Following datasets will be used for WA+ analysis in this study:

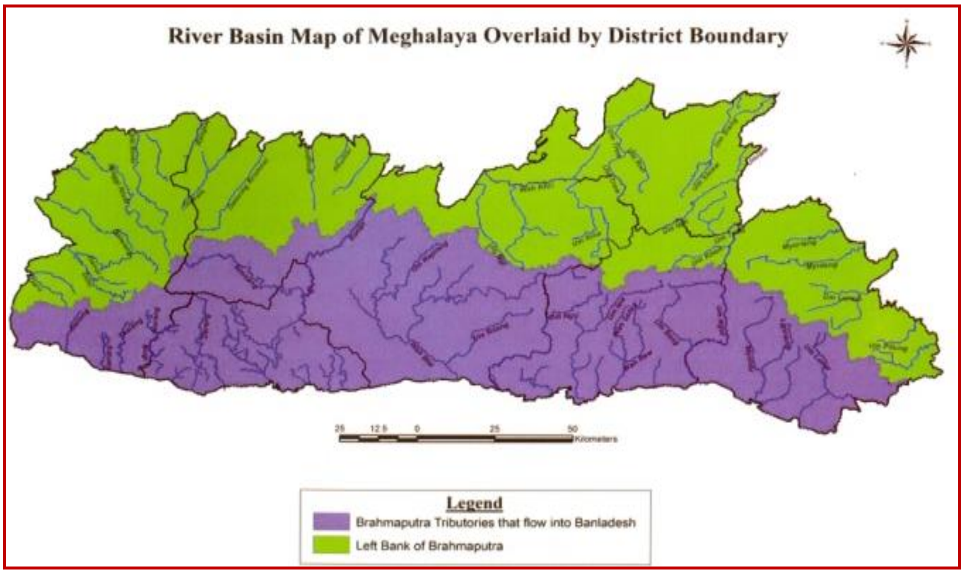


Figure 3: River basin map of Meghalaya overlaid by district boundary
(Source: WRD, Meghalaya)

- Precipitation (CHIRPS - or TRMM rainfall)
- Evapotranspiration (MODIS/ ETensV1.0/GLDAS)
- Meteorological data (GLDAS-Noah)
- WA+ system based Land Use / Land Cover (WALU using GlobCover, IWMI crop maps, MODIS, FAO, etc.)
- Soil moisture (EUMETSAT-ASCAT: Advanced SCATterometer (ASCAT)/GLDAS
- Vegetation, leaf area index (MODIS)
- Net primary production (NPP) and gross primary production (GPP) (MODIS)
- Crop types and crop calendar
- Basin DEM, boundary, drainage network map, etc.
- GRACE (Gravity Recovery and Climate Experiment) dataset
- GMIA (Global Map of Irrigated Areas) dataset
- MIRCA (Monthly Irrigated and Rainfed Crop Areas) dataset
- Grey Water Footprint/WPL datasets

7. Research Outcome from the Project:

- Water Accounts: Supply-Demand and Consumptions and Water Availability
- Water Consumption Patterns and beneficial non-beneficial consumptions.
- Accounts for Land Productivity and Water Productivity.
- LULC map, soil maps, and river networks.
- WA+ Report and Recommendations.
- Training modules on WA+ Framework.

8. Cost Estimates:

The total cost of the project: **₹ 14.50 Lakh**

a. Source of funding: NHP
b. Sub-head wise abstract of the cost:

Head	Amount (in Lakh)		
	1st Year	2nd year	Total
1: Manpower: JRF @31,000/ + HRA and others	5.00	5.00	10.00
2: Others (Hiring of services, field visits, consumables, stationary, printing of reports & brochures, and sample analysis, etc.)	1.00	1.00	2.00

3: Travel Expenditure	1.00	1.00	2.00
4: Contingency	0.25	0.25	0.50
Grand Total			14.50
	Rs. Fourteen Lakhs Fifty Thousand Only		

9. Work Schedule

a. Probable date of commencement of the project:
b. Duration of the project: 02 Years
c. Stages of work and milestone: Shown below

Project Year	**Aug. 2020-July 2021**				**Aug. 2021-July 2022 (Extended up to March 2023)**			
Project Quarter	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**
a. Data downloading, processing, and generation of data base	↔	↔						
b. Basic data analysis in WA+ framework, Ground truthing surveys for LULC and data collection from CWC, and state govt. departments		↔	↔					
c. WA+ Framework Application and Testing			↔	↔				
d. Development of Water Accounts					↔	↔	↔	
e. Detailed Analysis of Water Accounts and Validation and research paper publications						↔	↔	↔
f. Final report writing recommendations and Training							↔	↔

10.Progress till date:

We computed 7 gridded datasets (satellite and reanalysis) and compared the performance with the IMD datasets and based on the rank matrix statistics, the CHIRPS dataset is found best. We also computed extreme rainfall indices and percentage change analysis to quantify the variation in rainfall extremes between various time series durations (i.e. TS1:1983-1995, TS2:1996-2008 and TS3:2009-2021). The WaterPix (a hydrological model) was setup to prepare the inputs for estimation of the other components, such as supply and demand and water accounts. The computations for supply and demands (manmade and natural) and water accounts for the selected basins are in progress and the results will be discussed with WRD Meghalaya during the month of March-April, 2023 in the stakeholder’s workshop.

ONGOING STUDIES
SPONSORED RESEARCH PROJECT: NIH/WRS/2021-23/03

1. Title of the Project

Development of Water Accounts for the selected sub-basins of Brahmaputra, Barak and Irrawady-Chindwin basins in the state of Nagaland using Water Accounting Plus (WA+) Framework.

2. Project Team:

Dr P. K. Mishra, Scientist 'D'
Dr P. K. Singh, Scientist 'D'

3. Project Duration: 02 Years (04/21 – 06/23)

4. Objective of the Study

The major objective of this study is to apply the newly developed WA+ framework for the selected sub-basins of Brahmaputra, Barak and Irrawady-Chindwin basins in the state of Nagaland for estimating the status of the water resources. This will generate useful base data to help development of proper water management strategies and decision processes. The specific objectives are:

1. To set-up WA+ Framework for the selected study basins/sub-basins.
2. To estimate ET consumption patterns for the selected basins/sub-basins.
3. To estimate land and water productivity for the selected basins/sub-basins.
4. To develop Resource Base (Surface water & Groundwater) for the selected basins/sub-basins.
5. To develop capacity on WA+ to the State Govt. officials from WRD, Nagaland through training programmes

5. Scope of the Study:

The scope of this study is as follows:

a. To estimate ET consumption patterns and beneficial and non-beneficial water consumptions.
b. To develop accounts for agricultural services (i.e., land productivity and water productivity).
c. To collect hydrological and meteorological data.
d. To collect data on topography, soils, river networks, drainage networks and land-use & land-cover.
e. To validate, analyze and process the data collected and give necessary inputs.
f. To develop water accounts for the study basins/sub-basins.
g. To prepare the detailed WA+ report for study basins/sub-basins.
h. To impart training on WA+ to the state officials of Water Resources, Agricultural and other related Depts.

6. Study Area and Input Data

The state of Nagaland is a north eastern state of India and is surrounded by the states of Assam, Manipur, Arunachal Pradesh and also by Myanmar in the East. The state covers a geographical area of approximately 16580 km^2. The major part of the State is drained by the Brahmaputra basin (~10881 km^2, 65.6%) followed by Barak basin (~814 km^2, 4.9%) and by Irrawady-Chindwin basin (~4884 km^2, 29.5%). The state of Nagaland is divided into three river basins viz, rivers flowing to Brahmaputra, rivers flowing to Barak and the rivers flowing to the Irrawady-Chindwin basin.

Input Data

The WA+ framework focuses on the use of open source and remote sensing satellite datasets in an effort to maintain a high level of transparency and applicability in ungauged basins. Remote sensing is a reliable and objective source of data. Data products from the National Aeronautics and Space Administration (NASA), European Space Agency (ESA) and many other agencies are provided free of charge for all users regardless of nationality or intended application. Following datasets will be used for WA+ analysis in this study. Data sources are given in Appendix 1.

- Precipitation: Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)/ Tropical Rainfall Measuring Mission (TRMM)
  [now available as Global Precipitation Measurement (GPM)]
- Evapotranspiration (MODIS/ ETensV1.0/GLDAS)
- Meteorological data (GLDAS-Noah)
- GMIA (Global Map of Irrigated Areas)
- IWMI LULC map
- GlobCover LC v2
- MIRCA (Monthly Irrigated and Rainfed Crop Areas) dataset
- Leaf area index (LAI) and NDVI
- Net primary production (NPP) and gross primary production (GPP) (MODIS)
- Soil moisture (EUMETSAT-ASCAT: Advanced SCATterometer (ASCAT)/GLDAS
- GRACE (Gravity Recovery and Climate Experiment) dataset
- Crop types and crop calendar
- Basin DEM, boundary, drainage network map, etc.

The resolution of the above datasets varies from 250 m (MODIS) to 300 km (GRACE). However, all the dataset will be re-sampled to 250 m x 250 m resolution to develop water accounts of the study sub-basins/basins.

7. Project Budget

Head	Amount (in Lakh)		
	1st Year	2nd year	Total
1: Manpower: JRF@31,000/ + HRA and others	-	-	-
2: Work Station-high configuration	3.50	-	3.50
2: Others (Hiring of services, field visits, consumables, stationary, printing of reports & brochures, and sample analysis, etc.)	1.00	1.00	2.00
3: Travel Expenditure	1.50	1.50	3.00
4: Contingency	0.25	0.25	0.50
Grand Total			**9.00**
	Rs. Nine Lakhs only		

8. Expected Deliverables

- Water Consumption Patterns and beneficial non-beneficial consumptions.
- Land Productivity and Water Productivity.
- Basin/sub-basin wise Water Accounts: Supply-Demand and Consumptions and Water Availability
- WALU map, soil maps and river networks.
- WA+ Report and Recommendations of best practices suitable for the catchments
- Trainings on WA+ to the officers from Meghalaya WRD and other Implementing Agencies of the NHP.

9.Expected Timeline against the Deliverables:

Project Year	**Apr. 2021-Mar. 2022**				**Apr. 2022-Mar. 2023**			
Project Quarter	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**
a. Data downloading and processing, and generation of data bases and maps; data collection from CWC, and state govt. departments	←	→						
b. Data analysis in WA+ Framework, and		←	→					
c. Water Consumption Patterns and beneficial non-beneficial consumptions			←	→				
d. Accounts of Land Productivity and Water Productivity				←	→			
e. Catchment wise Water Accounts: Supply-Demand and Consumptions and Water Availability					←	──	→	
f. WA+ Report and Recommendations of best practices suitable for the catchments							←	→
g. Training modules on WA+							←	→

10. Progress till date:

Particulars	**Work Done**
Procurement of High Configuration System	Completed.
Generation of GIS layers for 3 basins and 9 sub-basins in Nagaland	Completed.
Data downloading and processing from open sources viz. CHIRPS, GMIA, LAI, GPP, NPP, Globcover, MIRCA (Rainfed and Irrigated), WDPA, Population, etc.	Completed.
Development of Water Accounting based Land use (WALU)	Completed.
Setting up of WA+ model for Sheet 2 (Evapotranspiration) and Sheet 3 (Agricultural Services including Land and Water Productivity) Generation	Completed.
Setting up of Water Pix model for Supply Generation	Completed.
Generation of Sheet 4 (Utilized flow), Sheet 5 (Surface water), Sheet 6 (Groundwater), Sheet 1 (Resource base)	Completed.
Training on WA+ to selected WRD officials	Organized during the month of November, 2022.
WA+ Report and Recommendations of best practices suitable for the catchments	Ongoing

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ONGOING STUDIES
SPONSORED RESEARCH PROJECT: NIH/WRS/2021-24/04

1. **Project Title:** Long term hydrological assessment for the development of water security plan into three sub-basins namely Barak, Minor rivers draining into Bangladesh and Minor rivers draining into Myanmar sub-basins in the state of Mizoram.

2.	**Duration of the project**	:	**3 years (04/21-03/24)**
3.	**PI and Co-PI from Lead Organization**	:	PI: Dr. Vishal Singh, Scientist- D Co-PI: Dr. M.K. Nema, Scientist- D Dr. P. K. Singh, Scientist- D
4.	**Investigators from Partner Organization**	:	1. Mr. K. Hamlet, Sr.EE 2. Mr. Vanlalpekhlua Sailo, AE

5. Objective of the Study

The major objective of this study is to apply the advance modeling framework for Barak, Minor rivers draining into Bangladesh (MRD-BAN) and Minor rivers draining into Myanmar (MRD-MYA) sub-basins in the state of Mizoram for water security plan. This will generate useful base data to help development of proper water management strategies and decision processes. The major objectives of the study area as follows:

a. To collect, prepare and evaluate various thematic datasets such as digital elevation model, land use/Land cover (LULC) map, soil map, population data (census) and hydro-meteorological data-sets such as precipitation, temperature, discharge etc.
b. Long-term Rainfall trend analysis based on rainfall frequencies and intensities to analyse the effect of climate change as per the standard guidelines.
c. Hydrological modelling, calibration and parameterization over Barak, Minor rivers draining into Bangladesh and Minor rivers draining into Myanmar subbasins in the state of Mizoram for the assessment of watershed components (including surface and groundwater) and water availability using SWAT and SWATCUP models (Arnold et al., 2012).
d. Analyzing the effect of LULC changes on the hydrological scenarios such as water availability (or water yield) at sub-catchments scale and discharge at the outlets.
e. Analyzing the effect of climate changes on the hydrological systems, with possible thresholds for resilience under different conditions and combinations anticipated.
f. To setup WEAP model (Levite et al., 2003) for calculating water demand of Mizoram state subject to mid-term water availability (say up to 2050) to increase water use efficiency and maintaining the adequate water supply sustainable development.
g. To prepare the detailed report for study basins/sub-basins in Mizoram state as per the mid-term hydrological assessment with the guidelines of water security plan with particular reference to demand points (domestic, irrigation or others) identified by the Water Resources Department, Government of Mizoram.
h. To impart training on “hydrological modelling” to the state officials of Water Resources, Agricultural and other related Depts, as well as officers from other implementing agencies of the National Hydrology Project.
i. Selection of dam sites with suggested capacity to meet the growing demand of water in the state.

6. Study area

Mizoram, with an area of 21,087 km^2 is largely divided into three major river basins: one is the Barak basin (8,935 km^2) in the central to northern part of the state, the second is Kolodyne basin (8,144 km^2)

in the southeastern part, and the third is Karnaphuli basin (3,999 km^2) in the southwestern part, as shown in Figure 1.

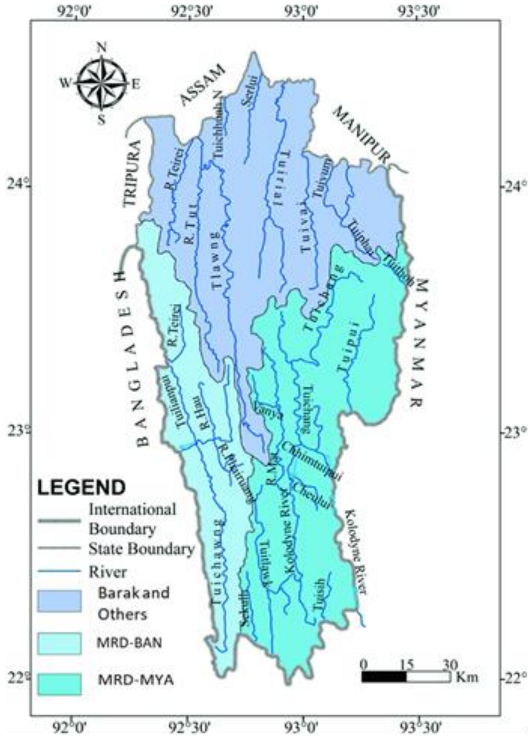


Figure 1: River basin map of the Mizoram showing river basins namely Barak and Other, Minor rivers draining into Bangladesh (MRD-BAN) and Minor rivers draining into Myanmar (MRD-MYA).

7. Brief Methodology

7.1 Processing of meteorological datasets

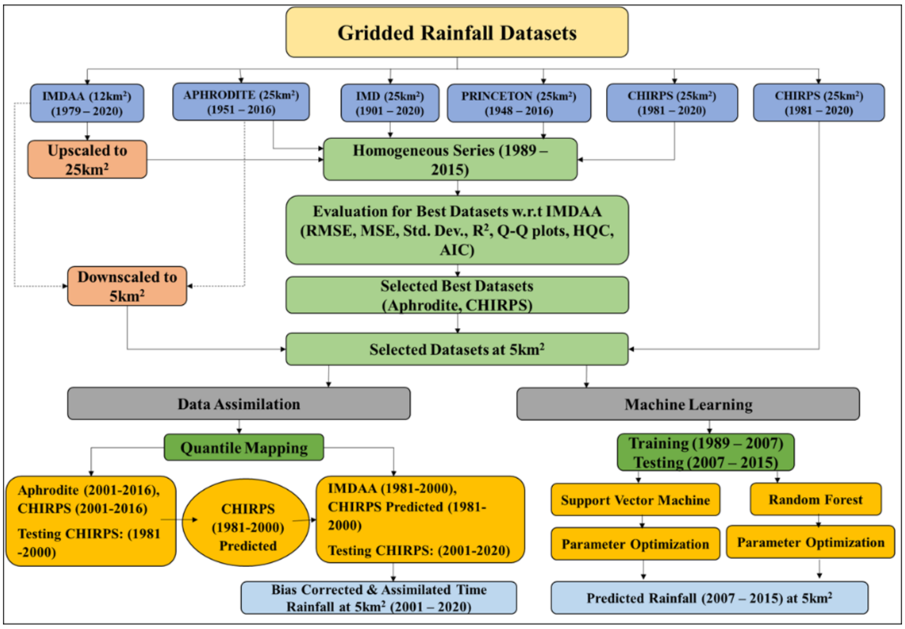


Figure 2: Processing of meteorological datasets and generation of new hybrid gridded rainfall.

7.2 Climate projections and rainfall indices

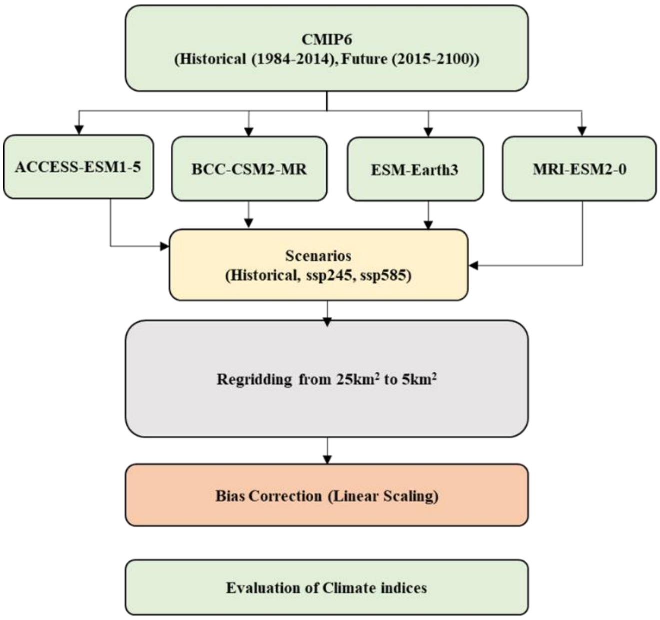


Figure 3: Analysis of rainfall indices to analyse changes in rainfall.

7.3 Overall modeling methodology

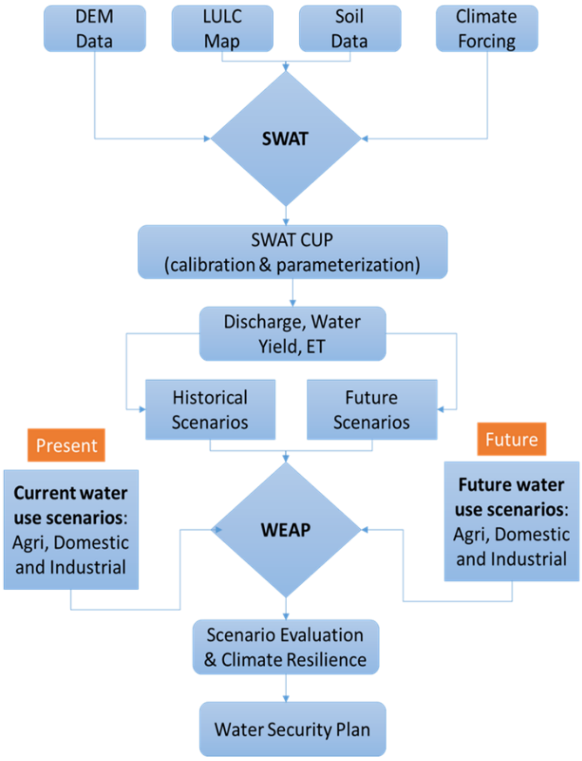


Figure 4: Overall modeling methods.

8. Expected Deliverables

- A detailed outcome of water balance components including surface and groundwater.
- Rainfall extreme trends discharge scenarios (up to 2050), with possible plans and thresholds for resilience with and without structural interventions under the anticipated conditions and combinations thereof.

- Basin/sub-basin wise water availability: Supply-Demand and Consumptions and Water Availability, considering a development period of 5 years and a planning horizon of 30 years.
- LULC change maps, soil maps and river networks.
- Guidelines and schema of water security plan, with particular reference to identified locations with significant demand. Planned developments will be taken into consideration.
- Report and Recommendations of best practices suitable for the catchments
- Trainings on hydrological models to the officers from Mizoram IWRD and other Implementing Agencies of the NHP.

9. Expected Timeline against the Deliverables

Project Year	**Mar 2021-Feb 2022**		**Mar 2022-Feb 2023**		**Mar 2022-Aug 2024**	
Project Quarter	**M 1-6**	**M 7-12**	**M 13-18**	**M 19-24**	**M 25-30**	
a. Data downloading and processing, and generation of data bases and maps; data collection from CWC, and state govt. departments	◄———	———►				
b. Data analysis, Trend generation, SWAT setup		◄———	———►			
c. Hydrological Assessment & Calibration		◄———	———►			
d. Projected Scenarios using GCMs and Climate Resilience Analysis		◄———	———	———►		
e. WEAP setup and water availability and demand assessment			◄———	———	———►	
f. Report and Recommendations of best practices suitable for the catchments					◄———	———►
g. Training modules on Hydrological Model				◄———	———	———►

10. Progress till date

Sl No.	All Planned Activity as per original work plan in approved PDS	Cumulative % Progress in the activity in this quarter	Comments / details of activities
1	Hiring Manpower: JRF	100%	The JRF has been recruited.
2	Nomination of Nodal-cum-Liasioning Officer from WRD Nagaland	100%	Chief Engineer cum Nodal Officer (NHP), WRD Nagaland has been approached to nominate a Nodal-cum-Liasioning Officer for smooth conduct of the study. SE K. Hamlet and AE Vanlalpekhlua Sailo have been nominated for the same.
3	Collection and Processing of Thematic and Meteorological Datasets	100%	Done. A new Gridded Hybrid Rainfall datasets have been generated.
4	Quality Check and Bias Correction of Hydro-meteorological datasets	100%	Done
5	Development of SWAT model	90%	Model setup has been done. Model improvements, Calibration and Validation have been done and all watershed components have been generated
6	Calibration and	60%	A manual calibration has been done at 4 gauges as per the

	Validation		available observed Q
7	Processing of Climate Model datasets	100%	For this study, the latest climate model datasets by Coupled Modelled Inter-comparison Projects (CMIP) under World Climate Research Programme (WCRP) named Coupled Modelled Inter-comparison Project Phase 6 (CMIP6) have been utilized. Initially 13 models, and each model includes five scenarios (historical, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5) were taken. After the Uncertainty Assessment of the Climate Models w.r.t. Observed Rainfall, four climate models viz. ACCESS ESM 1-5; BCC-CSM2-MR; EC-Earth3 and MRI-ESM2-0 considering three scenarios each (e.g. historical, SSP2-4.5, SSP5-8.5) have been selected for the final analysis. Bias correction of the selected model was done using Quantile Mapping method.
8	Rainfall analysis	100%	For this purpose, the bias corrected climate model datasets were divided into two terms viz. near term (2020-2050) and far term (2060-2090) and for each category annual average and climate indices were calculated as per the guidelines of IPCC. Climate indices considered here are: Dry days: if rainfall is <2.5 mm/day Wet days: if rainfall is >2.5 mm/day Dry spell frequency: if rainfall is <2.5mm/day for a continuous 5 days Wet spell frequency: if rainfall is >2.5mm/day for a continuous 5 days Maximum 1-day precipitation per year (Rx1D): maximum precipitation in a day WDx95: Number of wet days with daily precipitation over a 95 percentile
9	LULC Change Analysis	75%	Predicted LULC maps have been developed and their effects on hydrology has been analyzed
10	Water Availability and Demand	25%	The data inputs are prepared and the model setup is due.

ONGOING STUDIES
INTERNAL RESEARCH PROJECT: NIH/WRS/2020-23/05

1. **Title:** Monitoring and hydrological modeling of Henval watershed in Lesser Himalaya

2. **Project Team:**
   Dr Manish Kumar Nema, Scientist 'D'
   Dr Sanjay K Jain, Scientist 'G'
   Dr P. K. Mishra, Scientist 'D'

3. **Project Duration: 03 Years (08/20 – 07/23)**

4. **Objectives**
   a. To develop a baseline runoff and meteorological data of Henval watershed with the established experimental setup.
   b. To carry out Hydrological modelling of Henval river
   c. To model the spatial-temporal variability and temporal-stability of the soil moisture
   d. To compare and validate the satellite soil moisture data with the in-situ observations

5. **Present state-of-art**

Watershed is supposed to be the basic unit at which the hydrologic processes are studied and is central to most of the concepts in hydrology. Experimental hydrology still has a unique place with no alternative for testing and developing new research hypotheses and models. Given the importance of experimental hydrology, NIH has initiated an experimental hydrologic project for a small lesser Himalayan watershed, namely, Henval. In the first phase of the project, a state-of-art field observatory was established with various instruments and sensors during 2016-2019. Preliminary data analysis on the estimation of evapotranspiration by various methods and water balancing of the watershed was performed. The field station developed at Henval watershed is envisaged to operate for long-term monitoring of different hydro-climatic variables. This study is supposed to be the second phase of the project.

The field monitoring of the various variables and development of baseline datasets for the Henval watershed shall be a continuous process in this study. Hydrological modeling of the stream is planned to understand the catchment characteristics and runoff behaviour of the watershed. Soil moisture is the crucial variable for partitioning rainfall into infiltration and runoff, thus playing a fundamental role in runoff modelling and flood forecasting. Recently, the scientific community is making an excellent effort to address soil moisture estimation over large areas through in situ sensors, remote sensing, and modelling approaches. There is sizeable spatial-temporal variability of soil moisture that exists in field conditions. Currently, we are able to estimate soil moisture accurately at the point scale through in-situ sensors.

Moreover, satellite sensors can obtain less accurate measurements at a coarse scale (~20 km). Finally, spatial downscaling/upscaling approaches can be used to integrate the different techniques and observations with modelling. Data assimilation and merging methods can also be considered to integrate in-situ, satellite and modelled data optimally.

6. **Methodology**

In the present study, meteorological variables, soil and runoff monitoring shall be done within the established experimental watershed. Modelling of runoff, soil moisture monitoring and modelling and comparison and validation of satellite soil moisture product with in-situ sensors are proposed. The methodology for these is described in the following sections.

Hydrologic modelling:

Several models are available for runoff modelling. In the proposal work, a semi-distributed model with proven capabilities, namely the Soil and Water Assessment Tool (SWAT) model, will be used for the estimation of streamflow in the basin.

Soil moisture modeling

The SWAT, Soil Water Balance Model, etc. shall be applied to carry out soil moisture modelling. The observed soil moisture data shall do the calibration and validation of soil moisture model. Study of the effects of static factors such as land-use, topography, soil texture, etc. on the spatial variability of soil moisture also envisaged in this study.

Validation of Satellite-based Soil moisture products

Various satellite-based soil moisture products such as ASCAT, SMAP, SMOS, etc. with different resolution shall be validated and compared against the in-situ soil moisture sensor. The interrelation of soil moisture and surface runoff shall be performed.

7. **Research Outcome from the project:**
   - Validation of the SWAT model for a lesser Himalayan watershed.
   - Assessment of the spatial-temporal variability and temporal-stability the soil moisture
   - Validation of satellite-based soil moisture product for Himalayan watershed.
   - The error characterization of the satellite-based soil moisture products.
   -

8. **Cost estimates:**

   The total cost of the project: **₹ 10.2236 Lakh**

   a. Source of funding: NIH

   b. Sub-head wise abstract of the cost:

SN	Sub-head	Amount (₹)			
		Year - I	Year - II	Year - III	Total
1	Salary (Part-Time Field Staff)	156000	171600	188760	516360
2	Travelling expenditure	78000	78000	78000	234000
3	Experimental/ Rental Charges	66000	76000	76000	218000
4	Misc. expenditure	18000	18000	18000	54000
	Sub- Total:	318000	343600	360760	
	Grand Total:				**1022360/-**

9. **Work Schedule:**

SN	Description of Activity	2020-21			2021-22				2022-23				2023-24	
		Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
1	Data Collection and up-keeping of the instruments	■	■	■	■	■	■	■	■	■	■	■	■	■
2	Hydrological modelling		■	■	■	■	■							
3	Soil Moisture modelling				■	■	■	■	■	■				
4	Satellite data acquisition, assimilation and processing		■	■	■	■	■	■	■	■	■	■		
5	Validation and comparison of satellite and in-situ data							■	■	■	■	■	■	■
6	Report writing				■				■					■

10. **Progress till date:**

    This study is experimental in nature and a lot of instrumentation in terms of AWS, AWLR, SMS, etc. has been established in Henval catchment. The PI has regularly visited the catchment for the up keeping of filed sites and collection of hydr-meteorological data from time to time. In the previous working group meeting, the results related to soil moisture modelling using empirical models and data-driven machine learning algorithms were shared with the members. In pursuance of the study's second objective, an empirical model is formulated using available parameters in this study, i.e., rainfall, wind speed, air temperature, and near soil surface temperature. This model was calibrated and validated using the Kumargaon, Kanataal and Nagini sites in the lesser Himalayan region. It was also concluded that the learning models makes the process efficient and reliable. In the later part of the study's second objective, two deep learning hybrid models based on long-short term memory, namely, CNN-LSTM and RNN-LSTM, were developed and tested to model the sub-surface soil moisture at three stations located in a Lesser Himalayan catchment. Previously, SWAT model was setup and applied for runoff simulation at the Devnagar outlet on Henval for three years (2016-18). This time the modeling has taken into account of various hydro-meteorological data of five years (2016-20) and the results will be presented during meeting. The work is still ongoing, and findings will be shared in future working group meetings.

ONGOING STUDIES
INTERNAL RESEARCH PROJECT: NIH/WRS/2022-24/06

1. **Title:** Spatio-temporal Water Availability under Changing Climate and Land-use Scenarios in Wainganga River Basin

2. **Project Team:**
   Dr Manish Kumar Nema, Scientist 'D'
   Dr P. K. Mishra, Scientist 'D'
   Dr Rahul Jaiswal, Scientist 'E'

3. **Project Duration: 02 Years (04/22 – 03/24)**

4. **Objectives**

Wide-scale interventions and other water-related activities have occurred in the Wainganga River Basin (WRB), which sustain the northern industrial region of Nagpur and large expanses of highly irrigated rice-growing districts. The water demands of the basins have steadily increased over time, and among the diverse nature of the purposes driving such a continually growing demand for drinking water, an increased reliance on irrigated agriculture, as well as numerous developmental projects such as thermal power plants, are expected to intensify competition for the limited water resources. As a result, the study's goal is to examine the basin's water resources availability and, more importantly, to estimate the influence of current and future changes of climate and landuse on the Wainganga river basin's water balance. The specific objectives of the study are as follows:

a. To study the historical climate change, morphological properties and land use/land cover change pattern over the Wainganga river basin
b. To calibrate and validate a hydrological model at different spatial scales for the river basin using current land use and observed climatic conditions
c. To develop future expected land-use change and climate change scenarios (CMIP6) for the base period and compare them with the observed period
d. To model spatial and temporal future water availability using climate and land-use change scenarios
e. To quantify the uncertainty in modeling analysis arising from model parameters and input conditions
f. To prepare adaptation/management strategies under changing climate and land-use scenarios

5. **Present state-of-art**

Presently, the total water availability of the Wainganga basin is 9225 MCM (325.89 TMC). The various sectoral demands such as domestic, industrial and agricultural for the basins water resources have grown steadily over the years, leading to an intensification of competition and conflicts for the limited water resources. Therefore, the study aims to assess the basin's water resources availability and, further, to evaluate the impact of existing and other prospective water resources developmental initiatives on the overall water balance of WRB. It is an interstate river, and the water is being shared based on the Water Dispute Tribunal Award for the Godavari Basin (Eastern Godavari Basin (EGB)). The majority of the inhabitants in this basin depend on farming, fisheries, and forest-dependent livelihood activities. The WRB fall under the parts of the Eastern Vidarbha region of Maharashtra has been in the news for many farmer suicides for more than a decade due to crop failures and increasing debts. While most districts in Vidarbha are known for cotton and soybean cultivation, eastern-Vidarbha, through which Wainganga flows, is historically known for its paddy cultivation. Bhandara and Gondia districts are known as the 'rice bowls' of Maharashtra. The rice and sugarcane production in the region was supported by the Maji-Malguzari (MM) tanks, which needs to be rejuvenated. The MM tank system, albeit feudal, was a well-designed decentralized system for irrigation and could have served as a hallmark of development in eastern Vidarbha.

6. Methodology

Study Basin:

The Wainganga rises in the Seoni District of Madhya Pradesh at an elevation of 640 m above M.S.L. Wainganga basin extends over approximately 50,000 square kilometres up to the Ashti gauging site, which spreads across the States of Madhya Pradesh and Maharashtra. The total length of this river is ~638 km up to the Ashti gauging site just before the confluence with the Wardha River. In the beginning, it flows eastward for a distance of about 175 km and then Southward for a length of about 100 km in Seoni and Balaghat District of Madhya Pradesh. It also serves as a border between Madhya Pradesh and Maharashtra state for 32km. Before joining the Godavari, it flows about 479 km in the Bhandara, Chandrapur, and Gadchiroli District of Maharashtra. The Wainganga basin lies in the medium rainfall zone, situated between 900 mm and 1600 mm. Most of the rainfall is received during the southwest monsoon from June to October. In the winter, the minimum temperature varies from 7^0 C to 13^0 C. Maximum temperature ranges from 39^0 C to 47^0 C. Month of May is the hottest month, and December is the coldest month.

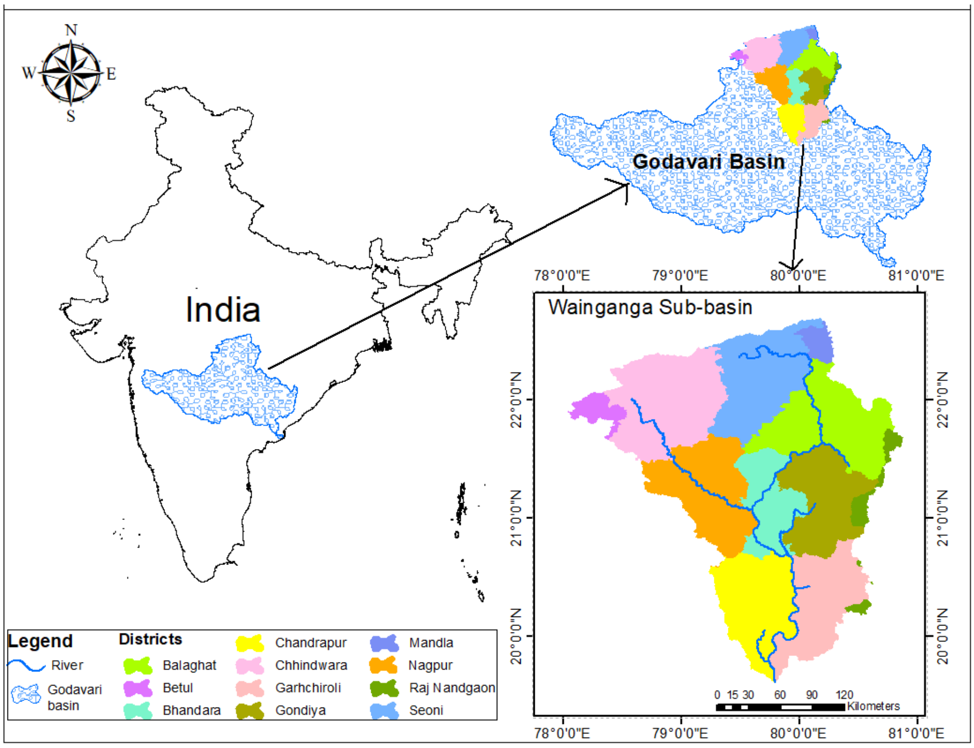


Fig. 1 Location Map of Wainganga River sub-basin of Godavari Basin in India

Research Approach:

A few activities/tasks have been defined to accomplish the study's research objectives, including collecting the data sets, field visits, surveys, analysis of collected data, model setup, scenario-based analysis, assessment of water availability, etc. The task-wise methodology proposed for analyzing the impact of climate change on the hydrology of Wainganga Basin is described below:

Task 1: Data collection, pre-processing and development of digital database including DEM, LULC, SOIL, Climatic time series, etc.

Task 2: Analysis of Trends for the climatic and hydrological extremes

Task 3: Modeling of surface hydrology and assessment of climate change impacts. In the proposal work, a semi-distributed model with proven capabilities, namely the Soil and Water Assessment Tool (SWAT) model, will be used to estimate streamflow in the basin.

Task 4: Water resources availability under changing climate & landuse scenario using the FDC based analysis. Uncertainty analysis shall be performed for the water availability assessments made using these scenarios

Task 5*:* Preparation of adaptation/management strategies /plans

7. Research Outcome from the project:

Assessment of the spatial-temporal water availability under the different climatic and land-use scenarios.

Future Land-use scenarios for the study region.

Climate change adaptation plan for the Wainganga river Basin

8. Cost estimates:

The total cost of the project: **₹ 9.72 Lakh**

a. Source of funding: NIH
b. Sub-head wise abstract of the cost:

SN	Sub-head	Amount (₹)		
		Year - I	Year - II	Total
1	Salary (Part-Time Field Staff)	156000	156000	312000
2	Travelling expenditure	150000	150000	300000
3	Data /Infrastructure/Equipment	50000	50000	100000
4	Workshop/ Meeting / Experimental Charges	20000	200000	220000
5	Misc. expenditure	20000	20000	40000
	Sub- Total:	396000	576000	
	Grand Total:			**972000**

9. Work Schedule:

SN	Description of Activity	2022-23				2023-24			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Data Collection, pre-processing and development of digital database	■	■	■					
2	Analysis of trends for the climatic and hydrological extremes	■	■	■	■				
3	Landuse modeling and predictions for the future periods			■	■	■			
4	Modeling of Surface Hydrology and Assessment of Climate Change Impacts			■	■	■	■		
5	Water Resources availability under changing climate & landuse scenario			■	■	■	■		
6	Uncertainty Analysis					■	■	■	■
7	Adaptation/management Strategies /Plans					■	■	■	■
8	Stakeholder's Workshop							■	
9	Report Writing					■			■

10.Progress till date:

The first task of the study has been completed in terms of collection of basic data, their pre-processing and development of digital database including DEM, LULC, SOIL, etc. The CMIP6 Data for the Wainganga basin has been downloaded and climatic series generation and their trend analysis has to be completed. For the land use land cover modeling, which is the second major objective of the study variety of spatial and non-spatial data has been collected and now the model has to be setup. For the hydrological simulation set-up of SWAT model has been attempted, but the model still needs fine tune-ups.

ONGOING STUDIES
SPONSORED RESEARCH PROJECT: NIH/WRS/2022-25/07

1. **Title:** Monitoring and Assessment of Mountain Ecosystem and Services in North-West Himalaya (Phase-II): Monitoring and Modeling of Hydrological Processes in Glaciated and Non-Glaciated Watersheds of North-West Himalaya

2. **Project Team:**
   Dr. Sanjay K. Jain, Scientist 'G'
   Dr Manish Kumar Nema, Scientist 'D'
   Dr P. K. Mishra, Scientist 'D'
   Dr. Praveen Thakur (IIRS)

3. **Project Duration: 03 Years (04/22 – 03/25)**

4. **Scope of the Work**

The scope of the work to be carried out in the project includes:

a. Characterizing spatial extent and patterns of hydrological cycle components in selected watersheds in Western Himalaya (Uttarakhand) using multi-scale EO data;
b. Assessment of watershed's topographical, morphological and hydro-meteorological spatio-temporal dynamics using a systematic and multi-site sampling using ground observations and EO inputs;
c. Determining the EO-based land surface parameters and hydrological cycle variables of the watersheds and its dynamics;
d. Developing hydrological models for multi-scale assessment of hydrological cycle components and water availability linking natural hydrological processes and anthropogenic water use under present and future climate scenarios;
g. Developing a web-based hydrological information system, supporting hydrological and spatial database, web analytics and data/information dissemination for water resources planning and management.

5. **Deliverables**
   - Establishment of long term, experimental watershed monitoring sites with field instrumentation for understanding various hydrological and snow/glacier processes which are important in overall water balance studies.
   - The updated geospatial-database on hydrological sources and water resources of the selected watersheds.
   - Quantification of hydrological response of the selected watersheds and assessment of basin level water availability in the Upper Ganga Basin of NWH region under present and future climate change scenarios.

6. **Cost estimates:**
   The total cost of the project: **₹ 30.91 Lakh**
   a. Source of funding: IIRS
   b. Sub-head wise abstract of the cost:

Head	Total grant (Lakh)
Recurring	
(i) Salary + HRA: 01 JRF or Project Fellow	**10.88**
(ii) Field work and Travel (Domestic)	**6.5**

(iii) Services (Field activities & other project costs: Field sampling for hydrological data collection and lab analysis of soil/water samples; contingency/consumables, skilled/non-skilled labor hiring for watersheds data collection), data, printing of project report/outputs and other charges.	**9.5**
(vi) Institutional charges/ Overhead	**4.03**
Grand Total*	**30.91***

Say **Rupees Thirty Lakh Ninety-One Thousand and Two Hundred only** from IIRS. *This is the maximum amount, which can be transferred during project duration. Actual budget transfer to be as per actual funds availability from ISRO, progress of work and utilization of given funds by the collaborating institute.

8. Project Schedule

Duration of project shall be **Three (03)** years from the date the project has been sanctioned by ISRO and approval of budgetary provisions.

Activity	Year I	Year II	Year III
Project initiation, Inception workshop	■		
Recruitment of project personnel	■		
Permission for field studies	■		
Workshop for field training	■		
Field instrumentation/sampling	■	■	■
Acquisition of Satellite based Earth Observation data	■	■	
Progress review/workshop	■	■	■
Hydrological data collection, development of web based data repository and information system	■	■	■
Development of hydrological models for multi-scale water resources availability		■	■
Generation of spatial layers on hydrological fluxes for present and future climate scenarios	■	■	■
Progress review and stakeholder workshop			■
Final Report generation			■

09. Progress till date:

- A workshop (online) was conducted to sensitize the project partners regarding the project outlines and deliverables by IIRS.
- A JRF has been recruited as provisioned in the project
- A Two-day training and exposure Programme was organized for all the SRFs/JRFs during 19-23 December, 2022 at IIRS, Dehradun.
- A joint field visit was conducted by NIH, Roorkee and IIRS, Dehradun to identify suitable sites for installation of AWS and equipments under the non-glaciated watershed component.

ONGOING STUDIES
SPONSORED RESEARCH PROJECT: NIH/WRS/2022-25/08

1. Title of the Project

Hydrological Assessment of Ungauged Basins (Aghanashini, Dasanakatte, Sita Nadi, Madisala Hole, Swarna Nadi and Gurupur River Basins) of the West Flowing Rivers in the Western Ghat Region of Karnataka

2. Objectives of the Study

The major objective of this study are as follows:

1. To collect, prepare and evaluate various thematic datasets such as DEM, land use/Land cover (LULC) map, soil map, and hydro-meteorological data-sets such as precipitation, temperature, discharge (if available) etc.
2. To analyze long-term hydro-meteorological variables such as precipitation, evapotranspiration, and water consumption patterns in the basin and assessment of their possible impacts on water management in the basins.
3. To estimate water potential of the west-flowing rivers, i.e., Aghanashini, Dasanakatte, Sita Nadi, Madisala Hole, Swarna Nadi and Gurupur River Basins using hydrological models and Frameworks.
4. To assess the effects of climate and landuse changes on the water yield using Budyko conceptual framework.
5. To analyze the hydrological sensitivity and resilience capacity of the basins under adverse climatic impacts.
6. To impart training on the hydrological models to the state officials of the water resources department including IAs of NHP.
7. To prepare the detailed sub-basin wise project report for the state water resources department for planning purposes.

3: Research Team:

PI:	Dr P K Singh, Scientist 'D', WRS Division, NIH Roorkee
Co-PI:	Dr Vishal Singh, Scientist 'D', WRS Division, NIH Roorkee
Co-PI:	Dr Sanjay K Jain, Scientist 'G' and Head, WRS Division, NIH Roorkee

4: Project Duration: 03 Years (04/22 – 03/25)

5: The Study Area and Input Data

Figure 1 shows the map of the west flowing rivers in the state of the Karnataka. As discussed above, this study is aimed to assess the water potential yields and other hydro-meteorological analysis of the six sub-basins, e.g., Aghanashini, Dasanakatte, Sita Nadi, Madisala Hole, Swarna Nadi and Gurupur River Basins.

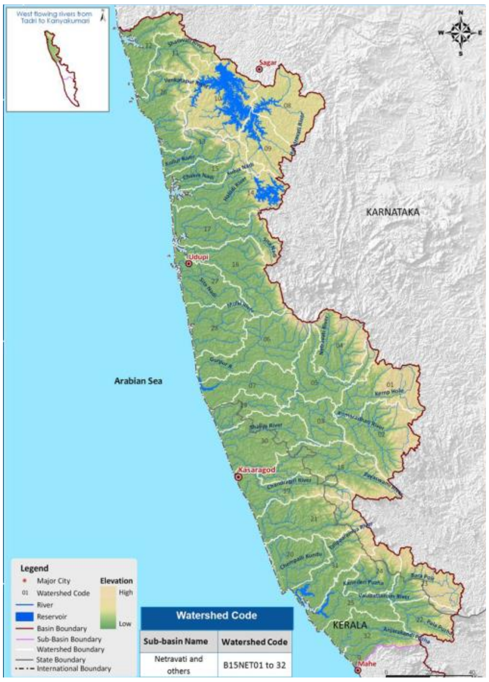


Figure 1: West-flowing Rivers in Karnataka (Source: IndiaWRIS).

6: Input Data

Looking into the un-availability of the measured/monitored hydro-meteorological datasets in these basins, it is planned to utilize the earth observation and satellite datasets for calibration and validation purposes and yield estimation in this study. Following datasets (not limited to) will be used in this study:

SI. No.	Data-sets/Name	Availability/Source/Resolution	Time-Period
1	DEM	SRTM/CARTOSAT – 30 m/ALOS-PALSAR 12.5 m.	
2	Daily Rainfall and Temperature Gridded (Observed)	IMDAA –12 km^2	1979-2020
3	Daily Rainfall Gridded (Satellite based-open sources)	CHIRPS – 5 km^2; TRMM+GPM -25 km2;	1991-2020
4	Other Hydro-Meteorological Datasets	NOAA/NASA/ ESA/ISRO	1991-2020
5	Population Data and population growth Data	As per census	2011 and older
6	LULC maps	Glob cover, NRSC, IWMI, ESRI	For different time periods
7	SOIL Maps	FAO, USGS, Water Base, Future Water Group Netherlands	As per availability

A detailed information about the data sources and their resolution can be had from their respective sources.

7: Methodology

The modelling tools/framework such as SWAT, HEC-HMS, WA+ and Budyko based approach will be applied for quantifying the water yield potential of these basins. The study will also assess the effects of climate and landuse changes on the water yield. Along with this, the hydrological sensitivity and resilience capacity of these basins will also be assessed using the Budyko framework. For climate change analysis CMIP5/CMIP6 projections will be used in this study. For LULC change and impact assessment, decadal and projected LULC maps will be prepared and analyzed accordingly. For future projection of LULC change Markov chain based approach will be applied in this study. Figure 2 shows the flow chart of the methodology.

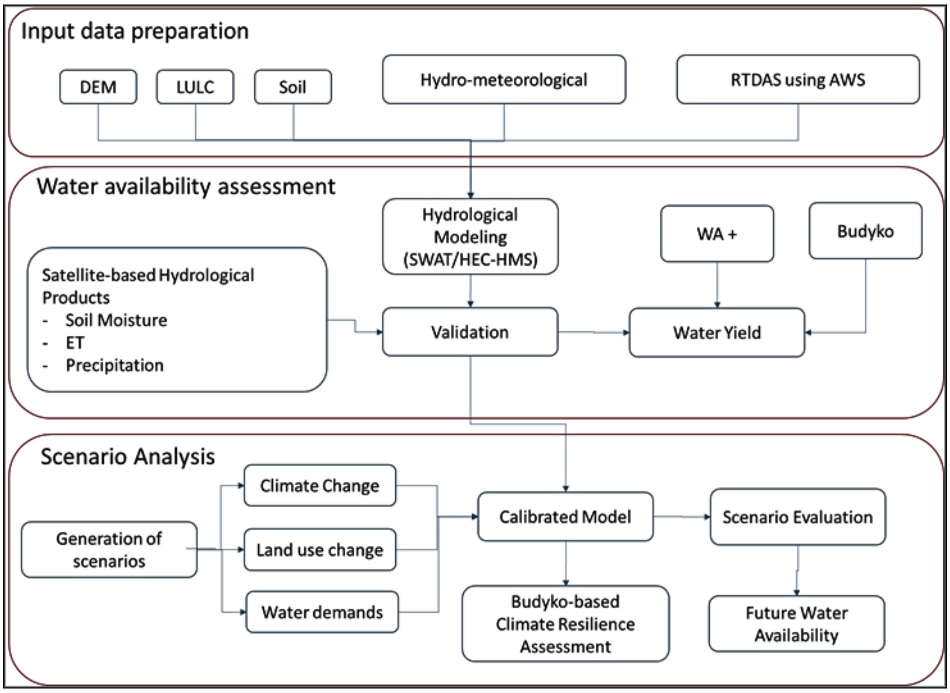


Figure 2: Modelling Steps

8. Project Budget: Year-wise breakup of the budget:

Sl. No.	Head	Amount (in Lakh)			
1:	**Manpower (Salaries/ wages of project staff)**	**1st Year**	**2nd Year**	**3rd Year**	**Total**
	JRF (02 nos.) as per DST Norms	8.50	8.50	8.50	25.50
2:	Travel Expenditure	2.00	2.00	2.00	06.00
3:	Meetings/Workshop	1.50	1.50	1.50	04.50
4:	Others (Hiring of services, field works, consumables, stationary, printing of reports & brochures, and sample analysis, etc.)	3.00	5.00	5.00	13.00
5:	Contingency	2.00	2.00	1.00	5.00
	GRAND TOTAL	**17.00**	**19.00**	**18.00**	**54.00**

9. Expected Deliverables

- Thematic maps: DEM, soil and LULC, stream network maps
- Improved and bias free high resolution gridded precipitation and ET datasets
- Basin wise water availability estimates: Historical (BAU)
- Revised basin-wise water availability estimates: CC with no LU change
- Revised basin-wise water availability estimates: LU change with no CC
- Revised basin-wise water availability estimates: both CC and LU change
- Resilience and Non-resilience basins under changing climates
- Sub-basin wise project report for the state water resources department for planning

- Training on the modelling frameworks to the state officials of the water resources department and other Implementing Agencies of the NHP.

10. Advantages, Challenges and Limitations

- The proposed modelling frameworks/tools will be very useful for estimating the water yield potential for ungauged basins using satellite and open data sources including the datasets obtained from the field.
- All satellite data products have some level of uncertainty and error which will be effectively taken care of in this study for generating error free and bias corrected datasets for future use.
- The hydrological resilience analysis will be an effective criterion to understand the historical as well as future changes in the basin to ensure the sustainability of the water resources.
- The main challenge of this study is that the study basins are ungauged hence the dependability on the satellite datasets will be on the larger side. Therefore, the alternative hydrological calibration strategies can be accounted utilizing the relevant hydrological variables such as ET and soil moisture which can be measured/estimated in the absence of the observed discharge datasets.

11. Period of Project:

- Three years from the date of the start of the project

Expected Outcome (Quantifiable Deliverables) of Key Activities with Timeline (Tentative):

Sl. No.	Expected Outcomes/Quantifiable Deliverables	1st Year				2nd Year				3rd year			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1:	Hiring Manpower												
	Data downloading and processing, and generation of data bases and maps; data collection from CWC, and state govt. departments												
4:	Analyse long-term hydro-meteorological variables												
5:	Hydrological Modelling: SWAT model Setup												
6:	Hydrological Modelling: HEC-HMS model Setup												
7:	WA+ and Budyko Frameworks:												
8:	Model's validation using satellite and observed (if available) datasets												
9:	Water potential of the west-flowing rivers												
10:	Hydrological sensitivity and resilience capacity												
11:	Training on the hydrological models												
12:	Detailed basin wise project report for the state water resources department and Regional Conference with NHP												

12: Progress till date:

Two manpower (JRFs) have been recruited under this project. There are six (06) ungauged basins. We first took two largest basins, i.e., Aghanashini (1353 km^2) and Gurupur (878.66 km^2) and SWAT model is setup. As these basins are ungauged so what we did we compared the model computed actual evapotranspiration (AET) and soil moisture with the satellite observed AET and soil moisture and tuned the parameters. Those parameters will be used to estimate the water yield at the different scales. Here we are also applying WA+ and hence the required satellite datasets have been downloaded and processed. Before the first inception workshop with WRD Karnataka at Bengaluru scheduled during 1-3 March 2023, we also had an on-line meeting with the officials to discuss the results and the procedural steps and their involvement with the project on January 20, 2023.

ONGOING STUDIES
SPONSORED RESEARCH PROJECT: NIH/WRS/2022-24/09

1. Title:
Climate change scenarios for Andhra Pradesh and its impact on streamflow and groundwater levels in Pennar River basin

2. Project Team

NIH, Roorkee	DRC, Kakinada	WRD, Govt. of Andhra Pradesh
Dr. Sunil Gurrapu (**PI**), Sc. D Dr. Nitesh Patidar, Sc. C	Dr. Y R S Rao (**PI**), Sc. G & Head Dr. R Venkata Ramana, Sc. E	Mr. T V N A R Kumar Chief Engineer, Hydrology Water Resources Dept.

3. Type of Study: Internal
4. Status: Ongoing
5. Duration: 2 years
Date of Start: 1st April 2022
Scheduled Completion Date: 31st March 2024

6. Objectives

1. Analyse CMIP6 projected rainfall and temperature data for the state of Andhra Pradesh and generate multi-model scenarios of climate change.
2. Develop/calibrate and validate a hydrological model to simulate surface water and groundwater levels for the Pennar River Basin.
3. Generate hydrological scenarios (i.e. streamflow and groundwater levels) using CMIP6 projected climate.

7. Statement of Problem:
It has been globally accepted that the changing climate is imposing significant alterations in the hydrological systems, which eventually is leading to the changes in the characteristics of hydrological extremes. In a most recent special issue on the impacts of climate on hydrological extremes, the focus was on the historically observed hydrological extremes and how these extremes are linked to the changing climate in several watersheds across the globe. Therefore, to evaluate the impacts of changing climate on the basin hydrology and/or hydrological extremes, the knowledge of complex interactions between climate and hydrological systems is vital. In addition to the changing climate, the hydrological dynamics of a basin are affected by the changes in catchment characteristics and river flow regime, caused by the land-use/land-cover changes from anthropogenic activities. In brief, the on-going changes in the global climate and the anthropogenic effects on regional/local climate would trigger imbalance in the hydrological systems and eventually result in disproportionate changes in the hydrological extremes. Several studies from the recent past indicate that the hydrological extremes would be more frequent and widespread in future due to extreme weather events perceived to be induced by climate change. Therefore, information on the impacts of climate change on the basin's hydrology and the basin's hydrological projections of the 21st century becomes a vital information for water managers, irrigation engineers, city planners, hydro-electric engineers etc. The proposed project aims to analyse the projected rainfall and temperature data from CMIP6 GCMs and generate multi-model climate change scenarios for the state of Andhra Pradesh. The second major objective of the project is to generate hydrological scenarios using a calibrated and validated hydrological model and evaluate the impacts of climate change on the hydrology and extreme hydrology of a selected watershed. The generated hydrological scenarios and the results from impact assessment will benefit water managers, irrigation and hydro-electric engineers, to plan and allocate water appropriately for its effective use and reduce negative impacts of floods and droughts.

8. Progress:
The first objective of this study was to generate multi-model climate change scenarios for the state of Andhra Pradesh. To do so, the global climate scenarios derived from General Circulation Model (GCM) runs conducted under the coupled Model Intercomparison Project Phase 6, CMIP6 (Eyring we

al., 2016) were to be used. The climate scenarios generated under CMIP6 were downscaled to a common grid of 0.25 degrees' x 0.25 degrees (~ 25 km x 25 km) by NASA and is made available through NASA Earth Exchange Global Daily Downscaled Projections, NEX-GDDP-CMIP6 Trasher et al., 2022). These datasets were statistically downscaled using Bias-correction Spatial Disaggregation (BCSD) method. These datasets are available for a total of 35 GCMs for 4 SSP scenarios (i.e. SSP2-4.5, SSP5-8.5, SSP1-2.6, and SSP3-7.0) for the period 2015-2100, as well as the historical period 1950 – 2014. Of the existing 35 GCMs, 10 GCMs were selected based on the recommendations from the recently published climate change impact studies, and for 2 SSP scenarios, one likely (SSP2-4.5) and one unlikely (SSP3-7.0). These datasets were extracted and analyzed for the state of Andhra Pradesh and various change scenarios of precipitation and temperature were generated based on the multi-model statistics. In addition, to accomplish the second objective, a VIC model was developed for the Pennar River basin with a resolution of 5 km. Catchment characteristics for the basin were generated based on 30 m SRTM dataset, FAO soil map, and LULC information from Copernicus Global Land Service (CGLS). Meteorological information from IMD dataset at a resolution of 25 km x 25 km is used to run the model. For the calibration and validation of the model, daily averaged streamflow from selected streamflow gauging stations was collected from IndiaWRIS and also from various other gauging stations maintained and operated by the state Water Resources Department, Andhra Pradesh. The VIC model was run with the readily available preliminary data and the model fine-tuning is required. To simulate the groundwater levels in the basin, it is proposed to develop a model based on machine learning tools. Later, these models will be used to generate multi-model hydrological scenarios for the Pennar River Basin.

9. Deliverables

1. Multi-model climate change scenarios for the state of Andhra Pradesh.
2. Calibrated and validated hydrological model for the Pennar River basin, ready to be used in the future studies on the assessment of climate change impacts.
3. Multi-model hydrological scenarios generated for the Pennar River Basin, ready to be used by the officials of Water Resources Department, Andhra Pradesh to make decisions on effective management of available water.

NEW STUDIES
INTERNAL RESEARCH PROJECT: NIH/WRS/2023-26/01

1. **Title:** Monitoring and Modelling of Gangotri (Bhojwasa) watershed under different Climate Scenarios

2. **Project Team:**
   Dr P. K. Mishra, Scientist 'D'
   Dr Vishal Singh, Scientist 'D'
   Dr Sunil Gurrapu, Scientist 'D'
   Dr Manohar Arora, Scientist 'F'
   Dr Sanjay K Jain, Scientist 'G'
   Mr. Jatin Malhotra, PRA

3. **Project Duration: 03 Years (04/23 – 03/26)**

4. **Background and Objectives**

The Gangotri Glacier (source of Bhagirathi River), one of the largest glacier of Himalaya, located in the Uttarakhand state (Central Himalaya, India) has immensely contributed to billions of people through irrigation, tourism, hydropower purposes (Singh & Jain, 2002; Kesarwani et al., 2015, Arora et al., 2016). Because of these reasons, hydrological studies in the Cryospehere regime of Himalaya has gained a massive momentum in recent times. Climate change and global warming has added more concern to the health of the Gangotri Glacier and the River Ganga as well (Singh et al., 2005; Arora et al., 2008 and 2010). It is, therefore, essential to study the hydrological system of the Gangotri Glacier System in a comprehensive way using observational methods, remote sensing based geospatial techniques and modelling so that prediction of future water supplies from these glacierized catchments in the downstream area can be performed precisely.

Department of Science and Technology (DST), in the year 1999, sanctioned a project to National Institute of Hydrology (NIH), Roorkee to carry out hydrological investigations on the Gangotri Glacier. Since then, many scientists and project staff from NIH has contributed immensely in carrying out the hydrological investigations through internal and external funding. To collect the information on the hydro-meteorological variables, NIH has established a standard observatory at about 3800 m altitude and set-up gauging sites at the basecamp at Bhojwasa. This observatory is equipped with Automatic Weather Station (AWS), ordinary and self-recording rain gauge, Thermograph, Max. & Min. thermometers, Dry & Wet bulb thermometers, Hydrograph, Pan evaporimeter, Anemometer, Wind vane, and Sunshine recorder. NIH is also carrying out the streamflow and sediment contribution through traditional approach. The installed AWS and Prefabricated Hut is quite old and require alteration, renovation and repairing. The site requires upgradation and adoption of new modern techniques for flow and sediment measurement.

To continue the long legacy of data monitoring and hydrological investigations of the Gangotri Glacier, the present study has been proposed with the following objectives:

- To conduct continuous observations of meteorological, hydrological and suspended sediment data to determine monthly and seasonal flow and sediment yield for the melt season.
- To carry out the seasonal characterization of the glacier melt.
- To estimate the suspended sediment yield from the Glacier.
- To set-up different hydrological model(s) for runoff estimation under different climatic scenarios.

5. **Methodology**

Study area:

The study will be conducted for the Gangotri Glacier up to the basecamp at Bhojwasa at an altitude of 3800 m. The Gangotri Glacier is a cluster of many glaciers comprising of main

Gangotri Glacier (length: 30.20 km; width: 0.20 – 2.35 km; area: 86.32 km^2) as trunk part of the system. The Gangotri Glacier is a valley type glacier system with total glacierized area of about 286 km^2. Total catchment area of the Gangotri Glacier and melt stream up to the discharge-gauging site established downstream at Bhojwasa is about 556 km^2. The elevation range of the Gangotri Glacier varies from 4000 to 7000 m, whereas elevation of the study area up to the gauging site lies between 3800-7000 m.

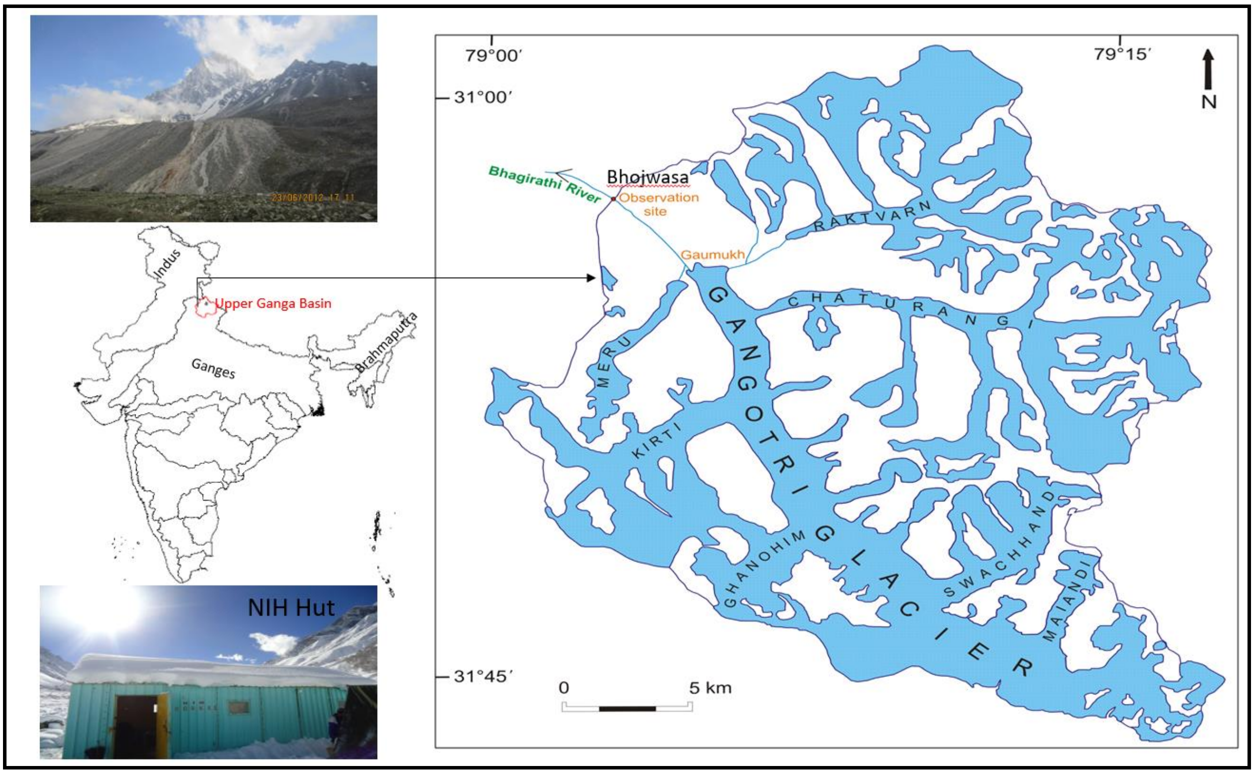


Fig. 1 Location Map of the Gangotri Glacier System

6. Research Approach:

A few activities/tasks have been defined to accomplish the study's research objectives such as conducting field visits during the ablation period (May-October), regular up-keeping and monitoring of equipments, collection of data, analysis of collected data, model setup, scenario-based analysis, etc. The task-wise brief methodology proposed is indicated below:

Task 1: Before conducting the field visit(s) for the ablation period (May-October)

- Obtaining permission from the Gangotri National Park, Uttarkashi
- Deployment of manpower
- Procurement and arrangement of logistics, insurance, chart papers, bottle and other accessories
- Calibration of equipments
- Actual field visit(s)

Task 2: During the field visit(s) for the ablation period (May-October)

- Cleaning of the Hut and Observatory site like fixing the fences, etc.
- Setting-up the Sunshine recorder, hydrograph, thermograph, tipping bucket rain gauge, ordinary rain gauge, wind vane, evaporimeter, etc.
- Identification of site and installation of staff gauge
- Measurement of (Rough estimate) stream cross-section
- Retrieving the data from the AWS

- Regular monitoring and keeping record of hydro-meteorological data and sediment sampling
- Winding-off the equipments and Closing-off the site

Task 3: After the field visit(s) during non-ablation period (November-April)

- Data entry, collation, compilation and analysis
- Hydrological modeling (HBV; SPHY; VIC)
- Analysis of sediment data
- Summarizing major findings and Report preparation
- Preparation of adaptation/management strategies/plans

7. Research Outcome from the project:

- Long-term Meteorological and hydrological data for the Gangotri Glacier
- Characteristics of the Gangotri Glacier under changing climate

8. Action Plan

Year	May to October	November to April	Remark
All Years	Field investigations & Data Collection	Data analysis	Interim & Final Report preparation

9. Cost estimates:

The total cost of the project: **₹ 57 Lakhs**

a. Source of funding: NIH

b. Sub-head wise abstract of the cost:

SN	Sub-head		Amount (₹)		
		Year - I	Year - II	Year - III	Total
1	Procurement of i. Discharge Monitoring Station ii. Sediment Sampler iii. Data logger (AWS) iv. GPS	30,00,000	-	-	30,00,000
2	Salary (Part-Time Field Staff)	4,50,000	4,50,000	4,50,000	13,50,000
3	Field visit (May-Oct.) (Refilling of cylinder; Insurance; Porter; Entry fee; Forms; Stationery; Filter paper; Bottles; Charts; Staff Gauge, Wooden blocks, and other Misc. items	3,00,000	3,00,000	3,00,000	9,00,000
4	Workshop/ Meeting/ Experimental Charges	-	-	1,50,000	1,50,000
5	Misc. expenditure (Contingency)	1,00,000	1,00,000	1,00,000	3,00,000
	Sub- Total:	38,50,000	8,50,000	10,00,000	57,00,000
	Grand Total:				**57,00,000**

NEW STUDIES
INTERNAL RESEARCH PROJECT: NIH/WRS/2023-28/02

1. Title: Glacier recurrence survey, Instrumentation and Modeling to study the Batal Glacier in part of Western Himalaya, India

2. Project Team:

Dr. Vishal Singh, Sc. D & PI
Dr. P. K. Mishra, Sc. D & Co-PI
Dr. Sunil Gurappu, Sc. D & Co-PI
Dr. Sanjay K. Jain, Sc. G (Head-WRSD) and Co-PI
Dr. Manohar Arora, Sc. F and Co-PI
Mr. Jatin Malhotra, PRA

3. Summary

This study has been proposed to carry out a research analysis over the Himalayan glaciers to assess the impact of glacier retreat and climate change in the long-term time frame (e.g. 21st century). The main purpose of this study is to explore the understanding of glacier-climate-topographic inter-relationship and quantify the Himalayan glacier responses to the river runoff, which is originated from the glaciers. For this purpose, initially, a glacier survey will be conducted to identify a new glacier focusing on Indus basin part of the Western Himalayan regions (e.g. Batal glacier-tentatively identified which is a part of Chandra Basin and other nearly situated glaciers). Based on the recurrence survey, a feasibility report will be prepared as per the Glaciers cryospheric, topographical and climatological characteristics. After the recurrence survey, a research observatory will be established near to the glacier for the long-term monitoring of various glacier and hydro-meteorological parameters.

The observatory will be equipped with scientific instruments such as Automatic Weather Station, Water Level Recorder, Soil Moisture Sensors. Sediment Samplers, Snow Gauge (Depth and Sensitivity) etc. The measured datasets will be utilized for the real time study of glacier changes and downstream based hydrological assessment. The second most important objective is to develop a real time modelling framework to compute the river runoff, sediment yield and other watershed components utilizing the hydrological models viz. SPHY/SWAT/VIC. In this study, the glacier retreating and mass changes through mass balance analysis will be performed utilizing the observation and satellite remote sensing datasets. Different glacier sizes may behave differently under different altitudes and topographical conditions and thus the timing and amount of resultant runoff may be varied. These aspects are still need to address in the Himalayan river basins under glacier retreat conditions. The analysis of interactions between precipitation, temperature, surface albedo, evapotranspiration (ET) and soil moisture at different altitudes in the proposed Himalayan river basins can be important to assess the magnitude of glacier retreats and changes in runoff components in terms of glacier melt, snow melt, baseflow and rainfall induced runoff.

3. Objectives

Following objectives have been defined under the current proposed:

- To conduct a glacier survey through physical verification and collect field observations by preparing the feasibility report as per the identified glacier (or group of glaciers) and also to setup the new glacier observatory for the long-term monitoring of glaciers.
- Instrumentation in the glacier site for the measurement of real time glacier and hydro-meteorological parameters.
- Development of an improved modelling framework to address glacier changes and its impact on river runoff.
- Glacier mass balance and seasonal characterization of glacier parameters.

4. Present state-of-art

A glacier survey in a physical model will be conducted to identify the most suitable glaciers for the analysis of glacier changes and its impact on river runoff and other watershed components. A feasibility report will be prepared as per the survey and the cryospheric, topographical and hydro-climatological characteristics of the glacier will be comprised. Then the instrumentation will be done in the glacier site for the analysis of different glacier parameters in the real time domain. The scientific instruments such as Automatic Weather Station, Water Level Recorder, Soil Moisture Sensors. Sediment Samplers, Snow Gauge (Depth and Sensitivity) will be procured and established for the measurements of glaciers. For glacio-hydrological analysis, the modeling based framework will be developed utilizing the widely used modeling tools such as SPHY, SWAT and VIC etc. However, as the Himalayan glaciers are unique in nature and thus some modifications will be done by incorporating the effect of local parameters mainly to enhance the accuracy of the computed outcomes. Model calibration and validation will be done utilizing real time remote sensing data products and observed hydro-observational datasets. The snow and glacier melt runoff contribution in total discharge will be accounted and their fluctuations will be analyzed. The comparative seasonal and monthly snow cover and glacier change (area/volume/thickness) will be computed to highlight the variability in the glacier mass and other parameters. The mass balance of selected glacier will be done as mass balance methods as utilized previously utilizing the remote sensing, and field observation datasets. The effect of slope, aspect and elevations will also be incorporated to analyze their effects on glacial retreating and resultant runoffAs per the seasonal changes in precipitation and temperature at different altitudes within the glacier body and its catchment area will be studied and their relation to evapotranspiration (ET), soil moisture, surface temperature, radiation and surface albedo will be explored. Surface albedo and radiation have been recognized as important drivers to affect the snow cover and snow water equivalent. The snowpack cold content and albedo decrease when the intensity of shortwave radiation and temperature increases.

5. Deliverables

- Feasibility of report on the glacier status in the western Himalayan region.
- Establishment of observatory and instrumentation for the real time monitoring and measurement of the snow and glacier parameters.
- Glacier mass-balance and other glacier parameters database.
- Real time information of glacier induced river flow and other watershed components in the form of digital database and maps.
- Conclusive remarks on glacier mass balance changes (in terms of area, thickness and volume).

6. Relevance to Centre for Cryosphere and Climate Change Activities

The above proposed study is a major objective of newly established Centre for Cryosphere and Climate Change at NIH Roorkee.

7. Duration of the project – 5 years (Apr. 23 – Mar. 28)

7.1 Stage of work and milestone:

Stage of Works	Year 1		Year 2		Year 3		Year 4		Year 5	
	6m	6m	6m	6m	6m	6m	6m	6m	6m	6m
A. Glacier Survey & Feasibility Report										
B. Instrumentation & Field Works (Procurement & Installation)										
C. Evaluation of Parameters, Database Organization& Data Pre-processing										

D. Development of Modeling Framework			■	■	■	■				
E. Modeling: Simulation and Analysis				■	■	■	■	■	■	
F. Modeling: Simulation and Analysis & Final report writing and research paper publications				■	■	■	■	■	■	■

8. Budget: Rupees - Seventy One Lacs Only (Rs. 71,00000/-)

SI. No.	**Name of Activity**	**Y1**	**Y2**	**Y3**	**Y4**	**Y5**	**Total Rs (in Lacs)**
1	Salaries and wages: (1 Resource Person- Junior/Senior)	5.00	5.00	5.00	5.00	5.00	25.00
2	Consumable materials: (Satellite Data/Other datasets)	5.00	1.00	1.00	-	-	7.00
3	Travel and field expenses: (Recurrence Surveys & Field Works)	3.00	2.00	2.00	2.00	1.00	10.00
4	Instruments: (AWS, Snow Gauge, Snow Depth, Snow Density Gauge, Water Level Recorder)	20.00	-	-	-	-	20.00
5	Other items and Contingencies	1.00	1.00	1.00	0.5	0.5	4.00
6	Non-recurring expenses	2.50	2.50	-	-	-	5.00
7	**Total Rs. (in Lacs)**	**36.5**	**11.5**	**9.0**	**7.5**	**6.5**	**71.00**

RESEARCH MANAGEMENT
AND
OUTREACH DIVISION

Scientific Manpower

S N	Name	Designation
1	Er. Omkar Singh	Scientist G & Head
2	Dr. A. R. Senthil Kumar	Scientist G
3	Dr. (Mrs.) Jyoti P. Patil	Scientist D (LCU)
4	Sri. Rohit Sampatrao Sambare	Scientist C
5	Sri Rajesh Agrawal	PRA
6	Sri N. R. Allaka	SRA

NATIONAL INSTITUTE OF HYDROLOGY
राष्ट्रीय जल विज्ञान संस्थान
आपो हिष्ठा मयोभुवः

APPROVED WORK PROGRAM FOR THE YEAR 2022-23

SN	Title of Project/Study	Funding	Study Team	Duration	Status
Internal Study					
1	Integrated assessment of water resources for sustainable use in Upper Dhasan basin in Bundelkhand region	NIH	Jyoti Patil (PI) T Thomas (Co-PI), P K Mishra Rohit Sambare	Sep 2020-Feb 2023	On-going
2	Establishing hydrologic regime and ecohydrological functions of Jhilmil Jheel wetland (Haridwar District, Uttarakhand)	NIH	Rohit Sambare (PI) V C Goyal (Co-PI), Suhas Khobragade, N R Allaka; Gajendra Singh-USAC, Dehradun; WI-SA, New Delhi; HESCO, Dehradun	Sep 2020-Aug 2023	On-going
3	Hydrology-based scenario planning for water productivity and optimization of income from farming practices in Mewat region, Haryana	NIH	A R Senthil Kumar (PI) Omkar Singh (Co-PI) Rajesh Agarwal, N R Allaka Scientist from KVK/Agri Univ.	Sep 2020-Aug 2022	On-going
4	Development of Water Security Plan for Healthcare Facilities: A Pilot Study for Swami Rama Himalayan University (SRHU-HIHT), Jolly Grant, Dehradun	NIH	Omkar Singh (PI) V.C. Goyal, Rajesh Singh (Co-PI), Jyoti Patil, Rohit Sambare, N.R. Allaka; Team from SRHU-HIHT, Dehradun	April 2022-Mar 2024	Proposed to drop the study due to non availability of requisite data/resource
Sponsored Projects					
1	Innovation Centre for Eco-Prudent Wastewater Solutions (IC-EcoWS)	DST (GoI)	V.C. Goyal (PI), Omkar Singh, Rajesh Singh, Jyoti P. Patil, Rohit Sambare, Project Team, HQ (IC-EcoWS) Partners: NIH, MNIT-Jaipur, IIT-Bombay, IRMA-Anand	Apr 2019-Mar 2024	On-going

PROPOSED WORK PROGRAM FOR THE YEAR 2023-24

SN	Title of Project/Study	Funding	Study Team	Duration	Status
Internal Study					
1	Integrated assessment of water resources for sustainable use in Upper Dhasan basin in Bundelkhand region	NIH	Jyoti Patil (PI) T Thomas (Co-PI), P K Mishra Rohit Sambare	Sep 2020- Feb 2023 (sought ext. till June 23)	On-going
2	Establishing hydrologic regime and ecohydrological functions of Jhilmil Jheel wetland (Haridwar District, Uttarakhand)	NIH	Rohit Sambare (PI) V C Goyal (Co-PI), Suhas Khobragade, N R Allaka; Gajendra Singh-USAC, Dehradun; WI-SA, New Delhi; HESCO, Dehradun	Sep 2020- Aug 2023	On-going
3	Hydrology-based scenario planning for water productivity and optimization of income from farming practices in Mewat region, Haryana	NIH	A R Senthil Kumar (PI) Omkar Singh (Co-PI) Rajesh Agarwal, N R Allaka Scientist from KVK/Agri Univ.	Sep 2020- Aug 2022 (sought ext. till June 23)	On-going
Sponsored Projects					
1	Innovation Centre for Eco-Prudent Wastewater Solutions (IC-EcoWS)	DST (GoI)	Omkar Singh (PI), V.C. Goyal (ex PI), Rajesh Singh, Jyoti P. Patil, Rohit Sambare, Rajesh Agarwal, NR Allaka, Project Staff (IC-EcoWS) Partners: NIH, MNIT-Jaipur, IIT-Bombay, IRMA-Anand	Apr 2019-Mar 2024	On-going

Proposed Trainings/Workshops (2023-24)

S.N.	Activity	Tentative Date & Month	Place	Target Participants	Team
1	5-days training on ‘Life Cycle Approach for Rejuvenation of Ponds and Lakes using Nature-Based Solutions’ sponsored by NWM	Apr/May/ June 2023	Roorkee	R&D Institutes/ University/Govt. Organizations	J P Patil/AR Senthil Kumar, Omkar Singh, Rohit Sambhare, Rajesh Agarwal, NR Allaka
2	Stakeholders workshop for Upper Dhasan Basin water resources assessment	May 2023	Bhopal	CWC, CGWB, State departments (Irrigation, WRD, Agril etc)	J P Patil, T Thomas, P K Mishra, Rohit Sambhare
3	Five-day training program on “Hydrology of water bodies and their development under climatic uncertainty”	Jun/Jul 2023	NIH Roorkee	Engineers in Irrigation/PHE/SWC departments	A. R. Senthil kumar, Jyoti Patil, Rohit Sambare, Santosh M Pingale, N R Allaka

Proposed other Outreach Activities (RMOD)

S.N.	Activity			
1	Preparation of short videos on R&D findings of selected NIH studies			
2	Coordination & Organizing activities under Azadi Ka Amrit Mahotsav-Phase 2.0			
3	Any other Outreach activity (exhibition) as assigned			
4	Outreach activity on "Water Conservation & Water Security" in Schools	Oct/Nov/ Dec. 2023	Schools (2 nos.)	Team: A. R. Senthil kumar, Omkar Singh, Rajesh Agarwal, N R Allaka

Study- 1 (Internal)

1. Title of the Study: Integrated assessment of water resources for sustainable use in Upper Dhasan basin in Bundelkhand Region, Central India.

2. Project team:

a. Project Investigator: Dr. Jyoti P. Patil
b. Project Co-Investigator(s):
Dr. T. Thomas (RC-Bhopal)
Dr Prabhash K Mishra
Er. Rohit Sambhare
Dr. V. C. Goyal (*Retired in Sept.2022*)

3. Type of Study: Internal; **Budget**: 41.0 Lakhs (*Expenditure: Nil*)

4. Date of start: 01.09.2020

5. Scheduled date of completion: 28.02.2023 (*Request to extend upto June 2023*)

6. Duration of the Study: 2.5 years (30 months)

7. Study Objectives:
The major objective of the study is to assess the demand and availability of water in Upper Dhasan basin located in the drought prone Bundelkhand region in Central India, and to develop a plan for the optimal water allocation using WEAP model and WA+ framework.

8. Statement of the Problem:

The Dhasan River is a major tributary of the Betwa river system which originates in Raisen district of Madhya Pradesh and flows through the various drought prone districts in Central India viz., Sagar, Tikamgarh, Chhatarpur districts in MP and Lalitpur, Jhansi and Hamirpur districts in UP. It is one of the important rivers in Bundelkhand region which has off late become a drought prone region due to the various issues facing the region including the overexploitation of the natural resources and changes in the weather pattern. The frequency of occurrence of droughts is once in 4 years. The variability of rainfall is the main reason for the regular water stress. However, the limited groundwater availability in the hard rock region coupled with low water holding capacity soils further aggravate the water stress thereby creating livelihood issues for the local population.

This study aims to have a holistic look into the overall water availability in the Dhasan basin, in the light of the committed storages of the planned projects and realistic assessment of the planned projects. The estimation of the water availability and water productivity using both the WEAP model and the Water Accounting+ framework in totality will help to understand the supply of available water along with the demands from various sectors in the drought prone region in Bundelkhand. The assessment of the reliability of these projects in the light of the climate change, based on scenario analysis for the estimation of the future water supply-demand and development of an optimal water allocation plan for the basin, shall provide a useful tool in the hands of the decision makers to fine-tune the water resources development and management policies accordingly. The State Government is interested in taking up such a project as this will provide them with an optimal water allocation plan in the present time as well as into the future. The Chief Engineer, BODHI, MP Water Resources Department has given the consent in this regard.

The water availability needs to be assessed for multiple scenarios of new and upcoming water storage infrastructure, plans for out of the basin water transfers as well as the highly uncertain impacts of the climate change on the water availability scenario in the basin. This will provide as realistic assessment of the present and future water availability scenario in the basin based on optimal water allocation policies and plans can be devised. Such an integrated effort will go a long way in managing the available water resources in the present and future and managing the demands in tune with the availability and constraints. This will result in the development of WEAP and WA+ based water allocation plan for the optimal use of water resources in the study area, which will be useful to the line departments and stakeholders including the Agriculture Department (agriculture), Water Resources Department (better water distribution for irrigation by integrated operation of projects), Public Health Engineering Department (water supply for domestic use) and Industries that may be benefitted, ultimately leading to the development of the region resulting in improved livelihood options for the local population.

9. Methodology

Study area:

The study has been selected in Upper Dhasan basin upto Garrauli G/D site on Dhasan river falling in Chhatarpur district (Figure 1). The area of Upper Dhasan Basin is 3565 sq. km.

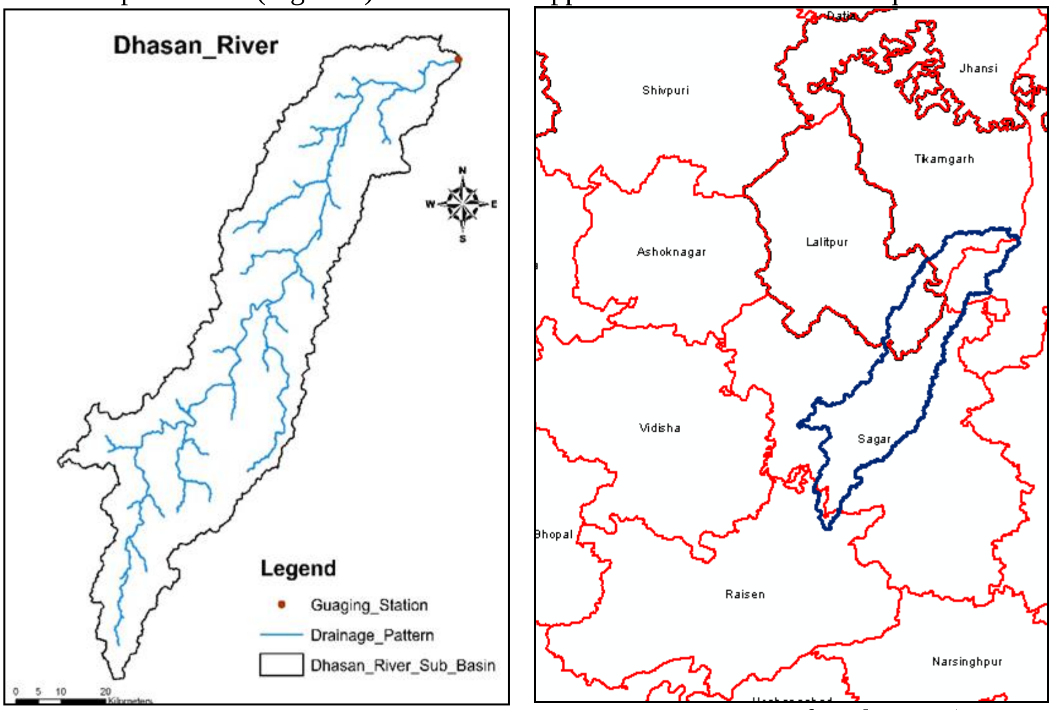


Figure 1 Location of study area (Upper Dhasan basin)

Detailed Methodology:

1. Preparation of data inventory including climatic, hydrologic, demographic and socio-economic data.
2. Processing and analysis of data.
3. Trend analysis of meteorological and hydrological variables.
4. Customization, calibration and validation of WEAP model for runoff simulation.
5. Estimation of water productivity and land productivity using WA+ framework
6. Assessment of environmental flow requirement using established techniques and water balance and supply demand scenario using WEAP and WA+ outputs.
7. Vulnerability assessment using IPCC approach
8. Assessment of climate change on the future water availability.
9. Water allocation planning for the present and future under alternate scenarios of upcoming water resource infrastructure, population growth, inter-basin water transfer and climate change using WEAP.
10. Stakeholder workshop and Final Report.

10. Analysis & Results

1. **Collection of information and Hydro-meteorological Data**

   a. The gauge and discharge data of Garaulli site, Madhya Pradesh was collected from Yamuna Basin Organization (YBO), Central Water Commission (CWC), Government of India from 1991-92 to 2019-20.

b. The daily meteorological data [Rainfall, Temperature (maximum and minimum)] of 17 grid points have been collected from IMD, Pune for 50 years (1971-2020).

The details of hydro-meteorological, spatial, and agriculture data is given in the following table1.

Table 1 Details of hydro-meteorological data

Data	Details	Source
Discharge data (Daily)	1991-92 to 2019-20	CWC
Rainfall (Daily)	0.25^o X 0.25^o ; 1971-2020	IMD
Temperature (Daily)	1^o X 1^o; 1971-2019	IMD
Geospatial Maps	Land use Land Cover (LULC) River and Water bodies Soil type	USGS earth explorer, NRSC
Agriculture	Major crops (kharif/ rabi), area under each crop, water requirements, irrigated area	Respective District Administrations, District Irrigation Plans (DIP)
Demand data	Population Livestock Industries	Census/ District Administration websites / District reports
Supply information	Water Supply, Groundwater source Tank capacity	IMD/ district authorities CGWB district reports Minor irrigation census

2. Spatial database

The spatial database of the basin such as Digital Elevation Map (DEM), LULC map, Drainage Network were created. The landuse of the basin is predominantly agriculture (58%). The area under each landuse is given in Table 2.

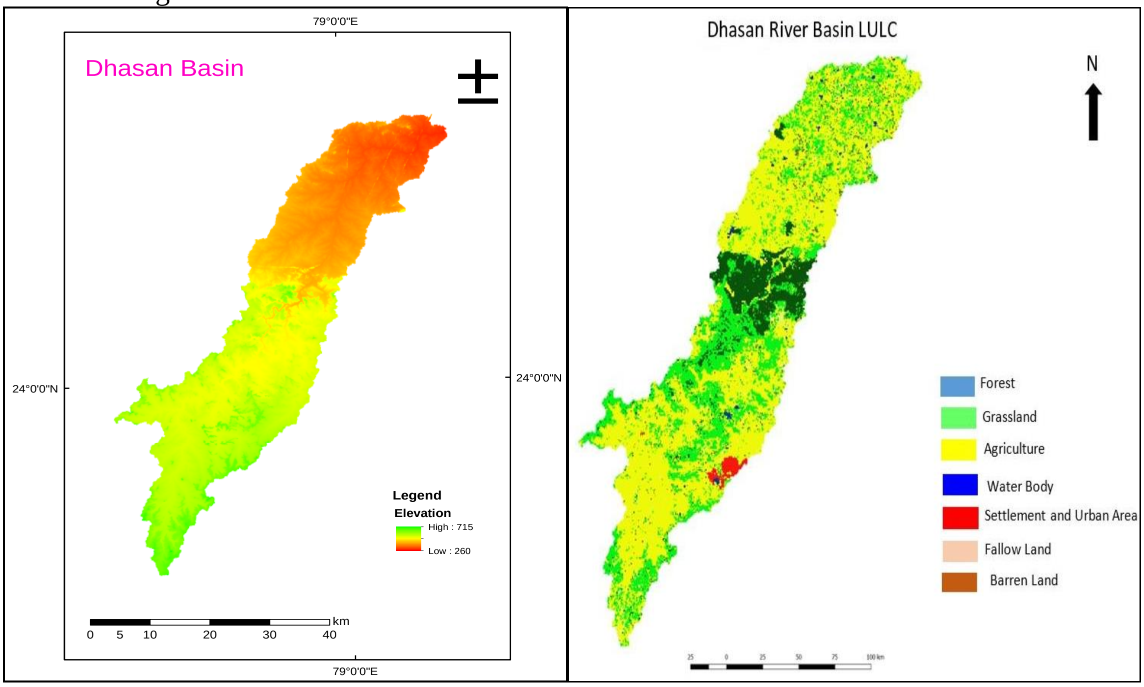


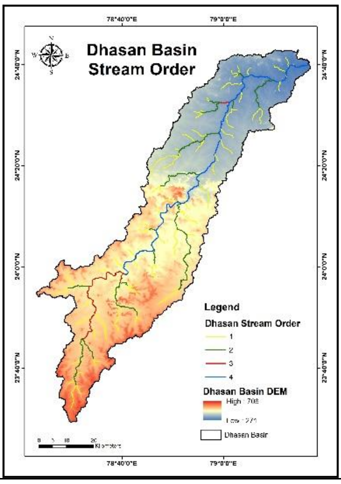
Figure 2 DEM and LULC maps

Table 2 Land use/land cover statistics of Dhasan river basin

Land use/cover categories	Area (km^2)	Percentage (%)
Agriculture Area	1982.23	58
Grassland	959.58	28
Forest Area	304.91	9
Barren land	74.02	2
Fallow land	58.20	2
Urban area	29.41	1
Water bodies	18.04	1

3. Morphometric Analysis of Upper Dhasan Basin

Morphometric Parameter	Value for basin
Area (A)	3565 km^2
Perimeter (P)	714 km
Maximum Elevation (H)	706 m
Minimum Elevation (h)	271 m
Length (L_b)	136.62 km
Highest Stream Order (U)	4
Stream Number	231
Stream Length	751 km



Derived Parameters			
Morphometric Parameter	**Value for basin**	**Morphometric Parameter**	**Value for basin**
Mean Stream Length (L_{sm})	3.9 km	RHO coefficient	0.162
Bifurcation Ratio (R_b)	7.095	Relief (B_h)	435 m
Stream Length Ratio (R_1)	3.44	Relief Ratio (R_h)	3.184
Mean Bifurcation Ratio (R_{bm})	2.37	Relative Relief (R_{hp})	98.880
Mean Stream Length Ratio (R_{1m})	1.15	Ruggedness Number (R_n)	91.785
Stream Frequency (F_s)	0.065 km^{-2}	Circulatory Ratio (R_c)	0.088
Drainage Density (D_d)	0.211 km/km^2	Elongation Ratio (R_e)	0.493
Drainage Texture (D_t)	0.323 km^{-1}	Form Factor (F_f)	26.094
Length of Overland Flow (L_o)	2.37 km	Lemniscates Ratio (K)	1.310
Drainage Intensity (D_i)	0.308 km^{-1}	Compactness Coefficient (C_c)	3.373

4. Analysis of meteorological and hydrological variables

For modeling purpose, the basin is divided into two catchments. The sub-watershed 1 (SW1) is upto Banda Irrigation project and sub-watershed 2 (SW2) is downstream of the Banda irrigation project, upto the outlet of the basin. The Table-3 summarizes indices estimated for SW1 and SW2 alongwith their trend using Kendall-tau significance test.

Table 3 Indices estimated for SW1 and SW2

Index	SW1		SW2	
	Value	Trend statistics	Value	Trend statistics
Mean Tmax (^{0}C)	32.56	0.0226	32.52	0.0172
Mean Tmin (^{0}C)	18.43	0.0193	18.96	0.0161
Mean Rainfall (mm/day)	2.91	-0.0044	2.78	-0.0082
No. of days RF>= 10mm	28.96	-0.0742	29.80	-0.1205

Max no. consecutive dry days (during Jun, Jul, Aug)	15	-0.1838	15	-0.1021
Max no. consecutive wet days (during Jun, Jul, Aug)	8	-0.0323	10	-0.0249
Greatest 3-day total rainfall (mm)	183.72	0.3426	170.82	-0.1295
Greatest 5-day total rainfall (mm)	219.28	-0.2357	210.08	-0.3429
Greatest 10-day total rainfall (mm)	301.61	-0.5746	282.53	-0.677

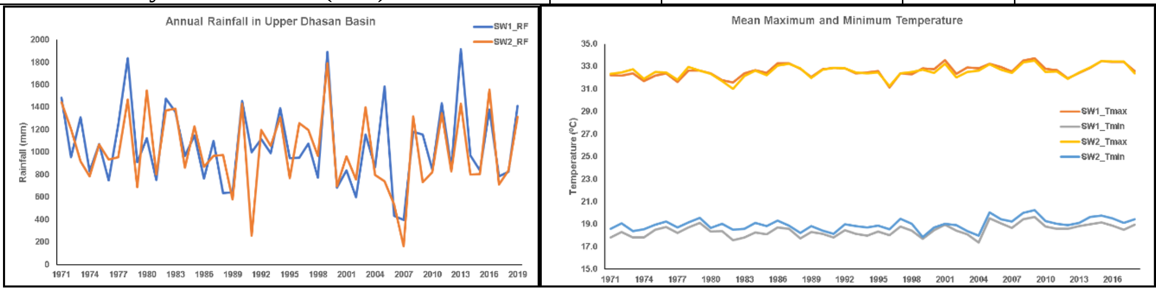


Figure 3 Annual rainfall and mean temperature variation in basin

5. Drought analysis: Meteorological drought analysis is completed using the observed data of the basin

6. WEAP model formulation

The WEAP model for formulated for complete Upper Dhasan Basin for the current account year 2015 by considering demands (agriculture, forest, domestic, industrial), supply resources (rainfall, groundwater, river and major surface reservoirs). The scenarios like population growth, increased irrigation efficiency, industrial growth and incorporation of rainwater harvesting structures were run in the WEAP to observe the unmet demands of the basin during 2021-2050.

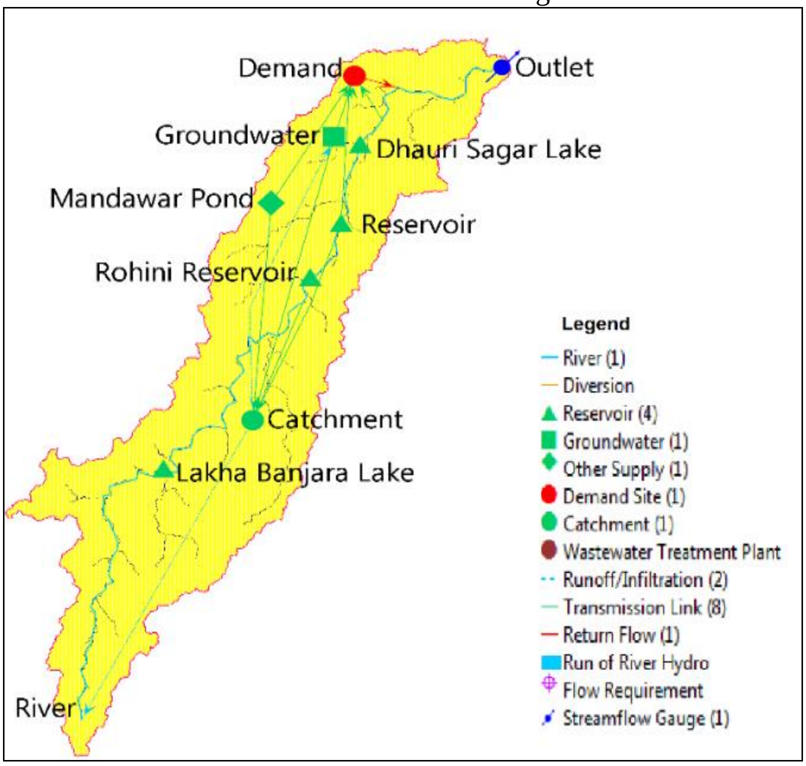


Figure 5 WEAP model formulation for Dhasan Basin

For detail analysis of water balance components and impact of proposed dams in the basin, the WEAP model will be formulated for two sub-catchments.

7. WA+ Framework

Precipitation and Evapotranspiration Variability

A preliminary analysis was carried out to understand the precipitation and evapotranspiration variability across the Betwa basin. Figures 6a shows the spatial variation of precipitation obtained from CHIRPS data (developed by the Climate Hazards Group InfraRed Precipitation with Stations) for the period of 2003-2014. It can be observed that the eastern and southern parts of the Betwa basin receives higher rainfall as compared to the rest part of the basin. Overall, the basin receives less rainfall with an annual average of 958 mm. In the contrary, the mean monthly ensemble ET is higher in the northern and central parts of the basin as shown in Figure 6b.

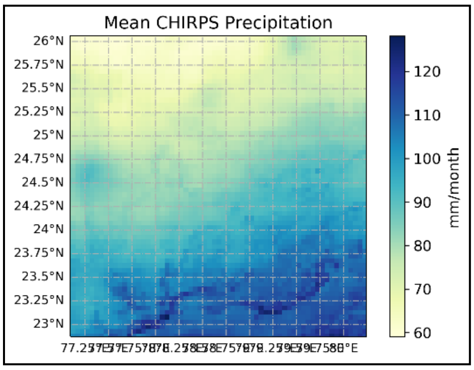


Figure 6a Spatial variation of mean monthly CHIRPS precipitation

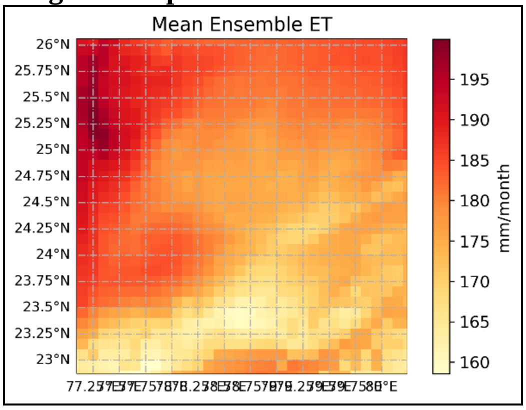


Figure 6b: Spatial variation of mean monthly ensemble ET

WA+ based land use land cover (WALU)

WA+ recognizes the influence of land use on water cycle and provides the link between water balance, land use and water use as well as management options to modify it, by grouping land use classes with common management characteristics. WA+ classifies LULC in to four major LULC classes segregated from 80 global land use classes based on the land use and water management practices as: (1) Protected Land Use (PLU); (2) Utilized Land Use (ULU); (3) Modified Land Use (MLU); and (4) Managed Water Use (MWU). PLU represents areas set aside for minimal disturbance by humans e.g. National Parks & Wildlife Sanctuaries, etc. ULU represents a land use that provides a range of ecosystem services and which has had little interference by man with less exploitation e.g., Grasslands, forest land, natural pastures, etc. MLU refers to land that is significantly modified by human activity. Here only the land use is modified e.g., Rainfed cropping systems, creation of plantation forests, etc. MWU represents the land use classes in which both the land use and water is managed with significant exploitation, e.g. Irrigated cropping systems. The WA+ based land use for the Betwa basin is shown in Figure 7. The land use distribution is presented in Table 4.

Table 4: Land use distribution for the Betwa basin generated using 8 different datasets

LULC	**Area (Km^2)**	**% area**
Forest	3828.25	10.62
Grassland	3756.81	10.42
Waterbody	1330.06	3.69
Barren/waste	2892.94	8.02
Builtup	6223.25	17.26
Agriculture	18018.44	49.98

Note: Distribution has been generated using 8 global datasets.

Development of Evapotranspiration Sheet [Sheet 2]

Sheet 2 presents provides information on water consumption in a basin as a total value and per water sector (land use type). Major inputs for the generation of Sheet 2 are RS-based evapotranspiration maps (ET), Leaf Area Index (LAI), Net primary production (NPP), Gross primary production (GPP), daily precipitation and a LULC map. Developed Sheets for wet and dry year for the Betwa basin is shown in Figure 8a and Figure 8b, respectively. The total water consumptions of the basin for the wet year, i.e., 2013-14 is found to be 41.5 km^3/year with further partitioning of ET into evaporation (E) from soil and Transpiration from different LULC. The total water consumptions of the basin for the wet year, i.e., 2013-14 is found to be 25.8 km^3/year. Sheet 2 also shows that the non-beneficial consumptions in the basin indicating further scope for water conservation practices to be adopted in the basin to minimize non-beneficial consumptions.

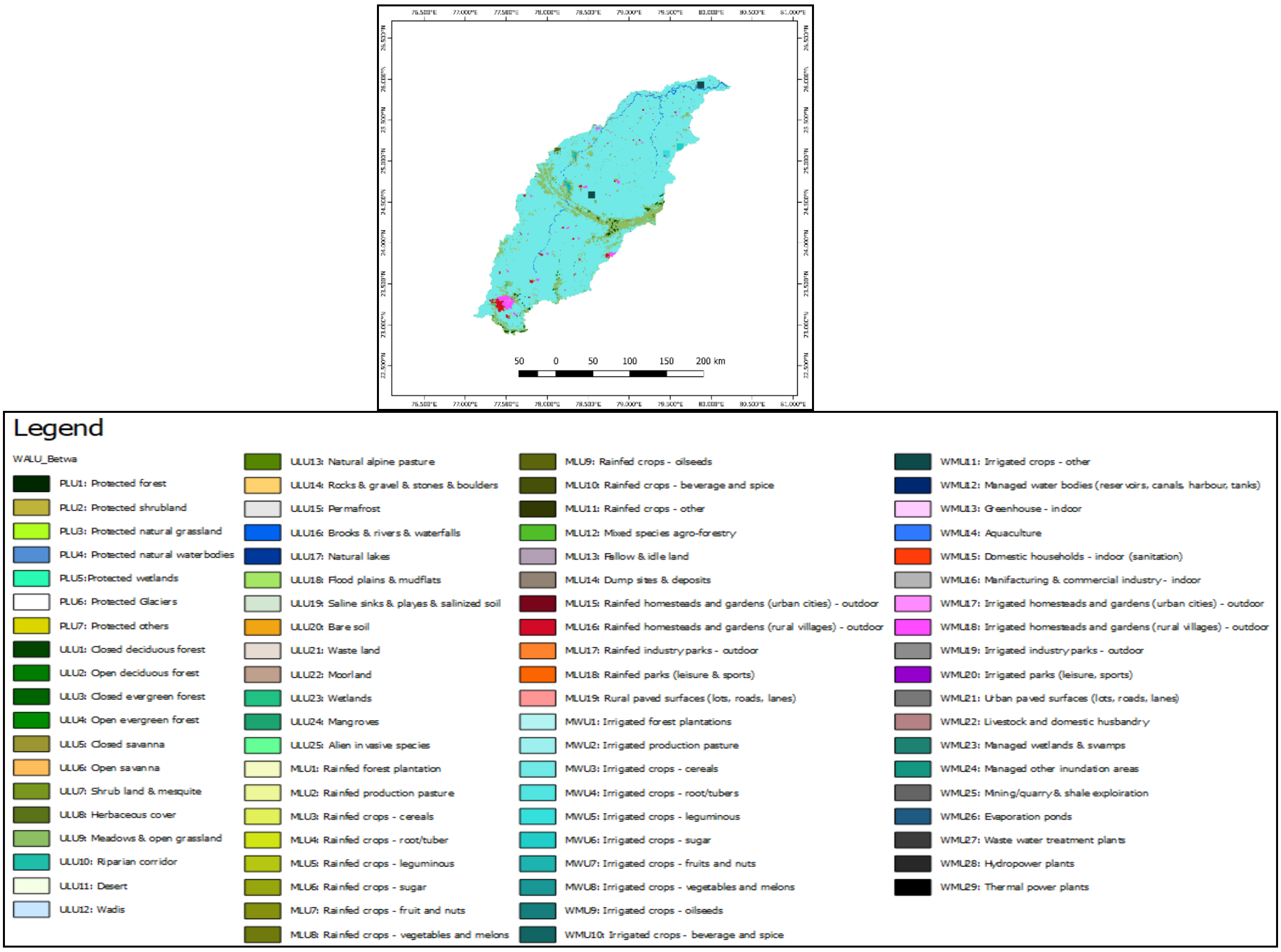


Figure 7: LULC map of Betwa basin generated using WALU

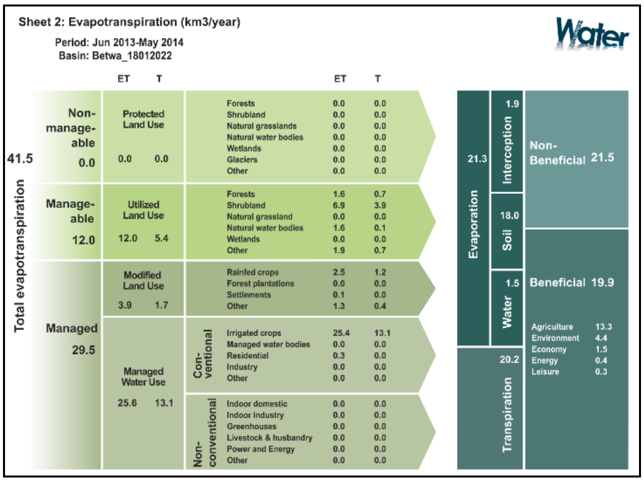


Figure 8a: Evapotranspiration Sheet: Sheet 2 for wet Year 2013-14.

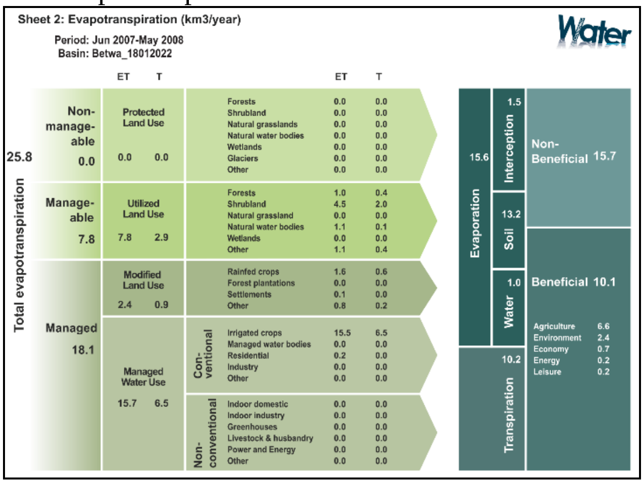


Figure 8b: Evapotranspiration Sheet: Sheet 2 for Dry Year 2007-08.

11. End Users / Beneficiaries of the study: Agriculture Department (agriculture), Water Resources Department (better water distribution for irrigation by integrated operation of projects), Public Health Engineering Department (water supply for domestic use) and Industries.

12. Major items of equipment procured: None.

13. Lab facilities used during the study: None.

14. Data procured or generated during the study: Spatial database of the study area

15. Output of the study:

- Nivesh, S, **Patil, Jyoti P.**, Goyal, V.C., et al. (2022) Assessment of future water demand and supply using WEAP model in Dhasan River Basin, Madhya Pradesh, India. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-022-24050-0 (**IF:5.19**)
- Sambhare R. and **Patil, Jyoti P.** (2023) Quantitative Morphometry Analysis of Upper Dhasan River Basin, Bundelkhand region, Central India. Special Edition on Mission LiEF (Lifestyle for Environment). IIT(ISM) Dhanbad (*Submitted*).

16. Study Benefits / Impacts: Outputs of the study will be used in preparation of ‘Integrated Water Management Plans at Sub-basin level and District level.

17. Shortcoming / Difficulties: The stakeholders workshop with the beneficiaries is to be conducted for sharing the findings of the study and taking feedback of the line departments

18. Future Plan: The stakeholders workshop is proposed to conduct during May 2023 and Final report of the study will be submitted by June 2023.

Study- 2 (Internal)

1. **Title of the Study:**

Hydrology-based scenario planning for water productivity and optimization of income from farming practices in Mewat region, Haryana

2. **Study group:**

Dr. A. R. Senthil kumar, Sc "G" RMOD
Sh. Omkar Singh, Sc "G", RMOD
Sh. Rajesh Agarwal, PRA, RMOD
Sh. Nageswara Rao Allaka, SRA, RMOD

3. **Date of start: September 2020**

4. **Duration of the study: 2 Years** ***(Request to extend upto June 2023)***

5. **Whether externally funded or not: Internal**

6. **Objectives:**

   a. To evaluate the existing cropping pattern and farming practices for estimation of farmer's income
   b. To carry out scenario analysis considering combinations of crop types and cropping pattern, land allocation, water allocation under climatic variability, etc.
   c. To develop plan for optimized income from farming practices encompassing food and water security.

7. **Statement of the problem**

The rising population and industrial growth with climate change makes difficult to meet the demand of agricultural activities. Continuous over exploitation of ground water under uncertain occurrence of rainfall is inevitable to continue the traditional cropping pattern. Traditional cropping pattern is neither good for soil health nor for food security. Farmer's income is often below optimal. Scientific planning considering cropped area, climate smart crop types, crop productivity, cropping pattern, farming input costs, and crop revenues, will evolve optimal utilization of available water and optimize farmer's income from farming practices. Scenario analysis with projected population growth, landuse changes, climatic conditions, water-efficient irrigation technologies, etc. shall provide a canvas of options to be considered for optimal income from farming practices in future. A scientific plan is needed to guide the farming community about optimizing their income from farming practices that lead to food and water security.

8. **Methodology**

The optimal income from agriculture for various scenarios of crop types and land resources in Mewat region, Haryana is evolved by setting up of WEAP tool with the combination of LINGO. The inputs to WEAP tool such as water demand from various sectors, priority of the demand, catchment details, hydrologic conditions and inflows, catchment hydrology (river flow, ground water, lakes/reservoir/storage tanks, springs, other storage structures etc), supply preference (operating rules/policy), return flows, minimum flow requirements, economic variables such as cost of water transmission etc. are prepared from the data obtained from various sources such as irrigation department, IMD, CWC and census department. The future climatic scenarios will be downscaled from GCM models for SSP245 and SSP370. The hydrological processes occurring in the catchment will be modeled and will be compared with the measured discharge time series. After the proper calibration of the model, the demand sites will be added into a model framework and different scenarios will be generated to assess the gaps in the water demand and supply and water availability at different locations and at the different period of time. The optimum income for agricultural sector will be arrived by LINGO using the input variables obtained from the scenario analysis of WEAP model for crop types and land resources. The optimization functions such as maximizing the net income from agriculture, minimizing the water usage, minimizing the cost of cultivation with the constraints of land area for crops, water availability based on the scenario analysis and cost of cultivation are considered for achieving the objectives. The scenarios such as change of cropping pattern (crop diversity) considering food security, change of cropping area with allowable limits, availability of water (normal, dry, very dry, wet and very wet), industrial and population growth and climate scenarios SSP245 and SSP370 from GCM models.

9. Results achieved with progress/present status:

Three blocks, Nuh, Nagina and Punhana of Mewat District have been selected for the setup of WEAP model based on the drainage network created from the toposheets of Survey of India. The total area of three blocks is 957.78 Sq.km. The total population by the end of 2020 is 7,71,093 (Urban- 80101 and rural - 690992) based on the 2011 census and the population projection of Haryana State by National Commission on Population. The gridded data of rainfall, maximum and minimum temperature have been obtained from IMD. The evapotranspiration has been estimated by Hargreaves method using the average maximum and minimum temperature and extra terrestrial radiation obtained from the following web-site:

https://www.engr.scu.edu/~emaurer/tools/calc_solar_cgi.pl. The crop area under Kharif and Rabi, livestock details of Nuh, Nagina and Punhana have been collected from and the Agriculture department and Animal Husbandry and Dairying Department, Nuh. The crop water requirement for Kharif and Rabi crops have been taken from literature. The monthly water consumption by rural and urban population is estimated by assuming daily consumption for rural and urban population as 70 lpd and 135 lpd respectively. The monthly consumption by the livestocks is estimated from the details derived from literature. The percentage share of landuse for agricultural land, forest land, settlement, fallow land and water bodies are 74, 8, 12, 5 and 1 respectively. The monthly crop coefficient (Kc) for different landuses and crops and the effective precipitation for evapotranspiration are estimated based on the literature and FAO report. The yield and market price of the Kharif and Rabi crops are obtained from literature. The ground water draft for all uses is taken from the CGWB report of 2012 for Mewat District. The cost of cultivation for major Kharif and Rabi has been obtained from the report of Directorate of Economics and Statistics, Ministry of Agriculture and Farmer Welfare for the year 2018-19. The cost of cultivation for Sorghum (dry fodder) and Brinjal (Kharif) and Berseem (green fodder) and Cauliflower (Rabi) have been obtained from SPACE Team (Dr. S. S. Grewal). The WEAP model is run with the inputs generated from different sources and literature for normal, wet, very wet, dry and very dry, population growth scenarios to find out demand and supply gap. The LP model is setup with objective functions of maximizing the farming income, minimizing the water usage and cost of cultivation with inputs from WEAP model and other constraints for crop area, yield and cost of cultivation for all the scenarios to evolve optimal crop area. The average precipitation, maximum and minimum temperature for SSP245 and SSP370 for the CMIP6 models, ACCESS-CM2 and ACCESS-ESM1-5 are extracted from the archive of NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6) for the period from 2015 to 2100 and are given as follows:

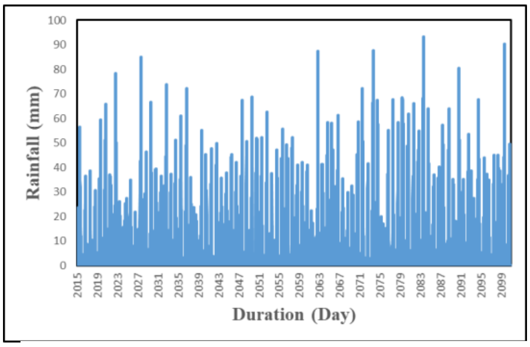


Fig 1. Average Rainfall for SSP245, ACCESS-CM2

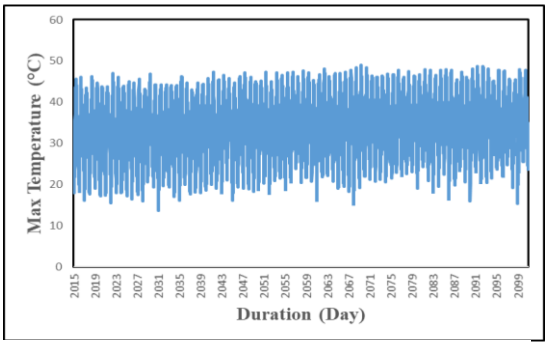


Fig 2. Average Maximum Temperature for SSP245, ACCESS-CM2

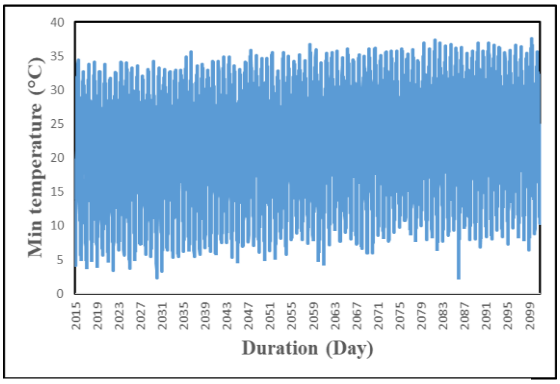


Fig 3. Average Minimum Temperature for SSP245, ACCESS-CM2

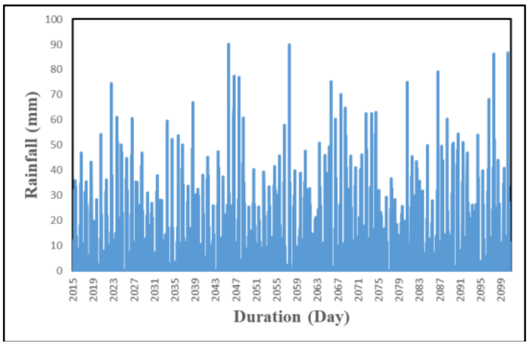


Fig 4. Average Rainfall for SSP370, ACCESS-CM2

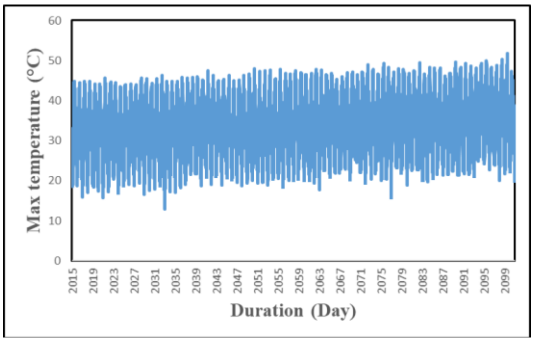


Fig 5. Average Maximum Temperature for SSP370, ACCESS-CM2

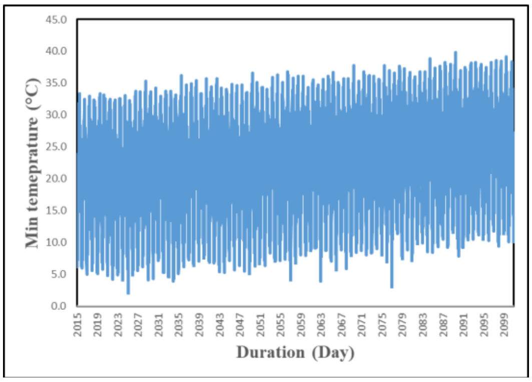


Fig 6. Average Minimum Temperature for SSP370, ACCESS-CM2

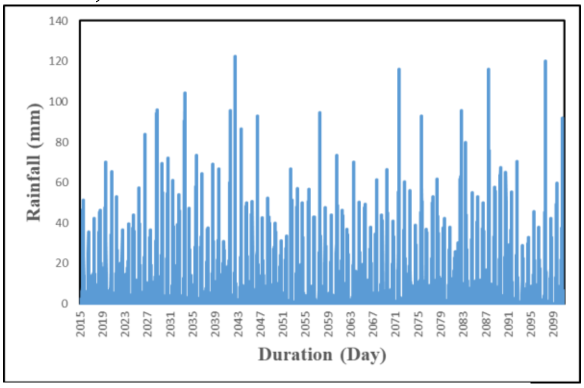


Fig 7. Average Rainfall for SSP245, ACCESS-ESM1-5

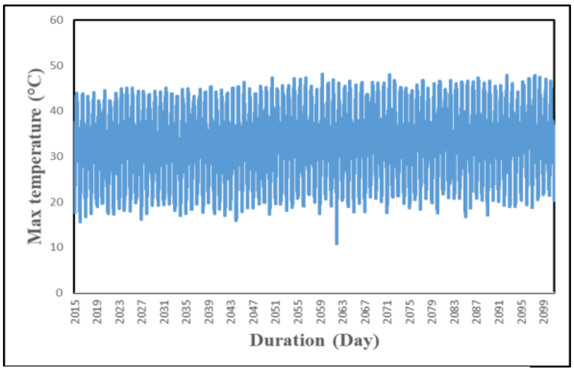


Fig 8. Average Maximum Temperature for SSP245, ACCESS- ESM1-5

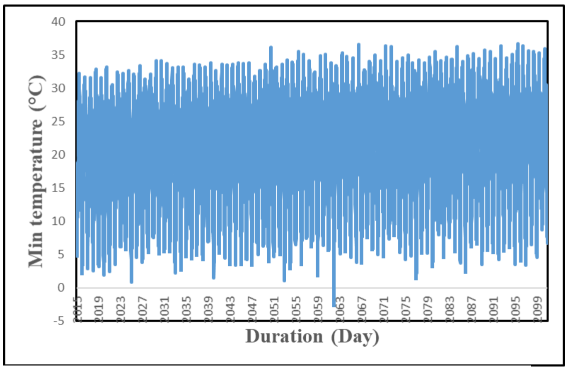


Fig 9. Average Minimum Temperature for SSP245, ACCESS- ESM1-5

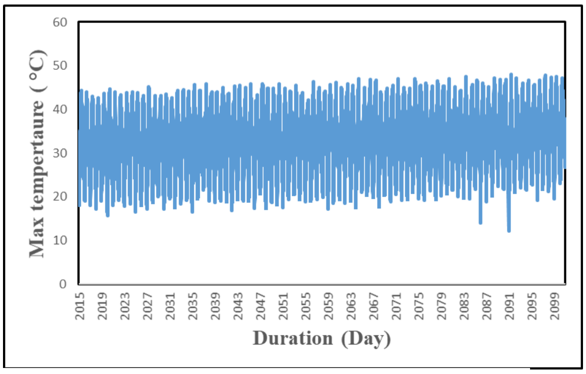


Fig 11. Average Maximum Temperature for SSP370, ACCESS- ESM1-5

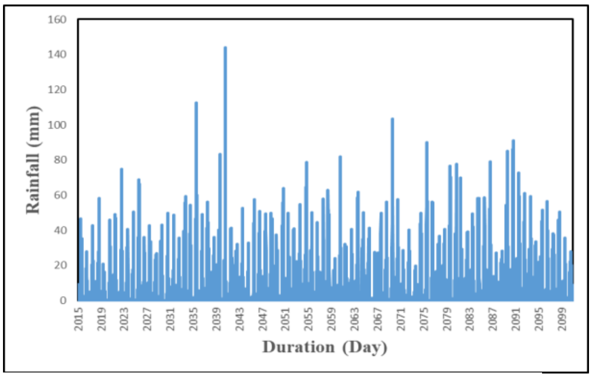


Fig 10. Average Rainfall for SSP370, ACCESS- ESM1-5

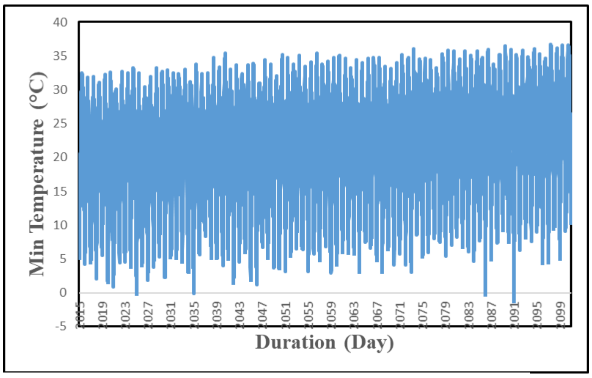


Fig 12. Average Minimum Temperature for SSP370, ACCESS- ESM1-5

Extension of the study upto June 2023 is requested to setup the WEAP model with the data of scenarios SSP245 and SSP370 of ACCESS-CM2 and ACCESS-ESM1-5.

10. Research outcome from the study

The following are outcome from the study

- Maximum net profit, minimum investment cost and minimum water usage for each scenario.
- Optimal land allocation for different crops (considering staple food, nutrition value), Kharif season and rabi season for each scenario.

Study-3 (Sponsored Project-DST)

1. **Title of the project: Innovation Centre for Eco-Prudent Wastewater Solutions (IC-EcoWS)**

2. **Study Team:** Er. Omkar Singh (PI), Dr. V.C. Goyal (Former PI), Dr. Rajesh Singh (Co-PI), Dr. Jyoti P. Patil, Er. Rohit Sambare, Rajesh Agarwal, NR Allaka
   NIH Project Team: Dr. Jyoti Singh, Dr. Shweta Yadav, Ms. Ritika Negi
   Project Partners: NIH-Roorkee, MNIT-Jaipur, IIT-Bombay, IRMA-Anand

3. **Funding:** DST (GoI), Cost: Rs. 5.1 Crore

4. **Duration: Apr 2019-Mar 2024**

5. **Objectives of the study**

The project **'Innovation Centre for Eco-Prudent Wastewater Solutions (IC-EcoWS)'** is funded by Department of Science & Technology (DST), Government of India. The National Institute of Hydrology (NIH) Roorkee is the leading institute for implementation of this project, in collaboration with the project partners from Indian Institute of Technology Bombay (IITB), Malaviya National Institute of Technology (MNIT), Jaipur and Institute of Rural Management, Anand (IRMA). The objectives of the project are:

- **Objective 1**: Establishment of a state-of-art Centre for Eco-prudent Wastewater Solutions (IC-EcoWS) to harness the potential Natural Treatment Systems (NTS) and other eco-prudent resource recovery technologies for water security and sustainability in India,
- **Objective 2**: Development of a Decision Support Tool (DST) based on Life Cycle Assessment (LCA) and Multiple Criteria Decision Making (MCDM) approach for selection of appropriate "Technology Packages" for resource recovery oriented wastewater treatment infrastructure,
- **Objective 3**: Establishment of few pilot study sites ("Live Laboratories") for detailed assessment of selected NTS in urban, peri-urban and rural settings, for both secondary and tertiary treatment requirements as per new CPCB norms as well as for select emerging pollutants,
- **Objective 4**: To explore innovative ideas on the development (e.g. use of pre-fabricated structures, efficient structures for control of solid waste in sullage) and application (e.g. retrofitting of existing village ponds, drains, linkage to livelihood options) of NTS for wastewater treatment,
- **Objective 5**: To organize capacity building, awareness creation, documentation and dissemination activities, and preparation of a TOT Module on NTS applications and an Indian handbook for promotion and propagation of NTS for resource recovery and wastewater treatment in India.

6. Results achieved with progress/present status: The Progress of project at NIH is given below:

Milestones	Activities	Target Month	NIH-Progress
Hiring of Project staff	Hiring of project staff	M6	Completed
Dev. of Centre Portal	Development of IC-EcoWS Centre Website and social media pages for information dissemination	M12	Completed
Organization of Users interactions Workshop	IC-EcoWS Project Inception Cum Need Assessment Workshop (8-9 August, 2019)	M12	Completed
	Report on First Annual Workshop- IC-EcoWS Project Inception Cum Need Assessment Workshop		
Establishment of Live Laboratories	Procurement of several technical and scientific lab equipment for setting up the IC-EcoWS Innovative Centre at NIH Roorkee	M18	Completed
	Establishment of horizontal sub-surface -flow constructed wetland for domestic wastewater treatment (Peri-urban residential area in Roorkee)		
	Installation of Online Monitoring System for water quality monitoring		
Development and Application of Innovative ideas on NTS	Pilot-scale natural treatment system (4 cell floating wetlands) for the treatment of domestic wastewater using identified plant species *Bacopa monnieri* and *Acorus calamus*	M24	Completed
	Treatment of domestic wastewater using floating treatment wetlands using *Phragmites australis,* and *Canna indica*	M30	Completed
	In-situ treatment of domestic wastewater in urban drain using floating constructed wetland/Bio-Inoculum-Solanipuram/Adarshnagar (Roorkee)	M36	Completed
	Pilot-scale demonstration unit for wastewater treatment of residential building using SSHF Constructed wetlands system at NIH Roorkee	M36	Completed
	Pilot-scale horizontal sub-surface-flow constructed wetland (HSSFCW) for Pesticide (chlorpyrifos) removal from synthetic wastewater using *Canna indica* in NIH Roorkee.	M49	Ongoing
	Lab-scale study to estimate biogas generation from *Canna indica* biomass collected from Subsurface Horizontal Flow Constructed wetlands system at NIH Roorkee	M52	Ongoing
	Performance evaluation of horizontal sub-surface-flow constructed wetland (HSSFCW) for the treatment of domestic wastewater at NIH Colony (Real-time Monitoring of Water quality parameters)	M55	Ongoing
Documentation and dissemination	Capacity building, awareness creation, and dissemination activities (Factsheets/policy briefs, reports on NTS)	M58	Ongoing