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KALEIDOSCOPIC VIEW OF RESEARCH JOURNEY AT NATIONAL INSTITUTE OF HYDROLOGY, ROORKEE (INDIA)

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ABSTRACT

The National Institute of Hydrology, Roorkee (NIH-R) is a premier research organization in India working in the areas of hydrology and water resources. It was founded on 16 December, 1978 and has completed forty years of existence encompassing a rich legacy of conducting basic, applied and strategic research for the country. This paper is attempted to trace the historical set up and to explore the scientific contribution of NIH-R in the form of research study reports, publications in journals and training courses in the last 30 years from 1991 to 2020. Broad theme areas of research contribution during blocks of five-year are identified and ranked. During the reported period, average annual research output of NIH-R has been fifty study reports, fifty-four papers in journals and sixteen training course. The output in terms of study reports has shown a decline since 2006-10 and publication of papers in journals picked up since 2001-05. NIH-R emphasized organizing training courses since 2006-10. Consistent (during whole period), and emerging and gap theme areas during the recent ten and five years are identified, which are important from the point of view of national interest. An important inference having a bearing on the future trajectory of NIH-R is to cultivate an alignment between the training themes/topics and the study areas pursued at NIH-R. A major lacuna noticed in the functioning of NIH-R is on effective utilization of young scientists in enhancing the scientific productivity. A commensurate enhancement in the research output with addition of new scientists is seen missing. Such exercise is also useful for evaluating the research productivity and benchmarking of NIH-R. Some specific suggestions and recommendations are made for improving the research output and on policy implications to develop strategic capability keeping in view the societal needs.

Keywords: *National Institute of Hydrology; Hydrology; Water resources; Research output; Scientometric analysis.*

INTRODUCTION

In a competitive world, every research institution is required to focus on continuous improvement in its performance and to remain in complete alignment with the expectations of its stakeholders. The physical performance of a research institution is measured in terms of the number of studies and projects carried out, number of research publications brought out, number of patents/other IPR items generated, financial resources generated from sponsored projects, consultancy projects and technology transfers, number of skill development activities and training courses organized, and number of outreach activities carried out, etc. Individually all these parameters are important, but for an optimal performance keeping in mind a long-term perspective, it is desirable to achieve a basket of performance deliverables. Such a performance is desirable to mitigate different risks, including market demand conditions, government policies and regulations.

A research institute's journey in time is known by the pursuit of research activities for which the organization was established, and by accomplishing the milestones of assignments at different times. For sure, the institute should have fulfilled the mandate given by its promoter(s) and also served the responsibility of contributing to the society at large. The main mandate of National Institute of Hydrology, Roorkee (NIH-R) is "To undertake, aid, promote and coordinate systematic and scientific work in all aspects of hydrology." To fulfill this objective, NIH-R conducts scientific studies- basic, applied, strategic, on all aspects of hydrology and water resources. In the last thirty years, the NIH-R has contributed significantly to the water sector in the country through basic and applied research in various frontier areas of hydrology. For dissemination of specialized knowledge and transfer of technology at national and international levels, NIH-R has published research papers and also conducted various training courses for field engineers, researchers, etc.

This paper is an attempt to track the journey of research outputs (e.g. scientific studies, research publications and training courses) produced by NIH-R during the last thirty years (1990-91 to 2019-20). The objective is to identify the strong and weak areas among the studies, and to identify the gap areas which are important from the point of view of national interest but could not be attempted during the reported period. Such exercise is also useful for benchmarking studies.

BACKGROUND AND HISTORICAL SETUP

NIH-R is a research institute established as an autonomous society in December 1978 by the then Ministry of Irrigation (now Ministry of Jal Shakti), Government of India. The original mandate of NIH-R was to provide R&D support on hydrology-related issues to the two major operational organizations in India i.e. Central Water Commission

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(CWC) and Central Ground Water Board (CGWB) dealing with the matters related to surface water and groundwater, respectively. NIH-R initiated research activities in February 1979 as a UNDP assisted project to concentrate on basic (theoretical) and applied (engineering) aspects of hydrology. The initial focus was on developing methodologies for solution of field problems using hydrologic analyses and synthesis. In particular, research dealt with (i) measurement techniques, data collection and processing, (ii) hydrological analysis of surface and/or ground water systems and the components/processes of hydrologic cycle, and (iii) hydrological synthesis and planning of surface water, ground water and conjunctive use. This phase (1979-1985) was considered as phase of establishment, and involved skill development of institute's scientific manpower, mostly on specialized training programs at overseas organizations and institutes of excellence.

The next phase coinciding with 7th five-year plan (1985-90) was utilized for consolidation, expansion and diversification of the institute's activities. The institute expanded from six to fourteen subject-oriented divisions, and broadened scope of research to multidisciplinary studies utilizing state-of-art tools and techniques such as Remote Sensing & GIS, Isotopic Applications, Advanced Analytical and Field Instrumentation. Six Regional Centres (RC) were established at Belgaum, Karnataka (July 1987), Guwahati, Assam (August 1988), Jammu, J&K (January 1990) Patna, Bihar (July 1991), Kakinada, AP (September 1991) and Sagar, MP (December 1995). Research studies focusing on region-specific water-related problems were undertaken at these RC. The institute started developing close interactions with the CWC, CGWB, India Meteorological Department (IMD), and with State Government departments to offer science-based solution to their specific field problems. During this phase, NIH-R started organizing training programs for the engineers and scientists of central and state organizations to develop their skills on hydrologic tools and techniques. Another major development was the establishment in 1989 of Indian National Committee on Hydrology (INCOH) with secretariat at NIH-R. INCOH's role was to foster collaboration with other countries and coordinate effective participation of India in International Hydrological Programme (IHP) of UNESCO and Operational Hydrology Programme of WMO. The IHP activity in India was earlier handled by HILTECH, having Secretariat with the CSIR, New Delhi. Under the aegis of INCOH, many research studies and outreach activities were undertaken by Indian scientists and researchers.

Research activities at NIH-R during 8th plan period (1991-96) were handled by eighteen problem-oriented scientific divisions encompassing some emerging areas of research such as snow hydrology, Lake Hydrology, watershed hydrology, mountain hydrology, nuclear hydrology, environmental hydrology. In order to strengthen laboratory-oriented studies, seven laboratories were established at NIH-R during this phase. Second phase of UNDP assisted project was undertaken during this period for development of capabilities in frontal areas of hydrology such as hydrological instrumentation, catchment hydrology, data processing and analysis, nuclear applications in hydrology, forest hydrology. The institute participated in an Indo-Dutch programme on Water Management (WAMATRA-II) with components of water quality, groundwater modeling, agriculture drainage, remote sensing applications, and instrumentation.

During the study period (1991-2020), NIH-R has seen major leap advances in technologies, from mainframe computers to highly compact and advanced desktop and laptop computers; photographic products of satellites to digital products, drone survey data, GPS surveys; hydrology models programmed in FORTAN and/or BASIC to Graphic User Interface (GUI) based advanced models with Python, Java, R scripts; manual field instruments to automated instruments with telemetry capabilities, etc. All these advancements have facilitated delivery in a fast-track mode. Also, NIH-R has undergone substantial capability development exercises in the form of major sponsored projects from UNDP, The World Bank, USAID, EC/EU, etc. NIH-R is now having third generation of scientists who are trained on modern modeling techniques.

METHODOLOGY

Assessing the impact of scientific research is a difficult problem. A section of scientific community has been using the citations to papers as a measure of impact of that work. However, this criterion is often criticized for its inherent limitations and drawbacks. For example, research could exist with wide social relevance but perhaps few citations. Evaluation of research impact beyond paper citations has been proposed in various forms, requiring improved documentation to capture the societal impacts of science(Wolf et al. 2014). Various techniques have been discussed in literature to estimate the production function of research institutions. Jyoti et al. (2006) have reported a framework for application of Balanced Scorecard (BS) tool in evaluating performance of R&D organizations in India. In another study, Jyoti et al. (2010) have identified various success factors to improve the performance of national R&D organizations and studied the cause and effect relationship among these factors. Gangopadhyay et al. (2015) and Laliene and Sakalas (2014) have applied Data Envelopment Analysis (DEA) methodology to analyze the performance of public funded R&D organizations.

Every five years, EFC/SFC Plan document is prepared which defines the thrust/priority areas of research to be undertaken by NIH-R. In between plan periods, some new studies are assigned by the controlling ministry, funding agencies, courts/tribunals, NGT, etc. Broad areas of studies to be pursued by NIH-R with GIA funding (intramural research) during a five-year Plan period are defined in the SFC/EFC Plan Document. Yearly work plan is prepared in consultation with the expert groups. Sponsored and consultancy projects (extramural research) are received intermittently with specified project deliverables and project duration. Research output of NIH-R is broadly categorized under three verticals: (i) Research study reports, (ii) research publications in journals, books, conferences, and (iii) training courses and workshops. These three output forms are the result of work carried out under both intramural and extramural research studies and projects. The results of studies and projects conducted by NIH-Rare delivered in the form of research/technical reports which are reviewed by the subject domain experts. Research publications based on the studies and projects are published in national and international peer-reviewed journals, and also presented in national and international conferences/seminars/workshops. Bibliographic data of these outputs from 1991 to 2020 was obtained from the Annual Reports of the Institute. Year-wise data was compiled and keywords assigned to each study. On the basis of keywords, studies and research publications were classified into broad subject categories like Ground Water, Surface Water, Water Quality, Decision Support System, Integrated Water Resources Management, Watershed, Arsenic contamination, Climate Change, Water Conservation, Isotope Applications, Hydrometeorology, Remote Sensing &GIS Applications, Snow and Glaciers, Floods, Droughts, Reservoir Sedimentation, River Basin Studies, Soil Studies, Dam Break and Lake Studies. Training courses are conducted based on the studies carried out and keeping in view the demand from field engineers, scientists, professionals etc. While organizing training courses, scientists of NIH-R take lead responsibilities and some specialists from other academic/research institutions are also invited as faculty. Information related with various training courses conducted from 1991 to 2020 was also obtained from the Annual Reports and the same methodology was adopted for categorization and analysis of training courses.

Yearly data is then organized in blocks of 5-year period. Using keyword search for major themes/topics, the number of study reports, research publications, and training courses during the six 5-year blocks was identified. Growth rate for research outputs during different blocks is also computed. Research hotspots were identified based on topics consistent during the period, topics with growing trend, and topics with declining trend. Emerging themes/topics during the recent ten years and five years were identified and a comparison was made between themes/topics covered in the study reports and trainings conducted.

Transformative Activity Index (TAI), as originally suggested by Guan and Ma (2004) and subsequently used by Garg et al. (2009), Joshi et al. (2010), Sinha and Joshi (2012), and Dwivedi (2016), was adapted to study the change in the output in two (or consecutive) blocks amongst specified subject categories. TAI is a useful index to study the thrust of research activity, which is carried out under different themes/categories, over a period of time. The formula used for calculating TAI is as follows:

$$TAI = \frac{\frac{\mathrm{Ci}}{\mathrm{Co}}}{\frac{\mathrm{Wi}}{\mathrm{Wo}}} x100$$

Where, Ci= Number of study reports of the specific subject category in the i^{th} block

Co= Total number of study reports of the specific subject category during the study period

Wi= Number of study reports of all subject categories in the i^{th} block

Wo= Total number of study reports of all subject categories during the study period

RESULTS AND DISCUSSION

Form and pattern of research delivery

NIH-R's output in form of study reports, research publications, and training courses is a reflection of the in-house research studies and sponsored projects conducted at different stages of time. For a research institute, variation in research output over different time periods is quite normal, as it depends not only on the available strength of scientific manpower but also on other factors such as focus on selected forms/types of output (study report/research paper/training courses), availability of laboratory and field instrumentation facilities, collaborations with scientists within India and abroad, mandate given by the controlling ministry, involvement of scientific manpower on activities other than research (e.g. establishment of infrastructure), availability of sponsored projects on specified subjects, etc. The quantum of research output during the six blocks of 5 years as well as for individual years during 1991-2020 is depicted in Table 1.

Study Reports and Research Publications

It can be observed from Table 1 that total 1,496 study reports were prepared at NIH-R on various water resources related topics and 1,616 papers published in national (659) and international (957) journals during the last 30 years. The papers presented in national and international conferences during the same period were 1,452 and 1,134, respectively. The average annual growth during 5-year period is shown in parenthesis, considering output in the first block of 1991-95 as the baseline. For the research papers, the third (2001-05) and fourth (2006-10) blocks have been the most productive years whereas the block of 2011-15 was the least productive period. Even the last block (2016-20) was not considered as a productive period, which also saw a significant drop in the number of papers in conferences. The growth of papers in national journals achieved its peak (~6%/year) in the second block (1996-00) and declined in all subsequent blocks. The fifth block (2011-15) was a peculiar case where growth of papers in journals decreased but growth of papers in conferences increased.

First upward jump in the number of study reports was noticed in the year 1995-96, which continued during subsequent years till 2003-04 with exception of 2001-02 (115) and 2002-03 (121). A significant drop in the number of reports was noticed in 2004-05, which continued till 2013-14 with exception in 2005-06 (45) and 2006-07 (36).

Table 1: Study reports and research publications during 1991-2020

S.N.	Year	Study reports	Book & Book Chapters	Papers in Journals		Papers in Conferences	
				International	National	International	National
1	1990-91	20	-	-	12	7	30
2	1991-92	39	-	5	17	16	15
3	1992-93	79	-	7	7	17	43
4	1993-94	49	-	7	29	13	16
5	1994-95	48	-	16	30	20	30
I	**1991-95**	**235**	**-**	**35**	**95**	**73**	**134**
6	1995-96	78	-	8	21	13	48
7	1996-97	82	-	8	31	9	35
8	1997-98	83	-	18	38	29	20
9	1998-99	83	-	15	19	10	52
10	1999-2000	93	-	16	17	17	45
II	**1996-00**	**419**	**-**	**65 (+6)**	**126 (+6)**	**78 (+1)**	**200 (+13)**
11	2000-01	90	-	19	23	48	37
12	2001-02	115	-	20	30	40	41
13	2002-03	121	3	24	25	38	35
14	2003-04	79	13	32	38	35	73
15	2004-05	23	9	41	21	45	61
III	**2001-05**	**428**	**25**	**136 (+14)**	**137 (+2)**	**206 (+26)**	**247 (+9)**
16	2005-06	45	38	43	26	44	39
17	2006-07	36	24	37	17	34	24
18	2007-08	15	22	48	25	18	59
19	2008-09	17	31	52	17	40	63
20	2009-10	18	6	41	27	40	74
IV	**2006-10**	**131**	**121**	**221 (+17)**	**112 (-5)**	**176 (-6)**	**259 (+2)**
21	2010-11	26	3	34	12	36	102
22	2011-12	19	17	23	11	36	106
23	2012-13	24	21	43	25	49	62
24	2013-14	25	14	55	23	90	44
25	2014-15	36	9	72	19	76	49
V	**2011-15**	**130**	**64**	**227 (+1)**	**90 (-4)**	**287 (+22)**	**363(+21)**
26	2015-16	31	9	63	13	48	100
27	2016-17	48	19	58	31	54	64
28	2017-18	33	20	58	17	104	18
29	2018-19	18	10	52	25	61	12
30	2019-20	23	2	42	13	47	55
VI	**2016-20**	**153**	**60**	**273 (+9)**	**99 (+2)**	**314 (+5)**	**249 (-23)**
	Gr. Total	**1,496**	**270**	**957**	**659**	**1,134**	**1,452**

The new incumbent Director who joined NIH-R in the year 2003 decided to publish only selected study reports, hence there was a sudden drop in the number. In case of papers in journals, first jump in the number was noticed in the year 1993-94, and the next significant jump was observed in 2003-04, which continued during all subsequent years (with minor fluctuations). Writing of books and book-chapters picked up from 2003-04 was consistently high during 2005-06 to 2008-09. It remained between 10 and 21 during 2011-12 to 2018-19 with couple of exceptions. During 2019-20, only 2 books or book-chapters were produced, which is the lowest number since 2002-03.The number of papers in conferences enhances significantly in the years when NIH-R has organized conferences where a large number of scientists have participated and presented papers.

Table 2shows break-up of study reports into various themes in five-yearly blocks from 1991 to 2020. It can be observed from the table that maximum study reports were published on the theme of river basins studies (362), out of which 235 reports were brought out during the initial fifteen-year period (1991 to 2005). This theme was consistently active during subsequent years. Next important themes are Groundwater and Hydrological Modeling, which attracted the attention of NIH-R Scientists. In the last thirty years,total 184 study reports were brought out on Groundwater, out of which 131 reports were published during initial fifteen- year period(1991-2005). Although with reduced number, this theme was also active during subsequent years. On hydrological modeling, 155 study reports were published, out of which122 reports were brought out in the during initial fifteen- year period (1991-2005). Flood studies combined with Surface water has been another major theme on which significant study reports (163) were published. The other major theme has been Water Quality (102 reports) whose output was significantly reduced during the recent fifteen years. Some topical themes like Water Conservation, Arsenic Pollution, Climate Change, Integrated Water Resources Management (IWRM) regularly attracted world's attention due to scarcity of freshwater, but these themes found limited space in studies conducted by NIH-R during the last thirty years (Table 2).

Transformative Activity Index (TAI) was used to study the change in the output in consecutive blocks amongst specified subject categories. Twenty subject themes as mentioned in Table 2 were clubbed into six major subject categories, i.e. (i) Surface water hydrology (SWH), (ii) Groundwater hydrology (GWH), (iii) Environmental hydrology (EH), (iv) Water resources management (WRM), (v) Hydrological modelling (HM), and (vi) Hydrological investigations (HI). TAI was computed for the above subject categories during different blocks, and change in TAI in two consecutive blocks was computed treating 1991-1995 as the baseline block. The values of (change in) TAI suggest (Figure 1) that research output for WRM was high during 2006-2010 and 2010-2015, but significantly decreased during the recent block (2015-2020). Research output under HM dipped during 2010-2015 but again picked up in the recent block.

Training courses

For dissemination of specialized knowledge and transfer of technology, training is an important part of the activities of any research institution. NIH-R regularly conducts training courses in various disciplines and practical hydrological problems, for benefit of field engineers, scientists, professionals, researchers, and students. Table 3presents a list of fifteen major themes on which training courses were organized during the last thirty years. Maximum number of training courses (68) were conducted on 'Water Resources Management', followed by 58 courses on the general theme of 'Hydrology' 51 courses on 'Remote Sensing and GIS', 49 courses on 'Groundwater',42 courses on 'Hydrological Modeling', and 41 courses on 'Flood Studies'. Some other important themes like 'River Basin Studies', 'Lake Hydrology', 'Drought Studies', 'Drainage', 'Forest Hydrology' and 'Agricultural Hydrology' are important from the research point of view but less number of training courses were conducted on these themes. Since most of the training courses are demand driven, the training topics are decided on suggestion of the demanding agencies.

Table 2: Theme-wise study reports during 1991-2020

Title/Block Year	1991-95	1996-2000	2001-05	2006-10	2011-15	2016-20	Total	Rank
River Basin Studies	84	76	75	26	50	51	362	1
Ground Water	30	57	44	12	25	16	184	2
Hydrological Modeling	39	56	27	12	8	13	155	3
Flood studies	28	34	36	9	7	16	130	4
Water Quality	20	30	23	9	12	8	102	5
RS&GIS Application	4	32	37	4	6	5	88	6
Soil Studies	15	39	19	1	3	2	79	7
Reservoir Sedimentation	17	14	27	9	3	3	73	8
Watershed hydrology	5	24	28	5	1	3	66	9
Lake Hydrology	12	22	18	6	3	2	63	10
Droughts	13	11	8	3	7	5	47	11
Snow &Glacier	12	13	7	5	7	3	47	12
Climate Change	0	6	4	5	14	10	39	13
Surface Water	5	9	5	5	6	3	33	14
DamBreak Studies	8	9	7	2	2	0	28	15
Isotope Application	3	1	5	2	5	1	17	16
IWRM	0	0	0	4	10	3	17	17
Arsenic Contamination	0	6	3	2	0	5	16	18
DSS	0	1	1	5	3	3	13	19
Water Conservation	1	2	2	0	1	1	7	20

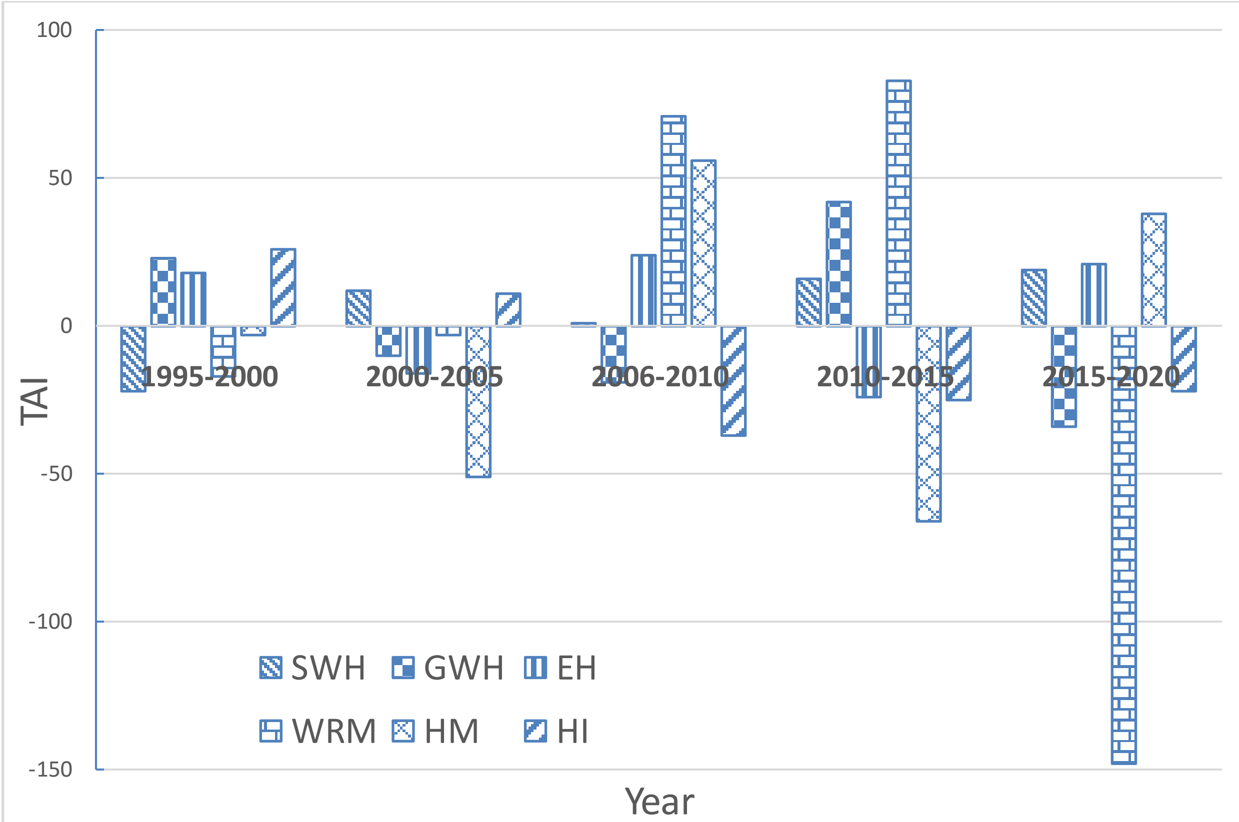

Fig. 1: Change in Transformative Activity Index (TAI) for major subject categories

Table3: Theme-wise training courses organized during 1991-2020

Topic	1991-95	1996-00	2001-05	2006-10	2011-15	2016-20	Total	Rank
Water Resources Management	1	4	5	11	21	26	68	1
Hydrology	11	6	3	11	11	16	58	2
RS&GIS Application	1	6	5	8	19	12	51	3
Ground Water	5	4	3	6	18	13	49	4
Hydrological Modeling	4	7	3	4	14	10	42	5
FloodStudies	10	6	2	8	6	9	41	6
Data Processing (HYMOS+ SWDES)	1	1	10	18	10	1	41	7
DSS	0	0	0	9	17	7	33	8
Water Quality	4	0	1	5	13	8	31	9
Surface Water	5	3	12	4	4	1	29	10
ClimateChange	1	0	0	3	9	12	25	11
River Basin Studies	0	3	1	5	0	8	17	12
Coastal Hydrology	0	2	0	3	5	2	12	13
Watershed Hydrology	1	2	0	4	1	4	12	14
LakeHydrology	0	1	2	1	4	3	11	15

Research outputs in key theme areas during the study period, and areas that emerged during the recent ten years and recent five years are indicated in Table 4. A direct correlation between the study areas and training themes is not seen (Figure 2).

Table 5 presents a consolidated view of the research outputs along with information on the change in leadership and recruitment of new scientists at NIH-R. Hatched areas in Table 5 show the periods of especially high or low productivity.The numbers in parenthesis show average annual output for each block period, which may be compared with the average annual output for the thirty period as a whole (as shown in the total row). The table shows improving trend in the study reports during block period 2016-2020 (153 studies). In case of research publications, papers in journals as well as in conferences

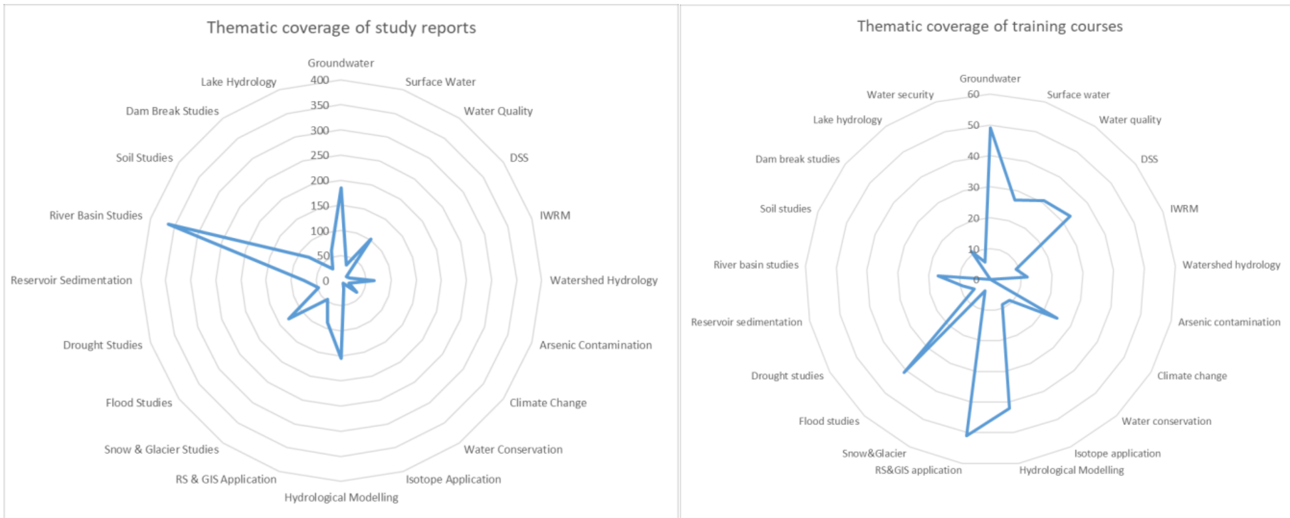

Fig. 2: Theme-wise coverage of study reports and training courses during 1991-2020

Table 4: Consistent, emerging and gap theme areas during 1991-2020

Activity	**Study reports themes**	**Training themes**
Recent 10 years (2011-20)	River basin studies (101), Groundwater (41), Climate change (24), Floodstudies (23), Hyd.modeling (21), Water quality (20), IWRM (13), DSS (6)	WRM (47), Groundwater (31), RS&GIS application (31), Hyd.modeling (24), DSS (24), Climate change (21), Coastal hydrology (7), IWRM (5)
Recent 5 years (2016-20)	River basin studies (51), Floodstudies (16), Groundwater (16), Hyd.modeling (13), Climate change (10)	Climate change (12), River basin studies (8), Water security (6), IWRM (5), Water conservation (5)
Consistent during 30 years	River basin studies (362), Groundwater (184), Surface water (33), Isotope applications (17)	Hydrology (58), Groundwater (49), Flood studies (41), Data processing (41), Water quality (31)
Emerged with time	Climate change, IWRM, DSS	WRM, Hyd.modeling, RS&GIS application, Lake hydrology, Coastal hydrology, IWRM, Water security
Declined with time	Water quality, Watershed hydrology, Hyd.modeling, RS&GIS application, Snow & glacier, Floodstudies, Droughtstudies, Reservoir sedimentation, Dam break studies, Soil studies	Forest hydrology, Drainage, Water logging, Hydro-meteorology

Table 5: Consolidated view of research outputs during 1991-2020

Years	**Study reports**	**Research publications**			**Training courses**	**Change in leadership**	**Recruitment of new scientists**
		Book & book chapters	Papers in journals	Papers in conferences			
1991-95	235 (47)		130 (26)	207 (41)	53 (11)	1993	1992 (2), 1994 (6)
1996-00	419 (84)		191 (38)	278 (56)	45 (9)	2000	1996 (14), 1997 (8)
2001-05	428 (86)	25 (5)	273 (55)	453 (91)	35 (7)	2003	
2006-10	131 (26)	121 (24)	333 (67)	435 (87)	81 (16)	2008	
2011-15	130 (26)	64 (13)	317 (63)	650 (130)	131 (26)		2011 (10), 2013 (2), 2015 (6)
2016-20	153 (31)	60 (12)	372 (74)	563 (113)	147 (29)	2017	2018 (4), 2019 (6)
Total	**1,496 (50/Yr)**	**270 (9/Yr)**	**1,616 (54/Yr)**	**2,586 (86/Yr)**	**492 (16/Yr)**		

received a significant jump during 2001-05. Since then, the pace of papers in journals remained at that level but publications in conferences received another jump during 2011-15. Publication of books and book chapters received a quantum jump during 2006-10 but later settled at about 60 (~12/year).

Since the year 2006, NIH-R paid more attention on conducting training courses as imparting training was an important component of The World Bank-funded Hydrology Project-II (2006-2014). As part of an EU-funded "SaphPani Project (2011-2014)" and another World Bank-funded "National Hydrology Project (2016-contd.)" training courses received increasing focus. During the period 2016-20, maximum 147 training courses (about 29 courses/year) were organized (Table 5).

NIH-R functioned with sanctioned strength of 105 scientists until 2001-02, after which the number declined to 83 and remained so until 2015-16. In between, few positions of scientists were retrieved from 'deemed abolition' status and new scientists could be recruited against those posts. Batches of new scientists were recruitedat NIH-R in 1992, 1994, 1996 and 1997 (Table 5). Major addition of new scientists was reported during 1996-1997 (22 scientists). A corroborative increase in the number of study reports and research publications was noticed during the next 5-year blocks (especially in the number of papers in journals). The other new entry of scientists was reported in the years 2011, 2013, 2015, 2018 and 2019. Addition of eighteen new scientists during 2011-15 has, however, made only a marginal increase in the number of study reports and papers in journals during 2016-20. A spurt in publications in conferences is noticed during 2011-15. This may be attributed to the introduction of Annual Performance Appraisal Report (APAR) marking scheme in 2012, which stipulated assigning weight age to papers in conferences. Therefore, scientists started publishing more papers in conferences. The number of study reports has seen a significant decline during 2006-10, which is sustained during subsequent periods. The new incumbent Director who joined NIH-R in the year 2003 decided to publish only selected study reports, hence there was a sudden drop in the number. Change in leadership at NIH-R is also reflected by mention of the year in Table 5. Leadership definitely has a bearing on the output of an institution. The vision and policies of the leader shape the quantity and quality of output.

Tracking the output during the recent 5-year period, only31 study reports per year is not a good number keeping in view the current strength of scientists (~83) at NIH-R.Number of outputs in terms of training courses seems to be on rise since 2006-10. A new batch of ten young scientists has joined NIH-R in the year 2018-2019, and their contribution will be reflected in the coming years. Also, if NIH-R scientists work in active collaboration with researchers of other academic and research institutions, the number of papers in journals should also grow.

CONCLUSIONS

The research journey of NIH-R during the last thirty years (1990-91 to 2019-20) is presented. The outputs produced in the form of study reports, research publications and training courses are analyzed to identify the research trends, strong and weak areas, and the gap theme areas which are important from the point of view of national interest but could not be attempted during the reported period are highlighted. The following specific inferences are drawn from the study:

1. The research output of NIH-R during the last thirty years (1991 to 2020) in the form of study reports, research publications and training courses is quite significant. However, the gap theme areas identified need introspection by the NIH-R leadership.
2. Training courses conducted by NIH-R are not in proportion to the studies conducted on particular themes. For example, maximum studies were conducted on the theme 'River Basin Studies' but training courses conducted on this theme are very less. In the area of 'Water Resources Management', maximum number of training courses were conducted but hardly any studies are reported on this theme. An alignment is needed between the training themes/topics and the study areas pursued at NIH-R.
3. NIH-R has generally not been able to draw benefit of the presence of young scientists by channelizing their output in themes/topics of national interest. HR policies need to be designed for effective utilization of the talent and skills of new scientists.
4. Hydrological community is experiencing challenges emerging from the rapidly changing science communication landscape. NIH-R could not engage with new modes of communication such as Fact Sheets, e-books, policy briefs, etc.

Let us look at some of the key takeaways from our analysis. Based on the present study, it may be inferred that in order to maintain a competitive edge NIH-R will need to:

1. Benchmark against similar institutions of excellence,
2. Cater to the emerging needs of the country in the water sector, e.g. water scarcity and water security; impacts of climate change on extreme events; Nature Based Solutions; storm water flooding,
3. Align with flagship schemes of the Government of India (e.g. Jal Shakti Abhiyan, Jal Jeevan Mission, PMKSY, Atal Bhujal Yojna),
4. Promote interdisciplinary research in collaboration with other national organizations,
5. Be in sync with hydrologic research going on at international level (research strands).

Policy Implications

Given the expectations from public-funded research institutions such as NIH-R, there are some critical policy implications emanating from our research. The first such implication is to develop strategic capability in the management of NIH-R, which is visionary with long-term goals and is sensitive to the immediate requirements of the country. Such a strategic capability needs to be built with elements of innovation, management principles, agile mode of functioning, rather than working on traditional mode which is less concerned with practical outcomes.

Second, developing strategic capability is inevitably linked with the enhancement of skills of research personnel. In order to remain relevant in the competitive world, NIH-R should invest in capacity building of its scientists and scientific staff. Next, in order to sustain research in some of the crucial subject areas/topics, for which younger scientists are not adequately trained, it would be desirable to engage experienced scientist for a reasonable period (3-5 years) so that younger scientists are able to pick up the work with confidence.

Hydrology is traditionally an integrative science with high societal relevance and geographic diversity. It is always emphasized that the main drivers of progress in the discipline of hydrology are societal needs, fundamental ideas and new technologies. NIH-R needs to give more attention to the studies of interdisciplinary nature having societal benefits. The scope of environmental hydrology, for example, may be broadened to cover interdisciplinary studies (e.g. societal and economic benefits from rejuvenation of water bodies; socio-economic and health aspects of controlling water pollution) in collaboration with organizations dealing with other disciplines like sociology, economics, health, etc. It is imperative for a leading research institution like NIH-R to keep track of the research strands, and keep innovating and invigorating. A good strategy for NIH-R would be to keep its researchers aligned with, and keep eye on, grand challenges of hydrology such as engaging with the list of unsolved scientific problems in hydrology that would invigorate research in the 21st century (https://iahs.info/IAHS-UPH/). It is hoped that the researchers at NIH-R would continue to further the science and practice of hydrology by presenting solution to challenging problems not only in India but also globally. While keeping their scientific vigour, researchers have to ensure that science of highest quality and with innovative content is published, and that they are not carried away by the tendency to publish premature research where the contribution is incremental or marred by self-plagiarism or other unethical practices (Quinn et al. 2018).

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