A Glimpse of Research & Development at NIH

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NATIONAL INSTITUTE OF HYDROLOGY
ROORKEE-247 667 INDIA
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PREFACE

National Institute of Hydrology (NIH) a premier Research and Development organization under the Ministry of Water Resources, River Development and Ganga Rejuvenation has been engaged in research activities in all aspects of hydrology. NIH is observing the 40^{th} Anniversary of its Foundation Day on 16^{th} December 2018. Over the last 40 years, the Institute has made many scientific contributions in the field of water sector. Hence, it has been decided to bring out a document on this auspicious occasion that contains abstracts of 40 selected studies completed by the Institute and abstracts of 40 selected research papers published by NIH scientists in reputed international journals. This document also contains a list of technical books authored by NIH scientists and a list of technical papers published in international and national journals in recent times.

The aim of this publication is to give a glimpse of the range of studies and publications contributed by the Institute over the years. The studies and papers included in this document have been selected after detailed consultations with various scientists. The key criteria in selecting studies and papers was to cover a wide range of topics and include papers from a large number of scientists presently in-service as well as those who are no longer in the institute. Of course, the recent studies are more in number to reflect the current focus and papers have been included on the basis of the impact factors of the journals and citations. All said and done, inclusion of a study or a paper in this document doesn't imply that this is amongst the best publications/studies from the Institute.

As water related problems of India are becoming more critical and important, new areas of research are being developed to provide innovative solutions. Keeping this in view, NIH is attempting to align its technical work so as to provide solution of existing and emerging problems. In the time to come, the studies that will be taken up by the Institute with an eye to three Ps: these should lead to solutions of Practical problems, should result in development of new Products, and should contribute to Policy development.

I am delighted to compliment scientists and other staff of the Institute who are doing excellent work. I am sure that in future, NIH would be able to complete even better studies by employing advanced technologies and would meet the expectations of its founders and the country.

(Sharad K. Jain)
Director

ACHIEVEMENTS AT A GLANCE

Publications	
International Journal	**877**
National Journal	**671**
International Conference	**1070**
National Conference	**1542**
Technical Studies	**980**
Consultancy Projects	**164**
Sponsored Projects	**33**
Training Courses organized	**460**
No. of Participants	**More than 9000**
National Seminar/Symposia/Conferences organized	**110**
International Seminar/Symposia/Conferences organized	**13**
M. Tech. thesis guidance	**358**
Ph.D. thesis guidance	**23**
Books authored	**17**

Major International Collaborations:

UNDP, WORLD BANK, UNESCO, EUROPEAN UNION, USAID, IHE, Netherlands, DHI, HEC, BGS-DFID, IAEA, ICIMOD, UNFAO, IWMI, CEH (UK) & CSIRO.

National Collaborations:

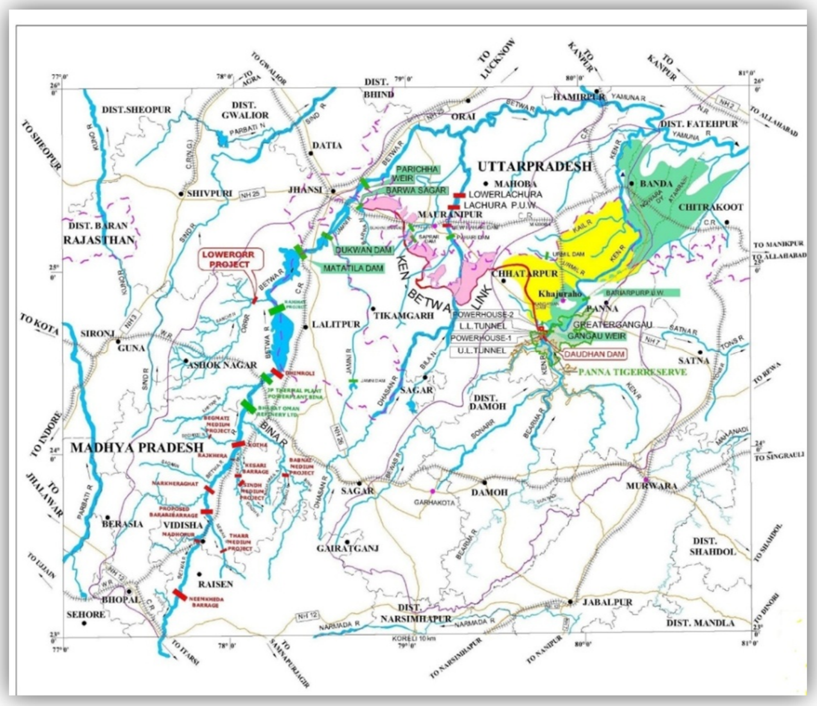
MoWR,RD & GR, CWC, CGWB, CWPRS, NWA, NWDA, WAPCOS, MoA, DST, DoLR, MoEF&CC, MoES, NGOs, PSUs, CPCB, Universities & Institutes, BARC, NRSC, IIRS, SAC, IISc., IITs, NITs, NGT and State Governments.

NIH Staff Strength **... Sanctioned total: 247; Group A 83**
... In position: 203; Group A 74

Abstracts of forty representative studies

1. Hydrological and Multi-reservoir Simulation Studies for DPR of Ken – Betwa Link

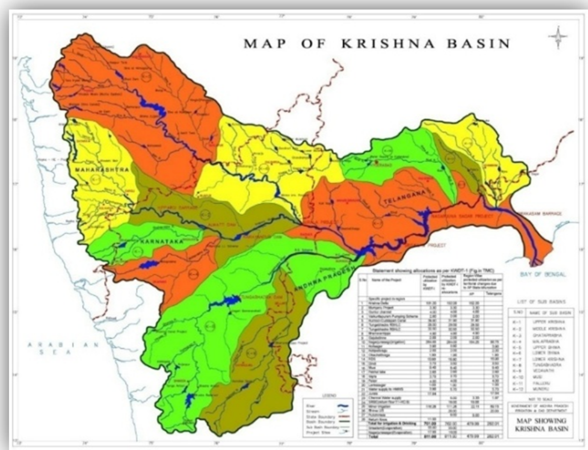
Ken-Betwa link project envisages diversion of water from the Ken River basin to Betwa River basin after meeting all the projected in-basin requirements in ultimate stage of development. Out of 1074 Mm^3 of planned diversion, after enroute utilization, 659 Mm^3 is expected to be transferred to Betwa River upstream of existing Parichha weir. Equal quantity of water is proposed to be saved in Upper Betwa basin for utilization through projects in M.P. The DPR of Ken-Betwa link project was completed in December, 2008. Subsequently, NWDA has taken up Survey & Investigation studies for ten proposed projects in Upper Betwa basin, namely Tharr, Babnai, and Lower Orr dams, and Kesari, Neemkheda, Barari, Narkheraghat, Bijrotha and Kotha barrages. As part of the aforesaid work, consultancy work for carrying out Hydrological Studies and Multi-Reservoir Simulation Studies for preparation of DPR of Ken-Betwa Link Project (Phase-II) was assigned to NIH, Roorkee. The hydrological studies for the proposed Ken-Betwa Link project was carried out in two stages. In the first stage, studies for water yield and balance, design and diversion floods, sedimentation, and reservoir simulation studies were carried out for the Ken River basin. In the second stage, studies dealing with water balance and design flood for four proposed projects in the Upper Betwa basin, hydrodynamic modeling and other studies were carried out.



For the ten proposed projects, the scope of present work included estimation of water yield, estimation of their design and diversion flood, estimation of sedimentation rate and revised elevation-area-capacity curves of storage structures, and simulation studies including multi-reservoir operation aspects. In addition, the task included dam-break analysis and back water influence studies for Lower Orr project and the multi-reservoir simulation of Ken-Betwa system. All these analyses were carried out and results were provided to NWDA and were used in preparation of DPR.

2. Project-wise Water Availability and Integrated Operation Analysis in Krishna Basin

The Krishna is the second largest river in Peninsular India. The river flows through Maharashtra, Karnataka, Andhra Pradesh and Telangana states gathering water on its way from innumerable rivers, and drops into the Bay of Bengal. Disputes among the riparian states namely, Maharashtra, Karnataka, and Andhra Pradesh had arisen earlier and a Tribunal namely, Bachawat Tribunal or Krishna Water Disputes Tribunal (KWDT-1) was constituted for adjudication of the disputes. KWDT-1 had gaven its decision in December 1973 and further report in May 1976. Based on grievances of riparian states, Central Government constituted KWDT-2 which rendered its decision in November, 2013. Subsequently, state of A.P. was bifurcated into Andhra Pradesh and Telangana and the term of KWDT-2 was extended with following terms of reference: a) KWDT-2 shall make project-wise specific allocation and b) KWDT shall determine an operational protocol for project-wise release of water in the event of deficit flows.



The Inter State and Water Resources (ISWR), Govt. of Andhra Pradesh requested NIH to carry out integrated water availability and operation analysis studies for the Krishna Basin. In this study, detailed water availability analysis for the projects having more than 3 TMC of water allocation at average, 65%, 75%, and 90% dependabilities in the ultimate stage of basin development was carried out. Further, integrated operation analysis of the whole system of 82 major reservoirs (having more than 3 TMC water allocations) under different scenarios of water availability was carried out using different policies of operation.

An exhaustive analysis was carried out for all aspects of the projects. A comprehensive MS-Excel workbook was developed for detailed analysis for water availability, as per the need of study. The workbook automates the procedure to a considerable extent. For the operation analysis, a computer program developed at NIH for integrated operation of a multi-purpose multi-reservoir system was modified to incorporate KWDT guidelines. Integrated operation of the major projects in the Krishna basin was simulated through two policies of system operation, i.e. standard linear operation policy and integrated operation policy for operation of the system under normal and deficit conditions.

The results indicate that integrated operation policy results in more rational operation of the system as it tries to distribute the deficit among different states such that their long-term annual utilization (especially in deficit years) is realized in close range to the specified percent utilization in normal conditions.

3. Mitigation and Remedy of Groundwater Arsenic Menace in India: A Vision Document

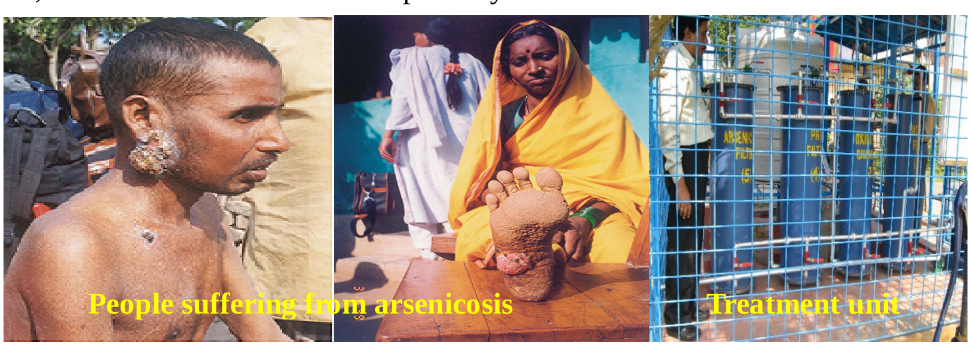
Occurrence of Arsenic (As) in groundwater in excess to the permissible limit of 50 μg/L (later revised to 10μg/L by BIS) in the Ganges-Brahmaputra fluvial plains in India covering seven states namely, West Bengal, Jharkhand, Bihar, Uttar Pradesh, Assam, Manipur, Chhattisgarh has emerged as a major threat. Numerous investigations have come out with number of findings, and alternatives propositions, which varied from identification of shortfalls to success stories. Although the exact sources and mobilization processes of such large scale occurrence of arsenic in groundwater are yet to be established, the cause is understood to be of geogenic origin. Release from soil under conditions conducive to dissolution of arsenic from solid phase on soil grains to liquid phase in water and percolation of fertilizer residues may have played a role in its further exaggeration.

Over the last 25 years since the groundwater arsenic contamination first surfaced in the year 1983, a number of restorative and substituting measures coupled with action plans focusing mainly towards detailed investigations to understand the physio-chemical process and mechanism, alternate arrangement to supply arsenic free water to the affected population, and development of devices for arsenic removal and their implementation at the field, etc. have been initiated, mainly in West Bengal. Despite number of corrective and precautionary measures, the spread of arsenic contamination in groundwater continued to grow and more new areas were added to the list of contaminated area. The problem resolving issues, thus, seemed to be partial and inadequate, which need to be strengthened by strategic scientific backing.

A vision document titled “Mitigation and Remedy of Groundwater Arsenic Menace in India” was prepared in year 2008 mainly focusing on: (i) up to date status of arsenic menace in India, (ii) state-of-the-art of scientific knowledge for cause of occurrence of arsenic, (iii) technologies available and applied for treatment of arsenic contaminated water, (iv) preventive and corrective measures taken so far and results thereof, (v) shortcomings, and possibility of employing success stories of one place to another region, (vi) further work to be undertaken, (vii) roadmap to achieve the targeted milestones, (viii) framework of activities to be taken up, etc.

The document illustrated the knowledgebase, understanding, status, technologies available followed by a critical appraisal. It also elaborated further work required for achieving sustainable solution for arsenic menace, roadmap to achieve those along with an envisaged ‘Plan of Actions’. A number of resource persons from all over the country have contributed in preparation of this document.

Based on the recommendations of this document, a dialogue initiation meet with the stakeholders was organized in year 2011 that was followed by constitution of ‘Core Committee’ by MoWR, RD & GR in year 2013. The ‘Committee on Estimates’ of 16th Lok Sabha took cognizance of this document and after consultative meetings on this matter, directed Government of India for deriving plan of action for arsenic mitigation. With the directive from the ’Group of Officers (GOO)’ of the Cabinet Secretariat, an ‘Inter-Ministerial Group (IMG)’ under the Chairmanship of Additional Secretary (WR, RD & GR) & Mission Director was constituted, and IMG had submitted its report in year 2016.



People suffering from arsenicosis Treatment unit

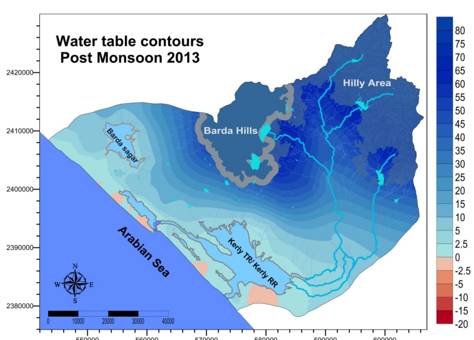
4. Coastal Groundwater Dynamics and Management in the Saurashtra Region, Gujarat

For the coastal communities of the drought prone Saurashtra region of Gujarat, groundwater is a major source of water supply. Due to proximity of the area to the Arabian Sea, almost the entire groundwater system along the coast of Saurashtra is affected by salinization; this adversely impacts the soil structure, crop yields, industrial growth and the source of drinking water supply of the region.

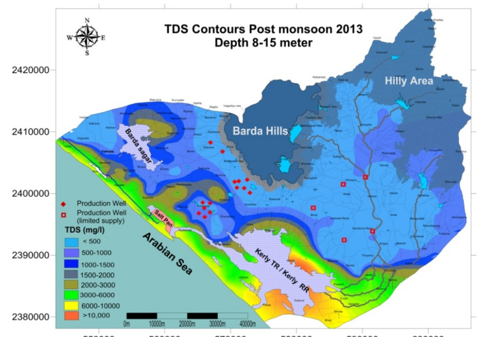
To investigate the coastal groundwater dynamics and the management strategies to protect and conserve the coastal aquifer system in the Saurashtra region, this study was initiated by NIH in collaboration with Gujarat Water Resources Development Corporation Ltd., Gandhinagar under the Hydrology Project Phase-II. The study focused on the Minsar river basin as the pilot basin. The work was accomplished through in-depth hydrogeologic field investigations, water quality and stable isotope analyses, numerical modeling of coastal aquifer system, water management aspects, and socio economic surveys to ascertain impact of groundwater salinity on coastal communities.

Investigations based on litholog and water level data revealed that Miliolitic limestone forms the potential aquifer system in the coastal belt. In the upland areas, the weathered zone of the Deccan Trap forms a good aquifer. Beyond a distance of 18 km from the coast, the groundwater is generally fresh. Further landward movement of salinity is curtailed by the strong seaward hydraulic gradient in the upland area. Several factors contribute to groundwater salinity in the Minsar basin. Gaj beds of Miocene age which were formed in marine environment, have contributed to groundwater salinity. Upconing of underlying saltwater due to groundwater pumpage for irrigation enhances the groundwater salinity for limited time periods. Close to the coast, seawater ingress in some pockets has given rise to elevated levels of salinity. In addition, high waves breaking along the seashore throw up a considerable amount of sea water in the form of spray, which is deposited on the coastal land surface and plants and adds to soil salinity.

Chemical analyses of water samples indicated the presence of ion exchange phenomena in the transition (mixing) zone of the freshwater-saltwater interface. Stable isotope investigations revealed that the zone of transition extends upto approx. 15 m ± 3 m altitude. Due to conservation measures taken by the Govt. of Gujarat over the last two decades, such as the construction of bandharas at the mouth of creeks, spreading channel laid parallel to the coast, construction of checkdams, and shelterbelt plantations, relatively more freshwater is available for crop cultivation, compared to previous decades. As an outcome of the study, a report on "Problems of Salination of Land in Coastal Areas of India and Suitable Protection Measures" was prepared by CWC and NIH which provides comprehensive information about coastal conditions, salinity and remedial measures already taken / to be taken in different coastal states and Union Territories of India.



Water table contours for post monsoon 2013 (red color indicates areas where water table is below mean sea level)



Contours indicating groundwater salinity during post monsoon 2013 (at depths 8-15 m below ground surface)

5. **Hydrodynamic Modelling of River Vishwamitri for Preparation of Flood Mitigation Plan for Vadodara City**

The present study deals with the preparation of flood mitigation plan for Vadodra city. Daily rainfall and flow data available at Pilol have been used to calibrate and validate the MIKE-NAM rainfall-runoff model. The model parameters are extended for the sub-catchments of Surya and Vishwamitri river for developing the rainfall-runoff relationships. River flow model for Vishwamitri river has been developed using MIKE-FLOOD. Altogether, 905 river cross-sections i.e. 336 in Surya and 569 in Vishwamitri have been considered in the hydrodynamic modelling. Also, 32 bridges; 10 in Surya and 22 in Vishwamitri river courses have been included in the model. The surveyed river-cross sections and contour maps have been used for developing the 1D and 2D flow model for the river reach. Design floods at Surya, Bhaniyara and Vadodara have been routed in the flow model and design flood for Vishwamitri river at Kalagoda gauging site has been estimated. No significant shifting in the river course within the study reach has been observed during the period of 2000 to 2015.

Flood moderation through channel improvement with and without embankments was studied. With embankments of 2 m, 3 m and 4 m height on both the banks of the river within city limit above NGL, the safe carrying capacity of river increases to 985 m^3/s, 1,160 m^3/s and 1,380 m^3/s, respectively. The channel improvement through the proposed modified channel section, in which for low flow, natural and existing channel profile is recommended; while for higher flow, the section is modified and proposed to be constructed using brick masonry. Channel improvement with 2 m embankment is adequate to safely pass the design flood.

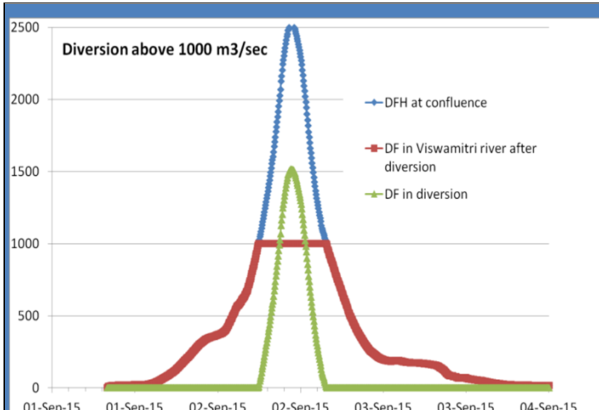


Fig: Effect of diversion of flood at Kalagoda

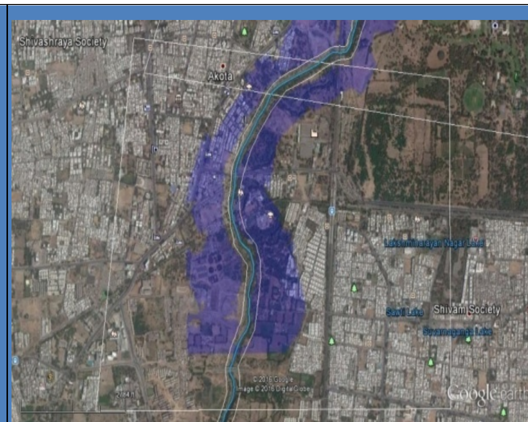
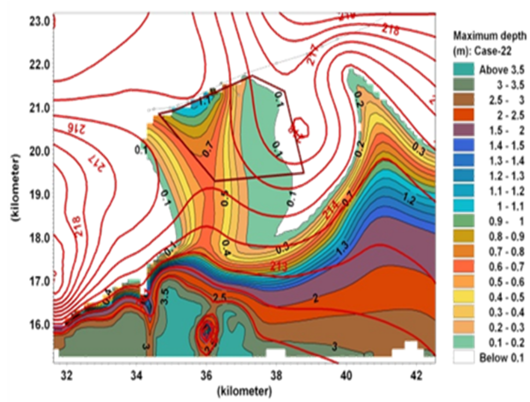


Fig: Flood Inundation map for river reach

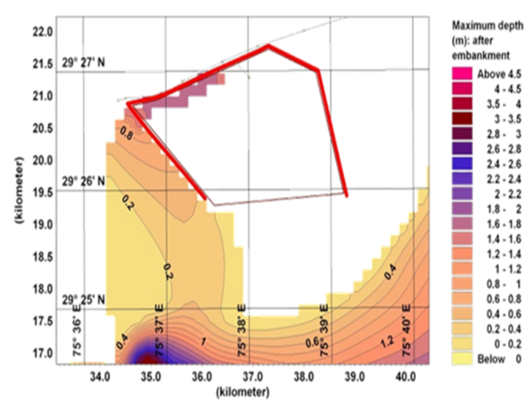
Five different methods of flood moderation alternatives in Vishwamitri river near Vadodara township were identified: (i) flood moderation through construction of embankments, (ii) flood management using existing reservoir, (iii) flood diversion, (iv) rainwater harvesting to moderate the peak discharge and (v) flood moderation through channel improvement. Flood moderation through channel improvement shows significant reduction in flood in the reach of the river Vishwamitri. The outcome of the study is being used by Vadodara Municipal Corporation for river front development and flood management plan for Vishwamitri river in the Vadodara city area.

6. Estimation of design basis flood and safe grade elevation for nuclear power project at Gorakhpur in Haryana

In this study, the maximum expected floods under various scenarios have been estimated and their routing to the proposed nuclear power plant site at Gorakhpur village in Haryana has been carried out for estimating the maximum flood level. The digital elevation model (DEM) has been prepared from the spot levels and contours extracted from topographical maps. The rainfall data and Probable Maximum Precipitation (PMP) have been obtained from India Meteorological Department. The 24 hour and 48 hour rainfall frequency analysis has been performed using L-moments to estimate the rainfall of various return periods. The synthetic unit hydrograph has been derived from catchment characteristics of the study area and flood hydrographs of various return periods have been computed.



Flood inundated area



Flood protection measure

Estimates of maximum flood have also been made by various other approaches including 'L-moments' based regional flood frequency analysis for ungauged catchments. The floods computed by various methods have been compared to derive the most severe floods of various return periods. The Probable Maximum Flood (PMF) has been computed from the PMP. The failure of Bhakra dam has been simulated using MIKE-11 package and the flooding effect on plant site has been evaluated.

The various sources of flooding at the plant site have been identified which include local rainfall, catchment floods routed to plant site and flooding due to breaching of Fatehabd Branch Canal and Bhakra Main Line. A coupled 1-D & 2-D flow analysis has been performed using the MIKE-FLOOD package. Flow in canals and the catchment drainage have been modeled in MIKE-11. Spills from canal and catchment drainage and local rainfall have been simulated in MIKE-21. The locations of canal breaching have been identified and simulated to study the flooding effect on plant site.

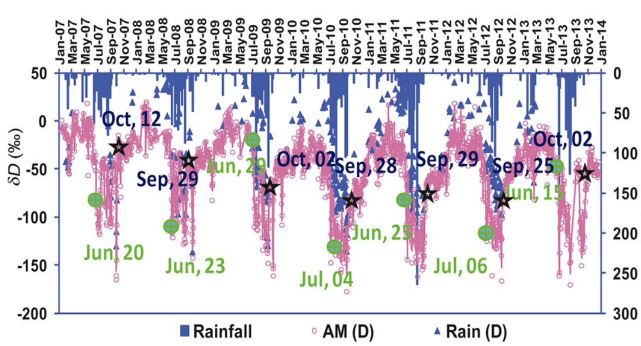
The various scenario of flooding have been considered and inundation depths and flood levels have been computed. The maximum flood level has been estimated for the plant site and considering the recommended freeboard, the safe grade elevation at the plant site has been computed. The additional flood protection measures have also been suggested. The estimated design flood and suggested safety measures for flood protection are being used in design and construction of the nuclear power project.

7. National Programme on Isotope Fingerprinting of Waters of India (IWIN)

A DST sponsored National Programme on Isotope Fingerprinting of Waters of India (IWIN) was carried out during 2007-2012. This program was initiated by PRL; NIH was one of the Coordinators. Other collaborators were: BARC, NRL, ICAR, CGWB, CWC, CPCB, IMD, NIO, Anna University, NGRI, CRIDA, and IIT, Kharagpur. Water samples from different sources like precipitation, groundwater, rivers, oceans and air moisture were collected and isotopic signatures of these sources were studied to understand the regional/local water vapour component in the local atmosphere, partitioning of water vapours into rain and re-partitioning of rain into various components as evapotranspiration, soil moisture, stream flow and groundwater, and residence time of vapours/water in different inland hydrological units. NIH collected precipitation, river, groundwater and water vapour samples and analysed isotopes (^{3}H, δ^{18}O, and δD) of samples. NIH contributed significantly in estimating the contribution of precipitation, snow and glacial melt to mountainous river like Bhagirathi/Ganga, developing several local and regional meteoric water lines.

A total of 9800 samples of air moisture, groundwater, Upper Ganga Canal (UGC) and precipitation were collected by NIH. Hydrogen (^{2}H/^{1}H) and oxygen (^{18}O/^{16}O) isotopic ratios were measured in precipitation samples collected from several locations in India. The meteoric water line developed for India by using isotopic data of precipitation samples, $\delta^2H = 7.93\ (\pm0.06) \times \delta^{18}O + 9.94(\pm0.51)$ ($n = 272$, $r^2 = 0.98$), differs slightly from the global meteoric water line. Regional meteoric water lines were also developed and were found to be different from each other due to differences in geographic and meteorological conditions. The altitude effect in the isotopic composition of precipitation for western Himalayan region also varies from month to month.

NIH monitored the onset and withdrawal of the SW monsoon during 2007-2013 by using the isotopic composition (δ^{18}O, and δD) of ground level vapours (GLV) at Roorkee. It was found that the isotopic of GLV depletes suddenly on the arrival of monsoon vapours and persistently almost 3–16 days before the first monsoon rainfall. This indicates that the vapour sources arrive before the visibility of clouds and provides the information of onset of monsoon. A new insight was developed that the isotopic signatures of air moisture/water vapours can be used to predict the arrival and withdrawal of monsoon at any place and this technique can predict the arrival of monsoon from 10 to 15 days in advance then the present technique. Monsoon vapours continue to arrive in the atmosphere even after stopping of rainfall for 4–30 days, which is clear from the difference in dates of onset and withdrawal of the SW monsoon with the depletion and enrichment in the isotopic composition of GLV (Figure). It was also observed from the back trajectory analysis of respective vapour samples over Roorkee that three major sources, viz. local vapor, western disturbance and monsoon vapour are controlling the fate of moisture over Roorkee. The d-excess in ground-level vapour (GLV) reveals the supply of recycled moisture from continental water bodies and evapo-transpiration as additional moisture sources to the study area. The intensive depletion in isotopic ratios was associated with the large scale convective activity and low-pressure/cyclonic/depression systems formed over Bay of Bengal.

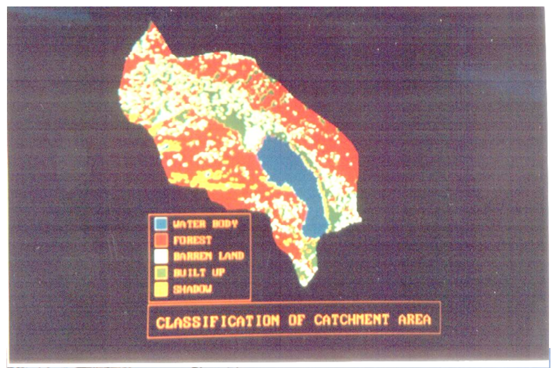


8. Integrated Hydrological Studies of Lake Nainital, Kumaun Himalayas, Uttarakhand Using Conventional and Isotope Techniques

Lake Nainital, located in Kumaun region, Uttarakhand, is a major drinking water source to the people living in and around the lake basin and a major tourist attraction. The lake condition has been deteriorated during the past few decades due to high rate of sedimentation and pollution. No systematic hydrological study was carried out in the past to understand the water balance components, sedimentation rate, and hydro-chemical characteristics. NIH carried out a comprehensive hydrological study of this lake during 1994-1996 under a project sponsored by UP State Dept. of Environment and again during 2001-2002 under a project sponsored by the then Ministry of Environment and Forest, GOI, to IIT, Roorkee. Recently, the lake is facing an acute water availability problem, mainly due to increased consumption of lake water. NIH was again requested (in 2017-18) by the Uttarakhand Govt. to investigate the reasons behind the decreasing water availability in lake Nainital.

The sub-surface inflow and outflow components were computed by integrating environmental isotope data with conventional hydrological data. The results indicated that the groundwater contributes about 50% of the total annual inflow to the lake. The sub-surface outflow is about 55% of the total annual outflow from the lake. Water retention time - WRT (volume/outflow) computed for the lake by isotopic mass balance, chloride mass balance and conventional water balance methods is about 1.93y, 1.77y and 1.92 y respectively. Isotopic analysis showed that the effect of evaporation in the lake is not manifested in its isotope characteristics.

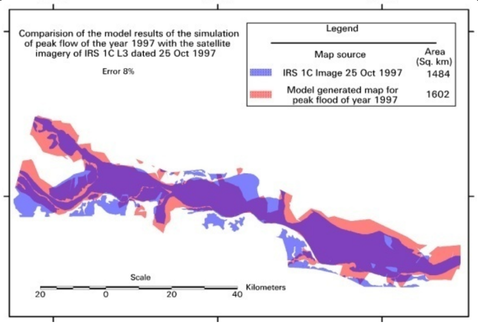
The estimated sedimentation rate obtained by ^{210}Pb varies from 0.48 cm/y to 1.24 cm/y; In case of ^{137}Cs, it varies between 0.60 cm/y and 1.35 cm/y; and it is 0.75 cm/y by radiometric dating methods. The estimated useful life of the lake is around 2200 years [2160±80 years (^{137}Cs) or 2480±310 years (^{210}Pb)]; this is much higher than the estimates by earlier investigators using short-term bathymetric data.



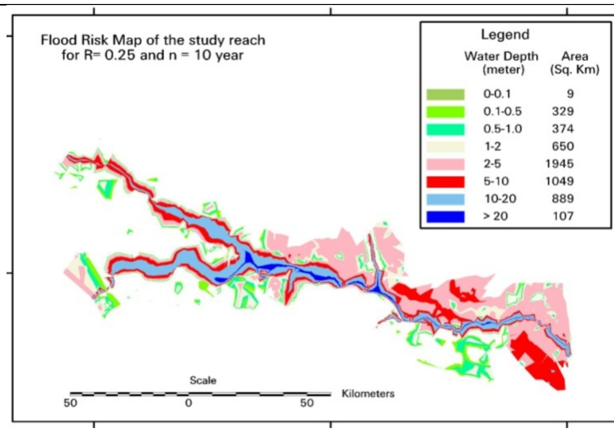
Investigations using isotopic and chemical approaches revealed that out of 14 springs that are located in Balia ravines, only 8 have hydraulic connection with the lake. The water quality studies include the analyses of major ions, namely calcium, magnesium, sodium, potassium, bicarbonate, sulphate, and chloride, in addition to the in-situ measurements of physico-chemical parameters such as temperature, pH and electrical conductivity were carried out for lake Nainital and its surroundings. Recommendations made to reduce the sedimentation rate and improving water quality of the lake were: a) Construct 0.5 m high wall at the entry points of the drains to restrict the entry of the sediments and waste into the lake. A circumferential drain will keep away the non-monsoon flow to lake and will reduce the pollutant load, b) Draining out polluted water from the middle/deeper portions of the lake during stratification period by installing a suitable siphoning device at the Tallital to reduce the pollution level in the lake, c) Remove of deltas from the areas near entry points of the drains and removal of the sediments from the shallow portions of the lake, d) install suitable water circulation devices to increase the D.O. level at the deeper depths in Tallital and Mallital lakes, e) study the weak zones prone to landslides and take remedial measures, and f) take afforestation measures in the Nainital lake catchment and reduce construction activities to the minimum. These recommendations were found fruitful, funds were sanctioned and several measures were taken by Uttarakhand Govt. to improve the conditions of lake and its catchment.

9. Flood Hazard Mapping and flood risk zoning for a river reach (Ganga between Buxar and Rajendra bridge)

A river flow model is developed in HECRAS for the 250 km river stretch of Ganga between Buxar to Rajendra bridge (Mokama). The hydrological data and river cross section data are obtained from CWC while the SOI toposheets have been used to develop the digital elevation model (DEM) of the study area. The flow model includes the mainstem of Ganga river and its four tributaries namely; Sone and Punpun on its right bank and Ghaghara and Gandak on its left bank. Floods of various return periods have been estimated using the L-moments approach. Rating curves are developed employing the Artificial Neural Network and the least squares techniques. The flow model is calibrated and validated for the maximum flood of the year 1997, 1998 and 2000 routed in HEC RAS model and the computed flood inundation maps are compared with inundation maps prepared from IRS satellite images for the corresponding periods. For 1997, error in inundation is computed as 8% while for the year 1998 and 2000 error of 6.9% and 9.35% are computed. Further, the inundation maps corresponding to various return periods viz. 2, 10, 20, 25, 50, 100, 200, 500 and 1000 years, have been developed. The water surface profiles along the main river and its tributaries have been computed.



Comparison of flooded area computed by HEC RAS model and observed by satellite imagery for the year 1997.

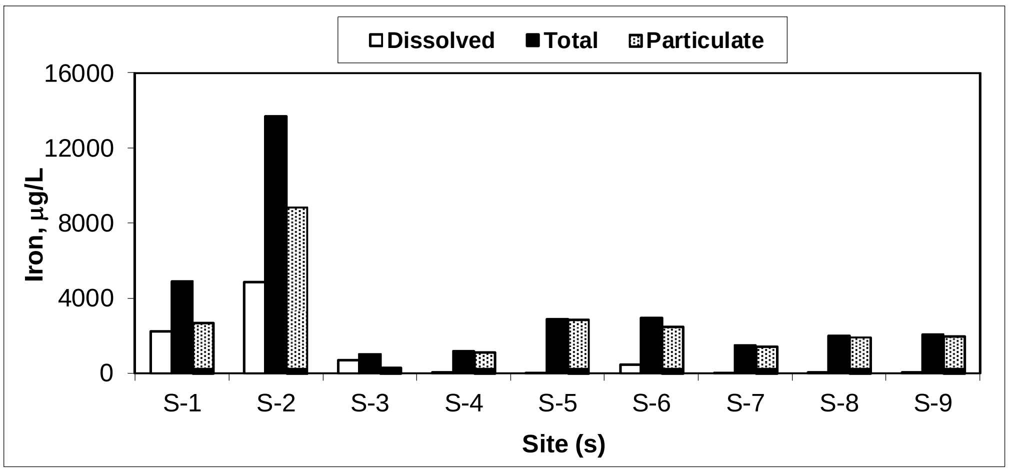


Flood risk zone map for a risk (R) of 25% over a period (n) of 25 years.

10. Metal Pollution Assessment through Aquatic Sediments: A Case Study of River Yamuna, 2002-03

The sediments existing at the bottom of water column play a major role in pollution scheme of the river systems. The presence of heavy metals in sediments is affected by the particle size and composition of sediments. The different fraction of sediment particle size gives different heavy metal concentrations in the same sediment samples. Therefore, analysis of sediments should be carried out with due consideration of the particle size of the sediment.

The water and sediment samples of river Yamuna were collected from nine sites from Delhi to Allahabad and analysed for heavy metals (Fe, Mn, Cu, Ni, Cr, Pb, Cd and Zn). The concentration of dissolved Fe, Mn and Cu exceed the drinking water limit at Okhla barrage. The concentration of dissolved Cr, Pb and Cd were within the prescribed limits. The variability of metal concentrations in the bed sediments was quite low as compared to the associated water column. The analysis of sediments of different size fractions indicates a general decreasing trend with increasing particle size.



Distribution of Iron at Different Sites

Metal concentrations in the bed sediments are positively correlated with organic matter content. Zinc, chromium, copper have correlation coefficient >0.7 indicating the strong affinity of these metals for organic fraction of the sediments. The general trend of relative mobility was observed to be Fe>Mn>Pb>Ni>Zn>Cr>Cu>Cd. The analysis of aqueous and sedimentary components clearly indicated that bed sediments provide a more stable base for contaminative studies and therefore an assessment of both the sedimentary and aqueous components should be undertaken to adequately characterize the aquatic environment.

The metal concentrations in different sediment size fractions showed a decreasing trend with increasing particle size. High correlation coefficients (>0.9) observed between Zn-Cr indicates their mutual dependence and identical behaviour during transport process. Metal concentrations in the bed sediments are positively correlated with organic matter content. Zinc, chromium and copper indicated strong affinity for organic fraction of the sediments. The general trend of relative mobility was observed to be Fe>Mn>Pb>Ni>Zn>Cr>Cu>Cd.

The results of the study clearly shows importance of sediment analysis for assessment of aquatic environment and help in identification of critical zones for formulation of their remediation plans.

11. Water conservation and management in Ibrahimpur Masahi village of Haridwar district (Uttarakhand)

Ponds are traditional means of water conservation and stored water is used for domestic & agricultural purposes. However, due to various reasons many ponds are dying-storage capacity is depleting & water quality is degrading. Hence, we need to rejuvenate the ponds by green and cheap technology so that the same can be replicated in large number of ponds at reasonable cost. This study was undertaken in Ibrahimpur Masahi village (District: Haridwar, Uttarakhand). The study area is about 14.26 km^2. Apart from water budgeting, rejuvenation of a severely degraded village pond (viz. de-weeding, de-silting/sludge removal, and establishment of Natural Treatment System-NTS) was carried out in consultation with concerned Gram Panchayat. Actions needed to be taken in the village to reduced water deficits include: (a) Change of flood irrigation system to drip irrigation to reduced the crop water requirement (50%), (b) Collection of runoff from village and creation of ponds in the vicinity aimed to enhance groundwater recharge, (c) Implementation of roof-top rainwater harvesting system to conserve rain water, (d) Implementation of natural wastewater treatment system for gainful recycling and reuse.

The water quality of the pond was also assessed before and after rejuvenation works. The key results are given below, which indicate good improvement in the water quality of this pond.

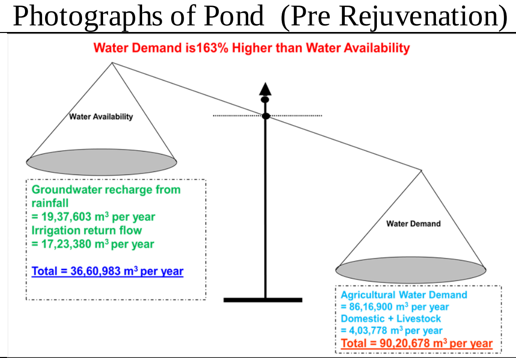
Key water quality parameters of pond (before & after rejuvenation, 2017-18)

Parameters	Before	After
pH	7.37	7.71
Turbidity (NTU)	48	43.1
Alkalinity (mg/l)	578	276
NO_3 (mg/l)	10.2	0.98
PO_4 (mg/l)	8.46	0
DO (mg/l)	0.25	5.5
FC (MPN/100 ml)	240	150

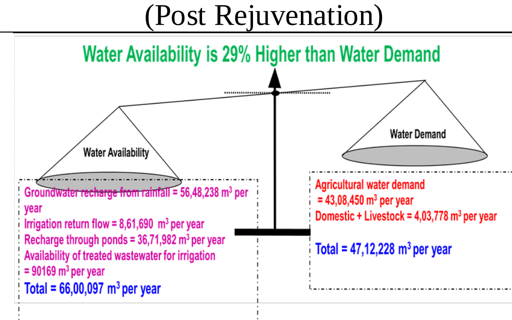
&

Photographs of Pond (Pre Rejuvenation)

(Post Rejuvenation)



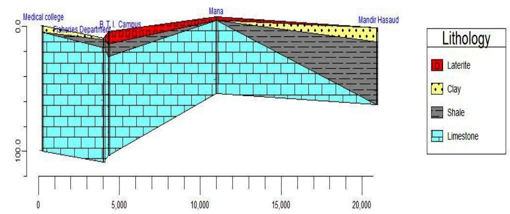
Water Budget of Ibrahimpur Masahi Village (As per Existing Practices)



Water Budget of Ibrahimpur Masahi Village (As per Suggested Practices)

12. SAPH PANI-Enhancement of natural water systems and treatment methods for safe and sustainable water supply in India (2011-2014)

Saph Pani was an European Union funded collaborative R & D project that involved a consortium of 20 partners from India, EU, Switzerland, Sri Lanka and Australia with total project cost of 47,81,225 € for a duration of 36 months. The project was aimed to study and improve natural water treatment systems such as riverbank filtration (RBF), managed aquifer recharge (MAR) and wetlands in India particularly in water stressed urban and peri-urban areas in different parts of the Indian sub-continent.



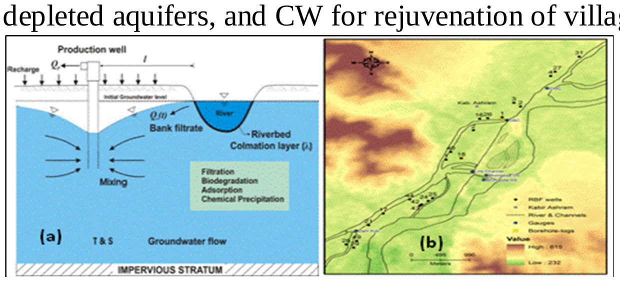
The objectives were to: (i) strengthen the scientific understanding of the performance-determining processes occurring in the root, soil and aquifer zones; (ii) study removal and fate of important water quality parameters such as pathogenic micro organisms and faecal indicators, organic chemicals, nutrients and metals; (iii) investigate the hydrologic characteristics and the eco-system functions; (iv) improve water resources management strategies; and (v) evaluate the socio-economic value of natural water treatment, taking into account long-term sustainability and comprehensive system risk management.

NIH was involved for study of RBF exclusively in Haridwar and in some other parts of Uttarakhand, and MAR in Raipur including modeling studies of both the systems. In addition, NIH had also the lead role in capacity building program including dissemination activities.

In Haridwar, 22 large diameter (10 m) bottom-entry caisson wells, 7 to 10 m deep, located along the right bank of the river Ganga at varying distances (10 m - 295 m) in the vicinity of the river and the upper Ganga canal (UGC) have been providing more than 50% (> 64,000 m^3/day) of drinking water requirement of the city. Performances of these 22 RBF wells were evaluated using the data gathered from extensive sampling campaigns and laboratory analysis of samples. Numerical modeling of river-aquifer-canal and well field interactions was also carried out by developing process based model and also by using Visual MODFLOW software.

In Raipur two sites were studied for identifying feasibility of MAR to augment groundwater resources. A comprehensive study comprising: extensive data collection, rigorous analysis of data for determining statistical values, trends, probability analysis, developing thematic maps, hydraulic parameters, relationships between variables, geological formations, concentration of lake water quality, surface runoff, evaporation rate, groundwater recharge, etc was carried out.

As a policy outcome of the project, a Handbook titled “Natural Water Treatment Systems for Safe and Sustainable Water Supply in the Indian Context” has been published by IWA. By working in the consortium of varied expertise, NIH has enhanced its understanding and expertise on three technologies, RBF, MAR and Constructed Wetland (CW) and promoting RBF for sustainable drinking water supply, MAR for augmentation of groundwater in depleted aquifers, and CW for rejuvenation of village ponds in the country.

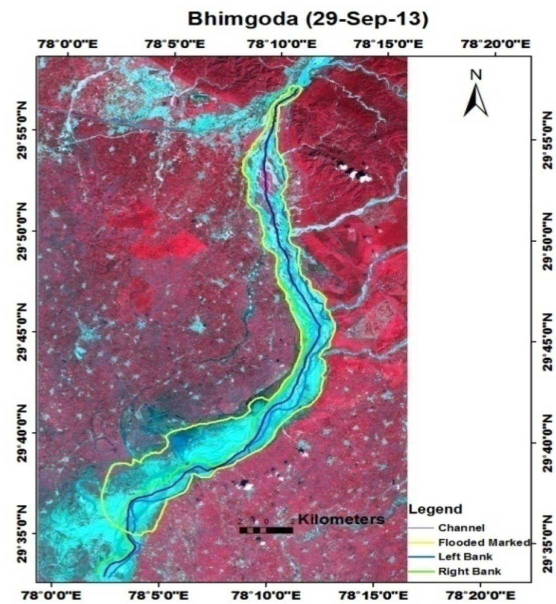


Lithological profile under- neath the Raipur city area and below the study sites.

RBF scheme at Haridwar (a) RBF processes and mechanism, and (b) distribution of 22 RBF wells in the vicinity of the Ganga and UGC at Haridwar

13. Flood zoning / mapping for River Bhagirathi at Uttarkashi and River Ganga from Haridwar to Laksar

The present study has been undertaken for determination of flood inundation for the two study areas: (i) Gangotri to Bathedi chungi, 10 km length of river Bhagirathi and (ii) Haridwar to Laksar, 50 km length of river Ganga falling within Uttarakhand. HEC-RAS software has been used for flood inundation modelling. Geometric input data for HEC-RAS models were created using HEC-GeoRAS software. In addition to modelling, flood mapping has been carried out using the satellite data. The flood inundation maps of study area have been prepared for the flow value corresponding to return period of 5, 10, 25, 30, 50 and 100 years. The value corresponding to 25 years return period is 11654 m^3/s for Haridwar stretch. The flow value corresponding to the flood of 2013 (June) was 11541 m^3/s. The value corresponding to 25 year return period flood and June 2013 flood are very close. Hence it can be seen that the post flood map of 2013 prepared from satellite data represents the map corresponding to 25 years return period flood. The flood map obtained in this study is matching more or less with the flood map produced using satellite data.



The area under river and flood inundated area comes out to be 124.98 km^2 and out of this total flood area comes out to be 59.42 km^2 corresponding to the 25 years return period flood. It was found that on both the banks, no built up land is inundated, and only some agriculture land is submerged.

The flood values corresponding to 5, 10, 25, 30, 50 and 100 years return periods for Maneri and Gangotri sites have been computed. The flood values corresponding to 25 years return period have been taken as 979.75 m^3/s and 1045.32 m^3/s. As per available discharge data, the highest value of discharge is 1241 m^3/s on 17th June, 2013 at Maneri site. This discharge value was transferred to Gangotri site and it comes out to be 1396 m^3/s. Flood inundation mapping was carried out for 1396 m^3/s and also corresponding to 5, 10, 25, 30, 50 and 100 years return period flood values. For this flood value, it is observed that the flood is not submerging any area on both the banks.

The results have been utilized for demarcation of likely inundated areas in the field.

14. Hydrological Studies in a Forested Watershed - A Case Study on Natural Regeneration of Sal Forest in Uttarakhand

Hydrological and micro-environmental parameters, viz., soil moisture, light intensity, and soil erosion are important factors that affect the natural regeneration in forests. These factors vary spatially depending on the overhead cover density of the forest. The present study was carried out in collaboration with Department of Forests, Govt. of Uttarakhand to study the effect of variation of soil moisture, light intensity and soil erosion on natural regeneration of Sal species (*Shorea robusta*) under different micro-environments due to overhead cover of varying forest density. Experimental plots of 40m×40m size were laid under different overhead cover densities in a small Sal forested watershed in the foothills of Himalayas in Nainital District of Uttarakhand State, India. The plots were monitored on a long term basis for soil moisture at multi- depths, light intensity and natural regeneration of sal. Rainfall, runoff, and sediment yield were measured at the watershed outlet using ANSWERS, a distributed parameter, event based hydrologic simulation model.

Results of the study revealed that the natural regeneration was highest under the canopy density C1 followed by canopy density C2, and C3 covers. The C3 cover showed the dying back of sal shoots over 4 years of study. The monthly average soil moisture was found to be highest at 100 cm depth under C3 cover followed by that under C2 and C1 covers. The computed correlation values between incremental score of plot regeneration and annual average light intensity indicated that the regeneration is largely dependent on the light intensity conditions during the year. The multiple linear regression analysis between the incremental score of regeneration and the average light intensity and average soil moisture content revealed that about 80% of variation in regeneration is explained by both the factors. Analysis of rainfall-runoff data revealed that the runoff from the watershed varied from about 5 to 15% of the event rainfall depending on the rainfall intensity. An analysis of spatial soil erosion under different cover densities did not indicate adverse effect of erosion on the regeneration.

The results of the study indicated that the soil moisture and light intensity are crucial parameters for management of natural regeneration in Sal forests. These results are useful in formulating the forest management plans that incorporate the practices to ensure adequate soil moisture and light penetration. Ensuring adequate regeneration and sustained productivity is a vital part of any scientific forestry system.

15. Hydrological study for rural drinking water supply options in a part of Bundelkhand region of Uttar Pradesh

The availability of groundwater in Bundelkhand region is limited to the weathered rock mantle only. Therefore, this region is unable to sustain drinking water supply especially in summer months. The sustained rural drinking water in the region has emerged as one of the challenging issues. The State Water & Sanitation Mission (SWSM), Department of Rural Development, Government of Uttar Pradesh entrusted this study to NIH, Roorkee.

The primary aim of this study was to carry out hydrological analysis in respect of water availability, location specific demands, measurement of shortage and to suggest suitable options for augmenting rural drinking water supply in the selected study sites in the Paisuni River basin in Chitrakoot district and Shahjad River basin in Lalitpur District. The study includes the analysis of rainfall departures with respect to mean and probability distribution of annual rainfall, estimation of ground water recharge, development of rainfall-runoff relationships, measurement of drinking water demands and identification of feasible source of water supply for the selected study sites. The analysis of long term rainfall records for the study sites indicates that the average frequency of drought in the region is once in five years. It is found that the magnitude of rainfall deficiency often recorded up to - 50% in the severe drought years. The ground water recharge in various parts of the study sites has been estimated and the rainfall – runoff relationships for study basin have been obtained using an auto calibration MIKE –11 NAM Model to estimate the specific runoff in different topography conditions. The ground water outlook maps, existing surface water resources and the location specific surface surplus potential in the study sites are considered as the key elements in deciding the development of possible source for water supply.

The villages located in various parts of the study sites have been grouped into clusters considering topographic feature, surface water and ground water availability and magnitude of water demand. The upstream regions of both the river basins have poor ground water potential and short-lived flow characteristics. Therefore, the provisions for monsoon surplus storages for these regions are essential to meet the demand. However, in the areas of flood plains with good groundwater potential, the option of groundwater pumping has been preferred. The direct intake schemes from river sections are proposed for regions along the constant river course.

A detailed plan of augmenting drinking water supply has been prepared for various clusters of the villages depending on topographic features, type of water availability sources and magnitude of water demand. The detailed maps of water supply options for various clusters of villages have been prepared and presented in the report. The proposed plan would be helpful in achieving the goal of assured drinking water supply for the study area.

16. Hydraulic Modelling for Brahmaputra Riverfront Development Project for Guwahati

Design flood for Brahmaputra river at Pandu GD site for 100 year return period has been estimated as 74,766 m^3/s using L-moments based flood frequency analysis. For development of river flow model, the surveyed river cross sections have been used at an interval of 0.5 km in the study stretch. The flow model for Brahmaputra river has been developed between IOC area and Pandu GD site in MIKE 11. The model was calibrated with 2015 flow data and validated with 2010-2014 flow data. The performance of model has been evaluated based on correlation coefficient varying in the range of 0.975 to 0.997. The water surface profile has been computed for the design flood and accordingly, the alignment and top level for left bank embankment was proposed. The maximum flood level for 100 year flood has been computed as RL 52.94 m at Guwahati gauging site (CWC site near DC court). The alignment of embankment on both banks of river Brahmaputra has been proposed based on the land availability (no settlement area), as identified from Google Earth. The alignment of embankment at spacing of about 100 m has been provided. The maximum flood levels for 25 years, 50 years and 100 years return period floods with proposed embankment at Guwahati gauging site (CWC site near DC court) have been computed as RL 52.24 m, 52.69, m and 53.20 m, respectively. The bank line shifting analysis of the study stretch has been carried out using temporal satellite images while river morphological analysis has been carried out to evaluate the stability of river bank line. The temporal satellite data between 1998 to 2014 show no noticeable shifting in the study stretch. Study of braiding behaviour of river has been carried out using satellite images.

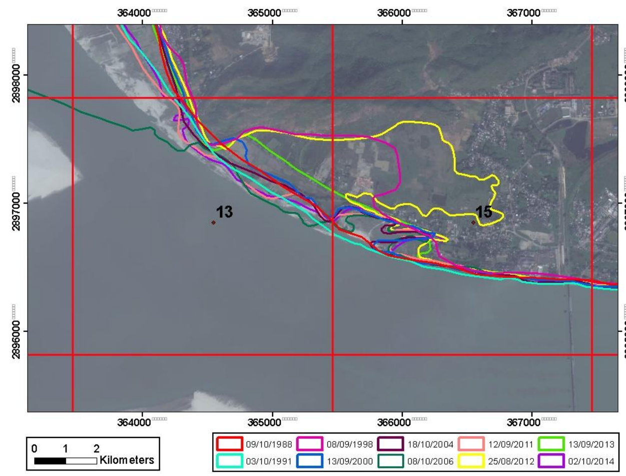


Fig: Shifting of river bank line

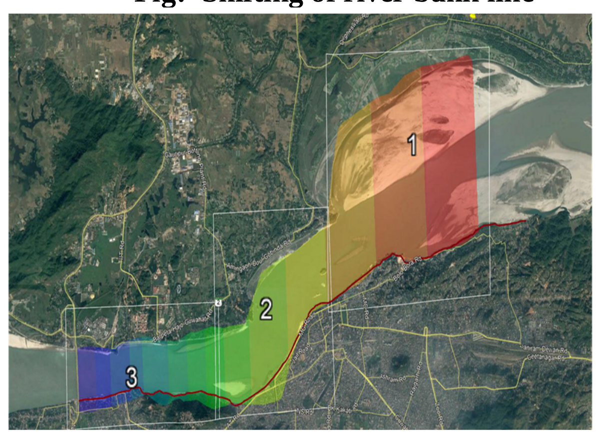
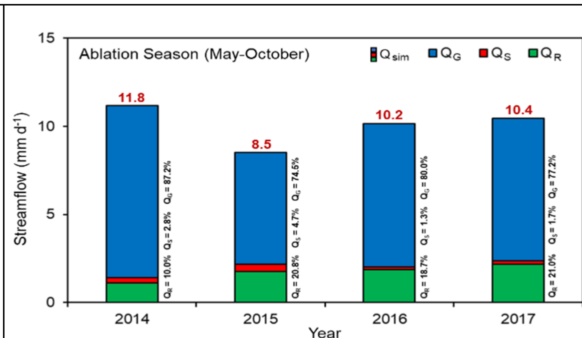


Fig: Inundation map for 100 year flood

The study concludes that low or no braiding was observed in the study stretch. The alignment of the top level of the left bank embankment is proposed. The scour depth for Guwahati gauging site was estimated as 23 m. The results/outcome of the study will be used by Guwahati Metropolitan Development Authority for riverfront development of Brahmaputra in Guwahati.

17. Monitoring and modelling of Gangotri Glacier

NIH has established a meteorological observatory and a streamflow gauging site downstream of snout of the Gangotri glacier at Bhojwasa and has been monitoring various hydrological and hydro-meteorological data during the ablation season (May to October) since year 2000. Rainfall, temperature, humidity, wind speed and direction, sunshine hours and the evaporation data have been collected during the ablation period. Gauge observations are taken round the clock at the gauging site with the help of automatic water level recorder. Samples of suspended sediment are also collected at the gauging site and concentration of suspended sediment is determined. An AWS was also installed in May 2009. The objective of the study are: (i) collection of hydrological and meteorological data to study the hydrological aspects of the Gangotri glacier by establishing a meteorological observatory and gauging site near the snout of glacier; (ii) estimation of total melt runoff from the Gangotri glacier and its distribution with time using continuously observed flow records; (iii) development of a hydrological model for estimation of glacier melt runoff using collected meteorological and hydrological data; and (iv) estimation of suspended sediment load in the river during the melt season.



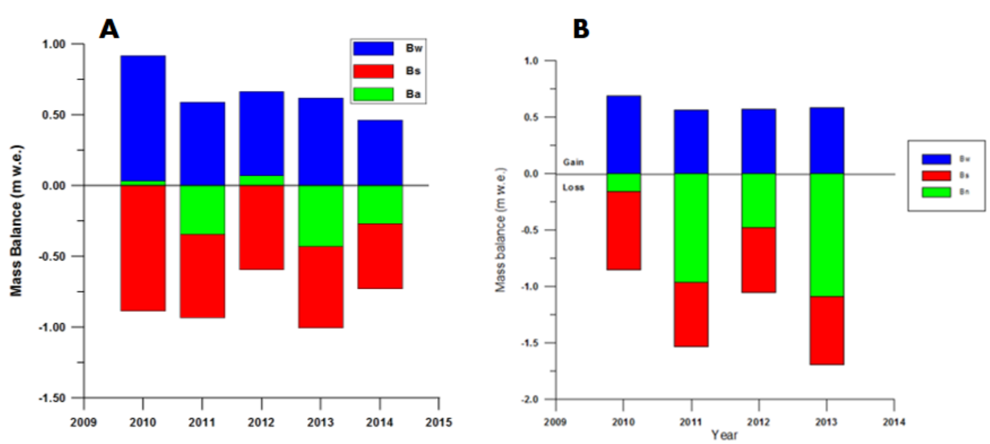
Mean temperature (May to October) has been observed as 9.11ºC; mean seasonal rainfall is observed as 260 mm; mean pan evaporations: 598 mm; and mean daily sunshine hours are 5.5 hours. Average daytime wind speeds are much stronger (4 times) than the night time winds. The records of wind direction show that during the day time, mostly wind blows from north-west.

Results suggest that increase in 0.2°C in average air temperature is observed by 2030 whereas average evaporation rates will be decreased by 0.04 mm. Similarly, precipitation pattern will follow upliftment trend and will be increased by 11 mm in the Gangotri Glacier valley. Since, streamflow in the glacierized catchment is highly dependent on the temperature fluctuation and precipitation pattern, slight increment of 0.04 mm in the Gangotri Glacier Streamflow is marked by 2030.

18. Glaciological studies of Phuche Glacier of the Ladakh range

The Phuche glacier has been selected as one of the benchmark glaciers for long-term glaciological research by DST-SERB under its programme on “Dynamics of Himalayan Glaciers” representing the cold-arid glacio-hydrological regime. This project has succeeded in laying a strong foundation for the long-term research by building infrastructure and monitoring stations at 4700 m a.s.l. and 5600 m a.s.l. at upper Ganglass catchment near Leh. Research station comprising of two automatic weather stations, one discharge station equipped with radar water level recorder and an FRP hut were put in place during the project period of five years. Along with this, a comprehensive glacier mass balance-monitoring programme generated winter and summer mass balance data of Phuche and Khardung glaciers for five years. Stable isotope data from nearly one thousand samples were also generated. Together, the project has developed one of the most comprehensive research database for a Himalayan catchment.

During the five-year study period, Phuche glacier lost (-)925 mm w.e. of ice reserve with mean annual mass balance of -185 mm w.e. Whereas, Khardung glacier experienced negative mass balance though out the observation period and experienced a cumulative mass loss of 2688 mm w.e. during four years of observation with an average annual mass loss of -672 mm w.e. For both the glaciers, annual mass balance response was found to be closely associated with the glacier ice exposure dates. Study also showed that the temperature variations in the month of May and June are more critical for glacier mass balance of cold-arid system than that of peak melt period of July and August. Average water availability for the 15.7 km^2 experimental catchment in summer is 4.21 $x10^6$ m^3 equivalent to 266 mm w.e. of specific runoff.



Winter and Summer mass balance of (A) Phuche and (B) Khardung glaciers

The climatological factors such as steep temperature gradient (~10 K/km) and steep precipitation gradient of winter months have strong influence on the glacier mass balance in the region.

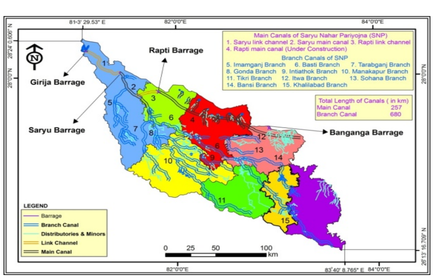
19. Groundwater Prospects in the Canal Command of Saryu Nahar Pariyojna and Possible Measures to Contain Rise of Groundwater level

Developing irrigation potential and bringing more areas under agriculture to attain food security are one of the important priorities of the 'National Water Policy'. The Saryu Nahar Pariyojna (SNP), located in eastern Uttar Pradesh, is a scheme to facilitate canal irrigation supply in areas of 14,040 sq. km. The districts to be benefitted by the project are; Bahraich, Gonda, Basti, Sidharthnagar, Balrampur, Sant Kabirnagar, Shravasti and Gorakhpur. MoWR, RD & GR has entrusted the study to assess *w*hether or not the SNP on its full scale development will have any future threat towards waterlogging and salinity.

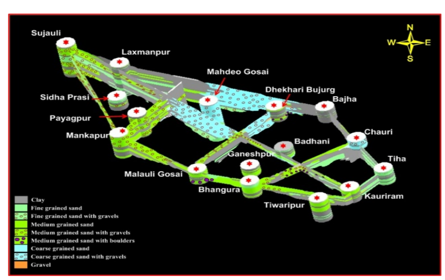
To accomplish the objectives outlined in the study, a comprehensive analysis of hydrologic and hydrogeologic features of the SNP catchment, viz. drainage systems, topography, soils, geomorphology, canal networks, rainfall, lithology, aquifer formations, groundwater levels & direction, infiltration rate, canal seepage, groundwater quality, etc. has been carried out. A number of field investigations and experiments were conducted to estimate the in-situ infiltration rates and collect soil samples for grain and textural analysis.

Analyzed results showed that: (i) the SNP canal command has widespread susceptibility to waterlogging in few districts. In the long run, the situation may aggravate further, if suitable groundwater management strategy is not adopted; (ii) during pre-monsoon period, about 5,783 sq. km (23.4% of the SNP command) has been identified as vulnerable to waterlogging in Bahraich and Gonda district particularly, along the routes of main and branch canals; (iii) during the post-monsoon period, about 90% area of the SNP catchment, nearly 22, 278 sq. km, has shown rise in groundwater table depth ≤ 3 m bgl; and (iv) after the full scale development of the canal networks, both the pre- and post-monsoon groundwater table may further rise and aggravate the problem of waterlogging.

The following has been recommended: (a) The SNP has provision to install 3600 tube wells, of which 100 have already been installed. Suggested installation of tube wells are in a series, at every 2 km on both sides of the canal at a distance of about 400 m to 450 m from the canal along Imamganj branch canal network in Bahraich district and Tarabganj branch canal in Bahraich and Gonda districts; (b) Currently, canals are operated for 8 months (July-February) in a year. To restrain the rise of groundwater table and waterlogging, particularly in Bahraich district, promote conjunctive use during November to February; after February until July only groundwater irrigation. In all other vulnerable areas in Gonda, Basti, Balrampur and Sidharthnagar districts, groundwater irrigation can be adopted during February through June; (c) To rationalize the conflict of interest on share of groundwater amongst water users, transfer surplus groundwater from vulnerable waterlogging zones to areas that have no threat to waterlogging, and harmonize users on uses of groundwater.



Index map of SNP along with its main, branch, link, distributaries and minor canals.



Fence diagram of lithostratigraphy of the SNP catchment

20. NIH_ReSyP – Reservoir Systems Package (Version 1)

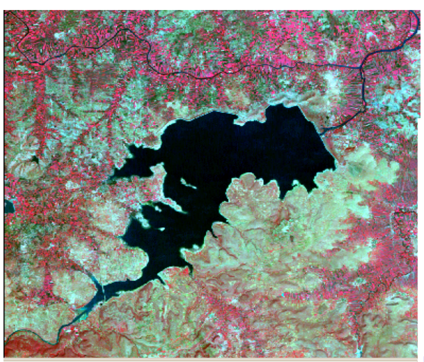
NIH_ReSyP is a WINDOWS based software package that has been developed for various kinds of reservoir analysis. Different modules of the software include capacity computation, storage-yield analysis, statistical analysis of flow data, initial rule curves derivation, operation analysis of a multi-purpose multi-reservoir system for conservation and flood control purposes, hydropower analysis, reservoir routing, interpolation and approximation of elevation-area-capacity table, and reservoir inflow computation including negative flow adjustment. The software has been named as *NIH_ReSyP* which expands as NIH_Reservoir-System-Package.

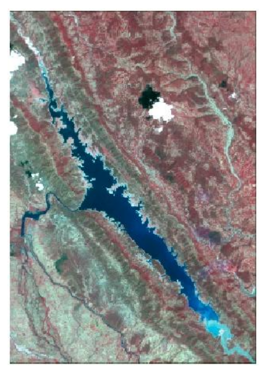
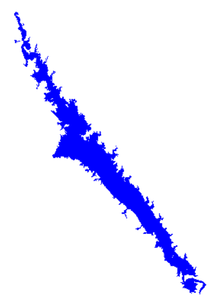
The software has been developed in Visual Basic and various computer programs developed in FORTRAN language at NIH have been linked. Various forms have been developed for easy preparation of data files. The help files are associated with each module. Sample input and output files get stored in a specific folder which can be initially worked with. It is easy for the users to select the data files and take the model runs. Results can be viewed in tabular as well as graphical form. It is aimed that the package will help the field engineers in India in carrying out various kinds of reservoir analysis. The package is available on NIH website and a number of training course have been organized for its applications.

21. Assessment of sedimentation rate of reservoirs using remote sensing techniques

Capacity surveys of reservoirs are important to study patterns and rate of sedimentation for defining appropriate measures for controlling sediment inflow, for managing the available storage in reservoir and for optimum reservoir operation schedule based on realistic assessment of available storage. Data from space platforms can play a significant role in reservoir capacity surveys. In the past, satellite remote sensing has emerged as an important tool in carrying out reservoir capacity surveys rapidly, frequently and economically. Multi temporal satellite data provide information on elevation contour areas directly in the form of water spread area. Any reduction the water spread area at a specified elevation over a period of time is indicative of sediment deposition at this level. When integrated over a range of water stages, it enables computing volume of storage lost due to sedimentation.

During five years 2002-2007, sedimentation rate in twenty-three reservoirs have been quantified using remote sensing techniques. These reservoirs include Nagarjunasagar, Hirakud, Gandhinagar, Tungabhadra, Linganamakki, Tawa, Ramganga, Ghatprabha, Matatila, Somasila, Lower Manair, Barna, Vaigai, Upper Kolab, Ravi shanker Sagar, Lower Bhawani, Singur, Bhakra, Nizamsagar, Tandula, Ghatprabha and Upper Kolab. During these five years, studies have been carried out at NIH Head quarters and its regional centres. This summary report describes the results of assessment of sedimentation rate using remote sensing techniques for these reservoirs. The zone of assessment, gross storage, sedimentation rate and capacity loss etc. have been provided in tabular form. As per this analysis, capacity loss per year varies from 0.95% to 0.027%. It was observed that reservoirs in South and central India are losing capacity at high rate in comparison to Northern Rivers. Among the reservoirs studied, Nizam sagar reservoir has lost more than half of its storage. It was contradictory to the belief that the reservoirs located in Himalayan region are having more sedimentation rate because of heavy soil erosion in Himalayan region.



Nagarjuna sagar which has the largest storage capacity in India has lost more than 20% of storage; it has the highest absolute sedimentation rate. Sedimentation rate per unit catchment area for reservoir in Narmada basin is the highest and is close to 10 times of the rate of many other reservoirs.

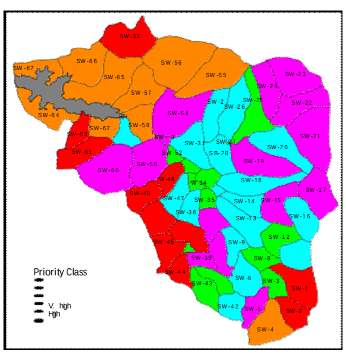
Large reservoirs (capacity more than 1000Mm3) are losing storage at the rate of about 9% per year.

22. Reservoir Sedimentation, Impact Assessment and Development of Catchment Area Treatment Plan for Kodar Reservoir in Chhattisgarh State

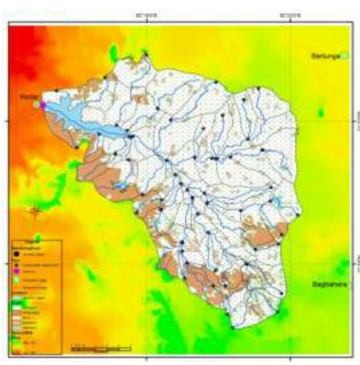
Sedimentation embodies the sequential processes of erosion, entrainment, transportation, deposition and compaction. An effective catchment area treatment (CAT) plan of a water resources project is a key factor in making the project eco-friendly and sustainable. In this study, sub-watersheds of the Kodar reservoir were prioritized using multi criteria decision analysis based on Saaty's analytical hierarchical process (AHP) considering nine different erosion hazard parameters. The SWAT model was used for sediment modelling and impact assessment of CAT plan. The study was carried out as a PDS under Hydrology Project-II for the Kodar reservoir (with catchment area 317 sq. km.) situated on river Kodar, a tributary of the river Mahanadi.

The objectives addressed include: (i) assessment of present status of reservoir storage by estimating revised capacity using remote sening data; (ii) identification of environmental stressed sub-watersheds based on soil loss, geomorphological characteristics, sediment yield, risk of erosion and soil loss; (iii) development of management plan for catchment area with area specific soil conservation measures for minimizing sedimentation in reservoir; and (v) impact assessment analysis using spatially distributed sediment modeling.

Sedimentation analysis of the Kodar reservoir indicated that 24.94 MCM of gross storage and 4.89 MCM of dead storage were lost in 32 years (1976-77 to 2008-09). The whole Kodar catchment was divided into sixty-seven sub-watersheds with area ranging from 0.05 sq. Km to 13.05 sq km for developing AHP based decision support. The study identified more than 21 sub-watersheds covering 117 sq km of Kodar reservoir catchment with very high to high priority category for treatment. The CAT plan identified suitability of 101.61 ha of land for afforestation, 114.86 ha for agro-forestry, 11.41 ha for development of grazing and 41 sq. km area for farm ponds. The mechanical measure under the CAT plan of Kodar reservoir catchment included 37 gully plugs, 22 nala plugs, 21 boulder bunds and 6 check dams. The Nash-Sutcliff efficiency of the SWAT model was obtained as 80.46% for runoff and 91.16% for sediment during calibration and 83.65% for runoff and 70.04 % for sediment during validation. The impact assessment analysis of sediment treatment showed that the maximum sediment load under Pre-BMP scenario in the month of Sept 2011 (2.97 t/ha) got reduced to 1.63 t/ha under same rainfall condition with the suggested measures.



Prioritized and suggested agronomic and mechanical measures for Kodar reservoir catchment



SWAT model application for Impact of best management practices for runoff and sediment yield

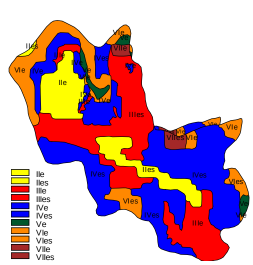
23. Comprehensive Watershed Management Plan for a Degraded Watershed in Bundelkhand Region of Madhya Pradesh

For watershed development programme, a holistic approach by adopting conservation, up-gradation and utilization of the available land and water resources in an integrated manner including restoration of ecological balance is essentially required to avoid long term degradation of watershed particularly in drought prone areas. Area-specific pertinent technologies are vital to increase agricultural outputs in rain-fed areas and also to arrest the ecological degradation. With these contexts, the degraded Tumri watershed in the Bundelkhand region of Madhya Pradesh, was considered for a comprehensive and in depth study.

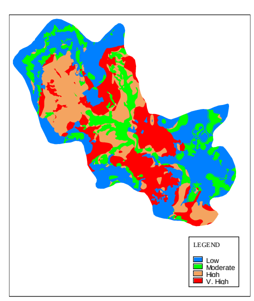
The objectives addressed were : (i) generation of database on hydro-meteorology, hydrology, soil, and process related parameters at watershed level and preparation of inventory; (ii) water budgeting for identifying and quantifying important components of hydrological cycle of the watershed; (iii) land capability classification and watershed prioritization to identify vulnerable areas for conservation measures; (iv) watershed modeling for estimation of runoff and sediment yield; (v) identification of site specific soil and water conservation measures for improving the overall health of the watershed; and (vi) impact assessment of proposed soil and water conservation/management practices of the watershed.

Water budget of the Tumri watershed for monsoon season (June to October) and non-monsoon season (November-May) showed that about 8.05 MCM water flows down the streams unutilized during monsoon season in a normal year. Thus, scope exists for creating more small surface water storage structures to meet the irrigation and drinking water demands. Land capability classification (LCC) by analysis of soil type, soil depth, slope class, erosion class and soil permeability indicated that the watershed has 11 land capability classes viz., Class II to VII. Soil erosion map prepared using the Universal Soil Loss Equation (USLE) and its analyses demonstrated that the average soil erosion from the watershed was 14.60 t/ha/yr. The impact analysis carried out for conservation measures by adopting forest plantations in 50% of the barren lands and pasture on the remaining lands, indicated reduced soil loss to 9.53 t/ha/year (a reduction of 70%). Watershed modeling by SCS-CN model showed that an outflow of 2.49 MCM during a severe drought year (2007-08) would be available at the outlet. The gross irrigation water requirement 1.056 and 5.619 MCM during the kharif and rabi season of, respectively indicated that these quantity of water could be harnessed by adopting storage structures to sustain the present cropping practices.

The sites for small water storage structures were identified based on drainage network, geology, contours, digital elevation model along with the decision rules framed for their selection. Seven storage sites were identified and their salient features viz., catchment area, height of the bund, area of submergence and storage capacity including the ponding depth were estimated. The zones for artificial recharge sites were also identified and about 14% area of the watershed was found suitable. The Tumri watershed could be developed as a guiding model based on the recommendations given from this comprehensive study. The outputs of this study could be used as guiding principles for development of watersheds in the Bundelkhand to mitigate the impacts of regular droughts in the region.



Land capability classification map

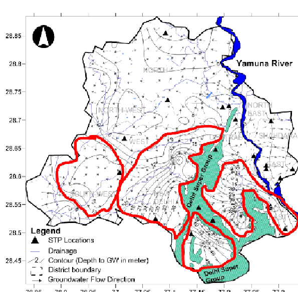


Soil erosion map

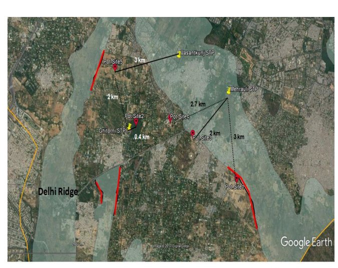
24. Feasibility and Scope of Managed Aquifer Recharge for Groundwater Augmentation in NCT, Delhi (2017)

NCT Delhi for drinking water supply of 16,753,235 (Census of 2011) populations uses an average of 755 MGD (Million Gallon per Day) raw water from outside Delhi and extracts 80 MGD of groundwater, against its estimated demands that vary between 708 MGD and 926 MGD. It has been projected that by 2021, NCT Delhi will have water demand of about 1,174 MGD. Less annual replenishment compared to withdrawal causing depletion of groundwater levels in many pockets. Brackish groundwater exists at shallow depths in some parts. NCT Delhi has the Yamuna flood water that causes flood like situation during monsoon period. On the other hand, it has a number of surface water bodies, which have been witnessing reduced surface storage capacities because of siltation and other factors. The augmentation of groundwater resource in depleted aquifer is urgently required to avoid aggravation of future geo-environmental hazards and also to match increasing groundwater demands. This eventually suggested the need of managed aquifer recharge (MAR) by identifying potential source of water for MAR. In that context, MoWR, RD & GR had referred this problem to NIH and CGWB for carrying out a comprehensive study. To work out the feasibility and scope of MAR in NCT Delhi, the following options were analyzed: (i) use of monsoon surface runoffs and Yamuna flood water by flood peak moderation as the source water for MAR, (ii) rejuvenation of surface water bodies by surface water runoffs and rainwater harvesting and use of rejuvenated water for MAR, and (iii) use of treated effluents from STPs located at different areas in NCT Delhi.

Major parts of New Delhi, Central Delhi, and complete South Delhi (Chhatarpur) areas were found depleted groundwater levels (between 15 m and 45 m) and these depletions are continuously on the rise. Chhatarpur area showed maximum depletion and uncontrolled and unabated groundwater extraction. The results of options analyzed for augmentation of depleted aquifers were as follows: (i) use of the Yamuna flood water by moderation as source water for MAR has limitation towards topographic elevation (20 m- 50 m) and distance (~ 10 to 55 km) for transport of water; (ii) use of urban stormwater runoffs by conservation as source water for MAR would require free flow of surface runoffs through drainage channels and would require infrastructural interventions to remove suspended solids and a lot of O & M cost would be involved; (iii) rejuvenation of existing surface water bodies to enhance groundwater recharge is one of the potential ways forward ,and enhanced groundwater recharge in areas with no risk of waterlogging can help dilute the concentration of groundwater quality, however, precaution would be necessary to stop entry of sewage water with the stormwater into the surface water bodies; (v) use of tertiary treated effluents from STPs found to be a logical way forward for MAR in areas of interest for use by overland applications, recharge basin approach, furrow methods, feeding to surface water bodies; (vi) some of the STPs are located on the depleted zones, or in nearby areas, which may involve less transport/lifting cost, and wastewaters of all STPs are treated minimum to the secondary level and an add-on component for tertiary treatment with the existing STPs is feasible and possible; (vii) as a pilot for performance evaluation and auditing, the tertiary treated effluents from the STP at Mehrauli and Vasant kunj can be implemented by transport from the respective STP to the Chattarpur area; and (viii) the potential sites for MAR in Chhatarpur area have also been identified. The outputs of this study have been shared with Delhi Jal Board (DJB) through MoWR, RD & GR for implementation.



Pre-monsoon groundwater table contours (bgl) map showing flow directions of NCT Delhi *(red polygon indicates depleted groundwater table).*

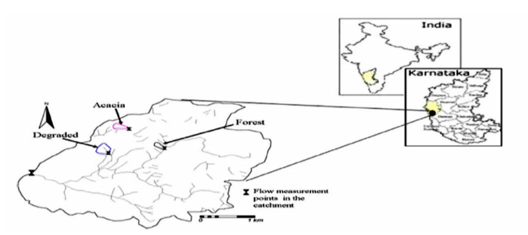


Feasible locations and areas for MAR in Chhatarpur area and their distances from Mehrauli and Vasant Kunj STP: red lines indicate stretch suitable for MAR using furrow method; and red circle indicate area suitable for MAR using recharge basin approach.

25. Hydrological Impacts of Land Cover Changes in Humid Tropical Watersheds Located in The Sahayadri Mountains, India

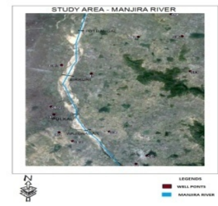
In this study an attempt has been made to understand the linkages between land cover and hydrological responses at the watershed-scale through long-term field measurement in the Sahayadri mountains (Western Ghats). These mountain ranges are important from the viewpoint of water resources in peninsular India from where almost all the major rivers originate. However, this region is undergoing significant changes in land-use/cover due to deforestation on one hand and afforestation of degraded and grasslands (by planting exotic species such as Acacia plants) on the other hand. This study was taken up with the following objectives: 1) To evaluate the controls exercised by climate, physical characteristics and nature of land cover on hydrological processes at the watershed scale, 2) To understand the role of unsaturated soil zone on hydrological response of watersheds through characterization soil physical and hydraulic properties and analysis of observed long-term spatio-temporal variations of soil moisture content, 3) To characterize the runoff regime of watersheds and investigate differences on account of the type of land cover 4) To develop modeling strategies for prediction of soil moisture at watershed-scale, 5) To develop a methodology to upscale knowledge gained at the watershed-scale to the catchment-scale for prediction of hydrological variables, 6) To simulate the likely impacts of land cover changes on catchment hydrological processes.

The major focus of the study was on field meaurements in three micro-watersheds located in the Sahayadri mountain region in the Uttara Kannada District, Karnataka State, India. These experimental watersheds, each possessing a different land cover (forest, degraded and acacia) were established for long term monitoring of soil matric potential, rainfall (depth and intensity), climatic variables and runoff during the period from January 2004 to December 2008. Physical and hydraulic properties of soil in the watersheds were characterized using in-situ and ex-situ procedures. Runoff was also measured at the outlet of the Biligihole catchment (in which the watersheds are located). Observations were subject to various analyses aimed at understanding the spatio-temporal behaviour of soil moisture and runoff as influenced by land cover. Regression-based models and also a conceptual parametric model for prediction of watershed-scale soil moisture were developed and tested using the observed dataset. Knowledge gained on watershed-scale hydrologic behaviour under different land covers was used to parameterize a catchment-scale hydrologic model for prediction of runoff at the outlet of Biligihole catchment. This model was then used to simulate runoff regime under various hypothetical scenarios of land use/land cover changes in the catchment. A major conclusion of this study was that in the Sahayadri mountain region, acacia plantations can help restore the hydrologic regime in situations where natural forests have been degraded.



26. Effect of Sand Mining on River and Groundwater Regime in Hard Rock Areas- A Case Study

Because of increased human activities within the riverine environment, a number of rivers in India are under tremendous stress. Sand extraction from river bed and flood plains is in ever increasing phase due to burgeoning demand for construction grade sand. The consequences of continuous sand removal from river bed are of serious nature to the river as well as the environment.



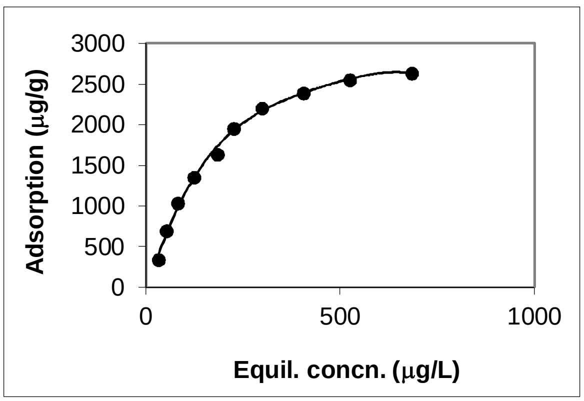
In-stream mining of sand can lead to irreversible damages to the river as well as the adjoining aquifer systems. However, it is noted that scientific studies pertaining to various aspects of the issue of sand mining are still meager. Excessive sand mining activities and environmental degradations have been reported by farmers as well as public in many rivers/ flood plains in erstwhile AP (presently, Telengana and Seemandhra). Therefore, a case study has been undertaken to study the impact of stream sand mining on river-aquifer system for the chosen stretch of the River Manjira (Godavari River Basin) in Nizamabad District of Telangana. River-aquifer interaction aspects have been investigated by formulating a three dimensional groundwater model of the region covering some of the existing sand mining reaches on the river.

In addition, the effects of sand mining on river system have been studied by employing a methodology consisting of field investigations, laboratory analyses, and river modeling. Profiles of cross-sections at various locations along the river stretch have been taken. Water and sediment samples have been collected and analysed. The HEC River Analysis System has been used to model the river channel processes for steady and quasi-unsteady state situations. Flows and sediment transport for different return periods have been generated as part of the analyses. Various scenarios due to sand mining activities (like widening and deepening of channel) have been envisaged to assess the effects of different intensities of river degradation. Simulations of flow conditions in the river as well as in the aquifer system were carried out to infer the effect of deepening and/ or widening of the river channel due to intense sand extraction activities.

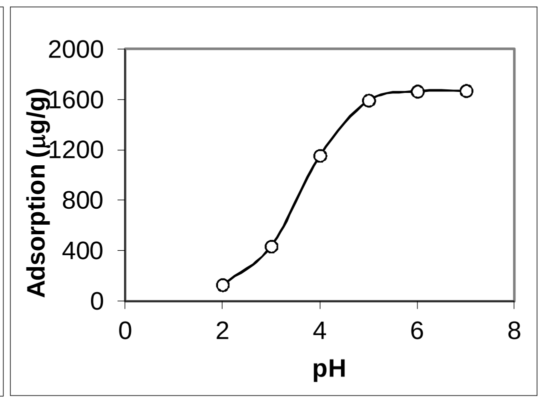
27. Adsorption of Cadmium on Bed Sediments of River Ganga, 2001-02

Adsorption is one of the important phenomena in water quality control, which determine the fate and transport of pollutants in the aquatic environment. The sediments existing at the bottom of a water body play a major role in the pollution schemes of water bodies. They reflect the current quality of the water system and can be used to detect the presence of contamination that do not remain soluble after discharge into surface water. Moreover, sediments act as carriers and possible sources of pollution. Therefore, the analysis of heavy metals in sediments and their adsorption characteristics permits us to detect pollution that could escape water analysis alone, and also provides information about the critical sites of the water system under consideration. River sediments provide much stable base for contaminative studies and can identify pollution sources that could escape detection by water analysis alone. Therefore, an assessment of both the sedimentary and aqueous phase should be undertaken to adequately characterise the aquatic environment.

In this study, the adsorption characteristic of cadmium on bed sediments of River Ganga at Hardwar has been studied. The effect of various controlling parameters, viz., initial concentration, solution pH, sediment dose, contact time and particle size, have been studied on the adsorption of cadmium ions. The optimum contact time needed to reach equilibrium is of the order of 60 minutes and is independent of initial concentration of cadmium ions. The adsorption curves are smooth and continuous leading to saturation, suggesting the possible monolayer coverage of cadmium ions on the surface of the adsorbent. The extent of adsorption increases with an increase of pH. Furthermore the adsorption of cadmium increases with increasing adsorbent doses and decreases with adsorbent particle size.



Effect of Equilibrium Concentration

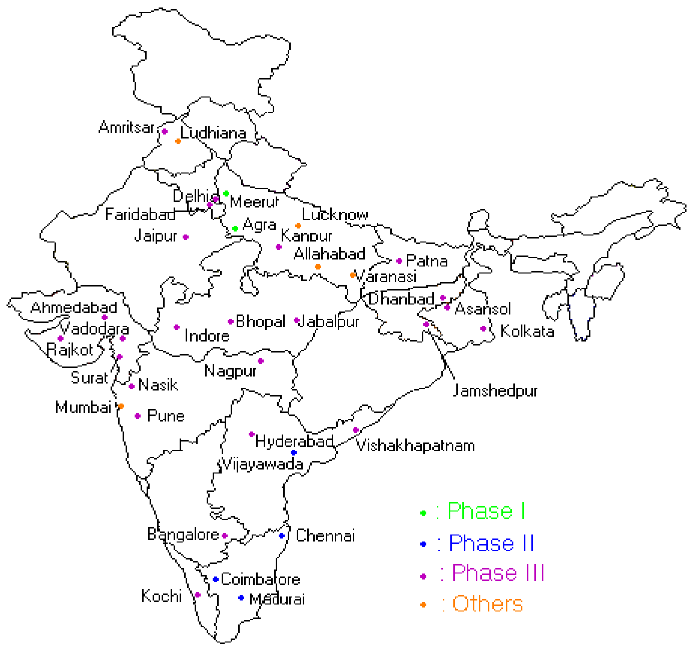


Effect of pH on Adsorption

The important geochemical phases, iron and manganese oxide, act as the active support material for the adsorption of cadmium ions. The adsorption data has been analysed with the help of Langmuir and Freundlich adsorption models to determine the mechanistic parameters associated with the adsorption process. An attempt has also been made to obtain thermodynamic parameters of the process, viz., free energy change, enthalpy change and entropy change. The negative values of free energy change (ΔG^o) indicates spontaneous nature of the adsorption of cadmium on the bed sediments and positive values of enthalpy change (ΔH^o) suggest the endothermic nature of the adsorption process. These parameters can be used for comparison and correlation with other river systems and demonstrates the role of sediments in pollution schemes of river system for proper assessment of water quality and in-turn for development of remediation plans.

28. Ground Water Quality Monitoring and Assessment in Metropolitan Cities of the Country, 2004-05

The ground water quality in Metropolitan Cities of the Country has been assessed to see the suitability of ground water for domestic and irrigation applications. Twenty five ground water samples were collected from each city during pre- and post-monsoon seasons and analysed for various physico-chemical and bacteriological parameters, heavy metals, pesticides and polynuclear aromatic hydrocarbons. This is the first time such comprehensive assessment of ground water quality in metropolitan cities of the country has been attempted. The hydro-chemical and bacteriological data was analyzed with reference to BIS and WHO standards, ionic relationships were studied, hydrochemical facies were determined and water types identified.



Metropolitan Cities

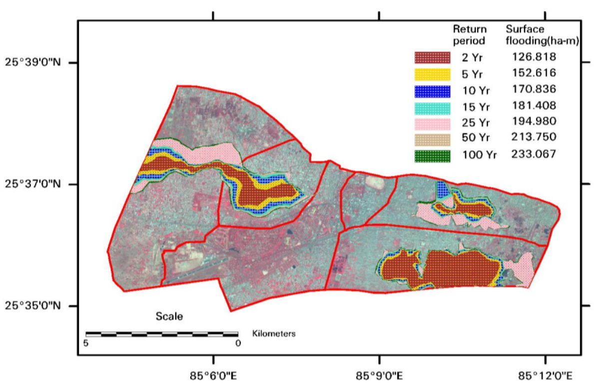
The quality of the ground water varies from place to place with the depth of water table. The bacteriological analysis of the samples indicates some sign of bacterial contamination at few locations. Inadequate maintenance of hand pump, improper sanitation and unhygienic conditions around the structure may be responsible for bacterial contamination at these locations. Pesticide analysis indicated the presence of some chlorinated pesticides at certain locations but their content was well within the permissible limits for drinking water at most of the locations. No organo-phosphorous pesticides and polynuclear aromatic hydrocarbons were detected in any of the ground water samples of the metropolitan cities. The suitability of ground water for irrigation purpose has been evaluated based on salinity, Sodium Adsorption Ration (SAR), Residual Sodium Carbonate (RSC) and boron content. An attempt has also been made to classify the ground water on the basis of different classification schemes, viz., Piper trilinear diagram, Chadha's diagram, Durov's plot, U.S. Salinity Laboratory and Gupta's classification.

The study has created a comprehensive water quality data-base for taking remedial measures for providing safe drinking water to the people in metropolitan cities of the country. The data-base will also be used as a reference for detection of changes in ground water quality in future.

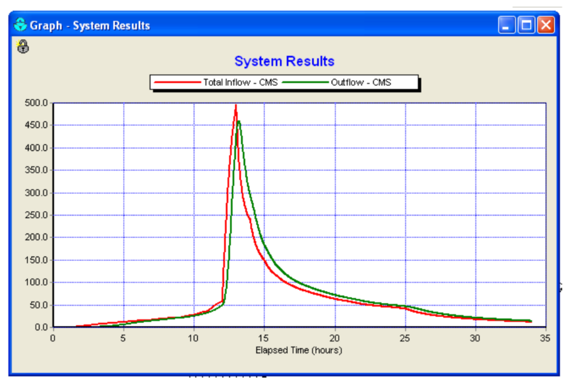
29. Urban Hydrology of Patna town

Patna has been facing acute drainage problem due to its topography. Patna was heavily flooded and there was a severe water logging in the town in the year 1990 and 1997. Small boats could be seen on the roads. Urbanization and inadequate / choked drainage system added to the severity of the problem. Efficient drainage and pumping is one of the means to dispose off rainwater of the town. This study simulated storm water runoff through the drainage networks of Patna Town using hydrodynamic Storm Water Management Model (SWMM).

For input to the model, different maps were prepared in GIS environment. The Digital Elevation Model (DEM) prepared for the study area was divided into 50 sub catchments depending on the topography, existing drainage network and the land use pattern of Patna. Satellite data was used for land use classification of Patna town. Annual daily maximum rainfall data during 1975 to 2007 were used for analysis of design storm of Patna town. Extreme Value (EVI) distribution was used to find the design storm for 2 to 100 years return periods. The simulation results were calibrated with the observed hydrograph at different outlets of the drains. After calibration, the model was simulated with the existing dimension of the drainage network without any blockage which yielded inadequacy of drainage system to dispose off the runoff even for two year return period storm and caused flooding and water logging in Patna town. The required dimensions of the drains were estimated mainly with respect to depth without disturbing the existing network and the model was simulated for return periods from 2 to 25 years as well as for the severe storm observed during 1975 to 2007 till no spilling of the drains were observed.



Surface Flooding for various return periods



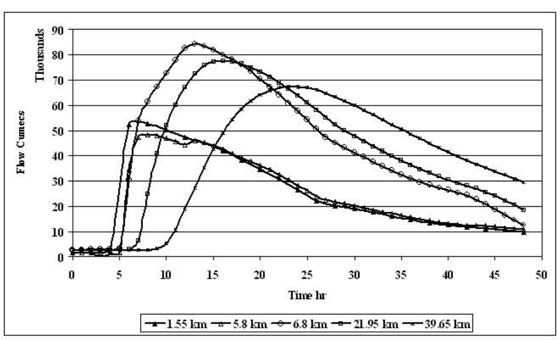
System Inflow–outflow hydrograph for 25 years return period flow

30. Dam break flood simulation for Maithon and Panchet dams using NWS DAMBRK model and inundation mapping

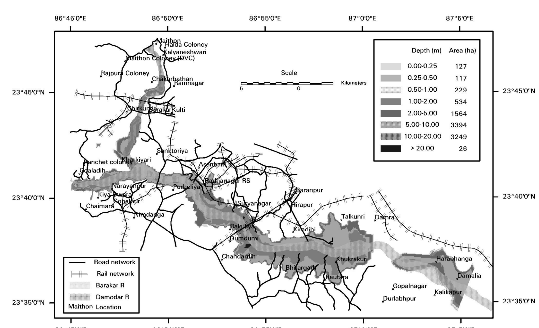
Dam break flood simulation of two dams, namely Panchet and Maithon, located on Damodar and Barakar river respectively have been performed using NWS DAMBRK model. The failure of Maithon dam has been simulated and its outflow at the confluence of the two rivers has been considered as lateral inflow while simulating the failure for Panchet dam. Four cases of failure scenarios have been considered: (i) failure of only Panchet dam, (ii) failure of only Maithon dam, (iii) failure of both Panchet and Maithon dam, and (iv) Safe passage of probable maximum flood from both the dams. The maximum discharge, maximum stage, maximum flow velocity and its time of occurrence at various cross sections along the Damodar and Barakar rivers have been computed.

The inundation maps showing the extent, depth and area of inundation have been prepared in GIS environment. For preparation of inundation map, the digital elevation model (DEM) of the downstream has been prepared using Survey of India toposheets available in 1: 25,000 and 1:50,000 scale. The river cross sections along the Barakar and Panchet rivers have been collected from Damodar Valley Corporation (DVC).

For dam break analysis, all gates of the dams are considered open and the reservoir is considered at FRL when peak of PMF enters into the reservoir. Three parameters, namely time of breach (T), side slope of breach section (S) and size of breach (W), are estimated based on Federal Agency guidelines (USA) and the recommended values as pr ‘User Manual of NWS DAMBRK’. The flood in Barakar river is considered separately and routed up to the confluence point to compute the outflow hydrograph. Four cases of failures of two dams in various combinations have been simulated. The attenuation of flood hydrograph in the downstream reach and flood level at various cross sections have been computed. The flood inundation maps are developed using the flood level data in GIS environment.



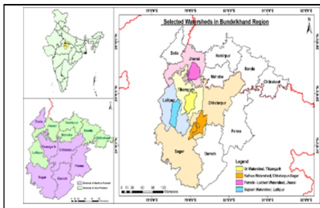
Attenuation of flood generated when both dams fail simultaneously (case-3).



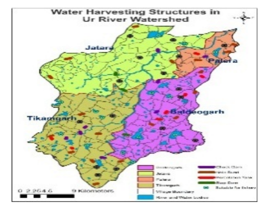
Inundation map for case 3.

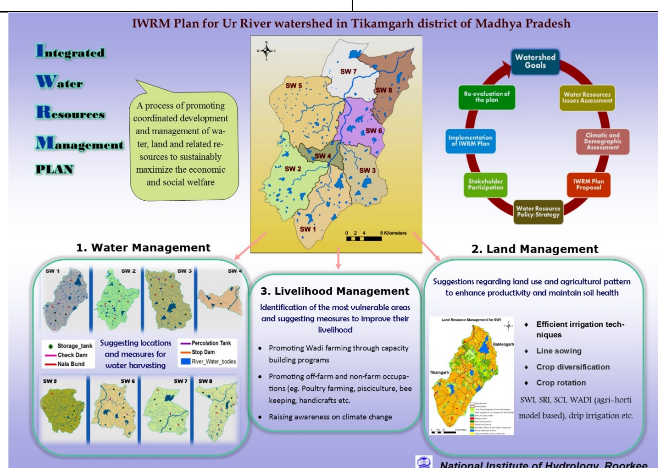
31. IWRM based development plan for water security in four districts of Bundelkhand region in India

Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India had sponsored a project titled "*IWRM based Water Plan for Water Security in the four Districts of Bundelkhand Region in India*". One watershed has been selected in each of the four districts viz., Tikamgarh, Chhattarpur, Jhansi and Lalitpur. The selected watersheds include Patrahi Lakheri watershed (Jhansi), Sajnam watershed (Lalitpur), Ur river watershed (Tikamgarh) and Kathan watershed (Chhatarpur). The size of the watershed is approximately 1000 sq. km and all the four rivers are ungauged. The project envisaged the development of IWRM Plan based on the principles of integrated water resource management, linking the water resources management with livelihood options and with participation of the local stakeholders. A Decision Support System (DSS) has been developed, which will prove to be an effective tool for the decision makers for optimal development and management of the water resources, considering a holistic approach by using the IWRM principles thereby leading to the improvement of livelihoods.







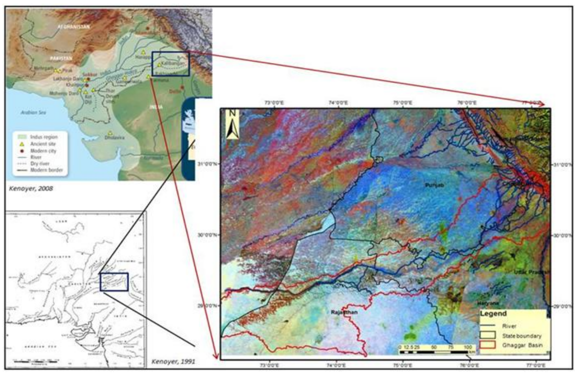


The findings from the overall assessment of four watersheds have been categorised under five broad deliverables– water balance assessment, livelihood vulnerability assessment, capacity building programmes, Bundelkhand DSS portal 'Jal-Jan-Jeevan' and Integrated Water Resources Management (IWRM) plans. The IWRM Plan of a watershed provides specific suggestions on the activities under the three themes of water, land and livelihood. The IWRM Plan developed for the four watersheds have been handed over to the respective District Collectors, who will be able to decide upon the management options to be implemented under various available development schemes in the district (especially under District Irrigation Plan).

32. The Structure and Dynamics of Groundwater Systems in Northwestern India Under Past, Present and Future Climates

India in last 40 years witnessed a revolutionary shift from large-scale surface water management to widespread groundwater abstraction, particularly in the northwestern states of Punjab, Haryana and Rajasthan. Groundwater (GW) depletion in this region is under vulnerable condition and has become a hotspot for GW management. The groundwater depletion rates in northwestern states of India has been highest in the world. Unmanaged use of groundwater becomes more challenging due to increasing demands from population and industrial development under the climate change scenario.

IIT, Kanpur; NIH, Roorkee; Geology Department, DU; NGRI, Hyderabad; Geography Department, Druham University; and Earth Sciences Department, Imperial College, London, jointly conducted the study sponsored by Ministry of Earth Sciences, GoI under Changing Water Cycle (CWC) Program in collaboration with Natural Environment Research Council, U.K. The main objective was to develop integrated geological and hydrological understanding of GW system in the study area. The role of NIH was to study the isotopic characteristics of GW, stream and rainwater to understand dynamics of GW.



Index map of the study area.

GW data of Haryana and Punjab for the period 1974 to 2010 were analysed to understand the GW level pattern and for trend analysis, which indicated a decline in GWL by 12-18 meters during 1974-2010 in few parts of Punjab and Haryana. GW was found continuously rising in a few pockets in the southwest and western part of the Punjab and Haryana, where the salinity was observed to be high, although the maximum area showed a GW decline since 1974. The depth to water level maps showed marked spatial and temporal variability, and distinct hotspots of GW depletion at the tens of kilometer scale in the study area. Initially, GW had shown a lateral expansion of depletion from 1974 to 1996, and thereafter both marked expansion and rapid decline in water levels from 1999 to 2010. The maximum decline in water level was observed along the Ghaggar River. The extensive GW abstraction for irrigation and other uses have resulted into the depletion of GW storage. Initially, GW storage gained between 1974 and 1996, and then depleted storage at the rate ~3.74 km^3/yr between 1999 and 2010. These results could be useful for micro scale planning and GW management practices.

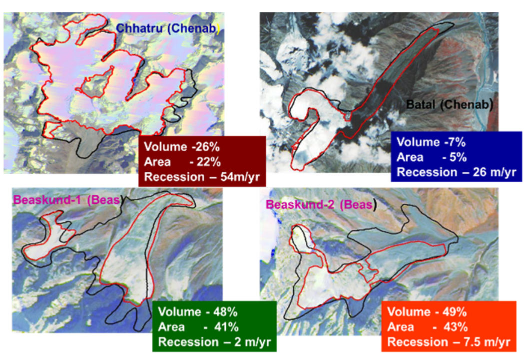
Based on isotopic signature and the subsurface lithology, the aquifer system has been divided into shallow (<80 m bgl) and deep (>80 m bgl) regimes, especially in the middle and downstream part of the study area. The shallow groundwater in the middle and downstream parts of the basin has a depleted isotopic signature with high d-excess and high tritium concentrations, indicating modern recharge that is dominated by leakage or return flow of canal network of Sutlej River. The stable isotopic composition of samples below 80 m bgl, in contrast, shows a close affinity with amount weighted average precipitation, indicating that the dominant recharge source is modern water, but low tritium concentrations indicate relatively long residence times in the lower reaches of the basin. The maximum recharge rate of 184 mm/year has been estimated for the Ghaggar basin. These results of the study can be used to prepare a management plan to mitigate the depletion of groundwater in the area.

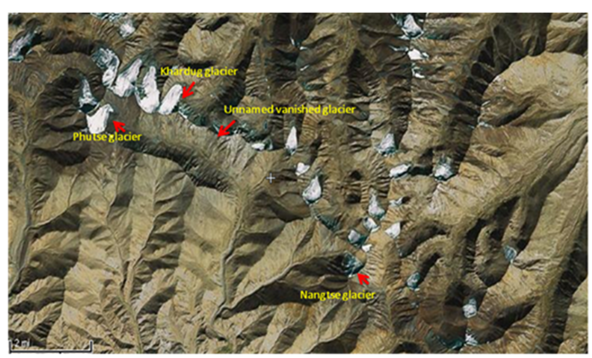
33. Change detection of selected glaciers in Western Himalayan Region

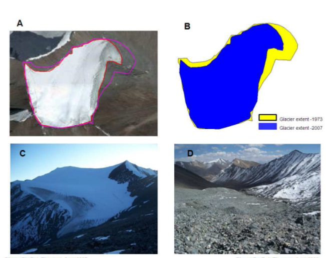
The objective of this study was to generate credible knowledge on the impact of climate change on Himalayan glaciers in western Himalayan region. This study was carried out in two stages. In first stage (2007-08), four glaciers in Chenab and Beas basins, located in different climatological, hydrological and geomorphological settings, were visited. In the second stage (2008 – 09), seventeen glaciers in the Kashmir, Ladakh, and Zanskar region were visited to collect the ground truth information. The study was carried out with the help of Survey of India toposheets, remote sensing images and extensive field survey and collection of ground truths.

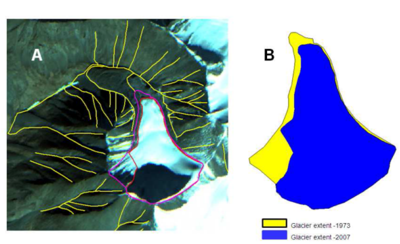
This study suggested that though changing climate have significant impact on the Himalayan cryospheric system and glaciers, yet small glaciers (which are more than 90% of around 9575 glaciers in Himalayas) are more susceptible to the changing climate. Across the Himalayan arc, glaciers exist in diverse climatological regimes and their response to climate vary considerably by their aspect and geomorphological characteristics. It was found that within a span of 27 years, 35 to 43% of the Beas Kund I & II glaciers have melted away. Vertical shrinkage was also found predominant for some low altitude glaciers in addition to the snout recession. Batal glacier was found to be experiencing lower rate of degradation with 5% change in the aerial extent but with substantial rate of frontal recession (25.7 m/year).

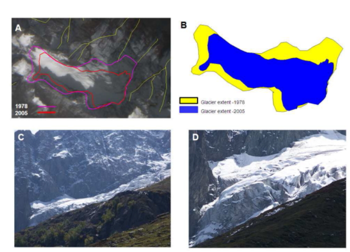
In the second phase, ten glaciers in the Ladakh mountain range, two glaciers in the Zanskar range and seven glaciers in the Drass and Kashmir region were investigated. Aerial and volumetric changes of these glaciers during the last three decades (27-34 years) were investigated using topographic method. In Ladakh range, lower extent of glacier is generally around 5200 m a.s.l., whereas glaciers in the Kashmir region are situated at altitude with glacier snout reaching up to 3600 m a.s.l. The results of the present study suggest that there is no 'altitude effect' on the glacier change in these two region. Change in the area covered by a glacier is an important parameter of the glacier change studies. Ladakh range is characterized by small glaciers and the area of glaciers evaluated range from 0.022 – 1.164 km^2. The area of glaciers selected in the Kashmir region range between 0.539 to 7.47 km^2. The percentage area change during the past 34 years in the Ladakh range was found to vary from 6.5 to 18.6 % (excluding highly degrading smaller glaciers of Khardug La). In the Drass and Kashmir regions, glacier aerial change was found to be in range between 2.9 to 34.5%.





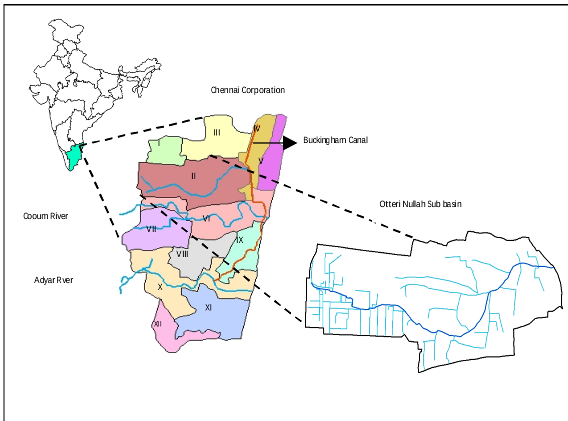


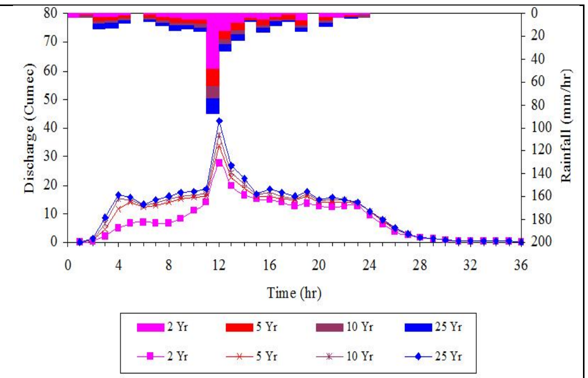




34. Stormwater Management in Otteri Nullah Watershed, Chennai Corporation, Tamilnadu

Storm water flooding is one of the major issues in the urban cities of India. The flooding frequency and magnitudes are increasing tremendously with heavy rainfall occurrence in a short duration under changing climatic conditions. In order to understand overland flow characteristics in storm water drains, an urban sub-watershed of Otteri nullah of 30 km^2 catchment in Chennai Municipal Corporation was selected for micro level study using the XP-SWMM software and hydrological measurements. The main objectives of the study were to: (i) evaluate existing storm water drainage network efficiency in the study area, (ii) find out the inflow-outflow hydrograph at various outlets and the water surface profile along the storm water drains, (iii) study the feasibility of improvement of the existing network of storm water drainage, and (iv) propose additional network to avoid urban flooding.





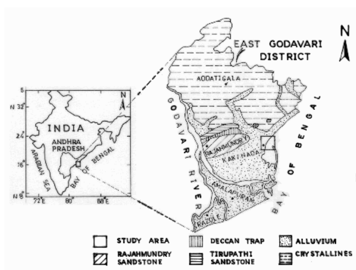
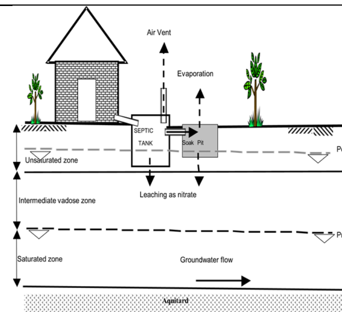
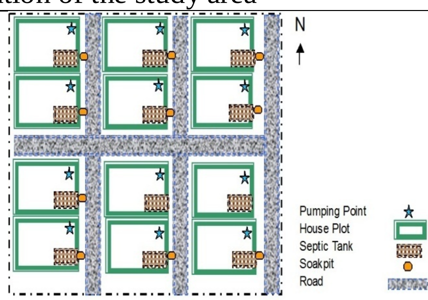
Location of the study area	Flood hydrograph for different design storms at the basin outlet

The hourly rainfall data at Nungambakkam for a period of 30 years (1980- 2009) was used for rainfall frequency analysis and to derive IDF curve. Using thematic layer of DEM, the study area was delineated into 88 micro watersheds and the drainage network was schematized using 121 nodes and 120 links serving as input to XP-SWMM model. Five tipping bucket rain gauges and two automatic water level recorders were installed in the study area. Based on measured rainfall and water level data for the year 2011 in the study area, few events were selected for the model performance in terms of runoff computation and to calibrate and validate the model.

It was found that even a peak discharge of 27.57 cumec is generated from the hyetograph of 24- hour design storm of 2- years return period having maximum hourly rainfall of 48.89 mm causing flooding at many locations. The storm water drain sections were then modified as proposed by PWD. The model simulation predicted adequacy of drainage network up to design storm of 5 years. Incorporation of flood water diversion link from Otteri Nullah, west of Annanagar to Cooum river indicated that there was 38% reduction in the peak flow against 2 years return period storm. The study is useful in understanding the storm water flow characteristics and for better management of storm water flooding. Hands-on-training programs were conducted for the field Officers of Chennai for use of the model in designing the storm water drains. Local community was also sensitized on urban flooding and its causes through the print and electronic media.

35. Assessment of Groundwater Quality and Nitrate Transport Modelling for the Coastal Aquifer of Kakinada, Andhra Pradesh

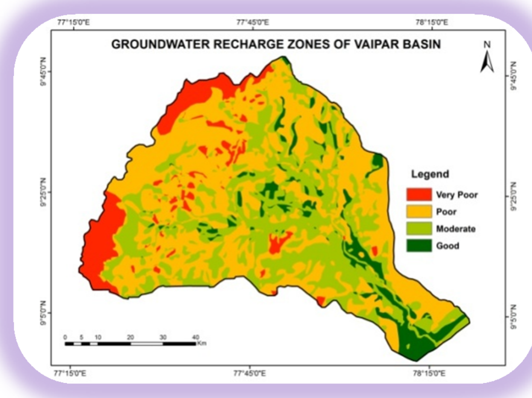
The main objectives of the study were: (i) characterization of groundwater quality in Kakinada urban coastal aquifer using multivariate and geostatistical analysis (ii) development of GIS based methodology for mapping nitrogen load from septic systems in and around Kakinada town, and (iii) nitrate leaching estimation from faulty septic systems using RISK-N model. The methodology mainly focused on establishment of groundwater observation well network and assessment of shallow groundwater quality spatially and temporally in and around Kakinada city. PCA and geostatistic techniques have been used for identification of contaminant types in the shallow aquifer. The population induced nitrogen load has been estimated from faulty septic systems and validated with groundwater nitrate concentrations. RISK-N, a semi analytical integrated model of unsaturated and saturated zones, was used to estimate nitrate leaching into shallow groundwater.

	
Location of the study area	Typical septic tank and sock pit
	
Conceptual layout of the house plots, pumping points, septic tanks and soak pits	Field photograph sowing soak pit system outside the house

The results of the study indicated that the salinity and nutrients are major contaminants in the shallow groundwater in Kakinada. Among the nutrients, nitrates are dominant (up to 250 mg/l) in the shallow groundwater. The Cl^-/HCO_3 ratio in the groundwater is limited to 7.37, indicating no sea water intrusion resulting from the historical marine coastal environment. The isotope values of groundwater samples indicated no direct connection between seawater and shallow groundwater and the present salinity is mainly due to diffusion effect of seawater (aquaculture practices and salt water creeks). The ranges of monthly septic system NO_3-N contributions to groundwater obtained by using RISK-N model during July 2002 to June 2003 in LB nagar, Madav nagar, and Suresh nagar areas were 51% to 65%, 61% to 98%, and 64% to 90% respectively. The RISK-N model application revealed that the average NO_3-N contribution from the faulty septic system to groundwater was around 71% and depends on the prevailing groundwater table conditions and nitrogen load. Therefore, it was recommended that the construction of septic tank should be as per the approved structural designs and the pumping wells should be as far away from the tanks as possible. If the sewage network system is not available and soak pit system is not feasible, then septic clean truck may be used for safe disposal of septic water rather than disposing into open drains.

36. Identification of Groundwater Recharge Zones In Vaippar Basin of Tamilnadu Using Remote Sensing and GIS Technique

This study focuses on identification of groundwater recharge zones in Vaippar basin, Tamil Nadu using Remote Sensing (RS) and Geographic Information System (GIS). Various fatrures like hydro-geomorphology, geology, drainage density, lineament density, landuse/lancover, slope, soil characteristics, etc. control the groundwater recharge potential in a basin. Integration of remote sensing with GIS for preparing various thematic layers, such as lithology, drainage density, lineament density, rainfall, slope, soil, and land-use assigning their weights in a spatial domain support the identification of groundwater recharge zones. The input parameters landuse/landcover map and lineament map were prepared using Landsat8 satellite data. Slope map was generated from the SRTM DEM. Soil map was digitized using NBSS&LUP maps. Various thematic maps such as lineament density, drainage density, slope, soil, geomorphology and wasteland were prepared and used in the study. These thematic layers were assigned appropriate weights through Multi Influencing Factor (MIF) technique and then integrated in the GIS environment to prepare the groundwater recharge zone map of the study area.

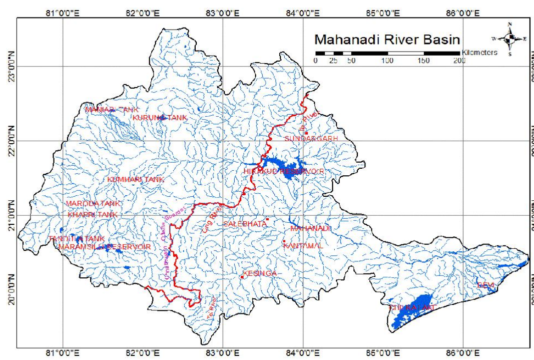


The identified groundwater recharge zones demonstrates that the potential zone is concentrated in the central and south-eastern region of the study area due to the distribution of alluvial plains and irrigated land with high infiltration ability. This indicates that soil type and slope play a vital role in groundwater augmentation. Moreover, the concentration of drainage density and lineament density also helps improve the infiltration to the groundwater system. In the study, the groundwater recharge zones in the Vaippar basin were categorized into four different zones namely, ‘good’, ‘moderate’, ‘poor’, and ‘very poor’ consisting about 5% , 38.2%, 44.3% and 12.5% of the total area respectively.

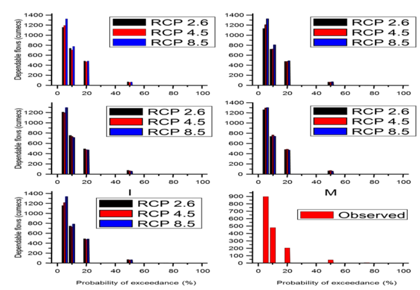
The results of study can serve as guide for implementing future artificial recharge techniques at suitable locations in the area in order to ensure sustainable groundwater utilization. This method can be widely applied to the larger watersheds with rugged topography for the exploration of suitable water management sites.

37. Statistical Downscaling and Assessment of Climate Change Impact on Hydrology for Mahanadi Basin

As water resources become r stressed due to increasing levels of societal demand, understanding the effect of climate change on various components of the water cycle is of strategic importance in the management of this essential resource. Climate change will affect water resources through its impact on the quantity, variability, timing, form, and intensity of precipitation. Gaining knowledge on potential climate change impacts on water resources is a complex process which depends on mathematical models capable of describing these processes in quantitative terms. The main objective of the study was to investigate the climate change related uncertainty in the estimation of extreme flood flows for the middle Mahanadi using a wide range of climate model scenarios.



Map showing gauging site for Mahanadi basin



Future Water Resources Scenario – Dependable Flows at Kesinga

In this study (i) trends in rainfall and runoff time series were detected (ii) precipitation was downscaled to estimate and predict future projection, and (iii) SWAT model was used for hydrological assessment. Trend analysis for daily discharge data showed that Tel river is experiencing an increasing trend whereas Ong tributary is experiencing decreasing trend. Daily, monthly and seasonal rainfall trends were analyzed for the period between 1961 and 2001 and no trend was observed. But there was significant evidence of fall in precipitation during monsoon period for two stations (Salebhata and Sundergarh) using Mann- Kendall sign test. Variation of rainfall shows that number of rainy days and total annual rainfall were decreasing and Kesinga sub-basin observed highest decrease in rainfall events in the Mahanadi basin. From the analysis, it was found that though there is decrease in number of rainy days, extreme rainfall events were increasing over Mahanadi basin.

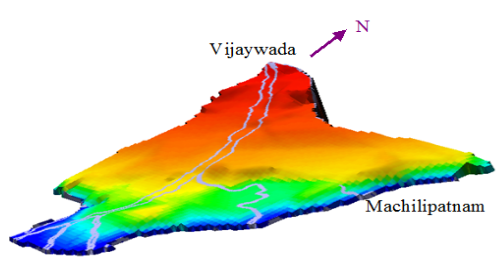
The precipitation data were downscaled using the delta change factor method combined with KnnCAD to obtain climate change projections for the future period of 2006–2149. Decadal analysis of projected rainfall showed that there is a decrease in rainfall from 10 to 32 % for some RCP scenarios. SWAT was applied for Mahanadi basin and simulation result indicated that the increase in the extreme rainfall events will get translated into floods in basin. The dependable flow analysis based on model simulations for the future time horizons indicated that the magnitude of the flood events is expected to increase substantially in comparison to observed historic floods. The modelling approach was also able to capture the changes in intensities of water, (probably rainfall) between the current time period and future time period. All the RCP scenarios indicated that there is an increase in intensities of rainfall in the future. The RCP-2.6 and RCP-4.5 indicated moderate increase in the intensities, whereas RCP-8.5 shows a significant increase. The percentage increase in the extreme intensities is relatively higher for smaller return periods.

38. Freshwater-Saline water Inter-relationships in the Multi-Aquifer System of Krishna Delta, Coastal Andhra Pradesh

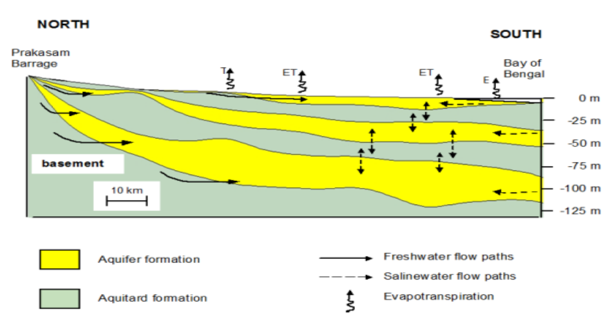
On farmers' complaints about increased salinity levels in the production wells pumping groundwater in the fertile plains of Krishna Delta, well-known for prolific paddy yields, this pilot study was initiated in collaboration with the State Ground Water Department, Andhra Pradesh during Hydrology Project Phase-I. The major objectives were to investigate groundwater salinity problem in the multi-aquifer system of Krishna Delta region, simulate the system through numerical modeling, and develop a management tool for planning a sustainable groundwater development program. To accomplish the study objectives, following works were undertaken: groundwater dating and stable isotope investigations, hydrogeologic investigations, and, numerical modeling of the aquifer system.

Study of litholog and water level data revealed existence of an upper aquifer system and a lower deep-seated aquifer. The upper aquifer system consists of three aquifer zones which are interconnected at places. The lower deep-seated aquifer existing at depths greater than 73 m is semi-confined to confined. The existing salinity that ranges from slight to moderately brackish in shallow and intermediate aquifer zones in the upper aquifer system, and highly brackish to saline in deeper aquifers that are located away from the sea coast, is due to paleo-geographic conditions (the migration of coastline over the geologic time scale). The present day seawater intrusion is limited to the deeper and intermediate aquifers near the sea \coast or near the river Krishna at the tail end. Major groundwater recharge areas lie in the northern part of the study area near the Prakasam reservoir and the area near Kaza where the canal network systems are intensively used for irrigation. The increased canal water irrigation has lead to freshening of the groundwater that was saline earlier due to the presence of sea.

Field investigations and variable density numerical modeling demonstrated that the net recharge to the groundwater system is sufficient to control the advancement of salinity front in the upper aquifer system. In general, the existing groundwater condition in Krishna Delta is not a classic case of saltwater intrusion from the sea, wherein the freshwater in an aquifer exists in a state of dynamic equilibrium with coastal waters. Reduction in freshwater recharge to the groundwater system leads to a lowering of the water table at the regional-scale that is accompanied by a rise in groundwater salinity in the shallow aquifer zone especially in places where strong vertical hydraulic gradients exist due to large groundwater drafts in the region. At local scale, saltwater upconing is encountered. To minimize such saltwater upconing, groundwater planning is needed at the local-scale. Subsequently, in another study taken up in collaboration with IIT Roorkee, modeling tools were developed to arrive at optimal design criteria for different types of skimming wells that can pump freshwater from aquifers with freshwater underlain by saline water. Using such skimming wells, groundwater can be pumped without any long-term groundwater salinization problems.



3D view of regional topography of Krishna Delta, Andhra Pradesh

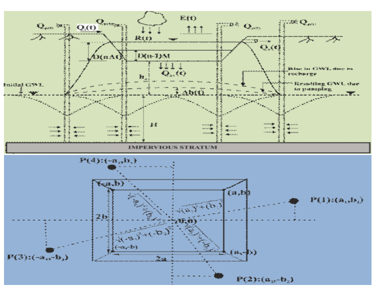


Schematic cross-section of coastal aquifer features within Krishna Delta showing possible groundwater flow paths and hydrological processes.

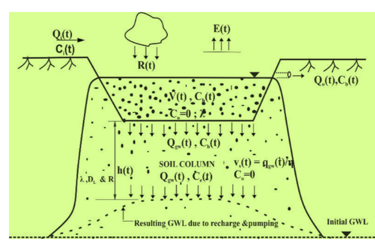
39. Web Enabled "Conjunctive Use Model for Management of Surface and Ground Water using concept of MAR and ASR"

Depleting groundwater level, and deteriorating quality of groundwater from anthropogenic and geogenic sources of contaminants are common concerns in India. The problems, such as a burgeoning population leading to a clear demand-supply gap, rapid urbanization, industrialization, increasing pollution of surface water and inadequate rainfall are the various factors for depletion of ground water levels. Practices like, **Rainwater Harvesting** (RWH) and **Artificial recharge (AR)**, can help in fulfilling requirement of agriculture and drinking water supply. But, there is large knowledge gap on social, economic and water quality aspects of **Managed Aquifer Recharge (MAR)** and on how best to organize the construction, maintenance and the use of recharged water. MAR together with Aquifer Storage Treatment and Recovery (ASTR) addresses a number of scientifically challenged issues. These are; identification of suitable location of pumping wells for aquifer storage recovery such that, pumping rate less than or equal to recharge rate, fate of contaminants' as they move beneath the recharge basin till reaches the groundwater table, distance of the wells from the recharge area to satisfy the travel time required for treatment of the recharged water, etc.

To deal with such issues, a comprehensive user friendly web-enabled "*Conjunctive Use Model for Management of Surface and Ground Water in a recharge basin using concept of MAR and ASR*" application has been developed using a process based semi-analytical models for surface and ground water management of a recharge basin. The model for simulation of aquifer responses due to recharge and extraction of recharged water has been developed by integrating the hydrologic components into basic water balance equation; and the models for simulation of contaminants' fate in the recharge basin and through the soil column underneath have been developed by considering: (i) in-basin mass balance with decay of contaminant and, (ii) 1-dimensional advection-dispersion-decay equation coupled with linearized sorption isotherm equation, respectively. The application will allow users to calculate time-varying depth of water in, and groundwater recharge from, a recharge basin consequent to the pumping in the vicinity of the basin for recovery of recharged water and to simulate the contaminant transport process in the basin and through saturated soil column before mixing with the groundwater. Users will be able to view the results in graphical and tabular form, users can also download and print the results. The recharge component (WE-GREM) has already been hosted in public domain (http:// http://nihroorkee.gov.in/WEGREM/WEGREM.html). The later part, i.e., MAR & ASR component will shortly be hosted in public domain.



Schematic diagram for Recharge and pumping calculation



Schematic diagram for Contaminant Transport

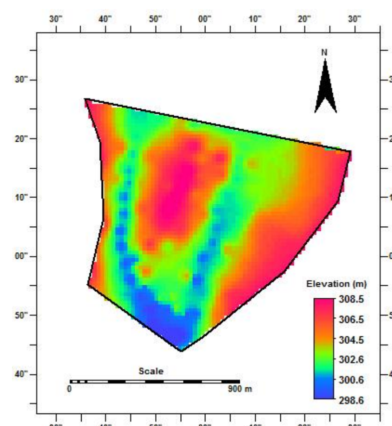
It is observed that there could be groundwater level depletion in the adjoining aquifer systems, and deterioration of river channel. The optimum levels of extraction of sand from river bed without harming either the riverine environment or the aquifer system have been defined based on the simulations for the particular river reach. From the investigations and modeling studies it is inferred that sustainability of the river as well as aquifer has to be maintained while removing bed load material from the river. Maintaining sustainable limits of groundwater levels in the adjoining aquifer system is important to ensure dependability on well discharges to support agriculture and domestic requirements. Site-specific guidelines based on the inferences of the study can be of use while framing policies for sustainable levels of sand mining and regulating such activities with a view to environmental protection. The study is expected to help in framing sustainable policy and eco-friendly guidelines while permitting extraction of river bed material for commercial use.

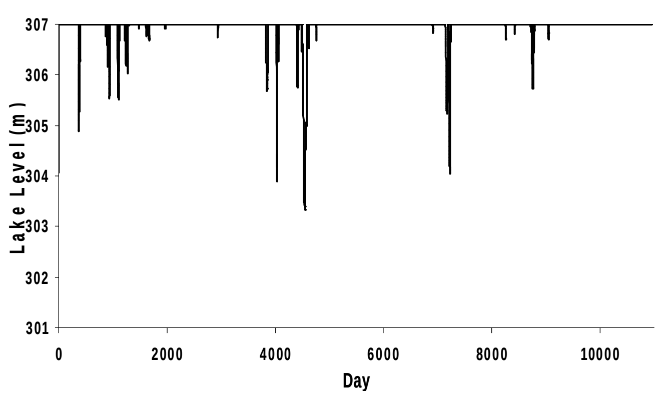
40. Hydrological Evaluation of an Artificial Lake

In the year 2007-08, an artificial lake was planned to be developed by the I&FC Department, Govt. of J & K on the River Tawi by constructing a barrage across the river at Jammu and raising the water level to a maximum of 6 m height. This study was taken up by the WHRC, Jammu on the directions of the Governing Body of NIH. The main objective of the study was the hydrological evaluation of the lake.

Only preliminary data about the proposed lake were available. Various ancillary methods and techniques were used and field survey was carried out to develop the minimum database required for the lake. The elevation-area-capacity curves for the lake were prepared using GPS and GIS. Infiltration tests were carried out in lake submergence and hydraulic conductivity was estimated using Guelph permeameter. A groundwater model has been set up for the lake and water loss due to seepage was estimated. The analysis showed negligible seepage from the lake under conditions of impervious embankments and barrage.

A computer model was developed for the simulation analysis of the lake. The model carried out daily lake simulations and estimated the reliability of maintaining the lake above specified elevations for different scenarios of seepage loss rates. Trend analysis for the inflow series was carried out. To account for the decreasing trend of inflows in the Tawi River, various scenarios of inflows were used for simulation analysis. Reliability tables for different scenarios of inflows and seepage losses were prepared which helped the concerned department in arriving at various decisions related to the lake. In general, it is observed that if seepage from lake can be controlled, then higher levels (> 4 m depth) can be maintained with reliability exceeding 80%. Generally, lake depth decreases in winter months due to smaller flows which coincide with the reduced recreation activities in the lake in the season.





Abstracts of forty representative paper: International Journal

Rainfall-runoff modeling through hybrid intelligent system

P. C. Nayak,[1] K. P. Sudheer,[2] and S. K. Jain[3]

Received 27 January 2006; revised 16 January 2007; accepted 21 February 2007; published 13 July 2007.

[1] This study explores the potential of integrating two different artificial intelligence techniques, namely neural network and fuzzy logic, effectively to model the rainfall-runoff process from rainfall and runoff information. The integration is achieved through representing fuzzy system computations in a generic artificial neural network (ANN) architecture, which is functionally equivalent to a fuzzy inference system. The model is initialized by a hyperellipsoidal fuzzy clustering (HEC) procedure, which identifies suitable numbers of fuzzy if-then rules through proper partition of the input space. The parameters of the membership functions are optimized using a nonlinear optimization procedure. The consequent functions are chosen to be linear in their parameters, and a standard least squares error method is employed for parameter estimation. The proposed model is tested on two case studies: Narmada basin in India and Kentucky basin in the United States. The results are highly encouraging as the model is able to explain more than 92% of the variance. The performance of the proposed model is found to be comparable to that of an adaptive neural based fuzzy inference system (ANFIS) developed for both the basins. The number of parameters in the proposed model is fewer compared to ANFIS, and the former can be trained in lesser time. It is also observed that the proposed model simulates the peak flow better than ANFIS. Overall, the study suggests that the proposed model can potentially be a viable alternative to ANFIS for use as an operational tool for rainfall runoff modeling purposes.

Citation: Nayak, P. C., K. P. Sudheer, and S. K. Jain (2007), Rainfall-runoff modeling through hybrid intelligent system, *Water Resour. Res.*, *43*, W07415, doi:10.1029/2006WR004930.

1. Introduction

[2] Rainfall-runoff modeling is one of the most important topics in hydrology and it is an essential measure in water resources planning and development. Modeling of rainfall-runoff dynamics is performed not only to provide a flood warning system to reduce flood risks but also in managing reservoirs particularly during the drought periods. It is well understood that the relationship between precipitation and runoff is extremely complex owing to temporal and spatial variability of watershed characteristics, heterogeneity in precipitation, as well as numerous factors involved in generating runoff. Among the components involved in transforming precipitation to runoff, the dominant ones are evaporation, infiltration, soil moisture, overland flow, and channel flow [*Beven*, 2000]. In addition, soil properties, land use, and geomorphology of watersheds also play an important role. Consequently, modeling the rainfall-runoff process is a complex task.

[3] Over the last 25 years, a large number of studies have been undertaken to enhance our understanding of rainfall runoff process. The modeling techniques can be broadly classified into two classes: the theory-driven (conceptual and physically based) approach and the data-driven (empirical and black box) approach [*Solomatine and Dulal*, 2003]. Although the theory-driven models provide reasonable accuracy, the implementation and calibration of such models can typically present various difficulties [*Duan et al.*, 1992]; requiring sophisticated mathematical tools, and some degree of expertise and experience with the model. Conventional systems−theoretic models like autoregressive models and their variations [*Box and Jenkins*, 1976] suffer from being based on the linear systems theory and may only be marginally suitable in capturing the highly complex, dynamic, and nonlinear rainfall-runoff process [*Jain and Srinivasulu*, 2004]. Owing to the difficulty associated with parameter optimization in nonlinear systems, the development of nonlinear system theoretic models are very limited [*Hsu et al.*, 1995].

[4] It is reported that most of the hydrologic models are still far from perfect and hydrologists need to put the models in better compliance with observations prior to use in forecasting [*Moradkhani et al.*, 2005]. In this context, data-driven models (DDM), which can discover relationships from input-output data without having the complete physical understanding of the system, may be preferable. While such models do not consider any physics of the hydrologic processes, they are, in particular, very useful for river flow forecasting where the main concern is with making accurate predictions of flow at specific river locations. During the last decade, there has been an increased interest in applying artificial neural network (ANN) and fuzzy inference system (FIS), which are the most common DDM tools, to river flow forecasting [*ASCE Task*

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Isotopic characteristics of Indian precipitation

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[1] Hydrogen (^{2}H/^{1}H) and oxygen (^{18}O/^{16}O) isotopic ratios were measured in precipitation (900 samples) collected from several locations in India during the period 2003–2006 (12 locations in 2003 and 18 locations in 2004–2006). The amount of rainfall along with air temperature and humidity were also measured. The meteoric water line developed for India using isotopic data of precipitation samples, namely, δ^2H = 7.93 (±0.06) × δ^{18}O + 9.94(±0.51) (n = 272, r^2 = 0.98), differs slightly from the global meteoric water line. Regional meteoric water lines were developed for several Indian regions (i.e., northern and southern regions of India, western Himalayas) and found to be different from each other (southern Indian meteoric water line, slope is 7.82, intercept or D excess is 10.23; northern Indian meteoric water line, slope is 8.15, intercept is 9.55) which is attributed to differences in their geographic and meteorological conditions and their associated atmospheric processes (i.e., ambient temperature, humidity, organ, and source of vapor masses). The local meteoric water lines developed for a number of locations show wide variations in the slope and intercept. These variations are due to different vapor sources such as the northeast (NE) monsoon that originates in the Bay of Bengal; the southwest monsoon (SW) that originates in the Arabian Sea; a mixture of NE and SW monsoons; retreat of NE and SW monsoons and western disturbances that originate in the Mediterranean Sea. The altitude effect in the isotopic composition of precipitation estimated for western Himalayan region also varies from month to month.

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1. Introduction

[2] The stable isotopes of hydrogen and oxygen can be used to characterize the precipitation and other sources of water in a region or area. Globally, the stable isotopic compositions of precipitation have been explained in the form of a global meteoric waterline (GMWL) by *Craig* [1961]. The GMWL represents the variation of δ^2H with respect to δ^{18}O in precipitation and can be used to identify the source of water, mixing, and other hydrological processes. The meteoric waterline is represented in its generalized form as δ^2H = A × δ^{18}O + d, where A represents the slope and d represents the intercept or D excess (^{2}H excess). The International Atomic Energy Agency (IAEA) of Vienna, Austria, in collaboration with the World Meteorological Organization (WMO), established the Global Network of Isotopes in Precipitation (GNIP) under which water samples are collected to monitor the isotopic composition (δ^2H, δ^{18}O) of precipitation. The data produced from this network form an important asset to isotope hydrology. (These are available at http://isohis.iaea.org.) The regression line for the long-term average of δ^2H and δ^{18}O [*Rozanski et al.*, 1993] data measured for precipitation at 219 stations under WMO-IAEA network adds some precision to the Craig line:

$$\delta^2\mathrm{H} = 8.17(\pm 0.07) \times \delta^{18}\mathrm{O} + 11.27(\pm 0.65), \quad (1)$$

where Vienna standard mean ocean water (VSMOW) was used as the standard for the isotopic measurements. *Kumar et al.* [1982] found the regional meteoric waterline for lower Maner Basin in the state of Andhra Pradesh in southern India, as

$$\delta^2\mathrm{H} = 7.6(\pm 0.4) \times \delta^{18}\mathrm{O} + 6.3(\pm 2.7)\ (n = 26). \quad (2)$$

[3] *Datta et al.* [1991] established similar LMWL for Delhi using the annual weighted mean values for the period 1961–1982 which is similar to that of *Das et al.* [1988] reported for the period 1961–1978.

$$\delta^2\mathrm{H} = 8.39 \times \delta^{18}\mathrm{O} + 11.41\ (r^2 = 0.95). \quad (3)$$

[4] *Datta et al.* [1991] also established LMWL for Delhi using the monthly (equation (4)) and composite weighted mean monthly (equation (5)) isotopic data of monsoon

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Improving real time flood forecasting using fuzzy inference system

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SUMMARY

In order to improve the real time forecasting of foods, this paper proposes a modified Takagi Sugeno (T–S) fuzzy inference system termed as threshold subtractive clustering based Takagi Sugeno (TSC-T–S) fuzzy inference system by introducing the concept of rare and frequent hydrological situations in fuzzy modeling system. The proposed modified fuzzy inference systems provide an option of analyzing and computing cluster centers and membership functions for two different hydrological situations, i.e. low to medium flows (frequent events) as well as high to very high flows (rare events) generally encountered in real time flood forecasting. The methodology has been applied for flood forecasting using the hourly rainfall and river flow data of upper Narmada basin, Central India. The available rainfall–runoff data has been classified in frequent and rare events and suitable TSC-T–S fuzzy model structures have been suggested for better forecasting of river flows. The performance of the model during calibration and validation is evaluated by performance indices such as root mean square error (RMSE), model efficiency and coefficient of correlation (R). In flood forecasting, it is very important to know the performance of flow forecasting model in predicting higher magnitude flows. The above described performance criteria do not express the prediction ability of the model precisely from higher to low flow region. Therefore, a new model performance criterion termed as *peak percent threshold statistics (PPTS)* is proposed to evaluate the performance of a flood forecasting model. The developed model has been tested for different lead periods using hourly rainfall and discharge data. Further, the proposed fuzzy model results have been compared with artificial neural networks (ANN), ANN models for different classes identified by Self Organizing Map (SOM) and subtractive clustering based Takagi Sugeno fuzzy model (SC-T–S fuzzy model). It has been concluded from the study that the TSC-T–S fuzzy model provide reasonably accurate forecast with sufficient lead-time.

1. Introduction

Real time flood forecasting is used to provide timely warning to people residing in flood plains and can alleviate a lot of distress and flood damage. Flood forecasting also provide useful information to water management personnel for making optimal decisions related to flood control structures and reservoirs operation. Floods are natural phenomena and are inherently complex to model. Conventional methods of flood forecasting are based on either simple empirical black box which do not try to mimic the physical processes involved or use complex models which aim to recreate the physical processes and the concept about the behavior of a basin in complex mathematical expressions (Lohani et al., 2005a). In between these two there is a wide variety of models, e.g. deterministic and stochastic, lumped and distributed, event driven and continuous or their combinations (Nielsen and Hansen, 1973; Box and Jenkins, 1976; Lundberg, 1982; Yakowitz, 1985; Yapo et al., 1993; Chatterjee et al., 2001), which are the basis of conventional flood forecasting system. Existing flood forecasting models are highly data specific and complex and make various simplified assumptions (Hecht-Nielsen, 1991; Hykin, 1992). For a reliable forecast Singh (1989) has listed three basic criteria, i.e. accuracy, reliability, and timeliness. Timeliness of forecasting is extremely important and this can be achieved by simple and robust forecasting models.

Recently there has been a growing interest in soft computing techniques viz. artificial neural networks (ANNs) and fuzzy logic. ANNs are basically data driven approach and are considered as black box models (Bishop, 1994) in hydrological context. These models are capable of adopting the non-linear relationship (Hecht-Nielsen, 1991; Flood and Kartam, 1994) between rainfall and runoff as compared to conventional techniques, which assume a linear relationship between rainfall and runoff. ANNs have strong generalization ability, which means that once they have been properly trained,

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Analysis of observed soil moisture patterns under different land covers in Western Ghats, India

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SUMMARY

An understanding of the soil moisture variability is necessary to characterize the linkages between a region's hydrology, ecology and physiography. In the changing land use scenario of Western Ghats, India, where deforestation along with extensive afforestation with exotic species is being undertaken, there is an urgent need to evaluate the impacts of these changes on regional hydrology. The objectives of the present study were: (a) to understand spatio-temporal variability of soil water potential and soil moisture content under different land covers in the humid tropical Western Ghats region and (b) to evaluate differences if any in spatial and temporal patterns of soil moisture content as influenced by nature of land cover. To this end, experimental watersheds located in the Western Ghats of Uttara Kannada District, Karnataka State, India, were established for monitoring of soil moisture. These watersheds possessed homogenous land covers of acacia plantation, natural forest and degraded forest. In addition to the measurements of hydro-meteorological parameters, soil matric potential measurements were made at four locations in each watershed at 50 cm, 100 cm and 150 cm depths at weekly time intervals during the period October 2004–December 2008.

Soil moisture contents derived from potential measurements collected were analyzed to characterize the spatial and temporal variations across the three land covers. The results of ANOVA ($p < 0.01$, LSD) test indicated that there was no significant change in the mean soil moisture across land covers. However, significant differences in soil moisture with depth were observed under forested watershed, whereas no such changes with depth were noticed under acacia and degraded land covers. Also, relationships between soil moisture at different depths were evaluated using correlation analysis and multiple linear regression models for prediction of soil moisture from climatic variables and antecedent moisture condition were developed and tested. A regression model relating near-surface soil moisture (50 cm) with profile soil moisture content was developed which may prove useful when surface soil moisture contents derived from satellite remote sensing are available. Overall results of this study indicate that while the nature of land cover has an influence on the spatio-temporal variability of soil moisture, other variables related to topography may have a more dominant effect.

1. Introduction

Soil moisture in the uppermost 1–2 m of the earth's surface is recognized as a key variable in numerous environmental studies, including those related to meteorology, hydrology, agriculture and climate change. Although the amount of soil water may seem insignificant when compared to the total quantity of water at the global scale, it is this thin layer of soil that controls the success of agriculture and regulates partitioning of precipitation into runoff and sub-surface water storage. Furthermore, soil moisture content is one of the few directly observable hydrological variables that play an important role in quantifying water and energy budgets necessary for climate studies (Jackson, 1993). The important role played by soil moisture on growth of crops/vegetation (Rodriguez-Iturbe, 2000), groundwater recharge (Hodnett and Bell, 1986) and partitioning of rainfall into runoff and infiltration (Merz and Plate, 1997) are well documented. Unlike discharge or climate variables, soil moisture is not monitored regularly – in spite of its importance. Given the tremendous spatial and temporal variability exhibited by soil moisture (Western and Bloschl, 1999), it is very difficult to observe soil moisture at fine spatial and temporal resolutions while covering even moderately large spatial domains. The complexity of the problem is further compounded by the fact that soil moisture varies both in the lateral and vertical directions.

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SCS-CN based time-distributed sediment yield model

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A/*S* ratio;
Curve number;
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SCS-CN method;
Sediment-excess;
Sedimentograph

Summary A sediment yield model is developed to estimate the temporal rates of sediment yield from rainfall events on natural watersheds. The model utilizes the SCS-CN based infiltration model for computation of rainfall-excess rate, and the SCS-CN-inspired proportionality concept for computation of sediment-excess. For computation of sedimentographs, the sediment-excess is routed to the watershed outlet using a single linear reservoir technique. Analytical development of the model shows the ratio of the potential maximum erosion (*A*) to the potential maximum retention (*S*) of the SCS-CN method is constant for a watershed. The model is calibrated and validated on a number of events using the data of seven watersheds from India and the USA. Representative values of the *A*/*S* ratio computed for the watersheds from calibration are used for the validation of the model. The encouraging results of the proposed simple four parameter model exhibit its potential in field application.

Introduction

Estimates of temporal variation of sediment yield are used to address a wide range of water quality and pollution problems through a variety of engineering, natural resource conservation planning, and land management methods. The process of sediment yield is extremely complex and mainly consists of detachment and transport of sediment particles by raindrops and runoff. The sediment particles, during their transport by overland flow, continuously fall due to gravity and are uplifted by the turbulence of flow, depending on the transport capacity of the flow which is largely governed by the rate of surface flow. Various approaches, ranging from empirical to physically based, have been employed to estimate the rate of surface runoff and the associated sediment yield (Wischmeier and Smith, 1965, 1978; Foster and Meyer, 1972; Williams, 1975; Lane and Shirley, 1978; Nearing et al., 1989; Woolhiser et al., 1990; Govindaraju and Kavvas, 1991;

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Hydrological time series modeling: A comparison between adaptive neuro-fuzzy, neural network and autoregressive techniques

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SUMMARY

Time series modeling is necessary for the planning and management of reservoirs. More recently, the soft computing techniques have been used in hydrological modeling and forecasting. In this study, the potential of artificial neural networks and neuro-fuzzy system in monthly reservoir inflow forecasting are examined by developing and comparing monthly reservoir inflow prediction models, based on autoregressive (AR), artificial neural networks (ANNs) and adaptive neural-based fuzzy inference system (ANFIS). To take care the effect of monthly periodicity in the flow data, cyclic terms are also included in the ANN and ANFIS models. Working with time series flow data of the Sutlej River at Bhakra Dam, India, several ANN and adaptive neuro-fuzzy models are trained with different input vectors. To evaluate the performance of the selected ANN and adaptive neural fuzzy inference system (ANFIS) models, comparison is made with the autoregressive (AR) models. The ANFIS model trained with the input data vector including previous inflows and cyclic terms of monthly periodicity has shown a significant improvement in the forecast accuracy in comparison with the ANFIS models trained with the input vectors considering only previous inflows. In all cases ANFIS gives more accurate forecast than the AR and ANN models. The proposed ANFIS model coupled with the cyclic terms is shown to provide better representation of the monthly inflow forecasting for planning and operation of reservoir.

1. Introduction

Forecasting of inflows into a reservoir is of vital importance for the efficient reservoir management and control. Efficient reservoirs management means better reservoir yields and improved flood protection through better operation policy. In general the operation policy for the reservoir may be daily, weekly or monthly depending on the main purpose of the reservoir. A multipurpose reservoir can have varied purposes such as flood control, water supply to industry, agriculture or municipality, and flow augmentation. If the reservoir is operated for flood control during the months of heavy flows the operation may be at vary short intervals such as a day or even several hours. However, in case of other purposes a larger interval of operation may be more practical. The monthly forecasts are generally useful in determining the monthly operation policy of a multipurpose reservoir particularly relating to an allocation problem. A widely used practice is a monthly reservoir operation over a 12-month horizon for managing reservoirs with agricultural allocation as the basic goal. Two important aspects of the monthly flows are: (i) seasonality of the time series is to be preserved, and (ii) correlation structure with the preceding months is to be incorporated.

Time series forecasting is the process of obtaining information from time series data for forecasting purpose using: (i) the self-projecting approach and (ii) cause-and effect approach. The self-projecting time series forecasting approach uses only the time series data of the activity to be forecasted to generate forecasts. The cause-and-effect time series forecasting approach derives forecasts on the basis of establishing relationship between the time series to be forecasted and one or more other series that influence or cause the first time series. Forecasting deals with the systems that receive thousands of inputs interacting in a complex nonlinear fashion and represented as highly noisy application (Atiya et al., 1999). During the last few decades, several types of stochastic models have been developed and proposed (Salas and Smith, 1981) for modeling hydrological time series and generating synthetic stream flows. Some of such stochastic models are autoregressive (AR), Moving Average (MA), Autoregressive Moving Average (ARMA), and Autoregressive Integrated Moving Average (ARIMA). These models are called system theoretic transfer function models because they attempt to establish a linkage between several phenomena without internal description of the physical processes involved. Broadly, the stochastic models are classified as Autoregressive Moving Average (ARMA) models (Box and Jenkins, 1970), disaggregation models (Valencia and Schaake, 1973), and models based on the concept of pattern recognition (Panu and Unny, 1980). According to Hipel (1985) in some cases of hydrological time series modeling a simple

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Suitability of Gamma, Chi-square, Weibull, and Beta distributions as synthetic unit hydrographs

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Summary Most available methods for synthetic unit hydrograph (SUH) derivation involve manual, subjective fitting of a hydrograph through a few data points. Because of this tedious procedure, the generated unit hydrograph is often left unadjusted for unit runoff volume. During recent decades, use of probability distribution functions (pdfs) in developing SUH has received much attention because of its similarity with unit hydrograph properties. In this study, the potential of four popular pdfs, i.e., two-parameter Gamma, three-parameter Beta, two-parameter Weibull, and one-parameter Chi-square distribution to derive SUH have been explored. Simple formulae are derived using analytical and numerical schemes to compute the distribution parameters, and their validity is checked with simulation of field data. The Gamma and Chi-square distributions behave analogously, and the Beta distribution approximates a Gamma distribution in a limiting case. Application to field data shows that the Beta and Weibull distributions are more flexible in hydrograph prediction than the Gamma, Chi-square, Gray [Gray, D.M., 1961. Synthetic hydrographs for small drainage areas. In: Proceedings of the ASCE, 87, HY4, pp. 33–54], SCS [SCS, 1957. Use of Storm and Watershed Characteristics in Synthetic Hydrograph Analysis and Application: V. Mockus. US Dept. of Agriculture, Soil Conservation Service, Washington, DC], and Snyder [Synder, F.F., 1938. Synthetic unit hydrographs. Trans. Am. Geophys. Union 19, 447–454] methods. A sensitivity analysis of pdf parameters on peak flow estimates of an UH indicated that Gamma and Chi-square distributions overestimate the peak flow value, for any overestimation in its parameter estimates. However, for the Beta and Weibull distributions a reverse trend was observed. Both were found to behave similarly at higher α (ratio of time to base and time to peak of UH) values. Further, an analogous triangular hydrograph approach was used to express the mean and variance of the UH in terms of time base and time to peak of the UH. This enabled a simple

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The impact of forest use and reforestation on soil hydraulic conductivity in the Western Ghats of India: Implications for surface and sub-surface hydrology

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SUMMARY

There is comparatively limited information in the humid tropics on the surface and sub-surface permeability of: (i) forests which have been impacted by multi-decades of human occupancy and (ii) forestation of land in various states of degradation. Even less is known about the dominant stormflow pathways for these respective scenarios. We sampled field saturated hydraulic conductivity, K^* at 23 sites at four depths (0 m, $n = 166$), (0.10 m, $n = 139$), 0.45–0.60 m, $n = 117$, (1.35–1.50 m, $n = 117$) under less disturbed forest (Forest), disturbed production forest of various local species (Degraded Forest) and tree-plantations (*Acacia auriculiformes*, 7–10 years old, *Tectona grandis*, ~25–30 years old, *Casuarina equisetifolia*, 12 years old) in the Uttar Kannada district, Karnataka, India, in the Western Ghats. The sampling strategy was also undertaken across three physiographic blocks and under three main soil types. Subsequently the determined K^* were then linked with rainfall intensity–duration–frequency (IDF) characteristics to infer the dominant stormflow pathways.

The Degraded Forest shows an *order of magnitude decline* in K^* at the surface as result of human impacts at decadal to century time scales. The lowest surface permeability is associated with the Degraded Forests over the Laterite (*Eutric Nitosols* and *Acrisols*) and Red soils (*Eutric Nitosols*) and infiltration-excess overland flow, IOF probably occurs. Further there is a progressive decline in K^* with depth in these soils supporting Degraded Forests. The *A. auriculiformes* plantations over the Red and Lateritic soils are progressively restoring the near-surface K^*, but their K^* still remain *quite low* when compared to the less disturbed forest permeability. Consequently these plantations still retain the 'memory' from the previous degraded state. In contrast the permeability of the Black soils (Vertisols) are relatively insensitive to *T. grandis* plantations and this soil group has a very low K^*, irrespective of land cover, so that IOF likely prevails. Overall, the Laterites are the most variable in K^* when compared to the other soil groups. Thus when compared to other studies, IOF is probably more prevalent in this region. More especially so, when taking into account the marked reduction in surface K^* during the wet season when compared to dry season measurements. In addition, we have demonstrated the potential for the 'infiltration – trade-off' hypothesis to be realized in this landscape under certain conditions of land degradation and restoration. It is most relevant to the combination of degraded sites and *A. auriculiformes* plantations on Red or Laterite soils using the less disturbed forests as the baseline. The intensity of forest use and effects of monoculture plantations on soil ecology (relative to native, mixed forests) is likely to be the critical factor in affecting surface K^* over time. Predicted changes in the intensity of rain events in the future is likely to enhance overland flow on degraded sites on all soils and especially on Black soils, and restoration efforts by all stake-holders, preferably using native or non-invasive species, are needed to address this concern.

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A neuro-fuzzy computing technique for modeling hydrological time series

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Abstract

Intelligent computing tools such as artificial neural network (ANN) and fuzzy logic approaches are proven to be efficient when applied individually to a variety of problems. Recently there has been a growing interest in combining both these approaches, and as a result, neuro-fuzzy computing techniques have evolved. This approach has been tested and evaluated in the field of signal processing and related areas, but researchers have only begun evaluating the potential of this neuro-fuzzy hybrid approach in hydrologic modeling studies. This paper presents the application of an adaptive neuro fuzzy inference system (ANFIS) to hydrologic time series modeling, and is illustrated by an application to model the river flow of Baitarani River in Orissa state, India. An introduction to the ANFIS modeling approach is also presented. The advantage of the method is that it does not require the model structure to be known a priori, in contrast to most of the time series modeling techniques. The results showed that the ANFIS forecasted flow series preserves the statistical properties of the original flow series. The model showed good performance in terms of various statistical indices. The results are highly promising, and a comparative analysis suggests that the proposed modeling approach outperforms ANNs and other traditional time series models in terms of computational speed, forecast errors, efficiency, peak flow estimation etc. It was observed that the ANFIS model preserves the potential of the ANN approach fully, and eases the model building process.

Keywords: Neural networks; Fuzzy logic; Fuzzy inference system; Time series modeling; Hydrological modeling

1. Introduction

Time series modeling for either data generation or forecasting of hydrologic variables is an important step in the planning and operational analysis of water resources. Traditionally, autoregressive moving average (ARMA) models have been used for modeling water resource time series because such models are accepted as a standard representation of

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Distribution of trace metals in the Hindon River system, India

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Abstract

The distribution of trace metals (Cu, Zn, Fe, Mn, Cd, Cr, Pb, and Ni) in water, suspended and bed sediments of the River Hindon, a highly polluted river in western Uttar Pradesh (India) has been studied. The river is polluted by municipal, industrial and agricultural effluents, and flows through the city of Saharanpur, Muzaffarnagar and Ghaziabad districts. The heavy metal concentrations in water were observed to depend largely on the amount of flowing water and are negatively correlated with flow. Sediment analysis indicates that the large amount of heavy metals is associated with organic matter, the fine-grained sediment fraction and Fe/Mn hydrous oxides. A high positive correlation of most of the metal ions in sediments with iron, manganese and organic matter indicate that these constituents play a major role in transport of metal ions. The heavy metal concentrations generally increased with the decreasing particle size of the sediments. Lower metal concentrations in bed sediments during post-monsoon season established that monsoon had a slight effect on status of metals in sediments by causing renewal and mobilization of metals from the sediments.

Keywords: Trace metals; Distribution; Bed sediments; River system

1. Introduction

In recent years, the fluxes of trace metals from terrestial and atmospheric sources to the aquatic environment have increased considerably (Forstner and Wittmann, 1981). Numerous studies have demonstrated that the determination of metal concentrations in suspended and bed sediments is more sensitive than the dissolved concentrations as indicators of contamination in hydrologic systems (Salomons and Forstner, 1984; Luoma, 1990). The presence of trace metals in sediments is affected by the particle size and composition of sediments (Yamagata and Shigematsu, 1970; Foster and Hunt, 1975; Hiraizumi et al., 1978; Asami and Sampei, 1979; Ogura et al., 1979; Forstner and Wittmann, 1981; Thorne and Nickless, 1981; Kristensen, 1982; Thomson et al., 1984; Sakai et al., 1986; Raymahashay, 1987; Krumlgalz, 1989; Combest, 1991; Sabri et al., 1993).

More than 97% of the mass transport of metals to oceans is associated with river sediments (Gibbs, 1977). A variety of factors such as basin geology, physiography, chemical reactivity, lithology, mineralogy, hydrology, vegetation, land use pattern and biological productivity regulate the metal load of a river system (Garrels et al., 1975; Warren, 1981; Aurada, 1983; Zhang and Huang, 1993). Martin and Meybeck (1979) studied elemental mass balance of material carried by major world rivers. Due to the relative mobility of metals during transport processes, sediment can reflect the present quality of the basin and the historical development of various hydrological and chemical parameters.

The metal contribution from Indian rivers, which carry 20% of the global supply of sediments to the

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Impact assessment of climate change on the hydrological response of a snow and glacier melt runoff dominated Himalayan river

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Abstract

The effect of climate change on snow water equivalent, snowmelt runoff, glacier melt runoff and total streamflow and their distribution is examined for the Spiti river. This is a high altitude Himalayan river located in the western Himalayan region. The total streamflow of this river has a significant contribution from snow and glacier melt runoff. Plausible hypothetical scenarios of temperature and precipitation changes based on the simulation of climate change over the Indian subcontinent by the Hamburg climate model are adopted in the present study. The UBC watershed model was used to simulate the hydrological response of the basin under changed climatic scenarios. The adopted changes in temperature and precipitation covered a range from 1 to 3°C and from −10 to +10%, respectively.

Snow water equivalent reduces with an increase in air temperature. However, no significant change is found in the snow water equivalent of the Spiti basin by the projected increase in air temperature ($T + 1$ to $T + 3$°C). An increase of 2°C in air temperature reduced annual snow water equivalent in the range of 1 to 7%. Changes in precipitation caused proportional changes in snow water equivalent. It is found that annual snowmelt runoff, glacier melt runoff and total streamflow increase linearly with changes in temperature (1–3°C), but the most prominent effect of increase in temperature has been noticed on glacier melt runoff for this high altitude basin. For example, an increase of 2°C in air temperature has enhanced annual snowmelt runoff, glacier melt runoff and total streamflow in the range of 4–18%, 33–38% and 6–12% respectively. The effect of change in precipitation (P–10 to P+10%) suggests a linear increase in snowmelt runoff and total streamflow, while, in general, glacier melt runoff is inversely related to changes in precipitation. Snowmelt runoff is found more sensitive than glacier melt runoff to changes in precipitation (P–10 to P+10%). Under a warmer climate scenario, snowmelt runoff and glacier melt runoff cause an earlier response of total streamflow and a change in flow distribution. The seasonal analysis of total streamflow indicates that an increase in air temperature produces an increase in the pre-monsoon season followed by an increase in the monsoon season. Implications of such seasonal changes are also briefly discussed. © 1997 Elsevier Science B.V.

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Application of the SHE to catchments in India Part 2. Field experiments and simulation studies with the SHE on the Kolar subcatchment of the Narmada River

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ABSTRACT

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The results of SHE modelling of the 820 km^2 Kolar catchment in Madhya Pradesh, Central India are presented. The data collection, the associated field investigations, the calibration and the modelling results are discussed along with the assessment of model parameters. Based on the experiences obtained in this study from modelling and field experiments, the necessity of fieldwork and the hydrological realism of the final model representation of the basin are discussed.

INTRODUCTION

Hydrological modelling of the Kolar catchment, a subcatchment of the River Narmada in Madhya Pradesh, Central India, was carried out within the framework of a cooperative project between the National Institute of Hydrology (NIH), Roorkee, India, and the three European organizations currently responsible for development of the Système Hydrologique Européen (SHE). For further details of the project, recent SHE developments and general conclusions regarding SHE applications to six subcatchments of the River Narmada, India, reference is made to National Institute of Hydrology (NIH) (1991) and to Part 1 of this paper (Refsgaard et al., 1992).

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Study of indices for drought characterization in KBK districts in Orissa (India)

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Abstract:

Drought is a temporary, random and regional climatic phenomenon, originating due to lack of precipitation leading to water deficit and causing economic loss. Success in drought alleviation depends on how well droughts are defined and their severity quantified. A quantitative definition identifies the beginning, end, spatial extent and the severity of drought. Among the available indices, no single index is capable of fully describing all the physical characteristics of drought. Therefore, in most cases it is useful and necessary to consider several indices, examine their sensitivity and accuracy, and investigate for correlation among them. In this study, the geographical information system-based Spatial and Time Series Information Modeling (SPATSIM) and Daily Water Resources Assessment Modeling (DWRAM) software were used for drought analysis on monthly and daily bases respectively and its spatial distribution in both dry and wet years. SPATSIM utilizes standardized precipitation index (SPI), effective drought index (EDI), deciles index and departure from long-term mean and median; and DWRAM employs only EDI. The analysis of data from the Kalahandi and Nuapada districts of Orissa (India) revealed that (a) droughts in this region occurred with a frequency of once in every 3 to 4 years, (b) droughts occurred in the year when the ratio of annual rainfall to potential evapotranspiration (Pae/PET) was less than 0·6, (c) EDI better represented the droughts in the area than any other index; (d) all SPI, EDI and annual deviation from the mean showed a similar trend of drought severity. The comparison of all indices and results of analysis led to several useful and pragmatic inferences in understanding the drought attributes of the study area. Copyright © 2007 John Wiley & Sons, Ltd.

KEY WORDS decile index; drought severity; drought duration; drought vulnerability; drought indices; effective drought index; standardized precipitation index

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INTRODUCTION

Drought characteristics over a region are primarily governed by regional climatic factors. Owing to a rise in global temperature, Earth is more likely to be subjected to frequent and prolonged hot days and dry spells and fewer frost and cold spells (Rosenberg, 1986). An increased frequency of dry spells often triggers a drought situation to arise, which leads to adverse economic and social impacts. Developing countries like India and others particularly suffer significantly from droughts. To improve our comprehension of the impacts of drought, it is necessary to understand the phenomenon and its progression in both qualitative and quantitative terms.

Rainfall data are widely used to calculate drought severity because long-term rainfall records are more readily available than other climatic or hydrological data. Though rainfall alone may not represent the spectrum of the entire drought attributes, it is the primary indicator of drought and is the basis of most drought watch systems. Therefore, it is necessary to understand the probability and frequency distribution of rainfall before examining droughts (Gibbs, 1987). Factors like the ocean–atmosphere system, sea-surface temperature anomalies, high albedo, solar–weather relationships, monsoon mechanism, extra-tropical factors, etc. that control the amount of rainfall also control drought attributes (Ponce *et al.*, 2000).

Several indices under different categories of drought have been developed in the past to characterize the drought, its attributes, and its impacts. The study of drought can be classified into four categories (Byun and Wilhite, 1999):

1. The cause of drought, understanding atmospheric circulation with respect to the occurrence of drought.
2. Determining the frequency and severity of drought to characterize the probability distribution of droughts of various magnitudes.
3. Evaluation of the impacts of drought and the loss and cost involved due to occurrences of drought.
4. Response, preparedness, appropriate mitigation and reduction of impacts.

Most of the work has been carried out in categories 1 and 2. Currently, work on category 4 is gaining momentum, with more emphasis on the development of a robust system to understand the drought before the remedial measures are suggested.

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Rainfall-runoff modelling using artificial neural networks: comparison of network types

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Abstract:

Growing interest in the use of artificial neural networks (ANNs) in rainfall-runoff modelling has suggested certain issues that are still not addressed properly. One such concern is the use of network type, as theoretical studies on a multi-layer perceptron (MLP) with a sigmoid transfer function enlightens certain limitations for its use. Alternatively, there is a strong belief in the general ANN user community that a radial basis function (RBF) network performs better than an MLP, as the former bases its nonlinearities on the training data set. This argument is not yet substantiated by applications in hydrology. This paper presents a comprehensive evaluation of the performance of MLP- and RBF-type neural network models developed for rainfall-runoff modelling of two Indian river basins. The performance of both the MLP and RBF network models were comprehensively evaluated in terms of their generalization properties, predicted hydrograph characteristics, and predictive uncertainty. The results of the study indicate that the choice of the network type certainly has an impact on the model prediction accuracy. The study suggests that both the networks have merits and limitations. For instance, the MLP requires a long trial-and-error procedure to fix the optimal number of hidden nodes, whereas for an RBF the structure of the network can be fixed using an appropriate training algorithm. However, a judgment on which is superior is not clearly possible from this study. Copyright © 2004 John Wiley & Sons, Ltd.

KEY WORDS rainfall-runoff modelling; ANN model; feed-forward network; multi-layer perceptron; radial basis function network; Indian river basin

INTRODUCTION

The rainfall–runoff relationship is one of the most complex hydrological phenomena to comprehend, owing to the tremendous spatial and temporal variability of watershed characteristics and precipitation patterns, and to the number of variables involved in the modelling of the physical process. Although hydrologists have been modelling rainfall-runoff processes since the mid-19th century, it is only in the last decade that artificial neural network (ANN) models have been applied to the same task. This interest has been motivated by the complex nature of hydrological systems and the ability of ANNs to model nonlinear relationships. ANNs are essentially semi-parametric regression estimators and are well suited for hydrologic modelling, as they can approximate virtually any (measurable) function up to an arbitrary degree of accuracy (Hornik *et al.*, 1989). The emergence of neural network technology has provided many promising results in the field of hydrology and water resources simulation. A comprehensive review of the application of ANNs to hydrology can be found in ASCE Task Committee on Application of Artificial Neural Networks in Hydrology (2000a,b) and in Maier and Dandy (2000).

Despite a plethora of studies on rainfall-runoff modelling using ANNs, there are still certain issues that need attention, such as optimal network structure, choice of transfer function or network type, and choice of training algorithm (Sudheer, 2000). The transfer functions that are most commonly employed in ANNs are sigmoidal-type functions, such as the logistic and hyperbolic tangent functions (Maier and Dandy, 2000). However,

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Refinement of predictive reaeration equations for a typical Indian river

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Abstract:

Dissolved oxygen mass balance has been computed for different reaches of River Kali in western Uttar Pradesh (India) to obtain the reaeration coefficient (K_2). A total of 270 field data sets have been collected during the period from March 1999 to February 2000. Eleven most popular predictive equations, used for reaeration prediction and utilizing mean stream velocity, bed slope, flow depth, friction velocity and Froude number, have been tested for their applicability in the River Kali using data generated during field survey. The K_2 values computed from these predictive equations have been compared with the K_2 values observed from dissolved oxygen balance measurements in the field. The performance of predictive equations have been evaluated using error estimation, namely standard error (SE), normal mean error (NME), mean multiplicative error (MME) and correlation statistics. The equations developed by Smoot and by Cadwallader and McDonnell showed comparatively better results. Moreover, a refined predictive equation has been developed using a least-squares algorithm for the River Kali that minimizes error estimates and improves correlation between observed and computed reaeration coefficients. Copyright © 2001 John Wiley & Sons, Ltd.

KEY WORDS correlation coefficient; dissolved oxygen; error estimation; predictive equations; reaeration coefficient

INTRODUCTION

The presence of dissolved oxygen in water is the primary criterion for the water quality of streams. Use of the reaeration coefficient, K_2, is essential for dissolved oxygen computation, to model streams and to allocate waste loads. The theoretical background to the reaeration coefficient is available in many studies. As per two-film theory (Lewis and Whiteman, 1924; Eckenfelder and O'Connor, 1961; Cleasby and Baumann, 1968; Metcalf and Eddy Inc., 1979; Manual of Practice for Water Pollution Control, 1988), mass transfer of oxygen occurs, through the gas and liquid interface, through a laminar flow in the two films (one gas and one liquid) and through turbulent flow in the body of the liquid, until a dynamic equilibrium is established. The rate of mass transfer, dD/dt, of oxygen from the atmosphere to the body of the turbulent liquid generally is proportional to the difference between the existing concentration D and the equilibrium or saturation concentration D_0 of oxygen in the liquid. The mathematical expression can be written as

$$\frac{dD}{dt} = (K_2)_T[D_0 - D] \quad (1)$$

where $(K_2)_T$ is the reaeration coefficient at test temperature T(°C). The value of $(K_2)_T$ is related to the value $(K_2)_{20}$ as follows

$$(K_2)_T = (K_2)_{20} \times 1{\cdot}024^{(T-20)} \quad (2)$$

For experimental appraisal of K_2, there are three basic approaches, namely, the dissolved oxygen balance technique (Streeter and Phelps, 1925; Churchill *et al.*, 1962), the distributed equilibrium technique (Zogorski

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Water Table Fluctuation in the Presence of a Time-Varying Exponential Recharge and Depth-Dependent ET in a Two-Dimensional Aquifer System with an Inclined Base

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Abstract: An analytical solution is presented for water table fluctuation between ditch drains in presence of exponential recharge and depth-dependent evapotranspiration (ET) from groundwater table in a two-dimensional gently sloping aquifer. The groundwater head above the drain is small compared to the saturated thickness of the aquifer. A sound mathematical transformation is devised to transform the two-dimensional groundwater flow equation into a simple form, which makes possible to obtain an analytical solution. The transient midpoint water table variations from the proposed solution compare well with the already existing solutions for horizontal aquifer. A numerical example is used to illustrate the combined effect of depth-dependent ET coupled with a time-varying exponential recharge on the water table fluctuation. The inclusion of a depth-dependent ET in the solution results in water table decline at a faster rate as compared to the case when ET is not considered. With an increase in slope of the aquifer base, water table profiles become asymmetric and the water table divide shifts towards the lower drain. The height of the water table profiles increases on moving away from the boundary of the aquifer and the highest level of the ground water table is obtained in the central portion of the aquifer basin due to the presence of drainage ditches on the aquifer boundary. When the effect of ET is incorporated in combination with recharge, the analytical solution results in accurate and reliable estimates of water table fluctuations under situations subjected to a number of controlling factors. This study will be useful for alleviation of drainage problems of the aquifers receiving surface recharge and surrounded by streams.

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CE Database subject headings: Analytical techniques; Drainage; Water table; Slopes; Aquifers.

Author keywords: Analytical solution; Drainage; ET; Recharge; Water table fluctuation; Sloping aquifer.

Introduction

Water table rise is a common occurrence in basins subjected to irrigation through canals in many parts of arid and semi-arid regions of the world. In this process seepage from canal beds, recharge from irrigated lands, and other sources leads to a rise in water table causing water logging, salinity, and a reduction in plant growth. These problems can be alleviated by providing adequate subsurface drainage. Schmid and Luthin (1964) reported problem areas in the pre-Alps in Switzerland and adjacent countries requiring drainage on sloping lands. Evapotranspiration (ET) seems the most significant factor amongst all processes in extraction of water from croplands of arid and semi-arid regions. Upadhyaya and Chauhan (1998) proposed a numerical solution of the one-dimensional nonlinear form of the Boussinesq equation and found that the analytical solutions even of linearized forms of the Boussinesq equation may be adopted for predicting water table heights for practical purposes provided the simplifying assumptions for the linearization are satisfied. A numerical solution of the Boussinesq equation for predicting the water table as affected by ET and drain outflow has been reported by Skaggs (1975). Gardner and Fireman (1958), Grismer and Gates (1988), Nikam et al. (1992), and Singh et al. (1996) proposed ET as a function of depth to ground water table in arid and semi-arid lands. An analytical solution for bi-level drainage is given by Upadhyaya and Chauhan (2000) incorporating the effect of ET as a function of water table height. They have shown the importance of ET in reducing the drainage costs. Cook and Rassam (2002) proposed an analytical model for water table dynamics for the case of drainage coupled with evaporation and highlighted the importance of incorporating the effect of evaporation in the drainage design.

A numerical solution of two-dimensional free surface flow to ditch drains in homogeneous and anisotropic soils with constant replenishment and instantaneous drawdown has been reported by Kumar et al. (2000). Singh and Rai (1980), Rai and Singh 1992, Rai et al. 1994), Ram and Chauhan (1987), Singh et al. (1991), and Ramana et al. (1995) studied the water table variation affected by the rate of recharge and concluded that reduction in the rate of recharge causes significant reduction in the rise of water table height. An analytical solution of a two-dimensional Boussinesq equation is presented by Manglik and Rai (2000) to predict the water table fluctuations in an unconfined aquifer due to time-varying recharge and withdrawal from multiple basins and wells using the finite Fourier sine transform. A numerical solution using a finite-difference technique has been proposed by Singh and Jaiswal (2006) for two-dimensional (2D) water table fluctuation

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Regional Flood Frequency Analysis Using L-Moments for North Brahmaputra Region of India

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Abstract: Data of 13 stream flow gauging sites of the North Brahmaputra region of India are screened using the discordancy measure (D_i) and homogeneity of the region is then tested employing the L-moments based heterogeneity measure (H). For computing heterogeneity measure H, 500 simulations are performed using the Kappa distribution. Based on this test, it is observed that the data of 10 out of 13 gauging sites constitute a homogeneous region. Comparative regional flood frequency analysis studies are conducted employing the L-moments based commonly used frequency distributions. Based on the L-moment ratio diagram and $|Z_i^{\mathrm{dist}}|$-statistic criteria, general extreme value (GEV) distribution is identified as the robust distribution for the study area. Regional flood frequency relationships are developed for estimation of floods of various return periods for gauged and ungauged catchments using the L-moment based GEV distribution and a regional relationship between mean annual peak flood and catchment area. Flood frequency estimates of gauged and ungauged catchments are compared; when, without meeting the criteria of regional homogeneity, data of all 13 gauging sites are used instead of data of only 10 gauging sites constituting the homogeneous region.

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CE Database subject headings: Flood frequency; India; Frequency analysis; Measurement.

Introduction

Design of different types of hydraulic structures and flood plain zoning, economic evaluation of flood protection projects, etc. require information on flood magnitudes and their frequencies. Regional flood frequency analysis resolves the problem of estimation of the extreme flood events for the catchments having short data records or ungauged catchments by substituting space for time data from various sites for estimating floods of different return periods, particularly for small- to medium-size catchments. Pilgrim and Cordery (1992) mention that estimation of peak flows on small- to medium-sized rural drainage basins is probably the most common application of flood estimation as well as being of greatest overall economic importance. In almost all cases, no observed data are available at the design site, and little time can be spent on the estimate, precluding use of other data in the region. The writers further state that hundreds of different methods have been used for estimating floods on small drainage basins, most involving arbitrary formulas. The three most widely used types of methods are the rational method, the U.S. Soil Conservation Service method, and regional flood frequency methods. The choice of method generally depends on the design criteria applicable to the structure and availability of data. As per Indian design criteria, frequency based floods find their applications in estimation of design floods for almost all the types of hydraulic structures such as small size dams, spillways, barrages, weirs, road and railway bridges, culverts, urban drainage systems, cross drainage structures, flood control structures, flood plain zoning, economic evaluation of flood protection projects, etc., excluding large and intermediate size dams. For design of large and intermediate size dams probable maximum flood and standard project flood are adopted, respectively (NIH 1992).

In India, a number of studies have been carried out for the estimation of design floods for various structures by different organizations. Prominent among these include the studies carried out jointly by the Central Water Commission (CWC), Research Designs and Standards Organization (RDSO), and India Meteorological Department (IMD) using the method based on synthetic unit hydrograph and design rainfall considering physiographic and meteorological characteristics for estimation of design floods (e.g., CWC 1987) and regional flood frequency studies conducted by RDSO using the USGS and pooled curve methods (e.g., RDSO 1991) for some of the hydrometeorological subzones of India. Besides these, regional flood frequency studies have also been carried out at some of the academic and research Institutions (e.g., Kumar et al. 1999). Several recent studies illustrate applications of L-moments in frequency analysis of environmental data sets (Hosking 1991; Stedinger et al. 1992; Guttman et al. 1993; Hosking and Wallis 1993; Vogel and Wilson 1996). Hosking and Wallis (1997) presented complete account of the L-moments approach in regional frequency analysis.

In this study, regional flood frequency relationships are developed, based on the L-moments approach for the gauged and ungauged catchments of the North Brahmaputra region of India. For this purpose, various frequency distributions, namely, extreme value (EV1), general extreme value (GEV), logistic (LOS), generalized logistic (GLO), normal (NOR), generalized normal (GNO), uniform (UNF), Pearson type-III (PE3), exponential (EXP), generalized pareto (GPA), kappa (KAP), and five param-

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Conjunctive Use of Surface and Groundwater for Coastal and Deltaic Systems

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Abstract: A regional conjunctive use model is developed for a near-real deltaic aquifer system, irrigated from a diversion system, with some reference to hydrogeoclimatic conditions prevalent in the east coastal deltas of India. Water resources are sufficiently available in these regions under average monsoon rainfall conditions, but their distribution in space and time has been ever challenging to water managers. Surface-water availability shows temporal fluctuations in terms of floods and droughts, and groundwater availability shows mainly spatial variability in terms of quality and quantity due to the hydrogeologic setting, boundary conditions, and aquifer properties. The combined simulation-optimization model proposed in this study is solved as a nonlinear, nonconvex combinatorial problem using a simulated annealing algorithm and an existing sharp interface model. The computational burden is managed within practical time frames by replacing the flow simulator with artificial neural networks and using efficient algorithmic guidance.

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Introduction

Conjunctive use has been defined in more ways than one, but in general it is defined as the allocation of surface water and groundwater in terms of quantity and/or quality so as to achieve one or more objectives while satisfying certain constraints. Coe (1990) defined conjunctive use with reference to stream diversion (or run-of-the-river) systems as the management of groundwater/surface water in a coordinated operation to the end that the total yield of such a system over a period of years exceeds the sum of yields of the separate components of the system resulting from an uncoordinated operation.

Management of water resources in coastal and deltaic regions irrigated by run-of-the-river schemes involves primarily two issues: First, availability of water resources in space and time, and second, seawater intrusion. Improper management arising out of excessive irrigation or increased groundwater exploitation often leads to waterlogging or seawater intrusion problems, respectively. Any conjunctive use model must address these two issues for application to coastal and deltaic regions.

Two general approaches have been used to simulate seawater intrusion in coastal aquifers. The freshwater and saltwater zones within an aquifer are separated by a transition zone in which there is a gradual change in density. The disperse interface approach explicitly represents the presence of this zone. Although disperse density dependent flow and transport models (Huyakorn et al. 1987; Das and Datta 1999) are presently available, their use in management models has been somewhat limited because of high computational burden. The second approach to the analysis of seawater intrusion problems is based on the simplifying assumption that the transition zone can be represented by a sharp interface (Bear and Dagan 1964; Polo and Ramis 1983; Essaid 1990; Bakker 2003).

Combined simulation-optimization models (Gorelick 1983) have been widely used to address the management issues. Willis and Finney (1988), Emch and Yeh (1998), and Das and Datta (1999), among others, have proposed a number of groundwater management models applicable for coastal aquifers. Although a number of studies have been reported on management issues related to coastal aquifers in general, not much attention has been paid to the issues unique to groundwater management in deltaic regions.

Also, as stated by Emch and Yeh (1998), the objectives and constraints in a coastal or deltaic aquifer management model are typically nonlinear, and therefore use of gradient-based methods for solving the optimization problem is beset with difficulties. Gradient-based methods for these problems are liable to get trapped in a local minimum. During the last 10 to 15 years, heuristic or nonexact methods have been developed for the purpose of correcting this problem. Among these, simulated annealing (SA) (Dougherty and Marryott 1991) and genetic algorithm (GA) are the two most popular methods. More recently, Wang and Zheng (1998) and Cunha (1999) have demonstrated the application of SA to hypothetical groundwater management problems in noncoastal regions.

Description of Study

Several coastal deltas of east India evolved during the Quaternary period with the deposition of sediment from large river basins

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Regional Flow-Duration Models for Large Number of Ungauged Himalayan Catchments for Planning Microhydro Projects

By R. D. Singh,[1] S. K. Mishra,[2] and H. Chowdhary[3]

Abstract: In the Himalayan region of India, most prospective sites for microhydro projects are ungauged and there are insignificant data for analysis. Design flow estimates are made using a regional flow-duration curve. Regional studies on Himalayan watersheds do not appear to have been reported in the literature. Therefore, models are developed for 1,200 ungauged watersheds of the Lower Himalayas. To this end, the region, comparatively larger in size than the catchment, is assumed to be hydrometeorologically homogeneous in its behavior. Formulation of models is based on data transfer between gauged watersheds of the same region, statistical normalization, and empirical regional relation. The performance of a specific model developed for Himachal Pradesh (Region C) is evaluated using the data of 13 watersheds in calibration and 4 watersheds in validation. It is found that the statistical approach of quantile estimation (nondimensional) performs satisfactorily in calibration as well as in validation. The simple power relation for mean flow-estimation, as well as the complete model, performs well in calibration and less satisfactorily in validation because of the short length of data.

INTRODUCTION

Electricity forms an integral part of modern social life. Similar to most developing countries, India is also facing power problems due to various reasons. The deficit is more in hilly areas, restricting opportunities for human settlement there. Consequently, large-scale micro-hydropower projects are being developed to cater to the power demands of these areas. For the dependable design of these projects, flow-duration curves are developed. As high dependability corresponds to low magnitude of flow, the project design is primarily concerned with the problem of low-flow estimation.

Low-flow estimation is more difficult than the estimation of high flow (Thomas and Benson 1975), especially at ungauged sites on either minor or principal natural streams (Frye and Runner 1970). Therefore, techniques of classifying watersheds into physiographic types and transferring low-flow data in dimensionless or specific form between watersheds within the same region were developed [e.g., Ineson and Downing (1965), McMahon (1969), Weyer and Karrenbury (1970), Riggs (1973), Simmers (1975), Musiake et al. (1975), Hines (1975), Yoon (1975), and Rodda et al. (1976)]. Most of the studies employed size, shape, and climatic characteristics and a few employed geological characteristics of the watersheds (for example, slope and area) for predicting mean flows (Wright 1970), leading to the development of numerical geological indices [e.g., Wright (1970, 1974), and Demuth and Hagemann (1994)]. Wesche and Richard (1973) and Skelton (1974) used cross-sectional properties of streams and Klassen and Pilgrim (1975) and Armbruster (1976) respectively developed flow recession and infiltration indices for deriving dependable flows.

The U.S. Geological Survey, Concord, New Hampshire, cataloged a large number of flow-duration curves obtained from spot gaugings at points not normally gauged, and Dingman (1978) synthesized these curves for ungauged points on unregulated streams, using mean basin elevation. Dingman found that mean flow relied on elevation, positive vertical precipitation gradients, and negative vertical evapotranspiration gradients. The contributions of several studies published by the Institute of Hydrology (IOH) (1980) revealed the paramount importance of regional relationships for low-flow estimation at ungauged sites and, consequently, led to the development of regional flow-estimation procedures.

Quimpo et al. (1983) estimated water availability at ungauged small hydropower sites in the Philippines using flow-duration and watershed characteristics (drainage area) and taking into account the spatial variability. Using simple multiple regression (Demuth 1993), Mimikou and Kaemaki (1985) parameterized monthly flow-duration characteristics in terms of mean annual areal precipitation, drainage area, hypsometric fall, and river length. Finnessey and Vogel (1990) developed a regional hydrological model for Massachusetts using a two-parameter lognormal probability density function. Empirical quantiles are found to be distribution independent (Loaiciga 1989) and are widely used for the sake of simplicity in preliminary or feasibility studies for water supply planning, effluent design, wildlife habitat and fishery resources management, estimation of hydroelectric power potential, environmental quality assessment, and flood control. These attempts contributed significantly to the derivation of the provisional Hydrology of Soil Types response classification, which relates the soil and geological properties to the low-flow response of gauged watersheds.

Regional studies on the ungauged Himalayan watersheds of India do not appear to have been reported in the literature. It is therefore useful to develop regional flow-duration models for these watersheds. Thus, the objective of this paper is to develop these models for 1,200 potential hydropower project sites located in the 13 states of the Lower Himalayas.

THEORY OF MODEL DEVELOPMENT

A flow-duration model for an ungauged site is developed using the concept of hydrologic data (nondimensional) transfer between the watersheds of the same hydrometeorologically homogeneous region. Flows are made nondimensional using mean flow and the resulting series is normalized using power transformation for estimating quantiles, as follows.

Assume that Q and q respectively represent the original and nondimensional flow series for a watershed. Then

$$q = \frac{Q}{Q_{\text{mean}}} \quad (1)$$

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NEW MOC MODEL OF SEAWATER TRANSPORT IN COASTAL AQUIFERS

By Anupma Sharma,[1] Deepak Kashyap,[2] and G. L. Asawa[3]

ABSTRACT: A new miscible seawater transport model, based on a variant form of the traditional method of characteristics (MOC), is presented. The distinctive features of this model are moving packets with preassigned volumes instead of concentration, numerical tracking of moving packets using fourth-order Runge-Kutta method, and direct computation of total transport due to advection and hydrodynamic dispersion. In addition to quantification of seawater circulation, the model output illustrates (1) the path followed by seawater inside the aquifer; (2) the buildup of seawater storage; and (3) the position and advance/retreat of a disperse interface. The model has been assessed using two benchmark test problems and subsequently applied to the Biscayne aquifer in Florida. All model runs were characterized by low mass balance errors (<0.2%).

INTRODUCTION

Indiscriminate groundwater development in coastal aquifers may lead to severe consequences from seawater intrusion. Mathematical modeling of seawater transport in coastal aquifers can assist in planning a sustainable groundwater development and in evaluation of various remediation strategies.

Present Status

Mathematical models that were developed to simulate seawater intrusion can be broadly classified into sharp interface models (accounting only for advection) and miscible transport models (accounting for both advection and hydrodynamic dispersion). Sharp interface models are suitable when the width Δ of the transition zone (termed disperse interface) is small relative to the thickness D of the aquifer. When Δ/D is not small, the distribution of seawater in the transition zone and its position must be estimated using a miscible transport model (Hill 1988; Pinder and Stohoff 1988).

Semianalytical solutions to the miscible transport problem, assuming homogeneous and isotropic conditions in the vertical plane, have been published by Henry (1960), Frolov and Khublaryan (1987), and Volker et al. (1985). Over the years the simple test problem considered by Henry has become a benchmark for miscible seawater intrusion analysis. Numerical solutions have been obtained using primarily the finite-element method (FEM) [e.g., Lee and Cheng (1974), Segol et al. (1975), Huyakorn et al. (1987), and Putti and Paniconi (1995)] with a few using the finite-difference method (FDM) [e.g., Intera (1979), and Gupta and Sivanathan (1988)]. However, solution of the miscible transport problem by conventional techniques, namely, FDM or FEM, is susceptible to numerical dispersion (Huyakorn and Pinder 1983). Several alternative techniques have been proposed to tackle the problem of numerical dispersion/oscillations in the simulation of contaminant transport. These include high-order, finite-element techniques (Price et al. 1968), high-order, FDMs (Morton 1980), an FEM with nonsymmetric weighting functions (Huyakorn and Nilkuha 1979), and the method of characteristics (MOC) (Garder et al. 1964).

In miscible seawater transport modeling, MOC has often been used to overcome numerical dispersion (Pinder and Cooper 1970; Reddell and Sunada 1970; Konikow and Bredehoeft 1978; Sanford and Konikow 1985). The traditional method is explicit and simulates the advective transport component by a continuous forward tracking of particles with preassigned concentrations. The dispersive transport component is computed using FDM or FEM. Galeati et al. (1992) employed a modified MOC, based on reverse particle tracking [as proposed by Neuman (1981)] to simulate seawater transport in a vertical plane. However, as noted by Neuman (1984) and Galeati et al. (1992), modified MOC is subject to some numerical dispersion compared to MOC.

Present Work

The present paper describes a miscible transport, numerical model for simulating regional transient seawater transport in a heterogeneous, anisotropic, confined, or unconfined coastal aquifer. The advective transport of seawater is simulated using a variant form of MOC in which particles with preassigned volumes are tracked across the solution domain. Total transport of seawater accounting for both the advective and dispersive components is obtained on solving the governing equation using finite differences.

The model accounts for nodewise variations of the intrinsic permeability (caused by heterogeneity of the flow medium) and of the specific weight, viscosity, and specific storage (caused by concentration variations). Thus heterogeneity is resolved at a macro (i.e., nodal) scale. Mechanical dispersion accounts for the heterogeneity at the microlevel. The proposed method is a variant form of MOC, which utilizes the continuous forward particle tracking and incorporates a number of modifications to the current approach. Volumes, instead of concentrations, are assigned to moving packets/particles, which allows an explicit mass balance of the intruding seawater and leads to a reduction in the number of moving packets. Instead of explicit velocities (i.e., Euler's algorithm), the packets are tracked forward with a weighted average velocity, computed by a fourth-order Runge-Kutta algorithm that is more accurate and permits the use of larger time steps. The precomputed advective transport is a source/sink term in the dispersive transport equation, yielding the total transport equation, whose solution gives the total transport due to advection and dispersion. Thus, a simultaneous occurrence of advection and dispersion is simulated by solving for the total transport directly instead of estimating the dispersive transport separately by taking a weighted concentration (at the current and previous time levels) and then adding the two transports to obtain the total transport.

The model is evaluated using two benchmark test problems and applied to the Biscayne aquifer in Florida to study the time lag in the advance/retreat of a disperse interface.

GOVERNING EQUATIONS

The problem of seawater transport in coastal aquifers can be formulated in terms of the following coupled equations: (1)

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DEVELOPMENT OF INTEGRATED SEDIMENT RATING CURVES USING ANNS

By Sharad Kumar Jain[1]

ABSTRACT: Correct estimation of sediment volume being carried by a river is very important for many water resources projects. Conventional sediment rating curves, however, are not able to provide sufficiently accurate results. Artificial neural networks (ANNs) are a simplied mathematical representation of the functioning of the human brain. Three-layer feed-forward ANNs have been shown to be a powerful tool for input-output mapping and have been widely used in water resources problems. The ANN approach is used to establish an integrated stage-discharge-sediment concentration relation for two sites on the Mississippi River. Based on the comparison of the results for two gauging sites, it is shown that the ANN results are much closer to the observed values than the conventional technique.

INTRODUCTION

The assessment of the volume of sediments being transported by a river is of vital interest in hydraulic engineering due to its importance in the design and management of water resources projects. Sediment rating curves are widely used to estimate the sediment load being transported by a river. A sediment rating curve is a relation between the sediment and river discharges. Such a relationship is usually established by a regression analysis, and the curves are generally expressed in the form of a power equation.

A number of attempts have been made to relate the amount of sediment transported by a river with flow conditions such as discharge, velocity, and shear stress. However, none of these equations have received universal acceptance. Usually, either the weight of the sediments or the sediment concentration is related to the discharge. Many times, these two forms are used interchangeably. McBean and Al-Nassri (1988) examined this issue and concluded that the practice of using sediment load versus discharge is misleading because the goodness of fit implied by this relation is spurious. They have instead recommended that the regression be established between sediment concentration and discharge.

Karim and Kennedy (1990) attempted to establish relations among the velocity, sediment discharge, bed-form geometry, and friction factor of alluvial rivers. Lopes and Ffolliott (1993) pointed out that an additional complexity is introduced to the sediment concentration and streamflow relationship due to a hysteresis effect. The sediment concentrations for a given level of streamflow discharge in the rising stage of a streamflow hydrograph are greater than on the falling stage. The conventional regression approach is not able to account for this hysteresis effect. A power equation is normally used to represent sediment rating and its transformation. Usually, the power equation is log transformed and linear regression with least squares is applied to estimate the parameters. While applying the equation, the data are retransformed to the original domain. The entire process introduces a bias in the estimates. This aspect has been examined by Ferguson (1986) and Jansson (1996). Jansson (1996) proposed a correction factor that is based on the variance of the data and claimed that the use of this factor leads to improvement in the results.

The process of establishing a rating relationship is basically a nonlinear mapping problem. Such problems frequently arise in hydrological analysis because many hydrological systems behave in a nonlinear manner. The statistical tools that are commonly used in such situations are regression and curve fitting. However, these techniques are not adequate in view of the complexity of the problem and there is room for much improvement. This paper is concerned with the application of an emerging, powerful tool, the artificial neural network (ANN), to this problem. This technique was used to develop stage-discharge-sediment rating curves for two sites on the Mississippi River.

OVERVIEW OF ANN

The human brain contains billions of interconnected neurons. Due to the structure in which the neurons are arranged and operate, humans are able to quickly recognize patterns and process data. An ANN is a simplified mathematical representation of this biological neural network. It has the ability to learn from examples, recognize a pattern in the data, adapt solutions over time, and process information rapidly. The application of ANNs to water resources problems is rapidly gaining popularity due to their immense power and potential in mapping of nonlinear system data.

A water resources system may be nonlinear and multivariate, and the variables involved may have complex interrelationships. Such problems can be efficiently solved using ANNs. The processes that involve several parameters are easily amenable to neurocomputing. Among the many ANN structures that have been studied, the most widely used network structure in the area of hydrology is the multilayer, feed-forward network. The remaining discussion is focused on such networks.

An ANN consists of a number of data processing elements called neurons or nodes that are grouped in layers. The input layer neurons receive the input vector and transmit the values to the next layer of processing elements across connections. This process is continued until the output layer is reached. This type of network in which data flows in one direction (forward) is known as a feed-forward network. The ANN theory has been described in many books, including the text by Rumelhart et al. (1986). The application of ANNs has been the topic of a large number of papers that have appeared in the recent literature. Therefore, to avoid duplication, this section will be limited to only main concepts.

A three-layer, feed-forward ANN is shown in Fig. 1. It has input, output, and hidden middle layers. Each neuron in a layer is connected to all the neurons of the next layer, and the neurons in one layer are not connected among themselves. All the nodes within a layer act synchronously. The data passing through the connections from one neuron to another are multiplied by weights that control the strength of a passing signal. When these weights are modified, the data transferred through

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TRANSMUTING SYNTHETIC UNIT HYDROGRAPHS INTO GAMMA DISTRIBUTION

By Sushil K. Singh[1]

ABSTRACT: A simple method for transmuting popular synthetic unit hydrographs (SUHs), such as those of Snyder, the Soil Conservation Service (SCS), and Gray, into the Gamma distribution has been proposed, the calculations for which can be performed on a calculator. It gives a smooth shape to an SUH, the area under which is guaranteed to be unity. Previous methods of SUH are shown to be the special forms of the Gamma distribution. The SUHs obtained using these methods are observed to be in serious error. The peak rate coefficient C_p in Snyder's method and the peak rate factor D_f in the SCS method have imparted physical and conceptual meaning. The possible unified conceptual interpretation of the popular SUHs in line with the conceptual models of instantaneous unit hydrograph (IUH) has been presented. The method can do away with the calculations for W_{50}, W_{75} and the exceptionally long tail of UH as is usually obtained using Snyder's method for fast responding catchments. It opens up the possibility for a variable dimensionless UH in the SCS method and gives a unified basis for the three popular methods in particular and the other methods in general. Application of the method has been illustrated through problems.

INTRODUCTION

Use of unit hydrograph (UH) for predicting storm runoff is a criticized, but widely used and accepted, tool in hydrologic analysis and synthesis. The UH at a specific point on the stream (gauging site) in a catchment is generally determined by using effective rainfall and surface runoff data observed for the gauging site. A synthetic UH (SUH) is used to arrive at the UH for ungauged catchments where the rainfall and runoff data are not available (e.g., at other points on the stream in the same catchment or for other catchments that have hydrological and meteorological conditions similar to that for which it has been calibrated). Therefore, an SUH relates UH parameters to the catchment characteristics. The qualifier ''synthetic'' denotes that UH is obtained for the catchments without rainfall-runoff data. The beginning of the SUH approach can be traced back to the distribution graph proposed by Bernard (1935). Since then, quite a few attempts have been made to synthesize the UH. The prominent approaches are by Snyder (1938), the Soil Conservation Service (SCS) (*Hydrology* 1972), and Gray (1961). A review of several methods is presented by Singh (1988). Chow (1988) defined three types of unit hydrographs: (1) Those relating hydrograph characteristics (peak flow rate, base time, and time to peak) to watershed characteristics (Snyder 1938; Gray 1961); (2) those based on a dimensionless UH (*Hydrology* 1972); and (3) those based on models of watershed storage (Clark 1945). The present study is an effort to synthesize different types of SUHs.

Popular methods of SUH either use a few points on a UH to manually fit a smooth curve [e.g., Snyder (1938)] or use a dimensionless UH to get a smooth shape of SUH [e.g., *Hydrology* 1972]. A greater degree of subjectivity and labor is involved in fitting a smooth curve manually over a few points to get an SUH and at the same time to adjust the area under the SUH to unity. The coefficient C_p in Snyder's method is a calibration parameter that varies over a wide range; hence, the method may not be viewed as a true synthetic one. The SCS dimensionless UH is assumed invariant regardless of shape, size, and location of the catchments, which may not be justified. The use of SUH proposed by Gray (1961) requires tedious computations or interpolation from tabulated values. Apart from their own merits and demerits, these methods are used separately, and no effort is reported in the literature to synthesize them, even when they describe the same process. The other disadvantage is that they cannot be interpreted in conceptual terms as applied to the conceptual models [e.g., Clark (1945), Dooge (1959), and Nash (1960)]. The present study is an effort in these directions.

In this paper, it is shown that the SUH obtained using popular methods can be transmuted into a Gamma distribution. A simple method for transmuting is presented, the calculations for which can be performed on a hand calculator. It gives a smooth shape for the SUH, which automatically satisfies the unit volume constraint. The peak rate factor and C_p were given a physical and conceptual interpretation. It has been observed that the UH obtained using Snyder's method and the SCS method cause serious errors for many cases. An added advantage of this proposed method is that the SUHs can be interpreted in a conceptual way as in conceptual models. Application of this method is shown in the examples illustrated in this paper.

POPULAR SYNTHETIC UNIT HYDROGRAPHS

The UH obtained for a gauged catchment by analyzing observed rainfall and runoff data is applicable for the gauging site at which the runoff data were measured. SUH is a tool to derive UH for the other gauging stations in the same catchment or for the other similar catchments for which runoff data are not available. Popular methods of obtaining an SUH are discussed below.

Snyder's Method

Snyder (1938) used five variables dependent on catchment characteristics to define an SUH: (1) Catchment lag t_1; (2) peak discharge rate Q_p; (3) base time t_b; (4) width of UH at $Q = 0.5Q_p$, W_{50}; and (5) width of UH at $Q = 0.75Q_p$, W_{75}. The expressions for t_1 and Q_p in U.S. customary units are as follows:

$$t_1 = C_t(LL_c)^{0.3} \quad (1)$$

$$Q_p = C_p \frac{645A}{t_1} \quad (2)$$

in which Q_p = peak discharge rate in cubic feet per second (ft^3/s); t_1 = catchment lag in hours measured from the center

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Hybrid-Cells-in-Series Model for Solute Transport in a River

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Abstract: A hybrid-cells-in-series (HCIS) model has been conceptualized to simulate transport of a conservative solute in a river. The concentration graph of the effluent from the first hybrid unit follows a skewed concentration-time profile more close to reality. When the linear size Δx of the hybrid unit is more than $4\,D_L/u$, where D_L=longitudinal dispersion coefficient, u= mean flow velocity, the concentration graphs at $n\Delta x$, $n=1,2,3,\ldots$ are approximately equal to that predicted by Ogata and Banks' model. The model parameters α, T_1, and T_2, which are the times of residence of solute in the plug flow zone, and in the first and second thoroughly mixed reservoir respectively, can be estimated from a time-concentration graph using: (1) partial moments, (2) three characteristics of the graph, i.e., time to peak, peak concentration and the partial first moment, and (3) least square optimization. The performance of the HCIS model has been verified using the data of field tests conducted in rivers. The model parameters estimated using one concentration graph simulate the concentration graphs observed at other location downstream with reasonable accuracy.

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Introduction

The cells-in-series (CIS), an alternate model to the one-dimensional advection–dispersion equation (ADE) model, has been analyzed and used extensively by many investigators (Bear 1972; Banks 1974; Van der Molen 1979; Beltaos 1980; Stefan and Demetracopoulos l98l; Yurtsever 1983; Beven and Young 1988; Young and Wallis 1993; Wang and Chen 1996) for studying transport of a solute in a flowing medium. In the CIS model, a reach length of a linear river is assumed to be comprised of a number of thoroughly mixed cells of equal residence time; the concentration of the effluent from a particular cell is equal to the concentration within the cell; output from a preceding cell forms input to the succeeding cell, and time is reckoned since injection of solute into the first cell. This implies that in the CIS model, the Eulerian reference framework is followed. Bear (1972) has described the dispersion of a conservative solute in mixing cells as a combination of two processes: complete mixing in the elementary cells and translation with the average flow velocity from one cell to the next through a connecting channel. The CIS model is similar to the Nash's cascade-of-linear-reservoirs model, which has been used for simulating unit hydrograph in surface water hydrology (Nash 1959).

Using Laplace transform technique, Banks (1974) derived an analytical expression for concentration of the effluent routed through n number of thoroughly mixed cells with equal residence time pertaining to a step input imposed at the boundary cell. Banks found that the integrand appearing in the expression of solute concentration of the nth cell has the form of a Poisson distribution. Replacing this integrand for large n by an integrand, which has the form of a Gaussian distribution, Banks has shown that the solute concentration derived using the CIS model is identical to the analytical solution of ADE model given by Ogata and Banks (1961) and the longitudinal dispersion coefficient D_L is equivalent to $\Delta x\, u/2$, where Δx= size of the cell, and u= mean velocity of flow. Thus, from near the source up to the $(n-1)$th cell, the CIS model does not simulate solute transport, which is governed by advection and dispersion, as the peak concentration and the spreading of the concentration-time profile do not match that of the ADE model. Near the source, the CIS model underestimates the peak concentration and exhibits more spreading. Comparing the CIS model with Banks and Ogata's advection–dispersion equation model, it has been shown by Banks (1974) that the CIS model does not adequately simulate the advection component.

Stefan and Demetracopoulos (1981) have also reported the limitations of the CIS model. These limitations are: (1) the CIS model does not reproduce persistence skewness in concentration–time profiles usually observed in tracer data from rivers; and (2) the travel time, rate of dispersion and the skewness are the function of the number of cells and these parameters cannot be varied independently, which restricts the usefulness of the model.

Beer and Young (1983) introduced a variant on the CIS model, which is designated as the aggregated dead zone (ADZ) model, to remove the discrepancy in simulating advection. The main difference in the ADZ model from the CIS model is that, in the ADZ model, a pure time delay was introduced into the input concentration, which allowed advection and dispersion to be decoupled (Rutherford 1994). The difficulties with the ADZ model are determination of model orders and estimation of the model parameters. Beer and Young (1983) have chosen the time series method (Young 1984) for estimation of model parameters. In unit hydrograph theory, while representing a watershed by combining linear channels and reservoirs, Dooge (1959) has derived an ex-

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MULTIVARIATE MODELING OF FLOOD FLOWS

By N. K. Goel,[1] S. M. Seth,[2] and Satish Chandra[3]

ABSTRACT: A systematic methodology for multivariate modeling of flood flows based on the partial duration series approach and bivariate normal distribution has been developed. The methodology provides univariate and bivariate modeling of flood characteristics and offers various possibilities of probability interpretation, which is not possible by conventional flood frequency methods. The two-step power transformation method has been used for normalization of the variables, required for the application of bivariate normal distribution. The application and validation of the methodology have been made by using daily flows of the Narmada River in Garudeshwar (India) and synthetically generated data.

INTRODUCTION

During the last two to three decades, flood frequency analysis mainly concentrated on the analysis of annual peak discharge series. It provides a limited assessment of the flood event, as risk of flooding is formulated in terms of flood peak magnitudes only. Hydrological phenomena like flood flows always appear as multivariate events that are characterized by various components such as volume, duration, and flood peak. In many aspects of water resources planning and management, information about the magnitude, duration, and volume of the critical flood events is essential. This requires the probability of the whole flood event rather than the probability of only peak discharge. In spite of its importance, very limited attention has been paid in the past to the study of the flood event as a whole. The present work is another step in this direction.

Although a general multivariate modeling approach to the flood problem offers improved practical applications, it requires considerably more data and more complex mathematical analysis. For these reasons, the present study is limited to bivariate flood modeling only.

REVIEW OF LITERATURE AND FORMULATION OF PROBLEM

Most of the papers in the area of flood frequency analysis deal only with flood peaks; extensive reviews exist in the literature on this aspect [e.g., Cunnane (1987)]. Limited attempts have been made in the past to model flood characteristics other than peak discharge. These attempts are briefly reviewed in this section.

Todorovic (1971) used the partial duration series (PDS) approach together with the mathematical assumptions of Todorovic and Zelenhasic (1970) to derive an expression for the distribution function of the time of occurrence of an extreme flood in a selected time interval. Todorovic and Woolhiser (1972) applied this theory to two rivers in the United States and found good agreement between observed and theoretical distributions.

Gupta et al. (1976) extended the work of Todorovic and Woolhiser (1972) and developed an expression for the joint distribution function of the largest flood peak and its time of occurrence. They also derived the distribution function of the time of occurrence of the largest flood for those two rivers in the United States, and modified the expression that was valid for independently identically distributed exceedances to apply to nonidentically distributed exceedances.

Todorovic (1978) presented three stochastic models based on the PDS approach. These models varied only in assumptions concerning properties of exceedances of the threshold level. He determined the distribution of time of occurrence of the largest exceedance, and derived the distribution function of the largest flood volume in a time interval (0, *t*).

Ashkar and Rousselle (1982) studied the multivariate and marginal distributions of flood magnitudes, durations, and volumes for three stations in Quebec. They considered flow hydrographs above a particular threshold of a triangular shape and showed that such an assumption was not unrealistic.

A theoretically more general model developed by Kavvas and coworkers (Kavvas 1982; Kavvas et al. 1983) treats flooding as a clustering phenomenon, and its mechanisms as centers of clusters of flood peaks. This model is mathematically very complex, which hinders its practical application.

Krstanovic and Singh (1987) used the principle of maximum entropy to derive a multivariate stochastic model for flood analysis. By specifying appropriate constraints in terms of covariances, variances, and cross covariances, multivariate Gaussian and exponential distributions were derived.

Correia (1987) derived the joint distribution of flood peaks and durations using the PDS approach and successfully applied it to two Portuguese rivers. He assumed the conditional distributions of flood peaks and volumes as normal. The approach seems to be promising, but the general applicability of the normality assumption of such conditional density functions is doubtful.

Sackl and Bergmann (1987) used the bivariate normal distribution as the bivariate parent distribution function for flood peaks and volumes of direct runoff after transforming the marginal distributions of both variables into normal. They fitted and tested the bivariate normal distribution using the equilines of the probability density function (ISO-PDF lines).

The use of the bivariate normal distribution for flood peaks and volumes seems to be quite appealing. However, improvements can be made in the normalization procedure and the extension of the methodology when using it with partial duration series.

DEVELOPMENT OF METHODOLOGY

The methodology for stochastic modeling of flood flows is based on the partial duration series approach and uses the bivariate normal distribution as the bivariate parent distribution function for two dependent variables such as flood volumes and flood peaks. The relevant details of the two-step power transformation for normalization of the variables and application of the bivariate normal distribution in the modeling of flood flows, along with basic definitions, are discussed in the forthcoming sections.

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Metal fractionation study on bed sediments of River Yamuna, India

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Abstract

The pollution of aquatic ecosystem by heavy metals has assumed serious proportions due to their toxicity and accumulative behavior. The toxicity and fate of the water borne metal is dependent on its chemical form and therefore quantification of the different forms of metal is more meaningful than the estimation of its total metal concentrations. In this study fractionation of metal ions on bed sediments of River Yamuna has been studied to determine the eco-toxic potential of metal ions. The investigations suggest that copper have a tendency to remain associated with residual, reducible and carbonate fractions. The Risk Assessment Code reveal that about 30–50% of lead at most of the sites exist in exchangeable fraction while 30–50% of cadmium at almost all the sites is either exchangeable or carbonate bound and therefore comes under the high risk category and can easily enter the food chain. Most of the copper is in immobile fraction at Delhi while at other sites, a sizable portion (10–30%) is found in carbonate fraction thus posing medium risk for the aquatic environment. Fractionation pattern of zinc shows low to medium risk to aquatic environment.

Keywords: Sequential extraction; Tessier scheme; Metals; Toxicity; Risk assessment Code; River Yamuna

1. Introduction

During recent years, the pollution of riverine system by heavy metals has attracted a lot of attention of the scientific community. Unlike organic pollutants, natural processes of decomposition do not remove heavy metals. On the contrary, they may be enriched by organisms and can be converted to organic complexes, which may be even more toxic. Metals are introduced into the aquatic system as a result of weathering of soil and rocks, from volcanic eruptions and from a variety of human activities involving mining, processing and use of metals and/or substances containing metal contaminants. Trace metals entering natural water become part of the water-sediment system and their distribution processes are controlled by a dynamic set of physical–chemical interactions and equilibria. The metal solubility is principally controlled by pH, concentration and type of ligands and chelating agents, oxidation-state of the mineral components and the redox environment of the system. Since each form may have different bioavailability and toxicity, the environmentalists are rightly concerned about the exact forms of metal present in the aquatic environment. The measurement of total metal may not be able to provide information about the exact dimension of pollution and thus the determination of different fractions assumes great importance.

The concept of speciation dates back to 1954 when Goldberg introduced the concept of speciation to improve the understanding of the biogeochemical cycling of trace elements in seawater. Kinetic and thermodynamic information together with the analytical data made it possible to differentiate between oxidized versus reduced, complexed or chelated versus free metal ions in solution and dissolved between particulate species. Florence [1] has defined the term speciation

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ARSENIC: OCCURRENCE, TOXICITY AND SPECIATION TECHNIQUES

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Abstract—The occurrence of arsenic in natural water has received significant attention during recent years. Arsenic exists in the environment in a number of valency states. The valency state of arsenic plays an important role for its behavior and toxicity in the aqueous system. The toxicity and bioavailability of arsenic can only be determined if all its forms can be identified and quantified. Therefore, the aim of this article is to provide a general description of the occurrence of arsenic in the environment, its toxicity, health hazards, and measurement techniques for speciation analysis. Different techniques used for speciation of arsenic, *viz*., spectrometric, chromatographic, electrochemical, etc. have been discussed. © 2000 Elsevier Science Ltd. All rights reserved

Key words—arsenic, toxicity, occurrence, speciation techniques, spectrometric, chromatographic, electrochemical

INTRODUCTION

Arsenic contamination in natural water is a world wide problem and has become a challenge for the world scientists. It has been reported in recent years from several parts of the world, like USA, China, Chile, Bangladesh, Taiwan, Mexico, Argentina, Poland, Canada, Hungary, Japan, and India (Robertson, 1986, 1989; Moncure *et al*., 1992; Schlottmann and Breit, 1992; Frost *et al*., 1993; Das *et al*., 1994, 1995; Chatterjee *et al*., 1995). Hering and Elimelech (1995) have reviewed the international perspective and treatment strategies on the problem of arsenic contamination in ground water.

There is a growing awareness that the toxicity of heavy metals is strongly dependent on their chemical form, resulting in increasing interests in the quantitative determination of individual species (Craig, 1986). Speciation of arsenic in environmental samples is gaining increasing importance, as the toxic effects of arsenic are related to its oxidation state. Many metallic ions are found in the environment in a variety of forms, that are differentiated not only by their physical and chemical forms, but also by their diverse toxic activities with respect to living organisms (Craig, 1986). Changes in the degree of oxidation of an element also have an important effect on the degree of bioavailability and toxicity (Stoeppler, 1992).

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The elements occur in the environment in different oxidation states and form various species, e.g., As as As(V), As(III), As(0) and As (-III); Sb as Sb(V), Sb(III), Sb(0), and Sb(-III); and Se as Se(VI), Se(IV), Se(0) and Se(-II). In oxidized environment As, Sb and Se appear mostly as oxyanions (Cutter, 1992). The valency state of an element plays an important role for the behavior of the element in the aqueous system. For example, toxicity of As(III) and Sb(III) is higher than that of their pentavalent species (Berman, 1980; Gesamp, 1986). Similarly Cr(III) is an essential element while Cr(VI) is highly toxic. The valency state of an element also determines the sorption behavior and consequently the mobility in the aquatic environment.

Many metals occur in natural waters in different physico-chemical forms. Among them simple hydrated metal ions are considered to be the most toxic, while strong complexes and species associated with colloidal particles are usually assumed to be less toxic (Russeva, 1995). Organometallic compounds of tin, mercury and lead (particularly simple methylated species) are more toxic than the corresponding inorganic species. Organoarsenic compounds represent an exception in this series (Prange and Jantzen, 1995). Current interest in the determination of different species of arsenic in natural waters is caused due the fact that physiological and toxic effects of arsenic are connected with its chemical forms. The toxicity of different arsenic species varies in the order: arsenite > arsenate > monomethylarsonate (MMA) > dimethylarsinate (DMA)

Analysis of long-term rainfall trends in India

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Citation Kumar, V., Jain, S. K. & Singh, Y. (2010) Analysis of long-term rainfall trends in India. *Hydrol. Sci. J.* **55**(4), 484–496.

Abstract The study of precipitation trends is critically important for a country like India whose food security and economy are dependent on the timely availability of water. In this work, monthly, seasonal and annual trends of rainfall have been studied using monthly data series of 135 years (1871–2005) for 30 sub-divisions (sub-regions) in India. Half of the sub-divisions showed an increasing trend in annual rainfall, but for only three (Haryana, Punjab and Coastal Karnataka), this trend was statistically significant. Similarly, only one sub-division (Chattisgarh) indicated a significant decreasing trend out of the 15 sub-divisions showing decreasing trend in annual rainfall. In India, the monsoon months of June to September account for more than 80% of the annual rainfall. During June and July, the number of sub-divisions showing increasing rainfall is almost equal to those showing decreasing rainfall. In August, the number of sub-divisions showing an increasing trend exceeds those showing a decreasing trend, whereas in September, the situation is the opposite. The majority of sub-divisions showed very little change in rainfall in non-monsoon months. The five main regions of India showed no significant trend in annual, seasonal and monthly rainfall in most of the months. For the whole of India, no significant trend was detected for annual, seasonal, or monthly rainfall. Annual and monsoon rainfall decreased, while pre-monsoon, post-monsoon and winter rainfall increased at the national scale. Rainfall in June, July and September decreased, whereas in August it increased, at the national scale.

Key words climate change; precipitation; rainfall trend; sub-division; non-parametric test; Mann-Kendall test; India

Analyse des tendances pluviométriques de long terme en Inde

Résumé L'étude des tendances de précipitation est très importante pour un pays comme l'Inde dont la sécurité alimentaire et l'économie dépendent de la disponibilité temporelle de l'eau. Dans ce travail, les tendances des précipitations mensuelles, saisonnières et annuelle ont été étudiées à partir des séries de données mensuelles de 135 années (1871–2005) de 30 sous-divisions (sous-régions) de l'Inde. La moitié de ces sous-divisions présente une tendance croissante de la précipitation annuelle, mais cette tendance n'est statistiquement significative que pour trois d'entre elles (Haryana, Punjab et Karnataka littoral). De même, une seule sous-division (Chattisgarh) présente une tendance décroissante significative parmi les 15 sous-régions qui présentent une tendance décroissante de la précipitation annuelle. En Inde, les mois de mousson de Juin à Septembre contribuent à plus de 80% de la précipitation annuelle. Pendant Juin et Juillet, les sous-divisions sont presque aussi nombreuses à présenter une précipitation croissante ou décroissante. En Août, les sous-divisions présentant une croissance sont plus nombreuses, contrairement à Septembre. La majorité des sous-divisions présente très peu de changement de précipitation pour les mois hors mousson. Cinq régions importantes de l'Inde ne présentent pas de tendance significative pour les précipitations annuelle, saisonnières et mensuelles pour la plupart des mois. Pour l'ensemble de l'Inde, aucune tendance significative n'a été détectée pour les précipitations annuelle, saisonnières ou mensuelles. Les précipitations annuelle et de mousson décroissent, tandis que les précipitations pré-mousson, post-mousson et hivernale augmentent à l'échelle nationale. Les précipitations décroissent en Juin, Juillet et Septembre, et croissent en Août à l'échelle nationale.

Mots clefs changements climatiques; précipitations; tendance pluviométrique; sous-division; test non-paramétrique; test de Mann-Kendall; Inde

INTRODUCTION

Although the subject area of climate change is vast, the changing pattern of rainfall is a topic within this field that deserves urgent and systematic attention, since it affects both the availability of freshwater and food production (Dore, 2005). Based on experimentation

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A new drain spacing formula

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Abstract A drain spacing formula is derived considering the variation in radial flux and the area above the drain level in the radial flow zone. The extent of the radial flow zone is ascertained by applying a mass balance and differentiability criterion of the water surface profile at the interface of radial and Dupuit-Forchheimer flow zones. The radial flow zone extends from the centre of the tile drain a distance of $2/\pi$ times the depth to impervious layer below the drain. For a normal ratio of recharge rate to hydraulic conductivity ($R/K \le 0.0025$), the water surface profile in the radial flow zone computed using Hooghoudt's formula is very different from the profile obtained by the new drain spacing formula; however, Hooghoudt's formula computes the maximum water table height which marginally differs from that found by the present method. For a ratio of high recharge rate to hydraulic conductivity ($R/K = 0.1$) and close drain spacing ($L/D = 2$), the difference in the maximum heights is 21%. Hooghoudt's formula overestimates the maximum water table position for $L/D < 40$. Unlike Hooghoudt's equivalent depth, the equivalent depth obtained using the present method is a function of the ratio of recharge rate to hydraulic conductivity.

Key words subsurface drain spacing; equivalent depth; Hooghoudt's drain spacing formula

Une nouvelle formule d'espacement de drains

Résumé Une formule d'espacement de drains est établie, compte tenu de la variation de flux radial et de l'aire au dessus du niveau du drain dans la zone d'écoulement radial. L'extension de la zone d'écoulement radial est identifiée par application d'un bilan de masse et d'un critère de différentiabilité du profil d'eau de surface à l'interface des zones d'écoulement radial et de Dupuit Forchheimer. La zone d'écoulement radial s'étend du centre du secteur de drainage jusqu'à une distance de $2/\pi$ fois la profondeur de la couche imperméable sous le drain. Pour un ratio normal entre le taux de recharge et la conductivité hydraulique ($R/K \le 0.0025$), le profil d'eau de surface dans la zone d'écoulement radial calculé avec la formule de Hooghoudt est très différent du profil obtenu avec la nouvelle formule d'espacement de drains; cependant, la formule de Hooghoudt calcule la cote maximale de la nappe avec une différence marginale par rapport à ce que donne cette méthode. Pour un fort ratio entre le taux de recharge et la conductivité hydraulique ($R/K = 0.1$) et un faible espacement des drains ($L/D = 2$), la différence de cote maximale atteint 21%. La formule de Hooghoudt sur-estime le niveau maximal de la nappe pour $L/D < 40$. Contrairement à la profondeur équivalente de Hooghoudt, la profondeur équivalente obtenue avec cette méthode est une fonction du ratio entre le taux de recharge et la conductivité hydraulique.

Mots clefs espacement de drains de subsurface; profondeur équivalente; formule d'espacement de drains de Hooghoudt

INTRODUCTION

The required spacing of subsurface parallel tile drains to contain the water table below the root zone in a shallow aquifer is determined using the innovative equivalent depth defined by Hooghoudt and the Dupuit-Forchheimer (D-F) equation with an assumption of a steady-state recharge. Hooghoudt's original drain spacing formula, derived using the method of images, contains an infinite series. By introducing the concept of equivalent depth, Hooghoudt replaced his original drain spacing formula with a simpler one, which is widely used. Hooghoudt assumed the flow to be radial upto a distance of $D/\sqrt{2}$ from the drains, where D is the thickness of soil layer below the tile drains, and converted the radial flow zones and the central D-F horizontal flow zone into a single equivalent D-F zone. While deriving the equivalent depth, the area of flow above the drain level has been neglected. The equivalent zone is bounded by vertically walled, fully penetrating ditches having the same water level as that in the tile drains and has a reduced saturated depth, such that the maximum water table heights above the drain

Evaluation of temperature trends over India

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Abstract The impact of climate change is projected to have different effects within and between countries. Information about such change is required at global, regional and basin scales for a variety of purposes. An investigation was carried out to identify trends in temperature time series of 125 stations distributed over the whole of India. The non-parametric Mann-Kendall test was applied to detect monotonic trends in annual average and seasonal temperatures. Three variables related to temperature, viz. mean, mean maximum and mean minimum, were considered for analysis on both an annual and a seasonal basis. Each year was divided into four principal seasons, viz. winter, pre-monsoon, monsoon and post-monsoon. The percentages of significant trends obtained for each parameter in the different seasons are presented. Temperature anomalies are plotted, and it is observed that annual mean temperature, mean maximum temperature and mean minimum temperature have increased at the rate of 0.42, 0.92 and 0.09°C (100 year)$^{-1}$, respectively. On a regional basis, stations of southern and western India show a rising trend of 1.06 and 0.36°C (100 year)$^{-1}$, respectively, while stations of the north Indian plains show a falling trend of –0.38°C (100 year)$^{-1}$. The seasonal mean temperature has increased by 0.94°C (100 year)$^{-1}$ for the post-monsoon season and by 1.1°C (100 year)$^{-1}$ for the winter season.

Key words annual trend; India; Mann-Kendall test; percentage of significant trend; seasonal trend; temperature anomalies

Evaluation de tendances de température en Inde

Résumé L'impact du changement climatique devrait avoir des effets variables dans et entre les pays. Une information au sujet de ce changement est nécessaire aux échelles globale, régionale et de bassin, par rapport à une multiplicité d'enjeux. Nous avons cherché à identifier les tendances dans les séries de température de 125 stations réparties en Inde, dans son ensemble. Le test non-paramétrique de Mann-Kendall a été appliqué pour détecter les tendances monotones dans les séries de températures moyennes annuelles et saisonnières. Trois variables associées à la température, c'est-à-dire la moyenne, le maximum moyen et le minimum moyen, ont été considérées et analysées en annuel et en saisonnier. Chaque année a été divisée en quatre saisons principales: l'hiver, la pré-mousson, la mousson et la post-mousson. Les pourcentages de significativité de tendance obtenus pour chaque grandeur et chaque saison sont présentés. Les anomalies sont identifiées, et il apparaît que la température moyenne annuelle, la température maximale moyenne et la température minimale moyenne ont augmenté respectivement de 0.42, 0.92 et 0.09°C (100 ans)$^{-1}$. Du point de vue régional, les stations du sud et de l'ouest de l'Inde montrent des tendances croissantes à hauteur de 1.06 et 0.36°C (100 ans)$^{-1}$, respectivement, tandis que les stations des plaines du nord de l'Inde présentent une tendance décroissante de –0.38°C (100 ans)$^{-1}$. La température moyenne saisonnière a augmenté de 0.94°C (100 ans)$^{-1}$ pour la saison de post-mousson et de 1.1°C (100 ans)$^{-1}$ pour l'hiver.

Mots clefs tendance annuelle; Inde; test de Mann-Kendall; pourcentage de significativité de tendance; tendance saisonnière; anomalies de température

INTRODUCTION

Human activities have increased the atmospheric concentration of greenhouse gases changing the Earth's climate on both global and regional scales. There is evidence that the recent climate is the result of both natural and anthropogenic forcing. In recent years the potential impacts of climatic change and variability have received a lot of attention

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Modelling of streamflow and its components for a large Himalayan basin with predominant snowmelt yields

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Abstract A conceptual snowmelt model, which accounts for both the snowmelt and rainfall runoff was developed and applied for daily streamflow simulation for the Satluj River basin located in the western Himalayan region. The model, designed primarily for mountainous basins, conceptualizes the basin as a number of elevation zones depending upon the topographic relief. The basic inputs to the model are temperature, precipitation and snow-covered area. The snowmelt is computed using the degree-day approach and rain induced melting was also considered. The model was calibrated using a data set of three years (1985/86–1987/88) and model parameters were optimized. Using these optimized parameters, simulations of daily streamflow were made for a period of six years (1988/89–1990/91 and 1996/97–1998/99). The model performed well for both calibration and simulation periods. The model was also used to estimate the contribution from the snowmelt and rainfall to the seasonal and annual flows.

Key words snowmelt model (SNOWMOD); degree-day approach; snow-covered area; streamflow simulation; summer season runoff

Modélisation de l'écoulement fluvial et de ses composantes pour un grand bassin versant himalayen à dominante nivale

Résumé Un modèle nival conceptuel, qui tient compte à la fois de la fonte de la neige et de l'écoulement pluvial, a été développé et appliqué pour la simulation des écoulements journaliers dans le bassin de la rivière Satluj, dans l'ouest de la région himalayenne. Le modèle, initialement conçu pour des bassins de montagne, conceptualise le bassin sous la forme de zones altitudinales dépendant de la topographie. Les entrées de base du modèle sont la température, les précipitations et la surface enneigée. La fonte est calculée à partir de l'approche degré-jour, sachant que la fonte induite par la pluie est également prise en compte. Le modèle a été calé à partir d'un jeu de trois ans de données (1985/86–1987/88) et les paramètres du modèle ont été optimisés. Sur la base de ces paramètres optimisés, les simulations de l'écoulement journalier ont été réalisées pour une période de six ans (1988/89–1990/91 et 1996/97–1998/99). Le modèle est satisfaisant pour les périodes de calage et de validation.

Mots clefs modèle de fonte de la neige (SNOWMOD); approche degré-jour; surface enneigée; simulation d'écoulement fluvial; écoulement estival

INTRODUCTION

There is substantial contribution from snowmelt runoff to the annual streamflows of the Himalayan rivers (Singh *et al.*, 1997a; Singh & Jain, 2002). The water yield from a high Himalayan basin is roughly twice as high as that from an equivalent basin located in the peninsular part of India. A higher water yield from the Himalayan basins is mainly due to the large inputs from the snowmelt and glaciers. Depending upon the climatic conditions, the snowpack depletes either fully or partially during the forthcoming summer season. Because of variation in climatic conditions and changes

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Assessing the vulnerability to soil erosion of the Ukai Dam catchments using remote sensing and GIS

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Abstract The investigation of basins for planning soil conservation requires a selective approach to identify smaller hydrological units, which would be suitable for more efficient and targeted conservation management programmes. One criterion, generally used to determine the vulnerability of catchments to erosion, is the sediment yield of a basin. In India, sediment yield data are generally not collected for smaller sub-catchments and it becomes difficult to identify the most vulnerable areas for erosion that can be treated on a priority basis. An index-based approach, based on the surface factors mainly responsible for soil erosion, is suggested in this study. These factors include soil type, vegetation, slope and various catchment properties such as drainage density, form factor, etc. The method is illustrated with a case study of sub-catchments immediately upstream of the Ukai Reservoir located on the River Tapi in Gujarat State, India. The area is divided into 16 watersheds and different soil, vegetation, topography and morphology-related parameters are estimated separately for each watershed. Satellite data are used to evaluate the soil and vegetation indices, while a GIS system is used to evaluate the topography and morphology-related indices. The integrated effect of all the parameters is evaluated to find different areas vulnerable to soil erosion. Two watersheds were identified as being most susceptible to soil erosion. Based on the integrated index, a priority rating of the watersheds for soil conservation planning is recommended.

Key words soil erosion; soil conservation; sediment yield; GIS; remote sensing; NDVI; slope; India

Estimation de la vulnérabilité à l'érosion des sols des bassins du Barrage Ukai à l'aide de la télédétection et d'un SIG

Résumé La planification de la conservation des sols nécessite une approche sélective pour identifier des unités hydrologiques plus petites que les bassins versants, dont l'échelle serait plus pertinente pour des programmes plus efficaces et ciblés de conservation. Un critère, généralement utilisé pour déterminer la vulnérabilité d'un bassin versant à l'érosion, est son apport solide. En Inde, les données sur l'apport solide ne sont généralement pas disponibles par sous-bassins si bien qu'il est difficile d'identifier les zones les plus vulnérables à l'érosion, à traiter en priorité. Nous proposons une approche basée sur un indice exprimé en fonction de facteurs caractérisant la surface du sol. Ces facteurs englobent le type de sol, la végétation, la pente et différentes propriétés du bassin comme la densité de drainage, un facteur de forme, etc. La méthode est illustrée avec un ensemble de sous-bassins à l'amont immédiat du Barrage Ukai, sur la Rivière Tapi, dans l'état de Gujarat en Inde. La zone est divisée en 16 sous-bassins, et différents paramètres caractérisant le sol, la végétation, la topographie et la morphologie sont estimés pour chacun d'entre eux. Des données satellitaires sont utilisées pour évaluer les indices liés au sol et à la végétation, tandis qu'un système d'information géographique est utilisé pour évaluer ceux qui sont liés à la topographie et à la morphologie. L'effet intégré de tous les paramètres est estimé afin d'identifier les différentes zones vulnérables à l'érosion. Deux sous-bassins particulièrement concernés ont ainsi été identifiés. Sur la base de l'indice intégré, un ordre de priorité pour la conservation des sols est recommandé.

Mots clefs érosion des sols; conservation des sols; apport solide; SIG; télédétection; pente; Inde

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Estimation of soil erosion and sediment yield using GIS

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Abstract A Geographical Information System (GIS) based method is proposed and demonstrated for the identification of sediment source areas and the prediction of storm sediment yield from catchments. Data from the Nagwa and Karso catchments in Bihar (India) have been used. The Integrated Land and Water Information System (ILWIS) GIS package has been used for carrying out geographic analyses. An Earth Resources Data Analysis System (ERDAS) Imagine image processor has been used for the digital analysis of satellite data for deriving the land cover and soil characteristics of the catchments. The catchments were discretized into hydrologically homogeneous grid cells to capture the catchment heterogeneity. The cells thus formed were then differentiated into cells of overland flow regions and cells of channel flow regions based on the magnitude of their flow accumulation areas. The gross soil erosion in each cell was calculated using the Universal Soil Loss Equation (USLE) by carefully determining its various parameters. The concept of sediment delivery ratio (SDR) was used for determination of the total sediment yield of each catchment during isolated storm events.

Estimation de l'érosion du sol et de l'exportation de sédiments utilisant un SIG

Résumé Une méthode fondée sur l'utilisation d'un système d'information géographique (SIG) est proposée et expérimentée afin d'identifier l'origine des sédiments et de prévoir leur exportation à l'exutoire des bassins lors d'évènements pluvieux. Des données des bassins de Nagwa et de Karso dans l'état du Bihar (Inde) ont été utilisées. Le SIG ILWIS (Integrated Land and Water Information System), système intégré d'informations sur la terre et les eaux a été utilisé pour mener les analyses géographiques. Le logiciel de traitement d'image ERDAS (Earth Resources Data Analysis System—Système d'analyse de données sur les ressources terrestres), a été utilisé pour l'analyse digitale de données satellitaires en vue de déterminer l'occupation et les caractéristiques des sols des bassins étudiés. Ces bassins ont été discrétisés selon un maillage dont les mailles sont hydrologiquement homogènes afin de représenter l'hétérogénéité des bassins. On a alors distingué les mailles des régions de ruissellement de surface et les mailles d'écoulement en chenaux selon l'importance de leur surface d'alimentation. L'érosion brute du sol dans chaque maille a été calculée en utilisant l'équation universelle des pertes en sol (Universal Soil Loss Equation—USLE) en déterminant soigneusement ses divers paramètres. Le concept de rapport de fourniture de sédiments (Sediment Delivery Ratio—SDR) a été utilisé pour la détermination de l'exportation totale des sédiments de chaque bassin durant des épisodes pluvieux particuliers.

INTRODUCTION

Soil erosion is one of the most critical environmental hazards of modern times. Vast areas of land now being cultivated may be rendered economically unproductive if the

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Watershed Prioritization Using Saaty's AHP Based Decision Support for Soil Conservation Measures

R. K. Jaiswal · T. Thomas · R. V. Galkate · N. C. Ghosh · S. Singh

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Abstract The identification of environmentally stressed areas for planning soil conservation measures requires an efficient decision support tool to provide appropriate weights for various topographical, morphological, climatological and management factors responsible for soil erosion. In the present study, Saaty's analytical hierarchy process (SAHP) with nine erosion hazards parameters (EHPs) including soil loss (*SL*), sediment yield (*SY*), sediment production rate (*SPR*), sediment transport index (*STI*), slope (*Slp*), Drainage density (D_d), channel frequency (C_f), form factor (R_f), circulatory ratio (R_c) has been used as a decision support system for identification of environmentally stressed sub-watersheds in Benisagar dam catchment of Bundelkhand region (Madhya Pradesh, India). The SAHP is a structured technique for dealing with complex decisions which involves building a hierarchy of decision elements, making comparisons between each possible pair in each cluster, provides weighting for each element within a cluster and checking the consistency of the decision based on a consistency ratio. The Benisagar dam catchment having excessive erosion due to undulating topography, limitation of soil depth and absence of conservation measures affects reservoir storages due to silting problems. For prioritization purposes, the Benisagar dam catchment has been divided in to 36 sub-watersheds with their areas ranging from 0.77 to 6.53 km^2 and all nine EHPs for various sub-watersheds have been computed. The pair wise comparison matrix and final weights for all the EHPs have been determined using SAHP with the acceptable limit of consistency ratio. The final priority ranks for sub-watersheds have been computed by summing the multiplication of SAHP weights and their corresponding normalized values of EHPs. From the analysis, it has been observed that eight sub-watersheds covering 20.15 km^2 and seven sub-watersheds covering 19.41 km^2 areas fall under very high and high priority respectively.

Keyword Saaty's analytical hierarchical process (SAHP) · Erosion hazard parameter (EHP) · Soil loss · Sediment yield · Sediment production rate (SPR)

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ORIGINAL PAPER

Flood hazard assessment with multiparameter approach derived from coupled 1D and 2D hydrodynamic flow model

Pankaj Mani · Chandranath Chatterjee · Rakesh Kumar

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Abstract Hydrodynamic flow modeling is carried out using a coupled 1D and 2D hydrodynamic flow model in northern India where an industrial plant is proposed. Two flooding scenarios, one considering the flooding source at regional/catchment level and another considering all flooding sources at local level have been simulated. For simulating flooding scenario due to flooding of the upstream catchment, the probable maximum flood (PMF) in the main river is routed and its flooding impact at the plant site is studied, while at the local level flooding, in addition to PMF in the main river, the probable maximum precipitation at the plant site and breaches in the canals near the plant site have been considered. The flood extent, depth, level, duration and maximum flow velocity have been computed. Three parameters namely the flood depth, cross product of flood depth and velocity and flood duration have been used for assessing the flood hazard, and a flood hazard classification scheme has been proposed. Flood hazard assessment for flooding due to upstream catchment and study on local scale facilitates determination of plinth level for the plant site and helps in identifying the flood protection measures.

Keywords Canal breach · Flood depth · Flood velocity · Flood duration · Flood hazard · Hazard classification scheme · Coupled 1D and 2D hydrodynamic flow model

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ORIGINAL PAPER

Glacial lakes and glacial lake outburst flood in a Himalayan basin using remote sensing and GIS

Sanjay K. Jain · Anil K. Lohani · R. D. Singh · Anju Chaudhary · L. N. Thakural

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Abstract Glacial hazards relate to hazards associated with glaciers and glacial lakes in high mountain areas and their impacts downstream. The climatic change/variability in recent decades has made considerable impacts on the glacier life cycle in the Himalayan region. As a result, many big glaciers melted, forming a large number of glacial lakes. Due to an increase in the rate at which ice and snow melted, the accumulation of water in these lakes started increasing. Sudden discharge of large volumes of water with debris from these lakes potentially causes glacial lake outburst floods (GLOFs) in valleys downstream. Outbursts from glacier lakes have repeatedly caused the loss of human lives as well as severe damage to local infrastructure. Monitoring of the glacial lakes and extent of GLOF impact along the downstream can be made quickly and precisely using remote sensing technique. A number of hydroelectric projects in India are being planned in the Himalayan regions. It has become necessary for the project planners and designers to account for the GLOF also along with the design flood for deciding the spillway capacity of projects. The present study deals with the estimation of GLOF for a river basin located in the Garwhal Himalaya, India. IRS LISSIII data of the years 2004, 2006 and 2008 have been used for glacial lake mapping, and a total of 91 lakes have been found in the year 2008, and out of these, 45 lakes are having area more than 0.01 km^2. All the lakes have been investigated for vulnerability for potential bursting, and it was found that no lake is vulnerable from GLOF point of view. The area of biggest lake is 0.193, 0.199 and 0.203 km^2 in the years 2004, 2006 and 2008, respectively. Although no lake is potentially hazardous, GLOF study has been carried out for the biggest lake using MIKE 11 software. A flood of 100-year return period has been considered in addition to GLOF. The flood peak at catchment outlet comes out to be 993.74, 1,184.0 and 1,295.58 cumec due to GLOF; 3,274.74, 3,465.0 and 3,576.58 cumec due to GLOF; and 100-year return flood together considering breach width of 40, 60 and 80 m, respectively.

Keywords GLOF · Glacier · NDSI · Mike 11

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ORIGINAL PAPER

Drought indicators-based integrated assessment of drought vulnerability: a case study of Bundelkhand droughts in central India

T. Thomas[1] · R. K. Jaiswal[1] · Ravi Galkate[1] · P. C. Nayak[2] · N. C. Ghosh[3]

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Abstract Decision makers face multifaceted challenge in characterizing drought climatology for appropriate water resources-related drought management strategies. This paper focuses on understanding and quantifying the drought vulnerability of Bearma basin in the Bundelkhand region of central India, which is one of the prominent climate extremes that the region is affected by frequently. Regular drought conditions have been prevailing in the region in the last decade with continuous drought from 2004 to 2007. An integrated approach using multiple indicators has been developed to spatially identify the vulnerable regions. The Bearma basin has been selected as a pilot basin to develop a methodology for integrated drought vulnerability assessment adopting spatially and temporally varying drought characteristics represented by drought indicators. The temporally varying indicators include standardized precipitation index (SPI), surface water drought index and groundwater drought index. The spatial information of the indicators was categorized in layers prepared in the spatial domain using a geographic information system, and integrated values of weights of various indicators have been computed on a 50 × 50 m grid scale. The SPI has been applied to quantify monthly precipitation deficit anomalies on multiple time scales (1, 3, 6 and 12 months). The drought characteristics including frequency, duration and intensity and magnitude have been calculated with the estimated SPI. The multiple indicator approach has been used for arriving at the drought vulnerable zones. The highly vulnerable areas are located in the southern and northern regions of the Bearma basin. It has been observed that more than 26 % of the basin lies in the highly and critically

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ORIGINAL ARTICLE

Stable isotopic composition of precipitation in the River Bhagirathi Basin and identification of source vapour

S. P. Rai · P. Purushothaman · B. Kumar · Noble Jacob · Y. S. Rawat

Received: 19 March 2013 / Accepted: 17 October 2013

Abstract River Ganges one of important rivers in the northern part of India receives water from two of its tributaries, Alaknanda and Bhagirathi. In this present study, we have tried to characterise the precipitation in the Bhagirathi River Basin. The study shows that isotopic composition of precipitation shows depleted nature during monsoon period due to moisture source from the oceanic region and from African region of Indian Ocean and enriched isotopic composition during non-monsoon period due to moisture source from westerlies and local evaporation. The study also shows that temperature and amount show expected positive and negative relationship with individual locations. A positive relationship is exhibited by amount for the entire region due to depleted isotopic composition with increase in altitude. The altitude effect shows that there is a depletion of up to −0.24 to −0.29 ‰ of isotopic composition with an increase in 100 m of elevation.

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Keywords Stable isotope of Oxygen and Hydrogen · Isotopic characterization of Precipitation · Source of moisture · Bhagirathi Basin · Uttarakhand India

Introduction

Stable isotopes of water (Oxygen and Hydrogen) have been used to understand various hydrological processes occurring in nature such as source of precipitation, hydrograph separation, surface water groundwater interaction, groundwater recharge, source identification of rivers, lakes, evaporation and evapotranspiration, etc. (Clark and Fritz 1997). Precipitation acts as a primary source of water on land. The meteoric processes modify the isotopic signature of precipitation at a given location. This signature serves as a natural tracer for identifying recharge source of groundwater (Gupta and Deshpande 2003). Thus, it becomes imperative to understand the variation in the stable isotopic composition of precipitation to understand the above-mentioned processes.

Globally, many studies have been carried out to understand the source of precipitation and the factors controlling their composition using stable isotopes of oxygen and hydrogen. Factors influencing isotopic composition of precipitation are source of moisture (Aravena et al. 1999; Andreo et al. 2004; Price et al. 2008), evaporation, condensation (Dansgaard 1964) and moisture exchange between land and atmosphere. These processes result in variation in isotopic signatures of precipitation from regional to continental scale (Guan et al. 2009). The depletion of isotopic composition of precipitation takes place with increasing distance from coast (Liu et al. 2008; Yu et al. 2005; Tian et al. 2005, 2008; Pang et al. 2006; Aravena et al. 1999; Bhattacharya et al. 2003), with

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The Cryosphere

Role of glaciers in watershed hydrology: a preliminary study of a "Himalayan catchment"

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Abstract. A large number of Himalayan glacier catchments are under the influence of humid climate with snowfall in winter (November–April) and south-west monsoon in summer (June–September) dominating the regional hydrology. Such catchments are defined as "Himalayan catchment", where the glacier meltwater contributes to the river flow during the period of annual high flows produced by the monsoon. The winter snow dominated Alpine catchments of the Kashmir and Karakoram region and cold-arid regions of the Ladakh mountain range are the other major glacio-hydrological regimes identified in the region. Factors influencing the river flow variations in a "Himalayan catchment" were studied in a micro-scale glacier catchment in the Garhwal Himalaya, covering an area of 77.8 km^2. Three hydrometric stations were established at different altitudes along the Din Gad stream and discharge was monitored during the summer ablation period from 1998 to 2004, with an exception in 2002. These data have been analysed along with winter/summer precipitation, temperature and mass balance data of the Dokriani glacier to study the role of glacier and precipitation in determining runoff variations along the stream continuum from the glacier snout to 2360 m a.s.l. The study shows that the inter-annual runoff variation in a "Himalayan catchment" is linked with precipitation rather than mass balance changes of the glacier. This study also indicates that the warming induced an initial increase of glacier runoff and subsequent decline as suggested by the IPCC (2007) is restricted to the glacier degradation-derived component in a precipitation dominant Himalayan catchment and cannot be translated as river flow response. The preliminary assessment suggests that the "Himalayan catchment" could experience higher river flows and positive glacier mass balance regime together in association with strong monsoon. The important role of glaciers in this precipitation dominant system is to augment stream runoff during the years of low summer discharge. This paper intends to highlight the importance of creating credible knowledge on the Himalayan cryospheric processes to develop a more representative global view on river flow response to cryospheric changes and locally sustainable water resources management strategies.

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1 Introduction

The role of high mountain areas of the world as an important source of freshwater for the population living in the adjacent lowlands has been highlighted by recent studies (Bandyopadhyay et al., 1997; Viviroli and Weingartner, 2004; Barnett et al., 2005; Viviroli et al., 2007). The Himalaya is one of the focal regions, both in terms of its cryospheric resources and the dependency of a huge population on rivers originating from this mighty mountain chain. The Himalaya nourish more than 12 000 glaciers (Kaul, 1999; ICIMOD, 2001) covering an area of about 33 000 km^2 (Rai and Gurung, 2005). River Ganga is being replenished by the meltwater from around 4000 glaciers spread over India and Nepal and River Indus is being fed by more than 3300 glaciers. Snow and glacier melt together with monsoonal precipitation determines the headwater flow regimes of large parts of the Himalayas, including central and eastern Himalayan tributaries of River Ganga and Brahmaputra. Snow and glacier melt contribution are very significant in many of these Himalayan rivers. On average, the annual snow and glacier melt contribution is estimated to be 60% in Satluj river at Bhakra dam (Singh and Jain, 2002), 49% in Chenab river at

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ELSEVIER

Simulation of Runoff and Sediment Yield using Artificial Neural Networks

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Daily, weekly, ten-daily, and monthly monsoon runoff and sediment yield from an Indian catchment were simulated using back propagation artificial neural network (BPANN) technique, and the results compared with the observed and with those due to single- and multi-input linear transfer function models. Normalising the input by its maximum for both the pattern and batch learning algorithms in BPANN, the model parsimony was achieved through network pruning utilising error sensitivity to weight a criterion, and it was generalised through cross-validation. The performance based on correlation coefficient and coefficient of efficiency suggested the pattern-learned artificial neural network (ANN) based runoff simulation to be superior to both single- and multi-input models in calibration. The single-input models were however superior in verification. The ANN based sediment-yield models performed better than both single- and multi-input models in calibration as well as cross-validation/verification.

1. Introduction

The rainfall–runoff–sediment yield is the most complex hydrological phenomenon to comprehend due to (a) the tremendous spatial variability of catchment characteristics and precipitation patterns and (b) the number of variables involved in modelling of the physical processes. The quantity of runoff and sediment yield resulting from a given rainfall depends mainly on rainfall intensity, duration, and distribution with initial soil moisture, land use, catchment geomorphology, *etc*. The determination of runoff is critical to many activities, such as designing flood protection works, protection of agricultural lands and water storage and release. The sediment outflow that occurs due to both rainfall and runoff abates the reduction of storage capacity of rivers and other hydraulic structures. It is also denounced as a carrier of pollutants such as radioactive materials, pesticides, and nutrients. Since the 1930s, a number of models have been developed for the simulation of processes of rainfall–runoff, runoff–sediment yield, and rainfall–runoff–sediment yield in a catchment fluvial system. These models have been broadly classified into regression, stochastic, conceptual or parametric, and system (dynamic) models.

The artificial neural network (ANN) modelling is the latest technique. This comprises both linear and non-linear concepts in model building, and can be operated with the dynamic or memoryless input–output system. Such models have the following major advantages (Vemuri, 1992); (1) the ANN model does not require a prior knowledge of the system and can be applied to problems not clearly defined; (2) the model has more tolerance to 'noise' and incomplete data, and therefore, requires less data for model development; and (3) the results are the outcome of the collective behaviour of data and thereby minimise the effect of any disturbed data. The gradient descending search optimisation embedded with back propagation algorithm (Rumelhart *et al*., 1986) enables diverse areas to be explored such as bio-medical engineering, food engineering, image processing, water resources engineering (Rumelhart *et al*., 1994; Shamseldin, *et al*., 1997).

Hydrologic applications of ANN include: the modelling of the daily rainfall–runoff–sediment yield process and snow–rainfall process; the assessment of the

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Radon concentration in groundwater of east coast of West Bengal, India

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Abstract This study was carried out to find out the distribution of radon (^{222}Rn) activity concentration measured in the groundwater samples from the East coast of West Bengal, India. The ^{222}Rn activity in 20 groundwater samples were measured using Durridge RAD-7and the values of ^{222}Rn were found between 1.9 ± 0.78 and 9.0 ± 1.13 Bq L^{-1} with average of 5.0 ± 0.83 Bq L^{-1}. These are well within the EPA's maximum contaminant level of 11.1 Bq L^{-1}.

Keywords Radon concentration · Groundwater · East coast · West Bengal

Introduction

Groundwater is the World's largest distributed storehouse of fresh water, which plays a very important role in supporting ecosystems and human water needs. While groundwater is usually of much higher water quality than surface waters, it is found to be more radioactive than surface water because of (i) passing through rock and soil formations, and (ii) dissolution of many compounds, minerals and radioactive substances. In the three natural radioactive series: uranium, thorium and actinium; the nuclides of the uranium series are dangerous to health because of their presence in drinking water as ^{226}Ra and ^{222}Rn [1]. The radium, radon and uranium are, therefore, the elements of main concern.

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Radon is a naturally occurring radioactive element having the properties of being colourless, odourless, chemically inert gas (forms stable molecules with highly electronegative ions), no taste, fairly soluble in water and organic solvents. The radioactive decay of radon produces floating subatomic particles that can damage the living cells. When radon is inhaled, 30 % of the radon progeny comes into contact with air passage in the lungs and adhere to its surfaces. The ingestion of radon and radium from water can give rise to an additional exposure dose to the stomach and whole body.

During the last decade, various studies were conducted worldwide to find the radon activity in drinking water. Duenas et al. [1] reported ^{222}Rn values ranging between 0.22 and 52 Bq L^{-1} in bottled water in Spain; Xinwei [2] reported radon concentration in drinking water from the municipal water supply system from well water, Baoji, China as 41 Bq $L{-}1^{-1}$ with a maximum of 127 Bq L^{-1}; Kralik et al. [3] found concentration levels of ^{222}Rn in domestic bottled waters commercially available in Austria between 0.12 and 18 Bq $L{-}1^{-1}$; Chau and Michalec [4] found concentrations of ^{226}Ra and ^{228}Ra ranging from 1 mBq L^{-1} to above 500 mBq L^{-1} in bottled water in Poland; Damla et al. [5] analyzed concentration activity of ^{222}Rn in tap water taken from Eastern Black Sea region of Turkey and found it in the range of 5.79–18.46 Bq L^{-1}; Singh et al. [6] measured radon concentrations in drinking water samples collected from different areas of the upper Siwaliks of Kala Amb, Nahan and Morni Hills of Haryana and Himachal Pradesh states of India and found the radon concentration varying from 0.87 ± 0.29 to 32.10 ± 1.79 Bq L^{-1}.

Many studies have been conducted for measuring the radon in drinking water [7, 8] due to its health hazard effects and also for its removal [9]. Burnett [10] found

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List of technical publications in national journals (2000-01 to 2017-18)

List of Technical papers published in National Journals during 2000-01 to 2017-18

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1. Arora, Manohar, Naresh Kumar and Rakesh Kumar (2017). "An Analysis of Causes and Circumstances of Extreme floods in Jhelum Basin', J. Indian Water Resour. Soc., 36(4).

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