Springer Water

Amarjit Singh
Dipankar Saha
Avinash C. Tyagi *Editors*

Water Governance: Challenges and Prospects

Springer

Springer Water

The book series Springer Water comprises a broad portfolio of multi- and interdisciplinary scientific books, aiming at researchers, students, and everyone interested in water-related science. The series includes peer-reviewed monographs, edited volumes, textbooks, and conference proceedings. Its volumes combine all kinds of water-related research areas, such as: the movement, distribution and quality of freshwater; water resources; the quality and pollution of water and its influence on health; the water industry including drinking water, wastewater, and desalination services and technologies; water history; as well as water management and the governmental, political, developmental, and ethical aspects of water.

More information about this series at http://www.springer.com/series/13419

Amarjit Singh • Dipankar Saha
Avinash C. Tyagi
Editors

Water Governance: Challenges and Prospects

Springer

Editors
Amarjit Singh
Former Secretary, Ministry of Water Resources, River Development and Ganga Rejuvenation
Government of India
New Delhi, India

Dipankar Saha
Former Member, Central Ground Water Board, Ministry of Water Resources, River Development and Ganga Rejuvenation
Government of India
Faridabad, India

Avinash C. Tyagi
Former Secretary General, International Commission on Irrigation and Drainage
New Delhi, India

ISSN 2364-6934 ISSN 2364-8198 (electronic)
ISBN 978-981-13-2699-8 ISBN 978-981-13-2700-1 (eBook)
https://doi.org/10.1007/978-981-13-2700-1

Library of Congress Control Number: 2018964903

© Springer Nature Singapore Pte Ltd. 2019
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Foreword by Dr. M. S. Swaminathan

The Indian subcontinent faces particularly severe water crises. While India's population is expected to cross 1.6 billion by 2050, the annual per capita freshwater availability in the country is expected to drop down to 1,200 cubic metres. In addition, the spatial and temporal variations in precipitation are likely to be accentuated significantly by climate change. As a result, many parts of the country are likely to be severely water stressed.

It has to be recognized, however, that the availability of water along with fertilizers and improved seeds has helped the country achieve **food self-reliance**; the production of food grains has gone up from around 50 mmt at the time of independence to about 275.7 mmt today. In 2012–2013, India exported food grains worth US $41billion vis-à-vis imports of US $20 billion. However, the *food security has come at the cost of water insecurity*. The water crisis is going to be further exacerbated by the growing demand for food grains; it is projected to be 450 mmt by the year 2050. At the same time, the availability of water for agriculture is likely to go down further (proportionally) as a result of increased usage of water by the industry and domestic consumers. Much would, therefore, depend on Improving Water Resources Management for agriculture.

Today, more than 60 percent of India's irrigation needs and 85 percent of its rural domestic water supplies come from groundwater. Although this ubiquitous practice has been remarkably successful in helping people to cope with seasonal water shortages in the past, it has led to rapidly declining water tables. In about 16 percent of the blocks, groundwater resources are overexploited. Dramatic regional aquifer depletion is observed, particularly in the northern regions such as Punjab, Haryana and Western UP, where the Green Revolution took root and much of the national grain production comes from.

The scarcity of water, which is being experienced in many parts of the country, is paving the way for interstate conflicts over sharing of this precious resource. This in turn is posing an enormous challenge to India's economic development in the coming decades. This requires urgent efforts at planning and implementing water infrastructure development plans and policies for conservation to avert a crisis in the coming years.

There is a dichotomy today in water resources distribution and economic development. Areas facing human migration (e.g. Bihar) are blessed with plentiful water resources but lack access to irrigation, while the recipients of migration, the states in the north-west have current access to irrigation, but depleting groundwater stocks. Land, water and labour resources, therefore, need to be considered in an integrated manner at the national as well as at the local level to assess strategies for economic development. Water constraints have to be identified and an infrastructure development and management pathway developed that is sustainable and appropriate for each region.

Water pollution is another major concern threatening health and economic productivity of people and ecosystem. Presently, municipal wastewater is responsible for approximately 80 percent of total surface water pollution in India as only about 10 percent of industrial and municipal wastewater is treated. Apart from seeping into the groundwater, the untreated waste is discharged into water bodies. A large swath of the country's groundwater is affected by geogenic contamination, which many researchers argue is triggered by overexploitation. Driven by ungainful employment in agriculture sector, unplanned cities are largely responsible for deteriorating water bodies all around. Together with lean season flow depletion, the resulting water pollution has the potential for disease epidemics and irreversible ecological loss resulting in collapse of the ecosystem as is evident from the disappearance of dolphins from Ganges, for example.

We have to be less dependent on the monsoons, and the focus should be on water use efficiency and agronomic advancements. Community participation could greatly facilitate this process. There are success stories available from different parts, and we must learn and replicate them after enriching with proper science and technological inputs. Unless this issue is addressed, it is likely to be the most significant source of risk for India's sustained economic growth and development.

Development efforts in various sectors without factoring water sensitivities, as being practiced at present is no more a viable option for the enhancing happiness, welfare and well-being of people. Actions to refine water management by improving water system reliability and resilience are needed. Governance of such a vital constituent of life on earth and its security needs to be objective, inclusive and transparent. While promoting economical and efficient use of water and preserving equity of use in support of overall development, particularly for enhancing rural livelihoods, greater awareness building of development managers in various fields is needed. There is a need to engender the capacity of different actors in this complex endeavour for overall sustainable development through continuously informed and active engagement of all the stakeholders as follows: the governments and administrative institutions, the development managers, the academia and research, the civil society and the individual users of water.

I am happy to see this book addressing some of these key issues through a wide array of articles contributed by the domain experts. The enriching articles range from surface and groundwater resource assessment and mapping, water quality, flood mitigation, involvement of civil society and community participation, rejuvenating the depleted aquifers, governance and financial issues of water sector and some well-laid-out thoughts on reforming the water sector, which is long due. I am sure the book will serve its intended purpose of generating informed debate while taking decisions in various sectors of development that are influenced by water and its timely availability in desired quantity and quality.

Our gratitude goes to Dr. Amarjit Singh for taking the trouble to compile such an informative book on water governance. I hope the book will be widely read and used.

Founder Chairman of M. S. Swaminathan Research Foundation, Chennai, India

Dr. M. S. Swaminathan

Foreword by Amitabh Kant

India is suffering from the worst water crisis in its history, and millions of lives and livelihoods are under threat. Currently, 600 million Indians face high to extreme water stress, and about two lakh people die every year due to inadequate access to safe water. The crisis is going to get worse by 2030 when India's water demand is projected to be twice the available supply (as per the McKenzie analysis). Therefore, how we manage our water, at the local, state and national levels, would determine India's ability to achieve rapid economic growth. It would determine whether we are able to improve the quality of life of our people in a sustainable manner.

The Sustainable Development Agenda 2030 adopted by the global community lays down a framework for the peace and prosperity on earth. Among the 17 goals adopted to monitor the progress of the Agenda, all the goals, except a couple, are intricately related to Goal 6 "Ensure availability and sustainable management of water and sanitation for all". Accordingly, all major development schemes such as Pradhan Mantri Krishi Sinchai Yojana (PMKSY) Swachh Bharat Abhiyan, Har Khet Ko Pani, Mahatma Gandhi National Rural Employment Guarantee Scheme, Pradhan Mantri Awas Yojana or Smart Cities focus on the efficient management of water resources.

Availability of both surface and groundwater in the country varies from one region to another. In view of limitations on availability of water resources and rising demand for water, sustainable management of water resources has acquired critical importance, for our country to move on a path of equitable development to ensure well-being and happiness of all its citizens. Despite large investments in the water management and a series of reforms undertaken in the water sector over the years, the situation is far from satisfactory. One of the shortcomings has been the lack of monitoring and assessment of impacts of development initiatives and reforms undertaken.

NITI Aayog has developed a Composite Water Management Index as a useful tool to assess and further enhance the effectiveness of management of water resources. The index serves as a useful tool to track performance in the water sector and take corrective measures. It provides useful information for the states and also for the concerned central ministries/departments enabling them to formulate and implement suitable strategies for better management of water resources. The Index has a set of 28 Key Performance Indicators (KPIs) covering irrigation status, drinking water and other water-related sectors. Critical areas such as source augmentation, major and medium irrigation, watershed development, participatory irrigation practices, sustainable on-farm water use practices, rural drinking water, urban water supply and sanitation and policy and governance have been accorded high priority.

Just like the water resources development process, reporting and monitoring of the index, however, is a multi-department and multidisciplinary task. It requires an understanding of water issues by the development workers who are not specialists in water sector, on the one hand, and the larger users and public, on the other. I am, therefore, delighted that this book, ***Water Governance – Challenges and Prospects***, edited by the former union secretary, Water Resources, Dr. Amarjit Singh and his colleagues, Dr. Dipankar Saha (former member of CGWB) and Sh A. C. Tyagi, ex-secretary general, International Commission on Irrigation and Drainage, is bringing out various facets of water management. The experts from various disciplines have lucidly brought out the challenges and prospects in the sustainable management of water resources. I am sure this will serve as a useful reference book for all those engaged in the efficient management of water resources for sustainable development of our country.

Water, if not managed properly, has the potential to change governments. There is a need to link good governance with good politics so that water becomes the top government priority.

Chief Executive Officer Amitabh Kant
NITI Aayog, New Delhi, India

Contents

Emerging Issues in Water Resources Management: Challenges and Prospects

Amarjit Singh, Dipankar Saha, and Avinash C. Tyagi

1 Introduction

Water resources management impacts almost all facets of the economy. Water is also the primary medium through which climate change influences the earth's ecosystem and therefore people. Water stress is already critical, particularly in most of the developing countries, and improved management is essential for sustainable management of this resource. Recognition of the centrality of water in the development process has not yet permeated the political and policy echelons in most of the countries of the world and India too it is not reflected adequately in national plans. To shape our water future – there should be a coherent approach involving science and technology, policy initiatives and community participation.

In 1961, when India was on the brink of mass famine, Dr. M. S. Swaminathan led the country to usher in the *Green Revolution* by making available water, chemicals (fertilizers and pesticides, etc.), and high-yielding variety seeds to the farmers that helped the country achieve food self-sufficiency. The production of food grains which was around 50 MMT at the time of independence has gone up to about 252 MMT in 2014–2015 (Ministry of Agriculture, 2017, 1). In 2012–2013 India exported food grains worth US $41 billion against imports worth US $20 billion, reflecting food security at national level.

A. Singh
Former Secretary, Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India, New Delhi, India

D. Saha (✉)
Former Member, Central Ground Water Board, Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India, Faridabad, India

A. C. Tyagi
Former Secretary General, International Commission on Irrigation and Drainage, New Delhi, India

© Springer Nature Singapore Pte Ltd. 2019

A. Singh et al. (eds.), *Water Governance: Challenges and Prospects*, Springer Water,
https://doi.org/10.1007/978-981-13-2700-1_1

However, this hard-earned food security has been achieved by compromising with water insecurity which is evident from the growing water crises being experienced in from community to sub-city to big city and basin level. Clashes between communities on account of sharing of this precious natural resource are no more exceptions. Further, majority of water bodies such as ponds, lakes, reservoirs, rivers, as well as aquifers are getting polluted. The present water crises are going to be further exacerbated by the growing demand for food grains, which is projected to be 450 MMT by the year 2050. At the same time, the availability of water for agriculture is likely to go down further (proportionally) as a result of increased usage of water by the industry and domestic consumers.

Growing complexity of water management in India as well as in most of the countries due to its limited availability, demographic and lifestyle changes, competing demands from different users and societal sectors and across administrative boundaries, and potential climate change poses increasingly intricate challenges for sustainable exploitation and management of this resource. Inter- and intrastate water disputes due to emotional, motivated, and biased approach, rather than the science-based discourse, are making cooperation and collaboration among basin states, the stakeholders, and sectors increasingly difficult. Ambitious societal development goals such as doubling the net income of farmers in the next 5 years, eradicating open defecation by building more toilets, scientific management of municipal solid waste, wastewater and industrial pollution management for cleaner water bodies, and building of smart cities have raised the bar for water management further.

This book, with contributions from renowned experts from various disciplines and on various facets of water management – with experience at the state, central, and global levels – attempts to present holistic perspective on how to use water as the key sustainable development tool. The articles in this book cover various perspectives such as water resources development, groundwater mapping and management, public-private participation in the sector, hydropower development, drinking and wastewater management, flood and environmental management, community management of water, civil society in water sector, its governance and financial issues, and need for research and development inputs. The articles identify good practices to assist different levels of governance and other stakeholders in engaging effective, fair, and sustainable water policies. They establish that good governance can shape policies into concrete deliverables through bold actions through interaction between science, polity, and society and harnessing the power of the people. With a view to improve water governance, various gaps such as policy gaps, institutional gaps, financial gaps, information gaps, accountability gaps that exist, and the capacity gaps that impact the water governance in the country have been identified and discussed.

2 Water Resources and Its Information Flow in India

India with 17.5% of the world's population has only 2.4% of the world's land resources and roughly 4% of the world's freshwater resources (India-WRIS 2012). Most of the rainfall in India, ~76% of it, occurs as a result of the southwest monsoon between the months of June and September, except in the state of Tamil Nadu, which falls under the influence of northeast monsoon and receives rainfall during October and November. The precipitation is highly variable both in time and space. More than 50% of precipitation takes place in about 15 days and less than 100 h altogether in a year.

Water resources management is essentially the management of a variety of risks. They include risks related to floods and droughts, risks related to health, as well as economic and financial risks. One of the most important inputs in water resources management, therefore, is the knowledge of the factors that influence the risks to water resource systems, in terms of both their current dynamics and future evolution. Hydrological data and forecasts are essential for the assessment of these risks and evolving suitable strategies to manage them ensuring the safety of people. Hydro-meteorological data and information enable people to think together in solving the various water-related problems. They help building trust essential for cooperative efforts and in avoiding interstate conflict. Success of policy-making, planning, development, and management of resources depends on timely dissemination of accurate water-related data and information to all stakeholders.

If the water resources are to be managed, distributed, and used equitably and efficiently, all the stakeholders need to share water resources data and information. Unfortunately, in India the collection, management, reporting, and quality of water and environmental data are often poor and incomplete. They are not easily accessible for a variety of reasons including security concerns. Even when the data does exist, it is not made available in public domain in an easily retrievable format. As a result more often than not, debates on water issues, even among government departments and among states, are bereft of scientific and data and information and are largely governed by perceptions, emotions, and myths.

Water information and data in India is collected by many different agencies both at central and state level. Indian Meteorological Department (IMD), Central Water Commission (CWC), Central Ground Water Board (CGWB), Central Pollution Control Board (CPCB), State Pollution Control Board (SPCB), etc. are some of the main agencies engaged in the process. Besides huge data is generated by activities of several departments in central and state governments like Ministry of Drinking Water and Sanitation (MOWS), Ministry of Rural Development (MORD), state water resources/irrigation departments, and state Public Health Engineering Departments (PHED). At the same time, each of the states has its own statistical agencies or departments that collect basic hydrological information including water use information. CWC and CGWB have contributed substantially in collection of hydrological data all over the country. Despite well-laid out standards by Bureau of Indian Standards and World Meteorological Organization (WMO), the collection, processing, and storage of data and information in the states lack quality, uniformity, and accessibility. Country lacks a structured quality management framework to enforce laid down standards and practices and ensure the authenticity of data being collected by multifarious agencies.

CWC and Indian Space Research Organisation (ISRO), since January 2009, are jointly executing the project “Generation of database and implementation of Web-enabled water resources information system of India” – India-WRIS – to provide water resources and related data, and information in a standardized GIS format to all concerned departments, organizations, and stakeholders provide "single-window" solution to the water-related issues. The system lacks authentic water use data, which many state departments fail to update in a timely manner. A lot more needs to be done to make the WRIS system transparent and operational for creating awareness about water issues, water budgeting, and accounting at various levels and enabling informed public debates.

With a view to improve the density of water observation stations, quality of data collection reliability, and accessibility and processing and to enable users to derive useful products, central government has been implementing the National Hydrology Project (NHP) with the objective to strengthen the capacity of water resources management institutions in the country (World Bank 2004). Despite 20 years of efforts under the project, the objectives of making data easily accessible to all the users is far from satisfactory. The NHP, now in its third phase, needs to be made a priority project with certain urgency and political commitment.

3 Water Resources Assessment

A reliable and scientific assessment of water resources availability is a prerequisite for proper planning, design, and operation of water resources projects catering to competing demands like irrigation, drought and flood management, domestic and industrial water supply, generation of electrical energy, fisheries, navigation, and other environmental issues. After initial empirical approaches to water resources availability assessment in the 1940s by Dr. A. N Khosla, the first statistical assessment of water resources potential in the country was made by CWC at 1869 billion cubic meters (BCM) in 1993 (Central Water Commission 1993) and was later reviewed and confirmed by "*National Commission for Integrated Water Resources Development*" in 1999. Till recently, the assessment of water availability has been based on this statistical approach.

Greater water usage in India for an increasing population, intensive irrigation, urbanization, and industrialization has resulted in the annual per capita water availability slipping from 5000 m^3 in 1950 to 1200 m^3, a water-stressed condition. Simultaneously, there are huge variations in the per capita water availability in different parts of the country. While the annual per capita water availability in the northeastern parts of the country is still around 5000 m^3, it is less than 300 m^3 in the South! Some of the sub-basins in India are already water scarce (Falkenmark et al. 1989).

3.1 Surface Water Resources

R. N. Sankhua and *V. V. Rao* in their article on *Water Resources Assessment of Basins of India Using Space Inputs* present a new approach using hydrological modeling and aggregation of meteorological data based on water budgeting exercise.

They assess the average annual water resource of the basins for the 30-year period (1985–2015), as 1914 BCM. Deterministic approaches to water resources assessment help create realistic scenarios. As the future is uncertain, discussing various possible futures with stakeholders creates more awareness of what to do in case of undesirable developments taking place.

In addition to the diminishing per capita water availability, there are huge temporal variations as most of the rain falls over a limited period of 2–3 months. In order to mitigate the risk of long dry spells and to meet the constant demand for water from domestic, industrial, and agriculture sector throughout the year, the monsoon flows need to be stored. The capacity for storage of surface runoff in the country is a lowly 300 BCM being low, large quantities of floodwater drains into the sea.

The new methodology, based on the conceptual model, will facilitate in generating various future scenarios of water availability as a likely consequence of climate change and assess the impact of various development scenarios such as future demands on water management. It would help in a scientific understanding of continuously growing demands and increasing stress on freshwater due to overabstraction, pollution, and climate change. It would provide better opportunities for improved water management, which are crucial for addressing the water insecurity and is likely to make hydrological dialogue among the basin states more scientific.

3.2 Groundwater Assessment

Aquifers serve as natural storages for precipitation that infiltrates into the ground. This groundwater plays a significant role in meeting the water demand for various purposes, particularly for its ubiquitous presence. In India, it contributes to 85% of rural drinking water needs, 50% urban water needs, and nearly 60% irrigation needs.

Assessment of groundwater that could potentially be withdrawn every year without touching the static or in storage resource is essential for its sustainable use. First such assessment was made in 1997 based on the "guidelines for assessment of groundwater," laid down by Groundwater Estimation Committee (GEC) in 1984 based on groundwater level fluctuation method. The methodology was later improved in 1997 to be based on water balance approach. CGWB, along with the states groundwater agencies, assesses the dynamic groundwater resources of the country periodically (2004, 2009, 2011, and 2013).

Groundwater development in the country is highly uneven (Saha et al. 2017). Out of the 6607 assessment units, 1071 units in the country with stage of development (SOD) of more than 100% are categorized as "overexploited." Another 217 assessment units, with SOD between 90 and 100%, are categorized as "critical." However this lump-sum data fails to enumerate the wide spatial and vertical variation in availability of water resources and aquifer complexities. The National Aquifer Mapping and Management Program (NAQUIM) launched in the year 2012 for scientific management of groundwater resources has been taken up for the entire country through intense hydrogeological investigations and data acquisition.

The article on *National Aquifer Mapping and Management Plan – A Step Toward Water Security in India*, *by Dipankar Saha*, *Sanjay Marwaha*, and *S. N. Dwivedi* discusses the key aspects of the NAQUIM. According to the authors, protection, preservation, and augmentation strategy for groundwater resources occurring in the aquifers under different hydrogeological environment call for an in-depth understanding of the groundwater system. A rigorous data collection, collation, and new data generation and its interpretation have been taken up for 2.9 million km^2 mappable area of the country. The two important aspects to the success of this program are (i) scientific part, which depends on the accuracy of the data proper understanding of the aquifers, groundwater resource availability, its regime dynamism and chemical quality, and its meticulous compilation to prepare the aquifer maps and management plans, and (ii) the implementation part, which depends on the involvement of the states and various stakeholders including the communities. The assessment unit would be largely aquifer based, with separate assessment to be undertaken for phreatic and confined aquifers making use of GIS.

The program provides scientific inputs for community-based management of groundwater to empower the communities for community-based management of aquifers through demystification of science. The strategy of demand management and supply augmentation, or a combination of both, with varying weightage will have different results under different hydrogeological conditions and the prevailing stress levels in the aquifers. Therefore, the outputs of the NAQUIM are unique and indispensable.

4 Quality of Water

A minimum good quality water flow should be ensured in all water bodies at all times as required for sustaining life and livelihoods dependent thereon. Freshwater ecosystems, such as river networks, lakes, wetlands, and groundwater, and their functions are closely intertwined with the characteristics of the watershed or catchment of which, they are a part. They literally act as the “sinks” into which landscapes drain, influenced by various hydrological and terrestrial processes, including waste generated through human uses.

Allocation of water for various purposes, including conserving the environment, preventing groundwater quality deterioration and seawater intrusion in coastal areas, supporting livelihood based on aquatic life and other uses of water, recreation, and cultural activities like bathing and festivities, should factor the needs for maintaining water quality in water bodies.

Unfortunately, even the monitoring of river water quality is disjointed and far from minimal. CPCB and CWC monitor water quality of rivers in India on a very limited scale at intermittent intervals varying from weekly to quarterly and with different objectives. The methodology adopted for collection of samples, the range and quality of testing, and management of resulting data and information are vastly disparate and do not always follow internationally acceptable standards (WMO 2013). CGWB is monitoring about 14,000 wells pan India once in a year, besides issue-specific analyses of groundwater samples as and when required. The Drinking Water and Sanitation Ministry under the Government of India is analyzing huge number of groundwater samples for specific contaminants like arsenic, iron, fluoride nitrate, salinity, etc. through PHED in states.

Freshwater ecosystems have specific requirements in terms of quantity, quality, and seasonality of their water supplies. Many of the lakes are in urban areas and face more threats of pollution and encroachment. The Ministry of Environment, Forests and Climate Change (MoEF&CC) developed a separate program called the National Wetland Conservation Program in 1983 and subsequently a National Lake Conservation Plan to conserve the urban lakes. However, according to the comptroller and auditor general's (CAG) report 2011, even an inventory of the lakes has not been initiated. Cataloguing, mapping, and earmarking of the water bodies on the ground and in the city maps, along with the channels feeding the water bodies, are the first initial step that needs to be undertaken to prevent further deterioration and extinction of water bodies. This information along with the legal framework for the protection of the water bodies need to be shared with key stakeholders and ownership of the water bodies, and the responsibility of the concerned administrative authorities needs to be clearly defined.

The issue of contamination of our water bodies has been highlighted by *Vinod Tare* in the article on *Managing and Sanctifying our Water Bodies*. He reiterates the key recommendations of the Ganga River Basin Management Plan-2015 that the "basin planning and management combine diverse natural resources (water resources, land resources, biological resources, etc.) and processes (river dynamics, geological phenomena, atmospheric processes, etc.) with traditional wisdom and grassroots knowledge. According to him, there is an urgent need for a concerted effort to salvage our threatened and rapidly degrading water bodies. He advocates decentralized action not only for greater synergy but also to ensure traditional and hands-on knowledge, and insights of many people can complement the compartmentalized actions of formal institutions and programs.

A large part of the country is affected by groundwater contamination, and many of them are already posing serious threat to public health (Saha et al. 2016). *S. P. Sinha Ray* and *L. Elango* deal the issue of groundwater contamination due to geogenic and anthropogenic sources in their article on *Deterioration of Groundwater Quality: Implications and Management*. Their article is based on the review of the contamination from geogenic sources like fluoride, arsenic, iron, nitrate, uranium, other trace elements, etc. in the groundwater system of India. It tries to raise awareness stakeholders and policy-makers and highlights the groundwater quality issues, its health impact, and its possible mitigation measures to enable sustainable management of groundwater resources.

Country needs a comprehensive approach to water quality monitoring and assessment (WMO 2013) covering various perspectives such as uses to which water is put; control and regulation of water quality in time and space; capacity of water bodies to assimilate pollutants; influence of human activities or natural processes on water quality; trends in water quality and the influences of policies on it; insight into future trends; and influence of water quality on other parts of the environment, such as marine coastal waters, soils, biota, wetlands, etc.

5 Legal Provisions

India is a republic with states having considerable autonomy. As most of the river basins in India encompass areas from more than one state despite water being in the State List under the Indian constitution, the union government has to play an important role as water management issues are best tackled by considering the river basin as a unit of management. Decision-making processes on interstate river issues are guided by the hydro-geographic context (upstream-downstream relationships), the existence/absence of central authority, inter- and intraorganizational, the socioeconomic characteristics, power balance, institutional and cultural differences, etc. (Clevering 2002). Almost all major river basins in the country are interstate in nature. With the existing constitutional provisions, the union government cannot proceed toward preparation of integrated river basin plans on its own and ensure the implementation without taking the concerned states into confidence.

M. E. Haque, *H. K. Varma*, and *Avinash C. Tyagi* in their article on the *Constitutional Provisions Related to Water* identify measures for ensuring reforms toward better management of water sector and suggest a road map for initiating the process of integrated planning for water resources. Drawing from various reports of the Central/State Finance Commissions as well as international experience, they counsel that integrated river basin planning of water resources with a focus on resolving existing hydrologic, ecologic, and socioeconomic problems must be initiated without any loss of time. Simultaneously actions would have to be initiated for (a) creating suitable mechanisms for pooling the expertise and develop integrated plans and (b) initiating dialogue for consensus building for legislative measures. They point out that the development of a comprehensive National Framework Law as envisaged under National Water Policy (2012) would facilitate this process.

Groundwater resources are often extracted exceeding the sustainable limit in various parts of the world particularly in Asia and North America. Worldwide about 1.7 billion people live in areas where groundwater resources and/or groundwater-dependent ecosystems are under threat (Gleeson et al. 2012). In Indian subcontinent the threat is looming large particularly affecting the northwestern part of India covering the states of Punjab, Haryana, and Western Uttar Pradesh and Rajasthan (Rodell et al. 2009). As per the replenishable groundwater resource estimation, about 16% of the assessment units are overexploited. It is really a challenge to make groundwater extraction sustainable. Regulation of groundwater extraction is being done in India by Central Ground Water Authority (CGWA) since 1997; however effectively the activity is boiling down to controlling industrial extraction (5–6% of total groundwater extraction of the country), while the issues related to irrigation extraction remain unattended.

Phillipe Cullet in his article *Governing Groundwater Fostering Participatory and Aquifer-Based Regulation* points out that the groundwater in India has been governed by legal principles developed in the nineteenth century that are neither appropriate today nor supported by the recent developments in the groundwater science. In the present scenario, it is imperative to evolve a legal regime that is adapted to the key role of the GW as well as to the environmental challenges that have arisen. According to him, the current legal framework based around near absolute claims of landowners over the groundwater found under their piece of land is socially as well as technically inappropriate. It does not leave space for aquifer-based protection and sustainable development of groundwater. At the same time, it is also socially inequitable, as the land ownership is skewed. He points to the need for a contemporary legal framework for effective governance of the GW sector. According to the author, the draft Model Groundwater (Sustainable Management) Act, 2017, under the consideration of the government, addresses these issues and proposes a new basis for protecting, regulating, and using groundwater. It is built around the recognition of groundwater as a common heritage of the community that must be appropriately protected and equitably used. It reflects existing legal provisions of the constitution, legal developments, as well as judicial pronouncements, in particular in the field of environmental law.

6 Agriculture Water Management and Participatory Approach

The water challenge is closely tied to food security, defined as the condition when "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO 2002). Food insecurity can trigger conflict, for example, the sharp increases in food prices in 2008, accompanied by cuts in food and fuel subsidies, reduced real incomes of, mainly urban, populations and triggered food riots in many countries. Water productivity in agriculture becomes a major concern when water is scarce. Water resource depletion has explicit economic costs as well as perceived social and environmental costs. In water-scarce regions in the country, water diversion for agriculture is in direct competition with the environmental and social needs of water. Water-use efficiency in irrigation is a highly misunderstood concept so much that even the targets set by national water mission are grossly vague (MoWR 2009).

In almost all the states, agriculture water is managed by irrigation managers who are essentially civil engineers with little exposure to water management let alone agriculture. Further, new agronomical practices often do not get transferred to the field. The need for dissemination of experience and knowledge on latest developments and international best practices in the field of water resources and other related allied fields needs to be recognized. It is desirable that the latest innovations and best agronomical practices reach state-level functionaries through a well-organized platform such as India Irrigation Forum (ICID 2016).

Currently, the ultimate irrigation potential (UIP) of India is estimated to be 139.9 Mha. Huge public investments have been made, providing irrigation facilities through major, medium, and minor irrigation projects creating 110 Mha of irrigation potential up to the year 2012. Forty-two percent of the irrigation is contributed by major and medium irrigation, while the rest is contributed by minor irrigation, largely based on groundwater resources. Presently, India's irrigation infrastructure is expanding at a slow rate of by 1.8 Mha per annum, which is one-third less than the maximum growth achieved in the past. The gross water demand for multiple uses is expected to double by 2025, requiring huge capital outlays to meet the demand. Government of India has launched the Prime Minister's Agriculture Irrigation Scheme (PMKSY) (Niti Aayog 2017) to complete 99 ongoing major and medium irrigation projects to irrigate 7.6 Mha of agriculture land.

For the last 20 years, efforts have been made in various states, supported by the World Bank to reform water sector, particularly the irrigation management. However, except for a couple of cases, the success of these efforts has been far from satisfactory and sustainable. The state of Madhya Pradesh has successfully revitalized its water resources sector for optimizing its use in agriculture. Apart from enhancing power supply to agriculture, the focus has been on canal reforms such as restoring canal management protocols, last-mile investments, reducing deferred maintenance, constant monitoring, animating irrigation bureaucracy, and vitalizing farmer organizations. The irrigated area in the state has gone up from 0.8 M ha to 3.6 M ha, a fourfold increase in the last 5–6 years.

However, the most important issue is equity in water resources development and distribution among the co-riparian farmers. This entails fairness, dignity, respect for mutual rights, and obligations. Unfortunately, management of irrigation projects in India has miserably failed in this important aspect. Tail-end farmers are often deprived of the benefits of the project, while others do not necessarily get their allocated water at the time required by them.

Since 1985, Union Ministry of Water Resources has been advocating farmers' participation in water distribution and management of tertiary systems. Special incentives have been given under the Centrally Sponsored Command Area Development Program. The concept of involvement of farmers in management of the irrigation system has been accepted as a policy of the Government of India and has been included in the National Water Policy adopted in 1987. In the article on *Farmers Participation in Managing Water for Agriculture*, *Phanish Kumar Sinha* traces the history of participatory irrigation management (PIM). The author indicates that PIM has not succeeded in India to the desired extent not because the idea is wrong but because the professionals implementing it have either not understood the process or the rationale of PIM concept does not suit their comfort zone of power and non-accountability. PIM is considered successful if it results in (i) an increase in percentage of water charges collection, (ii) expanded area under irrigation, (iii) ensuring equity of water distribution in terms of water availability in tail end, and

(iv) encouraging water saving. The author recommends that the state PIM acts/rules and other legal framework for PIM needs to be reviewed and made more farmer-friendly, simple, and based on ground realities. At the same time, the financial sustainability of the WUAs needs to be enhanced by allowing them to collect and retain prescribed water charges for operation and maintenance of the system and administrative expenses. The work of the WUAs needs to be facilitated by a PIM directorate at the apex level in the states. It should not only be responsible for regular monitoring of WUA activities but also honor best-performing WUAs to incentivize PIM. At the same time, the civil society involvement in PIM needs to be strengthened for supporting capacity development of WUAs and government functionaries.

As groundwater resource is intricately related to aquifers, the farmers and other stakeholders must understand and go for knowledge-based exploitation of the resource. Dhaval Joshi, Himanshu Kulkarni, and Uma Aslekar in their article on *Bringing Aquifers and Communities Together: Decentralized Groundwater Governance in Rural India* point to the urgent need for a groundwater governance agenda, which tackles the problems through effective amalgamation of scientific knowledge of hydrogeology, stakeholder engagement, and institutional arrangements. They outline a framework for an integrated groundwater governance paradigm that follows a bottom-up approach through decentralization, where participation of the community is primary. The knowledge and understanding of aquifers is prerequisite of participatory management of groundwater. The outcome of programs like NAQUIM should be demystified and should reach to the farmers in order to foster community management of this precious natural resource.

7 Rejuvenation of Aquifers

Development of groundwater in India is unprecedented and unstainable in large swath of the country. Overexploitation of groundwater over the decades, which is pervasive and expanding all over India, has resulted in steep decline of groundwater levels, diminishing well yields and even deterioration of water quality. About 60% of the irrigated areas in the country get their water supply from groundwater and presently, and more than 25 million wells are serving the irrigation sector. Decline in the groundwater levels is having its adverse impact through higher consumption of energy thus enhancing the adverse effect of carbon footprint. Apart from regulating groundwater extraction through government initiative and community based self-regulation approach, which has little impact yet, there are a number of supply and demand side options to address the situation. The most important supply side interventions are increasing water-use efficiency and artificial recharge to rejuvenate groundwater resources.

Government of India has given top priority on rainwater harvesting and artificial recharge. Rooftop rainwater harvesting is being made mandatory in urban areas by the central as well as many state governments. One of the major emphases of MGNREGA program under the Ministry of Rural Development is activities related to water, like water harvesting and artificial recharge. CGWB has prepared a conceptual master plan for artificial recharge for the country and also artificial recharge manual detailing the design of the structures under various hydrogeological, terrain, and climatic conditions (CGWB 2007). Besides there are many success stories created by the communities, which have turned poverty to prosperity in many parts of the country. The article on *Rejuvenation of Aquifers* by *S. C. Dhiman* focuses on the different aquifer systems in the country and the scope for their rejuvenation. According to him, there is a need to identify desaturated aquifers for identifying their water holding capacity. Simultaneously, surplus runoff for recharging at micro-watershed level needs to be estimated. Aquifer rejuvenation needs to be taken up at the local level keeping in view the variability in the larger system. There is a need to identify local aquifers and delineate their recharge and discharge areas. This will help involve local communities in the process of recharge.

In spite of increasing extraction of groundwater, there are positive imprints created by the considerable efforts undertaken up by the state and central government agencies, besides many local efforts by the communities, NGOs, and even by the industries. In their article, *An untold story of groundwater replenishment in India: Impact of Long-term Policy Interventions*, *Abhijit Mukherjee* and *Soumendra Nath Bhanja* use observations from NASA's GRACE satellite to show that positive groundwater replenishment is taking place in the south and western regions of the country, in parts of the states as a result of recent government policy changes and the grassroots efforts of local communities. A recent scientific study in the nature shows that the paradigm shift in groundwater withdrawal and management policies for sustainable water utilization appears to have started replenishing the aquifers in western and the southern parts of the country. However, groundwater contamination due to careless recharge through polluted water remains a concern and needs to be guarded against and closely monitored.

8 Hydropower: Sustainability and Environmental Concerns

Reliable and affordable energy is an important input for providing irrigation, industrialization, and expanding urbanization in the country. Due to rapid increase in population in the coming future, there will be 3–4 times increase in the demand for energy. Presently 33% of India's primary energy consumption is coming from renewable energy sector. As per an estimate hydropower is the second largest contributor in energy sector in India after coal based thermal power (Sharma et al. 2013). Although India is the seventh largest hydroelectric producer in the world, further exploitation of its untapped hydropower potential would benefit the country's economic development tremendously. This has to be done sensitively while addressing the environmental and rehabilitation concerns of the affected populations. The hydropower development may bring substantial alteration in the fluvial system and may also generate conflicts in the resource use pattern in local communities. Recognition of water energy and food interrelationship offers a promising conceptual approach that systematically evaluates water, energy, and food interlinkages by identifying trade-offs and synergies of water, energy, and food systems, internalizes social and environmental impacts, and guides in the development of cross-sectoral policies (Tamee et al. 2018). Unfortunately, in India development of socially and politically relevant resource policies has been limited. *Chetan Pandit* and *C. D. Thatte* in their *article Hydropower – The Way Ahead* give an overview of the potential of India's hydropower potential. According to them implementation work on many of these projects is stalled, due to environment-related concerns, which are mostly misunderstood or are wrongly projected. When a hydropower project installation is rejected on environmental grounds like related deforestation, the nation does not reduce correspondingly its energy requirements; in fact the resulting gap is largely made up by the ever available coal-based thermal energy! According to them, such alternative choice effectively replaces one-time felling of forest at one location, by undertaking perpetual mining of coal and resultant emission of corresponding additional GHG at some other location. According to the authors, although the government remains aware of the advantages of hydropower, it does include it in energy planning; it is unable to implement the plans on the ground in the face of sustained negative propaganda by the environmental lobbyists. Government needs to take cognizance of and remove such hurdles from the path of hydropower soonest, so that the country's energy mix is not constrained due to deficit of additional hydropower.

9 Floods and Droughts

Due to the changes taking place in the climate, extreme hydrometeorological events such as droughts, floods, and cyclones are on the rise. Droughts are one of the major environmental disasters in many parts of the world as well as in India that impose extensive damage on the environment and the economy. Recent predictions on climate change (Lavell et al. 2012) suggest this situation may worsen, projecting an increased frequency and severity of drought in these regions. However, effective disaster risk management, including the provision of advance warning to drought and the implementation of effective drought mitigation in response, may substantially reduce these adverse impacts. Drought preparedness and education can additionally increase resilience of affected societies, allowing them to cope better with drought and its impacts.

While many parts in the country are water scarce, others suffer from recurrent flooding. Recent observations indicate that the traditional arid, drought-prone areas are also subject to heavy monsoon rainfall at times. Almost every year, one or the other part of the country is affected by floods, giving rise to enormous damage to life, public and private properties, and disruptions to infrastructure, besides inflicting psychological and emotional instability among the people. Every year, one or the other city in the country comes to a standstill due to its vulnerabilities to flood inundations that arise from the neglect of urban planning and management.

The mighty Brahmaputra and its tributaries flow above the danger level across Arunachal and Assam state almost every year and affect adversely lakhs of people, inundating human habitations and farm land in several districts. It also damages the unique wild life and fauna along its floodplain. Similarly, large parts of Indo-Gangetic Plains get inundated year after year threatening safety of life and property. Despite the fact that large capital expenditure has been undertaken on both structural as well as nonstructural measures, the damage due to floods continues to rise. In his article, *Resilience Building in Flood Prone Areas: From Flood Protection to Flood Management*, *N. Choudhury* propounds that the discourse pertaining to flood management needs to move from flood protection to flood management through vulnerability reduction and resilience building. According to him, resilience building can take place through a mix of structural and nonstructural measures that aim toward reducing vulnerability, enhancing access to services, and maximizing productivity taking benefits of flood. These interventions – when undertaken in an integrated and a sustained fashion – would increase robustness and enhance resourcefulness, the key elements that contribute to resilience building in any system. Integrated management of floods (WMO 2009) would however require integration across multiple government departments, various disciplines and experts, and active participation of nongovernment actors along with the riparian population, who are exposed to flood hazards.

Scientific studies to understand the situation and to find innovative ways of dealing with floods are of primary importance and provide critical inputs in integrated management of floods. It's a multi-stakeholder, multidimensional, and multidisciplinary task and poses a formidable challenge for administrators, decision-makers, and water sector professionals, both in central and the state governments. Flood detention through reservoirs cannot be economically justified in a stand-alone mode. Moderation of flood peaks through detention in storages needs to be incorporated into multipurpose projects. In this context the article by *N. N. Rai* and *J. Chandrashekhar Iyer* on *Integrated Development of Reservoirs and Unified Control for Efficient Flood Moderation in Ganga Basin* is therefore particularly relevant. The focus of the article, which presents a case study, calls for cooperation and synergy among the riparian states for integrated development and operation of storages in the major sub-basins of Ganga river system, to effectively mitigate the flood damages. *N. N. Rai and T.S. Mehra* in another related article on *Flood Management Strategy for Brahmaputra Basin through Storage* discuss the issues related to the Brahmaputra River, a prime endowment of the Northeastern Region of India that has the potential to bring all-round growth and prosperity to the region. However, if left unmanaged it causes untold misery to the region. The authors advocate that 6 to 7 judiciously located storage projects with about 14 BCM of storage could turn around the biggest bottleneck of recurrent floods into a great opportunity of cheap and reliable nonpolluting power along with an efficient round-the-year navigation.

10 Governance of Water

National Water Policy (2002) emphasizes the need for adoption of Integrated Water Resources Management (IWRM) principles that focus on three basic pillars (GWP 2000): (a) creating an enabling environment of suitable policies, strategies, and legislation for sustainable water resources development and management; (b) putting in place the institutional framework through which to put into practice the policies, strategies, and legislation; and (c) setting up the management instruments required by these institutions to do their job.

Water governance is the set of rules, practices, and processes through which decisions for the management of water resources and services are taken and implemented. A framework for water governance (OECD 2015) focuses on demarcated roles and responsibilities, managing water at appropriate level, policy coherence, capacities and competencies, data and information as a public good, mobilization of financial resources, sound regulatory framework, transparency and accountability, greater stakeholders engagement, mechanism for equitable trade-offs, and monitoring and evaluation.

Unfortunately, in India, there is inadequate coordination between ministries dealing with water-related issues both at the central and the state level. For example, one of the most important inputs in water resources management is the weather and climate information. However, there is an absence of operational and operative interaction mechanism, based on sound hydrometeorological data, among the customers and end users as well as the service providers. There is an overall lack of knowledge about weather and hydrological observation tools, software, automatic production, and information dissemination systems among water professionals. The situation is similar, if not worse, regarding mechanisms essential for interaction of water managers with agriculture, urban planners, local municipalities, tourism, forest and environment functionaries, as well as end users.

Water governance and management in India has been undergoing structural changes for more than two decades. Reforms in the water sector began in the 1990s, but these efforts have been made in bits and pieces and have brought moderate positive results to different degrees in different states. A systematic evaluation of these reforms is called for. *Vidyanand Ranade* explores the key role of *governance in the water sector* in the development and management of water resources especially in the basins where availability of water falls short of demand. He advocates timely completion of irrigation projects, their proper maintenance, as well as performance evaluation of completed projects. The influence of water governance in the use of microirrigation systems, recycle and reuse of wastewater for irrigation, groundwater management, as well as demand management has been highlighted.

A huge investment has been made in the irrigation sector, which to the opinion of many is not yielding the desired results. We need to expand our explored irrigation to attend the food security and besides the issue of governance and technicality like water-use efficiency and participation of communities. The question is looming large who is to finance the mega expenditure for desired expenditure and what would be the morality. *Dr. DTV Raghu Ramaswami* in his paper *Financing aspects of sustainable water management in India* states about Rs 4820 billion has been spent to create an irrigation potential of 42 million Ha through major and medium irrigation and nearly one and half time of that is required to develop the remaining potential. Conventional investment plan may not be feasible for such a large scale of investment. Direct capital investment and the irrigation assets for a long time need to be supported with appropriate revenue mechanism. There is a lack of robust revenue modal and conducive framework to enable better participation. The paper presents an analysis on the extent and modalities of payment of user fees and weather there is a scope for ancillary revenues.

11 Stakeholders' Participation

Interactions between society, economy, and ecology are complex. Sustainable development in various sectors requires all parties involved in the development and management of common resources to share a collective understanding of the issues at stake. At the same time, effectively integrating nature and its services into local planning requires a high level of communication, participation, and cooperation.

Community-based interventions, such as recharging of groundwater through small water harvesting structures and strengthening the livelihood base of the most vulnerable through watershed management interventions, provide a proper example of integrated development of water resources. There is a need to mobilize effective action and advocacy on financing and implementation to increase access to safe drinking water and adequate sanitation for all and to improve the sustainable development and management of water resources.

Decentralized management of water through devolution of powers to *panchayats*, involvement of water users' associations in irrigation management in canal command areas, and participatory groundwater management suffer from lack of understanding and capacity of the end users. Institutional mechanisms to enhance capacities among civil society actors and bring greater water awareness to all stakeholders need to be set up with the support of civil society.

In developing and implementing spatial plans, an effective communication strategy is crucial for informing and consulting the stakeholders, providing greater understanding of complex issues, raising awareness, and avoiding possible misunderstandings. It is important to build awareness about water among the users and make available the required water information to be able to effectively communicate and engage with stakeholders within the water sector and with the other related sectors of development. Institutional mechanisms to enhance capacities among civil society actors and bring greater water awareness to all stakeholders need to be set up with the support of civil society. Water data needs to be treated as a public good. Informed participation of the civil society in policy formulation, planning, and management faces hindrance due to lack of availability of authenticated information in the public domain. Flow of information even among government agencies at state and central level is sometimes very slow despite initiatives such as WARIS due to its limited success.

Avinash C. Tyagi advocates for **c**reation of an enabling environment for capacity development of the grassroot-level NGOs through a consortium of knowledge-based professional NGOs, in his article on *Civil Society in the Water Sector*. He recommends that the government should **s**upport professional civil society organizations such as India Water Partnership to be able to provide multidisciplinary perspectives and create an independent evaluation mechanism to analyze and understand the region-specific reasons for the success and failure of policies and programs. This will help facilitate scaling up of the success stories achieved through NGO initiatives.

12 Capacity Development

Many states realize that they need more capacity. To date it has remained a concept of enormous generality and vagueness wrapped up in a host of concepts such as participation, empowerment, technical assistance, and organizational development. The calls for capacity development in irrigated agriculture suffer from these same vague generalities, with the focus remaining on water infrastructure development. Capabilities in climate change predictions and assessment of its impacts on water management, drought prediction and early warning, water quality modeling, various investigation techniques for groundwater, groundwater flow modeling, etc. are confined to academic and research institutions and lack application at operational level. At times, engineers dominating irrigation/water resources departments lack capability to adapt and use the development in the groundwater domain, ecological aspects and environment cost analyses, modern technologies, social engineering perspectives, and conflict management skills.

Only recently since 2012, with the initiative of the Union Ministry of Water Resources, an annual event, the India Water Week, has been started. Similarly to deliberate on groundwater issues, Bhujal Manthan has been initiated. The platform provides opportunity to state water managers in exchanging experiences and exposing them to the practices that are successful in other states and countries.

Many policy-makers and professionals have a simplistic interpretation of capacity development in terms of educating and training irrigators, technicians, and professionals. *E. J. James* and *Thomas J. Menachery*, in their article on *Capacity Development for Sustainable Water Resources Management in India*, elaborate the concept of capacity development through three elements at the context, organizational/human resources, and strategic levels. They explain the need for continuity of capacity development projects and highlight the key role of predetermining the threshold levels of capacity for planning and monitoring purposes for capacity building. Authors feel that the partnership with Water and Sanitation Program and other international programs and agencies can considerably help in capacity development.

13 Research and Innovations

Meeting current and future water challenges requires robust public policies supported by experience, knowledge, innovations, and research that reaches the field, industries, and different water supply agencies. There are major policy gaps such as those addressing water rights, wastewater management principles, water reuse and recycling, priorities and objectives of environmental flows, and data sharing. Research in the water sector in India is predominantly academic in its scope and content, which more often than not cannot be applied to solve field problems. Applied research, which hugely suffers from mono-disciplinary approach, is limited to undertaking field tests. Hardly any new methodologies have evolved for application in the field out of applied research. There is hardly any social science component to research and a complete absence of policy research in the water sector in the country. Indian R&D institutes largely work in isolation and have minimal contact with industries, user departments, and the foreign counterparts.

In their paper on *Research and Development in the Water Sector in India, Sharad K. Jain* and *M.K. Sinha* take stock of the current status of research and development (R&D) in water sector in India by presenting details of apex research institutions, key funding ministries, and schemes to promote research in water sector. The relevant strengths, weaknesses, and opportunities of R&D in the water sector have been presented. It is suggested that there is a need to broad base research activities to all aspects of water management, such as hydrological measurements and assessment, increasing water-use efficiency, Integrated Water Resources Management, water pollution control and treatment, river rejuvenation, flow forecasting, climate change impact assessment and real time decision support systems, etc. The paper outlines the paradigm shift required in approaches toward research and development in water sector in the country.

14 Institutional Arrangements

Complexities of water management require cooperation, collaboration, and convergence among institutions at various levels. Many organizations engaged in the water sector face intricate challenges requiring understanding and collaboration across multiple disciplines and multiple sectoral concerns to address integrated approaches to sustainable development, integrated water planning, multi-hazard risk management, climate change adaptations, watershed management, or even in getting alignment internally. Not all organizations are ready to make the shift that real collaboration requires and are at risk of living is silos and rendering themselves redundant. Institutions operating effectively at multiple levels would be required to be at the center of sustainable water resources management. The institutions would need to be flexible, promote appropriate use of innovative technologies and policies, and recognize the increasingly important role of non-state actors in ensuring food security and water security.

Fragmented institutions dealing with water at the center and at the state government levels need to be made a multidisciplinary powerhouse and proper operational-level coordination mechanisms established. Most of water resources departments in the states started as irrigation departments continue to remain construction oriented and have failed to realign themselves to the changing realties and requirements. For example, the roles and responsibilities of institutions engaged in water quality monitoring continue to be vague. Departments dealing with groundwater in most of the states are either rickety or even totally absent. Formal and informal platforms need to be made operational for multidisciplinary collaboration with well-defined goals, targets, and milestones.

In the concluding article by *Mihir Shah*, on *Paradigm Shift in Water*, advocates to adopt a unique process designed to fundamentally alter the principles, approach, and strategies of water management in India. He recommends that a new National Water Commission (NWC) be established as the nation's apex facilitation organization dealing with water policy, data, and governance with both full autonomy and requisite accountability. NWC should build, institutionalize, and appropriately manage an architecture of partnerships with knowledge institutions and practitioners in the water space, in areas where in-house expertise may be lacking.

The author articulates that the key mandate and functions of NWC should be to enable and incentivize state governments to implement all agriculture water management projects in reform mode, to ensure *har khet ko paani* (water to all agricultural land holders) and improved water resource management and water-use efficiency. The commission should work as knowledge management hub and powerhouse of multidisciplinary approach in water sector. It should lead the national aquifer mapping and groundwater management program; insulate the agrarian economy and livelihood system from pernicious impacts of drought, flood, and climate change and move toward sustainable water security; develop a nationwide, location-specific program for rejuvenation of India's rivers; create an effective promotional and regulatory mechanism that finds the right balance between the needs of development and environment; and promote cost-effective programs for appropriate treatment, recycling, and reuse of urban and industrial wastewater, among others.

15 Concluding Comments

India is changing through rapid urbanization, industrialization, and expanding cropping, giving rise to new priorities, demands, and challenges in the water sector. Per capita water resources in India are ceaselessly decreasing and have already been pushed to the water-stressed conditions and are fast moving toward water scarce conditions. Though there is considerable realization of the impending crisis, a rigid and conventional approach continues to be adopted for seeking solutions related to planning, investments, development, conflict resolutions, benefit sharing, etc.

Widespread water shortages in time and space domain and deterioration of its quality in many parts of the country are already impacting food productivity, health of living being, and rivers and ecology. Groundwater is depleting fast and rendering this important source prone to both geogenic and anthropogenic contamination. Large and medium cities face chronic drinking water shortages in summer and at the same time get deluged by contaminated rain waters even with little above normal rainfall events. Many basins experience seasonal water scarcity on a regular basis. There is broad consensus that India's water sector is facing serious challenges in every facet of water resources management. If this downward slide is not arrested timely, it will become exponentially more expensive, technologically difficult, and politically cumbersome to control in the future.

The current unsatisfactory performance of the water sector, emerging water scenario with its challenges and the ambitious sustainable development goals that the country has set for itself, calls for a paradigm shift in thought and implementation process. There is a need for science-based evaluation of existing policies, programs, and projects at various levels. They cannot be resolved only by infrastructure development. Policies in water domain and decision-making procedures have to be suitably modified to meet these challenges.

Since agriculture is the dominant freshwater user, this sector will have to accept lower allocations in the future, by design or by default. This puts new emphasis both on the efficiency of water use in agricultural and on the equity dimensions of its distribution. The transformation of irrigated agriculture – to become a responsive, service-oriented, and community-driven – is long awaited. The vision for water- and food-secured India can be realized through developing and utilizing maximum irrigation potential; improving irrigation use efficiency; harnessing groundwater potential in a sustainable manner; undertaking extension, renovation, and modernization of existing infrastructure; using urban and rural wastewater for irrigation development; and increasing water storage capacity, through revival of traditional water harvesting structures and water bodies, farm ponds, etc.

Adoption of the draft National Framework Law, as an umbrella statement of general principles governing the exercise of legislative and/or executive (or devolved) powers by the center, the states, and the local governing bodies, needs to get urgency. Water quality preservation needs to be given higher priority in the national water policy. Necessary legislation should be drawn for the preservation of the existing water bodies by preventing their encroachment and preventing them from becoming wastewater sinks. Reduce, reuse, and recycle of wastewater has to be a conscious policy thrust backed with appropriate legislation, institutions, capacity development, and incentives.

Institutions dealing with water at the center and at the state government levels need to be restructured and made multidisciplinary and result oriented rather than expenditure oriented. Complexities of water management require cooperation, collaboration, and convergence among institutions and communities at various levels. It is important to undertake an analysis of the role of each organization involved in water management and how they need to work more collaboratively and made to think and act differently to achieve the required objectives. Formal and informal platforms need to be made operational with well-defined goals, targets, and milestones. Institutional mechanisms, to enhance capacities among government functionaries and civil society actors and to bring greater water awareness among all stakeholders, need to be set up with the support of civil society.

Water sector issues as well as their solutions need to be dovetailed with the culture and attitudes of the people. The entire effort could be facilitated by reviving water respecting culture among the masses. An attitudinal change needs to be brought about among the political bosses, government functionaries, scientific and academic community, water managers, and the people with respect to water development issues. Water gets little media attention or public comment, unless there is a crisis. Water issues which are rarely a topic of popular concern need to be brought in public consciousness. There is a need to develop a dynamic long-term perspective and action plan with the adoption of new innovations using latest technologies through continuous trialogue between science, polity, and society.

It is high time that water gets the desired political priority lest it turns out to be Achilles' heel of our democracy.

Acknowledgements The editors gratefully acknowledge the contribution of Shri H.K. Verma, Executive Director, International Commission on Irrigation and Drainage, in conceptualizing the idea of the book and his support in finalizing many of the articles. Thanks are due to Shri Shakir Ali Khan, Research Scholar, Delhi University, for his support in formatting and editing the manuscript. We also gratefully acknowledge the comments and suggestions of other experts, too numerous to be named individually, who rendered their valuable time in support of this effort.

References

Central Water Commission (1993) .Report on Reassessment of Water Resources Potential in India. Available at: http://cwc.gov.in/main/downloads/1993_Reassessment_waterresourcespotential.pdf

CGWB (2007) Manual on artificial recharge on ground water, Govt of India. Available at: http://cgwb.gov.in/documents/Manual%20on%20Artificial%20Recharge%20of%20Ground%20Water.pdf. FAO, 2002

Clevering HJ (2002) Indicators of transboundary river conflicts. A comparative analysis on conflict indicators for ten large river basins. MSc. thesis report Integrated Water Management (number 54), Wageningen University and Research Centre

Department of Agriculture (2017) Annual Report 2016–17. Department of Agriculture and Framers Welfare, Govt of India, Krishi Bhawan, New Delhi. Available at: http://agricoop.nic.in/sites/default/files/Annual_rpt_201617_E.pdf

Falkenmark M, Lundquist J, Widstrand C (1989) Macro-scale water scarcity requires micro-scale approaches: aspects of vulnerability in semi-arid development. Nat Res Forum 13(4):258–267

FAO (2002) The state of food and agriculture. Food and Agriculture Organisation of United Nations Rome. http://www.fao.org/docrep/004/y6000e/y6000e00.htm

Gleeson T, Wada Y, Marc F, Bierkens P, Ludovicus P, van Beek H (2012) Water balance of global aquifers revealed by groundwater footprint. Nature. https://doi.org/10.1038/nature11295, https://doi.org/10.1038/nature08238

GWP (2000) Integrated Water Resources Management. Technical Advisory Committee, Background paper no 4. Available at: https://www.gwp.org/globalassets/global/toolbox/publications/background-papers/04-integrated-water-resources-management-2000-english.pdf

ICID (2016) Partnership for Agriculture Water Management. In: Proceedings of 1st India Irrigation Forum. Available at: http://www.icid.org/iif1_rep_2016.pdf

India-WRIS (2012) River Basin Atlas of India, Ministry of Water Resources, Government of India, RRSCO West, ISRO, Jodhpur

Lavell A, Oppenheimer M, Diop C, Hess J, Lempert R, Li J, Muir-Wood R, Myeong S (2012) Climate change: new dimensions in disaster risk, exposure, vulnerability, and resilience. A special report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge/New York, pp 25–64

MoWR (2009) Comprehensive mission document, National Water Mission under National Action Plan on Climate Change. Ministry of Water Resources, Govt of India. Available at: http://www.nicra-icar.in/nicrarevised/images/Mission%20Documents/WATER%20MISSION.pdf

Niti Aayog (2017) Road map of Pradhan Mantri Krishi Sinchai Yojana. Government of India. Available at: http://niti.gov.in/writereaddata/files/document_publication/PMKSY-Booklet.pdf

OECD (2015) OECD principles on water governance. OECD studies on water. OECD Publishing, Paris

Rodell M, Velicogna I, Famiglietti JS (2009) Satellite-based estimates of groundwater depletionin India. Nature 460:999–1002

Saha D, Shekhar S, Ali SR, Vittala SS, Raju NJ (2016) Recent hydrogeological research in India. Proc Indian Nat Sci Acad 82(3):787–803

Saha D, Marawaha S, Mukherjee A (2017) Groundwater resources and sustainable management issues in India. In: Saha D, Marwaha S, Mukherjee A (eds) Clean and sustainable groundwater in India. Springer, Singapore ISBN:978-981-10-4551-6

Sharma NK, Kumar P, Sood YR (2013) A comprehensive analyses of strategies, policies and development of hydropower in India: special emphasis on small hydropower. Renew Suatain Energy Rev 18:460

Tamee RA, Crootof A, Scott CA (2018) The water-energy-food nexus: a systematic review of methods for nexus assessment. Environ Res Lett 13(4). Published by IOP Publishing Ltd. Available at: http://iopscience.iop.org/article/10.1088/1748-9326/aaa9c6

WMO (2009) Integrated flood management: concept paper. Associated program on flood management. Switzerland, Geneva Available at: http://www.apfm.info/pdf/concept_paper_e.pdf

World Bank (2004) India hydrology project: implementation completion report review, ICRR 11813. Available at: http://projects.worldbank.org/P010485/hydrology-project?lang=en&tab=documents &subTab=projectDocuments

World Meteorological Organization (2013) Planning of water quality monitoring systems. Technical report series no 3, WMO no 1113. Switzerland, Geneva Available at: http://www.wmo.int/pages/prog/hwrp/publications/Technical_report_series/TR-No3water_quality_monitoring_systems.pdf

Dr. Amarjit Singh is from the Indian Administrative Service, & is a former Union Secretary, Ministry of Water Resources, River Development and Ganga Rejuvenation. In this capacity he has been intimately connected with several national endeavors, such as the National Aquifer Mapping and Management Programme, *Pradhan Mantri Krishi Sinchai Yojana* (PMKSY), Dam Rehabilitation and Improvement Programme, National Hydrology Project; Ganga Rejuvenation and Inter Linking of Rivers, to mention a few. The PMKSY is an ambitious scheme launched by the Prime Minister of India to ensure irrigation for every field, enhance efficiency of water use to double the income of the farmers. He led the Indian delegation for talks on Indus with Pakistan on several occasions.

In his early career he served in various capacities the drought prone Saurashtra region of Gujarat and has experienced firsthand the water woes of the people during rain deficient years! He worked closely with the World Bank for assistance for various health programmes and followed this up with a PhD at the Liverpool School of Tropical Medicine. His research work was widely published in leading scientific journals. His work in Gujarat for promoting PPPs in the Health Sector was widely appreciated and in 2008 he was awarded the Prime Minister's Medal for excellence in Public Administration.

He is a regular guest speaker at Lal Bahadur Shastri National Academy of Administration, Mussoorie and other prestigious institutions like the NDC. Presently he is Chairman of an Authority to regulate the real estate sector in Gujarat state of India.

Dr. Dipankar Saha is former Member (Head Quarters) Central Ground Water Board, under Ministry of Water Resources, River Development and Ganga Rejuvenation, Govt of India. He had also acted as Member Secretary, Central Ground Water Authority and Head of National Ground Water Training and Research Institute, Raipur. He spearheaded the National Aquifer Mapping and Management Programme, the largest ground water mapping endeavor in the world, as National Coordinator. He obtained PhD on *Ground Water Management* from Indian Institute of Technology Dhanbad. He has authored more than 50 papers in International Peer Reviewed Journals and delivered more than 300 lectures and key note address in national and International Seminars. He is professionally trained from Asian Institute of Technology, Bangkok and from JICA, Tokyo. He represented the country in World Bank session at Kathmandu, International Atomic Energy Agency at Ho-Chi Minh City, and Vienna, World Water Week – Stockholm, India-UK Water Security Exchange- Wallingford, Oxfordshire and led the Govt of India Delegation to Myanmar. He remained member of many high level National Committees and has Edited/Co-edited 5 books/Journals, the recent one is ***Clean and Sustainable Groundwater in India*** published by Springer. He is the recipient of ***National Geoscience Award – 2010*** conferred by Ministry of Mines, Government of India and *Ground Water Excellence Award 2014* conferred by International Association of Hydrogeologist-India Chapter in 2014. He is presently Secretary of International Association of Hydrogeologist-India Chapter.

Er. Avinash C. Tyagi a 1973 graduate from University of Roorkee, India and a post graduate from Indian Institute of Technology (IIT) Delhi, has vast experience in dealing with various facets of water resources management starting from hydrologic observation to disaster risk management to inter-state water dispute resolution to contributing to the national and international policy making. He served as Commissioner of Policy Planning in Ministry of Water Resources in India before leading Water and Climate wing at World Meteorological Organization (WMO) as Director. He was instrumental in reviving the International Commission on Irrigation and Drainage (ICID), an international professional non-governmental organization, as its Secretary General. A leader in true sense, both at WMO and ICID he introduced and successfully implemented a host of internationally acclaimed initiatives. He through his interaction with water, climate and disaster managers from various member countries of WMO and ICID, gained an intimate knowledge of issues related to water resources, climate change and disaster management in developing countries around the world and helped them through transfer of technology and capacity development. He interacted with policy makers, and ministers of many member countries. Er. Tyagi, is an ardent advocate of multi-disciplinary collaboration for resolving complex development challenges, and in continuing dialogue among various stakeholders and community participation in the water sector.

Water Resources Assessment of Basins of India Using Space Inputs

V. V. Rao and R. N. Sankhua

1 Introduction

Water quantity changes are mainly due to consequences of global and regional changes actuated by environmental factors, climate variation and human-induced changes. Increasing economic activities coupled with rapid expansion of population has put new challenges on management of available water resources. Irrigation has been the major consumer of water, followed by demands from other sectors such as drinking and industries in India, and this may continue to be so in the years to come. Science-based knowledge to assess water resources over a range of scales in spatiotemporal scale is essential to develop methodologies for sustainable water resources management both in terms of quantity and quality. This challenge affects the water community, decision-makers and common man. The water resources in India play a vital role in agriculture, forestry, fisheries, hydropower generation, livestock, industries, navigation, recreational activities, etc. Besides, the impact of climate change triggers enhanced evaporation due to warming, areal changes in rainfall intensity, duration and frequency, together affecting the hydrological parameters such as discharge, soil moisture, etc. It is impossible to properly plan, design, construct, operate and maintain water resource projects catering to competing demands like irrigation, drought and flood management, domestic and industrial water supply, generation of electrical power and navigation sans a reliable estimate of the water resources.

Decisions for managing water resources to bring solutions with changes in pressures were dependent on the water availability studies carried out at different

V. V. Rao
Group Director, Water Resources Group, National Remote Sensing Centre, Hyderabad, India
e-mail: vvrao@nrsc.gov.in

R. N. Sankhua (✉)
Director, Basin Planning, Central Water Commission, New Delhi, India

© Springer Nature Singapore Pte Ltd. 2019

A. Singh et al. (eds.), *Water Governance: Challenges and Prospects*, Springer Water,
https://doi.org/10.1007/978-981-13-2700-1_2

periods. Water resources potential of a basin reckons to natural (virgin) flow in the river basin. The average annual flow at the terminal gauge site determines the average annual flow of a basin. Sum of the observed flow, upstream utilization for irrigation, domestic and industrial uses both from surface and groundwater sources, increase in storage of reservoirs (both surface and subsurface) and evaporation losses in reservoirs and deducting return flows from different uses from surface and groundwater sources give the natural flow at a location on a river.

The water resources potential in the river basins of India has been assessed from time to time by various agencies. These studies adopted empirical formula, aggregation of observed basin terminal flow with upstream abstractions, etc. India was divided into 20 river basins comprising of 12 major river basins and 8 composite river basins.

The 12 major basins are (1) Indus, (2) Ganges-Brahmaputra-Meghna, (3) Godavari, (4) Krishna, (5) Cauvery, (6) Mahanadi, (7) Pennar, (8) Brahmani-Baitarani, (9) Sabarmati, (10) Mahi, (11) Narmada and (12) Tapi. The eight composite river basins include (1) Subarnarekha – combining Subarnarekha and other small rivers between Subarnarekha and Baitarani; (2) East Flowing Rivers (EFR) between Mahanadi and Pennar; (3) EFR between Pennar and Kanyakumari; (4) area of inland drainage in Rajasthan Desert; (5) West Flowing Rivers (WFR) of Kutch and Saurashtra including Luni; (6) WFR from Tapi to Tadri; (7) WFR from Tadri to Kanyakumari; and (8) minor rivers draining into Myanmar (Burma) and Bangladesh.

Basin-wise water resources availability in the country was carried out by CWC in 1993 and given in the report entitled "Reassessment of Water Resources Potential of India". The water resources potential of the country was reassessed as 1869 BCM. The glimpse of earlier assessment studies of basins has been depicted in Table 1.

Assessment of water resources potential of all the basins of India deduces relevance and efficacy of the plausible policy options available for water resources management and with a view to supporting overall and countrywide water policy issues.

Table 1 Glimpse of earlier assessment studies

S. no.	Year	Authority/method of estimation	Quantity (BCM)
1.	1901–1903	First irrigation commission/using coefficients of runoff	1443.2
2.	1949	Khosla's empirical formula	1673
3.	1960	CW and PC/statistical analysis of runoff data wherever available, and rainfall-runoff relationships were used where data were meagre	1881
4.	1988	Central water commission/general water balance approach	1880
5.	1993	Central water commission	1869
6.	1999	National Commission for integrated water resources development (NCIWRD)	1953

2 Objectives of the Present Study

Considering the need and data availability in the river basins, the following main objectives were set for the study:

1. To assess the long-term average annual water resources availability in the river basins of India during the period from 1984–1985 to 2014–2015 (30 years).
2. To compute water resources in the basins during extreme dry and wet conditions (minimum and maximum rainfall scenarios) during the last 30 years.

3 The Study Area

With a geographical area of about 329 million hectare (M. ha), India is a land of many mountains and rivers, some of them figuring amongst the mightiest rivers of the world. India has been divided into seven well-defined regions physiographically. The Northern Mountains comprise the Himalayan ranges, the great plains of the Indus and the Ganga and Brahmaputra river systems. In addition, hills of Western Ghats and Eastern Ghats, the Central Highlands, the Deccan Plateau and belts of land bordering the Arabian Sea and Bay of Bengal Sea comprise the study area. For the reassessment of water potential of India, total area of India was taken as 3.2345 Million km^2. This area does not include area of Indus above border, Lakshadweep Island and Andaman and Nicobar group of islands. The study area and the percentage of geographical area in each basin are shown in Figs. 1 and 2, respectively.

4 Input Data, Methodology and Thematic Focus

4.1 Geospatial Database

4.1.1 Land Use and Land Cover

The LULC data prepared by NRSC using Indian Remote Sensing (IRS) Advanced Wide Field Sensor (AWiFS) data was used in this study. The LULC data was available for the period of 11 years (2004–2005 to 2014–2015). Percentage-wise distribution of LULC pattern is given at Fig. 3. The two land-use patterns, (i) the predominant kharif only crop accounting for more than 18% of the total area of India and (ii) double/triple crops contribute maximum evapotranspiration, slightly varying from year to year. Deciduous forest is a major land class in forest cover classes, contributing to more than 10% of total forest cover in India.

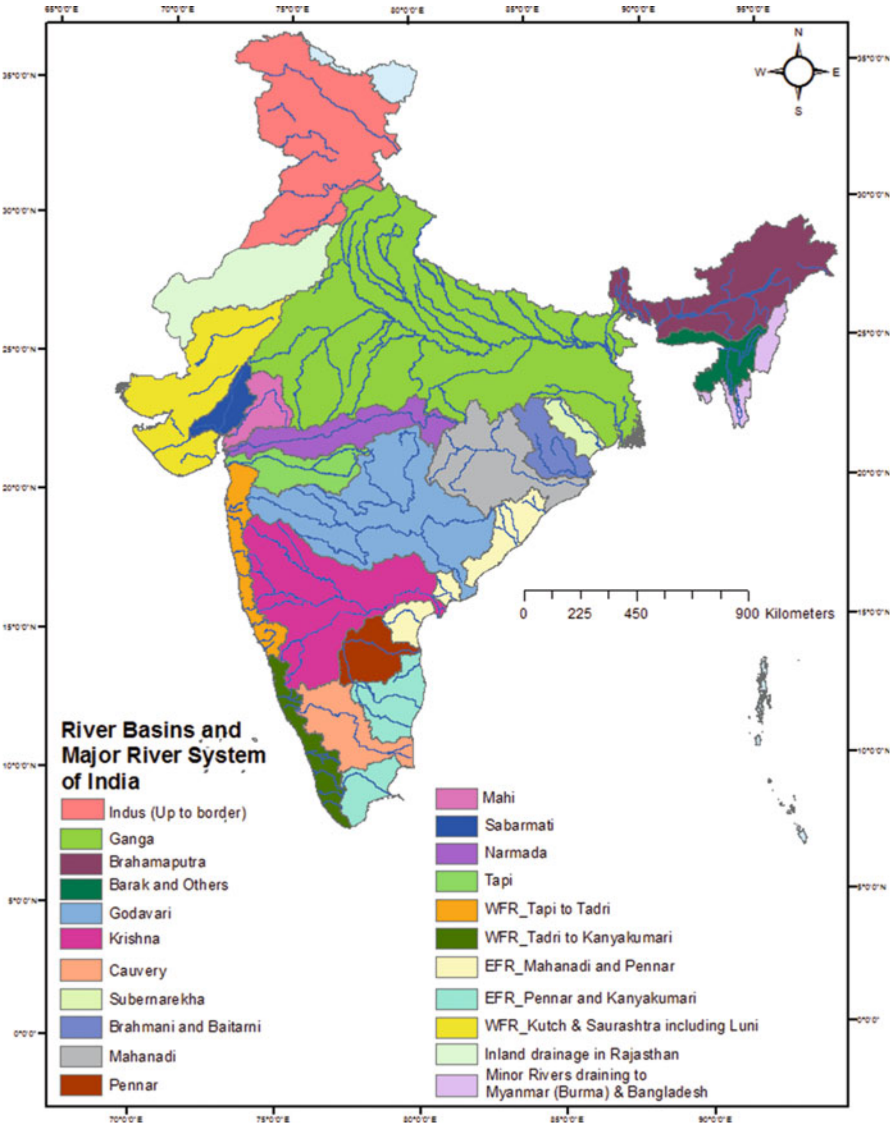


Fig. 1 Study area depicting all 20 basins of India

4.1.2 Soil Texture

The soil texture map prepared by the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) was used in this study. Predominant soil is loamy that accounts for low infiltration rate and more runoff in the basins, though loamy and clayey soils are the main soil textural classes in India. Soil textural classes in the study area are depicted in Fig. 4.

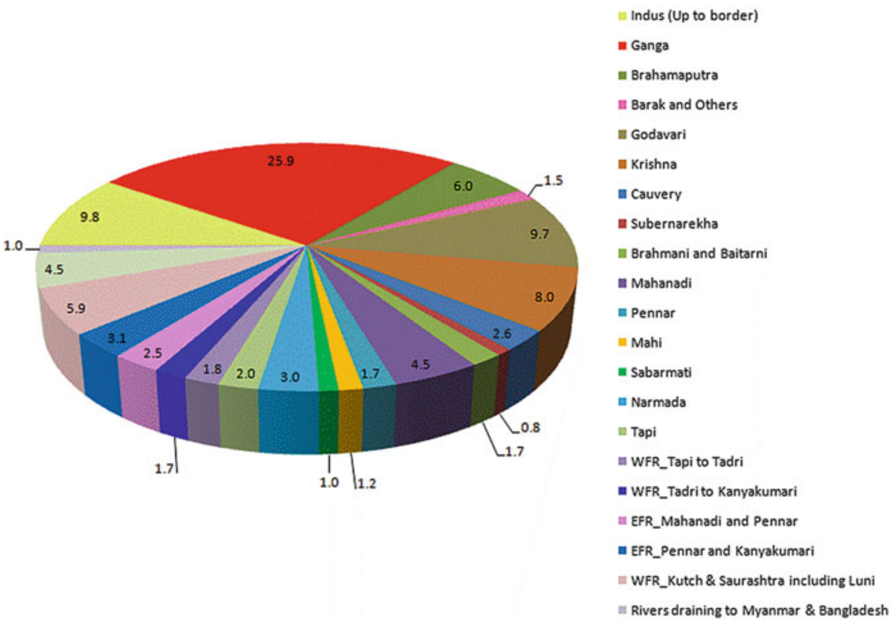


Fig. 2 Percentage of geographical area in each basin

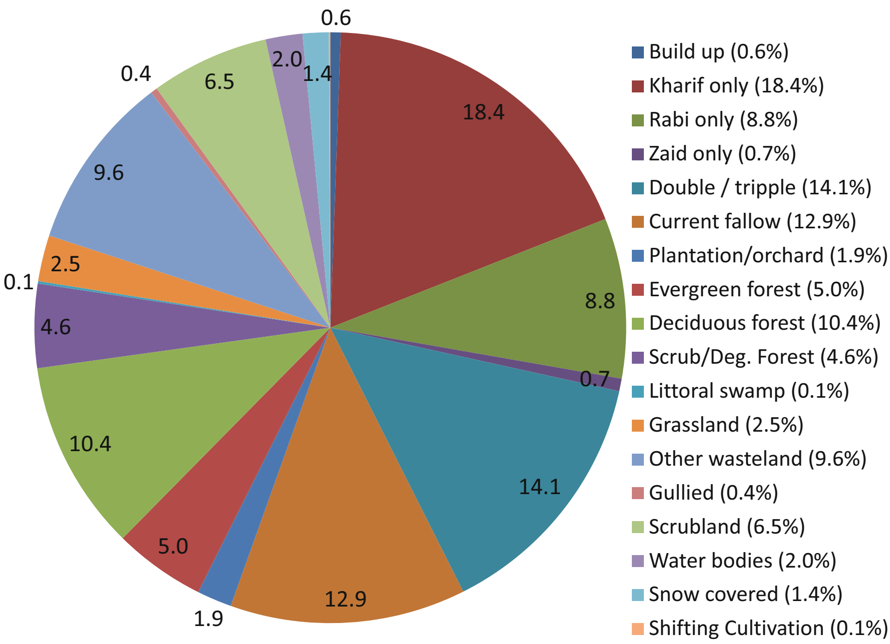


Fig. 3 Distribution of LULC in the year 2004–2005

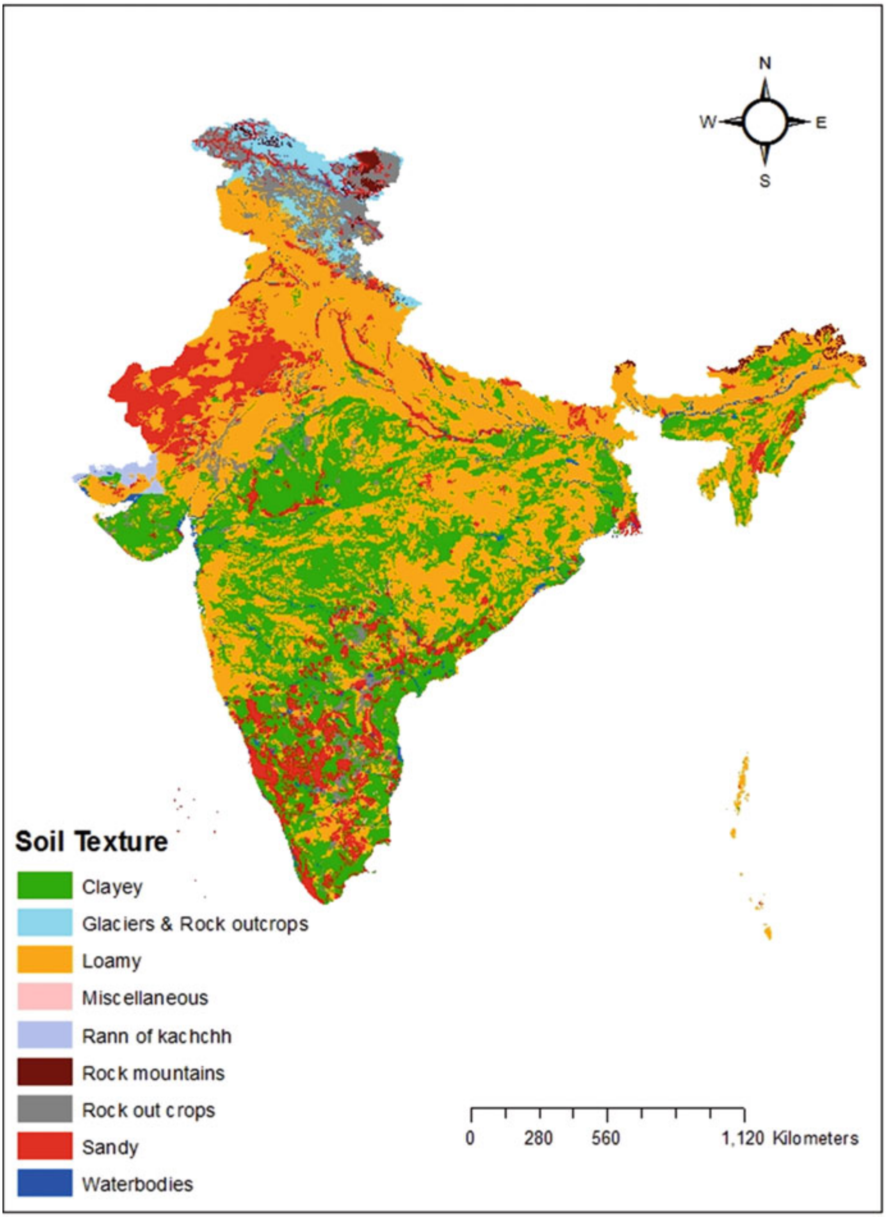


Fig. 4 Soil textural map of India

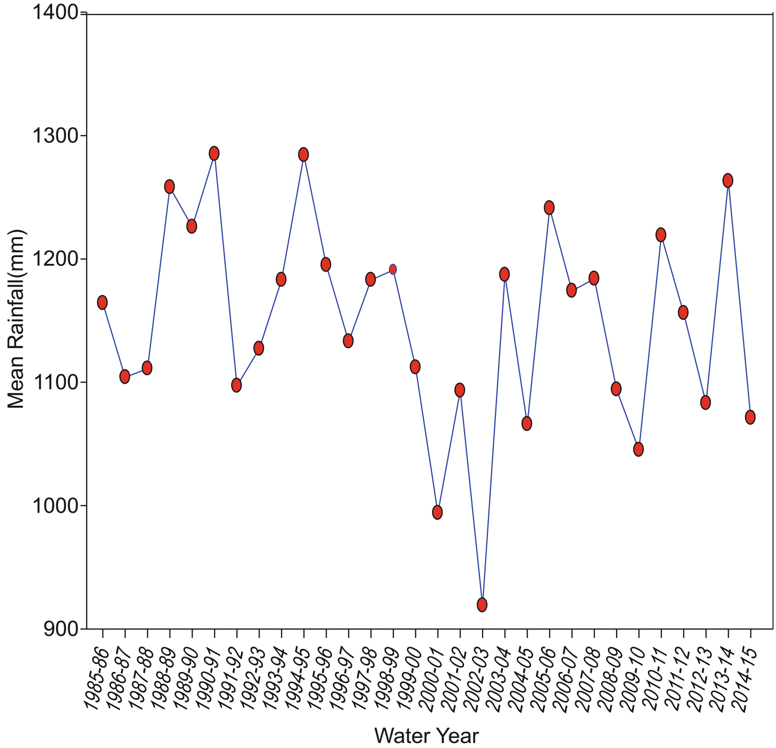


Fig. 5 Mean annual rainfall of India (1985–86 to 2014–15)

4.1.3 Digital Elevation Model (DEM)

The Shuttle Radar Topographic Mission DEM with 90 m resolution was used for delineating basin/subbasin boundaries of Indian river basins.

4.2 Hydrometeorological and Other Input Data

4.2.1 Rainfall Grids

Daily gridded rainfall data sets of high spatial resolution (0.25 × 0.25°) for the period of 30 years (1985–1986 to 2014–2015) prepared by IMD were used in this study. The annual rainfall of the study area is about 1105 mm. Variation of mean annual rainfall over 30 years is shown in Fig. 5.

4.2.2 Temperature Grids

$1 \times 1°$ spatial resolution daily gridded temperature data sets over India prepared by IMD were used in this study. The mean annual temperature during 2004–2005 was about 23.61 °C.

4.2.3 River Discharge

The daily discharge data was aggregated to annual scale and was used for calibration and validation of model computed runoff at subbasin level.

4.2.4 Reservoir Flux

Monthly reservoir level data in respect of the major reservoirs were collected from Central Water Commission. During the study period of 30 years, the reservoir level and corresponding volume data for the water year (June to May) were used in estimating the carryover of reservoir storage from 1 year to the next year. Reservoir flux is computed by subtracting the reservoir volume in May of succeeding year from June of current year as mentioned below.

$$\begin{aligned}\text{Reservoir flux} = {} & \text{reservoir volume in June of current year} \\ & - \text{reservoir volume in } \mathit{May} \text{ of succeeding year.}\end{aligned}$$

4.2.5 Groundwater Flux

The groundwater flux data prepared by CGWB was used in this study for estimating yearly groundwater fluxes. Water-year-wise groundwater flux was available in shape file format. The subbasin-wise yearly groundwater flux is calculated as detailed below:

1. Each district area is extracted using groundwater flux district shapefile provided by CGWB.
2. Groundwater flux district shapefile is generated by sub-setting using subbasin layer for each subbasin, and area of the district shapefile is calculated.
3. The area fraction of each district in the subset groundwater flux district shape is computed, and the area fraction is multiplied with the groundwater flux value given in the attributes for each year. The sum of all districts in subbasin gives the total groundwater flux for a subbasin.

4.2.6 Land Cover Coefficients

Based on the district-wise crop area statistics, district-wise major crops for each crop season were identified. The basins were divided into regions based on the historic district-wise crop statistics collected from various sources (http://lus.dacnet.nic.in/dt_lus.aspx). Each region specifies a unique crop for each crop season both spatially and temporally within the basin. Hence, the coefficients were taken as per the crop in that particular region/district. Different major crops for each season emerged. Hence, the coefficients are taken as per the crop in that particular region/district. On examining the cropping pattern within the basins, crop-growing seasons are decided.

Considering all the above factors, land cover coefficients are taken based on the report of FAO 56. The land cover coefficients were used in estimating the revised potential evapotranspiration (PET) values for each month by multiplying PET computed from Thornthwaite formula. The irrigation command areas in the basins were accounted for as depicted in Fig. 6. The total command area of completed irrigation/multipurpose projects up to 2015 is about 2,75,798 km^2.

4.2.7 Domestic, Industrial and Livestock Demand

The domestic demand is estimated taking into account the district boundaries of the year 2001 and 2011. Population statistics for intervening period and for the period beyond census years were calculated using geometric progression method. Domestic demand has been considered as 70 litres per capita per day (LPCD) for rural and 140 LPCD for urban population and 30 LPCD as livestock demand. Consumption at 15% of this demand is considered in the study. Since industrial demand statistics were not available, the same is assumed as 50% of the domestic demand for each year.

4.2.8 Evaporation from Major/Medium/Minor Reservoirs and Other Waterbodies

Evaporation was considered from the major storage schemes present in the basins. Evaporation from small reservoirs/waterbodies has not been considered in the study.

4.3 Broad Methodology

The integration of spatial data sets (DEM, LULC, soil texture, village census) with hydrometeorological data sets (rainfall, temperature, groundwater flux, reservoir flux and river discharge) in GIS environment for carrying out water balance

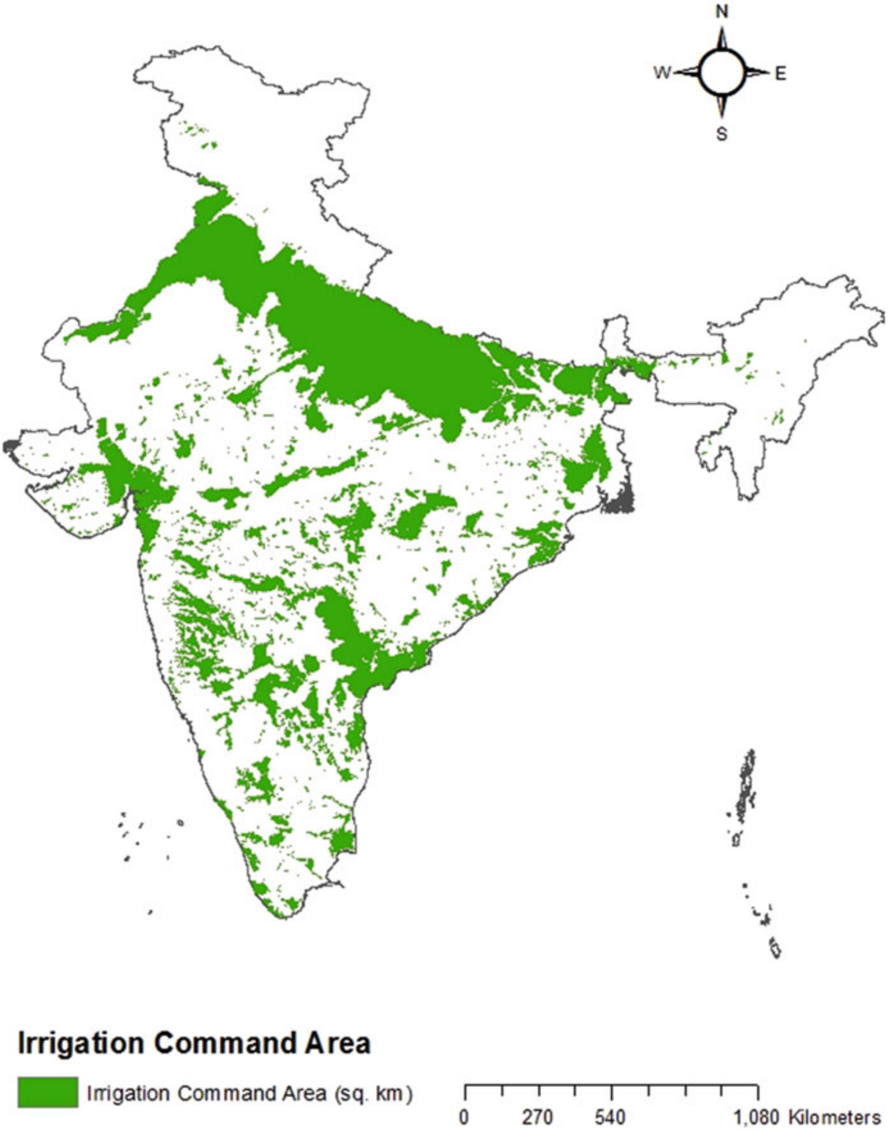


Fig. 6 Command area of basins (2014–2015)

computations at hydrological response unit level makes the modelling framework for the present study (Fig. 7). The 30-year water balance outputs were averaged to arrive at long-term average annual basin-level water resources.

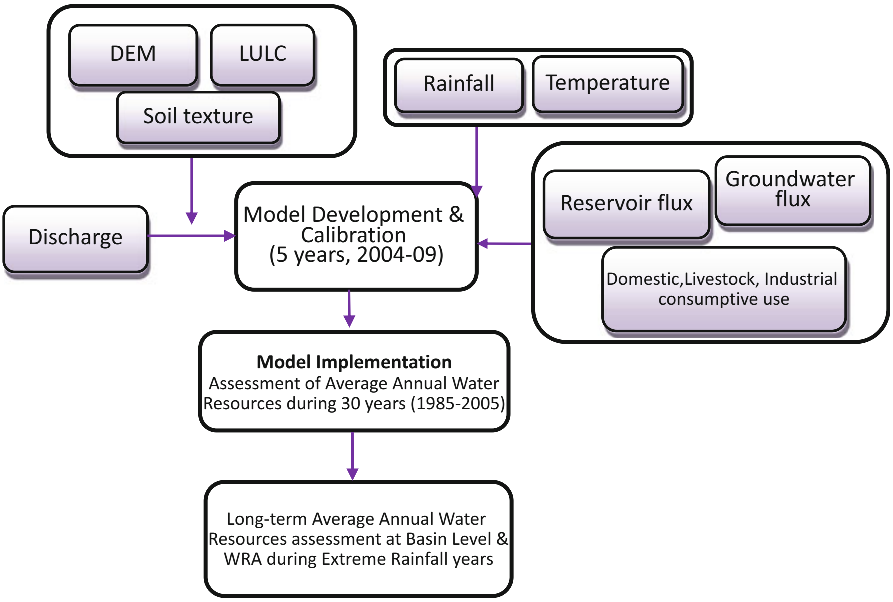


Fig. 7 Modelling framework of water resources assessment

For computing seasonal and geographic patterns of irrigation demand and the soil moisture stresses under which crop and natural vegetation can survive, the water balance has been used. Water table calculated for a single soil profile for a basin refers to the balance between incoming of water by precipitation and outflow of water by evapotranspiration, groundwater recharge and stream flow. Thornthwaite and Mather (1957) method of evapotranspiration calculation has been resorted to, which uses long-term average monthly rainfall, long-term average potential evapotranspiration and soil and vegetation characteristics. Owing to constraints of data availability, other methods could not be used. The last two factors are combined in the water capacity of the root zone. Computation of ET in this method is mainly based on temperature data only. By using Eq. 1, a monthly heat index (j) is calculated employing the mean monthly temperatures.

$$j = \left(\frac{t_n}{5}\right)^{1.514} \tag{1}$$

where

j = monthly heat index.
t_n = monthly mean temperature, °C (where $n = 1, 2, 3\ldots, 12$).

Annual heat index (J) is given by Eq. 2 adding together 12 monthly heat indices.

$$J = \sum_{1}^{12} j \tag{2}$$

Then, monthly PET for any month is calculated by using Eq. 3:

$$\mathrm{PET} = 16\mathrm{f}\left(\frac{10t_n}{j}\right)^{\mathrm{a}} \tag{3}$$

where

a is the cubic function of J

$$a = \left(675^{*}10^{-9}\right)J^3 - \left(771^{*}10^{-7}\right)J^2 + \left(179^{*}10^{-4}\right)J + 0.492 \tag{4}$$

f = factor, to correct for unequal day length between months.

It is required to adjust the value of unadjusted 30-day PET and 12 h of sunshine per day, modulating by factor (f). For other latitudes, f value has to be interpolated from Table 3.

Day length factor grid has been prepared in GIS environment. Temperature grids and day length grids are used to calculate PET through spatial modelling. These PET maps of study basin are prepared, and subsequently, PET grids of study basin are extracted.

4.3.1 Land Cover Coefficients

Thornthwaite method doesn't account for vegetative effect in water balance estimations (Peter E. Black). Monthly land cover coefficients have been derived for studying river basin using digital satellite data and integrated with PET to account for vegetation effect on PET. The method uses air temperature as an index of the energy available for ET, assuming the former is correlated with the integrated effects of net radiation and other controls of ET. The available energy is shared in some proportion between heating the atmosphere and ET. This method estimates PET only based on air temperature and does not consider the land cover and vegetation classes. The ET depends on vegetation cover on soil and vegetation types (Dolman et al. 2001). Hence, in this study, it is proposed to consider the effect of vegetation cover and its type in estimating the PET using the Thornthwaite method by using land cover-based coefficients.

$$\mathrm{PET}_{\mathrm{revised}}\left(\text{or } \mathrm{ET}_{\mathrm{LC(model\ estimated)}}\right) = \mathrm{PET}^{*}\text{Land cover coefficient} \tag{5}$$

The land cover coefficient for vegetation (K_c) integrates the effect of characteristics distinguishing field crops from each other. Thus, different crops do have

Table 2 Values of factor (f)

North Lat	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
0°	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10°	0.97	0.98	1.01	1.03	1.05	1.06	1.05	1.03	1.08	0.99	0.98	0.96
20°	0.93	0.96	1.00	1.05	1.09	1.11	1.10	1.07	1.03	0.98	0.93	0.91
30°	0.87	0.93	1.00	1.08	1.14	1.18	1.16	1.10	1.03	0.96	0.88	0.85
40°	0.80	0.89	0.99	1.10	1.20	1.25	1.23	1.15	1.04	0.93	0.83	0.78
50°	0.72	0.84	0.98	1.15	1.28	1.37	1.33	1.21	1.06	0.90	0.76	0.68

different K_c. The K_c primarily depends on crop type, crop growth stage and soil evaporation. Uniform K_c during all the months has been considered for the vegetation like forest, scrub land, etc. According to the crop growth stage and type of crop, variable coefficients have been taken in different months for agricultural lands. These coefficients are further calibrated using the field discharge data (Table 2).

After the calculation of $ET_{LC\ (model\ estimated)}$, the dry and wet seasons are identified. If ($P - ET_{LC\ (model\ estimated)}$) > 0, it is considered as wet season, otherwise it is dry season. The severity of the dry season increases during the sequence of months with excessive PET. The cumulative of negative values of ($P - ET_{LC\ (model\ estimated)}$), which is the accumulated potential water loss (La) for the dry season, is calculated from the end of the wet season.

The soil moisture (SM), which mainly depends upon the soil texture, root zone depth of vegetation and land use, is determined. Then, from the readily available tables or by using the empirical formula for dry months, the amount of water retained in the soil after various amounts of accumulated potential water loss is calculated. For wet months, SM values are determined by adding the excess precipitation to the SM value of the previous month until the total storage reaches the water-holding capacity of the soil.

The SM status for each month with ET exceeding precipitation is calculated using Eq. 6:

$$\mathrm{SM} = W * e^{\left(\frac{-\mathrm{La}}{w}\right)} \tag{6}$$

where

SM = soil moisture, mm.
La = accumulated potential water loss, mm.
W = water-holding capacity, which has been calculated for the different land use class and soil texture, mm.

The amount of silt and clay present in soil determines the ability of soil to retain water; the higher the amount, the greater is the soil moisture content. Based on the land use, root zone depth and soil texture, the water-holding capacity (W) of each pixel has been calculated. SM in each month is calculated based on accumulated water loss and W in the month. SM denotes the change in soil moisture in a month to its previous month. Actual evapotranspiration ($AET_{model\ estimated}$) represents the actual transfer of moisture from vegetation and soil to the atmosphere. When P exceeds $ET_{LC\ (model\ estimated)}$, it is assumed that there is sufficient moisture to meet the climatic demands and

$$AET_{model\ estimated} = ET_{LC\ (model\ estimated)} \quad (7)$$

Even if the soil moisture of root zone is not at its storage capacity but if $P > ET_{LC\ (model\ estimated)}$, it can be assumed that P will be sufficient to satisfy climatic moisture requirements, i.e. $AET_{model\ estimated} = ET_{LC\ (model\ estimated)}$. When meteorological demand is partially satisfied from the stored soil water (when $P < ET_{LC\ (model\ estimated)}$),

$$AET_{model\ estimated} = P + |\Delta SM| \quad (8)$$

In irrigated agricultural land (generally from canal and well irrigation), estimated consumptive irrigation input (P- $ET_{LC\ (model\ estimated)}$) is added to rainfall to equate $AET_{model\ estimated}$ to $ET_{LC\ (model\ estimated)}$ and $AET_{model\ estimated}$ calculated accordingly. This assumption is made assuming full irrigation water requirements are being met. The added estimated consumptive irrigation input has been subsequently adjusted while computing runoff. Then, we should identify the months in which moisture deficit (D) occurs. D, that exists only in dry period when $P < ET_{LC\ (model\ estimated)}$, is calculated by Eq. 9.

$$D = ET_{LC\ (model\ estimated)} - AET_{model\ estimated} \quad (9)$$

The quantity of excess water that cannot be stored is termed as moisture surplus (S). When storage reaches its capacity, surplus is calculated using Eq. 10.

$$S = P - (AET_{model\ estimated} + |\Delta SM|) \quad (10)$$

The actual runoff equals to the available annual surplus. However, due to the lag between the time of precipitation and the time the water actually moves the discharge site, monthly computed surplus is not the same as monthly runoff. It is assumed that for large basins, approximately 50% of the surplus water is available for runoff in any month. The remaining is detained in the subsoil, groundwater and the channels of the basin and is available for runoff during the succeeding month.

The complete basin has been divided into number of hydrological response units (HRUs) based on the land use, soil texture, root zone depth and command area, and runoff in each HRU has been estimated. Meteorological data of the concerned HRU is used in runoff calculations.

4.3.2 Hydrological Response Unit Generation

A hydrological response unit (HRU) is an area within the basin having the same soil type and land use, a homogeneous basic computational unit assumed to be in hydrologic response to land cover change. Depending on the number of soil textural classes and land cover classes, a number of HRU are derived within the basin. It is assumed that a particular soil textural class can have particular water holding capacity and a certain vegetation type to have a maximum root zone depth. So a combination of soil textural class and vegetation type results in different HRUs.

In addition to the derived HRUs, they are further categorized based on the irrigation command area boundaries. The HRUs within or outside the command boundary are assumed to meet all the AET demand considering the major crop season/seasons (i.e. kharif, rabi, zaid and double/triple) in the basin. For example, double/triple crop assumed to satisfy all the AET demand (i.e. Actual ET = $ET_{LC\ (model\ estimated)}$) whether it is within or outside command boundary.

In irrigated crop areas, both in canal irrigated and tube well irrigated, the water requirements in excess of precipitation are supplemented through irrigation sources. In the present study, all the cropped area within irrigation canal jurisdiction and double/triple cropped area were considered as irrigated. In general, these irrigated cropped areas will meet their complete water requirements through precipitation and supplementary irrigation. But availability of records of irrigation supplies is difficult to collect because the irrigation sources may vary from surface storage from reservoirs, tanks and groundwater sources such as open wells and deep bore wells. Hence, in the present study, irrigation supplies are computed from the precipitation and $ET_{LC\ (model\ estimated)}$. It is assumed as under these cropped areas, actual evapotranspiration attains potential evapotranspiration. It means, whenever precipitation (P) falls short of $ET_{LC\ (model\ estimated)}$, the shortage (i.e. $ET_{LC\ (model\ estimated)}$, $- P$) is met with supplementary irrigation (estimated consumptive irrigation input). To account for these irrigation supplies, the precipitation under the above-mentioned cropped areas was revised as detailed under:

$$\begin{aligned}\text{Precipitation (revised)}, P_{\text{revised}} &= P, \quad \text{when Precipitation} > ET_{LC\ (\text{model estimated})}\\ &= P + \left(ET_{LC\ (\text{model estimated})} - P\right), \quad \text{when Precipitation} < ET_{LC(\text{model estimated})}\end{aligned}$$

(for double/triple cropped area and cropped area within irrigation command jurisdiction)

4.3.3 Model Calibration and Validation

The runoff that is estimated from each pixel at monthly time step is aggregated within each subbasin. The monthly surface runoff was further aggregated to annual time step for all the subbasins. The estimated runoff for each subbasin is calibrated with observed discharge at annual scale. The negative groundwater flux computed indicates withdrawal of water from the last year groundwater storage and, if it is positive, increase in groundwater recharge from the last year. The unknown variables in the model are calibrated using the observed data during the calibration process, which is a trial and error method. The land cover coefficients are the main variable to be calibrated. Land cover coefficients need to be changed during the calibration process till the desired outputs are achieved.

Once the model is calibrated, it is validated with a new set of field data to check the calibrated parameters. In the present study, the model has been calibrated with the hydrometeorological data of 5 years which includes dry, wet and normal water years. The calibrated model has been validated with the data of all the remaining years. From these results, it can be inferred that the calibrated results are very well matching with the field observations. Calibration of the model is done using Eq. 11.

$$R_{\text{Calibrated/computed}} = (R_{\text{Model}} - F_{\text{GW}} - F_{\text{R}} - F_{\text{DIL}}) \approx R_{\text{o}}, \tag{11}$$

$R_{\text{Calibrated/computed}}$ = calibrated/computed runoff.
R_{Model} = model estimated runoff (output from Thornthwaite-Mather model).
F_{R} = reservoir Flux (− ve sign for drawdown and vice versa).
F_{GW} = groundwater Flux (− ve sign for drawdown and vice versa).
F_{DIL} = domestic, industrial and livestock consumption.
R_{o} = observed runoff at gauge sites.

The amount of water abstracted from the basin is given due to care along with the water imported from other basins/subbasins.

4.3.4 Water Resources Availability (WRA)

Water resources of the basin comprise of runoff at final outlet point of the river; upstream effective utilizations for irrigation, domestic, industrial and livestock uses; groundwater flux; and reservoir flux. This is expressed as

$$\text{WRA} = R_{\text{Calibrated/computed}} + \text{ECII} + E + F_{\text{DIL}} + F_{\text{GW}} + F_{\text{R}} \tag{12}$$

where SE is the evaporation losses from the reservoirs (computed) and ECII the estimated consumptive irrigation input provided (computed).

5 Results and Discussions

The total catchment area considered for the present study is 3.234 Million km^2 (excluding the areas of Indus above border, Lakshadweep Island and Andaman and Nicobar Islands), whereas the area considered for the 1993 study is 3.230 Million km^2. The maximum and minimum rainfall during the present study period have been estimated as 1255 mm (4412 BCM, year 1990–1991) and 889 mm (3125 BCM, year 2002–2003), respectively. The mean annual rainfall during the period of present study (1985–2015) is 3880 BCM (1105 mm) as compared to 3945 BCM (1123 mm, period 1955–1984) and 3853 BCM (1096 mm, period 1965–1984).

The average annual water resource of the basins for the study period of 30 years (1985–2015) has been assessed as 2001.54 BCM (Table 3). The water availability of all the 20 basins as reported in 1993 is reassessed now. There is reduction in water

Table 3 Water resources availability of Indian basins

Sl. no.	Basins	Catchment area (km^2)	Average rainfall in water year (1985–2015) (BCM)	Water resources availability (BCM)	
				Average	(75% dependable)
1	2	3	4	5	6
1.	Indus (within India)	317,707.8	330	45.53	37.15
2.	Ganges-Brahmaputra-Meghna				
	(a) Ganga	838,802.8	914	509.52[a]	471.76
	(b) Brahmaputra,	193,251.8	495	527.28[b]	480
	(c) Barak and others.	47,440.1	134	86.67	68.58
3.	Godavari	312,150.2	365	117.74	87.67
4.	Krishna	259,439.0	226	89.04	71.43
5.	Cauvery	85,167.0	81	27.67	22.62
6.	Subarnarekha	26,803.5	40	15.05	12.00
7.	Brahmani-Baitarani	53,902.4	83	35.66	25.00
8.	Mahanadi	144,904.9	200	73.00	49.00
9.	Pennar	54,905.4	40	11.00	5.42
10.	Mahi	39,565.6	35	14.22	9.14
11.	Sabarmati	31,901.2	25	12.42	7.23
12.	Narmada	97,162.1	108	58.21	45.24
13.	Tapi	65,805.8	59	26.24	21.23
14.	WFR from Tapi to Tadri	58,359.9	161	118.55	106.81
15.	WFR from Tadri to Kanyakumari	54,231.9	151	119.06	106.10
16.	EFR between Mahanadi and Pennar	82,073.1	97	26.41	17.41
17.	East flowing rivers between Pennar and Kanyakumari	101,656.9	98	26.53	18.21
18.	West flowing Rivers of Kutch and Saurashtra including Luni	192,112	100	26.95	21.00
19.	Area of inland drainage in Rajasthan desert	144,835.9	49	Negligible	Negligible
20.	Minor rivers draining into Myanmar (Burma) and Bangladesh	31,381.7	61	31.17	26.56
	Total	323,3561[c]	3880	**1999.20**[d]	

[a]Without contribution from Nepal (17.24 BCM). Considering contribution from Nepal, water resources availability in Ganga basin is 526.76 BCM comprising components, viz. 197.22 BCM in Upper Ganga, 192.60 BCM in Lower Ganga and 136.94 BCM in Yamuna subbasins

[b]Without contribution from Bhutan (63.50 BCM). Water resources availability in Brahmaputra basin, i.e. 527.28 BCM, comprises components, viz. 504.55 BCM in Brahmaputra and 22.73 BCM in Teesta

[c]Excluding area of Indus above border, Lakshadweep Island and Andaman and Nicobar group of islands

[d]Excluding contribution from Nepal (17.24 BCM) and Bhutan (63.5 BCM). This is a first approximation model result

Table 4 Possible reasons for deviation of the present study from the CWC, 1993 study

Sl. no.	CWC 1993 reassessment study	Current reassessment study
1.	(i) all basins were not studied during 1993 study	All basins are studied for the concurrent period, i.e. 1985–2015
	(1) 12 studied basins: 505 BCM	
	(2) 10 not studied basins: 1364 BCM	
	(ii) Indus, ganga, Brahmaputra, Narmada, Cauvery, Mahanadi, Meghna, area of inland drainage (Rajasthan desert), Barak and WFR (Kutch Saurashtra) were not studied	
	(iii) sum of average water availability for studies during different years was taken, which is not mathematically correct	
2.	Teesta basin was not studied at all	Teesta basin has been studied (22.73 BCM)
3.	Observed discharges at terminal G&D sites were considered, which, in itself, may not be free from errors	Proper calibration and validation exercises were undertaken in the present study on discharges
4.	No rainfall component was used in the studies	Rainfall grid (as obtained from IMD and GEFS) has been used for entire India
5.	(i) Utilization of data was mostly obtained from states, and wherever not available, assumptions were made	The consumptive use in irrigation has been assessed using scientific methods and GIS database for LULC, soil-texture, crop/vegetation parameters, temperature and command area boundaries
	(ii) utilizations from minor projects were seldom available	
6.	Return flow of 10% assumption in irrigation is a crude assumption	Instead of utilization minus return flows (both are approximate), directly the consumptive use was assessed
7	Groundwater data for year 1967–1968 and 1983–1984 used and interpolated for other years	Groundwater flux data (as obtained from CGWB) for entire India was used

availability in basins, viz. Indus (27.78 BCM), Ganga (15.5 BCM) and Brahmaputra (5.35 BCM). In the rest of the basins, there is increase in water availability (average increase being 7.4 BCM) having largest increase in Barak and others (38.31 BCM) and WFR from Tapi to Tadri (31.14 BCM).

There are variations in water availability in individual basins, but overall change being only an increase of 129.85 BCM. However, if contribution of Teesta Basin (22.73 BCM) is added to the 1993 study, the difference between the two studies is reduced to 107.12 BCM only. The possible reasons for deviation are outlined in Table 4. Therefore, it may be concluded that the present study corroborates the 1993 study. However, since the present study is based on the most advanced methodology, it generates more confidence in the results achieved.

6 Implications of the Study

Owing to the serious concern of increasing population, which is likely to increase to 1.66 billion by 2050, the implications of water resources could be as below:

1. By 2050, with the increasing population, the annual food requirement may exceed 250 million tons in India. The total demand for grains including livestock grain demand will increase to 375 million tons by that time. Further, there will be increase in the demand for food if national GDP is taken at 6.8% per annum from the year 2000 to 2025 and 6.0% per annum during the years 2025 to 2050. The per capita income would increase by 5.5% per annum. Increase in the per capita consumption of sugar, fruits and vegetables during the period from 2000 to 2050 (NCIWRD 1999) will create an additional demand for water. The requirement of water for livestock will rise from 2.3 BCM in 2000 to 3.2 BCM in 2050.
2. The average rainfall in 4 months (June to September) is about 730.7 BCM. The water requirement for average irrigation support in all the commands in the basins remains as 482 BCM against total completed command area of about 0.586 Million km^2 and rainfall of 3803 BCM excluding Andaman and Nicobar Islands and inland drainage in Rajasthan and Leh-Ladakh area. By promoting appropriate technological interventions of micro-irrigation, 'More crop per drop' can be achieved to improve water use efficiency in the agriculture sector.
3. Almost 75.30% of rainfall occurs in the 4 monsoon months (June to September). The total utilizable quantity of water is 690 BCM + 447 BCM = 1137 BCM per year. Interlinking of rivers will facilitate an addition of about 180 BCM of water. The unutilized water draining to the sea per annum is about 1166 BCM. Better water management would generate 4000 hectares more for one TMC of running water, and it could produce 5.5 tons per hectare. Thus, it would be possible to irrigate about 148 Mha of land annually to produce about 800 million tons of rice.
4. Proper implementation actions should be devised and adopted to respond to challenges, resources and capacity. Optimization of priorities and allocation of water resources to adapt interventions, reflecting the conditions in subbasins, should be adopted.
5. In the water sector, the national water planning entangles the national strategy framework for water resource management. At watershed level, adaptive institutional mechanism would be vital for management, and longer-term strategies need to be devised for management incorporating fluctuations in the water availability due to climate change.
6. Significant trade-offs are necessitated to suffice continued development, particularly in terms of the allocation between agricultural and urban-industrial water use in case of drier situations. These constraints are most likely to be experienced in some pockets of central, northern and south-western parts of India.
7. The viable agriculture and energy production will impact on water supplies to economic and social users. It warrants having a clear planning strategy to the trade-offs between water, energy and food production. Harnessing of excess monsoon runoff for enhancing groundwater storage will increase the availability of water to meet the growing demands and mitigate damages from floods to some extent.

7 Uncertainty and Confidence Interval in Average Annual Water Availability

Significant long-term implications for the quality and quantity of water may be noticed due to change in key climate variables, namely, temperature, precipitation and humidity. Water yield and AET are highly influenced by the weather conditions being the two major water balance components and dictated by temperature and allied parameters. Impacts of climate variability on the water resources are likely to affect irrigated agriculture, installed power capacity, in-stream flows for environment in the dry season and higher flows during the monsoon.

Based on a statistical analysis of the 30-year water availability series (base and future), at a 0.1 level of significance, the confidence interval could be estimated that comprised the average annual water availability. The greater range of this interval would render greater uncertainty related to the average annual water availability. If the range of confidence interval is increased indicating greater variability between the series consequently, greater uncertainties in estimating the availability are resulted. The average annual water availability during considering a 90% confidence interval was between 1955.70 BCM and 2042.90 BCM (range of 43.70 BCM). It could be seen that during the period (1985–2015), the average coefficient of variation (CV) is 0.09. The result indicates marginal increase in the variability of average annual water availability.

8 Limitations of the Study

The limitations of the study are as follows:

1. The model is setup at annual time step; monthly calibrations are not carried out.
2. Considering the availability of meteorological data in spatial environment, Thornthwaite-Mather method with suitable land cover coefficients is considered for PET calculations.
3. The water utilization due to irrigation has been estimated through the use of Mather method and other suitable literature in the absence of the withdrawal data uniformly throughout the basin.
4. Land use/land cover maps for the period 2004–2005 to 2014–2015 only are used for runoff calculation in the study. For runoff computations prior to 2004–2005, land use maps of 2004–2005 to 2014–2015 are adopted based on the mean annual rainfall of the year under consideration.
5. Kharif crop is assumed to be rain-fed outside of the command area boundary. Kharif-only crop within command boundary, double/triple crops and Zaid crop are considered as irrigated, either by surface or groundwater.
6. In irrigated agriculture land, $AET_{model\ estimated}$ is calculated by assuming that 100% water requirements are met from the rainfall and irrigation supplies together (AET = PET condition). Based on district-wise groundwater flux, component for each subbasins is worked out.

9 Way Forward

(a) The accuracy of the water resources potential of the basins made on the basis of the discharge measured on the river terminal sites depends directly upon the reliability of the discharge observation and the data on abstractions in the upstream. Improved estimates of abstraction would enhance the results of import or export from the basin, Vis-a-Vis reducing uncertainty.
(b) Irrigation for agriculture consumes most of the water in the basins. The domestic demand is estimated taking into account the district boundaries of the year 2001 and 2011. Population statistics for intervening period and for the period beyond census years were calculated using geometric progression method. Domestic demand considered as 70 LPCD for rural, 140 LPCD for urban population and Livestock demand at 30 LPCD. Consumption at 15% of this demand is considered in the study. Since industrial demand statistics were not available, the same is assumed as 50% of the domestic demand for each year. It is very essential that diversions for irrigation from major, medium and minor projects are recorded regularly and brought out as yearly booklets similar to rainfall records.
(c) More efforts are needed for developing and improving the hydrological observation network and making the data available through the common infrastructure using standardized formats. More gauging stations should be established at the terminal gauging sites of all the basins including composite basins of west flowing Rivers and east flowing Rivers, as the existing gauging stations are considered inadequate.
(d) There is also a need to modernize the equipment used for gauge and discharge measurements in the existing gauging stations in all the basins.
(e) The groundwater flux data prepared by CGWB was used in this study for estimating yearly groundwater fluxes. Basin-wise figures are worked out by area proportionate basis from the district-wise groundwater flux figures. The sum of all districts in subbasin gives the total groundwater flux for a subbasin. It would be more convenient if groundwater studies are carried out basin- or subbasin-wise.
(f) Improved estimates of precipitation and intercomparisons of these observations are important to validate the measurements and provide confidence for each measurement technique.
(g) Means should be devised for overcoming the limitations of the present study and implement in the future study of reassessment of basin water availability.
(h) It is also suggested to take up studies on improving methodological aspects such as estimation of fine resolution spatial rainfall estimates, spatial ET/water use estimates, snow-melt runoff contributions, accounting spatial and temporal variability in irrigation water use, groundwater abstraction/recharge and subbasin-level water availability and comparative studies with different hydrological models for water assessment. These studies will lead to improved parameterization and reliable estimates of water availability.

(i) There is a significant spatiotemporal variation in water availability. For improving water utilization, there is a need to create more storage. This would facilitate interbasin transfer and evening out this variation.
(j) The water availability at different stretches/subbasins/points along the river needs to be quantified (excess or deficit) through further studies.
(k) Thus, there is a need to further study the feasibility of water storage structures (reservoirs) and the areas where the stored water can be techno-economically utilized/transferred.
(l) In addition, utilizable water potential needs to be assessed. The regions need to be identified for utilization at the vicinity of point of surplus water, for rain-fed agriculture areas, water harvesting and conservation.
(m) The feasibility of import/export of water needs to be evaluated vis-à-vis analysis of intra- or interlinks proposed/ongoing by the central or state governments.
(n) Proposed IWRM studies contemplated under NHP need to consider these results and draw out a specific implication plan for the subbasins/basins.

10 Conclusions

The study presents water availability and thus reflecting solution options for improved water resources management adopting gainful implementation ways to foster progress and social acceptance. The stakeholders and decision-makers in each region, basin and state should exercise to identify the most appropriate mix of options for their particular situation depending on the challenges. Drought and flood planning with the ability to manage and respond to events outside the historic record development would be needed. Developmental plans of new industrial, urban or agricultural centres or long-term declines in runoff may occur over longer-term time horizons. Under different fluctuations in the water availability based on future climate change conditions, water resource infrastructures should have operational flexibility to perform efficiently. The demand projections do not consider these fluctuations as they are based on statistical forecast. Ways are required to examine the implications of different climate futures through models to provide sound decision-making.

Acknowledgement The authors extend sincere thanks to the chairman of the Central Water Commission and head of the National Remote Sensing Centre for their kind support. The support extended by the colleagues through their valuable suggestions and comments are gratefully acknowledged. The views expressed in the paper are personal of the authors.

References

Australian Water Resources Assessment (2012) Bureau of meteorology. Government of Australia. Available at: www.bom.gov.au/water/awra/2012/

Dolman AJ, Hall AJ, Kavvas ML, Oki T, Pomeroy JW (eds) (2001) Soil-vegetation-atmosphere transfer schemes and large-scale hydrological models, vol 270. IAHS Publ, Wallingford, p 37

FAO (2002) Crop evapotranspiration guidelines for computing crop water requirement. Irrigation and drainage paper no. 56. Available at: https://appgeodb.nancy.inra.fr/biljou/pdf/Allen_FAO1998.pdf

Ministry of Water Resources (1999) Integrated water resources development, a plan for the action. Report of the National Commission for Integrated Water Resources Development, vol 1, Government of India

Peter EB. Revising the Thornthwaite and Mather water balance. http://www.watershedhydrology.com/pdf/T&M%20Revisited.pdf

Thronthwaite CW, Mather JR (1957) Instructions and tables for computing potential evapotranspiration and water balance. Laboratory of Climatology, Publication no. 10, Centerton, NJ

V. V. Rao obtained BE in agricultural engineering from agricultural university, Coimbatore, MSc and PhD from Indian Agricultural Research Institute, New Delhi. He has a long experience in remote sensing and GIS application to water resource assessment, planning and management, irrigation water management, hydrology, snow and glacier hydrology, soil erosion and sedimentation and watershed management. As group director of water resource, in National Remote Sensing Center, Hyderabad. He is responsible for the development of new remote sensing and GIS-based application techniques and successful implementation of application in his domain. He coordinated with different ministries of Government of India for the utilization of space technology-based tools and applications. He was the project director of India WRIS project and also presently the nodal officer from ISRO for national hydrology project. As a team leader, he has received three ISRO team excellence awards.

R. N. Sankhua is presently working as director of basin planning, Central Water Commission, New Delhi. He obtained his BE (honours) in civil engineering from the National Institute of Technology Rourkela and ME (honours) (WRD) and PhD in fluvial hydraulics from IIT Roorkee. He has contributed 120 papers to international/national journals/international conferences/workshops and completed 17 technical studies on remote sensing and GIS. He guided about 30 master's dissertations and 6 PhD theses in the field of applications in water resources from IIT Roorkee and the University of Pune. He has authored four books on different domains of water research. He has delivered more than 1550 lectures including about 100 invited expert lectures at various institutes of repute. He has working knowledge of more than 100 software packages in water resources. He is a life member of professional societies like the Indian Society of Technical Education, Institute of Engineers (India), Indian Water Resources Society, Indian Society of Rock Mechanics and Tunnelling Technology, Indian Association of Hydrologists and Indian Geomatics Society. His areas of interest include IT in water resources, hydroinformatics, fluvial hydraulics, river engineering, and numerical and hydraulic modelling.

National Aquifer Mapping and Management Programme: A Step Towards Water Security in India

Dipankar Saha, Sanjay Marwaha, and S. N. Dwivedi

1 Introduction

India's food and drinking water security is largely dependent on the groundwater resources of the country. Besides, groundwater also caters a large component of the industrial demand. As a country, India is the largest extractor of groundwater in the world, with extraction to the tune of 252 billion cubic metre per year (BCM/yr) (Mukherjee et al. 2015; Saha et al. 2017). Presently, about 62% of our irrigation demand and 85% of rural drinking needs are drawn from aquifers. In urban water sector, despite the substantial investment in surface water-based pipe water supply, groundwater is considered as a dependable supplementary source contributing more than 50% of the total demand.

Overall, we are extracting about 62% of the total annual groundwater recharge in our country. However, if the extraction and recharge pattern is examined spatially, about 16% of our administrative blocks (talukas/firkas in certain states) are overexploited (Fig. 1), where extraction of groundwater resource is more than annual recharge (CGWB 2017).

About 65% of the overexploited blocks are concentrated in eight states distributed in the north-western, western and southern parts of India like Punjab, Haryana, Rajasthan, Gujarat, Maharashtra, Karnataka, Tamil Nadu and Telangana. On the other hand, in large swaths of the north-eastern, eastern and central parts of India, groundwater resources are underdeveloped, leaving further scope of further development of groundwater resource.

D. Saha (✉)
Former Member, Central Ground Water Board, Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India, Faridabad, India

S. Marwaha · S. N. Dwivedi
Central Ground Water Board, Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India, Faridabad, India

© Springer Nature Singapore Pte Ltd. 2019

A. Singh et al. (eds.), *Water Governance: Challenges and Prospects*, Springer Water,
https://doi.org/10.1007/978-981-13-2700-1_3

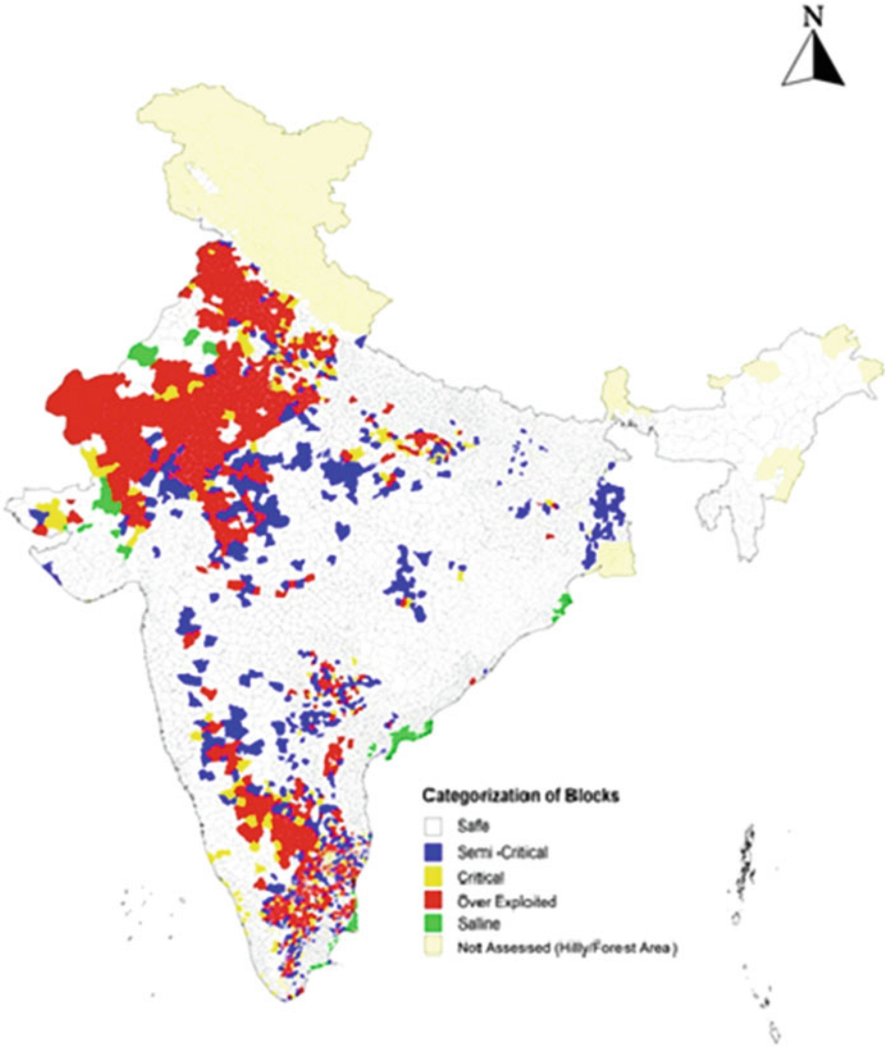


Fig. 1 Distribution of overexploited blocks in India. (After Saha and Ray 2019)

With the ever-increasing water demand fuelled by the spiralling population growth, demand for assured irrigation to achieve higher food grain production coupled with the changing lifestyle of an expanding urban population, a thorough assessment and understanding of the water resources is warranted. The dependence on groundwater is likely to increase further in the coming decades as creation of surface water reservoirs would be constrained owing to several pressing issues like availability of suitable sites, problems related to land acquisition, forest- and land submergence-related issues, etc.

Aquifers are the repository of groundwater. They need to be understood, mapped, measured and monitored for the efficient and optimal use of the available groundwater. Aquifer mapping refers to the entire process by way of which a wholesome understanding of the aquifers is made. It starts with delineating the aquifers in a three-dimensional environment, characterizing their hydraulic parameters and assessing the availability of groundwater resources and its extraction in an aquifer-specific environment along with the possibility of rejuvenating the depleted resources and chemical characters of groundwater. All these are achieved following the well-laid multidisciplinary scientific approach of investigations, data generation, analyses and synthesis. However, the crux lies in managing the groundwater resources in an efficient and sustainable manner. The management practices to enhance the resource availability as well as for its efficient use are required to be quantified and laid. The key challenge is to limit the total extraction of groundwater within the annual recharge, through a combination of demand and supply side interventions. The supply side interventions are primarily artificial recharge and rainwater harvesting, while the demand side interventions are adopting efficient irrigation practice, crop diversification and cropping calendar change, efficient use of water in industries, curbing wastage of domestic water, etc. However, since the irrigation sector consume more than 85% of total groundwater extraction, the focus remains on efficient groundwater use in irrigation sector.

2 History of Hydrogeological Surveys in India

Since its inception in 1972, Central Ground Water Board, the apex Government of India body for groundwater assessment, monitoring and management in India, has produced a series of hydrogeological maps of different scales based on field investigations. The baseline survey carried out during the initial phase was called systematic hydrogeological survey under which the first approximation of the groundwater resource availability in different parts of the country was assessed. Subsequently, the surveyed areas were revisited every 10 years to assess the changes that took place in groundwater regime including the chemical quality through reappraisal hydrogeological survey. The objectives of the study were to delineate groundwater worthy areas and select the areas or sites for drilling of successful tube wells. The aim was to assist the state governments and the stakeholders to develop the aquifers and derive the maximum benefit therefrom. The maps and wide array of information generated on groundwater potential, hydraulic characteristics and chemical quality of groundwater were refined through subsequent surveys and were compiled at the state level to prepare the state hydrogeological report and state groundwater development plan.

2.1 Aquifer Classification in India

The first map on hydrogeology was published by the Geological Survey of India in 1969 under the title 'Geohydrological Map of India' on 1:2 million scale. After

Table 1 Geographical coverage of different principal aquifers in the country

S. No	Principal aquifer system	Area (km^2)	(% of total Area)
1	Alluvium	9,45,754	29.82
2	Laterite	40,926	1.29
3	Basalt	5,12,302	16.15
4	Sandstone	2,60,416	8.21
5	Shale	2,25,397	7.11
6	Limestone	62,899	1.98
7	Granite	1,00,992	3.18
8	Schist	1,40,935	4.44
9	Quartzite	46,904	1.48
10	Charnockite	76,360	2.41
11	Khondalite	32,914	1.04
12	BGC	4,78,383	15.09
13	Gneiss	1,58,753	5.01
14	Intrusives	19,896	0.63

merger of the groundwater wing of GSI with CGWB in the year 1973, CGWB published the 'Hydrogeological map of India' in 1976 on 1:5 million scale followed by its revised edition in 1989. The first edition of the hydrogeological map on 1:2 million scale was published in 1985, and its second edition incorporating the data up to 2001 was published in the year 2002. The state and national level maps were further updated with newer data generated by Central Ground Water Board and State Ground Water Directorates to produce hydrogeological atlas of India on 1:2,50,000 scale (CGWB 2012). This was the first systematic approach to classify the country based on their hydrogeological characteristics using a GIS platform. The country has been divided into 14 principal aquifer systems (Table 1), which is further subdivided into 42 major aquifer systems.

Out of the 14 principal aquifer systems, the largest in expanse is the unit *Alluvium* which denotes the unconsolidated deposits of quaternary age which are either of fluvial, deltaic, lacustrine or Aeolian origin. This unit covers 31% of the geographical area of the country (Fig. 2) and spreads over mainly in the states of Assam, West Bengal, Bihar, Uttar Pradesh, Punjab, Haryana and Rajasthan.

This unit forms the best repository of groundwater and is being extensively exploited depending upon the availability of the resources. Around 35% of the country area is covered by a wide array of hard rock aquifers which includes these aquifer types: gneiss, banded gneissic complex, schists, gneiss, granite-gneiss, quartzites, charnockites, khondalites and intrusives. The aquifer system in these groups are characterized by a two-layered aquifers: a weathered zone (thickness and water holding capacity of which vary as per the aquifer types) underlain by a fractured/jointed aquifer system. The overall groundwater potentiality of aquifers falling in this group is moderate to low and covers a vast swath of central and south India, covering mainly the states of Jharkhand, Chhattisgarh, Madhya Pradesh, Telangana, Andhra Pradesh, Tamil Nadu, Karnataka and Kerala.

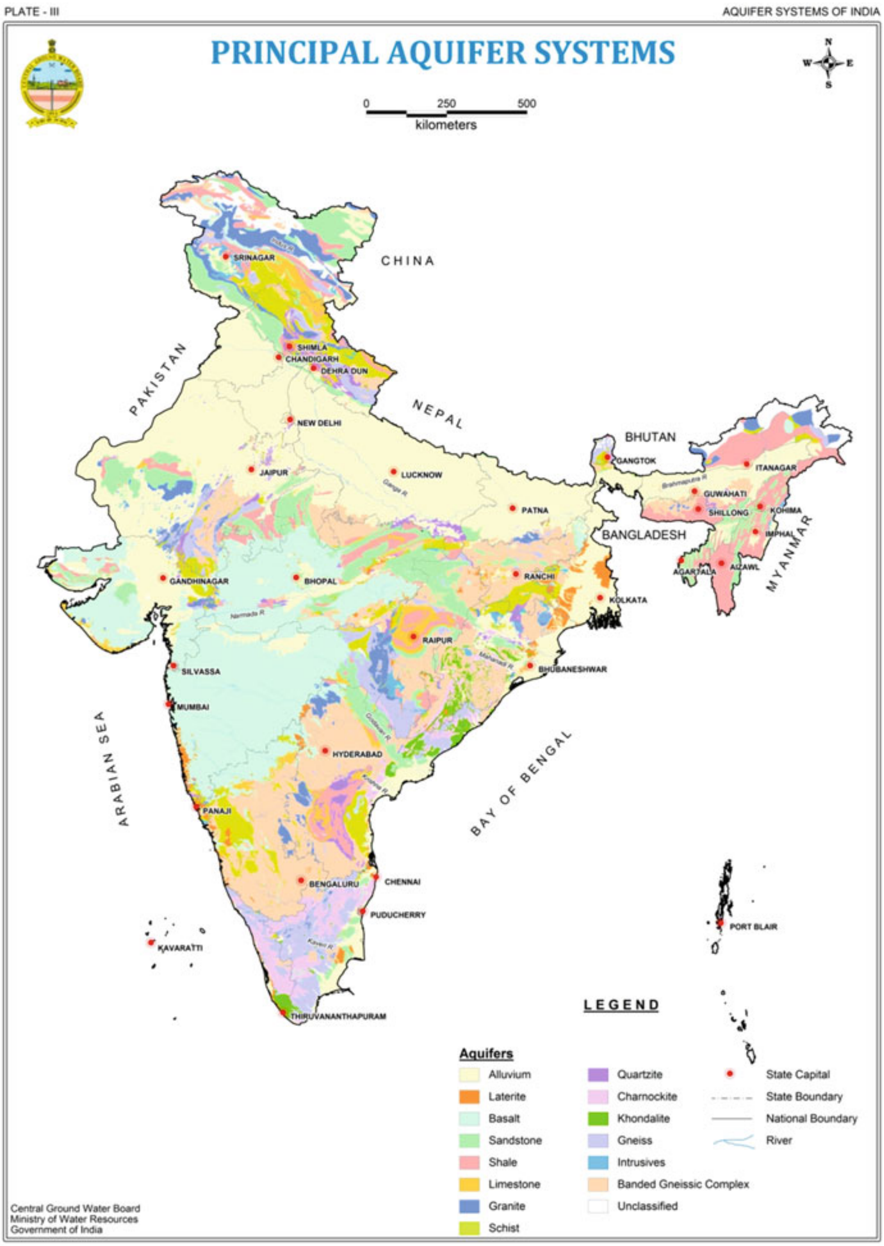


Fig. 2 Principal aquifer systems in India. (After Saha et al. 2016a, b)

The next important principal aquifer system is formed by the Basalts, which hydrogeologically mimics the characteristics akin to the layered alluvial aquifers, yet remains a hard rock aquifer (Saha and Agrawal 2006). In total, it covers ~17% of the total geographical area and is spread over the states of Maharashtra, Madhya Pradesh, Gujarat, Rajasthan and Karnataka. The overall potential of this unit is moderate to low.

Another prominent aquifer type is Shale, which accounts for about 7% area of the country and is available mostly in Chhattisgarh, Andhra Pradesh, Madhya Pradesh, Rajasthan and in north- eastern states as well as in Himalayan states. The overall aquifer potential is low to moderate; however, depending upon the consolidation and diagenesis of the sediments, the aquifer potential may increase to moderate to high. Limestone aquifer possesses the unique character of holding substantial volume of water in solution cavities. However, this unit covers only 2% of the geographical area and spreads over parts of Chhattisgarh, Andhra Pradesh, Karnataka, Gujarat and the Himalayan states.

3 Aquifer Mapping and Management Programme (NAQUIM)

The ambitious Aquifer Mapping and Management programme, often referred to as Aquifer Mapping in short, was launched in the year 2012 by the Central Ground Water Board (CGWB), under the Ministry of Water Resources, River Development and Ganga Rejuvenation during the 12th Five-Year Plan period (2012–17). The initial analysis reveals that out of 32 lakh km^2 area of the country, mapping is required in 25.9 lakh km^2. In these parts, the aquifer parameters are such that the aquifers can be exploited provided groundwater resource is available in them and/or groundwater resource can be rejuvenated by artificial recharge and rainwater harvesting.

3.1 Pilot Studies on Aquifer Mapping

To initiate the NAQUIM programme, CGWB had taken up six Pilot Aquifer Mapping in different hydrogeological terrains spread across the country as below:

1. Alluvial deposits of the Gangetic Plains, Bihar state (AQBHR)
2. Thin alluvial deposits underlying hard rocks, Rajasthan state (AQRAJ)
3. Basaltic rocks, underlain by Gondwana rocks, Maharashtra state (AQMAH)
4. Precambrian hard rocks, Karnataka state (AQKAR)
5. Coastal sediments, Tamil Nadu (AQTND)
6. Aeolian deposits in desert, Rajasthan state (AQDRT)

The location of the pilot study areas is shown on the map depicting the broad hydrogeological framework of the country, delineated on the basis of yield potential of the broad hydrogeological units (Fig 3).

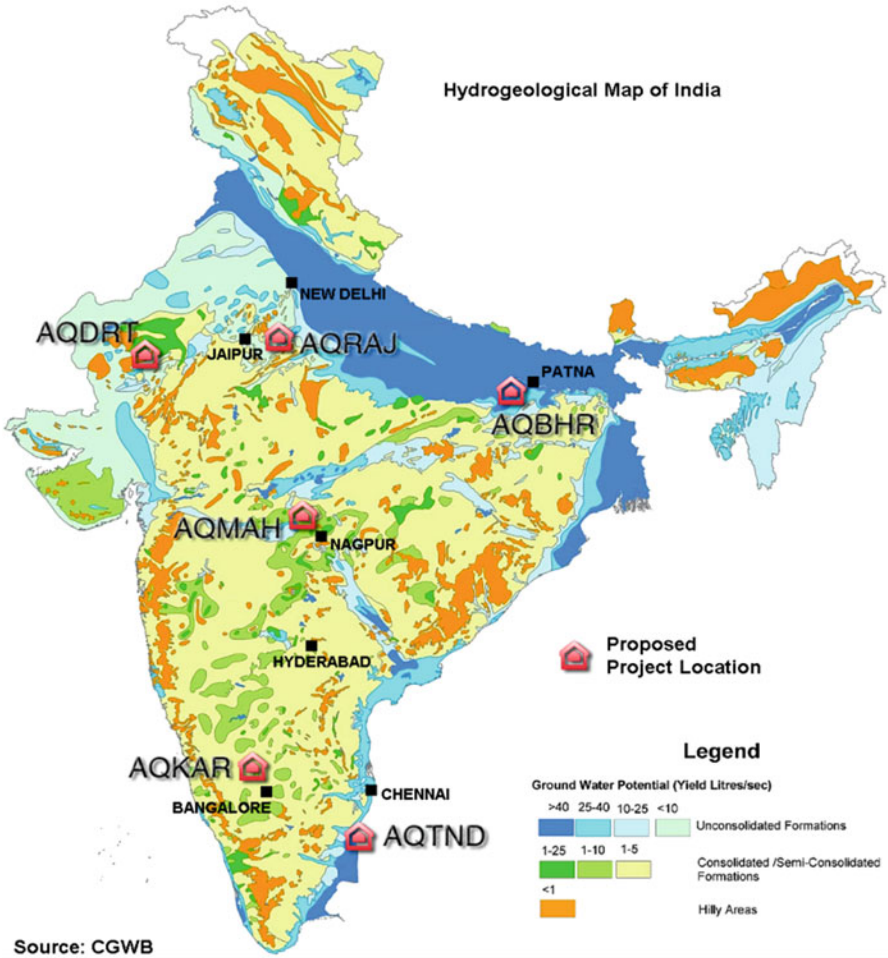


Fig. 3 Location of areas under pilot aquifer mapping. (Ahmed 2014)

The AQBHR represent prolific aquifer system of Indo-Gangetic-Brahmaputra Alluvial System. The AQRAJ represents the marginal alluvial-aeolian aquifers underlain by hard rocks with moderate rainfall, while AQDRT represents an aquifer system deep in the desert areas of Rajasthan. The AQMAH represents a typical trap aquifer underlain by semi-consolidated aquifers of Gondwana rocks, while AQKAR represents the low potential gneissic-granitic-schists-intrusive aquifer combination. The AQTND stands for the good potential coastal aquifers, where a delicate balance exists between freshwater from land and saline water wedge from sea. The objective of the pilot aquifer mapping was to carry out a detailed mapping of aquifers in the selected representative hydrogeological typologies through application of the state-of-the-art investigation techniques like transient electromagnetic, electrical resistivity tomography, heli-borne dual-moment electromagnetic survey, stable and radioactive environmental isotopes and groundwater flow modelling. Usefulness and applicability of different techniques in different areas have also been studied and protocols developed for applying such techniques at the national level. Each of the area selected for the pilot study represents different hydrogeological framework and groundwater regime behaviour. A brief description of the pilot study areas and the salient findings are given below.

3.1.1 AQBHR Bihar State

About 520 km^2 is covered in Maner area of Patna district located in the interfluve of the Sone and the Ganges Rivers (CGWB 2015e). This area represents a type of area of the Indo-Gangetic-Brahmaputra Alluvial Plain holding some of the most potential aquifer systems of the world (Saha et al. 2016a, b). The area is hugely groundwater dependent, and arsenic contamination has been reported from some parts. The study revealed multi-tier aquifer systems made up of quaternary sand within 300 m below ground. The deeper aquifer system is hugely exploited in Patna urban area, located in the study area, apart from excessive dependence on groundwater for meeting the requirements for rural drinking and irrigation purpose (Saha et al. 2014; Dwivedi and Singh 2015; Dwivedi et al. 2015). The recommendations include decongesting the heavy-duty deep tube wells from the urban area to the adjoining demarcated areas with equally prolific aquifers, tapping confined deeper aquifers for potable water supply in arsenic-contaminated areas and recharging the depleted deeper aquifers of Patna Urban area, which are exposed to the surface through a network of palaeochannels, at the southern part of the study area.

3.1.2 AQRAJ Rajasthan State

Located in the deep Thar Desert in Ramgarh area, Jaisalmer district, the study are spread over ~675 km^2 (CGWB 2015c). The aquifers are mainly sedimentary rocks of calcareous-argillaceous-arenaceous nature of Tertiary and Mesozoic era. Aquifers are encountered at the depths of 45–70 m and 125–160 m holding brackish water (EC 3500–4000 micromhos/cm). Groundwater level varies from 30 to beyond 100 m bgl at places. The area (some block as a whole) has been categorized under safe category, primarily because of very limited extraction of groundwater. The annual groundwater recharge is ~ 3.44 mm/year constituting only 2% of the annual rainfall (146 mm). Even this meagre resource is brackish in nature due to intrinsic property of the rock formations, thus rendering it unsuitable for use. The management interventions proposed in the desert project area are:

a) Upscaling the traditional water harvesting system in the area.
b) Along the Indira Gandhi Nahar Pariyojna (IGNP) canal, freshwater pockets are formed due to seepage from the lined canal which often leads to waterlogging

situation. In such areas, controlled use of groundwater can help mitigate the water crisis.

3.1.3 AQMAH Maharashtra State

An area of 360 km^2 has been taken up in Chandrabhaga watershed of ephemeral Chandrabhaga River in Nagpur district (CGWB 2015d). The major part is occupied by Deccan Trap basalt (313 km^2) of 60–195 m thick, while about 47 km^2 is occupied by Gondwana formation of Permian age. The area receives a normal annual rainfall of 980 mm. Major part of the watershed is having depth of weathering in the range of 3–6 m. Groundwater in Aquifer I generally occurring in the depth range of 20–30 m occurs under unconfined conditions, and in major part of the area, it is occupied by basaltic formation except in the north-eastern part where it is formed of Gondwana Supergroup. Aquifer II which generally extends beyond 30 m bgl is semi-confined to confined in nature. Aquifer III occurs in the Gondwana sediments underlying the trap. The stage of groundwater development is about 80%, and groundwater is mainly used for irrigation purpose (about 5368 ham) out of total draft of 5545 ham. Considering the low potential of the aquifers, the Aquifer Management Plan suggests adoption of unconventional measures like fracture seal cementation (FSC), hydro-fracturing, well jacketing (WJ), borewell blasting technique (BBT), etc. besides taking up normal water harvesting in the area. Model-based evaluation indicates that construction of check dam on Chandrabhaga River would lead to improvement of groundwater availability by 0.29 mcm. Another model-based scenario indicates that construction of 25 recharge wells would enhance annual groundwater recharge by 1.12 mcm.

3.1.4 AQKAR Karnataka State

Ankasandra watershed drained by Torehalla stream of Tumkur district spreading over 375 km^2 was selected for the pilot study (CGWB 2015f). The area receives about 680 mm rainfall, while the potential evapotranspiration is more than 1500 mm annually. The area is underlain by hard rocks of Achaean age. The water level is deep and at places is even more than 100 m bgl witnessing a continuously declining trend. The fractured aquifers below the weathered zone, albeit low yielding (3.6–7.2 m^3/hour), are heavily exploited. Gross groundwater draft for all uses is 3729 ham against a recharge of 1988 ham. However, the extraction is not uniform throughout the watershed, and in some of the villages, there is still scope for further development. Model-based estimate indicates that the available sub-surface storage space for recharging the aquifers so as to raise the groundwater level up to 10 m bgl is 6,39,345 ham. However, in view of the unavailability of surplus water for recharge, it is recommended to import source water from the adjoining areas and recharge them primarily through desilting of existing tanks.

3.1.5 AQTND Tamil Nadu

The study area (428 km^2) falls in Lower Velar Watershed, Cuddalore district (CGWB 2015a). The aquifer consists of regionally extensive sandstones that crop out within the Cuddalore aquifer system which holds huge lignite deposit. The area has following issues:

a) Heavy and continuous groundwater withdrawal for irrigation
b) Depressurized hydraulic heads for safe mining of lignite since 1955
c) Groundwater withdrawal for drinking water supply to Chennai City during lean periods from coastal areas
d) Threat of seawater intrusion in the event of reversal of hydraulic gradient or by upconing

Four highly potential aquifer systems have been demarcated with present annual groundwater withdrawal of 1213.58 mcm, which is presently safe with no threat of sea water intrusion. However, reversal in hydraulic gradient and consequently sea water intrusion may take place if total annual groundwater extraction exceeds 525 and 700 mcm/yr for Aquifer I (at the top) and Aquifer II, respectively. The present annual groundwater withdrawal from Aquifer III from which considerable pumping (120.8 mcm/yr) is taking place for lignite mining, the safe limit is 500 mcm/yr. Aquifer IV, the deepest, has present pumping of 12.79 mcm/yr mainly for Chennai water supply which can be increased to 550 mcm/yr.

3.1.6 AQDRT Rajasthan

The area covers around 600 km^2 in Baswa-Bandikui watershed forming a part of the Banganga river basin in Dausa district (CGWB 2015b). The area is categorized as ‘overexploited’. The area receives an annual rainfall of about 660 mm. Broadly two aquifer systems are identified: upper aquifer consists of unconsolidated alternate horizons of clastic sediments like fine- to medium-grained sand, alternating with finer-grained sediments like silt, silty clay and clay. The underlying hard-rock aquifer comprises a slice of weathered zone and lower fractured/crystalline hard rock including quartzites, gneisses, schists and phyllites. The upper aquifer ~60 m thick is heavily exploited and almost gets completely desaturated during the pre-monsoon period (Chatterjee et al. 2018). Groundwater flow modelling forecasts that the present rate of development would lead to drying up of the aquifers. A modelled scenario with a feasible artificial recharge plan shows improvement of groundwater situation in the study area. The recommendations include:

a) Notification of the Bandikui block for the purpose of groundwater regulation.
b) Artificial recharge to groundwater through suitable structures.
c) Use of water efficiency measures like sprinkler and drip irrigation.

3.2 National Coverage of NAQUIM

The learning of the pilot aquifer mapping was assimilated to take forward the NAQUIM programme nationwide. As per the approved plan of the Government of India, out of ~25 lakh km^2 mappable area of the country, 8.89 lakh km^2 were to be covered during 2012–2017.

There are four broad sets of activities under the NAQUIM programme:

a) *Data Compilation and Data Gap Analysis*: Synthesis of existing data collected from various agencies. The useful data were selected and placed in a GIS platform. Available data was compared with the data requirement as per the laid down guidelines for different hydrogeological-type areas through data gap analyses. The quantum of the data to be generated for various work items was determined.
b) *Data Generation and Integration*: Large array of data were generated by multiple activities such as (i) preparation of lithological log by analysis of drill cut samples from exploratory drilling and geophysical well logging and preparation of geological section to delineate aquifer using lithological log; (ii) determination of hydraulic parameters of aquifers by pumping test; (iii) analysis of groundwater samples for chemical and isotopic composition; (iv) digital analyses of remotely sensed data; (v) geophysical surveys like vertical electrical sounding survey, heli-borne dual-moment electromagnetic survey, transient electromagnetic survey and electrical resistivity tomography; (vi) aquifer-specific water levels; (vii) soil infiltration test and slug test; and (vii) groundwater draft assessment for different formations and aquifers. Upon integrating the data, the aquifer geometry is firmed up by building hydrogeological sections. The aquifers are attributed hydraulic properties, chemical quality, specific water levels, infiltration and percolation capacity, etc.
c) *Aquifers Map Preparation*: The delineated aquifers are characterized in terms of quality, yield potential as well as sustainability for yield. Delineating principal aquifer, contaminated aquifers, aquifers under stress, recharge mechanism and capacity of the aquifers, etc. The replenishable and in-storage resource estimated for different aquifer systems. The spatiotemporal behaviour hydraulic head in aquifer-specific environment is also established.
d) *Aquifers Management Plan Formulation*: Sustainable management of groundwater resources with demand and supply side interventions. Quantification of different contemplated interventions. Plan for artificial recharge and possibility of alternate aquifer-based water supply in contaminated areas. Plan for development in groundwater surplus areas.

Initial data analyses revealed that a considerable data gap exists in several parts of the country, for which substantial data is to be generated if timeline of achieving the programme targets is to be adhered. Data generation is required particularly in the field of drilling and construction of wells, conducting pumping tests, geophysical studies and chemical analyses of water samples. As the volume of data required is beyond the existing capacity of CGWB, it necessitates the requirement of large-scale outsourcing through private and PSU's participation as well as roping in research and academic institutes. In view of these limitations, the target for 2012–2017 was reprioritised from 8.89 lakh km^2 to 5.25 lakh km^2, targeting the overexploited areas of the country in addition to the Bundelkhand region covering the states of Madhya Pradesh and Uttar Pradesh.

3.3 Institutional Arrangement

To lay the roadmap and provide guidance in executing the programme along with monitoring the progress at the highest level, a *National Inter Departmental Steering Committee* (NISC) has been constituted. NISC is headed by the secretary of MOWR RD & GR, where the central government departments directly or indirectly involved in groundwater and the relevant state departments are also member. In Central Ground Water Board, a *Project Management Unit* (PMU) is formed under the leadership of the member (HQ) to coordinate the execution of the programme through regional offices, as well as to plan and monitor the progress. At the central level, for technical evaluation of the programme outputs, a *National Level Technical Evaluation Committee* (NLEC) has been constituted with domain experts. Considering the important role of the states in taking forward the outputs of the programme, *State Ground Water Coordination Committees* (SGWCC) have been formed in each state headed by the principal secretary of the related department to evaluate the outputs and lay the roadmap for implementing the plans.

Success of the programme warrants involvement of several departments through sharing of data and maps. Agreements have been made with Survey of India and Geological Survey of India for the required toposheets and geological maps. The soil maps and land use geomorphological lithological maps are being obtained from National Bureau of Soil Survey and Land Utilisation Planning and National Remote Sensing Centre. The isotope analyses are being done through Bhabha Atomic Research Centre and National Institute of Hydrology. For groundwater flow simulation through mathematical modelling, it is proposed to rope in the academic institutions with requisite expertise. To begin with, the IIT Kanpur and IISc Bangalore have been involved.

4 Outputs and Achievement under NAQUIM

As part of the programme, an area of 6.31 lakh km^2 has been covered till March 2017. The initial target area for 2012–2017 of 8.89 lakh km^2 was reprioritized to 5.26 lakh km^2 including pilot areas, in view of the rapidly deteriorating groundwater scenario of the country. The focus was given to water-stressed areas in the states of Haryana, Punjab, Rajasthan, Gujarat, Tamil Nadu, Telangana and Bundelkhand

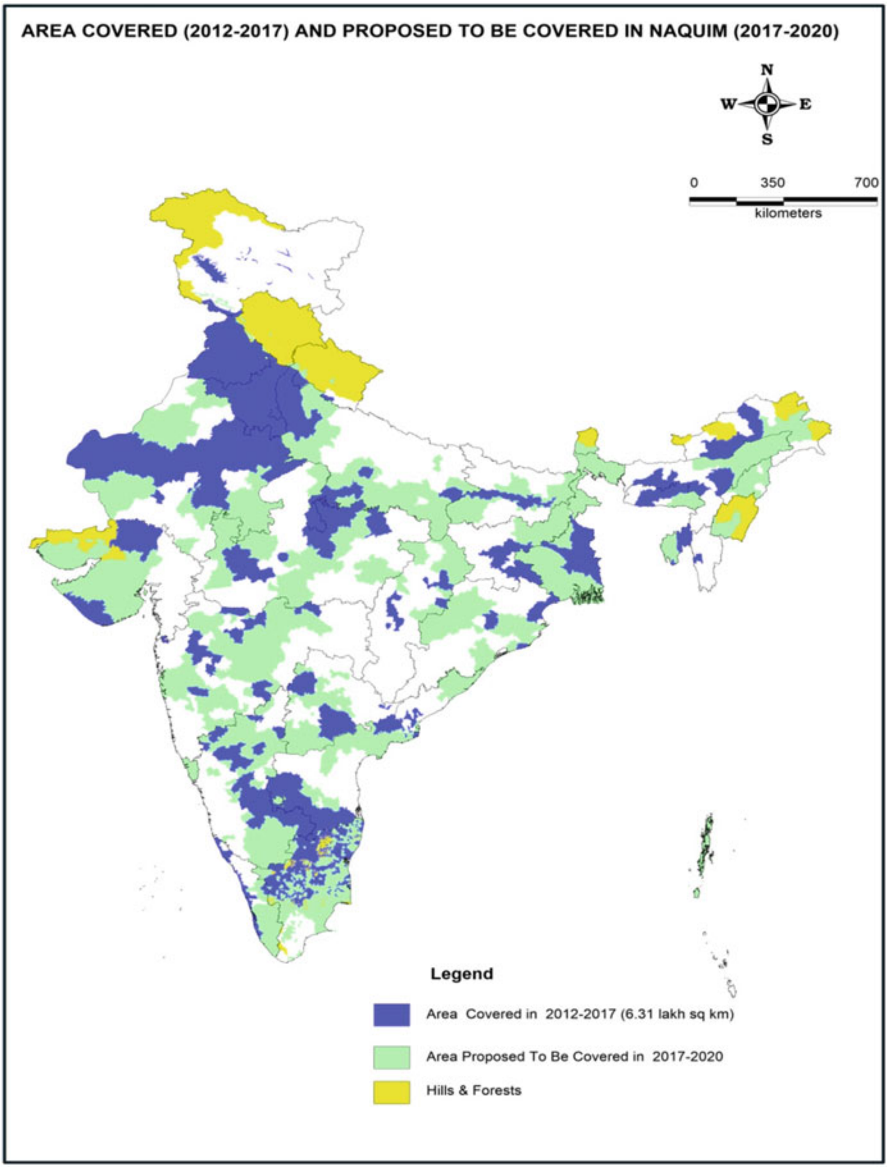


Fig. 4 Areas covered under NAQUIM Programme till March 2017 and proposed to be covered during 2017–2020

regions in Madhya Pradesh and Uttar Pradesh. Up to March 2017, 6.31 lakh km^2 has been covered, out of which 4.64 lakh km^2 lies in the demarcated prioritized areas, and the remaining 1.67 lakh km^2 is from the remaining parts of India (Fig 4, Tables 2 and 3).

Table 2 State wise area covered from the Priority areas

S. No	State	Mappable area (km^2)	Area under priority investigation	Area covered till March, 2017	Number of OE units covered by 2017
1	Andhra Pradesh	130769	28379	39141	44
2	Telangana	103900	26429	22328	7
2	Gujarat	159277	34768	31522	17
3	Haryana	44179	44179	44179	64
4	Karnataka	170703	48294	48311	32
5	Bundelkhand region	66193	66193	27484	9
6	Punjab	50362	50362	50362	105
7	Rajasthan	268378	166911	143275	98
8	Tamil Nadu	104635	45766	45339	314
9	NCR (UP and Delhi)	12283	12283	12283	37
	Total	**11,10,679**	**5,23,564**	4,64,224	**718**

The programme has translated into a number of success stories where the outputs have been adopted and implemented by the stakeholder departments. This unique programme has steered a holistic understanding of the aquifer system and offers a key to managing the precious groundwater resources. The newer insights obtained through programme are:

- **Static resource rapidly diminishing in some prolific aquifers:** Steepening of the declining trend in water levels of some of the prolific aquifer system in North West India, in the states of Punjab and Haryana. This reveals that the annual extraction is outstripping the annual recharge leading to situation of groundwater mining. Such aquifers are to be accorded the highest priority so that groundwater pumpage is reduced significantly coupled with water use efficiency measures so that management of these aquifers can be undertaken in a holistic way.
- **Large aquifer systems can be recharged in an integrated manner:** Traditionally, the recharge efforts in India are disintegrated and specific area centric. Systematic attempt towards large-scale integrated recharge should be taken up in hydrogeologically suitable area, with economic scenario and environmental consideration. Tapi Mega Recharge project benefitting Maharashtra and Madhya Pradesh states is one such big effort to mention, in this direction.
- **Artificial recharge is not an all-weather solution applicable everywhere:** Exemplified by alluvial aquifers in Kurukshetra district of Haryana and Ahmedabad district of Gujarat underlain by hard rock aquifers, demand side managements like crop diversification, micro-irrigation, and laying underground pipelines in place of open channels contribute more in improving the dismal scenario. Scanty source water availability would hinder any large-scale adoption

Table 3 State-wise area covered other than priority areas

S. No	State	Mappable area (km^2)	Area covered till March, 2017	Number of OE and critical units covered by 2017
3	Arunachal Pradesh	5461	1965	0
4	Assam	62194	6179	0
5	Bihar	90567	9607	0
6	Chhattisgarh	96000	10619	1
3	Dadra and Nagar Haveli	416	490	0
12	Jammu and Kashmir	9825	8220	0
13	Jharkhand	58417	17693	4
15	Kerala	28088	5200	1
5	Lakshadweep	26	32	0
16	Madhya Pradesh	269746	28080	9
17	Maharashtra	259914	31418	9
18	Manipur	2559	155	0
19	Meghalaya	2758	1627	0
21	Nagaland	2522	400	0
22	Orissa	119728	10193	0
6	Puducherry	463	293	1
27	Tripura	6198	559	0
28	Uttar Pradesh	240928	24401	37
29	Uttarakhand	4993	2811	0
30	West Bengal	71947	8008	0

of artificial recharge in areas of low rainfall and resultant low availability of noncommitted surface water.

- **Protection strategy for arsenic-safe deeper aquifers in the Gangetic plains**: It is well established that the deeper aquifers in the Ganges Basin are free from contamination (Saha 2009; Saha et al. 2010). They are being delineated all along the alluvial patches of the basin. But to keep the lower aquifer arsenic-free, regulated pumping of deeper arsenic safe aquifers should be adopted. In addition to that keeping safe distance between the wells would also help in protecting the arsenic safe zones from the threats of leakance- induced cross-contamination.

5 Conclusion

Aquifer Mapping and Management programme launched in India in the year 2012 is dedicated to the cause of scientific management of our groundwater resources. Protection, preservation, and augmentation strategy for our groundwater resources occurring in the aquifers under different hydrogeological environment calls for a wholesome understanding of the groundwater system. There can't be a one size fits all approach for tackling the groundwater problems owing to the inherent heterogeneity and anisotropy associated with the natural groundwater system, different level of groundwater extraction and contamination affecting various areas. Aquifer appropriate and aquifer-specific action plans for management which is being framed as an output of the NAQUIM programme can help mitigate the groundwater-related issues. The strategy of demand management and supply augmentation or a combination of both with varying weightage will have different results under different hydrogeological conditions and the prevailing stress levels in the aquifers, and therefore the outputs of the NAQUIM are unique and indispensable from the aquifer management point of view. The two important aspects to the success of this programme are (i) scientific part which depends on the accuracy of the data and its meticulous use to prepare the aquifer maps and management plans and (ii) the implementation part which depends on the involvement of the states and various stakeholders including the communities.

Acknowledgements The authors extend their sincere thanks to the chairman of Central Ground Water Board and Member Head Quarter for their valuable guidance and support and agreeing to incorporate the figures/data for this article. Thanks are extended to all members and RD of CGWB for their untiring support during the preparation of this manuscript. The views expressed in the paper are of the authors and not of the department.

References

Ahmed S (2014) A new chapter in groundwater geophysics in India: 3D aquifer mapping through Heliborne Transient Electromagnetic Investigations 84: 501. https://doi.org/10.1007/s12594-014-0156-5

Chatterjee R, Jain AK, Chandra S, Tomar V, Parchure PK, Ahmed S (2018) Mapping and management of aquifers suffering from over-exploitation of groundwater resources in Baswa-Bandikui watershed, Rajasthan, India. Environ Earth Sci 77(157)

Central Ground Water Board (2012) Aquifer Systems of India, Ministry of Water Resources River Development and Ganga Rejuvenation, Govt of India. Available at www.cgwb.gov.in

Central Ground Water Board (2015a) Pilot project report on aquifer mapping in Lower Vellar Watershed, Cuddalore district, Tamil Nadu, Ministry of Water Resources River Development and Ganga Rejuvenation, Govt of India. Available at www.cgwb.gov.in

Central Ground Water Board (2015b) Pilot project report on aquifer mapping in Baswa-Bandikui area, Dausa district, Rajasthan, Ministry of Water Resources River Development and Ganga Rejuvenation, Govt of India. Available at www.cgwb.gov.in

Central Ground Water Board (2015c) Pilot project report on aquifer mapping in Thar Desert, Jaisalmer district, Rajasthan, Ministry of Water Resources River Development and Ganga Rejuvenation, Govt of India. Available at www.cgwb.gov.in

Central Ground Water Board (2015d) Pilot project report on aquifer mapping in Chandrabhaga Watershed, Nagpur district, Maharashtra, Ministry of Water Resources River Development and Ganga Rejuvenation, Govt of India. Available at www.cgwb.gov.in

Central Ground Water Board (2015e) Pilot project report on aquifer mapping in Maner-Khagaul area, Patna district, Bihar, Ministry of Water Resources River Development and Ganga Rejuvenation, Govt of India. Available at www.cgwb.gov.in

Central Ground Water Board (2015f) Pilot project report on Aquifer Mapping in Ankasandra watershed, Tiptur and C.N. Halli talukas, Tumakuru district, Karnataka, Ministry of Water Resources River Development and Ganga Rejuvenation, Govt of India. Available at www.cgwb.gov.in

Central Ground Water Board (2017) Dynamic ground water resources of India as on March 2013, Ministry of Water Resources River Development and Ganga Rejuvenation, Govt of India. Available at www.cgwb.gov.in

Dwivedi SN, Singh RK (2015) Inter-aquifer water transfer through combination well for artificial recharging of the deeper aquifer system in Patna urban area. Curr Sci 108(7):1219–1221

Dwivedi SN, Shukla RR, Singh R, Adhikar SK, Purty SS, Roy GK (2015) Determining the recharging capacity of an injection well in a semi-confined alluvial aquifer. Curr Sci 109 (6):1177–1181

Mukherjee A, Saha D, Harvey CF, Taylor G, Ahmed KM, Bhanja N (2015) Groundwater systems of the Indian Sub-Continent. J Hydrol Reg Stud. https://doi.org/10.1016/j.ejrh.2015.03.005

Saha D (2009) Arsenic groundwater contamination in parts of middle Ganga plain, Bihar. Curr Sci (6):97

Saha D, Agrawal AK (2006) Determination of specific yield using water balance approach- a case study of Torla Odha water shed in Deccan Trap Province, Maharashtra State, India. Hydrogeol J 14:625–635

Saha D, Chandra PC, Sahu S (2010) Arsenic-safe alternate aquifers and their hydraulic characteristics in contaminated areas of Middle Ganga Plain, Eastern India. Environ Monit Assess. https://doi.org/10.1007/s10661-010-1535-z

Saha D, Dwivedi SN, Singh RK (2014) Aquifer system response to intensive pumping in urban areas of the Gangetic plains, India: the case study of Patna. Environ Earth Sci 71(4):1721–1735

Saha D, Shekhar S, Ali SR, Vittala SS, Raju NJ (2016a) Recent hydrogeological research in India. Proc Indian Natl Sci Acad 82(3):787–803

Saha D, Zahid A, Shrestha SR, Pavelic P (2016b) Ground water resources in the Ganges River Basin. In: Bharati L, Sharma BR, Smakthin V (eds) The Ganges river basin: status and challenges in water, environment and livelihoods. Routledge, Oxon, UK. isbn:978-1-138-90032-5

Saha D, Marwaha S, Mukherjee M (2017) Groundwater resources and sustainable management issues in India. In: Saha D, Marwaha S, Mukherjee M (eds) Clean and sustainable groundwater in India. Springer, Singapore. https://doi.org/10.1007/978-981-10-4552-3_1. isbn:978-981-10-4551-6

Saha D, Ray RK (2019) Groundwater resources of India: potential, challenges and management. In: Sikdar P (ed) Groundwater development and management. Springer, Cham. https://doi.org/10.1007/978-3-319-75115-3_2. isbn:978-3-319-75115-3

Dipankar Saha is a former member (Headquarters) Central Ground Water Board, under Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India. He had also acted as the member secretary, Central Ground Water Authority and head of National Ground Water Training and Research Institute, Raipur. He spearheaded the National Aquifer Mapping and Management Programme, the largest groundwater mapping endeavour in the world, as National eCoordinator. He obtained his PhD on groundwater management from IIT-ISM, Dhanbad. He has authored more than 50 papers in international peer-reviewed journals and delivered more than 300 lectures and keynote address in national and international seminars. He is professionally trained from the Asian Institute of Technology, Bangkok, and from JICA, Tokyo. He represented the country in World Bank session at Kathmandu; International Atomic Energy Agency at Ho Chi Minh City and Vienna; World Water Week, Stockholm; and India-UK Water Security Exchange,

Wallingford, Oxfordshire, and led the Government of India Delegation to Myanmar. He remained member of many high-level national committees and has edited/co-edited five books/journals; the recent one is *Clean and Sustainable Groundwater in India* by Springer. He is the recipient of the National Geoscience Award 2010 conferred by the Ministry of Mines and Excellence in Ground Water conferred by the Indian Chapter of International Association of Hydrogeologist in 2014. He is presently the secretary of the Indian Chapter of International Association of Hydrogeologist.

Mr. Sanjay Marwaha is working as Regional Director of Central Ground Water Board, Government of India. He completed his postgraduate studies at Panjab University, Chandigarh, and was awarded university medals for standing first in class both in his undergraduate and postgraduate studies. He had taken courses on groundwater management, geographic information system and remote sensing trained at ITC, Netherlands. During the past 30 years of experience, he is credited with a number of studies related to various facets of groundwater specially managed aquifer recharge in parts of semiarid areas of country. He has been associated with compilation of five volumes issued by the Government of India on various topics such as Groundwater Recharge Techniques, Perspective Plan of Groundwater Resources of India, Master Plan for Artificial Recharge in India and Punjab Water Quality Issues and Challenges. He has also authored more than 40 publications in national and international forums on various aspects of hydrogeology. Currently he is associated with one of the most ambitious projects ever taken for mapping of aquifers of India.

S. N. Dwivedi scientist C, Central Ground Water Board, Government of India, has over 14 years' experience in hydrogeological surveys, groundwater exploration, pollution studies, resource assessment and management of groundwater resources in different parts of states of Bihar and Jharkhand and north-eastern states of India. Has authored/co-authored over 25 papers in international/national journals/seminars and conferences and participated and presented paper in World Water Week 2011 at Stockholm. Main research interests include sustainability of aquifers, geogenic contamination, groundwater modelling and application of isotopic techniques in groundwater investigations. He was awarded Gold Medal by Rajiv Gandhi National Groundwater Training and Research Institute, ILTC Batch 2003–2004, and Smt Savitri Chadha Memorial Young Scientist Award for Ground Water Studies for the year 2017 by Indian National Committee of International Association of Hydrogeologist.

Managing and Sanctifying Water Bodies

Vinod Tare

1 Introduction

Increasing use of fossil fuels and minerals has propelled global economic growth in the industrial age. But ever-increasing industrial production often implies the release of harmful wastes into the environment. Moreover, increase of such industrial production fuels the demand for other natural resources such as land, water and biotic resources as well as the release of even more pollutants from their consumption. Taken together, these factors cause major environmental disturbances, and their cumulative impacts can devastate the very ecosystems on which the life of a nation is crucially dependent. Primary among such vulnerable ecosystems in India are its water bodies. And India, like many other developing countries of the world, is saddled with the unenviable task of saving its rapidly degrading water bodies for the country's long-term productivity without compromising her immediate growth prospects.

The key to understanding the benefits and harms that we are exposed to in a changing production-consumption environment is the ecosystem concept. An ecosystem is a part of the biosphere comprising a dynamic interrelationship of animal, plant and microorganism communities and the hosting nonliving environment with seamless interaction among them as a functional unit. The ecosystems extend various services that are beneficial to people. The services include *provisioning services* or *products* (such as water, food, fibre and energy), *regulating services* (e.g. flood regulation, droughts, land degradation, diseases and microclimate, groundwater recharge, water purification, silt dispersal and prevention of salt water intrusion), *supporting services* (e.g. soil generation, nutrient cycling and distribution

V. Tare (✉)
Environmental Engineering and Management, Department of Civil Engineering, IIT Kanpur, Kanpur, Uttar Pradesh, India
e-mail: vinod@iitk.ac.in

© Springer Nature Singapore Pte Ltd. 2019

A. Singh et al. (eds.), *Water Governance: Challenges and Prospects*, Springer Water,
https://doi.org/10.1007/978-981-13-2700-1_4

and biodiversity maintenance) and *cultural services* (such as spiritual, aesthetic and recreational services). The aforesaid services contribute to better living conditions for us by way of basic material for a good life, health, freedom and choice, amicable social interaction and security (UN Water 2013; Smith and Barchiesi 2009; MEA 2005).

In India, humans have been an integral part of ecosystems for millennia, but in modern times – in particular, in the past several decades – many of its diverse ecosystems have been exploited so rapidly that they have degraded en masse. Not only that, some of them have become extinct altogether while others have become gravely threatened. And, hence, the vital life-supporting services provided by these ecosystems are enormously reduced even as our material consumption has increased manyfold. Our water bodies are no exception to this phenomenon, and it is imperative that institutional measures are urgently initiated to save and revive our remaining water bodies in order to secure our future. Otherwise, the vital services that they provide us with can become so scarce that no amount of industrial products could conceivably compensate for them.

2 Main Threats to Water bodies in India

India's water bodies – surface water bodies (rivers, lakes, ponds, marshlands, estuaries, etc.) and aquifers– have provided a secure basis to our civilizational achievements all through history. But they have been seriously impacted in the modern age by inappropriate domestic, industrial, agricultural and sociocultural activities. The basic problems are all too well-known but need to be reiterated here for the importance they deserve. A key problem behind the degradation of our water bodies is the gross overextraction of water from them, thereby shrinking or decimating these ecosystems. Another widespread problem that has extensively degraded our aquatic ecosystems is the despoiling of their water quality by indiscriminate pollutant and waste discharges into them.

Both the above factors are widely known in India. However, less often emphasized as a third major factor that severely affects our water bodies (as well as other ecosystems) is that of encroachment (apart from the direct structural interventions made in them like dams, barrages, bridge piers and embankments). The problem of land encroachment is often overlooked, but its importance cannot be overstated. Increasing human activity in areas that intrinsically belong to surface water bodies (that is including their riparian areas and floodplains) is a major cause for their degradation. This problem can be easily grasped from a broader perspective, namely, that as compared to the rest of the world, India is not as critically deficient in water as it is in terms of land. For, as is often noted by government agencies, about 4% of world water resources remain in India, with 17% of the globe population squeezed in the country which covers only 2.4% of the world's land mass (Ministry of Agriculture 2014; MoWR 2008). Obviously, therefore, India's land constraint is much more critical than that of water in global terms. Hence human demands on land can be expected to be much more critical in India than that of water. Moreover land, unlike water, is not a renewable resource. Hence over-exploitation of land will have much longer-term repercussions on aquatic ecosystems.

India's land constraints also affect our water bodies in other ways than by direct land encroachment. Thus, increasing conversion of forested areas and grazing pastures to agricultural land and similar conversion of fallow land to built-up areas adversely affects the hydrological regime and perhaps even the rainfall regime in a basin (IITC 2015a). Besides they reduce the ecosystems' capacities for primary production and regulation of floods, droughts, water purification, etc. Thus short-sighted land-use changes in our river basins inexorably contribute to the deteriorating state of our water bodies.

There are, of course, additional anthropogenic factors that adversely affect our water bodies, such as overexploitation of biotic resources, silt and energy from them and the introduction of exotic aquatic species. Such factors, too, have significantly contributed to the overall deterioration of our water bodies.

3 Assessing and Quantifying Sources of Pollution

Various types of anthropogenic wastes are generated in India as shown in Fig. 1 (IITC 2015b). Two broad types of wastes, whose improper disposal adversely impacts the quality of our water bodies, are (1) liquid wastes and (2) solid wastes. There are two types of solid waste, (1) hazardous and (2) non-hazardous. Domestic, commercial and agricultural activities generate non-hazardous waste, while industrial activity generates non-hazardous as well as hazardous waste.

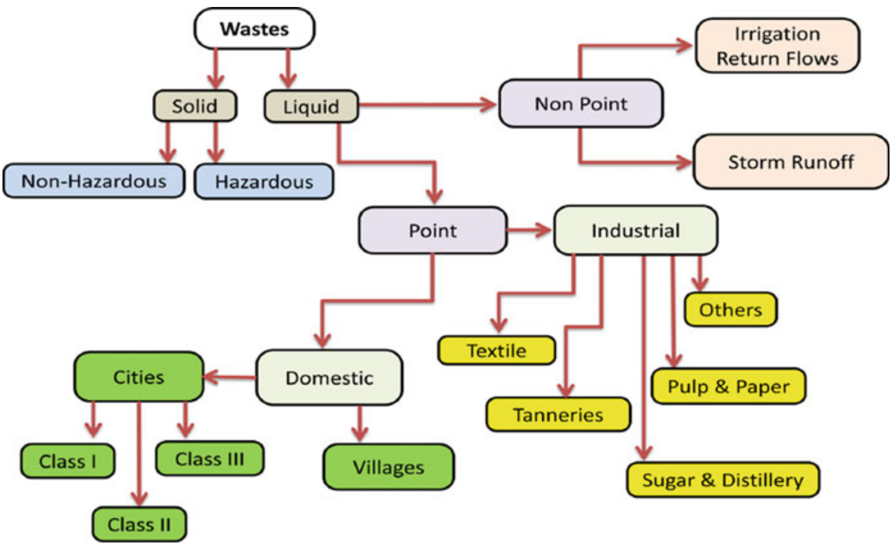


Fig. 1 Various types of waste generated

When pollutants are dissolved or suspended in water and transported away from source, they are called liquid waste. Such sources, where liquid wastes are generated, are called point source, and they can be formed by domestic, industrial and commercial activities. Thus the towns and villages are point sources generating liquid waste. Besides, the other major point source of liquid waste is the industries.

The source of liquid waste can be non-point or distributed. The garbage accumulation and open defecation, which are widely practised even today by humans and cattle, contribute to accumulation of filth and pathogens in water. This is accumulated in the surface runoff during monsoon and pollutes water bodies as non-point source. Overuse of chemical fertilizers and pesticides is also a major source of non-point pollution as it accumulates in surface water bodies as well as leaches downward, joins water level and pollutes groundwater.

While there is some estimate of liquid wastes generated and discharged into water bodies from some point sources, such as from major cities and industrial units, there is little information on such wastes generated from small towns and villages. And, information on liquid wastes from distributed sources is virtually non-existent. Thus no meaningful quantification is possible on the actual ingress of pollutants into our water bodies. However, pollutant ingress into water bodies can be broadly identified as occurring in three ways, viz. (1) by direct discharge of pollutants into water bodies, (2) when polluted surface runoff join water bodies and (3) seepage from polluted aquifers that oozes out and joins the water bodies.

There can be three ways of direct discharge of pollutants that occur: (i) when municipal and industrial solid waste, animal carcasses, unburned/partially burned human bodies, devotional offerings, etc. are dumped, (ii) when liquid wastes from point sources are discharged into water bodies and (iii) bathing with an intention of body cleaning; washing of clothes, animals and vehicles and direct defecation; etc.

The origin of non-point pollution of surface water bodies are (i) surface runoff charged with excess fertilizers and pesticides applied in fields and (ii) surface runoff carrying solid waste, i.e. human and animal faeces, garbage, industrial waste, etc.

A part of the liquid waste (generated both from point and non-point sources), described above, infiltrates and percolates downward through the vadose zone to pollute groundwater. This results in alteration of geochemical processes of the subsurface waters, leading to mobilization of otherwise immobile minerals (e.g. iron, manganese, arsenic, etc.), endangering human and animals through usage of such waters. Seepage of polluted groundwater also results in pollution of water bodies.

4 Monitoring the State of Water bodies

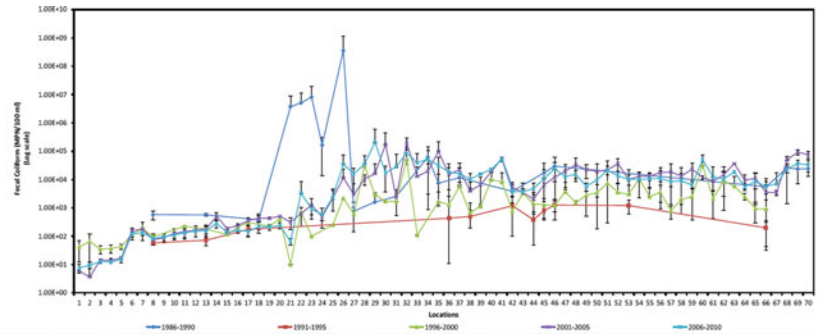
Presently there is very little actual monitoring of water bodies in India. For groundwater aquifers, even the scales and extents are often unknown, though detailed mapping has been started by the government. On the other hand, mapping of major wetlands in India has been carried out from satellite images since the last decade (e.g. SAC 2011; CIFRI, undated), but other meaningful information about the geology, hydrology, water quality or biodiversity are scanty. Even where some monitoring studies have been conducted by academia or other institutions, the works remain largely dispersed and ignored, since there is no single agency or institutional mechanism to collate, process and synthesize the information. For a very few select water bodies, such as the major rivers of India, some monitoring work is carried out by government agencies like CPCB and CWC, but here too the available information is often inadequate for a comprehensive assessment of the specific river's status. It is instructive in this context to broadly review the available information about India's most important river, National River Ganga.

4.1 Hydrological Status of Ganga

The most significant cause for the Ganga River's degradation is considered by some experts to be due to the large number of barrages and dams in the river network and the concomitant overextraction of water, with about 60% of the flow being abstracted for irrigation alone (see e.g. Wong et al. 2007). But quantitative hydrological information about Ganga, being classified by the government, is unavailable to public scrutiny. Some data were nonetheless made available to the IIT Consortium for hydrological modelling studies to prepare the Ganga River Basin Management Plan 2015. As discussed in a GRBMP report (IITC 2015a), however, the data are quite inadequate to make reliable estimates of hydrological parameters or to accurately predict future hydrological events in the basin. And the actual estimates of water resource potentials by government agencies were found to be equally unreliable. The obvious need is to carry out systematic hydrological monitoring on a continuous basis and make the information widely available for independent review.

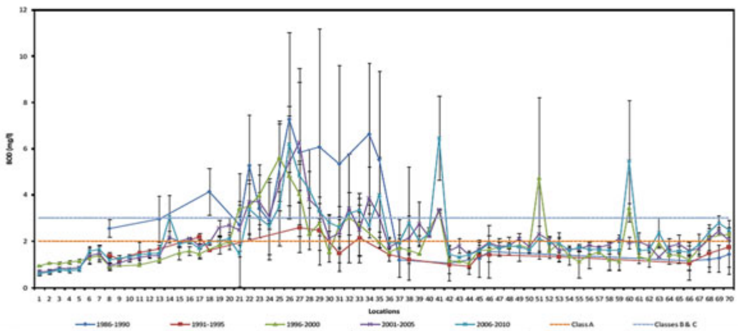
4.2 Water Quality Status of Ganga

Some water quality data at selected stations on River Ganga are available, and they indicate varying, but often poor, water quality status. For instance, the water quality data of Ganga River reveals that at Devprayag where the Bhagirathi and the Alaknanda joins and further downstream, the average faecal coliform numbers are 100 times more than the acceptable levels for bathing (Fig. 2) (IITC 2015b). Further downstream, particularly downstream of large urban centres like Kanpur, the faecal coliform numbers are 1000 times or more than the limits. At a few locations, the organic loading (biochemical oxygen demand or BOD) is also recorded as high and



1	Uttarkashi u/s (Bhagirathi)	15	Bijnore u/s (Ganga)	29	D/s Deehaghat	43	Hajipur u/s (River Gandak)	57	Sultanganj d/s
2	Uttarkashi d/s (Bhagirathi)	16	Bijnore d/s (Ganga)	30	Vindhyachal, PakkaGhat	44	Hajipur d/s (River Gandak)	58	Bhagalpur u/s
3	Devprayag u/s (Bhagirathi)	17	Garhmukteshwar u/s	31	Varanasi u/s	45	Patna u/s	59	Bhagalpur d/s
4	Devprayag u/s (Alaknanda)	18	Garhmukteshwar d/s	32	DashashawmedhGhat	46	Patna d/s	60	D/s Champanala
5	Devprayag d/s (Ganga)	19	Anoopshahr u/s (Ganga)	33	D/s at Kaithy	47	Fatuha u/s	61	Kahalgaon u/s
6	Ranipur u/s (Ganga)	20	Anoopshahr d/s (Ganga)	34	Near Malviya Bridge	48	Fatuha d/s	62	Kahalgaon d/s
7	Ranipur d/s (Ganga)	21	Fatehgarh u/s	35	Tarighat	49	Barh u/s	63	D/s NTPC Drain
8	Rishikesh u/s	22	Kannauj u/s (a/c with Ramganga & b/c with Kali)	36	Buxar u/s	50	Barh d/s	64	Sahebganj u/s
9	Rishikesh d/s	23	Kannauj d/s (a/c with Kali)	37	Buxar d/s	51	Mokama u/s	65	Sahebganj d/s
10	Haridwar u/s	24	Kanpur u/s (Bithoor)	38	Chapra u/s (Ghaghra)	52	Mokama d/s	66	Rajmahal d/s
11	Har-ki-Paudi	25	Kanpur d/s (Shuklaganj)	39	Chapra d/s (Chapra)	53	D/s Bata - McDowell	67	Berhampore (Middle)
12	Lalta Rao	26	Kanpur d/s (Jane Village)	40	Arrah u/s (River Gangi)	54	Munger u/s	68	Palta (Middle)
13	Dam Kothi	27	Allahbad u/s (Ujahni, Fatehpur)	41	Arrah d/s (River Gangi)	55	Munger d/s	69	Dakshineswar (Middle)
14	Mishrpur	28	Bathing Ghats at Sangam	42	Koliwar (River Sone)	56	Sultanganj u/s	70	Uluberia (Middle)

Fig. 2 Variation in 5-year average faecal coliform at various locations along the Ganga River (IITC 2015b)



1	Uttarkashi u/s (Bhagirathi)	15	Bijnore u/s (Ganga)	29	D/s Deehaghat	43	Hajipur u/s (River Gandak)	57	Sultanganj d/s
2	Uttarkashi d/s (Bhagirathi)	16	Bijnore d/s (Ganga)	30	Vindhyachal, PakkaGhat	44	Hajipur d/s (River Gandak)	58	Bhagalpur u/s
3	Devprayag u/s (Bhagirathi)	17	Garhmukteshwar u/s	31	Varanasi u/s	45	Patna u/s	59	Bhagalpur d/s
4	Devprayag u/s (Alaknanda)	18	Garhmukteshwar d/s	32	DashashawmedhGhat	46	Patna d/s	60	D/s Champanala
5	Devprayag d/s (Ganga)	19	Anoopshahr u/s (Ganga)	33	D/s at Kaithy	47	Fatuha u/s	61	Kahalgaon u/s
6	Ranipur u/s (Ganga)	20	Anoopshahr d/s (Ganga)	34	Near Malviya Bridge	48	Fatuha d/s	62	Kahalgaon d/s
7	Ranipur d/s (Ganga)	21	Fatehgarh u/s	35	Tarighat	49	Barh u/s	63	D/s NTPC Drain
8	Rishikesh u/s	22	Kannauj u/s (a/c with Ramganga & b/c with Kali)	36	Buxar u/s	50	Barh d/s	64	Sahebganj u/s
9	Rishikesh d/s	23	Kannauj d/s (a/c with Kali)	37	Buxar d/s	51	Mokama u/s	65	Sahebganj d/s
10	Haridwar u/s	24	Kanpur u/s (Bithoor)	38	Chapra u/s (Ghaghra)	52	Mokama d/s	66	Rajmahal d/s
11	Har-ki-Paudi	25	Kanpur d/s (Shuklaganj)	39	Chapra d/s (Chapra)	53	D/s Bata - McDowell	67	Berhampore (Middle)
12	Lalta Rao	26	Kanpur d/s (Jane Village)	40	Arrah u/s (River Gangi)	54	Munger u/s	68	Palta (Middle)
13	Dam Kothi	27	Allahbad u/s (Ujahni, Fatehpur)	41	Arrah d/s (River Gangi)	55	Munger d/s	69	Dakshineswar (Middle)
14	Mishrpur	28	Bathing Ghats at Sangam	42	Koliwar (River Sone)	56	Sultangan/s	70	Uluberia (Middle)

Fig. 3 Variation in 5-year average BOD5 at various locations along the Ganga River (IITC 2015b)

adversely impacting the river ecosystem (Fig. 3) (IITC 2015b). Some data are also available on concentrations of nutrients like nitrogen and phosphorus, and of some inorganic salts, but data regarding loading of pesticides and heavy metals into the Ganga river system is scanty. Water quality monitoring needs to be more intense and judicious than at present.

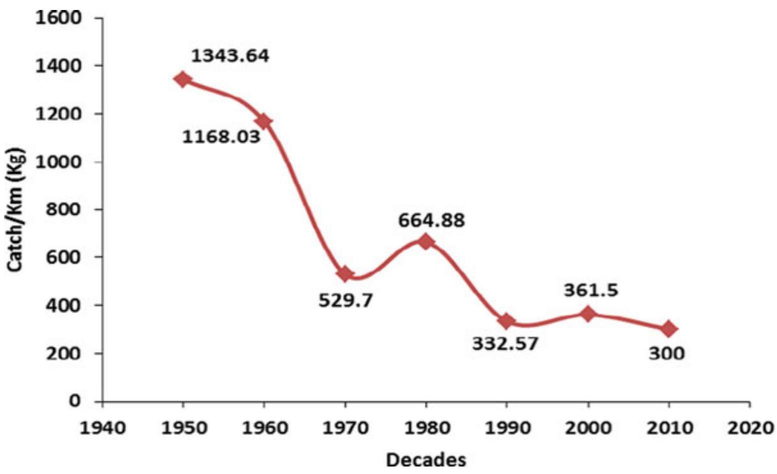


Fig. 4 Fish catch per km at Allahabad between 1950 and 2010 (IITC 2015c)

4.3 Ecological Status of Ganga

It is but obvious that the Ganges River system holds the richest freshwater fish fauna in the subcontinent. Over 140 fish species and 90 amphibian species in 5 areas are reported as supporting birds which is unique in comparison to similar systems. Besides five species of freshwater cetaceans which include famous freshwater dolphin (endangered) of the Ganges and also the rare freshwater shark, *Glyphis gangeticus* is also reported. The unique Sundarban delta supports over 289 terrestrial, 219 aquatic animals, 315 bird, 176 fish and 31 crustacean species (Wong et al. 2007). But it is a fact that there is hardly any monitoring of the biodiversity of the Ganga River by any agency, except some sporadic studies. Thus only a very rudimentary (if not outdated) idea about her biodiversity can be arrived at from the present monitoring (or non-monitoring) system. For instance, the fish catch at Allahabad since the last century is documented. Thus the progressive reduction of fish catch recorded at Allahabad between 1950 and 2010, provided in Fig. 4 (IITC 2015c), gives a preliminary idea of the steep ecological decline in the middle stretch of Ganga River. However no quantitative estimate can be made from such data about the overall biodiversity or its loss in the Ganga River near Allahabad or elsewhere.

India is a vast country having many significant water bodies, but many of India's numerous water bodies are vastly neglected. While large rivers are monitored to some extent, other water bodies are virtually outside the knowledge purview. Even in major cities that house India's administrative and knowledge centres, there is no credible monitoring of water bodies; and this is despite the fact that devastating floods in Indian cities like Chennai and Srinagar in recent years have been widely attributed to the rapidly degrading wetlands and the blocked or disappeared natural waterways in the catchment.

In the absence of any systematic monitoring mechanism for water bodies, it is natural that one depends on stray information from sporadic studies and news reports to arrive at a very sketchy idea of the status of our water bodies. A few illustrative examples of such information may be cited here to realize how the lack of authentic monitoring has contributed to the deplorable status of our water bodies:

- *"Bangladesh, India, Nepal, and Pakistan annually pump a total of about 210–250 cubic kilometres of groundwater … Groundwater use will increase by 30 percent, with the PRC, India, and Pakistan accounting for 86 percent of total groundwater abstraction in Asia. Such rampant expansion in use and its impact on declining water tables, water quality, and the continued demand for energy will become more pressing," said the ADB, in its report Asian Water Development Outlook 2016* (Saeedi 2016).
- *Uttar Pradesh has lost more than 1 lakh water bodies (out of 8, 75,345 tanks, ponds, lakes and wells) to the hands of illegal encroachment in one year till November 2013 as per the state revenue department* (Babele 2014).
- *According to a survey conducted by Lucknow Municipal Corporation, there were around 964 ponds in the city in 1952. The number declined to 494 in 2006* (Verma 2016).
- *There are 1012 water bodies in Delhi but, only 905 could be traced (in 2016). Of the total water bodies traced, 338 are dry, 168 encroached and 107 non-traceable* (Sharma and Singh 2016).
- *There were 159 water bodies spread in an area of 2003 ha (in Greater Bangalore) in 1973; that number declined to 147 (1582 ha) in 1992, which further declined to 107 (1083 ha) in 2002, and finally there were only 93 water bodies (both small and medium size) with an area of 918 ha in the Greater Bangalore region, in 2007* (Bharadwaja 2016).
- *The physico-chemical characteristics of 80 lakes of 3 different valleys (of Bangalore) monitored for a period of 24 months (revealed that) 98% lakes are encroached and 90% lakes are fed by sustained inflow of untreated sewage and industrial effluents* (Ramachandra et al. 2016).
- *In Central Kolkata … there is fall of 7 to 11 m in ground water level in last 45 years from 1958 to 2003* (Kolkata Municipal Corporation 2012). *(But) in a confidential interview a Kolkata Municipal Corporation official told that … groundwater levels have plummeted in various parts of the city. … Kolkata officially has about 17,000 stand posts, 12,000 hand tube wells and around 2500 large tube wells mainly catering to multi-story buildings, but the actual figures are far higher* (Basu 2015).

5 Report Card of Orinoco River Basin: A Case Study

It should be noted here that basins of large water bodies are diverse in nature, and hence there are no standardized metrics that perfectly define the health of a waterbody or its basin. As an example of basin-wide monitoring, the "Orinoco River Basin Report Card 2016" of the Orinoco River, Colombia (Garcia 2016), may be cited. The report card is based on the conception of basin values in terms of water, biodiversity, management/governance, economy, ecosystems and landscapes and people and culture as depicted in Fig. 5. And the key indicators of basin health

Fig. 5 Conceptual framework of Orinoco River basin values (WWF 2016)

were conceived as given in Box 1. The data needed were accordingly culled from various sources to arrive at a composite value (63%) for the basin's health. This method is not a given absolute, however, and it is possible that for other basins or for the same basin at a future date, different indicators and their weights may be adopted to obtain a better overall indicator of basin health. What is significant is the attempt to obtain a quantitative indicator of basin health, which is entirely lacking in India. It is imperative, therefore, that environmental valuation of our water bodies and their basins are carried out, water audits and accounts are conducted and a regular mechanism of their monitoring and comprehensive basin-specific data banks are established at the outset, in order to holistically manage and sanctify our water bodies.

Box 1: Key Health Indicators of Orinoco River Basin (WWF 2016)
Water Quality Index: The water quality index assesses the status of water quality variables (total suspended solids, dissolved oxygen, electrical conductivity, chemical oxygen demand and pH) based on data from the environmental information system indicators (IDEAM).

Risks to Water Quality: The risks to water quality index estimate pressure to water quality due to pollution loads discharged by industry and water use by domestic, livestock and coffee processing sectors (IDEAM).

Water Supply and Demand: The water supply and demand index is the balance between the availability of water in the watershed, the environmental flow requirements and the water demand by different economic sectors (IDEAM).

Natural Land Cover: The natural land cover indicator measures landscape conversion by comparing the area of natural to non-natural (developed) in the basin, based on satellite imagery for 2012. Loss of natural land cover impacts biodiversity in the basin (PEMO).

Stable Forest Area: This indicator measures the amount of forest that has remained stable in the Amazonian transition subbasins for the period 1990–2014, where forests are the main or dominant ecosystem. Forest area was calculated using satellite imagery.

Terrestrial Connectivity: Wildlife depends on connectivity between different ecosystems and habitats. The landscape shape index (from University of Massachusetts, Amherst) was used as a measure of fragmentation of terrestrial habitats within each basin.

Fire Frequency: Fire has been shaping parts of the savanna ecosystems for thousands of years. The fire indicator examines the average frequency of fires over the last 3 years (2013–2015) in each subbasin compared to historical fire trends.

(continued)

Box 1 (continued)

Ecosystem Services: The ecosystem services regulation indicator is based on the average of climate regulation by carbon storage, hydrologic regulation index that measures the amount of moisture that can be retained in basins and the soil erosion susceptibility zoning that shows the different erosion rates based on land assessment methods.

Human Nutrition: The human nutrition indicator assesses the percentage of children aged 0–4 with a healthy body weight. This indicator is a proxy for the capacity to provide enough food for people in the basin. Information on human weight was available from the National "Survey of the Nutritional Status in Colombia" conducted in 2010.

Mining in Sensitive Ecosystems: This indicator examines the presence of mining concessions within sensitive ecosystems including páramos, montane forest, riparian forest, wetlands and flooded savannas.

River Dolphins: River dolphins are listed as a vulnerable species in Colombia and are an important indicator species of river health where they are present. Data from the Omacha Foundation includes estimates of abundance and habitat use patterns in the Meta, Orinoco, Bita, Arauca, Guaviare and Inírida.

6 Managing Water bodies for Enabling Them to Provide Eco-services

As evident from the previous section, our water bodies are both neglected and overexploited. This is probably because they continue to be considered as natural entities whose conditions and usefulness are independent of human acts. Hence there has been no meaningful attempt to estimate the economic value of our water bodies, even of the important ones. Now India is a vast country having many significant water bodies, but it has only 26 Ramsar wetlands (refer to Table 1). Even if one were to consider only the Ramsar sites as our important water bodies, their environmental valuation could lead to some meaningful appraisal of the importance of our water bodies, thereby providing an impetus for their monitoring.

To manage our water bodies well, therefore, a definitive step is that their environmental valuation is carried out at the earliest. However, since value-specific data may be scarce at present, the valuations should be a continuous process based on updated and more reliable data as and when they become available.

To assess actual water use and availability, water accounting and water audits should also be carried out regularly, preferably on basin or subbasin scales. In case such audits indicate that anthropogenic water usage exceeds sustainable limits during a specified time span (say 1 year), water budgets should be prepared and

Table 1 List of Ramsar wetlands in India (ENVIS, undated)

S. no.	State/UT	S. no.	Name of Ramsar site
1.	Andhra Pradesh	1.	Kolleru
2.	Assam	2.	Deeparbeel
3.	Gujarat	3.	Nal Sarovar Bird Sanctuary
4.	Himachal Pradesh	4.	Pong Dam
		5.	Renuka
		6.	Chandra Taal
5.	Jammu and Kashmir	7.	Wullar
		8.	Tso Moriri
		9.	Hokersar
		10.	Mansar and Surinsar
6.	Kerala	11.	Ashtamudi
		12.	Sasthamkotta
		13.	Vembanad Kol
7.	Madhya Pradesh	14.	Bhoj
8.	Manipur	15.	Loktak
9.	Orissa	16.	Chilika
		17.	Bhitarkanika
10.	Punjab	18.	Harike
		19.	Kanjli
		20.	Ropar
11.	Rajasthan	21.	Sambhar
		22.	Keoladeo NP
12.	Tamil Nadu	23.	Point Calimere
13.	Tripura	24.	Rudrasagar
14.	Uttarakhand	25.	Upper Ganga
15.	West Bengal	26.	East Kolkata Wetland
	Total	**26 sites**	

implemented for future time spans so that water bodies are not dewatered into extinction while avoiding human water wars. Demand-side management with emphasis on recycle/reuse of grey water (instead of fresh water) on the supply side can effectively solve most of our persistent water problems.

Simultaneously basin-wide scientific, technical and socioeconomic databases should be created through a well-organized monitoring process (see, e.g. IITC 2015d) in order to formulate suitable management measures. Since such a monitoring system is presently ignored despite there being a plethora of government agencies in the water sector, an appropriate agency must therefore be established or designated to co-ordinate and oversee such monitoring. An example of such a body is the NRGBMC proposed for the National River Ganga Basin (IITC 2015e). Pending such a focussed and institutionalized programme, management of our water bodies will continue to remain ad hoc and inadequate in the foreseeable future.

7 Issues Related to Managing Wastewater

The main problems with anthropogenic wastewater management relate to the quantity and quality of the waters. From the overall national perspective, industrial wastewaters may not be quantitatively very high at present, but they often contain very harmful chemicals that are toxic or degrade very slowly in the natural environment or are high in salt content; hence it is necessary to fully treat and reuse them while discharging an absolute minimum at a safe location such as into oceans instead of inland water bodies (IITC 2015b).

Domestic wastewaters are often voluminous, especially those produced from urban clusters. They are harmful to the environment for their significant organic content and pathogen components. Hence they must be treated as completely as possible before releasing them into water bodies or – a better option – reusing them (IITC 2015b).

Agricultural wastewaters are probably the largest volumetric component of wastewater generation in India. Since this wastewater generation is distributed over vast agricultural lands, wastewater treatment may not be a feasible option. The obvious measures needed, therefore, are (i) to minimize their waste generation potential by minimizing soil tillage and the use of chemical fertilizers and pesticides, as well as the recycling of agricultural refuse, and (ii) minimize the wastewater generation and spillage into water bodies by minimizing irrigation water use and recycling the irrigation return flows (IITC 2015f).

The above measures need to go hand in hand with detailed data inventory of actual wastewater generation and their management, without which efficient wastewater management cannot be sustained over the long term.

8 Sanctifying Water bodies: Applying Science with Traditional Wisdom

According to Government of India 2009 data, the per capita water availability was more than 5000 m^3/year in the year 1951. This per capita quantity has been declining with increasing population and now stands at less than 1200 m^3/year by pushing the nation from the water adequate status to water-stressed country. Majority of nation's freshwater supply comes from the surface water and replenishable groundwater sources. Although rainfall frequency and intensity may have changed, historical average annual rainfall volume may not have changed drastically. Thus in calculation of per capita water availability, while the numerator has remained the same, the denominator has increased exponentially and likely to increase further in the coming decades indicating that water stress situation could further exacerbate unless steps are taken in the direction to change the water equation.

There are several steps that can be taken immediately to reverse the situation. The water availability can be increased by using the water a number of times through much enhanced reuse and recycle practices. The cities should embrace decentralized wastewater treatment mechanisms and reuse the water as much as possible where it gets generated reducing freshwater demand. Government and local authorities should consider developing policies to promote the grey water techniques by separating the faecal stream from the rest of the wastewater stream. The wastewater stream that has not been in contact with faecal matter can be treated to tertiary level and can be further treated using advanced treatment mechanisms such as reverse osmosis to supplement the freshwater demand. It is important to note that it is much less expensive to treat sewage than desalination of sea water.

However, for all of the above solutions to prevail, understanding the water budget at local level is the key. Once the data is available at the local level, the data can be aggregated at the city, state or at the national level. Every local municipality should conduct water audits to understand the consumption and immediate and future water demand including the assessment of the available water quantities. The audit should include assessment of the non-revenue water and the losses through water distribution networks as well. This will prepare local authorities to understand how efficiencies can be brought to lessen the demand for fresh water and at the same time will also increase the preparedness to face drought years.

8.1 Interlinking of Water bodies at Local Scale (Town/Village)

At present there is a debate going on the merits and demerits of interlinking of water bodies on national scale. However, the fact is that with rapid urbanization, to fulfil the water demand from these urban areas, the water is already being imported from hundreds of kilometres faraway places for meeting the current water demands. For example, the city of Indore in the state of Madhya Pradesh gets its water from Narmada River, whereas the city of Bangalore in Karnataka state gets its water from Cauvery River located about 100 kilometres from the city; similarly the city of Hyderabad gets its water from River Krishna located 116 kilometres away. The cost of conveying this water from its source to destination requires pumping and comes with huge costs in terms of power, and there are losses associated with distributing over such a long distance as well. In case of Indore, it costs about INR 30 per cum, and in case of Bangalore, it costs about INR 82 per cum. Furthermore, this horizontal conveyance alone cannot meet the growing demand, and there is vertical transport of water from groundwater aquifers to meet the additional water demands.

At present, the water that is being imported into urban areas both horizontally and vertically gets converted into sewage and is being transported over 15 to 20 kilometres for treatment and gets partially treated. In most cases, either partially treated or untreated wastewater is allowed to flow into lakes, ponds, *nallahs*, rivers or any nearby waterbody. This has already contaminated majority of the urban water bodies across the country. In addition to contaminating the surface water bodies, this eventually percolates into groundwater with organic load and contaminates the groundwater and renders it useless.

Now that the water is already being transmitted across great distances, as opposed to conveying further away for partial treatment, a good solution would be to develop decentralized wastewater treatment systems. The decentralized treatment systems if maintained and operated properly can provide water for reuse and recycling. The treated water can then be let into the local water bodies for maintaining a healthy flow through the waterbody. Most of the small tributaries in India are seasonal with flows showing up only during the monsoon season. However, with importing millions of litres of water on continuous basis and converting most of this water into sewage and instead of letting it into our water bodies, if tertiary treated water is let into these water bodies, the fully treated sewage can serve as source of fresh water, and the water bodies once contaminated can be turned into fresh water bodies.

The interlinking of the water bodies at local level can serve multiple objectives. At present, lack of water resources management plans has led to urban flooding during the heavy rains causing massive traffic problems and in some cases deaths as well. However, interlinking of local water bodies will create a network of water bodies and work as bulwark against flooding. There are other benefits such as developing recreational areas in the middle of the cities, providing with freshwater source leading to enhanced water security for the region as a whole and most importantly reducing the huge costs associated with transportation of the water over hundreds of kilometres.

8.2 Separating Sewage from Storm Water Drainage Network

The development and management of natural/storm water drainage systems go hand in hand with the development of the sewer systems. Majority of urban drains today carry sewage throughout the year as well as storm water runoff for 3 to 4 months during the monsoon season. This has to stop. The sewage needs to be collected and treated at local level that can be reused and recycled. The usage of septic tanks, soak pits, open drains carrying mostly swage, etc. needs to be addressed so that only sewage is conveyed to locally decentralized treatment facilities.

8.3 Catchment Clean-Up

Any good watershed management plan is not complete without a comprehensive solid waste management (solid waste and animal dung) component. This is especially true where animal waste generated is not managed properly. The solid waste can ultimately reach the water bodies as non-point source or through *nallahs* and increase the organic load significantly. The solid waste management components include educating the population living inside the catchment area to providing facilities for solid waste management. Also, it is important to note that the animal waste produced, especially the cow dung, can be used as manure in the organic farming. The cow dung that can be a valuable fertilizer, if not used properly and disposed of as a waste, can be a liability on the water bodies.

8.4 *Traditional Knowledge and Science*

Worshipping water bodies has been a part of Indian culture since time immemorial. Even today, most of the households across the nation keep Ganga water in the prayer room, and it is part of all the daily rituals. This is extremely scientific when analysed carefully. When looked at Indian civilization that has thousands of years of history, the current sorry state of the water bodies can be attributed only to the last few decades of rapid urbanization that has cut off the population from its traditional value-based system and not yet fully integrated with the Western scientific education system. The water that was revered and considered sacrosanct will naturally be protected by the users who rely on this very water for their survival. This served as a governance mechanism that needed no constant vigilance or enforcement. This can be illustrated with a few examples.

The misuse of the water from the Ganga River has been cautioned in our ancient scriptures. The edict below in Sanskrit has clearly lay prohibition on 13 types of human actions, viz. defecation, gargling, throwing of used floral offerings, rubbing of filth, flowing bodies (human or animal), frolicking, acceptance of donations, obscenity, considering other shrines to be superior, praising other shrines, discarding garments, harming anyone and making noise.

गंगां पुण्यजलां प्राप्य त्रयोदश विवर्जयेत्। शौचमाचमनं सेकं निर्माल्यं मलघर्षणम्।
गात्रसंवाहनं क्रीडां प्रतिग्रहमथोरतिम्। अन्यतीर्थरतिंचैवः अन्यतीर्थ प्रशंसनम्।
वस्त्रत्यागमथाघातं सन्तारंच विशेषतः॥
ब्रह्माण्डपुराण (८०० ई०)

Further, a verse from another scripture says "A sin of human being is purified by taking bath in Holy River *Saraswati* for three days, in Holy River Yamuna for one week and in Holy River Ganga in one dip. However, all sins of human being are purified only by viewing the holy River Narmada".

त्रिभिः सारस्वतं तोयं सप्ताहेन तु यामुनम्।
सद्यः पुनाति गांगेयं दर्शनादेव नार्मदम्॥
(मत्स्य पुराण १८५/१० – ११)

This clearly suggests how simple norms were used to protect rivers having different biophysical settings from human impacts.

Traditional knowledge has many more such examples not only in the scriptures but also in the practise. However, with urbanization and more importantly, the drinking water that gets imported into urban areas from distant places has taken water out of our mind, and similarly, the disappearance of the wastewater from the houses has disconnected the water pollution from the people. Making water an important part of education and reviving our traditions can be a very successful and essential tool for keeping our water bodies healthy.

9 Conclusion

The present article highlights the urgent need for a concerted effort to salvage our threatened and rapidly degrading water bodies. Such effort must be led by the government, but cannot remain confined only to government policies and programmes. Decentralized actions must be allowed, even encouraged, to fortify the process. Thus non-state actors – such as local bodies, user communities, NGOs and academia – should be accommodated into the management space. This is not only because the whole population is a beneficiary of the water bodies but also because traditional and hands-on knowledge and insights of many people can complement the compartmentalized actions of formal institutions and programmes (IITC 2015e).

It should be also noted that water bodies, especially surface water bodies, need to be managed on basin scales, which implies systematic monitoring and documentation of basin-wide processes that are grossly lacking in India. As noted in the Ganga River Basin Management Plan 2015, “Basin planning and management combine diverse natural resources (water resources, land resources, biological resources, etc.) and processes (river dynamics, geological phenomena, atmospheric processes, etc.) with traditional wisdom and grassroots knowledge. Hence, it is necessary to build a comprehensive data bank to enable meaningful analyses and obtain quantitative indicators” of the basin’s status (IITC 2015e). The monitoring requirements need to be detailed and revised from time to time based on improved understanding of human-technology-environment interactions in the basin. And this is one activity in which the government must focus its efforts irrespective of contributions from non-state actors.

Acknowledgements Assistance provided by Dr. Gautam Roy and Mr. Shyam Prasad in collating the information and preparing the manuscript is highly appreciated.

References

Babele P (2014) 10 Ponds were vanished for T3 terminal of Delhi Airport. India Today, New Delhi Sept. 05, 2014. Available at http://indiatoday.intoday.in/story/uttar-pradesh-drought-illegal-encroachment-ponds-delhi-airport/1/381203.html. Accessed on 8 Aug 2016

Basu J (2015) Kolkata, a water-rich city turning water-poor. The Third Pole Nov. 11, 2015. Available at https://www.thethirdpole.net/2015/11/11/kolkata-a-water-rich-city-turning-water-poor/. Accessed on 29 Aug 2016

Bharadwaja AS (2016) Bengaluru lost its water bodies, and here's what is, Citizen Matters, Jan 11, 2016. Available at http://bangalore.citizenmatters.in/articles/bangalore-water-bodies-ndwi-images-research. Accessed on 09 Sept 2016

CIFRI (undated) Mapping of Inland Water Bodies of Bihar. CIFRI, Barrackpore Available at http://ahd.bih.nic.in/Docs/CIFRI_Report_Inland_Mapping.pdf. Accessed on 20 Sept 2016

ENVIS (undated) List of Wetlands of International Importance under Ramsar Convention. Hosted by WWF-India, New Delhi. Available at http://www.wwfenvis.nic.in/Database/State-wise_4470.aspx. Accessed on 19 Sept 2016

Garcia J (2016) Orinoco River Basin 2016 Report Card. Omacha Foundation, Colombia. Available at http://assets.worldwildlife.org/publications/897/files/original/English_Version_Orinoco_River_Report_Card_3_High_Res.pdf?1467757591&_ga=1.197164203.545681390.1475156350. Accessed on 25 Sept 2016

IITC (2015a) GRBMP 2015 – Mission 1:AviralDhara. IIT, Kanpur. Available at: http://nmcg.nic.in/writereaddata/fileupload/8_Mission%201_Aviral%20Dhara.pdf. Accessed on 17 Sept 2016

IITC (2015b) GRBMP 2015 – Mission 2:NirmalDhara. IIT, Kanpur. Available at: http://nmcg.nic.in/writereaddata/fileupload/47_Mission%202_Nirmal%20Dhara.pdf. Accessed on 17 Sept 2016

IITC (2015c) GRBMP 2015 – Mission 3: Ecological Restoration. IIT, Kanpur. Available at: http://nmcg.nic.in/writereaddata/fileupload/57_Mission%203_Ecological%20%20Restoration.pdf. Accessed on 17 Sept 2016

IITC (2015d) GRBMP 2015 – Mission 8: Environmental Knowledge-Building and Sensitization. IIT, Kanpur. Available at: http://gangapedia.in/?q=content/mission-8-environmental-knowledge-building-and-sensitization. Accessed on 17 Sept 2016

IITC (2015e) GRBMP 2015 – Main Plan Document. IIT, Kanpur. Available at: http://nmcg.nic.in/writereaddata/fileupload/13_GRBMP%20-%20MPD.pdf. Accessed on 17 Sept 2016

IITC (IIT Consortium) (2015f) GRBMP 2015 – Mission 4: Sustainable Agriculture. IIT, Kanpur Available at: http://nmcg.nic.in/writereaddata/fileupload/3_Mission%204_Sustainable%20%20Agriculture.pdf. Accessed on 17 Sept 2016

Kolkata Municipal Corporation (2012) Ground Water Information Booklet. KMC, West Bengal. Available at: http://cgwb.gov.in/District_Profile/WestBangal/Kolkata%20Municipal%20Corporation.pdf. Accessed on 11 Sept 2016

Ministry of Agriculture (2014) State of Indian Agriculture 2012–13. New Delhi. Available at: http://164.100.47.132/paperlaidfiles/AGRICULTURE/State%20of%20Indian%20Agriculture%202012-13%20%28English%29%20with%20cover.pdf. Accessed on 07 June 2014

Ministry of External Affairs (2005) Ecosystems and Human Well-being: Synthesis. World Resources Institute, Washington DC. Available at: http://www.millenniumassessment.org/documents/document.356.aspx.pdf. Accessed on 20 Sept 2016

Ministry of Water Resources, Government of India (2008) Integrated Water Resources Development and Management. Theme Paper Water Resources Day – 2008, New Delhi

Ramachandra TV, Asulabha KS, Sincy V, Sudarshan PB, Bharath HA (2016) Wetlands: Treasure of Bangalore, ENVIS Tech. Report 101. Indian Institute of Science, Bangalore. Available at http://www.indiawaterportal.org/sites/indiawaterportal.org/files/wetlands_treasures_of_bangalore_ces_iisc_2016.pdf. Accessed on 15 Sept 2016

SAC (2011) Information Brochure: National Wetland Inventory and Assessment. Indian Space Research Organisation, Ahmedabad

Saeedi TA (2016) Rampant groundwater use to make energy demand pressing: ADB. The News International, Karachi August 31, 2016. Available at: https://www.thenews.com.pk/print/146459-Rampant-groundwater-use-to-makeenergy-demand-pressing-ADB%C2%A0#. Accessed on 01 Sept 2016

Sharma R, Singh S (2016) The Sunday Standard. Apr. 10, 2016. Available at http://www.newindianexpress.com/thesundaystandard/The-Death-of-Delhis-Water-Bodies/2016/04/10/article3372019.ece. Accessed on 6 Aug 2016

Smith DM, Barchiesi S (2009) Environment as infrastructure: Resilience to climate change impacts on water through investments in nature. Intl. Union for Conservation of Nature, Switzerland. Available at: http://www.worldwatercouncil.org/fileadmin/world_water_council/documents_old/Library/Publications_and_reports/Climate_Change/PersPap_02._Environment_as_Infrastructure.pdf. Accessed on 19 Mar 2013

UN-Water (2013) Water Security & the Global Water Agenda. United Nations University, Ontario. Available at http://www.unwater.org/downloads/watersecurity_analyticalbrief.pdf. Accessed on 01 Apr 2013

Verma R (2016) Lucknow's water bodies perish at the hands of unregulated construction. Down to Earth, Friday February 12, 2016. Available at: http://www.downtoearth.org.in/news/lucknow-s-water bodies-perish-at-the-hands-of-unregulated-construction-52811. Accessed on 12 Aug 2016

Wong CM et al. (2007) World's Top 10 Rivers at Risk, WWF International. Gland, Switzerland. Available at: http://d2ouvy59p0dg6k.cloudfront.net/downloads/worldstop10riversatriskfinalmarch13_1.pdf. Accessed on 16 July 2016

WWF (2016) Orinoco River Basin Report Card 2016. Available at https://www.worldwildlife.org/pages/orinoco-river-basin-report-card. Accessed on 10 Jul 2017

Vinod Tare is a professor of environmental engineering and management at the Indian Institute of Technology Kanpur and also held Sir M. Visvesvaraya Chair Professor established by the Ministry of Water Resources. He has obtained master's and doctoral degrees in environmental engineering from Indian Institute of Technology, Kanpur and subsequently did Post Doctoral research at the Illinois Institute of Technology, Chicago. He has guided numerous masters' and doctoral dissertations. He was the chairman of the first India Water Impact Summit 2013 held at New Delhi and International Conference on Water Harvesting, Storage and Conservation (WHSC 2009). Dr. Tare is a consultant/advisor to many government organizations, NGOs, industries and institutions. He has developed nature-friendly toilet systems with potential for deployment in Indian Railways, communities, house boats, and large congregation, such as Kumbh Mela. Dr. Tare was the leader of the consortia of seven IITs for the preparation of Ganga River Basin Management Plan submitted to the National Ganga River Basin Authority chaired by the prime minister. He is the founding head of the Centre for Ganga River Basin Management and Studies at IIT Kanpur established by the Government of India. Dr. Tare was also the chair of the Second India Water Impact Summit 2017 held at Delhi. The summits witnessed the presence of central and state government ministers as well as ministers and ambassadors of other countries.

Deterioration of Groundwater Quality: Implications and Management

S. P. Sinha Ray and L. Elango

1 Introduction

A major attraction of using groundwater for drinking purposes is that it usually requires little or no treatment, but this is no longer the case. The quality of groundwater is deteriorating rapidly due to geogenic and anthropogenic activities which are excessive exploitation, disposal of waste and spillage of chemicals, removal of vegetation, etc. Active research is carried out across the globe in determining the groundwater quality of various regions since several decades where high concentration of various ions such as fluoride, arsenic, iron, nitrate, etc. in groundwater has been reported (Brindha et al. 2011). Various researchers have identified excess concentration of fluoride in groundwater in India, China, Japan, Sri

Lanka, Iran, Pakistan, Turkey, Southern Algeria, Mexico, Korea, Italy, Brazil, Malawi, North Jordan, Ethiopia, Canada, Norway, Ghana, Kenya, South Carolina, Wisconsin, and Ohio (Brindha et al. 2011). The well-known areas subjected to excess arsenic concentrations in groundwater are Bangladesh, India (West Bengal), Argentina (Pampas), Australia, the USA, Brazil, Russia, and China. Very high concentrations of nitrate (>100 mg/L) in groundwater were reported in India (Zhao 2015), and concentrations of nitrate above 50–100 mg/L were reported in several other countries like Australia, Argentina, South Africa, China, Mexico, Iran, and the USA (Zhao 2015). Iron contamination in groundwater has become one of the most discussed issues nowadays. The high concentration of iron is observed in several countries by many researchers in India, Bangladesh, Australia, New Zealand, China, Russia, Iran, Kazakhstan, South Africa, Brazil, the USA, Canada, and Sweden

S. P. Sinha Ray (✉)
Centre for Ground Water Studies, Kolkata, India

L. Elango
Department of Geology, Anna University, Chennai, India

© Springer Nature Singapore Pte Ltd. 2019

A. Singh et al. (eds.), *Water Governance: Challenges and Prospects*, Springer Water,
https://doi.org/10.1007/978-981-13-2700-1_5

(Rajmohan and Elango 2005; Lepokurova and Ivanova 2014). Nitrate is one of the major threats to the groundwater system in India. Various scientists have found concentration of nitrate beyond permissible limit (Brindha et al. 2012). Mitigation methods have become indispensable to avoid further contamination of groundwater and also to improve the groundwater quality which requires knowledge about the causes and effects of deterioration of groundwater quality.

2 Various Groundwater Quality Issues in India

2.1 Geogenic Sources

The high concentration of fluoride, arsenic, and iron in the groundwater is due to the impact of geology and geochemical processes in an area. Fluoride in groundwater above 1.5 mg/L will be considered as not suitable for drinking purposes as recommended by BIS & WHO. High fluoride concentration above permissible limit has been reported from Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan, Tamil Nadu, Telangana, Uttar Pradesh, and West Bengal. Groundwater with high fluoride concentration in different states were studied by several researchers, at Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Kerala, Maharashtra, Orissa, Rajasthan, Tamil Nadu, Telangana, and West Bengal.

Excess arsenic in groundwater is being observed in many new locations in the last decade in addition to earlier ones which is indicative of great concern, especially in West Bengal and Bihar. The WHO limit for arsenic content in drinking water is 10 ppb. However, the maximum permissible limit of arsenic in drinking water is 50 ppb (if alternative source is not available) according to BIS. High levels of arsenic in groundwater above permissible limit were found in the alluvial plains of Ganges covering six districts of West Bengal. Some other Indian states which are affected by arsenic in groundwater are, namely, Bihar, Chhattisgarh, Jharkhand, and Uttar Pradesh.

More than one lakh habitations are having excess iron, the value being as high as more than 50 mg/L in India. The permissible limit for iron in groundwater is 0.3 mg/L as per WHO guidelines. The highest value (52 mg/L) has been found in Lakhimpur, Assam. Deterioration of groundwater quality by widespread contamination of iron occurs in Assam, Chhattisgarh, Karnataka, Orissa, and West Bengal. Localized pockets are observed in the states of Bihar, Uttar Pradesh, Punjab, Rajasthan, Maharashtra, Madhya Pradesh, Jharkhand, Tamil Nadu, and Kerala. The geogenic contamination of groundwater due to iron was studied by several researchers in Assam Chhattisgarh, Karnataka, Orissa, and West Bengal.

The chronic exposure of uranium radionuclides in groundwater is a potential health risk factor in India. The permissible limit of uranium in groundwater is 0.03 mg/L as per WHO guidelines. The high concentration of uranium in groundwater occurs in Andhra Pradesh, Jharkhand, Orissa, Meghalaya, Rajasthan, Telangana, and Punjab.

2.2 Anthropogenic Sources

Industrial discharges, urban activities, agriculture fertilizers, and disposal of sewage wastes are affecting the groundwater quality adversely. Leakage of spills from oil tanks, release of chemical effluents from dying industries, fertilizers and pesticides applying to agricultural land, and leakage in septic tanks and from waste disposal sites tend to accumulate and migrate to the groundwater table leading to contamination of the groundwater system. Such contaminations can render groundwater unsuitable for potable use.

2.2.1 Agriculture

Intensive use of chemical fertilizers and pesticides in the agricultural land results in the leaching of the residual nitrate causing high concentration of nitrate in groundwater. Pollution of nitrate in groundwater results from intensive application of fertilizers and pesticides. Health hazards in infants and animals and eutrophication of water bodies may be due to high nitrate concentrations. The acceptable limit is 45 mg/L (BIS) and 50 mg/L (WHO). In India, nitrate concentration above permissible level of 45 mg/L has been reported from Andhra Pradesh, Bihar, Haryana, Himachal Pradesh, Kerala, Madhya Pradesh, Maharashtra, Orissa, Rajasthan, Tamil Nadu, Telangana, West Bengal, and Uttar Pradesh.

2.2.2 Industries

Due to rapid industrialization growth, major cities of India generate large quantity of industrial effluents which is dumped into the nearby water bodies. The shallow aquifer of Ludhiana City has been polluted by the stream effluents from 1300 industries around the city. The chemical effluents from tanneries in Vellore district of Tamil Nadu were released into Palar River that contaminates the groundwater of the region. The disposal of untreated effluents from various industrial units in Baddi-Barotiwala industrial belt of District Solan, Himachal Pradesh, results in the contamination of groundwater by heavy metals. The extensive industrial activities in the region of Pydibhimavaram industrial area, Andhra Pradesh, India, resulted in the contamination of aquifer due to chloride, sulfate, nitrite, and trace elements of Fe, Ni, Cd, and Pb from the industrial effluents. The industrialized area where petrochemical storage tanks are located in Chennai, Tamil Nadu, was affected by PAH pollution from the early 1990s. In addition, the Centre for Science and Environment from new studies could find in eight places in Gujarat, Andhra Pradesh, and Haryana traces of heavy metals such as lead, cadmium, zinc, and mercury.

3 Aquifer Contamination Relation Dynamics

Geochemical analysis is the major approach for defining ionic concentrations in groundwater. The nature of groundwater is very complex and it becomes challenging for interpretation. Consequently, the origin and chemical composition of groundwater can vary considerably. Hence, it is necessary to thoroughly examine the spatial and temporal groundwater chemistry in an aquifer to interpret the sources and processes of groundwater contamination.

3.1 Spatial Variation in Groundwater Quality

Spatial variation of hydrochemical constituents of groundwater acts as a tool to interpret the hydrogeological condition of the aquifer. The predictable changes in the quantity and quality of dissolved constituents in groundwater during the transit of areas of recharge and discharge are useful to analyze the physical and hydrogeological properties of groundwater system. Variations in different geologic formation can cause the changes in groundwater chemistry. Mineral composition of rocks, weathering pattern, soil type, flow pattern, vegetation cover, and climate change are the major phenomena to determine the groundwater chemistry. Significant difference in geochemistry of groundwater is observed at varying depths which also accounts for spatial variation.

3.2 Temporal Variations in Groundwater Quality

Temporal variations of aqueous chemical constituents within hydrogeologic environments provide a valuable insight into the natural physiochemical processes, which govern groundwater chemistry. Temporal variation is an approach to examine the variation of ionic concentration with elapsed time at each well. The temporal variations in chemical concentration of groundwater are attributed due to rapid groundwater movement after recharge in shallow aquifer system, natural or artificial fluctuations of the zone of saturation into and out of weathering profiles, and mixing of groundwater of differing chemistries in highly pumped aquifers.

4 Impact on Public Health

The most widespread groundwater contamination in India is fluoride. The next important contamination is arsenic. Both inland brackish water and coastal saline water under marine and estuarine contribute to salinity hazards. Iron and manganese in groundwater are also widely distributed in India. Uranium, radon, and strontium contaminations from geogenic source are reported from limited areal extent in parts of the country. Chromium pollution in groundwater is due to anthropogenic activities, especially in leather industrial areas. Selenium contamination that is localized in Punjab and Himachal Pradesh has also been reported. Nitrate contamination, resulting from biologic nitrification process mainly due to agricultural activities, has caused point-source pollution in various parts of the country. Uptake of excess level of the above contaminants in the human health through drinking water and through food chain is described below.

4.1 Arsenic

Significant research on health effects of chronic arsenic toxicity in human has been carried out in India during the last 30 years. Based on the magnitude and duration of dose, the symptoms of such toxicity occur. “Raindrop” pattern of pigmentation is normally marked in the non-exposed part of the body, such as the trunk, buttocks, and thighs. Arsenical hyperkeratosis appears predominantly on palms and the plantar aspect of the feet. Although ingestion of dose may be the same, keratosis and pigmentation incidents in male folks are double compared to females.

The evidence of carcinogenicity in humans from exposure to arsenic has also been detected. Other diseases from arsenic toxicity may also cause respiratory distress myocardial depolarization and cardiac arrhythmias and also gastrointestinal effects. Arsenic exposure during pregnancy can adversely affect several reproductive end points including spontaneous abortion, preterm birth, still births, and neonatal and prenatal mortality that have also been documented. Chronic exposure to arsenic may also cause skin cancer, urinary bladder cancer, and lung cancer in addition to gangrene, pedal edema (non-pitting), etc. Guha Mazumder (2015) have indicated from studies that the impact of dietary arsenic intake in human body can provide a potential pathway of arsenic exposure even when arsenic intake through water was reduced to 50 μg/L in arsenic endemic region in West Bengal.

4.2 Fluoride

Excessive intake of fluoride (more than 1.5 mg/L) may result in slow, progressive crippling scourge known as fluorosis. However, low-level fluoride is required by

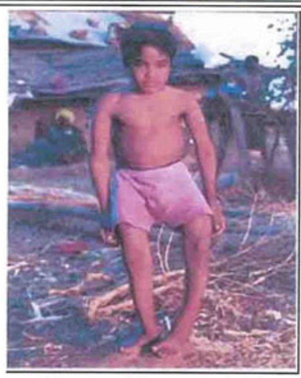
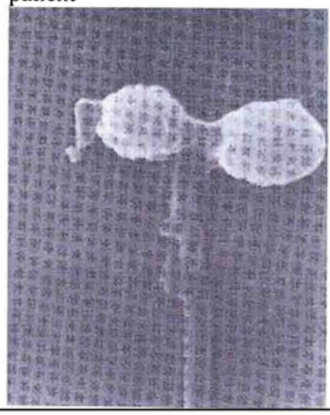
Dental Fluorosis • Occurs if exposed to high fluoride during permanent dentition • Chalky white teeth initially • Yellow to brown pigmentation in the middle of the teeth away from the gums • In severe form the teeth becomes brittle and the enamel chips off	
Skeletal Fluorosis In Children • Pain in the lower limbs • Knock knee • Bow leg • Anterior bowing of the lower limb bones. In adults • Stiffness of the back and neck muscles • Unable to bend forward • Unable to stand straight	
Non Skeletal/ Soft Tissue Fluorosis Gastrointestinal system: • Gas in the stomach • Loss of appetite • Constipation Haemopoetic system: • Anaemia and tiredness Endocrine glands: • Delayed puberty • Destruction of thyroid gland Genitourinary system: • Infertility due to abnormal sperm Renal system: • Chronic renal failure Central nervous system • Low I Q	Double headed sperm in fluorosis patient 

Fig. 1 Fluorosis manifestations

human system in preventing dental carries (Sinha Ray 2015). Normal-level fluoride in water, urine, and blood is up to 1 mg/L, 0.1 mg/L, and 0.02 mg/L, respectively.

Fluorosis occurs in three forms: dental, skeletal, and non-skeletal fluorosis (Fig. 1). Dental fluorosis becomes visible from discoloration of permanent teeth aligned horizontally and/or discoloration in spots away from gums, mostly in children. Luster and shine of dental enamel and change of color from white to brown to black are caused by dental fluorosis, whereas skeletal fluorosis results from the deposition of excess quantity of fluoride in bones. Both children and adults undergo crippling deformity and deformity of knee joints.

In skeletal fluorosis, generalized bone and joint pain occur in mild cases which are followed by stiffness of joints with restricted movement of the spine and joints. Finally flexion deformity develops in the spine and joints. Crippling deformity; bad effects on skeletal muscle, gastrointestinal system, and ligaments; or combination of all are symptoms of non-skeletal fluorosis. Compared to female patients, male patients are highly affected by non-skeletal fluorosis due to calcium deficiency in red blood cell and also due to strenuous work (CGWB 1999).

4.3 Iron

High iron (more than 0.3 mg/L) makes the taste of the water astringent. It may appear brownish due to precipitation of ferric hydroxide and may stain utensils, laundry, and equipment. As per EPA, although iron in drinking water is safe to ingest, the iron sediments may contain trace impurities or harbor bacteria that can be harmful. Excess iron stored in the spleen, liver, and bone marrow can cause hemochromatosis. Chronically consuming excess amounts of iron causes iron overload. Chronic ingestion of excess iron can lead to a severe disease damaging the body organs. Such disease if remains unattended may cause heart disease, liver problems, and diabetes.

4.4 Manganese, Uranium, Radon, Strontium, Chromium, and Selenium

Excess manganese, if deposited in the basal ganglia, may create neurological problems. Generally low intake of uranium does not cause any health problem. Intake of a large amount of uranium might damage the kidneys. Long-term chronic intakes of uranium isotopes in food, water, or air can be carcinogenic. The prescribed limit by WHO is 15 μg/L. The prescribed radioactivity exposure limit is 1 mSv/year. A study conducted in the USA estimates 12% lung cancer deaths are linked to radon (radon-222 and its short-lived decay products). Strontium is nontoxic, and a daily intake of 0.8–5 mg is harmless, if it contains nonradioactive strontium. The risk involves from intake of radioactive strontium is mainly carcinogenic and mutagenic mechanism, possibly increasing infant mortality. The toxicity and carcinogenic properties of chromium (III) in the cell can lead to DNA damage. The acute toxicity of chromium (VI), due to its strong oxidation properties, can reach the blood system and damage the kidneys, liver, and blood cells through oxidation reactions. Selenium exposure in humans takes place either through food or water with symptoms like loss of finger, toe nails, and hair and progressive deterioration of health. It can also cause nausea, headache, tooth decay, and staining of teeth and nails with brittleness and longitudinal streaks.

4.5 Nitrate and Salinity

Ingestion of nitrate can cause methemoglobinemia in infants under 6 months of age. In intestinal tract of infants due to bacteriological action, ingested nitrate is converted to nitrite causing methemoglobinemia, and its severity may cause death. Ingestion of high amount of nitrate may result in various gastric problems owing to formation of nitrosamines in adult human. The study revealed that about 2 million hectares of land is affected by brackish to saline water. Generally such brackish water occurs within 100 m depth. However, like geogenic contaminants, brackish waters do not affect health hazards.

5 Mitigation Measures

Potential mitigation techniques are vital for improving the quality of contaminated water. The mitigation methods vary depending on the origin, type, and nature of contamination. Avoiding the potential zones of contamination is the best way, but water scarcity and limited options of alternate source prevent us, and therefore better technological and economical mitigation strategies should be adopted.

5.1 Critical Concerns

The primary task of providing contaminant-free safe water needs to address the following critical concerns:

- Water quality monitoring and health risk assessment
- Deciphering both contaminated and safe sources
- Provision of alternate sources of safe drinking water
- Mechanism for sharing transparent information system by stakeholders
- Planned restriction of excessive use of groundwater for irrigation and agriculture in critical areas

5.2 Technology Options

Based on the experience in India and neighboring countries, the following are major technological options for providing safe water in groundwater contaminated areas:

- Tapping groundwater from alternate pollution (arsenic, fluoride, chromium, nitrate, etc.)-free aquifers at a deeper levels and scaling off the polluted aquifer on the top.

- Large-scale surface water-based piped water supply for the communities by drawing water from the rivers and treating them for pathogenic microbes.
- Conservation and quality upgradation of traditional surface water sources like ponds, dug wells, etc.
- Removal of pollutants from groundwater by in situ and ex situ treatment techniques.
- These technologies can be used both for large-, medium-, and short-scale water supply projects. Domestic filters for household uses can also be developed based on such appropriate technologies.

6 Policies and Strategies for Groundwater Quality Management

Effective policies for groundwater protection must consider organizational and social environment in the country, groundwater quantity-quality scenario, economic viability of protection measures being proposed, and also societal acceptability. While framing the policy, people, governmental organizations, and other stakeholders need to be associated.

6.1 International Practices

In addition to other policies, the European Union (EU) groundwater protection policy primarily considers six basic principles like high degree of protection, precautionary measures, preventive measures of pollution, corrective measures at source, and policy of polluter pays together with environmental protection. It also takes into account pricing of water resources and larger involvement of the citizens. To implement the principle of "the polluter pays," effective and suitable financial instruments need to be enforced.

6.2 Indian Perspective

Safe drinking water is a constitutionally guaranteed right in India. Indian constitution provides that water supply comes under state subject. Although union government is empowered for setting standards, state governments under its set department take care of domestic water supply in rural and urban areas. The Indian National Water Policy also emphasizes regular monitoring of water quality. It is estimated that around 37.7 million Indians are affected by waterborne diseases annually, which resulted in economic burden being $600 million a year.

The overdependency on groundwater has caused 66 million people in 22 states at risk due to excessive fluoride and around 10 million people at risk due to arsenic in 6 states. There are also problems due to excessive salinity, especially in coastal areas, and iron, manganese, nitrates, and other contaminants. The major groundwater contaminants that affect human health are fluoride, arsenic, nitrate, and fecal coliforms. Waterborne diseases like diarrhea, gastroenteritis, hepatitis, jaundice, cholera, typhoid, polio, etc. are mainly caused by coliforms and related pathogens in groundwater.

Chakraborti et al. (2011) examining India's groundwater quality management scenario suggested a number of policy options like artificial groundwater recharge, increasing groundwater efficiency, enhancing crop productivity, crop diversification, protecting uncontrolled groundwater withdrawal promoted by highly subsidized agricultural electricity, educating and mobilizing communities by awaring pollution challenges, and strengthening the communities for groundwater quality protection.

6.3 Groundwater Quality Data Assimilation

Generation of reliable and accurate information regarding the water quality should be the primary action. While CPCB and State PCB laboratories have set standards for surface water effluent quality, the Bureau of Indian Standards (BIS) has been responsible for developing drinking water quality standards for India. The Central Ground Water Board (CGWB) along with the State Ground Water Agencies is primarily responsible for monitoring groundwater quality. Other institutions like the National Environmental Engineering Research Institute (NEERI), the National Institute of Hydrology, and the All India Institute of Hygiene and Public Health, various universities, etc. undertake regular water quality research. All State Public Health Engineering Departments have established water quality testing laboratories in state, district, and zonal levels. The huge data on groundwater quality being collected by different agencies need to be collated, and data banks need to be established, both centrally and state-wise.

6.4 Institutional Issues for Policy Development

A groundwater quality protection policy framing requires primarily creation of a Policy Task Force involving key institutions of environment, health, agriculture, industry, water resources, and local government with the setting up of a lead agency to coordinate the policy and strategy for groundwater protection and management. A well-conceived institutional framework having clear-cut accountability of responsibilities may bring desired changes in achieving groundwater protection requirements.

6.5 Capacity Building

Interdisciplinary training under inter-sectoral coordination may ensure a better competence and skills for resolving groundwater issues. In planning and managing groundwater resources, "catchment" should be considered as an integrated unit. Community-based water quality monitoring approach may yield better results. Education of local people in both aspects of hygiene and availability of resources quality-wise will help in improving public health.

6.6 Legislative Framework

A land owner is having the right to collect and dispose all water under this land and on the surface within his own limits as per Easement Act, 1982(Suhag 2016). The land owner, therefore, has significant power over groundwater, while landless people who use groundwater do not have any power over groundwater, and excludes landless groundwater users from its purview.

Although under Article 21 supreme court and various high courts gave judgements on water-related concerns like access to safe drinking water and considered safe drinking water as a fundamental right, state legislative assemblies only can make laws on this subject as the constitution provides water under the state list. The central government through circulation of Model Bills provides guidelines based on which the state governments may enact their laws.

Since abstraction of groundwater has a great influence on water quality, a sound legal instrument and its effective enforcement can only control it. It is being realized worldwide that considering the utmost importance of groundwater, both quantity and quality, individual "rights" may be substituted by permissions.

For getting maximum benefit for groundwater protection policies and regulation, some specific tools and incentives may be deployed. The introduction of incentives may be as effective as legal control and prohibitive measures. Provisions as laid down for environmental protection and pollution control can be extended for protection of groundwater quality.

6.7 Groundwater Quality Monitoring

There are four major objectives of monitoring groundwater quality, namely, determination of background groundwater quality, determination of permit compliance, detection of groundwater contamination, and characterization of the effectiveness of corrective action. They also found that groundwater quality variables may sometimes exhibit seasonality and predictability cyclic behavior and are frequently non-normally distributed. It was also found that significant variability occurs in vertical concentration gradients, horizontal concentration gradients, time or volume of pumping, sample collection procedures and data management procedures, and suggested skewness test for evaluating the normally assumption in groundwater quality data.

6.8 Tools for Groundwater Quality Protection

To restrict the contamination of groundwater, stringent application of price mechanism in which "polluter pays" can be useful. The use of incentives is often as effective as the use of prohibition or controls. Legislation developed for general environmental protection and pollution control can be employed to deal with the activities which affect the quality of groundwater. Important tools that can be used to protect groundwater are wellhead protection plans, vulnerability assessment, codes of practice, economic instrument, education, community awareness and involvement, and land-use planning.

6.9 Aquifer Mapping and Aquifer Modeling

Scientists are increasingly taking the help of mathematical simulation techniques in different types of groundwater development schemes based on evaluation of hydrogeological mapping and information collected thereon. Applying a model is an exercise in thinking about the way a system works without any deleterious effect. Aquifer mapping should be suitably designated to collect accurate and precise informations about hydrological and hydrogeological components pertaining to concerned aquifer system to be modeled. Nevertheless, aquifer modeling is going to be the emerging tool in groundwater protection in the near future.

6.10 Land-Use Planning and Management

Land-use planning and pollution of groundwater are interrelated. Planning controls for protection of groundwater taken up by the state governments may also be incorporated in national planning process and regional planning. For protecting groundwater, controls on land zoning and subdivisions implemented by the state governments can provide effective tools. By providing suitable incentives, abstraction practices that cause groundwater pollution can be curbed. Tax incentives to use less susceptible to leaching or degradation of soil by a specific type of fertilizer or pesticide can be an effective tool. Price mechanism can also be used to restrict the amount of contamination that reaches groundwater; stringent application of "polluter pays" principle may reduce the contamination effect.

6.11 Water Resource Management

Water resource management that can have an impact on groundwater quality is artificial recharge to groundwater system using potable water. Artificial recharge helps in diluting some pollutants in the aquifer. Maintaining an effective water balance by controlling discharge-recharge relationship can also enhance the sustainability of groundwater development schemes. Rainwater harvesting practices can be an important means to sustain large-scale groundwater withdrawal resulting in quality hazards, especially in small watersheds and mini-water supply schemes. Since the practice is proving to be quite effective, it is necessary to have such wise water management, and a national approach should be developed to ensure that artificial recharge and rainwater harvesting schemes form the integral part of the overall groundwater quality protection strategies.

6.12 Consultation and Participation

Understanding the needs of the community is a prerequisite and part of the process of establishing a dialogue from which a mutual trust can be developed for achieving common goals and plans. Regular collection of information and educating the beneficiaries on knowledge, attitude, and practices are necessary for ensuring accurate assessments, progress of monitoring, and development of trust among all stakeholders. Dissemination of information on transparent basis is a primary requisite for development plans. For information gathering and also for dialogue and negotiation, community participation may be a continuous process.

6.13 Mass Awareness and Social Empowerment

IEC material should be suitably tailored to create sufficient awareness among the rural and urban communities about early precautionary signals related to the diseases like arsenicosis, fluorosis, etc. based on the sound water quality monitoring.

6.14 Issue of Social Convergence

To address the issues of water quality monitoring and interventions jointly, all the agencies including government organizations and NGOs and other stakeholders, decentralized water testing, as being propagated by different agencies should be considered with proper emphasis. Community awareness needs to be built up in the context of such social convergence by upgrading the existing laboratories managed by both government agencies and NGOs so that capacity in terms of monitoring and analysis of microbial parameter data management, at the local level, can be enhanced. There is a need for addressing bacteriological and chemical contamination in totality.

6.15 Nutrition Management

The nutrients and the sources often recommended for nutritional interventions for fluoride and arsenic are calcium (milk, dahi, green leafy vegetables, sesame (til) seeds, cheese/paneer, drumstick, arbi, etc.), iron (beetroot, apple, raw or green banana), vitamin C (amla, guava, lemon, oranges, tomato, sprouted cereals, and pulses), vitamin E (vegetable oil, nuts, whole grain cereals, dried beans, etc.), and antioxidants (papaya, carrot, pumpkin, mango, spinach (palak) and other leafy vegetables, garlic, onion, chili, pepper, cabbage, cauliflower, radish, lychee, watermelon, soybean, mushrooms, ginger, sweet corn, etc.). For arsenic patients, selenium-rich food like meat, etc. have also been found useful.

7 Conclusion

Toxicity in groundwater has already posed considerable problems in India. Protecting groundwater from toxic contaminants, geogenic and anthropogenic, needs effective management. Groundwater system, very complex in nature, the chemistry of toxic chemical, constituents in groundwater, source of contaminated chemical constituents, and the efficacy of different component of groundwater quality protection have not yet been completely understood. Because of uncertainty in planning for groundwater protection, it is imperative that groundwater quality plans be continuously reviewed and reassessed. Effective steps need to be taken commensurate with availability of the technology options.

Acknowledgment Thanks are extended to Shri Abhijeet Roy and other scientists of the Centre for Groundwater Studies. The second author would like to thank Mr. M. Thirumurugan, Research Scholar, Department of Geology, Anna University, Chennai, for his assistance in the preparation of this chapter.

References

Brindha K, Elango L, RNV N (2011) Spatial and temporal variation of uranium in a shallow weathered rock aquifer in southern India. J Earth Syst Sci 120(5):911–920

Brindha K, Rajesh R, Murugan R, Elango L (2012) Nitrate pollution in groundwater in some rural areas of Nalgonda district, Andhra Pradesh, India. J Sci Eng 54(1):64–70

CGWB (1999) High incidence of arsenic in ground water in West Bengal. Central Ground Water Board, Eastern Region Kolkata Available at www.cgwb.gov.in
Chakraborti D, Bhaskar D, Mathew TM (2011) Examining India's groundwater quality management. Environ Sci Technol 45:27–33
Guha Mazumder DN (2015) Human health hazards due to arsenic and fluoride contamination in drinking water and food chain, International seminar on Challenges to ground water management: Vision 2050: 385–392.
Lepokurova OE, Ivanova IS (2014) Geochemistry of iron in organogenic water of Western Siberia, Russia. Procedia Earth Planet Sci 10:297–302
Rajmohan N, Elango L (2005) Distribution of Iron, Manganese, Zinc and Atrazine in groundwater in parts of Palar and Cheyyar river basins, South India. J Environ Monitor Assess 107:115–131
Sinha Ray SP (2015) Geogenic fluoride contamination in groundwater- integrated fluorosis management. Bhujal Manthan, CGWB, Kurukshetra Available at: www.cgwb.gov.in
Suhag R (2016, February) PRS publication. Overview of ground water in India. Available at: http://www.prsindia.org/administrator/uploads/general/1455682937~~Overview%20of%20Ground%20Water%20in%20India.pdf
Zhao Z (2015) A Global Assessment of Nitrate Contamination in Groundwater. Report, pp. 1–27

S. P. Sinha Ray got his postgraduate degree in applied geology from Jadavpur University in 1964 and obtained PhD (science) degree from the same University in 1974. He joined Geological Survey of India in 1966; subsequently, his service was transferred to Central Ground Water Board in 1972. He is a former Member (SML) of Central Ground Water Board. He has more than 40 years of extensive experience in groundwater exploration, development and management. By virtue of his long association with the apex body of the country dealing with groundwater resources, he has acquired a very rich understanding on the particular subject. Besides the country, he has also gained knowledge and working experience in other countries like Algeria, Bangladesh, the USA, Korea and Zimbabwe. He has also contributed in various national and international publications. He attended training on "Ground Resources Development" organized by Overseas Technical Cooperation Agency, Japan, Tokyo, in 1973, and training on "Computer and Databases" in San Juan, Puerto Rico, by US Geologist Survey in 1992. He is the founder president of the NGO, the Centre for Ground Water Studies, Kolkata (founded in 2003), who is committed to carry out research, investigation, consultancy and HR development for groundwater scientists.

L. Elango Anna University, Chennai, with an experience of over 35 years in the field of hydrogeology has a master's degree in science and engineering and a PhD in hydrogeology. He has carried out his postdoctoral work at the University of Birmingham, UK. His research interests include hydrogeochemistry, groundwater contamination and transport. He has participated in professional training programmes at Danish Hydraulic Institute, Swiss Federal Institute of Technology and UNESCO Institute of Water Education, Delft. He has published about 140 research papers in various journals and edited 8 books. He has organized workshops sponsored by the UNESCO's International Hydrology Programme, the World Bank and the German Consulate. Besides projects sponsored by Indian agencies, he carried out international projects with the support of the European Commission, British Geological Survey, Australian Research Council and Russian Academy of Sciences. He is a vice president of the International Association of Hydrological Sciences.

Constitutional Provisions Related to Water and Integrated Planning and Management of a River Basin: A Review

M. E. Haque, H. K. Varma, and Avinash C. Tyagi

1 Introduction

Water resource development in India in a sustainable manner is a complex challenge. These challenges are required to be understood in proper perspective and addressed on priority because they directly impact each and every member of the society. The challenges are related to several aspects of the resource – declining per capita water availability, deterioration in water quality, and increasing and competitive demand for water for various purposes, e.g. drinking water needs and irrigation requirements for growing population, water demands for industrial development, environmental needs, etc.

Water is a subject which impacts all citizens. Therefore, participation of people from all section of the society in such discussions is desirable. However, many a times such discussions lack an appreciation of the complexities associated with water and water management, restricting discussions to specific issues, with an urge for arriving at simplistic instantaneous solutions. As a result, a series of faults in earlier planning and deficiencies in water management are flagged, and in general, emphasis is laid on integrated planning.

Although there is urgent need for integrated planning for water resources and undertaking measures for reforms toward better management of created facilities for efficient and optimal water resource utilization, on most of the occasions, the

M. E. Haque (✉)
Former Member, Central Water Commission, Government of India, New Delhi, India

H. K. Varma
Executive Director, International Commission on Irrigation and Drainage, New Delhi, India

A. C. Tyagi
Former Secretary General, International Commission on Irrigation and Drainage, New Delhi, India

© Springer Nature Singapore Pte Ltd. 2019

A. Singh et al. (eds.), *Water Governance: Challenges and Prospects*, Springer Water,
https://doi.org/10.1007/978-981-13-2700-1_6

issues of addressing challenges in water sector end up with a call for review of constitutional provisions.

This paper confines itself to review of the constitutional provisions relevant to integrated management of the resource through proper planning and management. In this background, the contents of this paper have been restricted to (a) review of the constitutional provisions related to water resources, (b) suggesting road map for initiating the process of integrated planning for water resources and (c) identifying measures for ensuring reforms toward better management of water sector.

2 Constitutional Provisions

2.1 Specific Provisions

Three most often referred-to provisions related to water in Constitution are (a) Entry 17 of the List I (State List) of the Seventh Schedule, (b) Entry 56 of the List II (Union List) of the Seventh Schedule and (c) Article 262 of the Constitution. These provisions as included in the constitution are quoted as under.

Entry 17 of List II (State List) of the 7th Schedule

Water, that is to say, water supplies, irrigation and canals, drainage and embankments, water storage and water power subject to provisions of entry 56 of List I

Entry 56 of List I (Union List) of the 7th Schedule

Regulation and development of inter-State rivers and river valleys to the extent to which such regulation and development under the control of the Union is declared by Parliament by law to be expedient in the public interest

Article 262

Disputes relating to Water – Adjudication of disputes relating to waters of inter-State rivers or river valleys

1. Parliament may by law provide for the adjudication of any dispute or complaint with respect to the use, distribution or control of the waters of, or in, any inter-State river or river valley.
2. Notwithstanding anything in this Constitution, Parliament may be law provide that neither the Supreme Court nor any other court shall exercise jurisdiction in respect of any such dispute or complaint as is referred to in clause (1).

(Source: Constitution of India, March 2016, http://lawmin.nic.in/olwing/coi/coi-english/coi-4March2016.pdf)

2.2 Other Related Provisions

Apart from the above-mentioned provisions in the constitution about water resources, the issues related to water and water uses also appear in several articles and/or schedules of the Constitution are quoted as under.

1. Article 243ZD in respect of Committee for district planning which inter-alia provides that every District Planning Committee shall, in preparing the draft development plan, have regard to matters of common interest between the Panchayats and Municipalities including spatial planning, sharing of water and other physical and natural resources, the integrated development of infrastructure and environmental conservation and the extent and type of available resources, both financial or otherwise.
2. Similar provision exist in respect of Committee for Metropolitan planning under Article 243ZE
3. Additional powers of the Bodoland Territorial Council to make laws Article 244(2) – Sixth Schedule – Entry 3B (vii) flood control for protection of village, paddy fields, markets and towns (not of technical nature) and Entry 3B (xiii) irrigation.
4. Following Entries of List I (Union List) of Seventh Schedule
   - Entry 24. Shipping and navigation on inland waterways, declared by Parliament by law to be national waterways, as regards mechanically propelled vessels; the rule of the road on such waterways,
   - Entry 25. Maritime shipping and navigation, including shipping and navigation on tidal waters, provision of education and training for the mercantile marine and regulation of such education and training provided by States and other agencies,
   - Entry 30. Carriage of passengers and goods by railway, sea or air or by national waterways in mechanically propelled vessels, and
   - Entry 57. Fishing and fisheries beyond territorial waters.
5. Following Entries of List III (Concurrent List) of Seventh Schedule
   - Entry 20. Economic and social planning, and
   - Entry 32. Shipping and navigation on inland waterways as regards mechanically propelled vessels, and the rule of the road on such waterways, and the carriage of passengers and goods on inland waterways subject to the provisions of List I with respect to national waterways.
6. Following Entries of Eleventh Schedule
   - Entry 3. Minor irrigation, water management and watershed development,
   - Entry 11. Drinking water, and
   - Entry 13. Roads, culverts, bridges, ferries, waterways and other means of communication.

(Source: Constitution of India, March 2016, http://lawmin.nic.in/olwing/coi/coi-english/coi-4March2016.pdf)

There is no specific mention of “water” in the Entry 20 of the List III (Concurrent List) of Seventh Schedule; however, this entry undoubtedly covers the matter related to planning of water resources – a resource which is not only a lifeline of the social system but also an essential input for economic development.

3 Review of the Constitutional Provision Related to Water

Without giving any commentary on several provisions related to water in the constitution, it may be mentioned that the need or desirability of reconsideration of the provisions has been highlighted from time to time and that such points have been considered and examined by several committees in the past.

3.1 Need for Review

Majority of the river basins in the country are interstate river basins, and the matters related to water dispute continue to be in the news in one form or the other. The water disputes and delay in dispute resolution has undoubtedly affected the process of planning of water resources in an integrated manner and has contributed to relatively poor planning in respect of development of water resources.

For example, for a very long time, many of the envisaged projects of Krishna basin could not be taken up for techno-economic appraisal and investment clearances from central agencies for want of final award on water sharing by the Tribunal. At the same time, respective State Governments have gone ahead with the launching of such unapproved projects, without all needed evaluation and also without ensuring the availability of adequate funds essentially required for timely completion of the projects, perhaps with the objective of laying their claims on more and more water of the basin. Such exercise has two distinct impacts – first a setback to the integrated planning and second long gestation periods for the projects resulting in unproductive investment for relatively longer time.

Another very serious problem arises when, on the basis of claims of the respective States, water sharing is decided by the Tribunal without any comprehensive and serious planning exercise for the optimal utilization of the scarce water resources. It remains a fact that the decision for allocation to the States for various uses and for various projects and its regulation limit the scope of integrated planning and put certain degree of constraint in achieving the objective of optimal utilization of scarce water resources. In the absence of proper regulation policies, the complaints of lower riparian States have become a regular feature. Interestingly, the complaints are not limited to release of lesser water during the lean years but also relate to excess water resulting in flood-like situation in years having more water in the river system.

3.2 Reviews Undertaken in the Past

Many a times, and through most recommendations at various fora, a message has been conveyed that integrated planning and reforms cannot be taken up and implemented without reviewing the existing constitutional provisions, and in this regard, the suggestions are, generally, limited to either (a) the subject water should be brought into the List III (Concurrent List) of the Seventh Schedule of the constitution or (b) a suitable act may be considered under Entry 56 of the List I (Union List) of the Seventh Schedule.

Relevant extracts from the report of such Commissions are reproduced hereunder.

3.2.1 Sarkaria Commission[1]

The Government of India, in June 1983, had constituted a Commission under the Chairmanship of Justice R. S. Sarkaria to review the working of the existing arrangement between the Union and the States. The Commission had submitted its report in January 1988 dwelling upon issues related to interstate water disputes also. The matters related to optimum utilization of the water resources and need for its comprehensive planning have also been examined and discussed in the Report of the Commission. Specific recommendations made by the Commission in respect of constitutional provisions are quoted as under.

> We are, therefore, of the view that the existing arrangements which allow the States competence in regard to matters in entry 17, List II—subject, however, to Union's intervention when found necessary in public interest only in inter-State river and river valleys—is the best possible method of distributing power between the Union and the States with respect to this highly sensitive and difficult subject. We are, therefore, unable to support the suggestion that "Water" should be made a "Union subject".
>
> (Source: Report of the Commission on Centre-State Relation [Sarkaria Commission Report], Inter-State Council Secretariat, Government of India, 1988)

3.2.2 National Commission on Integrated Water Resources Development[2]

To look into the issues related to Integrated Water Resources Development, a high-powered Commission, set up by the Government of India in 1996, also examined the issues related to constitutional provisions about water. Specific observations of the Commission in its report submitted in September 1999 are quoted as under:

> We are not, therefore, proposing any change in the scheme of the constitution. What is needed now is for the Union to pass laws to more effectively deal with inter-state rivers. There is also need for the Union to put in place Centre-State consultative mechanisms of an effective kind, through which the Centre and the States could agree on a number of issues relating to water.
>
> (Source: Report of the National Commission for Integrated Water Resources Development, 1999, MOWR)

[1]Government of India (1988), Report of the Commission on Centre-State Relation [Sarkaria Commission Report], Interstate Council Secretariat, Ministry of Home Affairs, New Delhi.

[2]Ministry of Water Resources (1999), Report of the National Commission for Integrated Water Resources Development (Volume I), New Delhi (No change required as name of report and reference).

3.2.3 Punchhi Commission[3]

The government of India had constituted a Commission on Centre-State relations in April 2007, headed by Justice Madan Mohan Punchhi, former Chief Justice of India, to look into the new issues of Centre-State relations, considering the changes in the polity and economy of India post Sarkaria Commission. The sharing of resources including the interstate river waters was kept in the terms of reference, which would review the working of the existing arrangements between the Union and the States in this regard. The planning and implementation of the mega projects like interlinking of rivers were also considered. Specific recommendation of the Commission in respect of constitutional provisions related to water is quoted as under.

> A view has been expressed that perhaps such a harmony can be achieved by shifting "water" to the Concurrent List or by "nationalization" of inter-State rivers. We do not see merit in these proposals. Items in the Concurrent List can be acted upon both by the Centre and States. The Constitutional provisions at present do not preclude this. Moreover such a shift in the case of water would lead to similar demands say in the case of "land". We are not in favour of initiating such a ripple effect in Centre-State relations.
>
> Moreover, good governance calls for decentralization, because of the variety of local problems and solutions. This is more so in the case of water. The Constitution gives a direct responsibility to the States and through Parts IX and IXA enjoins upon them to proceed with a further set of devolutions to Local Bodies. This to our mind is the appropriate path to a decentralized action on water related matters. Nationalization connotes ownership and this is difficult to establish in the case of flowing water. What is required is regulation of water use and for that nationalization is not a requirement.
>
> The Constitutional provisions as they stand are sufficient to address the issues of water use and management. A national consensus must emerge on water policy and this in turn should guide the enactments of the Centre (under Entry 56 of List I) and those of the States (under Entry 17 of List II). We are not, therefore, proposing any change in the scheme of the constitution. What is needed now is for the Union to pass laws to more effectively deal with inter-state rivers. There is also need for the Union to put in place Centre-State consultative mechanisms of an effective kind, through which the Centre and the States could agree on a number of issues relating to water.
>
> (Source: Report of the Commission on Centre-State Relation [Punchhi Commission Report], Volume 6 (page 43-44), Government of India, 2010)

3.2.4 Chawla Committee

A Committee was constituted by the Government of India constituted under Shri Ashok Chawla, the then Finance Secretary, with a view to examine the issues related to enhancing the effectiveness and sustainability in utilization of natural resources in a transparent manner, consistent with the needs of the country to achieve accelerated economic development. The Committee also examined the matters related to water

[3]Government of India (2010), Report of the Commission on Centre-State Relation [Punchhi Commission Report], Interstate Council Secretariat, Ministry of Home Affairs, New Delhi.

resources. Specific recommendations of the Committee in respect of constitutional provisions are quoted as under.

> The Committee sees an urgent need to have a comprehensive national legislation on water. This can be either done through bringing water under the Concurrent List and then framing the appropriate legislation; or, by obtaining consensus from a majority of the States that such a "framework law" is necessary and desirable as a Union enactment. The legal options in this regard need to be examined by the Ministry of Water Resources.
>
> The national legislation should clarify a common position on a number of issues, e.g., need to consider all water resources as a conjunctive, unified whole; water as a common property resource; principles of allocations and pricing and so on. The framework legislation should recognize that pollution also leads to conjunctive use of water, which makes the resource unusable for other purposes.
>
> (Source: Report of the Committee on Allocation of Natural Resources, Government of India, January 2011, Chapter 10-Water, Recommendation 34 (pp132), http://www.cuts-ccier.org/pdf/Report_of_the_Committee_on_Allocation_of_Natural_Resources.pdf)

From the specific observation of the Sarkaria Commission and Punchhi Commission on Centre State relations, it is apparent that changes in constitutional provisions are not favoured by these commissions, probably, in view of sensitivities associated with the subject and its direct impact on various other matters on the Centre and State relations. It is also observed that the National Commission on Integrated Water Resources Development Plan has also indicated that specific changes in the constitutional provision may not be needed and that the water-related matters can be addressed through appropriate legislative measures by the Union Government. However, Chawla Committee which was primarily to look into the issues of natural resources has come out with the suggestion of comprehensive national legislation on water, but even the Chawla Committee has also not suggested for any change in the constitutional provision. In this regard, provisions for water policy are very amply clear and explain the situation.

3.3 Proposed National Framework Law

The National Water Resources Council adopted the National Water Policy 2012[4] which highlights the need for evolving a National Framework Law as under.

> There is a need to evolve a National Framework Law as an umbrella statement of general principles governing the exercise of legislative and/or executive (or devolved) powers by the Centre, the States and the local governing bodies. This should lead the way for essential legislation on water governance in every State of the Union and devolution of necessary authority to the lower tiers of government to deal with the local water situation.
>
> Such a framework law must recognize water not only as a scarce resource but also as a sustainer of life and ecology. Therefore, water, particularly, groundwater, needs to be managed as a community resource held, by the state, under public trust doctrine to achieve

[4]Ministry of Water Resources (2012), National Water Policy 2012, New Delhi.

food security, livelihood, and equitable and sustainable development for all. Existing Acts may have to be modified accordingly.

There is a need for comprehensive legislation for optimum development of inter-State rivers and river valleys to facilitate inter-State coordination ensuring scientific planning of land and water resources taking basin/sub-basin as unit with unified perspectives of water in all its forms (including precipitation, soil moisture, ground and surface water) and ensuring holistic and balanced development of both the catchment and the command areas. Such legislation needs, inter alia, to deal with and enable establishment of basin authorities, comprising party States, with appropriate powers to plan, manage and regulate utilization of water resource in the basins.

(Source: http://mowr.gov.in/sites/default/files/NWP2012Eng6495132651_1.pdf: National Water Policy, 2012, Section 2)

4 Integrated Planning for Water Resources

4.1 The Constitutional Logjam

Majority of the water resource development planning in India is carried out in isolation for specific sites. No doubt, there are multipurpose projects, but even in case of such individual projects, the concept of integrated plan for utilization of available resources is missing. The detailed project report (DPR) in respect of individual project is never prepared after due consideration of the process of identification of all possible alternatives and their critical evaluation.

In India, majority of the river basins spread over more than one State; thus the role of the Union Government is critical in this direction. However, in view of the existing constitutional provisions, the Union Government cannot proceed towards preparation of such integrated plan on its own and ensure the implementation without taking the concerned States into confidence. It also remains a fact that the idea of establishment of river boards has not materialized despite the existence of a River Board Act since 1956 as the States are observed to be less interested since they perceive this as a loss of power.

River basin management in India, to date, has explored solutions of specific problems, and all the boards established function as Advisory Committee/Board with the exceptions of Cauvery River Authority and Narmada Control Authority which are formed under the directions of Tribunals. The only example with integrated planning as main objective was preparation of "Preliminary Memorandum on Unified Development of Damodar River" by M. L. Voorduin[5] (August 1944). Based on that plan, work was taken up. However, all the components included in the plan have not yet been fully implemented because of various reasons.

[5]Damodar Valley Corporation, Web Site, Preliminary Memorandum on Unified Development of the Damodar River submitted by Mr. M. L. Voorduin in August 1944 (no change as reference name).

The Bhakra Management Board, often cited as a successful example, was constituted under the Punjab Reorganisation Act, 1966. The master plan prepared on harnessing the potential of the Sutlej, the Beas and the Ravi was prepared considering the Bhakra and Beas projects as a major part of the plan. Subsequently with the effect from 15 May 1976, the Bhakra Management Board was renamed as Bhakra Beas Management Board (BBMB). Since then, the BBMB is engaged in regulating the supply of water and power generated from Bhakra Nangal and Beas projects to the five States and one Union territory, viz. Haryana, Punjab, Himachal Pradesh, Delhi, Rajasthan, and Chandigarh.

Invoking the constitutional provision under Entry 20 of List III (concurrent list) of the Seventh Schedule which provides for social and economic planning could also be considered. Undoubtedly, a question whether such exercise will be acceptable to the concerned parties, i.e. the State Governments, is quite pertinent. However, a professional approach will definitely help the stakeholders in appreciating the issues and selecting a better option, thus achieving the objective of improved management of the resource.

The Union Ministry of Water Resources, River Development and Ganga Rejuvenation and NITI Aayog (erstwhile Planning Commission) are fully involved with the process of appraisal of almost all of the major and medium irrigation projects and multipurpose projects for water development. The Central Water Commission undertakes technical evaluation and also provides technical support in improving the project features. The Central Water Commission is also actively associated with the appraisal of hydropower projects which are given necessary clearances by the Ministry of Power.

During the course of appraisal, several reform measures towards improving the efficacy of the system is suggested and incorporated in the plans by central agencies. The reform measures are also introduced in respect of projects which are provided necessary financial assistance by the Union Government under various projects such as Command Area Development and Water Management Programme (CAD&WM), Accelerated Irrigation Benefit Programme (AIBP), Flood Management Programme, Pradhan Mantri Krishi Sinchai Yojana (PMKSY), etc.

While several projects in the country have been developed based on bilateral or multilateral agreements among the party States, the only sincere effort made towards the preparation of comprehensive plan through such a mechanism was the establishment, by Union Government, of Sone River Commission for preparation of comprehensive plan for development of Sone River Basin. The Commission was created with the agreement amongst the party States. However, no serious efforts were made towards consensus building among the stakeholders towards the process of implementation of the plan prepared by the Sone River Commission. With changing scenario, particularly the creation of more States and related social issues, the review of the works of Sone River Commission is necessary. The creation of Brahmaputra Board and Ganga Flood Control Commission is the right step towards effort for development of comprehensive and integrated plan for water resource management.

Perhaps, it is in this background that the issue of review of constitutional provisions has been undertaken from time to time. Further, in view of the opinion expressed by various Commission/Committees as also the suggestions emerging at different fora, the changes in the existing constitutional provisions related to water appear to be a very challenging exercise.

4.2 Other Regulatory Mechanisms

While undertaking exercise of Integrated Water Resources Planning (IWRP) in a comprehensive manner, it is essential to take into account all possible aspects such as water availability from all sources (rain water, groundwater, surface water, etc.), water demand from all sectors (domestic, agriculture, industries, energy, environment and ecological), water quality (surface and groundwater), water-related disasters (floods, droughts), environmental protection and enhancement, hydraulic structures and financial planning with due consideration to possible climate change impact on water resources and involvement and consultation of different stakeholders in a transparent manner.

The lack of appropriate regulatory mechanism in respect of groundwater has led to its overexploitation in large parts of the country. Further, indiscriminate discharge of untreated or partially treated industrial, domestic and agricultural waste and effluents into waterbodies is polluting these water sources making them unfit for use. So there is need to regulate groundwater development and effluent discharge into fresh waterbodies. Governance issues related to groundwater development, management and regulation and water quality aspects are discussed in detail elsewhere in the journal. Water-related disasters especially floods are affecting large section of the society every year at different places. So it is important to consider various aspects of integrated flood management encompassing both structural and nonstructural measures, community participation, climate change adaptation mechanism, etc. Various legal issues related to flood forecasting and warning, flood risk hazard mapping and flood plain zoning are discussed in respective articles in this journal.

It is high time for the Union Government to look into integrated plan for development and management of water resources of the country by strengthening the constitutional and legal mechanism for facilitating the process.

4.3 Institutional Mechanism

Apart from the conceived loss of power, an independent say in the development is one of the prime reasons for disagreement between the States on the development of water resources of an interstate basin, even if they are undertaken by independent authorities. In this regard, the following extract from the Note of the Labour Department, under Dr. B. R. Ambedkar, to the Finance Department vide file no. DW.I-1(25) CWINC/47 page 36[6] is quite relevant.

> . . . It is essential that the Centre should take over such responsibility it can in respect of waterways control. The problems are immense and there must be an All-India body with

[6]Central Water Commission (1993), Ambedkar's Contribution to Water Resources Development, New Delhi (name of publication as reference, no change required).

sufficient weight to be able to give an opinion with conviction which Provinces will respect and accept.

Obviously, with the element of respect, many hurdles can be overcome as the concerned parties will be willing to accept a plan which is based on professional and unbiased approach and presents a win-win situation from overall perspective. But it would require competence of highest order. The task is an achievable task for a highly competent team of professionals who can visualize all possible alternatives and are capable of evaluating the pros and cons of such alternatives not merely through a questionable set procedure but in wider perspective of social and economic planning. Such exercise will definitely help the decision-makers in convergence and arriving at the most logical conclusions.

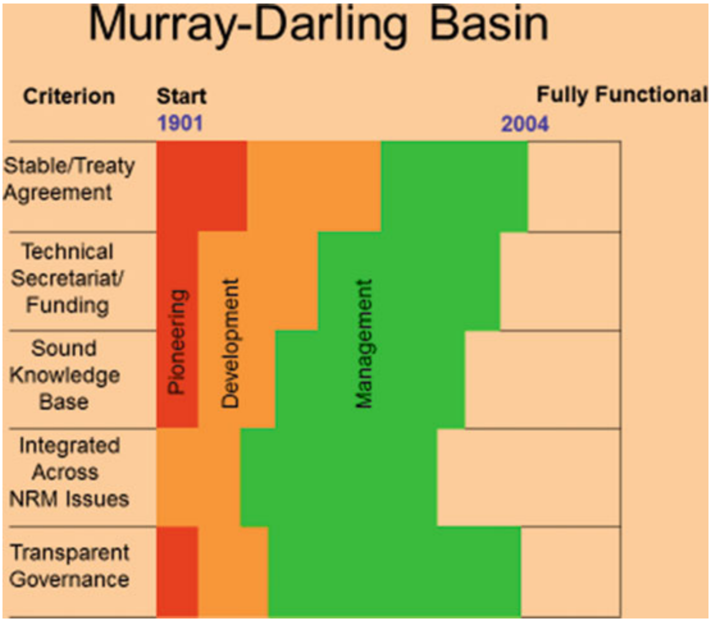
Further, the latest knowhow in respect of integrated planning and system studies are also available with various academic institutions and research stations in the country. What is required is the translation of such knowledge to address the field problems. Sincere efforts towards pooling of the available expertise would definitely help in moving towards the goal of preparation of integrated plan for development and management of water resources in the country. A beginning in this direction will undoubtedly support the decision-makers in appreciating the gains from such approach. Such exercise can be initiated without any delay by reorganization and strengthening of the existing institutions with suitable mechanism for involving the stakeholders as well as the experts and professional.

4.4 Towards Consensus Building

It remains a fact that water-related issues have inherent contradictions which often emerge as conflicts among "uses" as well as among "users". Such conflicts are visible at all level – from a community well in rural areas to municipality tap in semiurban to supply of water to different utilities in cosmopolitan to interstate disputes of serious nature. Any effort towards integrated water resource planning, development and management would succeed only if such contradictions and causes of disputes are understood and addressed in proper perspective. It has to be accepted that these contradictions and disputes have roots in socio-economic and socio-political profile of the society who are dependent on and aspire to get benefitted from specific source of water.

Therefore, for putting in place an integrated water resource planning, development and management process, it is necessary to (a) initiate a proper understanding of the expectation of all stakeholders, (b) to undertake critical evaluation, (c) identify all possible scenario and then (d) bring them closer through a plan with win-win situation for all. In this background, a step by step, sincere and persistent effort is essential. Further, such initiatives have to be taken up at all levels – professional, administrative and political. It may not be out of place to mention that despite a number of successful model for integrated basin management in the form of river basin organization, etc. in practice world over and also a few models for integrated planning and management with limited objectives, the task of putting in place an effective mechanism for integrated water resource planning, development and management is a gigantic task. It would be interesting to see how some of the successful models have evolved.

The process of evolution of Murray-Darling Basin is described as consisting of three phases, namely, (a) pioneering phase (1900–1920), (b) development phase (1920–1967) and (c) management phase (1968 onwards). The evolution of various components is illustrated as under.



5 Constitutional and Institutional Reforms for Better Management of Water Resources

At present in India, comprehensive and integrated river basin management planning approach with focus on resolving existing hydrologic, ecologic and socio-economic problems through holistic policies is not current. Given the emerging challenges of water scarcity and the need to address all development in a sustainable manner, integrated river basin planning of water resources must be initiated without any loss of time. Delays, due to whatsoever reasons, are not desirable as such delays are bound to result in less than optimal benefits from the most precious gift of the nature, i.e. water. Undoubtedly actions have to be initiated simultaneously for (a) creating suitable mechanism for pooling the expertise and develop the integrated plans and (b) initiating dialogue for consensus building for legislative measures.

The exercise to build consensus on constitutional reforms and evolve suitable mechanism is required to be pursued vigorously; it would not be appropriate to simply wait and hope for the best. A confidence building exercise in the spirit of federalism needs to be initiated and consistently pursued at the highest political level. The development of well-intentioned National Framework Law as envisaged under National Water Policy should also be expedited.

Persistent and sincere efforts are needed to build and share common information platform, understand the development issues involved, undertake confidence building measures and create an environment of trust among communities sharing the basin. In the present scenario of political and professional mistrust prevalent in the country, as is evident from multifarious legal stalemates, such a persistent approach has been missing for want of clear vision and lack of leadership at political, professional and administrative levels.

The need for changes in the process of planning, development and management at the earliest is duly established. These efforts have to be institutionalized. Union Government has to play a very effective role of advisor, evaluator and monitor. In this regard, three important elements as under are necessarily required:

1. Well-established multidisciplinary system which can provide sound technical support and advice on purely evidence-based and scientific basis. This may call for pooling of all available human, technical and financial resources.
2. The plan produced by the Union must include all possible alternatives along with the pros and cons of all such identified alternatives which will help in decision-making process with due consideration to all factors including the social and economic factors.
3. A well-established monitoring mechanism involving not only the professionals and official from the Union Government and the State Government but also experts from academic and research institutions and non-governmental organization actively associated with the related activities.

Acknowledgement The view expressed in this paper is authors' personal. Thanks are extended to the colleagues for their valuable support during the preparation of this manuscript.

References

Central Water Commission (1993) Ambedkar's Contribution to Water Resources Development, Ministry of Water Resources, New Delhi. Available at www.mowr.gov.in

Government of India (1988) Report of the Commission on Centre State Relation. Sarkaria Commission Report, Inter-State Council Secretariat, Ministry of Home Affairs, New Delhi. Available at interstatecouncil.nic.in.

Government of India (2010) Report of the Commission on Centre - State Relation, Punchhi Commission Report, Inter-State Council Secretariat, Ministry of Home Affairs, New Delhi. Available at interstatecouncil.nic.in

Government of India (2011) Report of the committee on Allocation of natural Resources, Chapter 10 -Water Recommendation 34 http://www.cutsccier.org/pdf/Report_of_the_Committee_on_Allocation_of_Natural_Resources.pdf

Ministry of Water Resources (1999) Report of the National Commission for Integrated Water Resources Development (Volume I), Govt of India, New Delhi. Available at www.mowr.gov.in

Ministry of Water Resources (2012) National Water Policy, Government of India, New Delhi. http://mowr.gov.in/sites/default/files/NWP2012Eng6495132651_1.pdf

Voorduin ML (1944) Preliminary Memorandum on Unified Development of the Damodar River, Damodar Valley Corporation. Available at dvc.org.in

M. E. Haque is a former Member of Central Water Commission, Government of India and is presently associated with Mahadayi Water Disputes Tribunal. He has wide professional experience in water resources planning, particularly in the areas of policy issues, hydrological analysis and teaching and research in hydrology. His experience includes teaching at postgraduate level at the Department of Hydrology, University of Roorkee (now, IIT Roorkee) and research at National Institute of Hydrology, Roorkee. He also worked as a consultant of Asian Development Bank and National Water Development Agency.

Mr. Harish Kumar Varma is an Executive Director at the International Commission on Irrigation and Drainage. Mr. Varma has more than 39 years of work experience in various aspects of water resources planning, development and management while working in Central Water Commission and Water and Power Consultancy Services (India) Limited. He has worked with Asian Development Bank (ADB) in the field of irrigated agriculture and water management, integrated water resources management, climate change, water use efficiency improvement programme, etc. His main fields of activities include operation and maintenance of hydrological network, flood control and drainage, water resources system modelling, hydrodynamic modelling, investigation and preparation of detailed project report for hydropower/multipurpose projects, administration of loan and technical assistance for projects funded by ADB.

Er. Avinash C. Tyagi a 1973 graduate from the University of Roorkee, India, and a postgraduate from the Indian Institute of Technology (IIT) Delhi, has vast experience in dealing with various facets of water resources management starting from hydrologic observation to disaster risk management to interstate water dispute resolution to contributing to the national and international policy-making. He served as commissioner of policy planning in Ministry of Water Resources in India before leading water and climate wing at World Meteorological Organization (WMO) as director. He was instrumental in reviving the International Commission on Irrigation and Drainage (ICID), an international professional non-governmental organization, as its Secretary General. A leader in true sense, both at WMO and ICID, he introduced and successfully implemented a host of internationally acclaimed initiatives. He, through his interaction with water, climate and disaster managers from various member countries of WMO and ICID, gained an intimate knowledge of issues related to water resources, climate change and disaster management in developing countries around the world and helped them through transfer of technology and capacity development. He interacted with policy-makers and ministers of many member countries. Er. Tyagi is an ardent advocate of multidisciplinary collaboration for resolving complex development challenges and in continuing dialogue among various stakeholders and community participation in the water sector.

Governing Groundwater: Fostering Participatory and Aquifer-Based Regulation

Philippe Cullet

1 Introduction

Groundwater use has become pervasive over the past 50 years. Its importance can be gauged first from the fact that it is the source of around 80% of drinking water needs.[1] In addition, groundwater has also become the primary source of irrigation, accounting today for around 60% of agricultural use.[2] This extremely rapid increase in the reliance on groundwater for the most important water uses that support domestic needs and agricultural livelihoods in particular has led to over-exploitation in many parts of the country. It is therefore not surprising that 16% of assessed blocks are overexploited and another 14% semi-critical or critical.[3] In addition, the quality of the available water is rapidly diminishing, and many areas are, for instance, increasingly affected by fluoride.[4] There are thus issues of quantity and quality that affect an increasing number of aquifers.

[1]Planning Commission, 12th Five Year Plan (2012–2017) – Faster, More Inclusive and Sustainable Growth – Volume 1 (Government of India, 2012) 145.

[2]PS Vijay Shankar, Himanshu Kulkarni & Sunderrajan Krishnan, 'India's Groundwater Challenge and the Way Forward' (2011) 46/2 *Economic & Political Weekly* 37 and Aditi Mukherji, Stuti Rawat & Tushaar Shah, 'Major Insights from India's Minor Irrigation Censuses: 1986–1987 to 2006–2007' (2013) 48/26–27 *Economic & Political Weekly* 115.

[3]Central Ground Water Board, Ground Water Year Book – India 2016–2017, p 45.

[4]For example, K. Brindha and L. Elango, 'Fluoride in Groundwater: Causes, Implications and Mitigation Measures', *in* Stanley D Monroy ed., *Fluoride Properties, Applications and Environmental Management* (Nova Science Publishers, 2011) 111–36.

P. Cullet (✉)
Centre for Policy Research, Delhi and Professor of International & Environmental Law, SOAS University of London, London, UK
e-mail: pcullet@cprindia.org

© Springer Nature Singapore Pte Ltd. 2019

A. Singh et al. (eds.), *Water Governance: Challenges and Prospects*, Springer Water,
https://doi.org/10.1007/978-981-13-2700-1_7

From a regulatory perspective, the increasing reliance on groundwater, its over-exploitation and diminishing quality confirm that priority should be given to protection and conservation measures and to uses that are socially equitable. At present, the existing regulatory framework is incapable of providing an effective framework for conservation of groundwater at aquifer level. Indeed, existing rules essentially focus on the right of access to groundwater at the level of individual plots. This essentially precludes the adoption of measures looking beyond restrictions to the rights of individual landowners to abstract water. The existing regulatory framework is also largely insensitive to the social dimensions of groundwater use. Existing rules give landowners essentially unrestricted control over groundwater. In a context where land ownership is skewed and where the poor essentially rely on groundwater for access to drinking water, the dichotomy between rules of access favouring owners of the land and reliance of the overwhelming majority of people on groundwater is an increasing source of concern and conflict. This is particularly problematic in a context where groundwater is the primary source of water for the realisation of the fundamental right to water.

The existing challenges concerning protection and use of groundwater are caused in part by the existing regulatory framework. While it is often assumed that the crises are caused by an absence of regulatory framework, this is an inappropriate basis for addressing the problems we face. In fact, aquifer depletion has taken place in part because the legal framework has for decades specifically permitted landowners to take as much groundwater as they see fit with hardly any restrictions or safeguards in place. This is essentially what has prevented effective regulatory action over the past few decades since governments have hesitated in taking measures that would likely be opposed by large landowners whose political support may be crucial at the time of elections.

What is needed at this juncture are thus new forms of regulation for groundwater, as officially acknowledged in the 12th Five-Year Plan.[5] This requires introducing measures allowing local management of what is a common heritage of the community. The seriousness of the crisis has led the Government of India to take several initiatives in the 2010s to provide a new model legal framework that states should be able to adapt to their needs and specific situation.[6] The latest proposal, the Model Groundwater (Sustainable Management) Act, 2017, provides a strong basis on which states can build a legal regime able to address the need to protect and use groundwater in a way that is socially equitable and environmentally sustainable.

[5]Planning Commission (n 1) para 1.115 states that '[n]ew model legislation is needed for protection, conservation, management and regulation of groundwater'.

[6]The first was the Planning Commission's Model Bill for the Conservation, Protection and Regulation of Groundwater, 2011.

2 Existing Groundwater Regulation and Shortcomings

Access to groundwater has been regulated since the middle of the nineteenth century by rules that were set in judicial decisions adjudicating disputes related to the use of land for industrial activities or mining, rather than for drinking water or irrigation. Further, the context for the existing rules was that of England where the climate and water uses differ significantly from India.[7] The primary feature is that groundwater should not be subjected to the same rules as surface water,[8] on the (now discredited) understanding that the two were distinct. Consequently, judges refrained from applying the usual rules for access to surface water that significantly limited landowners' rights of appropriation. Judges decided on the basis of their understanding of hydrogeology that the most appropriate solution was to let landowners take as much water as they wanted, including at the expense of a neighbour whose own use of groundwater might be affected.[9]

The only exception that was made concerned groundwater deemed to flow in defined channels. In this case, the rules of limited appropriation in force for surface were to be applied, and use was limited to domestic uses, cattle, irrigation and manufacturing activities.[10] This confirms that judges understood the rules for percolating groundwater as an exception to the usual rules that were much more restrictive in terms of what they allowed landowners to do. This should have been the starting point for a progressive evolution of rules concerning access to groundwater, particularly in view of science providing new insights on the movement of groundwater. This did not happen during the twentieth century and is yet to be fully taken up.

2.1 Addressing a Mounting Crisis Without Changing the Rules: The 1970/2005 Model Legislation

The crisis engendered by the rapid spread of mechanised pumps was noted by policy-makers early on. The spread of the green revolution that led to renewed emphasis on the need for irrigation led to a massive spurt – essentially unregulated – in drilling that resulted in rapidly declining water tables.[11] This led the central government to take up the need for regulating access to groundwater seriously and to adopt a model bill for adoption by states.

---

[7]For example, NS Soman, 'Legal Regime of Underground Water Resources' (2008) *Cochin University Law Review* 147.

[8]*Chasemore v Richards* [1859] 7 HLC 349, 374.

[9]*Acton v Blundell* [1843] 152 ER 1223, 1235.

[10]BB Katiyar, *Law of Easements and Licences* (13th ed., Universal Law Publishing 2010) 797.

[11]For example, BD Dhawan, 'Economics of Groundwater Utilisation: Traditional versus Modern Techniques' (1975) 10/25–26 *Economic & Political Weekly* A31, A39.

The Model Bill to Regulate and Control the Development and Management of Groundwater, 1970, was adopted to give states the means to intervene and restrict free access under certain conditions. This early initiative was not taken up by states before the end of the 1990s, apart from a few states that adopted groundwater legislation specifically focused on drinking water.[12] In the meantime, the central government revised the model legislation several times (1974, 1992, 1996), up to a last iteration adopted in 2005. These different revisions did not alter the basic character of the model legislation, and as a result, the Model Bill to Regulate and Control the Development and Management of Groundwater can be seen as the framework proposed by the government from 1970 to 2005 (hereafter referred to as (Groundwater Model Bill 1970/2005).

The regulatory framework proposed by the central government in 1970 was one that was in keeping with mainstream views on governance at the time that gave overwhelming emphasis to a centralised authority. In the case of groundwater governed by states, this translated into proposals for a state-level groundwater authority. The main functions of this authority were to notify areas of concern where the government should take measures to control groundwater use by landowners. Decisions were to be taken at the level of the state government,[13] and this consequently failed to provide space for decision-making by panchayats or even any other form of participation of the public. In a context where groundwater is understood as the most local source of water, the legislative scheme was at odds with reality on the ground. Once an area was notified, anyone seeking to use groundwater had to apply for a permit, with the exception of groundwater use limited to manual extraction mechanisms, such as handpumps.[14]

In addition, under the Groundwater Model Bill 1970/2005, all extraction mechanisms needed to be registered, whether the area was notified or non-notified.[15] This information could be used by the state-level authority to determine whether to grant or deny permits. Such decisions were to be based on different elements, including groundwater availability, the amount of water that was to be extracted and the distance between extraction points.[16] One of the crucial elements in decision-making is the use to which the water is to be put. In this regard, the model legislation did not specify that drinking water was the first priority of use.[17] Yet, in a concession to the prioritisation scheme that would become pervasive in water policies adopted from

[12]Madhya Pradesh peya jal parirakshan adhiniyam, 1986. Other states that have drinking water-specific groundwater legislation are Karnataka Ground Water (Regulation for Protection of Sources of Drinking Water) Act, 1999, and Maharashtra Ground Water Regulation (Drinking Water Purposes) Act, 1993.

[13]Model Bill to Regulate and Control the Development and Management of Ground Water, 2005, s 5.

[14]Ibid s 6.

[15]Ibid s 8.

[16]Ibid s 6(5).

[17]Ibid s 6(5)(a) only provides that the purpose has to be taken into account while s 6(5)(h), which is the only sub-section referring to drinking water, only considers it as an indirect factor.

the 1990s onwards, an exception to the permit requirement was made for hand-operated devices that were understood as having for primary function the fulfilment of drinking water needs.[18]

The states that have legislated on groundwater over the past two decades have generally followed relatively closely the template given by the Groundwater Model Bill 1970/2005.[19] Limited attempts to domesticate the model legislation to the needs of individual states can be identified, but, on the whole, there has been no attempt to think beyond the proposed model. This is surprising in view of the diversity of situations faced by different states in the country. One of the points that has been addressed in several acts concerns the structure of the authority put in place. Different states have provided, for instance, their own distinct balance of official and non-official members.[20] Other differences include the scope of application of the act, with some applying to all groundwater and others only applying to areas that are notified.[21] The state that has gone furthest in adapting the model legislation is Andhra Pradesh that maintains the top-down regulatory structure but puts the regulation of groundwater in a broader context of environmental protection.[22] In addition to the fact that state legislation fails on the whole to take the challenge of groundwater regulation beyond the model devised in 1970, there has also been limited implementation of the existing statutory provisions in most states.

2.2 Critique of the Existing Regulatory Framework

The regulatory framework as it stands is an inappropriate response to the challenges that the country face in terms of groundwater at the end of the 2010s. The rules put in place in the nineteenth century were never meant to address the complex situation that prevails today where groundwater is the main source of water for the main uses of water and the primary source for realising the fundamental right to water. An entirely new framework is called for to ensure that aquifer-based protection

[18] Ibid s 6(1).

[19] These include Andhra Pradesh, Bihar, Goa, Himachal Pradesh, Karnataka, Kerala, Tamil Nadu and West Bengal. The following union territories have also adopted groundwater legislation: Chandigarh, Dadra and Nagar Haveli, Lakshadweep and Puducherry.

[20] In Goa, the act simply authorises the government to nominate members without specifying their origin. Goa Ground Water Regulation Act, 2002, s 3(2). In Kerala, only 4 of the 13 members of the Authority are civil servants, while the rest are made of a combination of people with different expertise. Kerala Ground Water (Control and Regulation) Act, 2002, s 3(3).

[21] For the former, Kerala Ground Water (Control and Regulation) Act, 2002, and for the latter, West Bengal Ground Water Resources (Management, Control and Regulation) Act, 2005.

[22] Andhra Pradesh, Act to Promote Water Conservation, and Tree Cover and Regulate the Exploitation and Use of Ground and Surface Water for Protection and Conservation of Water Sources, Land and Environment and Matters, Connected Therewith or Incidental Thereto, 2002.

measures are put at the centre of a regulatory regime that is premised on ensuring equitable access to groundwater.

The first reason for reform is that rights of access to groundwater are delinked from the current scientific understanding of the connexions between surface and groundwater that we now understand as being unitary.[23] Existing rules are still premised on the idea that ground and surface water are two unconnected bodies that can therefore have their own distinct rules.

In addition, existing rules were developed in a context where mechanical pumping techniques in widespread use today had not even been invented. They are thus unable to provide effective and appropriate answers to the type of situation that arises when a landowner extracts water at a much higher rate than their neighbours and in the process ends up depriving them of their own access to water. This may happen because different farmers in a locality have different capacities to drill and to pump and can happen in situations, like bottling plants located in an area where other landowners also extract water from the same aquifer. This can lead to formal conflicts, as in the case of the Plachimada bottling plant in Kerala.[24]

A second reason that explains the need for reform is that existing rules were never suitable for the country in which they have been implemented. The rules were developed for a country and at a time when judges or policy-makers had probably never thought about the issue of water scarcity or at least not in the way in which it presents itself in a tropical country. While some parts of India may enjoy climatic conditions relatively similar to England where groundwater rules were developed, this is not the case for the vast majority of the country.[25] In addition, the rules in place were not developed in view of the complex pattern of water use that exists in India, in particular with regard to the overwhelming importance of the irrigation sector as the primary user of (ground)water.

Another issue arising from the existing regulatory framework is that it links land ownership with groundwater access. It therefore indirectly assumes that landowners are the only users of groundwater. This therefore disregards everyone else, a fiction that does not reflect today's reality of nearly every person having a stake in groundwater protection and use because it is their source of drinking water and maybe for other uses too. In a context where well ownership is skewed in favour of large landowners, seeing groundwater as a prerogative of landowners is problematic in terms of social welfare.

Finally, existing rules conceive groundwater as a substance to be regulated on a landholding basis rather than on an aquifer basis. The current regulatory framework

---

[23]For example, M Sophocleus, 'Interactions Between Groundwater and Surface Water: The State of the Science' (2002) 10/1 *Hydrogeology Journal* 52.

[24]C.R. Bijoy, 'Kerala's Plachimada Struggle – A Narrative on Water and Governance Rights' (2006) 41/41 *Economic & Political Weekly* 4332.

[25]For example, SD Attri and Ajit Tyagi, Climate Profile of India (India Meteorological Department 2010).

is thus entirely incapable of addressing groundwater as a common heritage of the community that needs to be protected for the benefit of the environment and the community and used in a manner that benefits all members of the community. At present, there are not only virtually no restrictions on the amount of water each individual landowner can extract but also no mechanism that can force different landowners to collaborate to ensure protection of the aquifer. Rather, each individual landowner is indirectly encouraged to pump as much as they can, in the knowledge that their gains will not need to be shared while the pain will be shared by everyone sharing the aquifer. This is prejudicial to everyone and the environment, and the only temporary winners are on the whole the bigger landowners that have the capacity to use and abuse the resource until it is exhausted.

3 Groundwater Regulation in a Time of Increasing Scarcity: The Model Groundwater (Sustainable Management) Act, 2017

It is now widely accepted that the groundwater legal regime needs to change. Yet, introducing change has proved difficult in practice because it remains relatively easy to ignore the groundwater crisis due to its partly hidden nature and the fact that in the short term, it may be politically more attractive to foster groundwater mining. At the same time, in various parts of the country, the crisis has reached a level where it cannot be ignored, and new responses need to be given to ensure that the situation does not get worse in the future. Several states have thus started to take measures to address the crisis. Some states have taken limited regulatory action, such as in the case of Punjab where legislation was passed to reduce groundwater use by prohibiting the sowing and transplanting of paddy before specific dates.[26] This is despite the fact that Punjab has been generally opposed to introducing groundwater legislation and in response to a crisis caused directly by the additional groundwater irrigation facilities created in recent decades.[27] In other cases, groundwater regulation has been appended to irrigation legislation, as was done in Gujarat. This includes the introduction of a water rate on percolating groundwater within 200 m of canals, as well as a licensing system for irrigation-related tube wells. Beyond these examples, as mentioned above, some states have adopted a statute based on the Groundwater Model Bill 1970/2005.

The picture of groundwater regulation thus seems to be an evolving one and confirms that many states have responded to the serious groundwater crises they are facing. At the same time, while states are addressing the challenge, they are doing so

[26]Punjab Preservation of Subsoil Water Act, 2009. Haryana adopted similar legislation, Haryana Preservation of Sub-Soil Water Act, 2009.

[27]Planning Commission, 12th Five-Year Plan (2012–2017) – Economic Sectors – Volume 2 (Government of India 2012) 5 and 43.

in a limited manner. In particular, the focus of all the acts adopted is on top-down measures seeking to control use of groundwater by specific users. No beginning towards conceiving groundwater regulation from a protection perspective and from an aquifer-wide basis has been made. Yet, there is a need for a complete rethinking of the premise on which groundwater regulation is conceived. Firstly, it is imperative to ensure that groundwater regulation be more clearly focused on the different main dimensions of groundwater protection and use. This implies not only understanding the priority of use as being on drinking water, something that is already the case in practice, but also linking the need for access to safe water with the focus on protection of the aquifer. Secondly, regulation must start at aquifer level, and both protection and use must be conceived at that level. This implies severing the link between access to groundwater and land in favour of an understanding of groundwater centred around its community dimensions, the fundamental right to water and livelihood-related uses.

Any new legal regime needs to be based on principles that reflect the needs of the sector and are in conformity with today's legal framework. This new set of principles is far from what we have today since groundwater rules have not evolved for decades, while the rest of the legal framework has changed considerably. The Model Groundwater (Sustainable Management) Act, 2017 (Groundwater Model Act, 2017), offers a template for introducing these new principles and ensuring more socially equitable use and aquifer-level protection of groundwater.

3.1 Groundwater as a Common Heritage: Recognition as a Public Trust

In a context where the first stumbling block preventing the emergence of a more socially equitable and environmentally sustainable legal regime is the legal status of groundwater, the Groundwater Model Act, 2017, addresses this directly. The preamble starts by recognising that 'private property rights in groundwater are inappropriate given the emerging status, conflicts and dynamics of groundwater' and that 'groundwater in its natural state is a common pool resource'.[28] On this basis, the Model Act provides at section 9 that groundwater is 'the common heritage of the people held in public trust' and that '[i]n its natural state, groundwater is not amenable to ownership by the state, communities or persons'.

Section 9 is potentially a game changer since it forces all actors to recognise that the current groundwater crisis forces us to radically alter our perception of groundwater and start by recognising its shared nature. This recognition of groundwater as a shared substance is a logical consequence of earlier judicial decisions. Indeed, it is already more than two decades since the Supreme Court recognised surface water as

[28]Model Groundwater (Sustainable Management) Act, 2017, preamble.

falling under the public trust doctrine.[29] Subsequently, at least one case has applied the same to groundwater.[30]

The switch from exclusive control by landowners to an understanding of groundwater as a shared substance is extremely important in giving a signal to all groundwater users that no one can appropriate it to the detriment of others and that everyone has a duty to contribute to its protection for the present and future generations. In the present context, the public trustee is the state because this is the easiest anchoring point for courts in the different countries where it has been introduced or extended to water, starting with California in the 1980s.[31] Yet, this can only work if the state includes its different manifestations from the local to the central level, something that has not been effectively conceptualised until now. Further, this implies that the trustee must take its fiduciary duty very seriously to avoid any dilution of the trust or it being taken over by private interests. The first decision of the Supreme Court in 1996 was very clear in stating that no privatisation of the public trust can be condoned.[32] In subsequent decisions, the Court has restated this position and added an intergenerational dimension to the protection duties.[33]

The recognition of groundwater as falling under the public trust doctrine is a significant conceptual development after more than 150 years during which individual landowners were essentially left to pump as much as they wanted. This change can contribute to more equity in access to groundwater, but the sole introduction of public trust is not sufficient in itself to ensure positive outcomes. This must be linked to a set of principles that ensure its application from the local to the state level and linked to a series of substantive principles, in particular concerning protection of the aquifer.

3.2 Groundwater as a Local Source of Water: Subsidiarity and Decentralisation

Significant emphasis has been put since the 1990s on the need to strengthen governance at the local level. The two constitutional amendments of 1992 triggered a series of changes in state-level legislation through which Panchayati Raj Institutions were allocated water-related competences, such as concerning drinking water and minor irrigation.[34] In urban areas, municipalities now have powers over water

[29]*MC Mehta v Kamal Nath* (1997) 1 SCC 388 (Supreme Court of India, 1996).

[30]*State of West Bengal v Kesoram Industries* (2004) 10 SCC 201 (Supreme Court of India, 2004).

[31]*National Audubon Society v Department of Water and Power of the City of Los Angeles* 33 Cal 3d 419, 441 (Supreme Court of California, 1983).

[32]*MC Mehta v Kamal Nath* (1997) 1 SCC 388 (Supreme Court of India, 1996) para 34.

[33]*Fomento Resorts and Hotels Ltd v Minguel Martins* (2009) 3 SCC 571 (Supreme Court of India, 2009) paras 36, 40.

[34]Constitution of India, art 243G and 11th Schedule.

supply.[35] This confirms that decentralisation of water governance has been debated for years and is already in principle implemented. Yet, neither water law in general nor groundwater law specifically provides for regulatory control by the local bodies of governance. At present, the bases for regulation of groundwater on the basis of subsidiarity and decentralisation exist, but they need to be integrated in groundwater-specific legislation to ensure that decentralisation progresses beyond devolution from the Union to the state level.[36]

The Groundwater Model Act, 2017, takes up the challenge of implementing the decentralisation mandate for groundwater. It starts by recognising that '[c] onservation, use and regulation of groundwater shall be based on the principle of subsidiarity'.[37] Essentially, this strengthens the decentralisation framework to add a bottom-up dimension to decentralisation and conceiving regulation starting at the local level.

This is taken up more specifically by organising decentralised governance around existing units of territorial governance.[38] Since these boundaries do not necessarily coincide with those of aquifers, the Model Act includes coordination mechanisms to ensure that where aquifer straddle more than one panchayat or more than one municipality, its protection and use can be organised through coordination measures at a higher level. This is indeed one of the functions of district groundwater councils that are tasked with coordinating the formulation of groundwater security plans where aquifer boundaries do not correspond with the boundaries of a single panchayat/municipality.[39]

The institutional framework of the Model Act is divided between urban and rural areas because this corresponds with the existing division between municipal law and panchayat laws. This includes the setting up of a groundwater sub-committee as part of the village water and sanitation committee in rural areas and a municipal water management committee in urban areas.[40] At higher levels, committees are set up to ensure coordination between lower-level committees and to address issues that can only be addressed at a higher level, in keeping with the subsidiarity principle.[41]

[35]Constitution of India, art 243 W and 12th Schedule.

[36]For example, Rahul Banerjee, 'What Ails Panchayati Raj?' (2013) 48/30 *Economic & Political Weekly* 173.

[37]Model Groundwater (Sustainable Management) Act, 2017, s 6.

[38]Ibid, Chap. 6.

[39]Ibid, s 17.

[40]Ibid ss 14(1) and 16(1).

[41]Ibid ss 15, 17 and 18.

3.3 Making the Right to Water a Reality Through Groundwater: Opportunities and Challenges

A third element that has been the object of much attention in recent years is the recognition of the fundamental right to water. This has been repeatedly confirmed by high courts and the Supreme Court since the early 1990s.[42] At present, the right is firmly established in the legal framework, but it only exists in terms of judicial decisions that limit themselves on the whole to establishing the broad contours of the right. This is not problematic in itself, but the expectation would be that legislation takes this task ahead. This has not happened, and there is in fact no legislation focusing specifically on drinking water, the core dimension of the right to water.

One of the dimensions that consequently remains under-regulated is water quality. Drinking water quality standards have existed for a number of years and provide effective reference points.[43] In addition, administrative directions of the government already provided a minimum standard for drinking water quantity in rural areas (40 l per person per day) that would be the standard against which the right could be assessed.[44] These standards are very important but do not in themselves constitute a fully fledged regulatory framework for realising the fundamental right to water. This is further reflected in the fact that in rural areas, administrative directions have become the regulatory framework that governs drinking water.[45]

The Groundwater Model Act, 2017, takes up this challenge directly and is the first instrument that seeks to statutorily specify the content of the right to water. It thus provides that '[e]very person has a right to sufficient quantity of safe water for life within easy reach of the household regardless of, among others, caste, creed, religion, community, class, gender, age, disability, economic status, land ownership and place of residence'.[46] It further gives for the first time quality standards statutory backing and specifies duties and safeguards concerning the provision of drinking water through groundwater.

3.4 Conserving Groundwater: Groundwater Protection Zones and Groundwater Security Plans

As noted above, one of the key missing dimensions of existing groundwater regulation is the absence of a conservation framework. This is not necessarily surprising since groundwater rights were developed much before conservation and

[42] *Subhash Kumar v State of Bihar* AIR 1991 SC 420 (Supreme Court of India, 1991) para 7.

[43] Bureau of Indian Standards, Drinking Water – Specification (Second Revision, IS 10500), 2012.

[44] Government of India, Accelerated Rural Water Supply Programme Guidelines.

[45] For example, Government of India, National Rural Drinking Water Programme, 2010.

[46] Model Groundwater (Sustainable Management) Act, 2017, s 4.

protection concerns arose. At the same time, the past four decades have seen the fast development of environmental law that does not find place in the existing regulatory framework for groundwater. Interestingly, water has been part of the scope of environmental law for decades, as reflected in the Water (Prevention and Control of Pollution) Act 1974 and the Environment (Protection) Act 1986 whose definition of environment includes water.[47] At this juncture, groundwater legislation needs to reflect and integrate principles of environmental protection. This includes principles enshrined in recent environmental legislation, in particular the precautionary principle, the polluter pays principle and sustainable development.[48] Such environmental principles are indispensable to build a new regulatory framework on strong protection bases.

In this context, one of the major advances brought by the Groundwater Model Act, 2017, is the inclusion of a protection regime based, for instance, on the precautionary principle.[49] The two key instruments for groundwater protection are groundwater protection zones and groundwater security plans. Groundwater protection zones will be zones of particular significance for conservation where 'appropriate measures regarding regulation on the extraction and use of groundwater, rules regarding afforestation and deforestation, land use changes including wetlands, prohibition of waste disposal, waste water recycling, quality standards for discharge of effluents, regulation of mining leases will be adopted and enforced'.[50]

Groundwater security plans are to be prepared for every watershed and administrative unit at the lowest possible level.[51] Their objectives include the attainment of sufficient quantity of safe water for life and sustainable livelihoods by every person, ensuring water security at all times and providing measures to preserve and improve the quality of groundwater.[52] The plans constitute one of the main novelties of the new legal regime and provide the building blocks for regulating groundwater at aquifer level on the basis of participatory decision-making.

4 Conclusion

India as a whole is increasingly reliant on groundwater. Yet, the regulatory framework governing groundwater has not been updated since the nineteenth century and is based on a mistaken understanding of hydrogeology. Further, there has been a qualitative shift in the importance of groundwater since the middle of the twentieth century that has turned it into the main source of water for all uses. The present legal

[47] Environment (Protection) Act, 1986, s 2(a).

[48] National Green Tribunal Act, 2010, s 20.

[49] Model Groundwater (Sustainable Management) Act, 2017, s 7.

[50] Ibid s 13(5).

[51] Ibid s 11(3).

[52] Ibid s 11(2).

regime that gives precedence to the individual interests of landowners is neither capable of providing the basis for the necessary aquifer-wide protection measures nor suited to face the challenges of an increasingly complex sector.

Groundwater is a shared common heritage, and the legal framework needs to be based on the recognition that groundwater must not be regulated as a private resource. In a context where surface water has already been recognised as a public trust for two decades and where it is imperative to regulate surface and groundwater together, the first necessary step is to recognise groundwater as a public trust. This must be applied at all levels, starting at the panchayat/municipality level to ensure that the trustee is in close contact with the trust and can be held accountable for its actions.

The Groundwater Model Act, 2017, proposed by the Ministry of Water Resources, River Development and Ganga Rejuvenation takes up the challenge of proposing a new regulatory framework for groundwater based on the recognition of its nature as a common heritage that needs to be protected in an environmentally sustainably manner while being used in a socially equitable manner. The conceptual rationale for change is clear in the face of the mounting crisis of groundwater. At the same time, serious challenges remain on the way to adoption of this new framework by states that need to take a long-term view of the need for regulation and accept that groundwater is primarily a local source of water that needs to be preferably regulated, conserved and managed at the local level. In addition, in states that take a progressive view of groundwater regulation and adopt legislation based on this new framework, further challenges will arise at the implementation level. Indeed, local regulation and management is an ideal to aspire to, but it requires a governance framework at the local level that functions well and has access to the necessary resources to deliver. The very different status of local governance in different states means that some states will find it much easier than others to implement the principles outlined in the Groundwater Model Act, 2017.

Challenges notwithstanding, a change of paradigm is unavoidable. From a short-term perspective, it may seem easier to avoid addressing the crisis. Yet, the more state governments wait to deal with the issue, the more difficult it will be to convince politically powerful landowners that a regulatory change is needed. The earlier we manage to convince all actors to take action, the better for aquifers and for long-term sustainability of access to groundwater for all.

Philippe Cullet is a Professor of International and Environmental Law at SOAS University of London and a Senior Visiting Fellow at the Centre for Policy Research in New Delhi. He received his doctoral degree in law from Stanford University, an MA in development studies from SOAS University of London, an LLM in international law from King's College London, and his undegraduate law degree from the University of Geneva. His work and publications focus on environmental law, natural resources law, water and sanitation law and policy, human rights, and the socio-economic aspects of intellectual property. His latest books include *Water Law in India – An Introduction to Legal Instruments* (OUP, 2nd ed 2017 – co-edited with S. Koonan) and *Right to Sanitation in India – Critical Perspectives* (OUP, in press – co-edited with S. Koonan & L. Bhullar). He was a member of the Ministry of Water Resources, River Development and Ganga Rejuvenation Committee drafting the Draft National Water Framework Bill, 2016 and the Model Groundwater (Sustainable Management) Act, 2017.

Farmers' Participation in Managing Water for Agriculture

Phanish Kumar Sinha

1 Introduction

India is expected to face a water gap of around 750 billion cubic metre (BCM) by year 2030. Experts suggest that this gap can be solved with 'improving agriculture's water efficiency and productivity' only. This makes a strong case for increasing water use efficiency and crop productivity in irrigated agriculture. The irrigated agriculture in the command of medium and major irrigation projects is constrained by low performance in terms of efficient water use and equitable distribution of water due to all pervasive presence of government machinery handling every aspect of irrigation water delivery without participation from the farmers. In addition, the small and marginal landholdings are burgeoning which are economically unviable for agriculture.

A realization is emanating that the existing government centric institutional setup, particularly in canal systems, for irrigation water management requires a paradigm shift. The National Water Policy, 12th Five Year Plan document and National Water Mission Comprehensive Mission Document have stressed on community involvement in irrigation water management through Water Users' Associations (WUAs), generically known as participatory irrigation management (PIM). The state water policies have, by and large, also shown consensus and resolve to promote farmers' participation in irrigation management.

Currently, out of the total 28 states, some 24 states of India have adopted the PIM approach partly or fully by forming Water Users' Associations (WUAs). Although over 93,000 Water Users' Associations, covering an area of 17.84 million hectare (m ha), have been formed in India, yet their success in making desired impact on land and water productivity through better irrigation management is quite limited.

P. K. Sinha (✉)
Freelance Consultant in Participatory Irrigation Management (PIM), Capacity Building and Development, Lucknow, India

© Springer Nature Singapore Pte Ltd. 2019

A. Singh et al. (eds.), *Water Governance: Challenges and Prospects*, Springer Water,
https://doi.org/10.1007/978-981-13-2700-1_8

The paper examines the reasons for success and failure of Water Users' Associations in India and concludes that the lacklustre performance of WUAs is not because the idea is wrong, but because the people implementing it (often irrigation/water resources/command area departments) have not understood the process right. Instead of rigid acts, rules and target-oriented WUA formation, focusing on principles of water management and change management in implementing the WUA programme has great potential to pay rich dividends.

2 Background: Why Farmers' Participation in Managing Irrigation Water Is Important

McKinsey & Company published a report titled 'Charting Our Water Future'[1] prepared by '2030 Water Resources Group' which predicts an unmet demand of around 750 BCM in India by the year 2030. The report also analyses various technical options with associated cost estimates to meet this gap and suggests that the best option, costing $5.9 billion (including annualized capital and net operating expenditures), lies in improving the agriculture's water efficiency and productivity coupled with rehabilitation of existing infrastructure and last mile canals. In effect, India's year 2030 water gap of around 756 BCM could also be solved with 'improving agriculture's water efficiency and productivity only'; however that requires $ 8.4 billion net annual expenditure by 2030 (including annualized capital and net operating expenditures). On the other hand, 'infrastructure only' solution needs an yearly expenditure of $ 23 billion (3–4 times more) by 2030 and that also would only meet 60% of the gap. This makes a strong case for increasing water use efficiency and crop productivity in agriculture, but the McKinsey report does not elaborate upon the institutional resources/framework required to implement identified technical options. It is also very important to know the environmental settings in which these institutional resources and framework will function.

2.1 The Environmental Settings for Irrigated Agriculture

2.1.1 All Pervasive Presence of the Government in Major and Medium Irrigation Projects

The country holds an estimated 139.9 million hectare as ultimate irrigation potential, which includes 58.5 m ha by major and medium projects, whereas minor irrigation

[1] http://www.mckinsey.com/client_service/sustainability/latest_thinking/charting_our_water_future

projects cover 81.4 m ha[2] of which the states of Uttar Pradesh, Bihar, Madhya Pradesh and Andhra.

Pradesh account nearly half share of that. A wide gap of 23.6% is observed between irrigation potential created (IPC) and irrigation potential utilized (IPU) for the major and medium irrigation schemes[3]. Major and medium irrigation projects are funded, planned, constructed, maintained and operated exclusively by the government. The reason for underperformance of this sector is primarily poor service delivery and inadequate maintenance of irrigation systems. Low revenue recovery and galloping establishment expenses also contribute significantly.

Various evaluation studies of major and medium irrigation projects in India show that the water use efficiencies at project level are around 30–35%. As per the studies, an improvement of 5% irrigation efficiency would end up in additional irrigation for another 10–15 million ha[4].

2.1.2 Rapidly Increasing Number of Small and Marginal Landholdings Which Are Not Economically Viable for Agriculture

Another major concern is rapidly increasing number of small and marginal landholdings[5], on which stand-alone agriculture is not economically viable. As shown in Fig. 1, the size of average landholding in India has shrunk to 0.93 ha which is categorized as a marginal landholding.

On the other hand, the delivery of water for irrigation, record keeping of irrigated area, collection of fees, distribution of water as required, managing conflicts, etc. has become a stupendous task under government-managed major and medium schemes which are under the jurisdiction of the state irrigation departments (IDs) under the states. To take advantage of modern package of agricultural practices as well as economy of scale in irrigation and other input management, the farmers shall have to adopt a model of community management ably backed and supported by the government and private agencies.

---

[2]The irrigation projects in India are classified into three categories: (i) major, (ii) medium and (iii) minor irrigation projects. Projects having more than 10,000 ha cultivable command area (CCA) are termed as major projects, the projects having more than 2000 ha (up to 10,000 ha) are termed medium projects and the projects below 2000 ha CCA are termed as minor projects.

[3]Of India's 58.5 m ha ultimate irrigation potential on major and medium projects, the irrigation potential created is 45.34 m ha and irrigation potential utilized is 34.66 m ha (Water and Related Statistics, December 2013, published by CWC, Government of India).

[4]The report on the State of Indian Agriculture placed by the Government to the Rajya Sabha in March 2012, (http://pib.nic.in/newsite/erelease.aspx?relid=80852).

[5]The landholdings up to 1 ha are termed as marginal landholdings and between 1 and 2 ha are termed as small landholdings.

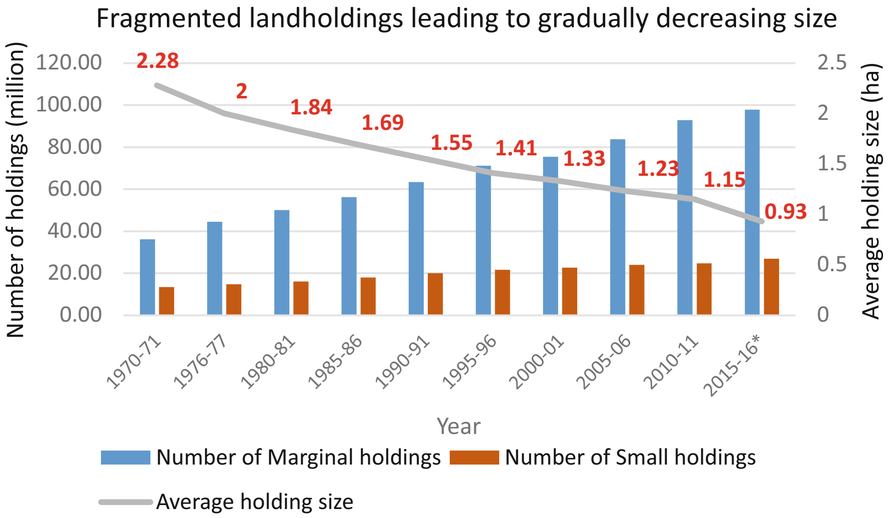


Fig. 1 Increase in numbers of small and marginal landholdings and their decreasing size in India (All India Report on Agriculture Census 2010–2011, Ministry of Agriculture and Farmers Welfare (2015). The figures of 2015–2016 have been projected by the author)

2.2 The Participatory Irrigation Management Approach

A growing concern as well as a realization is that the existing government-centric institutional setup, particularly on tank and canal systems, for irrigation water management requires a paradigm shift where farmers have to play the key role in irrigation water management. The National Water Policy and the state water policies have reached a consensus to promote farmers' participation in irrigation management through Water Users' Associations (WUAs), generically known as participatory irrigation management (PIM). Para 7.5 of NWP 2012 advocates to give statutory power to Water Users' Associations (WUAs) to collect charges of water as well as to retain a component of the revenue. They should also manage the volume of water earmarked for them besides maintaining the distribution system under their jurisdiction. The rates may be fixed by them based on the floor rates adopted by water regulatory authorities (WRAs). The rationale of promoting PIM through WUAs can be summarized as follows:

(i) The user's participation promotes sense of ownership with the irrigation system. Users are more likely to abide by rules and regulations set for management of the system and water distribution if they are part of the rule setting process and regulation.
(ii) Users have better information and access to local resources. Management, operation and maintenance (MOM) is need based, cost effective and timely.
(iii) The livelihood of water users depends on canal system; hence their stakes and motivation in maintaining the canal system are higher than government agencies.

(iv) WUAs are not constrained by the bureaucratic functioning and will be more responsive to farmer's needs.
(v) In India, 72% landholdings are below 1 ha in size, and 12% landholdings vary from 1 to 2 ha which are not viable for modern agriculture methods and technological interventions on 'stand-alone' basis. The economy of scale for backward and forward linkages is also not possible unless small and marginal landholders form an organization to manage it.
(vi) A management entity is required at the on-farm level as an interface between the main system supplier and the individual farmer if water distribution and system maintenance are to be carried out effectively at this level. A farmers' association can address this need and does so in many countries with smallholder irrigation (Mexico, Turkey, Philippines, Kyrgyzstan, etc.)

3 History and Current Status of PIM

3.1 International Scenario

The farmers are managing irrigation water amongst themselves in some countries like Netherlands, Spain and Nepal since centuries. Vijayanagara canals and large number of tanks in South India were also managed by the farmers in ancient times. The formal transfer of irrigation management to farmer groups/associations was initiated in the 1950s in the USA. It was followed in 1960s by France and in 1970s by Taiwan. Between 1980 and 1990, there was prolific spread of PIM in all developing countries, namely, Brazil, Bangladesh, Chile, Dominican Republic, Indonesia, Mauritania, Madagascar, Niger, Peru, Pakistan, Philippines, India, Mexico, Haiti, Senegal, Sudan, Somalia, Tanzania, Turkey, Sri Lanka, Laos, Vietnam, China, Vietnam, Zimbabwe and many more which started experimenting with their own version of PIM.

The impact of PIM largely depends upon the social conditions, institutional arrangements, commitment and enabling environment, but, more or less, some universal results observed are:

(i) Better water availability in the irrigation system.
(ii) Increase in equity of supplies between head and tail reaches of the system.
(iii) Although the cost of maintenance and repair of the system did not reduce substantially, the quality of maintenance and repair was found to be superior.
(iv) Increase in productivity.
(v) Increase in water rates collection.

The institutional arrangements across the countries for PIM range between complete agency/government controls to complete WUA control as summarized below (Table 1).

Table 1 Overview of type of institutional arrangements for PIM around the world

Type of institutional arrangements	Responsibilities for					Example countries
	Regulation	Ownership of assets	O & M	Collection of water charges	Unit of representation	
Full agency/government control	Agency	Agency	Agency	Agency	Agency	In most of developing countries
Agency control but O & M with user input	Agency	Agency	Agency	Agency	WUA	Sri Lanka, Thailand, Vietnam, Philippines
Shared management	Agency	Agency	Both	Both	WUA	Turkey, Albania
WUA owned/agency regulation	Agency	WUA	WUA	WUA	WUA	Dutch Water Boards, Japan, Mexico
Full WUA control	WUA	WUA	WUA	WUA	WUA	New Zealand, Nepal
Irrigation management company/board	Agency	Company	Company	Company	Company and User Committees	France, China, Australia, USA

3.2 Indian Scenario

The Government of India took up the initiative of promoting PIM through the programme of Command Area Development (CAD) in several states in 1985. Later, the National Planning Commission (now NITI Aayog) set up a Special Working Group on PIM to review and suggest the strategies for the 9th Five Year Plan (1997–2002). PIM has also been actively promoted through state Water and Land Management Institutes (WALMIs), the World Bank Assisted Water Resources Consolidation/Restructuring Projects and the Indian Network on Participatory Irrigation Management (India NPIM). Some nongovernmental organizations (NGOs) like Society for Promoting Participative Ecosystem Management (SOPPECOM), Samaj Parivartan Kendra in Maharashtra and the Development Support Centre (DSC) in Gujarat have contributed significantly in promoting PIM. Currently, out of the total 28 states, some 24 states of India have adopted the PIM approach partly or fully by forming Water Users' Associations (WUAs) by enacting specific PIM Acts or amending existing irrigation acts. The leading states are Andhra Pradesh, Chhattisgarh, Telangana, Gujarat, Karnataka, Haryana, Madhya Pradesh, Orissa, Maharashtra, Rajasthan, Tamil Nadu and Uttar Pradesh. According to the latest estimates, the number of Water Users' Associations (WUAs) formed in India is 93,668[6], covering an area of 17.84 million ha (Table 2). A large number of WUAs, unfortunately, have been established on paper to complete the official targets without any organizational and capacity building efforts to make them functional.

4 Impact of PIM

The success of WUAs in handling irrigation management has been mixed. Wherever WUAs have been formed based on principles of organizing on water management and principles of change management with participatory procedures, for example, WUAs supported by Development Support Centre (DSC) in Gujarat and Madhya Pradesh, WUAs in Waghad Irrigation Scheme supported by Samaj Parivartan Kendra in Maharashtra and Tank User Groups supported by DHAN Foundation in Karnataka, the results are encouraging. But wherever the PIM is implemented in top-down fixed target mode, it has failed to take off. In a nutshell, PIM has so far failed in India not because the idea is wrong, but because the people implementing it (often engineers) have either not understood the process and rationale of forming the WUAs or the PIM concept does not suit to their comfort zone of power and non-accountability. So far, a suitable model for implementing PIM on large scale

[6]Original figure of 84,779 Nr. WUA /17842.20 thousand ha area covered adopted from Hand Book on Water and Related Statistics 2016 (page 65) published by CWC. The number of WUAs in UP (802 WUA) given in CWC publication is corrected to 9691 WUA by the author.

in India has yet to be found – it doesn't mean however that the idea is wrong, rather the implementation. A few positive impact studies are summarized below.

4.1 Uttar Pradesh Water Sector Restructuring Project Phase-1 (UPWSRP-1)

418 WUAs were established and registered under 'Societies Registration Act' in 2004. The WUAs were entrusted with a limited activity of maintenance of the minor with funding arrangement through UPWSRP-1. Impact of this intervention was

Table 2 Number of Water Users' Associations (WUAs), area covered and irrigation potential created in different states

Sl. no.	State	Number of WUAs formed[a]	Area covered (000 hectare)[b]	Irrigation potential created (000 ha) on major/medium/ minor schemes[c]	% area covered by WUA
1	Andhra Pradesh	10,884	4179.25	9699.7	43.1
2	Arunachal Pradesh	43	10.97	92.6	11.8
3	Assam	847	95.02	790.3	12.0
4	Bihar	80	209.47	8127.9	2.6
5	Chhattisgarh	1324	1244.56	1578.8	78.8
6	Goa	84	9.54	56.0	17.0
7	Gujarat	8278	662.99	7229.1	9.2
8	Haryana	8490	1616.27	4669.2	34.6
9	Himachal Pradesh	1173	140.56	263.0	53.4
10	J & K	383	32.79	770.0	4.3
11	Jharkhand	0	0.00	1025.8	0.0[a]
12	Karnataka	2787	1418.66	4543.2	31.2
13	Kerala	4398	191.22	2030.2	9.4
14	Madhya Pradesh	2062	1999.64	7639.0	26.2
15	Maharashtra	2959	1156.22	9363.8	12.3
16	Manipur	69	29.40	157.4	18.7
17	Meghalaya	159	20.17	96.9	20.8
18	Mizoram	390	18.23	13.6	134.0[b]
19	Nagaland	24	3.44	135.0	2.5
20	Orissa	20,794	1757.71	3744.9	46.9
21	Punjab	4845	610.29	9130.4	6.7
22	Rajasthan	1994	1144.45	9235.6	12.4
23	Sikkim	0	0.00	33.8	0.0
24	Tamil Nadu	1910	935.66	5825.7	16.1

(continued)

Table 2 (continued)

Sl. no.	State	Number of WUAs formed[a]	Area covered (000 hectare)[b]	Irrigation potential created (000 ha) on major/medium/ minor schemes[c]	% area covered by WUA
25	Tripura	0	0.00	113.6	0.0
26	Uttar Pradesh	9691	318.69	29,222.1	1.1[c]
27	Uttarakhand	0	0.00	1023.8	0.0
28	West Bengal	10,000	37.00	5351.6	0.7[d]
	Total	**93,668**	**17,842.20**	**121,963**	**14.6**

Source: Main sources are 'Water and Related Statistics 2010' and 'Water and Related Statistics 2016' published by Central Water Commission, New Delhi. However, the data related to Uttar Pradesh has been updated by the author based on his investigations

Note:

(a) WUAs are sporadically constituted without any funds/IMT or specific legal backup. They are for namesake and as good as not constituted

(b) Value may be more than 100% due to the fact that status of WUA area covered is based on 2015 data, while irrigation potential created is up to 2007

(c) Uttar Pradesh has huge irrigation potential created in comparison to any other state in India. That is why the low coverage by WUA is seen

(d) The 10,000 WUAs shown in the table are on state tube wells with very small command. Hence the low coverage is seen

[a]Original Figs. (84,779 Nr. WUA /17842.20 thousand ha area covered) adopted from Hand Book on Water and Related Statistics 2016 (page 65) published by CWC. The figures of UP (802 WUA) are corrected (9691 WUA) by the author

[b]Adopted from Hand Book on Water and Related Statistics 2016 (page 65) published by CWC

[c]Water and Related Statistics 2010 (pages 134–135) published by Central Water Commission, Government of India

evaluated in terms of (i) increase in irrigated area, (ii) equity in water distribution across the head to tail and (iii) reduction in the cost of silt clearance of the minor canals.

4.1.1 Increase in Irrigated Area

It was seen that average irrigated area in a WUA in Rabi season rose from 76.84 ha to 80.37 ha (4.6%) in years 2004–2005 (Rabi 1412 Fasli[7]) in comparison to previous 5 years' average (Fig. 2).

Further rise of 6.9% in average Rabi irrigated area was seen in years 2005–2006 (Rabi 1413 Fasli) in comparison to years 2004–2005 (Rabi 1412 Fasli). Similar results were obtained for kharif irrigated area also.

[7]In India, particularly Northern India, land revenue and irrigation records are maintained in 'Fasli year'; Fasli year is a 12-month period and is counted from July to June.

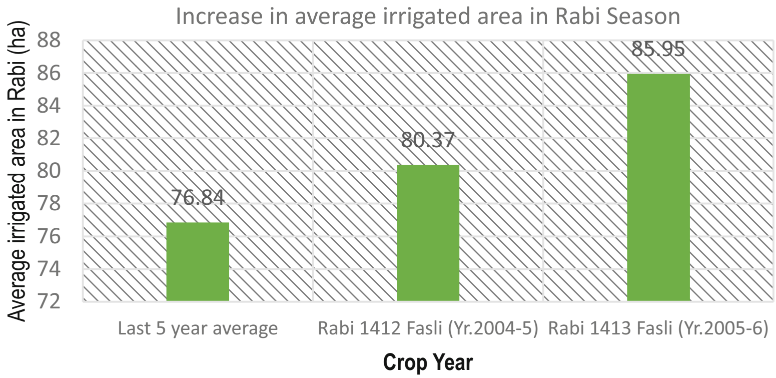


Fig. 2 Increase in irrigated area after partial management transfer to WUA

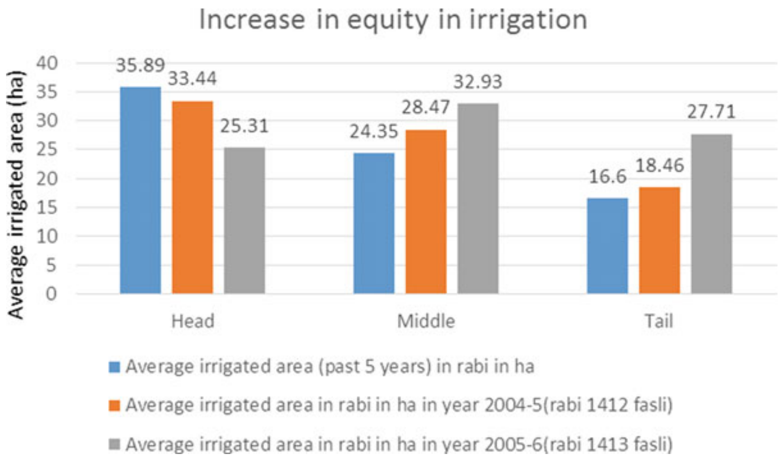


Fig. 3 Increase in equity of Rabi irrigation

4.1.2 Equity in Irrigation in Head and Tail Areas

In addition to the increase in the total area irrigated as shown above, the further analysis of increased area shows that the equity in water supplies improved significantly. Out of total increased area, the maximum increase in area was observed at the tail reach followed by the middle reach, while the head reach area was reduced. It is a remarkable achievement by any standard (Fig. 3).

4.1.3 Reduction in the Cost of Silt Clearance of the Minors

One of the objectives of bringing about institutional change in irrigation sub-sector in the form of WUAs is to improve cost effectiveness of maintenance work by

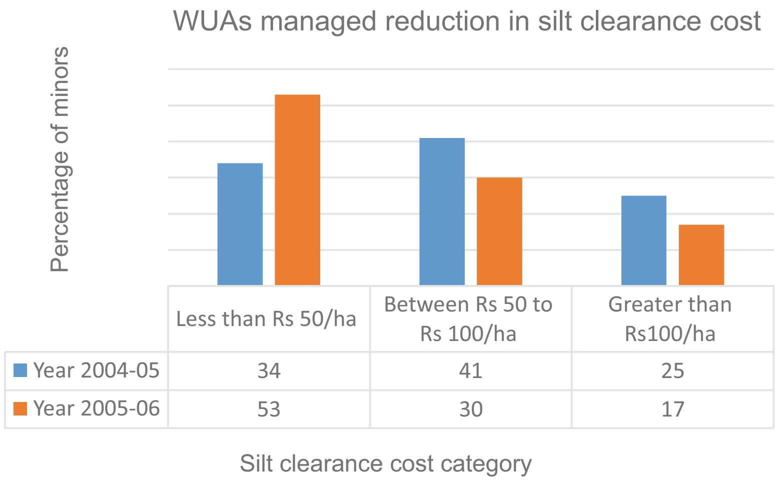


Fig. 4 Reduced cost of silt clearance in canals after IMT

utilizing indigenous know-how, community supervision and local wisdom. The results in Fig. 4 show that the number of minors de-silted at less cost increased from 34% to 53%, while the number of minors with higher costs of silt clearance gone down from 25% to 17%.

4.2 Dharoi Irrigation Scheme of Gujarat

PIM has been adopted since 1995 in the Dharoi irrigation scheme in Gujarat. Today irrigation management in the Right Bank Main Canal Command area of Dharoi dam is carried out by 196 irrigation cooperatives (ICs). About 129 irrigation cooperatives (IC) have been formed by an NGO named Development Support Centre (DSC), whereas remaining cooperatives have been constituted by irrigation department directly or by other NGOs. All these cooperatives are managing canal water irrigation. In addition, there are several private mandalis who are also managing bore well irrigation where source of water is groundwater.

The impact of PIM in the Right Bank Main Canal Command area was evaluated by Arid Communities and Technologies with support from DSC and Agha Khan Foundation. Increase in irrigated area, switch over to more remunerative crops and improvement in water use efficiency were observed after irrigation management transfer to WUAs. It was found that the area covered under irrigation rose to around 62% after PIM[8]. Wheat, mustard and castor crops significantly increased in the

[8] Study on design of Dharoi Dam vs Actual Command Area Irrigated (Impact of PIM in Right Bank Main Canal Area of Dharoi Dam), Research Report, December 2011, page 37 sponsored by DSC and Agha Khan Foundation.

command areas, whereas slight decrease was seen in cumin seed, isabgol, grass and vegetable crops. Another major impact was seen in terms of adoption of improved crop variety by the farmers. Indigenous cotton and castor sown earlier in the area were replaced by BT cotton and hybrid castor. Efficient water use was also recorded. Annually computed water use per hectare area was about 0.4031 MMscf (0.01141 million m^3)/ha during year 1979–1980 which reduced to 0.188MMscf (0.00532 million m^3)/ha during 2009–2010.

4.3 *Waghad Project of Maharashtra*

In 1991, the Maharashtra Government taking cue from guidelines for participation of farmers in water management of irrigation systems (issued by the MoWR, GoI) established three WUAs on three minors at Ozar offtaking from Waghad Right Bank Canal, namely, (i) Mahatma J. Phule WUA, (ii) Jay Yogeshwar WUA and (iii) Banganga WUA. Water entitlement to each WUA was given at minor head on a volumetric basis. Though the Maharashtra Government fixed volumetric rates of water cess to be paid to the department, the WUAs were free to determine the rates to be paid by the farmers to the WUA. WUAs had freedom to grow crop of their choice within their sanctioned entitlement. With the success of WUAs formed at Ozar, the farmers in the command of other minors of Waghad Project came forward to form WUAs, and all 24 minors of the project had its WUA by the year 2004. The federation of WUAs, namely, Waghad Project Level WUA (PLWUA), was also established in 2003, and the irrigation management of the project was transferred to Waghad PLWUA in November 2005. A brief overview of improvement in some measurable indicators is given in Table 3.

One of the positive impacts of PIM in Maharashtra is the introduction of volumetric supply and pricing of water to WUAs. The state has made it mandatory to allocate water to WUAs on volumetric basis. Irrigation water is supplied to WUAs at the minor/tertiary level where it is measured by an inbuilt measuring structure like standing wave flume (for discharge >300 lps) or cut throat flume (for discharge <300 lps, Plate 1) and charged on volumetric basis, which enables the WUA to know how much water it is receiving against the planned allocation and to use it more efficiently. The WUA has the freedom to provide water to its members either on crop area or supply time basis (proxy to volumetric basis at the field level) and also to decide water charges to be paid by the members. The water rates on volumetric basis to be charged by the Water Resources Department are fixed by the government.

WUAs usually charge higher water rates to their members than the Water Resources Department in order to cover the additional costs associated with management, operation and maintenance of the on-farm system. By providing improved

Table 3 Improvement in measurable indicators after irrigation management transfer (IMT) to Project Level WUA at Waghad Irrigation Project

Sl. no.	Measurable indicator	Before IMT (2006–2007)	After IMT (2013–2014)
1	Area irrigated (ha)	8393	9745
2	Volumetric delivery	At minor head	At main canal head
3	Water saving	–	30% in comparison to 2004–2005
4	Water charges recovery (million INR)	1.012	2.577
5	Percentage of recovery of water charges	72% of the water billed for the actual irrigated area	100%
6	Change in cropping pattern	Cereal, grapes, vegetables	Crop diversification to floriculture, medicinal plants in addition to grapes and vegetables
7	Irrigation methods	75% flood, 25% drip and sprinkler	60% flood, 40% drip and sprinkler
8	Average net income of farmer (INR/ha)	80,000	120,000

Note on Waghad Medium Irrigation Project (Feb 2015) prepared by Executive Engineer, Palkhed Irrigation Division

Plate 1 Volumetric discharge measurements and use of drip irrigation in Maharashtra

levels of service and assured water supply and transparency in the billing system, farmers willingly pay the higher rates. An important factor in the improved level of service provision is that the additional service fee charges enable the WUA to employ paid field staff to manage the water distribution and maintain the system on a daily basis.

The major achievements of PIM visible at Waghad Project Level WUA are (i) increase in irrigated area (16%), (ii) cent percent realization of water charges, (iii) increase in drip irrigation to get better yields and saving in water, (iv) adopting more remunerative cropping pattern (grape, pomegranate, rose and medicinal plants) and (v) development of rural entrepreneurship[9].

There is increase in irrigated area especially at the tail ends as all WUAs (24 Nr) under the Waghad Project Level WUA have adopted the rule that the turn to take canal water will start by tail and gradually reach to upstream of the canal. Increasing the supply of water to the tail ends makes good business sense for the WUAs as it increases the number of users willing to pay the service charge, thus spreading the MOM costs over a greater number of water users.

4.4 WUA-Managed Collective Action in Chhattisgarh Irrigation Development Project

Chhattisgarh Irrigation Development Project (CIDP), an ADB-supported project initiated around 2005, is also a good example of what can be achieved through WUAs collective action. When the project started, PIM was a new idea, WUAs were weak, farmers were poor (and many were tribal), and irrigation efficiency and crop yields were at very low levels (CIDP baseline surveys reported 2.8 t/ha in 2008). The pivotal mechanism adopted was capacity building of WUAs through ‘learning by doing’. WUAs were mobilized, motivated and assisted by TA consultants, NGO specialists and senior community organizers (SCOs) and community organizers (COs). The COs and SCOs were selected from market in a transparent way, and promotions and incentives were based on participatory performance assessment. WUAs are motivated and assisted to:

(i) Manage water, ‘year-round’ (100% by WUAs in most of minor systems including sluice control and shared management in medium systems).
(ii) Construct field channels collectively (progress is slow).
(iii) Organize seed production and be self-sufficient in seeds.
(iv) Organize group and ‘advanced’ nurseries, to minimize ‘staggered cultivation’.
(v) Undertake input supply and output marketing to members.
(vi) Organize the adoption of improved package of (agricultural) practices (POP). This includes on-farm water management; seed testing and weed control; soil testing and fertilizer management; and pest and disease control including the identification of major pests and diseases, integrated pest management (IPM) and precautions in the application of chemicals.
(vii) System of Rice Intensification (SRI), which ‘saves water and time’.

[9]Indian Network on Participatory Irrigation Management, Report on ‘Assessment of Successful Water Users’ Associations (WUAs) in Gujarat, Maharashtra, Rajasthan and Madhya Pradesh to identify the factors of sustainability of PIM’ sponsored by NABARD, September 2015 (pages 62–66).

As a result of above interventions through WUAs, the kharif yield rose from 2.8 t/ha in 2008 to 5.9 t/ha in 2012 in an area of 100,000 ha covered under Intensive Intervention Programme (IIP) of CIDP. Self-sufficiency in WUA-managed seed production system and accelerated adoption of System of Rice Intensification (SRI) were also witnessed between years 2010 and 2012.

5 Strengths of Successful Water Users' Associations

To define a successful WUA is a very complex task. If the WUAs are assessed with reference to achievement of objectives mentioned in the State PIM Acts, hardly any WUA will pass the test of success. On a pragmatic note, a WUA which has succeeded in increasing (i) percentage of water charges collection, (ii) area under irrigation, (iii) equity of water distribution in terms of water availability in tail ends, (iv) encouraging water saving and (v) collective action for input and produce can be considered as a successful WUA. By this standard, there are many examples of successful WUAs in Gujarat and Maharashtra on government irrigation schemes. Many informal Water Users' Associations have been found quite successfully running in Gujarat, Madhya Pradesh and Maharashtra lifting water from rivers for irrigation through community efforts and resources. The success of WUAs constituted on public irrigation systems is heavily dependent, at least in the initial stages, on the attitude and support of irrigation department/line agencies. Main strengths and weaknesses of successful WUAs in Gujarat and Maharashtra as well as good practices adopted by Water Resources Departments (WRDs)/line agencies to support them are briefly discussed here in the following para.

5.1 Strengths of WUA

5.1.1 WUAs in Gujarat

In Gujarat, fixing hourly rates for irrigating a unit area, authorization to collect water charges over and above rates fixed by the government, payment of water charges to the government after retaining WUA share of water charges collection (30% + 20% for 100% collection in time), stress on consensus than election, taking irrigation charges in advance and good upkeep of financial records and annual balance sheet make the WUA effective and responsive. The assistance and support of an NGO, namely, Development Support Centre (DSC), is also an asset for WUAs.

5.1.2 WUAs in Maharashtra

In Maharashtra, volumetric supplies of water to WUAs, hourly charging system for irrigation water from the farmers, tail to head irrigation scheduling, separate office building for WUA, and stress on consensus for office bearers and good rapport between lower and upper level WUAs make the WUAs an engine of entrepreneurship. The system of transparent accounting and publication of annual reports by WUAs and the assistance and support of an excellent NGO, Samaj Parivartan Kendra (SPK), is also an asset for WUAs.

5.2 Good Practices by WRD/Line Agencies Contributing to Success of WUAs

5.2.1 Supplying Irrigation Water Through WUAs

WRD, Maharashtra, and Sardar Sarovar Narmada Nigam Limited, Gujarat, have taken a policy decision that irrigation water will not be supplied directly to farmers; instead it is supplied to WUAs and the WUAs will supply water to the farmer members.

5.2.2 Supplying Irrigation Water on Volumetric Basis/Per Irrigation Basis

The Department of Water Resources in Maharashtra and Gujarat supply irrigation water to WUAs on volumetric basis, and the WUA supplies it further to farmers on volumetric/hourly basis which prevents wastage and improves water use efficiency. In Madhya Pradesh it slightly differs but on the lines of volumetric basis as the irrigation fee is charged on ‘per irrigation basis’ which prevents the farmers to provide extra irrigation.

5.2.3 Consultation with WUAs in Construction and Rehabilitation Work

Maharashtra Government has taken a decision that work of distribution system with discharge capacity less than 1 m^3/sec shall be executed once WUAs are constituted. Also, execution of rehabilitation work done by contractors will be done under supervision of contract management committee which constitutes chairman of WUA, one member especially from tail end/divisional accountant and Executive Engineer of the concerned project. Under Gujarat PIM Act, the WUAs are expected to carry out ordinary repairs of irrigation facilities up to minor canal level, but in case special repairs are needed, the department will carry out the special repairs in consultation with WUAs.

5.2.4 Special Treatment to WUAs in Carrying Out New Works, Remodelling and Rehabilitation Works

Gujarat PIM Acts provide that WUAs may enter into contract with the WRD for construction of new works and remodelling and rehabilitation of existing works. As per the government policy, the work given to the WUA will be considered equivalent as departmental work. Earnest money or security deposit shall not be asked from the WUA. Deduction of income tax shall not be made at the time of payment for the work done as the WUA is working on the principle of no-profit. 2% of the estimated cost of work will be admissible to WUA as contingency. Inclusion of labours welfare up to 2% and outside consultancy cost up to 10% shall be acceptable by the department provided the expenses do not exceed the approved estimated cost. The WUA shall have to share 10% of estimated amount as contribution to implement the works of repair and rehabilitation. In case of new works, WUA shall have to share 5% of estimated amount. At the time of entrusting the sanctioned work to WUA, one third of sanctioned amount shall have to be given to WUA without any mortgage. While releasing funds to the WUA by the Government, the contribution of WUA will be deducted.

5.2.5 Taking Assistance from NGOs in Formation and Capacity Building of WUAs

Gujarat PIM Rules provide for engagement of NGO for the purpose of formation or establishment of WUA and carrying out various activities lay down under the rules by the officer in the rank of Superintending Engineer and above. The SE may invite and engage the competent and reputed NGO or a successful WUA who is successfully working in different irrigation sector and will be able to promote WUA and supporting them in PIM through motivation as facilitator or community organizer. In case of non-availability of facilitator or community organizer, the SE may assign the competent assistant engineer (AE) or additional assistant engineer (AAE) who is devotee and capable of promoting WUA and supporting them in PIM through motivation. The Government shall give incentive to that AE or AAE for such assigned activity as per norms laid down from time to time for payment of facilitator or community organizer.

In Gujarat (Dharoi Irrigation Project), Maharashtra (Waghad Irrigation Project), Chhattisgarh (CIDP) and Uttar Pradesh (UPWSRP-1), the NGOs have helped in the establishment and capacity building of WUAs. It has been observed that the continuous handholding is needed by an NGO for 3–4 years for capacity building of WUAs. After exit of NGO, the good will, cooperation and assistance of the WRD to WUA are essential for their sustainability.

6 Critical Issues in Upscaling of PIM

6.1 PIM Acts Should Be Farmer-Friendly, Simple and Practical

The PIM Acts and Rules in each state have been prepared by the Government, mainly by the WRD/CAD without wider consultations with the stakeholders, particularly, farmers. These rules are rigid, lengthy, cumbersome, procedure ridden and cut-off from the ground realities. These acts can be crudely termed as the wish list of the water sector reforms which the government could not implement all through the years. That is why even the most successful WUAs in terms of managing distribution of canal water and maintenance and repair of irrigation system have not been able to implement many provisions of the Act.

Andhra Pradesh enacted the first PIM Act in 1997 which coincided with the emergence of donor support to irrigation reforms in India with PIM as the core component of reform projects. Though the consultation process before the Act was conducted but being maiden act of its kind, the first-hand experience was not available. The Madhya Pradesh PIM Act 1999 and Rajasthan PIM Act 2000 were enacted in hurry probably to avail the donor funding as these acts are remarkably similar to AP PIM Act although the ground conditions of M.P. and Rajasthan are quite different to each other as well as Andhra Pradesh. The Maharashtra PIM Act 2005 and the Gujarat PIM Act 2007 were based on feedback from existing WUAs, and a lot of consultations were made. So far, the Maharashtra PIM Act 2005 is better in providing enabling environment to the WUAs. Maharashtra PIM Act is also the best act in terms of provision for women participation as it reserves a 2-year term for a women president besides one third reservation for them in each level of management committee. Still all acts have many weaknesses in common:

(i) PIM was initially driven by donor support to irrigation reforms in India, and most officials perceived it as an outside agenda. The concept, need and rationale of PIM were not adequately discussed with government agency officials which leads to weak commitment of the agency officials and hasty drafting of PIM Acts.
(ii) All acts are based on the premise that office bearers of a WUA will be keen to provide voluntary services and notifying every farmer as a member in the command area of WUA will act as a binding force.
(iii) The process of formation of WUAs is full of procedures, and WUAs are expected to carry out more functions voluntarily with resource generation from own efforts than the WRD was carrying out with salaried staff and resources at their disposal.
(iv) The training and capacity building, involvement of NGOs and private sector participation in PIM are vital yet neglected areas in all PIM Acts. Only Gujarat PIM Rules associated with the Act provide for deployment of NGO for formation and handholding of WUAs.

(v) While provisions of women participation have been made in the PIM Acts (except Andhra Pradesh, Gujarat, Rajasthan and Tamil Nadu), the social constraints and difficulties related to women participation have not been addressed.

(vi) The PIM Acts stress on elections for WUA management committee and office bearers. It has been experienced that the elections generally create undesirable after effects to spoil the collective action environment in the community. There should be inbuilt incentive on consensus and elections should be conducted as the last resort. For example, Andhra Pradesh Government provides a financial incentive to those WUAs which are constituted through the proposal/election of consensus candidates. It will be proper to revisit the PIM Act in each state and make it realistic and farmer-friendly as each state has enough experience and feedback to undertake midcourse corrections.

The responsibilities of office bearers of WUA under the PIM Acts call for their full-time involvement. It also calls for cash contributions and fund raising from the farmers to support an agenda in which the farmers do not perceive any gain or incentives for themselves. The whole concept of PIM is based on voluntary WUAs. It needs to be compensation oriented. The farmers have to be convinced that there are adequate compensation and incentives for their effort in the formation of robust WUAs.

It is noteworthy that most successful WUAs in Maharashtra and Gujarat are not, strictly, functioning according to PIM Acts of their state. These WUAs in Gujarat were already functional under cooperative act before the Gujarat PIM Act 2007 came to existence. Most WUAs in Gujarat are still functioning as irrigation cooperatives and are reluctant to switch over to PIM Act. Similarly, successful WUAs in Waghad Project, Maharashtra have informally abrogated certain provisions of Maharashtra PIM Act for smoother functioning.

There is immediate requirement to modify the State PIM Acts based on experiences gained in implementing PIM Acts since the last 15 years.

6.2 Need to Adopt a Step-by-Step Approach for Large Systems

On large and medium irrigation systems, farmers are traditionally dependent on the government for irrigation water delivery since the British period, and they lack initiative to organize for water management unless backed up and regularly supported by the WRD. On the other hand, WRDs do not like this democratic system to encroach in their comfort zone of 'powers without accountability to the users'.

Besides the attitudinal constraints, there are technical and organizational constraints as well. The canal irrigation systems are often quite large, and it is difficult to organize WUAs on them for two reasons: (1) the number of the farmers is quite large requiring investment of huge resources at the initial stages, and (2) water users at lower level of the irrigation system are not able to establish the cause-effect relationship between their efforts and commensurate gains. The State PIM Acts elaborate in detail how higher-level WUA organizations at the distributary and up-to project/scheme level should be formed in one go. Experiences from other countries, such as Mexico and Turkey, have shown that it is important to get the lower-order WUAs functioning correctly before moving above the outlet or minor canal. Once the WUAs are able to manage, operate and maintain their systems within the outlet or minor command, they will be interested, and able, to start getting involved in the management of the higher-order canals. The best example of this is Gujarat where the act provides for WUAs at minor level canal only. But once the minor level WUAs began functioning well and stabilized, the informal WUAs at distributary level have been set up by the farmers without waiting for amendment in the Act. Conversely, Madhya Pradesh started with formation of WUAs at minor, distributary and project level in one go but had to backtrack to WUA at minor canal level only.

It was also noted that in the projects supported by the World Bank, Asian Development Bank, Japan International Cooperation Agency, etc., the formation of WUAs is mandatory, and PIM was implemented in project mode with rigid targets focusing more on number of WUAs formed and ignoring the quality of processes and other aspects of strengthening and capacity building of WUAs.

6.3 The WUAs Shall Have to Extend Their Scope

Right now, WUAs are focused on repair and maintenance of irrigation facilities below minor head, canal water distribution amongst farmers, irrigation recording and revenue collection. The core objective of establishing WUA, namely, using canal water efficiently and economically, saving canal water to extend more area under irrigation facility, ensure equitable distribution of water up to the tail end and maintain canal infrastructure will not attract the real participation of farmers unless these objectives are clearly linked with agriculture productivity and income generation for the farmers. For this to happen, the WUAs need to have an entrepreneurial orientation and should extend their scope to backward and forward linkages of agriculture. The WUAs have to be a hub of rural development through proper mix of local labour, available resources and developmental schemes like MNREGA, National Horticulture Mission and various schemes in agriculture sector. WUAs have to develop new markets and strategies to satisfy myriad needs of the farmers on the one hand, and, on the other hand, WUAs have to discover new sources of water in the framework of integrated water resources management including rainfall conservation, groundwater and surface water.

6.4 WUAs Must Be Sustainable Without Subsidies

The WUAs will be able to carry out their functions only if they are financially sustainable. The authority to fix water rates to be charged from the farmers lies with the state government. The only exception is Maharashtra where WUAs can fix water rates to be charged from the farmers. WUAs determine and collect water charges from the users directly in Gujarat, Maharashtra and Rajasthan. Except Gujarat, the water charges collected by the WUAs are deposited in government treasury, and prescribed % of collected revenue is paid back to WUAs by the state governments. In Uttar Pradesh and Andhra Pradesh, the water charges are collected by the Revenue Department, but the prescribed % of collected revenue is paid back to WUAs by the state governments. In Maharashtra, 75–93% of the revenue collected is ploughed back to the WUAs. In Rajasthan, 50% of the revenue collected is ploughed back to the WUAs. In Uttar Pradesh, 60% of the revenue collected and in AP 90–95% of the revenue collected are ploughed back to the WUAs. In Gujarat, WUAs are allowed to retain 30% of revenue collected for ordinary repairs and maintenance of canal and can retain additional 20% if 100% tax is collected in time.

Since the water rates fixed by the states are very low, the resultant share to WUAs is also low in terms of absolute value. Another difficulty faced by WUAs in this regard is bureaucratic delays in ploughing back of collected revenue from the government treasury to the WUA. This process varies from a few months to a few years. Since WUAs have not generated any other sources of income, the delay in ploughing back of money cripples the WUAs. The only good point is that the funds to WUA are linked with water charges collection which motivates WUA to increase area under irrigation as well as cent percent recoveries. All WUAs can also avail one-time management grant of Rs 1200/ha under Command Area Development and Water Management Program (CADWMP).

WUAs in all states have common concern and complaints that the funds given by the government are too meagre to provide salary to staff and carry out repair and maintenance of the irrigation system simultaneously. Since staff salary cannot be stopped, the repair and maintenance of the system suffers. The PIM Acts allow WUAs to resort to multiple sources of fund collection, viz., set their own service fee and levy taxes, seek contribution from members and get donations, grants and many more. For financial sustainability of WUAs, the following measures are necessary:

(i) The government rationalizes the irrigation rates. The increase in irrigation rates will proportionately increase the share of WUA.
(ii) Instead of plough back of funds causing inevitable delays, WUAs may be allowed to retain funds as in Gujarat.
(iii) The WUAs should be trained and motivated to seek alternative sources of funding as provided in the PIM Acts.
(iv) The WUAs should be made aware of financial avenues available to them. For example, it was observed in Rajasthan that fixed deposit against one-time management subsidy was renewed every year with interest and the WUA office bearers did not know that they could utilize its interest portion.

6.5 WUAs Should Be Made Capable to Manage the Environment

Waterlogging, salinity, unsustainable groundwater extraction and contamination of soil and land are major issues in irrigated agriculture which are crucial for agriculture productivity. Since surface water (canal water) and groundwater (wells, tube wells) are integrated source with mutual interdependence, the focus on canal water only will not be helpful in tackling environmental problems. In addition, a single source either canal water or groundwater may also not be able to provide adequate irrigation around the year. PIM Acts in all the states provide for role of WUA in groundwater management also. The Maharashtra PIM Act even allows WUAs to levy water charges on use of groundwater and recycled water (Para 27(3) of the Act). But the WUAs are entirely focused on canal water management leaving the groundwater management as an individual responsibility. It is necessary for WUAs to focus on all water resources in the command and should extend their role in integrated irrigation water management for their sustainability.

6.6 Training Is Required at All Levels

Participatory irrigation management is an approach which encourages the users' involvement in the decision-making as well as implementation of irrigation water conveyance, delivery, distribution, utilization and the drainage from minor canal level upwards in the cardinal canal system. The integration of activity and decision as well as joint management is a new concept both for the irrigation agency and also for farmers. Such a change demands special skills and attitudes in both the agency involved in irrigation and the farmers in regard to the roles and responsibilities presently being discharged. Unfortunately, still a lot requires to be done on the training as well as capacity building efforts of farmers/officials on implementation of PIM. Lot of synchronization is also required in the field.

State WALMIs, Krishi Vigyan Kendras (KVKs), NGOs, agriculture universities, IndiaNPIM and other training institutes should have a network to pool training resources and generate training resources through training of trainers (ToT) as the challenge of training and capacity building is huge in comparison to resources available in the states.

The major problem with the training of farmers arises from largely classroom trainings being imparted by WALMIs, KVKs and other training institutes. New and innovative training methods like Farmer Field Schools (FFS) which are conducted at the farmers' fields and are based on 'learning by doing' are much more effective. Similarly, the 'exposure visits' to successful projects during the training have been found quite effective than mere classroom training which has very limited impact on the participants. Chhattisgarh Irrigation Development Project (CIDP) is a good example where the training based on the concept of 'learning by doing' and through FFS resulted in strengthening of WUAs and achievement of project objectives.

6.7 Government Agencies Need to be Reoriented

WUA requires interaction and support from many government agencies like the ID/WRD, CADA, Department of Agriculture, Department of Horticulture, Groundwater Department, Rural Development Department, etc. These agencies work in isolation and often at cross-purposes. The Department of Agriculture promotes crop varieties and crop practices, while IDs are suppliers of irrigation water. Both the departments never sit together to sort out which crop varieties and crop practices are to be promoted based on available water. Across the states, the presence of agriculture and other agencies to support WUAs is negligible. In Madhya Pradesh, an ex-officio member from agriculture department is co-opted in the management committee of WUA as per MP-PIM Act. Still the support of agriculture department is not visible in field.

It is suggested that WRD/agency responsible for promoting WUA should constitute multidisciplinary PIM cells in each irrigation division, on the pattern of Uttar Pradesh and Tamil Nadu, which should provide single window support to WUAs on training and capacity building requirements and act as an interface between WUA and various farmer-friendly schemes of other line agencies/departments so that WUAs develop as a credible and efficient institution for the water users.

6.8 Effective Monitoring of WUAs at Each Level

Monitoring is an effective tool to guide the WUAs on the right track for sustainability. The PIM Acts of each state have provisions for monitoring of WUAs by the WRD at each level, but WRDs are mostly reluctant or short of time/skill to do it in a proper manner. Mostly it is a crude exercise in controlling/restraining WUAs. Many important activities like quality, relevance and timing of training deliveries, routing of water charges to WUA, audit compliances, etc. are not focused in monitoring which may lead to misappropriation of WUA funds and weak WUAs. Therefore, it is necessary to establish regular monitoring mechanism through dedicated PIM cells created for this special purpose.

7 Conclusions and Recommendations

A big gap is visible between the PIM policies, acts and rules declared by the state governments/central government and its implementation on ground. The acts and rules are made in haste without wider consultations with the stakeholders and thus lack practical perspective. A criticism of the participatory irrigation management programme in India to date is that it has been mandated on paper, but often not supported in practice with the resources and expertise required to change the status quo. The reason of this lacklustre performance emanates from attitudinal and operational constraints which are listed below:

(i) On large and medium irrigation systems, farmers are traditionally dependent on the government for irrigation water delivery since the British period, and they lack initiative to organize for water management unless backed up and regularly supported by the WRD. On the other hand, WRDs do not like this democratic system to encroach in their comfort zone of 'powers without accountability to the users'.
(ii) PIM was initially driven by donor support to irrigation reforms in India, and most officials perceived it as an outside agenda as the idea was not adequately discussed and internalized by them.
(iii) PIM was implemented in project mode with fixed targets focusing more on numbers than the desired results.
(iv) The legal framework for PIM was prepared in haste ignoring ground realities.
(v) The training and capacity building efforts for the farmers and officials for the implementation of PIM have been inadequate and largely unsynchronized with requirements on the field.

Building any organization requires meticulous planning, time, effort and resources; formation of effective water users' associations is no different. Building sustainable, self-reliant water user organizations is a time- and resource-consuming activity, which cannot be achieved without full and strong commitment from the state governments and particularly Irrigation/Water Resources Departments. Evidence exists in several locations in India that where adequate time, effort and resources are committed viable WUAs can be formed, with significant benefit to the users and to the wider society in that irrigation scheme which becomes more efficient and productive.

Recommendations

(i) The State PIM Acts/Rules and other legal frameworks for PIM need to be revised in the light of past experiences in implementing PIM on ground and feedback from the stakeholders. The revised act should be more farmer-friendly, simple and based on ground realities. It's a good idea that the MoWR, RD & GR, Government of India, prepares and issues a model draft of PIM Act for the guidance of the states.

(ii) For the financial sustainability of the WUAs, it is very important that the WUAs are given the responsibility of collection of water charges and are allowed to retain prescribed water charges with them for operation and maintenance of the system and administrative expenses. The current system of deposition of all collected moneys with the government and then reallocation of the money through government channels is time consuming and restrains the financial viability of WUA.

(iii) Each state government and the central government should institute annual awards to encourage best performing WUAs at the state and the national level, respectively, to motivate WUAs to perform better and keep verifiable records.

(iv) There should be a PIM Directorate at MoWR, RD & GR, Government of India, level to act as a National Resource Centre for PIM. It should guide and assist the states in awareness, communication, training, research and benchmarking-related activities in PIM implementation.

(v) Each state WRD should have PIM Directorate at the apex level which should be responsible for regular monitoring of WUA activities in the state. Each division of WRD should have PIM Cells to assist and coordinate WUA activities.

By focusing on the core principles of water management and change management, robust WUAs can be multiplied to bridge the management gap between the main system run by the Irrigation Department and the field plots managed by large numbers of smallholder farmers. There is enormous potential for saving water and increasing productivity of land and water in agriculture through formation and strengthening of WUAs. It is the time for midcourse corrections in the light of a decade of implementation experience to make combination of WRD and the Water Users' Associations more effective and productive.

Acknowledgements The author expresses his sincere thanks to his colleagues for valuable input and support during the course of preparation of the manuscript.

Phanish Kumar Sinha is currently serving as president of the Indian Network on Participatory Irrigation Management (INPIM). He is a fellow of the Institution of Engineers (India) and Indian Water Resources Society. He graduated in civil engineering from Indian Institute of Technology, Roorkee (erstwhile Roorkee University) in 1969 and started his career as an irrigation engineer in Uttar Pradesh Irrigation Department. He obtained his master's degree in sociology as well as in business management during professional career. After superannuation, he worked as a freelance consultant with many international NGOs, FAO, Asian Development Bank and the World Bank. His core area of expertise is training in water management and implementation of participatory irrigation management (PIM). He has presented several papers on PIM in national and international seminars and has studied water management institutions in Holland, Germany, France, Turkey, Afghanistan, Malaysia, Sri Lanka, Bangladesh and many Indian states.

Bringing Aquifers and Communities Together: Decentralised Groundwater Governance in Rural India

Dhaval Joshi, Himanshu Kulkarni, and Uma Aslekar

1 Introduction

India's per-capita groundwater use, just over 200 m^3 per year (CGWB 2011), is not the highest in the world. However, with its population of over 1.25 billion, India's groundwater use, estimated from various sources, exceeds 260 km^3 per annum, the highest in any country in the world. The annual groundwater draft for irrigation, domestic use and industries in India is estimated to be 231 billion cubic metres, and the stage of groundwater development of the country as a whole is 61% (CGWB 2011). Groundwater is an important source for drinking water, irrigation, industries, livestock and domestic usage. Nearly 90% India's rural water supply is sourced from groundwater (DDWS 2006, 2009). With more nearly 650,000 villages, this figure implies that nearly 600,000 villages depend upon groundwater for their daily drinking water and domestic needs.

Irrigation has been the prime mover of agricultural growth in India (Shah 2010; Kulkarni et al. 2009). Much of the recent expansion in irrigated area is on account of groundwater. In India, groundwater-irrigated areas witnessed a spectacular increase from around 11.9 million ha in 1970–1971 to 33.1 million ha in 1998–1999 with a 178% increase in 28 years (Shah 2005). It is now an accepted fact that 70% of water in agriculture is groundwater (Ministry of Agriculture 2013). The use and exploitation of groundwater have not been limited to rural areas and agriculture but have rapidly transgressed into other sectors like urban water supply and industrial use. Half the water used in the growing towns and cities of India is groundwater (Narain and Pandey 2012). This groundwater use is largely outside the ambit of formal public water supply and contributes to filling in the gap between a rapidly growing demand and the limits to public water supply (Shah and Kulkarni 2015).

D. Joshi · H. Kulkarni (✉) · U. Aslekar
Advanced Center for Water Resources Development and Management (ACWADAM), Pune, India

© Springer Nature Singapore Pte Ltd. 2019

A. Singh et al. (eds.), *Water Governance: Challenges and Prospects*, Springer Water,
https://doi.org/10.1007/978-981-13-2700-1_9

India's unprecedented growth in the usage of groundwater is also important given that many regions of the country are drought-prone. While groundwater resources actually constitute drought buffers in many regions of the world (Calow et al. 1997; Moench 1992), extreme events and natural disasters show an increased usage of groundwater; it is observed that during floods in many regions of India, groundwater often provides the primary respite in meeting the immediacy of water for life. The unprecedented usage of groundwater has meant increasing vulnerability to resource uncertainty by India's rural and urban population. This vulnerability has led to two broad implications. Firstly, various degrees of groundwater exploitation have resulted in decrease in basic availability of groundwater and in some areas to persistent, interannual water scarcity. Secondly, problems of groundwater contamination have emerged, sometimes in association with reduced availability, leading to an acute scarcity of good quality water. Nearly 60% of India's districts have become vulnerable to problems of exploitation or contamination or to both during the last 10–15 years (Kulkarni and Shankar 2009), endangering the water security of many regions in the country. In an agrarian country like India, this becomes very critical since most of the population dependent on this resource has either been marginal and small landholders, farmers with limited entitlements and from drought-prone regions. In India, small and marginal farmers are 78%, operating less than 2 ha land having access to 32% of the total land. But they own 45% of wells and tube wells and account for almost 40% of the groundwater-irrigated area (Mukherji 2004). Such a growth is now evident across different hydrogeological and agroecological typologies in India (Kulkarni et al. 2009) (Fig. 1).

Groundwater stocks have crossed limits of extraction, as a result of decades of development and use of groundwater, leading to problems related to availability or quality of the resource. As per the Planning Commission Report (2009), about 60% of the blocks in the country either face issues of availability, quality or, in some cases, both. Quality issues related to geogenic pollution like fluoride and arsenic have emerged in some regions of the country, while issues related to salinity have emerged in other regions. Groundwater contamination has serious implications on human well-being and health.

Groundwater exploitation or over-abstraction can be described as a situation in which average abstraction rates from aquifers is greater than or closer to average recharge rates (Custodio 2002). India's groundwater resources are periodically assessed using a method that considers the ratio of extraction to annual replenishment. Some 16% of the blocks (sub-districts) across the country show over-exploitation of groundwater, while more nearly one-third show various stages of development above the threshold of what is considered 'safe' status (CGWB 2014).

Groundwater resources development has not been uniform in India, resulting in a variety of combinations between the degree of dependence (even in a single sector like agriculture) and the problems of exploitation and contamination. Moreover, the diverse aquifer settings in India have resulted in differential impacts on society, the economy and the ecosystem. Understanding the diversity and developing interdisciplinary approaches to groundwater management that range across multiple scales of interventions are all required in tackling the issues of groundwater overuse and

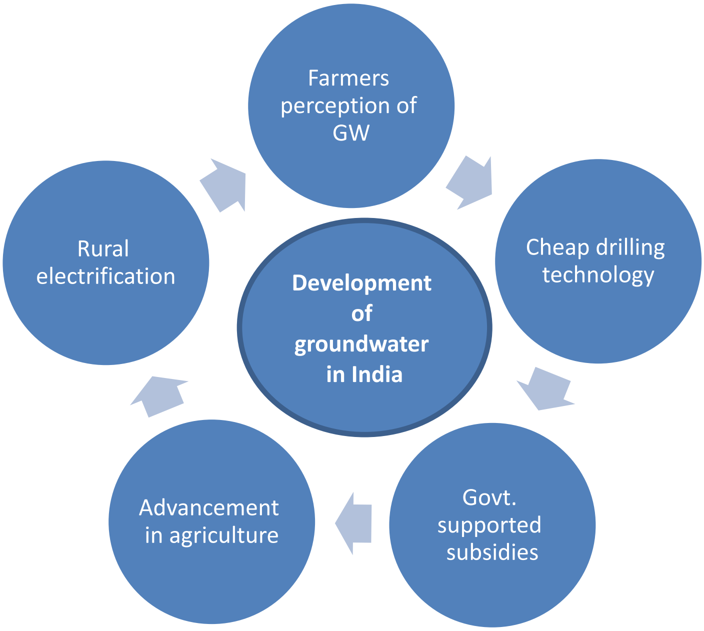


Fig. 1 Factors contributing to groundwater development in India

contamination in India. Most significantly, a decentralised system of groundwater governance seems most appropriate, given the appropriately labelled atomistic patterns of groundwater usage in different part of the country.

2 The Need for a Groundwater Governance Framework

Groundwater development has been called the ‘silent revolution’ because of the role of individual, private owners in the development of access to groundwater resources (Llamas and Martinez-Santos 2005). The proliferation of wells has, on the other hand, been fuelled by cheap drilling technologies, farmer’s perception of drilling deeper to find ‘more water’ and various subsidies in agriculture, the most significant one being subsidy on electricity, even as rural electrification has continued to expand. Hence, exploratory approaches to finding more and more groundwater dominate approaches of managing aquifers, a common pool resource.

Figure 2 is a generalised impact package of a depleting shallow aquifer. The most obvious impact of a depleting aquifer is the fall in water levels – an aspect that is relatively easy to imagine and, therefore, shown in the diagram. However, there are other impacts that have social, economic and environmental implications. While potential groundwater abstraction may follow a trajectory of increase and decline, the abstraction has a positive correlation with a burgeoning agrarian economy, which

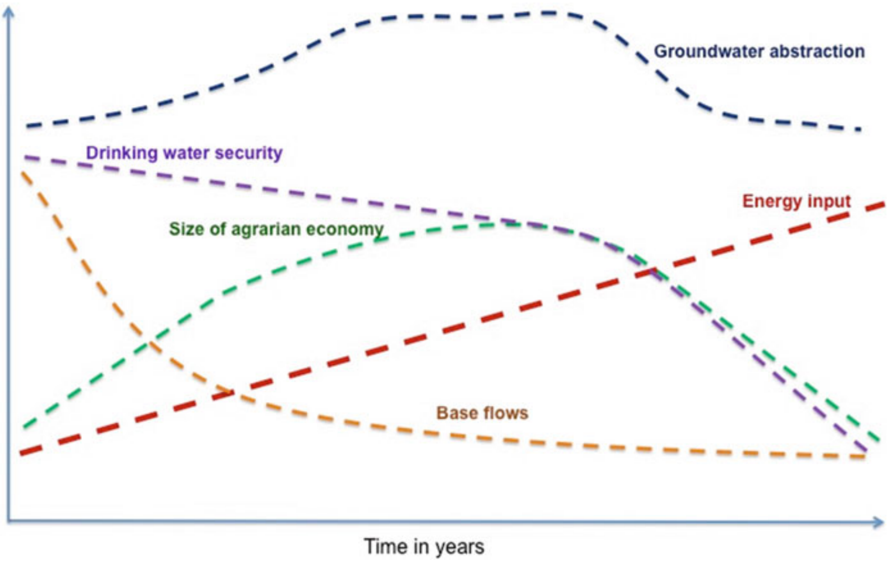


Fig. 2 A depleting aquifer has many dynamics accompanying water level decline

is sustained by exploring more and more groundwater – creating deeper and more sources – which subsequently builds into a competition between domestic water, water for agriculture and ecosystem water even at local scales. Energy inputs (and costs) increase, while base flows to streams and rivers declines, affecting e-flows in myriad ways.

Understanding the physical complexity of groundwater resources is fundamental in developing management approaches to groundwater (Burke and Moench 2000). There is very little effort towards understanding the nature and characteristics of the resource, particularly at scales where groundwater management is necessary, i.e. at the scale of a watershed or a cluster of villages. Aquifers, the units of groundwater resource, had limited recognition in the planning, development and management of groundwater, although recent efforts made in policy reforms are promising enough (Shah 2013).

Groundwater is a common pool resource wherein aquifer forms the resource system, while groundwater forms the resource unit, more often owned by individuals through wells and bore wells. Like many natural systems, it is not necessarily 'equally' divisible. Hence, it also bears the property of being 'unequally substractible' – increased availability to one individual can result in decreased availability to another. Although renewable, an aquifer has defined limits of stocks (arguably to some degree of elasticity) and resource units it can support, and therefore, the 'common pool' nature of groundwater is being increasingly finding importance in water management and governance in India (Shah et al. 2012; Shankar et al. 2011; Kulkarni et al. 2015).

Groundwater management, therefore, is not just about recharging aquifers but also about managing groundwater resources comprehensively, including acknowledging the role of groundwater in the environment and in providing environmental services. All of these need to be part of a process at local scales, given the atomistic uniqueness of India's groundwater usage. Moreover, aggregated numbers of groundwater overdraft will have different consequences in regional aquifer settings such as the alluvial aquifers in the Ganga Plains from the hard-rock aquifers of western and peninsular India. What may be common to both is the process of understanding aquifers and social processes of catalysing community or collective decisions and actions such as in many examples of participatory groundwater management (Kulkarni et al. 2004; Vijay Shankar et al. 2011). Moreover, groundwater management itself is perhaps only a means to a logical end of groundwater problems. Institutions and regulation are also important in this regard, given the scale of the problem and the need to ensure the sustainability of good practices on groundwater management. The integration between scientific knowledge of aquifers, community level decisions regarding supply and demand of groundwater, actions about efficient and equitable use of groundwater, regulatory functions and institutional framework define groundwater governance. Groundwater governance is as important as the decisions and actions in groundwater management. Given India's predisposition to decentralised access to groundwater resources, a bottom-up approach to groundwater governance is necessary for the sustaining both community efforts and government regulation through direct and indirect instruments of management of groundwater resources.

3 Groundwater Governance: The Global Context

'Groundwater Governance: A Global Framework for Action' project, led by FAO, defines groundwater governance as 'an overarching framework and a set of guiding principles that determines and enables the sustainable management of groundwater resources and use of aquifers' (FAO 2016). According to the World Bank, groundwater governance comprises of responsible collective action in order to ensure socially sustainable utilisation and effective protection of groundwater resources for the benefit of humankind and dependent ecosystems (Foster et al. 2010). It essentially means achieving a balance between instruments of protecting aquifers and moderating use of groundwater from such aquifers which forms the basis of a groundwater governance framework (Kulkarni and Vijayshankar 2014).

Groundwater governance is also defined as 'the process by which groundwater is managed through the application of responsibility, participation, information availability, transparency, custom, and rule of law; further, it is the art of coordinating administrative actions and decision making between and among different jurisdictional levels one of which may be global' (Varady et al. 2013). However, on a more practical basis, groundwater governance is better thought of as the governance of

Table 1 Comparative analysis of groundwater governance scenario in four countries

	China	Mexico	Spain	India
Type of government	Communist	Federal republic	Democracy	Democracy
Ownership of groundwater	State owned	National property (Since 1992)	State owned (Since1985)	Not clear
Groundwater law/policy	Yes	Yes	Yes	Yes (partially)
GW management institutions	Local government institutions	COTAS (aquifer management councils)	River basin managing agencies	State governments
Community participation	Limited	Limited (awareness generation, resource monitoring and education)	Limited (more in managing of irrigation network than irrigation management)	Community based efforts for recharge augmentation

aquifers that are not only complex but include uncertainties in the dynamics and flow of groundwater.[1]

Efforts for governing the invisible and fugitive groundwater resource have received mixed responses throughout the globe. Countries have tried and tested various instruments for governance and management of groundwater. The USA has adopted a tradable property right regime for self-governance of groundwater. Experiences from Kansas and Texas states of the country highlight the challenges in doing so. The problem of transaction costs when it comes to setting up institutions to monitor and regulate a tradable property rights regime becomes a deterrent (Shah 2014). For this very reason, the Kansas groundwater authority carefully exempt numerous de minimis users in order to reduce them to manageable levels. It is interesting to note how prioritising groundwater governance in the USA has led to various states adopting a common framework of the priorities of water quality and contamination, conflicts between users and declining groundwater levels (Megdal et al. 2015).

In India, for example, wherein there are millions of groundwater users, it would be merely impossible to allocate and monitor groundwater use through a State or Federal System. The Murray Darling river basin of Australia, which is considered to be a model for integrated river basin management, exempts all users consuming water for domestic and livestock needs or irrigating land less than 2 ha from the legal and institutional framework. If such a strategy is adopted for India, nearly 95% groundwater irrigators will be exempted (Shah et al. 2006).

The type of government and administrative set up, defining the ownership of the resource, existence of sound groundwater policy and its amalgam in the larger water policy of the state define the nature of groundwater governance in various countries (Mukherji and Shah 2005). Table 1 cites examples of four different countries on the basis of these characteristics and their ensuing outcomes. While still quite broad-

[1] http://www.oecd.org/cfe/regional-policy/8-Tour-de-table-Andrew-Ross.pdf

based, the outcomes seem to be significantly influenced by the socio-political milieu in each of the countries.

Various Middle Eastern countries of Asia, wherein the role of state is strong and visible, have adopted policy-level changes to influence the groundwater management outcomes. Saudi Arabia, for example, had enacted a policy change to discourage wheat cultivation in the country, which is the biggest driver of groundwater use, and shift towards high-value crops. This changed reduced the area under wheat cultivation by 50% in 2010 and also reduced water consumption for irrigation from 17.3 BCM to 15 BCM (Closas and Molle 2016). A policy change of this order highlights the strong role of the state, while the success is also because of the smaller number of users growing wheat in case of Saudi Arabia.

Jordan on the other hand has attempted the administrative instrument of 'water policing' wherein the government tried to regulate groundwater use through licencing of wells and issuing each farmer with a groundwater quota. However, researchers have observed that these quotas were never enforced. In order to address this, the state, through a by-law, introduced a penalty for abstraction above the sanctioned quota, but that remains unenforced due to strong pressures from farmer interest groups and lack of administrative capacity (Shah 2014).

The case of Mexico is interesting, wherein the government through the Law of Nations Water established aquifer management councils known as *Comités Técnicos de Aguas Subterráneas* (technical water councils – COTAS). Although it has proved beneficial in educating and building capacities of resource users, they have not been efficient in management of the resource – the fundamental premise for their creation. Researchers argue that lack of technical expertise and financial autonomy subdued the outcomes of the COTAS (Sandoval 2004).

4 Groundwater Governance in India

While the lessons from the global context are rich and varied, one needs to exercise caution while trying to adapt or implement similar groundwater governance mechanisms, when it comes to India. Three clear reasons are behind why we need to be cautious. Firstly, India has a diverse hydrogeological setting, which highlights the granularity of groundwater resource regimes and their interactions with the stakeholders, who measure in millions. Secondly, millions of India's groundwater users are dependent on the resource for livelihoods, drinking water security as well as many ecosystem services that these groundwater systems provide. Thirdly, India has a disintegrated framework of water governance with states being proactive in planning and implementation of water resources agenda, around the broad guiding principles provided in various policies. The agencies engaged in water resources planning and management are working in silos with few spaces for engagement and arrangement.

The case of groundwater is even more interesting. The country has established various agencies at national and state level who are assigned the responsibilities of groundwater assessment. The Central Groundwater Board established in 1971 is the national agency responsible for assessment of groundwater, monitoring, management, exploration and regulation of groundwater resources in the country. Various states have an entity that deals with groundwater. However, the groundwater agencies across states are neither of one type nor are their roles and responsibilities consistent. In some States, these are in the form of agencies or departments embedded within a larger ministry. In most cases, the state department or groundwater board or groundwater agency is tasked with carrying out assessment of groundwater, providing technical inputs linked with groundwater issues and conducting training for allied programmes like drinking water and sanitation or watershed management.

India has a long history of implementing legislation pertaining to groundwater. However, much of that has not met with success, given the diversity, the sheer number of resource users and the general lack of awareness about legislative instruments, reemphasising the need for decentralised groundwater governance (Cullet 2014). Increasing rural electrification has also led to massive development of groundwater-dependent irrigation systems with more and more farmers opting for wells or bore wells or tube wells for irrigation. This, in turn, led to development of a flat tariff or, in case of some states, a 'free electricity' policy environment. Today states like Punjab and Haryana, with most number of overexploited districts (CGWB 2011), have free electricity, rendering the cost of groundwater draft to nearly zero. This has fuelled more and more abstraction of groundwater at the cost of depleting water levels over the years, leading to increasing issues of poor drought resilience and deteriorating groundwater quality. Various state governments, with the intention of regulating groundwater use, have adopted indirect instruments like electricity control to reduce groundwater draft. The case of Gujarat's *Jyotigram Yojana* is well documented (Shah et al. 2008). It involved separation of feeders for farm and nonfarm use. By controlling the hours of electricity supply, the state has attempted to control groundwater draft. However, these had negative implications especially for the small and marginal landholders or those who were dependent on groundwater markets for irrigation water. Due to reduction in power supply, farmers with access to irrigation sources prioritised irrigation of their lands, thus affecting those who were dependent on the markets. The large holders, specifically from those regions tapping deeper aquifers, were affected too, since they needed more power to draw groundwater from deeper depths (Shah and Verma 2008).

Many efforts in the past have also attempted community-based management of groundwater either through self-regulation or convergence with government programmes like Integrated Watershed Development Programme and the farmer-managed groundwater systems. Ralegan Siddhi, a village from western Maharashtra, has demonstrated, through the leadership of Anna Hazare, the potential for communities to rally around key water resources issues at village level. Efforts like these are dependent on the local leadership and it is critical to institutionalise the approach to ensure long-term sustainability. Hiware Bazaar, a village very close to Ralegan Siddhi, implemented the watershed development programme in the village in 1995 and adopted norms for groundwater regulation through the instrument of the Gram Sabha. Rainfall and groundwater levels are used to decide on the crop plan to be adopted after the monsoon season. Water-intensive crops like sugarcane or banana are generally not cultivated, with some key riders. Thirdly, they adopted a complete ban on bore wells for irrigation purposes. The Andhra Pradesh Farmer Management Groundwater Systems (APFAMGS) was an intensive programme that was carried out between 2003 and 2009. The programme used various tools like participatory hydrological monitoring, farmer water schools and crop water budgeting for regulation of groundwater use (Das and Burke 2013). As a result of the programme, which was carried in 661 habitations, a pool of local resource persons for groundwater was generated, and many farmer groups shifted to crop water budgeting as a practice for management of the scarce resource. These efforts highlight the potential of communities to manage groundwater resources through a package of training and capacity building, self-regulation and role of local governance institutions.

4.1 The Emerging Dimension of Groundwater Competition

The intensive and extensive extraction of groundwater as a consequence of increasing dependency on groundwater in India is leading to severe competition around already stressed groundwater resources. Aquifers as a common pool resource are coming under competition, even resulting in conflict between different users. Sectoral conflicts around water spilling out in the open in many regions of India (Joy et al. 2008). However, while groundwater conflicts may appear few and far between, their proliferation as a consequence of increased dependency alongside a variety of issues around extraction and contamination is evident in the form of competition within agriculture, domestic, industrial and ecosystem users but also sectoral competition across these four broad user-types of groundwater. Groundwater competition (leading to conflict) is a result of a race between the supply and demand wherein the stocks (availability and quality) are seldom gauged, with many phases of groundwater competition preceding direct groundwater conflict (Kulkarni and Vijay Shankar 2014; Kulkarni and Patil 2017).

The extremely varied nature of aquifer conditions across India's geologically diverse settings imply that groundwater competition is not only complex but that a range of drivers operate across the aquifer settings to drive the competition towards potential conflict. Moreover, the competition around groundwater and its impact are often a result of the nature of aquifers on one side, the dissected usage of water from an aquifer system and the socio-economic drivers that operate groundwater usage patterns on the other. Moreover, the lack of management and governance efforts at scale, while dealing with creating sources, accessing these sources and distributing the water for various uses, deepen the competition around groundwater resources in a region.

Similar water management responses to water scarcity across a wide-ranging aquifer typology lead to differentiated manifestations of competition having serious social, economic and ecologic ramifications (Kulkarni and Patil 2017). Ease of access to technology such as drilling rigs, pump sets and irrigation infrastructure has enabled individual users to be able to easily jump into an arena that is already quite competitive. With nearly 40 million wells, easy access can quickly turn into instruments of competition over groundwater. As stocks deplete and contamination problems set in, the very access can often turn into inequitable situations, where some users gain while others lose. Even in alluvial North Gujarat, competitive extraction leads to falling water levels resulting in shutting down of access to the lower castes (Dubash 2002). On the other hand, differential impacts of irrigation are evident across social groups accessing a hard-rock aquifer systems in Tamil Nadu (Janakarajan and Moench 2006).

Further, groundwater competition can also be viewed as the tension between the hydrogeological boundaries (aquifers) and the political-administrative boundaries (e.g. of villages, taluka or blocks, districts, states) although manifestations across different aquifer systems will be different (Kulkarni and Patil 2017). Often, tensions between administration or government on one side and hydrogeological nuances of aquifer and human behaviour on the other side are actually detrimental to efforts of groundwater management and governance. Many practitioners find it difficult to reconcile administrative (village), hydrological (watershed) and hydrogeological (aquifers) in their efforts for efficient, equitable and sustainable groundwater management. While many features of groundwater competition and conflict are discussed as examples, the largest gap is in understanding the competition in the context of aquifer settings and the opportunities of converting competition to co-operation that are in tune with the broader framework of groundwater governance. The characteristics of groundwater competition and conflict are not sufficiently researched, discussed and debated as part of the larger groundwater management and governance effort in India. Groundwater management and governance must allude to the nature of groundwater competition and contextual development of responses that are able to build responses to such competition while addressing specific issues such as groundwater depletion, contamination, reduced stream and river flows, etc. Fairness and justice are as important in the framework of groundwater governance as are the buzz words of efficiency, equity and sustainability.

4.2 Integrating Science, Participation and Regulation Towards a Governance Framework

This article intends to elaborate the framework put forth by Kulkarni and Vijayshankar (2014) which identifies science, participation and regulation as the three pillars of the groundwater governance framework in India. Existing understanding that has emerged through field work and case studies by ACWADAM over the last decade forms the basis for this discussion. One could begin by understanding a pictorial depiction of the framework in the form of a graphic (Fig. 3), wherein groundwater governance should include a strong component of hydrogeology

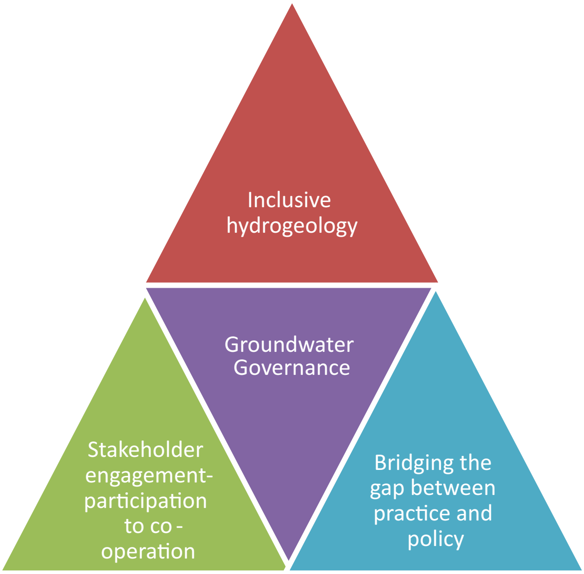


Fig. 3 Groundwater governance framework. (Adapted from Kulkarni et al. 2014)

(science), the stakeholder (users of groundwater who engage in the science to enable collective action) and a system of bridging the practice – policy gap.

A. Embedding hydrogeology in groundwater governance

Water management efforts have recognised the critical aspect of resource boundaries for identifying interventions and deciding upon the scale of groundwater management. The integrated watershed development programme, which has a long history in the context of decentralised water resources development and conservation in India, has included a clear focus on watersheds as units of intervention. The irrigation development institutions at the state level, on the other hand, focus on the river basins within which their interventions are planned and implemented. However, this does not seem to be the case when it comes to groundwater resources development and management. Although, one of the principle objectives of decentralised water conservation programmes has been the recharging of groundwater, applying hydrogeological principles at the scales of such watershed programmes seems to be missing both in the planning and execution of such programmes. For example, watershed development programmes focus on various land treatments for soil and water conservation. While they take the local slope, topography, geomorphology and soil conditions into consideration, the understanding of the geology of the area has not been part of the main programme design. Experiences from across the country suggest that unless the local hydrogeology is considered, the impacts or outcomes of such programmes are not necessarily optimised. There are some experiences that clearly point to increased efficiencies in such programmes with hydrogeological inputs, such as in the Dhara Vikas Programme implemented for spring water management in the State of Sikkim

(Tambe et al. 2012). Similarly, the participatory groundwater management programme implemented in different regions of the country has also shown how improvements to the efficient planning and implementation of such programmes can be achieved through the mapping of aquifers and identification of appropriate recharge zones in a watershed.

While the process of understanding the local hydrogeology includes the aquifer conditions, identifying areas with groundwater recharge potential in order to augment groundwater and the patterns of groundwater usage, in the area, it is equally important to pay attention to other important hydrogeological considerations, discussed below.

A.1 The diversity of hydrogeological systems across the country

Groundwater accumulation and movement are governed by the hydrogeology of a region. The types of rock and their properties, viz. porosity and permeability, form the fundamental parameters on which the accumulation and movement of groundwater are based. India's large geological diversity implies a high degree of variability in groundwater accumulation and movement. Hence, it becomes evident that hydrogeological factors be taken into consideration while planning and executing groundwater management measures, even something as seemingly straightforward as groundwater recharge. Hence, the methodology that can be adopted in the case of alluvial aquifer systems of the Indo-Gangetic plains would differ from that adopted in the hard-rock regions of peninsular India.

India consists of six predominant hydrogeological regimes (Fig. 4), viz. alluvial (unconsolidated), volcanic, crystalline, sedimentary (hard), sedimentary (soft) and mountain systems (Kulkarni and Vijayshankar 2014). About 72% of the areas consist of consolidated rock formation, including over 50% of hard-rock regions. The rest comprises the unconsolidated alluvial systems of the Indo-Gangetic plains. There is a diversity amongst the hard-rock regions, with mountain systems predominantly feeding springs, mainly in the Himalayan region wherein aquifers are recharged from a distant location. The volcanic systems, representing the central and western parts of India, comprise rocks like basalt, which have formed due to lava deposits millions of years ago. The peculiar characteristics of volcanic systems are the heterogeneous nature of the aquifer system wherein we find a range of transmissivity and storativity values even within a single aquifer system (Deolankar 1980; Kulkarni et al. 2000).

A.2 The problem context

While designing and implementing groundwater improvement programmes, it is necessary to understand the local groundwater situation. The scale of assessment conducted by CGWB focuses on a district level analysis, while in case of Groundwater Surveys and Development Agency (GSDA), the Maharashtra state agency for groundwater, the unit of groundwater assessment is watersheds.

In a study conducted by ACWADAM in Purandar block of Pune district of Maharashtra, three different scenarios emerged (Badarayani 2009). Most of the villages were overexploited in terms of groundwater development based on

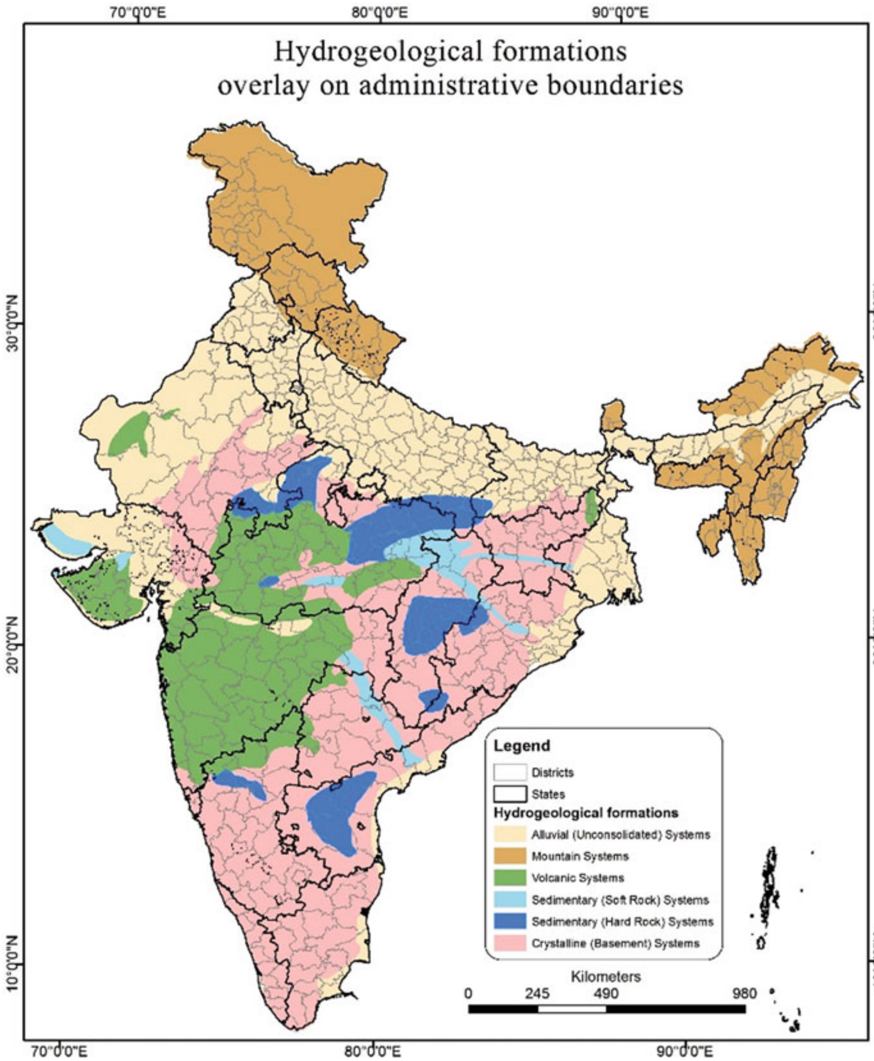


Fig. 4 Hydrogeological formations of India

GEC (Groundwater Estimation Committee) methodology of 1997, some villages which did not show evidences of groundwater exploitation were affected by water quality, while Pondhe village had neither groundwater exploitation nor any groundwater quality issues. But given the scale of assessment, which was 'block level' in this case, the entire block was termed a 'dark zone' (critical under GEC 1997) with regard to groundwater. But aquifers in Pondhe could not be labelled critical or exploited in any way, implying that regional data sets can have iniquitous and unjust implications, particularly when aquifers are local in nature.

Spring water is part of many mountain hydrological systems. Springs contribute to regional and local water security by provisioning natural groundwater discharge that is used in a variety of uses. Springs can be defined as the points or areas of natural groundwater discharge to the surface. Much of the population in the Himalayas, Western and Eastern Ghats of India are dependent on springs for their drinking water and livelihood needs. It is only in recent times that spring water has become the focus of policy attention in India.

Today, many of these spring systems are dwindling as a consequence of factors like climate change, changes in land use and land cover and sometimes due to the effects of natural disasters like earthquakes and landslides. Spring depletion is leading to serious water security issues in the mountain states, which until recently had not been part of the larger discussions and action on groundwater resources.

Palampur Municipal town, which is part of Kangra district of Himachal Pradesh, has been tapping a spring system upstream of the town since 1952. Over the last few years, the municipal authorities observed the decline in spring discharge and as a result shifted to Neugal river for their water demand. However, in an effort to revive the spring system, the town authorities formed an agreement with the Bohal Forest Development Society for ensuring protection of the recharge area of the spring and preserving its discharge. This elaborate process involved mapping the springshed area, monitoring of spring, identification of recharge area for the spring and proposing recommendations for springshed management (Fig. 5). These efforts, through a multi-stakeholder framework, aimed to ensure spring sustainability for securing water supply to the Palampur Municipal town. While the process was comprehensive and supported by GiZ (now GTZ) in partnership with different teams, including their own consultants, ACWADAM's inputs on how basic hydrogeology can be used to catalyse decision and action around the management and governance of groundwater is being stated as important here.

A.3 Integrating scientific inputs at appropriate scales of governance

Groundwater systems are part of the larger hydrological processes that shape the nature of water resources in any given region. Aquifer systems interact with a range of other processes that make this a much complex and dynamic feature of the resource. Therefore, it becomes critical to collect data at appropriate scales, both spatial and temporal, for effective community decision and action for managing aquifers as common pool resources. Groundwater data sets in India are evolving, but most data sets are indicative, but not representative (Kulkarni and Vijayshankar 2014). Hence, they fall short in pursuing various objectives of to decentralised groundwater management. For example, the CGWB collects data for about 1172 odd observation wells in the state of Maharashtra where the number of watersheds is about 1531, while the number of groundwater sources is in the range of 2–3 million (GSDA 2014). Any decision based on such a sparse dataset may lead to poor outcomes for resource management. It may be able to provide a regional perspective on the status of groundwater resources but may not be able to cater to decision-making at micro-scales, where such management has become imperative given the highly granular nature of groundwater access and extraction in India.

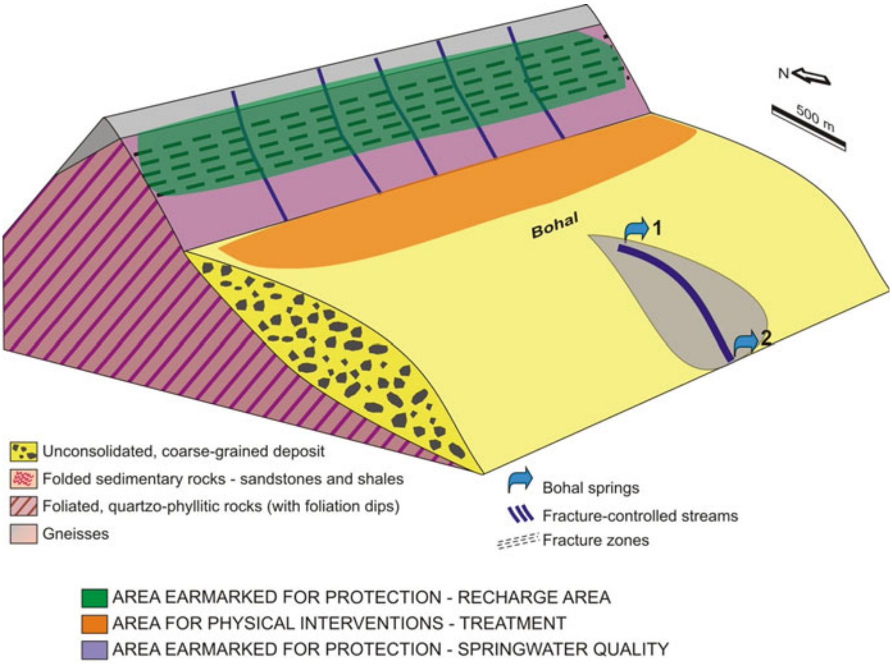


Fig. 5 Management strategy for Bohal Spring system, Himachal Pradesh.

An important function of aquifer systems is the contribution of base flows to river systems. It is for this reason that many rivers of peninsular India flow even after monsoon and some of them are perennial in nature. However, river basin level planning efforts lack this important contribution. Even the intense debate over the Sardar Sarovar Dam project on Narmada river in Central India did not include much discussion on the role of groundwater in ensuring riverine flows (Ranade 2005). In an assessment of CGWB data set for 2004 and 2009, for the Mahanadi river basin, it was observed that there is increase in groundwater draft across the entire Mahanadi basin. It is perhaps this single most significant factor that has led to the reduction in recharge, base flows and groundwater availability across the basin (Patil et al. 2017). Groundwater development has not been consistent across the basin. In a detailed study of the upper, middle and lower reaches of Hasdeo basin, which represents one of the major upper subbasins of the Mahanadi river system, it was observed that although groundwater development in the form of proliferation of dug wells and bore wells is evident in the lower reaches of the Hasdeo basin, it has not yet been the case in the upper and middle reaches of the basin. The hydrogeological settings in these two regions of the basin also contribute to inconsistent groundwater development (Patil et al. 2017). It also leads to varying degrees of competition between users and uses and spatially nuanced changes in base flows. All the above aspects point to integrating scientific inputs at appropriate scale of governance becomes central to arrive at strategies for management of the resource.

B. Stakeholder engagement and groundwater governance

Every fourth cultivator in India owns a well, with close to a million wells sunk or drilled every year. It is important, therefore, that these stakeholders are informed about the concept of an aquifer and the need for community-based, participative approaches. Stakeholder participation emphasises ensuring integration of water users and beneficiaries of a programme in the planning and implementation process. Reed (2008) has discussed in detail the arguments and claims over the need for stakeholder participation. Stakeholder participation becomes much more critical in case of management of common pool resources like groundwater because stakeholders, through formal institutions of governance, are capable of influencing the decisions and outcomes of any water security programme.

B.1 The common pool nature of the resource

A common pool resource refers to a natural or man-made resource system that is sufficiently large as to make it costly to exclude potential beneficiaries from obtaining benefits from its use (Ostrom 1990). Groundwater occurs in aquifers, and since it is not possible to exclude multiple users from appropriating an aquifer or a system of aquifers, groundwater constitutes a common pool resource. Unlike many other common pool resources, groundwater is a fugitive resource, i.e. it cannot be held ‘captive’ underneath a defined piece of land due to its flow and stock features, defined by the porosity and permeability of the rocks that constitute aquifers. More significantly, groundwater is also an invisible resource with variable properties of stocks and flows defined by aquifer storativity and transmissivity. It is made visible only partially through surface structures like wells. The nature of groundwater could be one reason for the incomprehensible, decentralised, almost individualist means of resource access in India. The atomistic development of groundwater resources in large parts of South Asia, and particularly in India, has led to the anarchy of groundwater in the region. The effects of large-scale groundwater access in India have mainly been in the form of resource depletion and co-terminal contamination of groundwater.

The impacts of exploitation and co-terminal contamination of groundwater are also quite varied, given the high degree of diversity in aquifer conditions across India. Nearly 60% of India’s districts have become vulnerable to the effects of over-exploitation and/or contamination, the relationship between groundwater dependency (especially for agriculture) and the degree of exploitation being quite complex (Kulkarni et al. 2015). It is clear that north-western India and peninsular south-eastern India are the two regions of major groundwater exploitation, while the shift to aggressive groundwater development is being envisioned in the eastern Indian region, perhaps to wean away the pressures from regions of groundwater over-exploitation. Large-scale groundwater development in the Eastern States of India is feasible for the country to launch a second ‘green revolution’ (CGWB 2017). Many of these regions also fall under the ‘irrigation-deprived’ districts where access

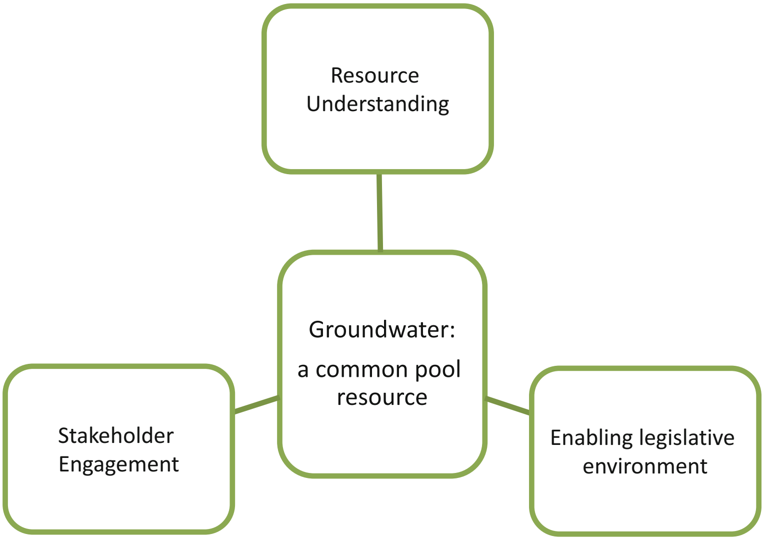


Fig. 6 Managing groundwater as a common pool resource through a combination of resource understanding, people's engagement and legislation

to irrigation for farmers is envisioned through wells, pumps and pipelines (Shah et al. 2016). The implications of this shift must been seen not only in the context of different historical trajectories of groundwater development to exploitation, explained in elaboration by Shah, but also in context to the diverse hydrogeological settings of the country. The long-term groundwater exploitation in the north-western regions was largely in alluvial aquifers, while in the peninsular southeast, it was in hard-rock aquifers. Groundwater usage began in the alluvial aquifers way before it took off in the hard-rock aquifers, although both are nearly at the same stage of development with different sets of implications in both these regions today (Kulkarni and Vijayshankar 2014). Eastern India is dominantly underlain by hard-rock geology, and hence the likelihood of more rapid aquifer depletion is envisaged there as a consequence of aggressive groundwater development which, under circumstances of easier access to technology and market availability, only requires a shorter repeat of the history in the Northwest or Southeast. This aspect must be included as a cautionary principle in the strategic management of groundwater resources from this region, even while popular call for aggressive groundwater development is being quickly answered. To avoid negative consequences, it is even more important to pitch such development within the framework of participatory groundwater management and governance beginning with the simple framework provided in Fig. 6.

Korakati Gram Panchayat is part of the Sandeshkhali block of 24 North Parganas district of West Bengal. It is part of the Sunderban delta region with a network of rivers, distributaries and canals. Through a study conducted by ACWADAM and PRASARI, it was observed that there are a staggering 1663 tube wells and

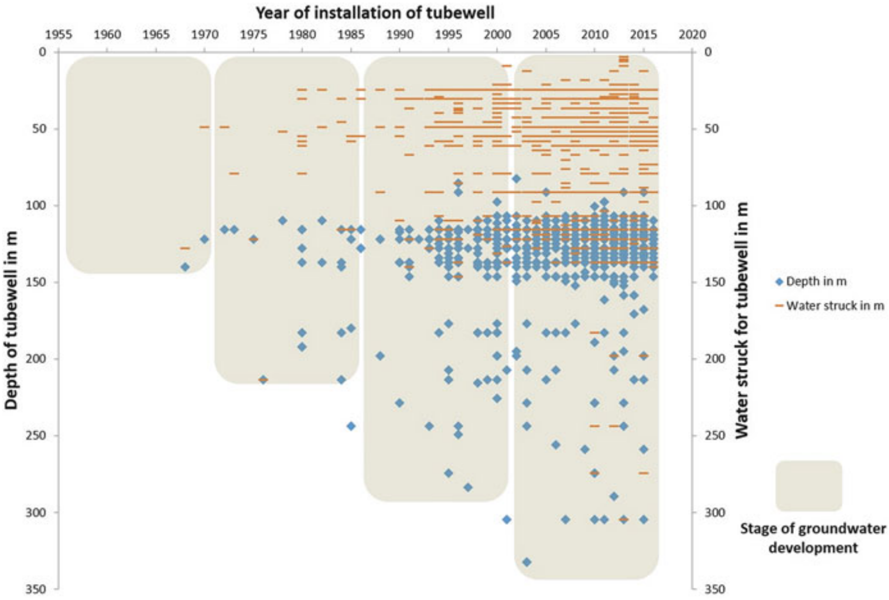


Fig. 7 Graph depicting depth of groundwater sources and water struck over last 60 years in Korakati Gram Panchayat

handpumps in this one Gram Panchayat alone. This number highlights the dependency on groundwater for drinking water security and increasingly for irrigated agriculture in the village, a village occupying a region surrounded by deltaic rivers.

Figure 7 depicts the development of groundwater sources in the form of tube wells and handpumps from 1955 till present. As it can be seen in the graph, the groundwater development accelerated at a rampant pace in the last decade and a half. The graph also depicts the depth at which water was struck during the drilling of these tube wells. It highlights the multiple aquifer system that the village currently taps. The area is underlain by alluvial systems and hence extensive aquifer systems are found. The unconfined aquifer systems are saline and hence not used for human and agricultural consumption. The competition to drill deeper has intensified during the last few years.

As a part of this exercise, it was found that between 1955 and 2000, about 170 tube wells were drilled for irrigation purposes – 170 tube wells over 45 years. Since 2000 about 185 new tube wells drilled, i.e. 185 over 17 years – implying that the frequency of drilling tube wells has increased nearly three times. One can also divide the timeline into stages of groundwater development, based on the drillers' and stakeholders' narratives that state three 'depth thresholds' – 150, 225 and 300 feet. While there are many sources now, people report that such large-scale drilling is leading to scarcity of drinking water as users compete over the same aquifer systems for multiple uses. Drying up of handpumps which are the only reliable source of safe drinking water in the area is leading to serious problems of access and quality, increasing the vulnerability of the population to scarcity and contamination. Hence, while quantities might seem unlimited in such alluvial systems, fresh water lenses available in each of the units of the multi-aquifer systems are actually limited, making groundwater quality (salinity in this case) the virtual boundary for different aquifers in such a system.

In an area dominated by the delta topography, underlain by alluvial systems and an active tidal zone, the problems posed for groundwater management need an altogether different strategy, thus highlighting the localised context of groundwater problems and solutions.

B.2 Stakeholder engagement: the stepping stone to aquifer sustainability

The socio-economic characteristics of the stakeholders (local resource users) shape the development and consequent problems around groundwater (Livingston 2009). The multitude of users and uses makes it critical for stakeholder engagement in the process of groundwater management. Stakeholder engagement, often referred to as participation, has been classified into various typologies based on the levels of engagement by the stakeholders. Based on the level of engagement, it can be classified as nominal participation, passive participation, activity linked participation, active participation and empowering participation (Agarwal 2001). In most of the water resources development programmes, stakeholder engagement is limited to either nominal, passive or activity linked participation. Essentially, stakeholders are party to the decisions that are taken either at a higher authority level within the government or through some committee entrusted with the work. Empowering participation, implying an engagement wherein the stakeholder has a voice and capacity to influence group decisions, is largely missing, except perhaps in augmenting groundwater (artificial recharge) or in supply side interventions, both usually a part of watershed development activities. Comprehensive understanding of aquifers leading to efficient supply and equitable demand management have been largely missing from programmes on groundwater.

The following table summarises different levels of participation in the groundwater management arena, with implications on stakeholder behaviour and response (Table 2). Participation or engagement in the process ranges from being party to decisions taken or being part of the process of decision-making through an interactive and empowering participation.

The example of Pani Panchayats, meaning water councils, highlights the importance of stakeholder participation. Pani Panchayats were formed in Western Maharashtra as a response to a major drought in 1972, which exposed the poor resilience of agricultural communities to the vagaries of nature. Pani Panchayats were farmer groups who shared water, in many cases groundwater from a common set of wells, formed norms and rules for use of groundwater and for ensuring conservation efforts for the same. It was one of the first efforts which attempted de-coupling of land and water rights. About more than 100 such Pani Panchayats were formed in the Purandar block of Pune district in the State of Maharashtra. These informal groups not only addressed the issues of groundwater scarcity but also aimed to have an equitable and just management of the resource (COMMAN 2005).

Table 2 Levels of participation in groundwater management. (Adapted from Agarwal 2001)

Level/type of participation	What it means for groundwater management?
Nominal and passive	Being part of meetings, surveys, group discussions – Not necessarily effecting decisions
Consultative	Being asked about what measures should be adopted for water security – Without a guarantee of influencing the decisions
Activity specific	Undertaking specific tasks like hydrological monitoring, rainfall measurement, organising meetings, etc.
Active	Being part of gram Sabha discussions and decision-making process for groundwater management – Comprehensive institutional engagement
Interactive	Undertaking specific actions on the ground, based on scientific inputs and agreed-upon decisions like planning of watershed structures based on hydrogeology, net planning, well and pump regulation, groundwater budgeting for crops, etc.

B.3 Protocols derived on the basis of local context

Protocols are rules or norms derived and formulated on the basis of the hydrogeological understanding of the resource. These protocols constitute a package of norms which influence or enable sustainability of the groundwater resource, especially in improving efficiency and equitability in the access to and usage of groundwater. However, such protocols depend upon the aquifer, aquifer conditions and the stage of groundwater extraction. The national-level groundwater assessment has been made possible through a methodology developed initially by the Groundwater Resources Estimation Committee (GEC 1997) and revised later in 2009 (MoWR 2009). The methodology involves use of an index called 'stage of groundwater development', indicating the proportion of extraction to availability (based on estimates of annual replenishment of groundwater). When the value of the stage of groundwater development of an area (district or sub-district – taluka/block/mandal) is less than 70%, it is considered as *safe*; between 70% and 90%, it is *semi-critical*; between 90% and 100%, it is *critical*; and more than 100% is considered *overexploited*.

Stages are not just restricted to arithmetic indices representing groundwater extraction versus recharge or storage. Stages also represent socio-ecological transitions as groundwater is developed, accessed and extracted over a period. DebRoy and Shah (2004) present four such socio-ecological stages of groundwater resource development. The drivers and impact of such stages are often interchangeable especially in the transition from one stage to another. Clearly, aquifer conditions, say water availability at the end of the summer season, change during such stages (COMMAN 2005), also indicating why the nature of management options become different during different stages of groundwater resource development.

Table 3 highlights some of the key protocols which form the part of the decisions and actions for groundwater management at an aquifer, village or watershed level

Table 3 Template of protocols for different stages of groundwater development

Protocols	Stage 1	Stage 2	Stage 3	Stage4
Geo-hydrology in WSD		✓	✓	✓
Protection of recharge areas	✓	✓	✓	✓
Efficient well use		✓	✓	✓
Pump capacity regulation				✓
Distance (wrt drinking water well) regulation			✓	✓
Depth regulation (wrt drinking well)			✓	✓
Regulation of agricultural water use				✓
Groundwater management through sharing		✓	✓	✓

during different stages. The table is indicative of the need for a variety of interventions as one gets into intensive efforts in managing and governing groundwater resources in India.

The protocols need to be designed considering the local hydrogeological settings and the aquifer properties like storativity and transmissivity. Many villages today, through a participatory groundwater management framework, have adopted such protocols to varying degrees (Kulkarni et al. 2009). The deepest well in the village is the drinking water well tapping the unconfined aquifer. All the other private, irrigation wells are at a lesser depth than the drinking water well. This ensures year-long availability of drinking water in the village. Crop planning based on groundwater availability is another key aspect of the protocol approach.

Protection of recharge areas enables securing groundwater recharge function in an unconfined aquifer system. Identification of potential recharge areas based on groundwater movement and local hydrogeology proves crucial for planning of watershed/groundwater recharge programmes. A provision for protection of recharge area by notifying such areas has been created under the Maharashtra Groundwater (Development and Management) Act, 2009.

Regulation of agricultural water use can be adopted through various means. It may include using improved varieties of crops which use less water, decreasing the area under water intensive crops or agreeing to a cropping pattern change. Hiware Bazar village, for example, plans winter cropping based on well water levels, indicating a crop plan based on groundwater availability that is optimised through a backward linkage to an effective watershed management plan (Singh 2012).

Based on hydrogeological investigations and community participation, a package of aquifer-based groundwater management strategy can be devised, as was done with a group of farmers from Dewas district of Madhya Pradesh (Kulkarni et al. 2004). Well use schedule can be effectively designed by identifying and allocating well use, based on the hydrogeological properties like storativity, transmissivity of the aquifer and specific capacity of the wells, particularly when the aquifer is heterogeneous.

C. Bridging the gap- policy and practice

C.1 Local governance institutions and groundwater regulation

The 73rd constitutional amendment recognises Gram Panchayats as institutions of local self-government (Sivaramakrishnan and John 2014). The Gram Panchayats are entrusted with 29 subjects, which include land development activities like water resources management and watershed development, provisioning of civic amenities like drinking water supply and sanitation facilities and maintenance of community assets which include water conservation structures and piped water supply schemes. The Gram Panchayat also constitutes a Water Supply and Sanitation Committee with members nominated in a Gram Sabha as well as representatives of the elected body of the Panchayat.

However, it has been observed that although the framework provides for comprehensive role of Gram Panchayats for management and governance of natural resources including groundwater, their role has been limited to provisioning and mediating government welfare schemes. Although it is mandatory for the Gram Panchayats to convene a Gram Sabha, at least three times in a year, this has not been seen in many cases. Gram Sabhas are intended to be active spaces for engaging all the stakeholders in the process of rural development. Given the decentralised, atomistic development of groundwater, establishing a groundwater management and governance system today is possible through the constitutional status of a Gram Sabha. The gram panchayat, which is the executive arm of the gram sabha, in many ways, can play a big role in helping design and shape protocols of groundwater management. The potential areas in which the gram sabha can play such roles are illustrated in Fig. 8.

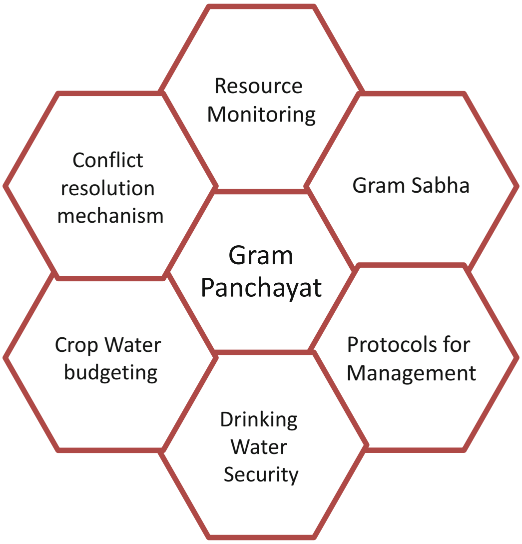


Fig. 8 Role of Gram Panchayats in groundwater management and governance

Experiences in villages like Randullabad and Takarwan, wherein Gram Panchayats actively engaged in the process of groundwater resource monitoring, understanding and arriving at decisions for management, imply a scope for decentralised governance of the resource (ACWADAM 2014). Existing water and sanitation committees, the watershed development committees in these village derived protocols for managing the resource. For example, in Randullabad village of Koregaon taluka of Satara district, the Gram Panchayat has adopted a complete ban on bore wells in the village, thus securing the unconfined aquifer systems for groundwater dependency. The depth regulation protocol has also been adopted, where the drinking water dug-well is the deepest in the village, and no irrigation well will be as deep as the water supply well. This ensures aquifer storage allocation for drinking water for year-round supply. In Takarwan, the Gram Panchayat, based on hydrogeological inputs, arrived at a decision to desilt one of the three percolation tanks in the village. Embedding capacities in terms of groundwater resource understanding and subsequent management decisions proved crucial in case of these villages.

C.2 Groundwater legislation as an enabler of good governance

Government of India developed a central model bill for groundwater in as early as 1970. Despite water being a subject that is largely governed by state governments, most states began formulating groundwater legislation only after the 1980s. While quite a few have formal Groundwater Acts, most states have found difficulty in implementing groundwater legislation. In order to understand this, we will take the case of Maharashtra. The Maharashtra state government adopted a Maharashtra Groundwater (Protection of drinking water sources) Act in 1993, and subsequently rules were formed in 1995. Although groundwater is a single resource entity which caters to multiple users as well as uses, the legislation focused only on ensuring drinking water security in 'scarcity declared' villages. Much of the provisions and powers in the legislation were vested to the District Collector. A vague awareness about the 1993 Groundwater Act prevailed even while the Act was implemented only in overexploited watershed or areas declared as scarcity hit during a particular year (Phansalkar and Kher 2006). As a result, the Act remained limited in its area of jurisdiction. Thirdly, the Act refers only to the drinking water aspect linked to groundwater. However, it is evident today that groundwater dependency encompasses all aspects of human development, be it livelihoods, agriculture, drinking water and sanitation and public health. The Act missed the premise that a single aquifer system often caters to all types of users and uses, where different types of uses come into conflict even within a single village that depends on groundwater for meeting agricultural and domestic needs (Kulkarni and Vijay Shankar 2014).

Given this background, Maharashtra has now adopted a more comprehensive legislation called the Maharashtra Groundwater (Development and Management) Act, 2009. The legislation, for the first time, recognises aquifers as unit of engagement and planning while providing a proactive role for community engagement for groundwater resources management. It established a three-tier institutional system at state, district and watershed level for planning and management. The state groundwater agency, in this case the GSDA (Groundwater Surveys and Development

Agency), acts as a single technical agency and is entrusted with responsibilities ranging from aquifer mapping, aquifer delineation, inputs to groundwater management as well as decisions taken with respect to area of influence for protecting and securing drinking water supply sources. The biggest challenge posed to the implementation of the Act will be in terms of the huge human resources needed to undertake multiple tasks for the implementation. Large-scale capacity building of both the authorities who implement the Act and the stakeholders who will be bound by it will be required in making differences on the ground.

The latest Draft Model Bill for groundwater (Ministry of Water Resources 2009) has made an attempt to get into the details about the characters of the resource, the variety of groundwater stakeholders and existing institutional structures that will provide the link from State level down to the village or watershed level institutions. Most significantly, it has kept the Panchayat at the centre of the legislation itself. However, it still remains to be seen how the Model Bill will be adopted and reformed to better legislation in different States of India.

C.3 Nested institutions and conflict resolution mechanisms

Given the nature of the resource, it is essential that mechanisms for management and regulation are established at various levels of governance. Groundwater is a resource that functions at various levels from a watershed to river basin, and hence, it is necessary that provisions and mechanisms are established for integrating the resource dynamics with stakeholder participation and regulatory functions. Nested institutions will play a critical role in engaging with both the resource (aquifers) and stakeholders (communities) in bringing about significant reforms to process of regulation. Figure 9 presents a structure that it nested through three levels of

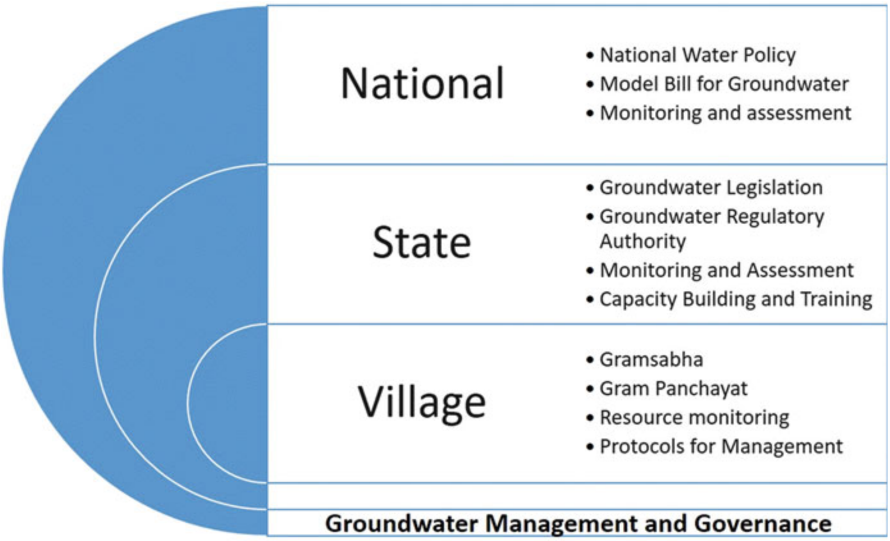


Fig. 9 Mechanisms for regulation and management of groundwater at various levels of governance

governance. The instruments of governance at each level are also quite distinct. Monitoring the resource and developing mechanisms for management need to emerge at the smallest unit, i.e. the village or watershed (group of villages). These need to be further linked to river basins which are tied to the state machinery for administrative purposes. A state-level groundwater regulatory authority can ensure equitable and efficient use of groundwater. Water being a state subject, groundwater legislation is within the purview of the state governments. Creating an enabling regulatory framework which is inclusive of aquifers as units of management and recognising the right of communities to organise around management of the resource will form the two important components of groundwater governance. Capacities will need to be built at various levels, beginning with institutional capacity enhancement within the panchayats. Moreover, capacities will also need to be updated within the state-level bureaucracy, particularly in making their processes of interaction more participatory than authoritative.

5 Conclusion: Towards a Decentralised Groundwater Governance Framework

A decentralised framework for groundwater governance, which is based on sound scientific understanding, engagement of stakeholders of the resource and congruent regulatory instruments, is clearly required for addressing India's groundwater problem. The command and control approach of legislation may only create more alienation amongst the communities' dependent on the resource. It should be noted that while we attempt to tackle the chaos of groundwater linked problems, much of the population today is dependent on this resource for their livelihoods, drinking water security amongst other needs. Mitigating and avoiding competition around groundwater resources is clearly required

Decentralisation does not only mean political or administrative devolvement of powers, functions and responsibilities but should comprise a grounded framework encompassing complimentary groundwater management and governance. The larger institutional framework should be an enabler of good groundwater governance, through improved understanding of the resource, monitoring and data-driven decision-making and collaborations that defined robust actions around the management of the resource. Hence, decentralised governance of groundwater holds the key to address challenges in sustainability that include establishing improved equity in the access, distribution and management of groundwater from India's diverse aquifer systems.

Acknowledgements The authors would like to thank Arghyam Trust, Bengaluru and Bharat Rural Livelihood Foundation (BRLF), New Delhi, for supporting our work on participatory groundwater management and springshed management across India. We would also like to thank Ford Foundation, New Delhi, for supporting the work on groundwater governance in India. The engagement with stakeholders (communities, resource persons and government officials) in the field and the ensuing interactions deepen our understanding about the resource and its socio-economy, and hence our work will not be complete without acknowledging them all.

References

ACWADAM (2014) Participatory groundwater management in Randullabad. Action Research Report ref no. ACWA/Hydro/2013/H28. Pune. Available at: www.acwadam.org

Agarwal B (2001) Participatory exclusions, community forestry, and gender: an analysis for South Asia and a conceptual framework. World Dev 29(10):1623–1648

Badarayani U (2009) Hydrogeological studies for improved groundwater management strategies in the dryland areas underlain by Deccan basalts: an initiative in Purandar taluka. Available at: www.acwadam.org

Burke JJ, Moench MH (2000) Groundwater and society: resources, tensions and opportunities. Themes in groundwater management for the twenty-first century. Department of International Economic and Social Affairs, Statistical Office, United Nations. ISBN: 9789211044850

Calow RC, Robins NS, MacDonald AM, MacDonald DM, Gibbs BR, Orpen WR, Appiah SO (1997) Groundwater management in drought-prone areas of Africa. Int J Water Resour Dev 13 (2):241–262

Central Ground Water Board (2011) Dynamic ground water resources of india (as on March 2009). CGWB Publ

Central Ground Water Board (2014) Dynamic groundwater resources of India (as on 31st March 2011) Ministry of Water Resources River Development and Ganga Rejuvenation, Govt of India. Available at: www.cgwb.gov.in

Central Ground Water Board (2017) Annual Report – 2015-16. Ministry of Water Resources River Development and Ganga Rejuvenation, Govt of India. Available at: www.cgwb.gov.in

Closas A, Molle F (2016) Groundwater governance in the Middle East and North Africa region. International Water Management Institute, Colombo. https://doi.org/10.13140/RG.2.2.11109.29922

COMMAN (2005) Managing groundwater resources in rural india: The community and beyond. British geological survey commissioned report CR/05/354

Cullet P (2014) Groundwater law in India: towards a framework ensuring equitable access and aquifer protection. J Environ Law 26(1):55–81. https://doi.org/10.1093/jel/eqt031

Custodio E (2002) Aquifer overexploitation: what does it mean? Hydrogeol J 10(2):254–277

Das SVG, Burke J (2013). Smallholders and sustainable wells: a retrospect – participatory groundwater management in Andhra Pradesh (India), Food and Agriculture Organisation of the United Nations. Rome, 2013. p 173. Available at: http://www.fao.org/docrep/018/i3320e/i3320e.pdf

Deolankar SB (1980) The Deccan basalts of Maharashtra, India – their potential as aquifers. Groundwater 18(5):434–437

Department of Drinking Water Supply, Government of India (2006) Summary of nation-wide statistics from Rajiv Gandhi drinking water mission. DDWS, ministry of water resources, GoI, New Delhi

Department of Drinking Water Supply, Government of India (2009) Mid-Term appraisal of the 12th Five Year Plan – Rural water supply, mimeo. DDWS, Ministry of water resources, GoI, New Delhi

Dubash NK (2002) Tubewell capitalism: groundwater development and agrarian change in Gujarat. Oxford University Press, New Delhi. https://doi.org/10.1111/j.1944-8287.2004.tb00232.x

FAO (2016) Global framework for action: to achieve the vision on groundwater governance. Food and agriculture organisation, Rome. www.fao.org/3/a-i5705e.pdf

Foster S, Garduno H, Tuinhof A, Tovey (2010) Groundwater governance: conceptual framework for assessment of provisions and needs (English). GW MATE strategic overview series; no. 1. Washington, DC: World Bank

Groundwater Surveys and Development Agency (2014) Report on the dynamic groundwater resources of Maharashtra (2011–12). Pune. Available at: https://gsda.maharashtra.gov.in

Janakarajan S, Moench M (2006) Are wells a potential threat to farmers' well-being? Case of deteriorating groundwater irrigation in Tamil Nadu. Econ Polit Wkly 41(37):3977

Joy KJ, Gujja B, Paranjape S, Goud V, Vispute S (2008) Water conflicts in India: a million revolts in the making. Taylor and Francis p441. ISBN: 978-0415424110

Kulkarni H, Patil S (2017) Competition and conflicts around groundwater resources in India. Forum for policy dialogue on water conflicts in India. Pune, 38p. Available at: waterconflictforum.org/books-reports

Kulkarni H, Vijay Shankar PS (2009) Groundwater: towards an aquifer management framework. Econ Polit Wkly 44(6):13–17

Kulkarni H, Vijayshankar PS (2014) Groundwater resources in India: an arena for diverse competition. Local Environ 19(9):990–1011

Kulkarni H, Deolankar SB, Lalwani A, Joseph B, Pawar S (2000) Hydrogeological framework of the Deccan basalt groundwater systems, west-central India. Hydrogeol J 8(4):368–378

Kulkarni H, Vijay Shankar PS, Deolankar SB, Shah M (2004) Groundwater demand management at local scale in rural areas of India: a strategy to ensure water well sustainability based on aquifer diffusivity and community participation. Hydrogeol J 12(2):184–196

Kulkarni H, Badarayani U, Upasani D. (eds) (2009) Groundwater management- typology of challenges, opportunities and approaches. Arghyam- ACWADAM publ. ACWA H-09-2

Kulkarni H, Shah M, Vijay Shankar PS (2015) Shaping the contours of groundwater governance in India. J Hydrol: Reg Studi 4:172–192

Livingston M (2009) Deep wells and prudence: towards pragmatic action for addressing groundwater overexploitation in India. Report, World Bank

Llamas MR, Martínez-Santos P (2005). Intensive groundwater use: silent revolution and potential source of social conflicts. Available at: http://www.rac.es/ficheros/doc/00245.pdf

Megdal SB, Gerlak AK, Varady RG, Huang LY (2015) Groundwater governance in the United States: common priorities and challenges. Groundwater 53(5):677–684

Ministry of Water Resources (2009) Groundwater resource estimation methodology. Report of the Groundwater estimation committee, Ministry of water resources, government of india

Ministry of Agriculture, Government of India (2013) "State of indian agriculture: 2012–13," Department of agriculture and co-operation, Ministry of agriculture, government of india, New Delhi, p 221

Moench MM (1992) Chasing the watertable: equity and sustainability in groundwater management. Econ Polit Wkly 27:51–52

Mukherji A (2004) Groundwater markets in Ganga-Meghna-Brahmaputra basin: theory and evidence. Econ Polit Wkly 39(31):3514–3520

Mukherji A, Shah T (2005) Groundwater socio-ecology and governance: a review of institutions and policies in selected countries. Hydrogeol J 13(1):328–345

Narain S, Pandey P (2012) Excreta matters: how urban India is soaking up water, polluting rivers and drowning in its own waste. Centre for Science and Environment. ISBN: 9788186906552

Ostrom E (1990). Governing the commons: the evolution of institutions for collective action. Cambridge University Press. ISBN: 978-0521405997

Patil S, Kulkarni H, Bhave N (2017) Groundwater in the Mahanadi River basin. Forum for policy dialogue on water conflicts in India Pune. Available at: http://conflicts.indiawaterportal.org/node/11

Phansalkar S, Kher V (2006) A decade of Maharashtra groundwater legislation: analysis of the implementation process. Law Environ Dev J 2(1):67

Ranade R (2005) 'Out of sight, out of mind': absence of groundwater in water allocation of Narmada Basin. Econ Polit Wkly 40(21):2172–2175

Reed MS (2008) Stakeholder participation for environmental management: a literature review. Biol Conserv 141(10):2417–2431

Sandoval R (2004) A participatory approach to integrated aquifer management: the case of Guanajuato State, Mexico. Hydrogeol J 12(1):6–13

Shah T (2005) Groundwater and human development: challenges and opportunities in livelihoods and environment. Water Sci Technol 51(8):27–37

Shah T (2010) Taming the anarchy: groundwater governance in South Asia. Routledge

Shah M (2013) Water: towards a paradigm shift in the twelfth plan. Econ Polit Wkly 48(3):40–52

Shah T (2014) Groundwater governance and irrigated agriculture. TEC Background Papers 19:69. Available at: www.gwp.org

Shah M, Kulkarni H (2015) Urban water Systems in India. Econ Polit Wkly 50(30):57–69

Shah T, Verma S (2008) Co-management of electricity and groundwater: an assessment of Gujarat's Jyotirgram scheme. Econ Polit Wkly 43(7):59–66

Shah T, Singh OP, Mukherji A (2006) Some aspects of South Asia's groundwater irrigation economy: analyses from a survey in India, Pakistan, Nepal Terai and Bangladesh. Hydrogeol J 14(3):286–309

Shah T, Bhatt S, Shah RK, Talati J (2008) Groundwater governance through electricity supply management: assessing an innovative intervention in Gujarat, western India. Agric Water Manag 95(11):1233–1242

Shah T, Giordano M, Mukherji A (2012) Political economy of the energy-groundwater nexus in India: exploring issues and assessing policy options. Hydrogeol J 20(5):995–1006

Singh S (2012) Local governance and environment investments in Hiware Bazar, India. Ecological economics from the ground up. Routledge, London, pp 191–202

Sivaramakrishnan A, John J (2014) Natural resource governance by Panchayati Raj Institutions: issues and opportunities. In: Paper presented at 'Governing Shared Resources: Connecting Local Experience to Global Challenges, the Twelfth Biennial Conference of the International Association for the Study of Commons', Cheltenham England. Available at: https://dlc.dlib.indiana.edu/dlc/bitstream/handle/10535/1804/Sivaramakrishnan_107801.pdf?sequence=1&isAllowed=y

Tambe S, Kharel G, Arrawatia ML, Kulkarni H, Mahamuni K, Ganeriwala AK (2012) Reviving dying springs: climate change adaptation experiments from the Sikkim Himalaya. Mt Res Dev (International Mountain Society Publ) 32(1):67–72

Varady RG, van Weert F, Megdal SB, Gerlak A, Iskandar CA, House-Peters L, McGovern ED (2013) Thematic paper no. 5: groundwater governance: a global framework for country action. Available at: http://www.yemenwater.org/wp-content/uploads/2015/04/GWG_Thematic5_8June2012.pdf

Vijay Shankar PS, Kulkarni H, Krishnan S (2011) India's groundwater challenge and the way forward. Economic and PoliticalWeekly XLVI (January (2)), 37–45

Dhaval Joshi is working as a social scientist with Advance Centre for Water Resources Development and Management (ACWADAM) since 2014. His background is in environmental sciences with experience of working in the domain of socio-hydrogeology. Mr. Joshi has played a key role in developing the social extension of the knowledge on aquifers in bringing about community behaviour change. He has authored no of publications about this process. He has also developed games that help understand human behaviour around groundwater resources. He uses these games for grass-root trainings on aquifers and groundwater governance. Mr. Joshi is anchoring an important programme of ACWADAM that involves building institutional capacities on groundwater with civil society organizations across the tribal-dominant pockets of central and eastern India. He is also coordinating a programme on the convergence between decentralized groundwater management and governance, including anchoring a specialized training on groundwater governance that ACWADAM has introduced since 2017.

Himanshu Kulkarni a hydrogeologist by qualification, has been working on the science of groundwater with its applications in policy and practice for nearly 35 years. He leads ACWADAM, one of India's leading think-tank on groundwater resources. ACWADAM has partnered with a variety of organizations on piloting and mainstreaming the ideas of participatory groundwater management including spring water management in the mountains, across India's diverse aquifer typology. ACWADAM's partnerships have also extended to neighbouring Nepal and Bhutan. Dr. Kulkarni has been actively involved in the advocacy for stronger programmes on groundwater management in India, through his inputs, as chairman, Working Group on Sustainable Groundwater Management for India's 12th Five-Year Plan and subsequently through various committees of central and state governments of which he has been a member. He also teaches at Shiv Nadar University, Noida, and Tata Institute of Social Sciences, Mumbai, apart from mentoring interns and publishing key results.

Uma Aslekar is senior scientist with ACWADAM. A geographer by education, Ms. Alsekar completed her MSc in geomorphology at the University of Pune and works on issues linked to groundwater management and governance, especially in the state of Maharashtra. She leads ACWADAM's portfolio on participatory groundwater management (PGWM) while anchoring all the work in Maharashtra. Ms. Aslekar has helped build a variety of partnerships on PGWM in Maharashtra. She has also led discussions during Gram Sabhas and has increasingly involved women to participate in generating knowledge and information on groundwater in different villages. Ms. Aslekar conducts special sessions on groundwater quality and grass-root governance in ACWADAM's training and capacity building programmes. She also plays a crucial role in ACWADAM's action research programmes, including key international collaborations.

Rejuvenation of Aquifers

S. C. Dhiman

1 Introduction

The growing human needs and advancements in technology are persistently increasing greater human interventions on land-water resources. Unscientific and ill-planned use of land-water is fast resulting into a gross misuse and abuse leading to progressive imbalance in demand and supply of water. The increase in demand of water to meet the growing needs has put stress on water resources. The erratic rainfall and near utilisation of surface water resources have catapulted ground water to be a major source of water.

The unplanned and non-scientific development of water resources to meet the ever-increasing demand to fulfil the drinking and domestic requirement of ever-increasing population, agriculture, expanding industry needs and urbanisation leads to the over-exploitation of limited water resources. This has further accelerated the stress on the available water resources due to changing rainfall patterns, urbanisation, water pollution and saline water ingression. It has caused alteration of river water flow systems – droughts and floods, declining water levels (desaturation and drying aquifer zones) and increased energy consumption for lifting water from progressively deeper water levels – resulting in drying up of a large number of dug wells, bore wells, tube wells and spring and increasing in cost of ground water extraction, etc. This situation warrants an urgent attention to evolve integrated approach for management of water from all the sources in a holistic manner so as to harness during the period of availability, i.e. rainy season, either by harvesting or recharging the stress aquifers for reviving the drying aquifers.

S. C. Dhiman (✉)
Former Chairman, Central Ground Water Board, Government of India, New Delhi, India

© Springer Nature Singapore Pte Ltd. 2019

A. Singh et al. (eds.), *Water Governance: Challenges and Prospects*, Springer Water,
https://doi.org/10.1007/978-981-13-2700-1_10

2 Rainfall and Climate

India is having a diverse climatological conditions varying from extreme cold arid desert in Ladakh region to extreme hot arid condition in Rajasthan desert. Rainfall distribution and water availability are totally controlled by the physiographic, hydrologic and climatic conditions. Rainfall varies from as low as 100 mm in western Rajasthan to as high as 9000 mm in Meghalaya averaging to 1197 mm. However 12% of the country receives an average rainfall of less than 610 mm annually, and only 8% receives more than 2500 mm. An average yearly volume of 400 bcm (billion cubic metres) of water is being received as rainfall and snowfall of which 1122 bcm is utilisable and 1183 bcm is lost to sea as runoff (*83% monsoon and 17% non-monsoon runoff*).

India is the second most populous country of the world. The population of India has increased from 1361 million in 1951 to 1210 million in 2011. The per capita water availability in the country has decreased from 5177 cu.m/yr. in 1951 to 1869 cu.m/yr. in 2000. India was water rich till 2001 but has become water stressed (between 1700 and 1000 cu.m/year) after 2010, and after 2050 it will become water scarce (below 1000 cu.m/person) and ultimately water hungry if it continues with the same trend in the future. The present water use is 634 bcm of which 83% is for irrigation. This is projected to grow to 1447 bcm by 2050 against utilisable quantum of 1123 bcm. Hence, the demand will outstrip the availability in another 30–40 years.

3 Status of Ground Water Resources: a Historical Perspective

In the 1950s, the source of ground water was envisaged as supplementing source to surface water for irrigation and drinking water supplies. The first ever assessment of water resources in the country was done by the first irrigation commission in 1901 which was 1344 billion cubic metres (BCM) and followed by the National Commission on Agriculture in 1949 which was 167 MHam which also included ground water resources. The first national report on ground water (GW) resources, 1995, estimated total replenishable GW in India to be 432 bcm with a net draft of 115 bcm (stage of development as 32%) (Chatterjee and Purohit 2009). With increased development of GW, the net ground water draft increased to 231 bcm (stage of development 58%) in 2004 and 243 bcm (stage of development 62%) in 2011. The number of overexploited districts increased from 3% in 1995 to 15% in 2011 in the country (Saha et al. 2018).

The increasing dependence on ground water has resulted in the large-scale and often indiscriminate development in the country, without due regard to the recharging capacities of aquifers to conserve the surface runoff or rainwater or snowmelt. The imbalance between recharge and withdrawal mainly in the low rainfall regions has resulted in over-exploitation of ground water resources. In

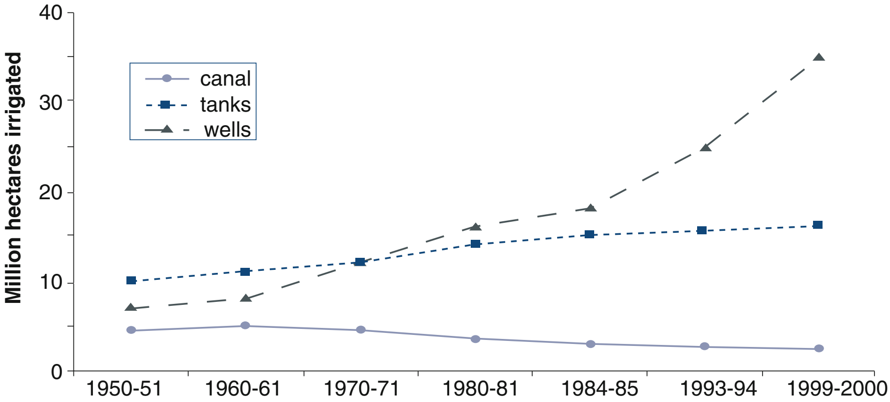


Fig. 1 Evolution of canal, tank and well irrigation in India (Bhatia 2005)

western alluvial plains and, Indo-Gangetic plains, ground water has been exploited even more than 200%, while in Peninsular region ground water development has reached critical and overexploited stage.

Ground water, on account of its near-universal availability, dependability and low capital cost, is the most preferred source of water to meet the requirements of various water sectors in India. This has also caused a paradigm shift of dependency from surface water to ground water. Owing to the decentralised availability of ground water and its easy accessibility, it forms the largest share of accessibility for drinking water supplies (89% of GW is used for agriculture and drinking water supplies, 40.5% of urban and 85% of rural drinking water supplies). Wells including tube wells provide 61.1% of water for irrigation followed by the canals (24.5%). Over the years there has been a decrease in surface water use and continuous increase in ground water (Fig. 1).

As mentioned above increased use and limited recharge have contributed to lowering of water levels so much that a large number of dugwells (DWs) and tubewells (TWs) have dried up. This has caused the change in river flow pattern, i.e. decrease in inflow/dying of the river, declining water levels (desaturation of aquifer zones) and increase in energy consumption for lifting water from progressively deeper levels.

4 Situational Analysis

Over the last decade, there has been a paradigm shift from ground water development to ground water management. The importance of ground water for national development has become more general "ground water management" to more specific "aquifer management" for the sustainable management and revival of the overexploited/dried-up aquifers of the country. This necessitates the need to understand each of the aquifers to assess the potentials of aquifers and their disposition in

3D: hydrological parameters, water quality and their relationship within the surface water systems.

Thus, the priority of planning of development of potential hydrogeological units has become the management of aquifer units. The aquifer units have been segregated into 14 principal aquifers and 42 major aquifers on 1:250,000 scale (Fig. 2) of which the following aquifers like alluvium, basalt, basal granitic complex, sandstone and granite and gneisses are important. Alluvium covers over 31% of the country and includes major Indo-Gangetic-Brahmaputra alluvial plains, forming a highly potential regional multiple aquifer system ranging in depth to more than 800 m. Alluvium aquifers also include minor/localised aquifers as valley fills in mountainous and rocky terrains. In peninsular region granite, gneisses, quartzites, schist, shales, etc. form the main aquifers with poor to moderate yields, occupying approximately 35% of the area. Basalts, sandstones, limestones and other sedimentary rocks form multiple aquifers with moderate to high yields, covering an area of 34% (Table 1).

Indo-Gangetic-Brahmaputra Plains, coastal areas and isolated valley fill within the hard rocks form the major aquifers ranging in thickness up to 800 m or more (30% area of the country). These aquifers are multilayer and extensive in areal extension. The shallow aquifers are highly developed. The alluvial aquifers are being overexploited in the states of Rajasthan, Haryana, Panjab, Uttar Pradesh, Maharashtra, Tamil Nadu and Gujarat; basalt and laterites and multilayered sandstones (sedimentary) in Madhya Pradesh, Maharashtra, Karnataka and Rajasthan, while crystalline rock aquifers in Rajasthan, Andhra Pradesh Karnataka and Tamil Nadu states (Tables 2 and 3).

In plateau region, basalt (16% area) and basal granite complex along with granites, gneisses, shale, schist, etc. form the major shallow unconfined aquifers in weathered and fractured zone ranging in depth to about 50 m and fractured zones to about 100 m. Multiple aquifers are sometimes formed within basalts. Most of these aquifers are in critical and overexploited stage of development (Fig. 3).

5 Ground Water Recharge Potential and Scope of Rejuvenation of Aquifers

Artificial recharge is a process by which ground water is augmented at a rate exceeding under natural condition of replenishment and is accelerated through percolation of stored or flowing surface water which otherwise not percolating to the aquifers. The imbalance between natural replenishment of ground water reservoir and continued excessive exploitation of ground water resources in various parts of the country has caused the over-exploitation of ground water. This has resulted in declining ground water levels and drying up of aquifers particularly in low rainfall regions and drying rivers or reduction in river flows.

The important techniques used for recharging are surface spreading techniques, sub-surface techniques, recharge pits and shafts, induced recharge from surface

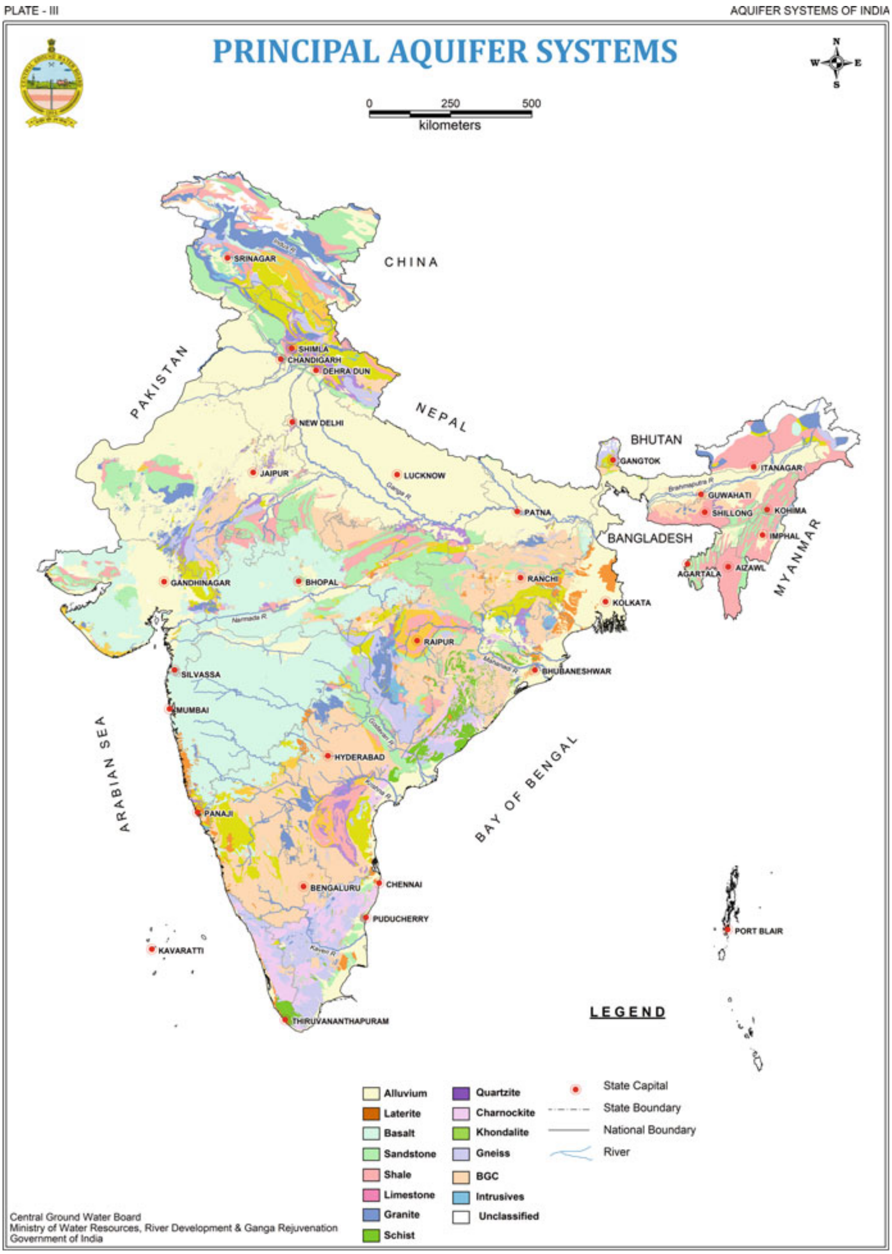


Fig. 2 Principal aquifer systems of India (Saha et al. 2016)

water sources, aquifer modification by bore blasting, hydrofracturing, etc. In addition to the above, ground water sealing cementation techniques are also used to arrest sub-surface flows.

Table 1 Principal Aquifer systems of India

	Principle Aquifer	DTWL (m bgl)	Thickness of Weathered Zone(m)	Fracture Zones (m bgl)	Yield (m3/ day)	Aquifer Formations
	Aquifer Systems of India					
1	**Alluvium** (29.82 %)	2-40	2-1200		10.0-6480	Younger/ Pebble/ Gravel/ Bazada/ Kandi / Older Alluvium/ Aeolian Alluvium / Glacial Deposits/ Valley Fills/ Coastal Alluvium
2	**Laterite** (1.29 %)	5.0-20	5-40		5.0-6048	Laterite / Ferruginous concretions
3	**Basalt** (16.15 %)	5-20	5-60	30-280	1-480	Basic Rocks (Basalt)/ Ultra Basic/
4	**Sandstone** (8.21 %)	2.0-40	20-600	20-160	5.0-3682	Sandstone/Conglomerate/Sandstone with shale/coal beds/Sandstone withClay/Sandstone/Conglomerate
5	**Shale** (7.11 %)	5.0-40	40-250	20-150	8.0-2880	Shale with Shale , limestone and sandstoneSandstone/ Limestone
6	**Limestone** (1.98 %)	5.0-40	8-451		4.0-2100	Miliolitic Limestone/ Dolomite/Limestone with Shale/ Marble
7	**Granite** (3.18 %)	5.0-40	5.0-40	15-200	10-1440	Acidic Rocks / Acidic Rocks
8	**Schist** (4.44%)	5.0-20	5.0-72	10-180	2.73-562	Schist/ Phyllite / Slate
9	**Quartzite** (1.48%)	5.0-40	8.0-30	15-150	2.0-400	Quartzite
10	**Charnockite** (2.41%)	2.0-40	5.0-45	15-291	0.5-3024	Charnockite
11	**Khondalite** (1.04 %)	5-10	5-20	4.0-291	20-1500	Khondalites , Granulites
12	**BGC** (15.09 %)	5-20	5-100	30-200	2-3624	Basement Gneissic Complex
13	**Gneiss** (5.01 %)	5-15	3-35	20-200	10-2500	Undifferentiated metasedimentaries/metamorphic/ Gneiss/ Migmatitic Gneiss
14	**Intrusive** (0.63 %)	5-20	6-13	12-150	0.02-258	Basic Rocks

5.1 Assessment of Recharge Potential of Aquifers

Even if the source water in the form of surplus runoff is available, one of the most important aspects of ground water recharge is the availability of sufficient space in the respective aquifers for ground water storage in space and time. It was attempted to assess the recharge potentials of the aquifers to decipher the unsaturated zone of the unconfined aquifer using the pre-monsoon water level of 2009 (Fig. 4). Based on the specific yield and thickness of unsaturated zone, it was approximated that a total volume of water required to recharge the aquifer so as to bring the water level up to 3 m below ground level is 1240 bcm.

From the above data, it may be observed that a total of 1240 bcm is required in all the basins. To recharge a total of about 25.95 lakh sq. km of area which is available for recharge depending upon the availability of source water in time and space and water received in all the basins is either conserved in situ or as stream flows along the water sources or diverted to the adjoining areas in basin depending upon the nature of aquifers and physiography.

Table 2 Aquifer wise area under overexploited blocks (area in sq. km)

State name/aquifer code	Alluvium	Laterite	Basalt	Sandstone	Shale	Limestone	Granite	Schist	Quartzite	Charnockite	Khondalite	BGC	Gneiss	Intrusives	Total
Andhra Pradesh	218.1	150.0	198.0	480.4	4365.3	576.7	1505.0	76.9	1674.6		257.8	11943.2	1.4	7.2	21454.6
Delhi	866.1								136.2						1002.3
Gujarat	15827.7		1058.5	1469.3	859.7	375.8	56.7	0.0	0.0				16.5		19664.2
Haryana	25261.6			0.0				0.0	201.3						25462.8
Jharkhand	229.4	0.0		124.3			1.9	343.7	17.1			500.0	55.7	1.3	1273.3
Karnataka	64.1	214.5	12574.9	117.6		2464.3	0.0	5323.2		0.0		46716.5	0.0	0.0	67475.2
Kerala							0.0	0.0		0.0		0.0	266.4		266.4
Madhya Pradesh	479.7	33.2	18175.8	319.8	356.6	0.0			0.0			0.0			19365.1
Maharashtra	2828.3		5000.9	1.5											7830.8
Punjab	37770.3			45.6											37815.9
Rajasthan	123620.7	74.1	7432.6	20501.5	11748.5	904.2	12157.0	3257.3	5366.6	173.2	74.1	17658.0	15711.6	469.8	219149.0
Tamil Nadu	5959.3	136.1		2246.7	122.8		503.3	7.5		13138.2	616.6	2206.8	18939.0	298.2	44174.3
Uttar Pradesh	20115.0			156.7	0.0				11.3			1355.8			21638.8
Grand total	**233240.2**	**607.9**	**44440.7**	**25463.6**	**17453.0**	**4320.9**	**14223.9**	**9008.6**	**7406.9**	**13311.4**	**948.4**	**80380.3**	**34990.5**	**776.5**	**486572.7**

Table 3 Aquifer wise area under critical blocks (area in sq. km)

State name/ aquifer code	Alluvium	Laterite	Basalt	Sandstone	Shale	Limestone	Granite	Schist	Quartzite	Charnockite	Khondalite	BGC	Gneiss	Intrusives	Total
Andhra Pradesh	6.89	444.47	497.04	281.05			237.02	75.66				4414.47	27.81		5984.41
Delhi	392.05														392.05
Gujarat	4764.74	5.94	789.69	1861.08	1634.54	44.03	119.23	88.14	40.90				16.61		9806.91
Haryana	7296.86			0.76				0.00	36.97				4.00		7338.59
Jharkhand				17.65				2.01		42.46		438.44			500.56
Karnataka	73.56	27.97	2721.29			41.71	0.00	921.98				9365.84	0.00		13152.35
Kerala	45.18	6.88								6.36	0.00		468.17		526.59
Madhya Pradesh	454.18	6.38	1127.35	348.62	1180.04	635.78		9.37					14.60		3776.32
Punjab	995.20														995.20
Rajasthan	11388.64		0.00	1209.84	713.72		139.43	2.05	85.41			13.46	985.94	41.06	14579.53
Tamil Nadu	1040.71			349.31			93.62	112.24		3724.36	131.97	627.39	4329.90	12.97	10422.47
Uttar Pradesh	7800.79			0.01	9.74				140.73			620.23			8571.51
Grand total	34,414	492	5135	4068	3538	722	589	1211	304	3773	132	15,480	5847	54	76,201

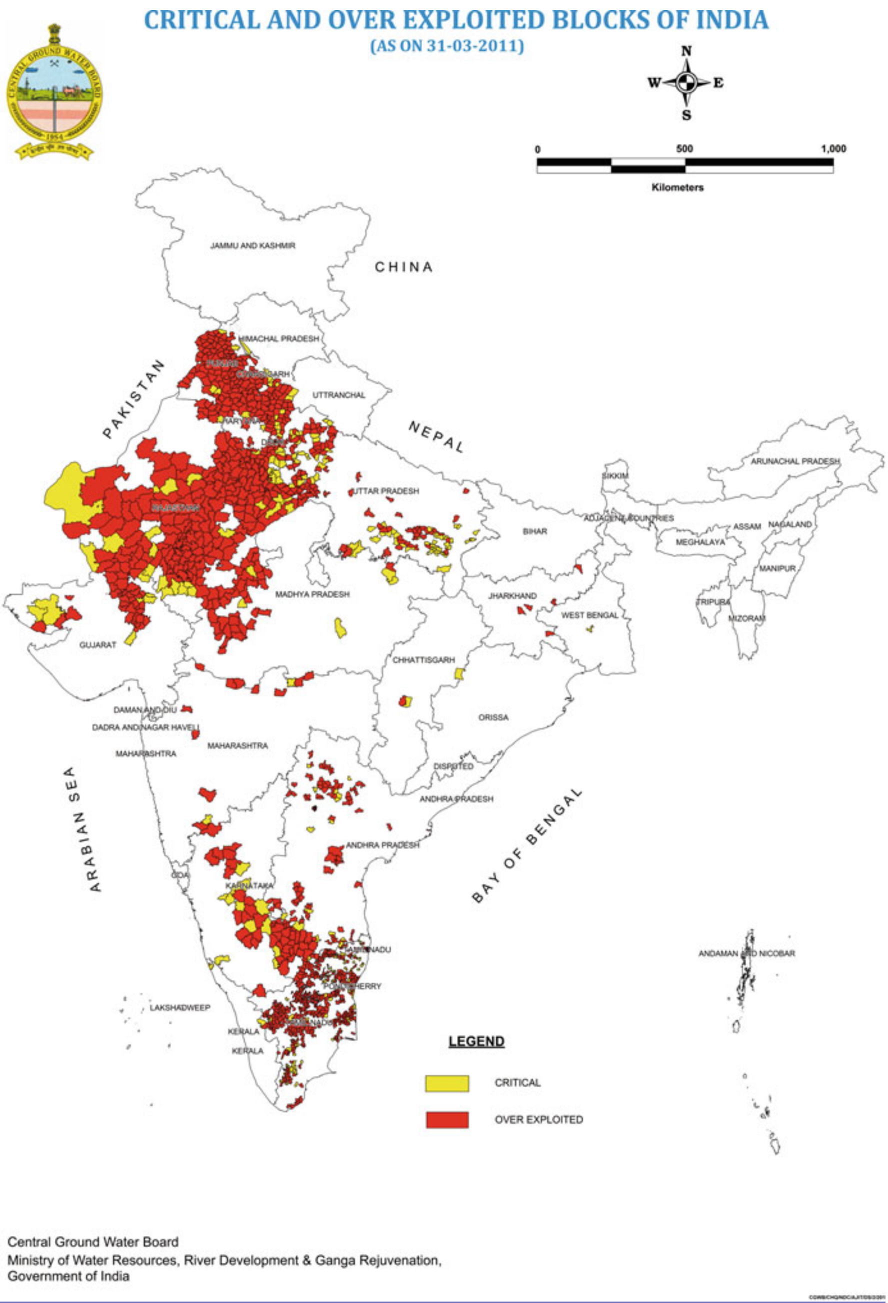


Fig. 3 Status of ground water development

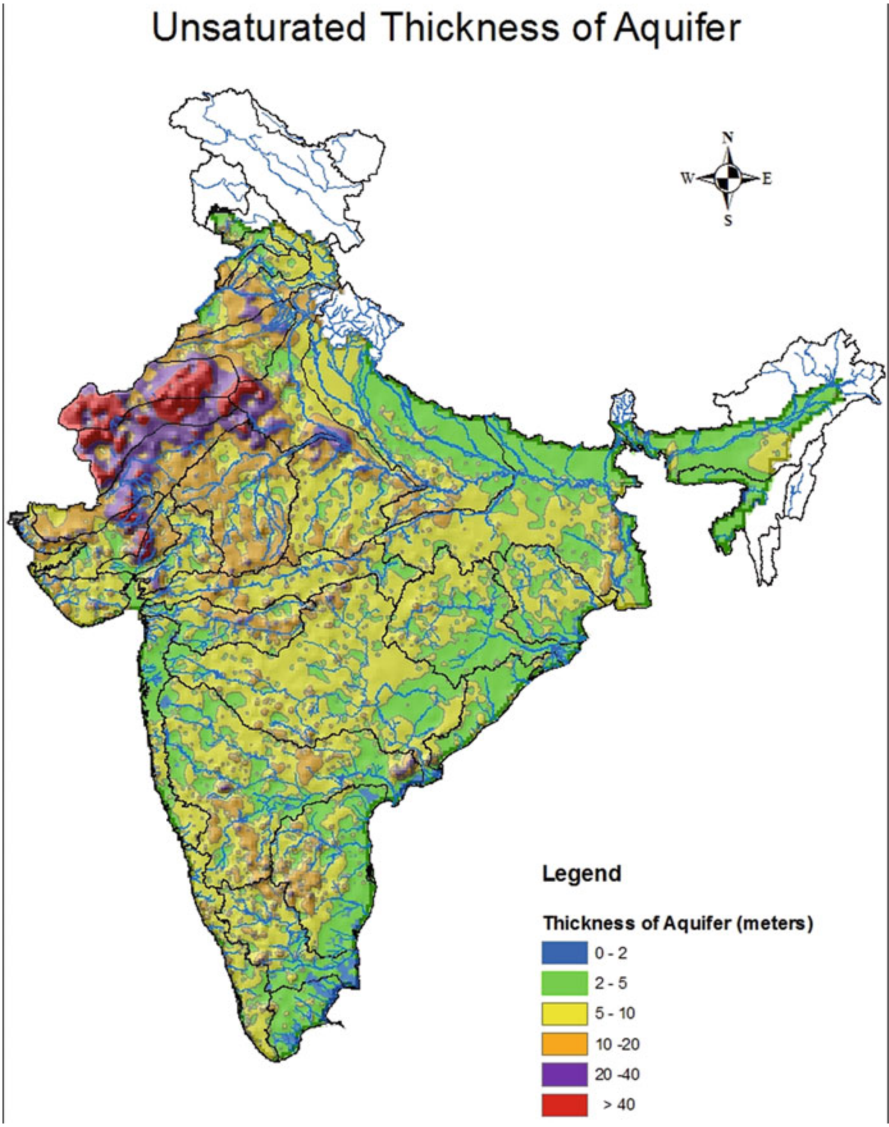


Fig. 4 Thickness of unsaturated zones

5.2 Surplus Water Resource Availability

A major part of the precipitation flows into the rivers as runoff, and part of it infiltrates into the aquifers, and a part remains as glaciers or ice caps. Monsoon rainfall is usually torrential in nature, and its major part is being lost to sea as rivers flow. The availability of surplus monsoon runoff and recharge potential of aquifers in a basin is a time-dependent variable of the rainfall and evaporation as also natural recharge from precipitation and runoff losses. Harnessing of excess monsoon runoff to create additional ground water storage will not only increase the overall availability of water to meet the growing demand but will also help in controlling damages from floods. The aquifers-sub-surface reservoirs are very attractive and technically feasible alternatives and may be considered as "warehouse" for storing surplus monsoon runoff. In order to assess the availability of water, the entire country has been divided into 14 major and medium river basins depending upon the hydrological framework by Central Water Commission. River flow data of gauge and discharge terminal sites has been analysed with the purpose to estimate the surface runoff to sea basins and is tabulated in Table 4.

From Table 4, it can be analysed that the total annual runoff being lost to the sea from different basins is to the tune of 155,425 bcm of which the monsoon runoff is 1298 bcm (84.5%). The committed volume of water required for ongoing and

Table 4 Basin wise flows as observed at terminal sites

Sl. no	Basin name	Monsoon runoff (MCM)	Non-monsoon runoff (MCM)	Annual runoff (MCM)
1	Subarnarekha	7713	549	8202
2	Brahmani-Baitarani	18,495	3556	22,051
3	Mahanadi	41,756	6446	48,202
4	Godavari	79,583	7730	87,313
5	Krishna	16,362	3250	19,613
6	Pennar	907	626	1532
7	Cauvery	4874	3048	7921
8	Tapi	4065	1625	5690
9	Narmada	22,220	3305	25,524
10	Mahi	4245	482	4585
11	Sabarmati	1135	13	1147
12	WFR- Kach.-Saur. and Luni	1606	33	1639
13	WFR-South of Tapi	57,277	7939	65,060
14	EFR B-Mahanadi-Godavari	6194	1285	7423
15	EFR B-Pennar-Cauvery	155	1347	1494
16	EFR-South of Cauvery	140	660	796
17	Ganga-Brahm-Meghna Basin	1,032,234	213,797	1,246,030
	Total	1,298,960	255,691	1,554,225
	Total (BCM)	1298.96	255.69	1554.22

Source: www.cgc.gov.in

WFR: western flowing river, *EFR:* eastern flowing river proposed projects is 172 bcm, and balance surplus annual runoff works out to 1382 bcm available for recharge including ecological flows.

This 1382 bcm can be utilised/conserved within the various basins either by recharging to the aquifers or harvesting in surface water reservoirs for sustaining the flow in the rivers during the lean period to replenish/revive the dried-up/ overexploited aquifers.

The surplus monsoon runoff in these basins can be harnessed/conserved either by storing in surface water reservoirs or tanks constructed along the rivers or in adjoining areas or by diverting excessive flood flows that will also recharge the aquifers. For the management of the aquifers occurring in these basins, these are classified into the following.

5.2.1 The Himalayan Rivers

The main Himalayan river basin is constituted with drainage of Indus and Ganga-Brahmaputra-Meghna river system. These are receiving flows from glacier and snowmelt along with the rainfall during monsoons. In hilly areas, even though the rainfall is comparatively high, scarcity of water is often felt in the post-monsoon and pre- and snowfall season. During monsoon season, due to high rainfall and heavy flooding, most of the water available is lost as surface run off to the sea. The basin areas of these rivers are subdivided into the following.

Mountain Area

In the Outer and Higher Himalayan mountain region, fluvial valley fills and fault/ weathered rock formations and in Trans Himalayas formations, contact zones along with fluvioglacial and morainic deposit form the main aquifers. These aquifers are localised and occur within the valleys within the hard rocks. Traditional percolation wells, infiltration galleries and shallow tube wells are the major ground water abstraction structures along with the springs. These aquifers are being recharged with the stream/river flows in lower and higher Himalayas and with snow melt in Trans Himalayan region. Aquifers dry with drying of the stream flows. Check dams, sub-surface dykes, gulley plugging along with the soil-water conservation measures and traditional rainwater harvesting practices have successfully revived these aquifers in Sikkim, Himachal Pradesh, Uttarakhand and North-eastern regions. In Trans Himalayan region mainly in Leh and Kargil areas in Jammu and Kasmir and Lahaul and Spiti district of Himachal Pradesh which are dried up because of the freezing of all water bodies. There is no flow in the rivers, and all the water sources dry up in the same way as in the lower Himalayas, and acute water scarcity conditions are experienced during summers. Snow harvesting with artificial glaciers and artificial recharge to ground water with snowmelt flow into traditional water bodies “Zing” which are the most suitable practices in this region for conserving water and recharging and reviving the aquifers. With the urbanisation and increase in the water demand, most of the drinking water supplies earlier used to be from springs, and stream waters are now from tube wells/bore wells in fluvioglacial aquifers. The over withdrawal of ground water is causing to dry up aquifers during pre-snowfall periods. These aquifers can recharge with snowmelt and snow harvesting.

Springs, the major source of water in such terrains, are also depleted during the post-monsoon period. In such areas, rainwater harnessing and small surface storages at strategic locations in the recharge areas of the springs can provide sustainable yields to the springs by increasing the recharge during and after rainy season with river or stream flows in higher and lower Himalayan regions. In Trans Himalayan region, spring discharge recedes or dries up prior to the snowfall, and discharge revives with the snow-melting season. Irrigation and drinking water sustain mainly with spring and snowmelt waters.

With the increase in population and urbanisation in the hills, the traditional water supply sources, viz. springs and stream, are getting dried up, and stream flows polluted in acute water scarcity conditions are experienced in summer. This can only be managed by conserving surface water during the period of availability and both in surface water reservoirs and in aquifers.

There are success stories in the country such as "Springs-shed Development Program" (*Dhara Vikash*) wherein the aquifers above the spring have been protected leading to sustainable flow in the springs and ultimately to rivers too.

Alluvial Terrain

Unconsolidated riverine and aeoline deposits, deposited in vast plains of Indus-Ganga-Brahmaputra vast plains with multiple and thick and extensive aquifers, extend from Rajasthan to North-east. These are extensively developed for domestic needs and irrigation purposes in the western part of the Indo-Gangetic Plains.

Most of the over-exploited (OE) areas in Delhi, Haryana and Uttar Pradesh are located in alluvial aquifers in Yamuna subbasin of Ganga River. Parts of OE areas in Haryana and Rajasthan also fall in Ghaggar river basin – an inland river basin. In Panjab all of the OE areas fall in alluvial aquifers in Satluj River subbasin and Ghaggar river basin. The surplus runoff in these areas may be tapped in the upper parts of the basins for improving the conditions of the aquifers and increasing the base flow to the river systems. In addition to the revival of ponds and flood plain development of the rivers mainly in the influent zones of the rivers, excessive surface runoff or flood flows can be conserved in the aquifers for the revival of the stressed aquifers by recharging by constructing recharge shafts or by creating pondages in the flood plains.

5.2.2 Deccan and Coastal Rivers

Rivers of plateau region called the Deccan Rivers are mainly rain fed and sustain flows after rainfall with ground water discharge from the water conserved in aquifers using monsoon flows, therefore fluctuating in volume. The major east flowing rivers

(Godavari, Krishna, Cauvery, Mahanadi, etc.) and West flowing rivers (Narmada, Tapti, etc.) are the main rivers flowing over the Deccan Plateau which are known as Deccan rivers.

The main aquifers in Krishna Godavari river basins are basalts, sandstones and granites while in Cauvery, Narmada and Pennar are alluvium, basalts, charnockites and laterites. In Mahanadi river basin, sandstone, alluvium, limestone and shale form the main aquifers. The occurrence of ground water is restricted to weathered residuum generally to a depth of 50 m, and fracture extends generally to a depth of about 100 m.

All of these aquifers (basalts, BGC, granite, gneiss, schists, shales, quartzite, laterite, charnockite, khondalite aquifers) in the river basins of the plateau region are water stress, and majority of the blocks are either under overexploited or critical stage of development. All of these rivers are rain fed, and recharge of the aquifers in this region is rainfall dependent.

Check dams and bandharas are the traditional water harvesting structures in lateritic and basaltic aquifers. Hiware Bazar and Ralegaon Siddi villages exhibit famous model for water harvesting and water conservation in the basaltic and lateritic aquifers. In Hiware Bazar village, in addition to check dam and soil water conservation practices, ground water flow has also been diverted towards the village by creating fracture zone to form a pathway for ground water flow by borehole blasting techniques.

In Krishna River basin, underlain by basalts, granites and laterites, the excessive flood flows were used to be diverted to the adjoining areas for storage in a series of tanks for irrigation and recharging of the aquifers traditionally. Such practices are also very common in all types of aquifer regions on local scale, contributing in sustaining the water demand to a larger extent in rural areas. Similar practices need to be upscaled, enabling to utilise the flood flows.

Kshipra river subbasin in Ujjain, famous for cotton mills, is marked with a unique traditional system of water harvesting and conservation which was developed to meet the water requirement of Heera Mill (a cotton mill) by connecting large diameter dug wells through tunnels which ultimately take the water to a storage tank for meeting the water need of the mill and domestic water needs of about 1000 employees. The Heera Mill was functional from 1910 to 1975. The dug wells are still in use for domestic water supplies. CGWB has experimented recharging of deeper aquifer zone in basalt aquifers by constructing recharge shafts up to a depth of 200 m, along the Kshipra River. The river carries excessive flood water for 5–6 months in a year as observed at Kathoda Rao, Unda and Dabhala Rewari sites. It was estimated that about 15,000 m^3/year water can be recharged through this shaft. The diagram (Fig. 5) is prepared to show the different layers of basalt in the Kshipra river in the study area. With the recharge the water level rose about 7.0–9.5 m and revived the aquifers, those that were getting dried earlier in the vicinity of the recharge sites.

Coastal streams are small in length and have limited catchment's areas. Most of them are non-perennial. The recharge to ground water is to be maintained for sustainable ground water flow towards sea to minimise sea water ingression in

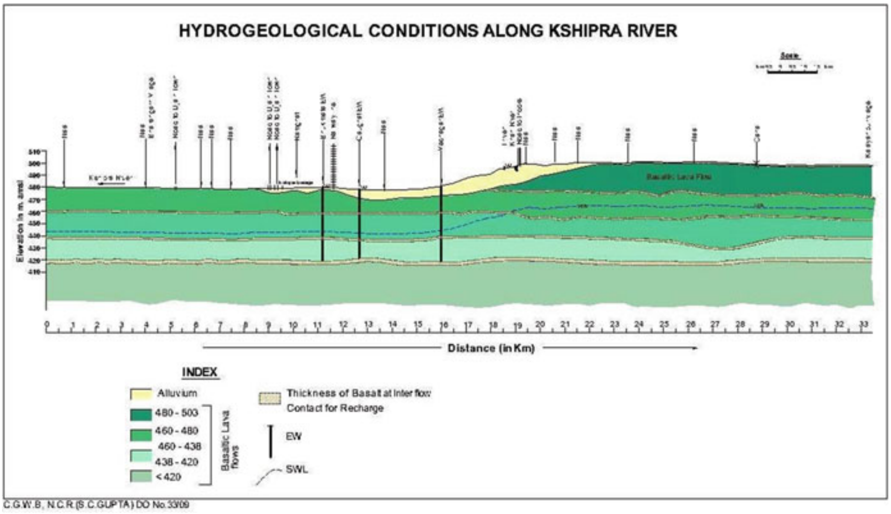


Fig. 5 Schematic diagram showing change of ground water level in recharge shaft at Kithoda Rao in Kshipra River, Ujjain

both shallow and deep aquifers. Most of these schemes rely on the injection of fresh water into the aquifers through wells in order to build up a pressure barrier that will retard or reverse encroachment of salt water resulting from excessive withdrawals from the wells. In such schemes, most of the injected water is not directly available for use but serves as a hydraulic mechanism to allow better use of existing ground water reserves. The river/stream runoff flowing into the sea is conserved in check dams by constructing surface or subsurface dykes or ponds in coastal region to recharge the aquifers and to control sea water ingression which is commonly practiced. In urban areas recharging with vertical shafts in ponds/tanks and along the streams is practiced to conserve rainwater and storm runoff which is most effective. This has also helped in improving the water quality-wise affected aquifers during tsunami in Tamil Nadu. The deeper desaturated/depleted aquifers in sedimentary and alluvial formations in Neyveli Lignite mining area have been successfully experimenting the recharging of these aquifers with flood waters. CGWB also has experimented the recharging of deeper aquifers at a depth of 400 m in Ariyalur district, Tamil Nadu. In coastal areas the desaturated aquifers can also be recharged by constructing series of recharge wells along the river courses to conserve the flood flows during rainy seasons. There is also a scope of utilising the overflows from the water reservoirs existing along the coastline. It is evident from these studies that traditional wisdom/practices and modern technologies are to be put together for conservation and the long-term sustainability of ground water resources (Fig.6).

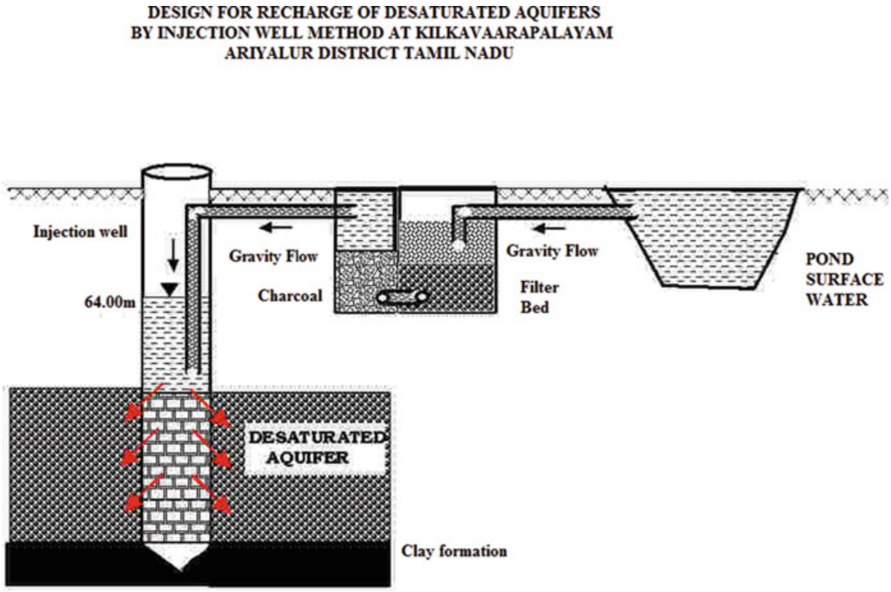


Fig. 6 A schematic diagram showing the design of recharge well at Kavarapalayam Ariyalur village, Tamil Nadu

5.2.3 Inland Drainage Area

In the desert region of Western Rajasthan, the streams of inland drainage basin are mostly ephemeral and do not drain into the sea and get lost in desert sand and salt lakes and are known as Desert Rivers. Such rivers are Luni, Rupen, Saraswati, Ghaggar, etc. The surplus runoff availability in these areas is poor, and the potential evapotranspiration is even up to more than 2.5 m/year. In such regions of the country, rainfall varies between 150 and 600 mm/year, receiving 3–5 major showers with less than 10 rainy days. The annual water resource planning has to be done by conserving the rainfall and by storing the available water either in surface or in sub-surface reservoirs. Hence there is need to conserve the available sources and reduce the evaporation losses from the surface water bodies. Traditionally the water needs were and are fulfilled by harvesting every drop of rainwater in water tanks/tankas or in tanks and ponds, and simultaneously overflows were being recharged to ground water. Forts and palaces in this region have their own well-planned water harvesting systems, e.g. in Mehrangarh Fort Jodhpur, Chittorgarh fort, Ranthambore Fort, etc. With urbanisation in desert region, ground water sources developed, and most of the aquifers had been dried up, “mining of ground water” mainly in Luni and Kantli basins.

The imported water-canal water has affected the aquifers with excessive recharge in canal command areas. Water level was more than 40–50 m prior to the advent of canal irrigation and risen to near surface level. Similarly in Jodhpur City, non-utilisation of ground water has also resulted similar conditions. Aquifer management is necessary in such conditions in all such type of terrains.

6 Way Forward

Unlike in other parts of the world, India's ground water is essentially linked to the water supply strategies for drinking, irrigation, industrial, etc. in the country. Also, the implications of ground water exploitation in the country result in drying up of large no. of dug wells and bore wells due to declining water levels, drying up springs, reduction in river flows and deterioration in water quality. This necessitates to look for replenishing stressed and overexploited aquifers through the water received over the areas in the watersheds/catchment/basins during rainy seasons which otherwise are lost as surface runoff. This volume of surface runoff is required to be assessed and conserved either as surface storage or in sub-surface by recharging the aquifers at the time of its availability during the monsoons and can be utilised during the non-monsoon period to sustain the water needs as has been in practice particularly in the basin.

Prior to the taking up of recharge projects, recharge potentials of aquifers, availability of water resources, scope for water harvesting and conservation of water in *dams/bunds/talavs* and recharging to aquifers are to be assessed using the standard practices being used throughout the world.

- The information on the aquifer systems, including their vertical and later the extent, is available on a very macro scale wherein the size of the aquifer is of the order of hundreds of kilometres. Similarly, surplus run-off information is available normally at the outlet of the basin mouth.
- Aquifer rejuvenation needs to be taken up at local level keeping in view the variability in the larger system. There is a need to identify local Aquifers and delineate recharge and discharge areas. This would help implementation of rejuvenation scheme at a macro level with a vision of big aquifers.
- There is a need to identify desaturated aquifers for identifying their water holding capacity.
- There is a need to estimate surplus runoff for recharging at micro-watershed level using the standard practices being used throughout the world.

Acknowledgements The author is indebted to his former colleagues, viz. Sunil Kumar, Regional Director; Sujeet Sinha, Sc D; S.K. Swaroop, Sc D and Dr. Dipankar Saha of Central Ground Water Board, for their valuable suggestions and support in compiling this article. Significant insights on artificial recharge and traditional practices are developed by interacting with the communities and local level experts whose contribution is also greatly acknowledged.

References

Bhatia R (2005) Water and growth. World Bank, Washington, DC
Chatterjee R, Purohit RR (2009) Estimation of replenishable groundwater resources of India and their status of utilization. Curr Sci 96(12):1581–1591
Saha D, Shekhar S, Ali S, Vittala SS, Raju NJ (2016) Recent hydrogeological research in India. Proc Indian Natl Sci Acad 82(3):787–803
Saha D, Marwaha S, Mukherjee A (2018) Groundwater resources and sustainable management issues in India. In: Saha D, Marwaha S, Mukherjee A (eds) Clean and sustainable groundwater in India. Springer hydrogeology. Springer, Singapore. https://doi.org/10.1007/978-981-10-4552-3_1

Subhash Chand Dhiman is superannuated as Chairman of Central Ground Water Board and Central Ground Water Authority, Government of India. He obtained his master's degree from Panjab University, Chandigarh, and PhD from the University of Rajasthan, Jaipur. He has authored numbers of papers in international journal and spearheaded many activities like leading the preparation of Aquifer Atlas of India. He also initiated National Aquifer Mapping Program of the country and supervised the study on "Subterranean Ground Water Discharge to Sea". He remained as a member in Supreme Court Expert Committee on sustainable development and intergenerational equity in Goa iron ore mining area. He has significant contribution to a wide array of studies like open-cast lignite mines in Gujrat and metalliferous mines in Rajasthan, "ground water quality in Inland and Coastal Aquifers", delineation of buried palaeochannel courses in Indian Thar Desert, UNDP Project on artificial recharge to groundwater in Mehsana area of Gujarat, rain water harvesting and artificial recharge to groundwater and for rejuvenation of springs in Himalayan Region of Himachal Pradesh, Jammu and Kashmir, Uttarakhand.

An Untold Story of Groundwater Replenishment in India: Impact of Long-Term Policy Interventions

Abhijit Mukherjee and Soumendra Nath Bhanja

1 Introduction

Rapid depletion of groundwater storage (GWS) at world's densest populated areas (Rodell et al. 2009; Feng et al. 2013; Voss et al. 2013; Bhanja et al. 2014) would make billions of people suffer from socioeconomic stress in the near future. Water management framework design becomes further complex due to changes in hydrological cycle in the form of increasing atmospheric water vapor content; alteration in patterns, intensity, and extremes of precipitation; snow cover reduction; and change in soil moisture as well as runoff, in the current global warming scenario (Bates et al. 2008). Most of the global hydrological models are not capable enough to simulate groundwater storage over all of the places of the globe at an optimum accuracy; it might be due to absence of groundwater pumping, irrigation, and reservoir impoundment (Sacks et al. 2009) or deficiency in groundwater or surface water components (Maxwell and Miller 2005).

The Gravity Recovery and Climate Experiment (GRACE) has been continuously monitoring the change in earth's gravity with exceptional accuracy (Tapley et al. 2004; Famiglietti and Rodell 2013). The change in gravity field has been related to

A. Mukherjee (✉)
Applied Policy Advisory for Hydrogeoscience (APAH) Group, Department of Geology and Geophysics and School of Environmental Science and Engineering, Indian Institute of Technology (IIT)-Kharagpur, Kharagpur, West Bengal, India
e-mail: abhijit@gg.iitkgp.ernet.in

S. N. Bhanja
Athabasca River Basin Research Institute (ARBRI), Athabasca University, Athabasca, AB, Canada

© Springer Nature Singapore Pte Ltd. 2019

A. Singh et al. (eds.), *Water Governance: Challenges and Prospects*, Springer Water,
https://doi.org/10.1007/978-981-13-2700-1_11

the variation in mass in the fluidic layers of the earth, i.e., air and water. To compute terrestrial water storage (TWS) estimates, different algorithms are utilized to remove the signals lined to solid earth processes (Wahr 2007), atmospheric and oceanic waves (Flechtner 2007). Numerous studies report groundwater storage depletion across the globe (in either basin-scale or continental-scale) using satellite-based approach (e.g., Rodell et al. 2009; Tiwari et al. 2009; Reager and Famiglietti 2013; Voss et al. 2013; Richey et al. 2015). The earlier studies converted groundwater levels to groundwater storage using a constant specific yield value in the entire study region. For example, Rodell et al. (2009) and Panda and Wahr (2016) both used a uniform specific yield value of 0.12. Bhanja et al. (2016) has developed a specific yield database for the country.

In situ and satellite-based groundwater storage anomalies are estimated in this chapter. The in situ data has been retrieved from a well-maintained network of groundwater level monitoring locations in India and studied across different parts of India.

2 Methodology

2.1 In Situ Groundwater-Level Observations

Groundwater level (GWL) information are obtained from the Central Ground Water Board (CGWB, India) in January 2005 to November 2013. The data are collected from typically unconfined aquifers (~87%) (CGWB 2014b), from >19,000 observation wells having GWL data of four times a year (late post-monsoon (January), pre-monsoon (May), monsoon (August), and early post-monsoon (November)). To use the continuous data for anomaly analyses, observation locations are selected based on the availability of at least three seasonal data in the years. Outliers were removed following the inter-quartile approach (Davis 2002), which reduced the well numbers to 3907. CGWB has been maintaining the densely spaced monitoring wells network very well; this is linked with observation of very less spatial error that might be arising as a result of groundwater spatial variability (Bhanja et al. 2017a). GWL anomaly (GWLA) in the individual well has been estimated by subtraction of time-averaged depth to water table from the depth of water table in each observation time. The sign was reversed in the process for depth below the surface rule. The GWLA are converted to GWS anomalies ($GWSA_{obs}$) using specific yield values for each well (Bhanja et al. 2016; MacDonald et al. 2016). $GWSA_{obs}$ median values within each grid cell were utilized to build $1^0 \times 1^0$ gridded data in the study area and for comparing with $GWSA_{sat}$.

2.2 Aquifer-Specific Yield Computation

High-resolution ($0.1^0 \times 0.1^0$) specific yield map is made using hydrogeology map of India (Bhanja et al. 2016). The tributaries and the main channel of Ganges is the largest river system in India having a catchment area of ~86.1 million ha (CWC 2010). Indus-Ganges-Brahmaputra (IGB) rivers system has created a regional aquifer system in parts of the northern and eastern India, which is considered to be one of the most prolific aquifers in the world (Mukherjee et al. 2015). On the contrary, central and southern India has been consisting of Pre-Cenozoic crystalline rocks, sedimentary formations, and multilayered basalt of the Indian craton (CGWB 2014b).

The aquifers are composed of six hydrogeological units, such as unconsolidated sedimentary aquifers; consolidated, permeable sedimentary aquifers; sedimentary aquitards; folded metasediment/metamorphic aquifers; jointed crystalline aquifers; and fractured crystalline aquifers (Bhanja et al. 2016).

The S_y values (Table 1) are segregated from the CGWB database (CGWB 2012a). The S_y information were characterized according to the aquifer hydrogeology shown in Fig. 1. Ranges and mean specific yield information are provided in Table 1. Details on S_y can be found in Bhanja et al. (2016) (Fig. 2).

Individual S_y values are allocated to the wells located in hydrogeologic formation. Observed GWS are computed by multiplying Δh and S_y values. GWS anomaly has been calculated by subtracting all time-averaged GWS from the individual data.

2.3 Gravity Recovery and Climate Experiment (GRACE)

Gridded ($1^0 \times 1^0$), monthly mean liquid water equivalent thickness (LWET) data were obtained from NASA-JPL archive. Mascon solutions (RL05) are used for 133 months in January 2003 to December 2014 (Watkins et al. 2015). Several data processing techniques are used to separate the TWS signal from the data (details can

Table 1 Specific yield values of different hydrogeologic formations shown in Fig. 1

	Hydrogeology	S_y range	Mean S_y
1	Unconsolidated sedimentary (high hydraulic conductivity)	0.06–0.20	0.130
2	Consolidated, permeable sedimentary (medium hydraulic conductivity)	Up to 0.08	0.043
3	Sedimentary aquitards (low hydraulic conductivity)	Up to 0.03	0.018
4	Folded metasediments/metamorphics (low hydraulic conductivity)	Up to 0.03	0.018
5	Jointed crystalline (low to variable hydraulic conductivity)	0.01–0.03	0.020
6	Fractured crystalline (low to variable hydraulic conductivity)	Up to 0.04	0.023

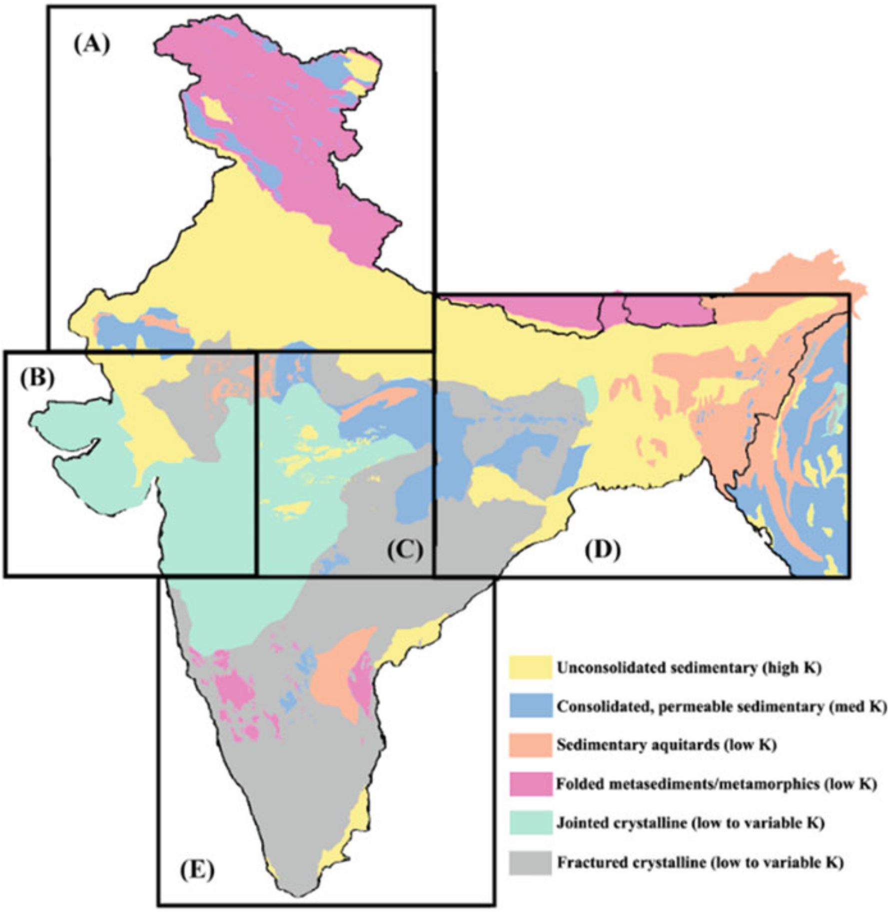


Fig. 1 Hydrogeology map of the ISC. The five HMZs are marked. (Modified from Bhanja et al. 2016)

be found in http://grace.jpl.nasa.gov/data/get-data/jpl_global_mascons/ accessed on 26 April, 2016). Degree 2 and order 0 coefficients are substituted using the coefficients obtained from Satellite Laser Ranging (Cheng and Tapley 2004). Geocenter corrections have been retrieved from Swenson et al. (2008). Glacial isostatic adjustment (GIA) values in the data are separated following Geruo et al. (2013). One of the major differences between SH and mascon approach is linked to the division of the globe in spherical, 3^0 equal area mass concentration blocks in mascon approach (Watkins et al. 2015). Further, use of the a priori values leading to the omission of correlated noise (stripes), as a result, post-processing filters are no more required to be used in mascon approach (Watkins et al. 2015). Another benefit of mascon

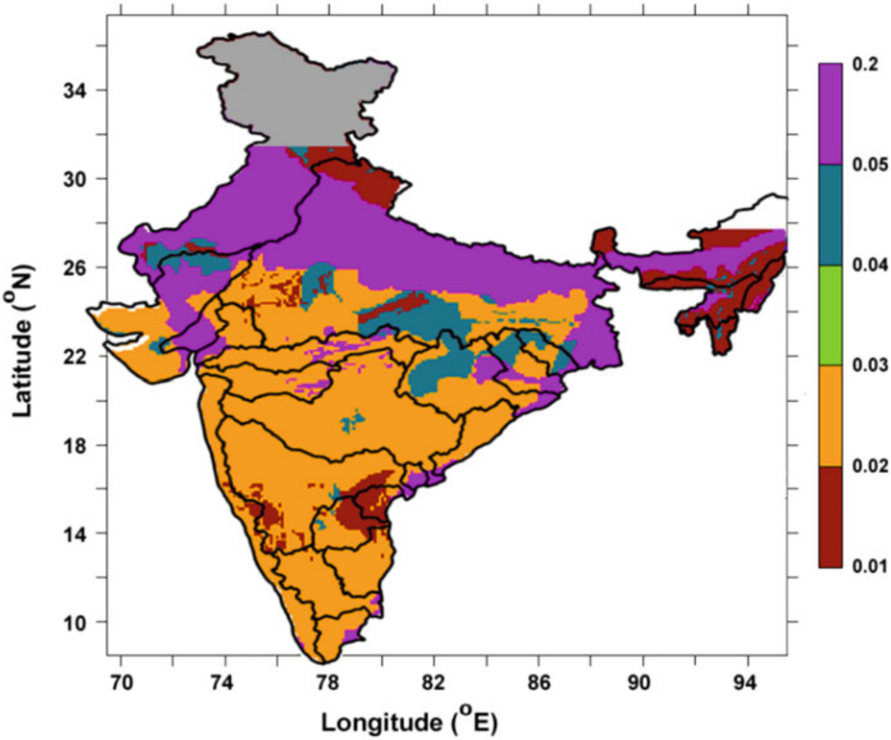


Fig. 2 Specific yield map ($0.1^0 \times 0.1^0$) of the study region. Specific yield fractions are shown in color bar. (Modified from Bhanja et al. 2016)

approach over the spherical harmonics solutions deals with the comparatively lower dependency on scale factors for estimating the mass change calculations in the river basins (Watkins et al. 2015). The scale factors are multiplied with the TWS solutions for consideration of local-scale phenomena.

2.4 Satellite-Based Groundwater Storage Anomaly Estimation

The anomaly in satellite-based groundwater storage (ΔGWS) has been estimated after separating the anomalies of other water components such as the soil moisture anomaly (ΔSM) and surface water (ΔSW) equivalents (surface runoff data used here). The study region has never experienced snow accumulation (exception is the northernmost Himalayan region); hence, snow data are not used. Time-averaged data has been removed from individual data to compute the anomaly (Δ). Continuous observation data for SM and SW were not available; we used the model estimates from the NASA Global Land Data Assimilation System (GLDAS) (Rodell et al. 2004). The combination of three different GLDAS models' output, such as the Community Land Model (CLM), Variable Infiltration Capacity (VIC), and Noah models, is used to avoid any bias associated with a particular model. The CLM simulation includes soil moisture in ten different soil layers (0–343 mm) and other models, while VIC and Noah simulation includes soil moisture in three layers (0–190 mm) and four layers (0–200 mm), respectively. For estimating anomaly in any of the components, time-averaged value for that component has been subtracted from the individual data. Finally, the groundwater storage (ΔGWS) anomaly is estimated by removing anomalies of ΔSM and ΔSW from the TWS anomaly.

3 Results and Discussions

3.1 Groundwater Storage Estimation

In situ groundwater level trends show simultaneous occurrence of wells with increasing and decreasing water level between 2005 and 2013 (Fig. 3). However, parts of the IGB basin mostly show reducing groundwater levels, whereas parts of western and southern India show increasing trends (Fig. 3). The GWS anomaly shows strong spatial variability in the study region (Figs. 4 and 5). Observed GWS data indicate renewal in GWS in western (HMZ B) and southern (HMZ E) zones at a rate of 1.06 ± 0.03 and 0.31 ± 0.02 km^3/year. On the other hand, the northern (HMZ A) and eastern (HMZ D) zones are experiencing rapid GWS depletion at rates of 4.55 ± 0.11 km^3/year and 3.59 ± 0.14 km^3/year, respectively (Figs. 4 and 5). Satellite-based estimates indicate rapid depletion in northern (zone A) and eastern (zone D) zones at a rate of -1.40 ± 0.14 and -1.16 ± 0.35 cm/year (-14.02 ± 1.37 km^3/year and -14.49 ± 4.36 km^3/year) in the study period, respectively (Fig. 5). These depletion observations are in line with the satellite-based findings of northwest (17.7 km^3/year, between 2002 and 2008) (Rodell et al. 2009) and northern (54 km^3/year in 2002–2008) (Tiwari et al. 2009) India and Bangladesh (located at eastern zone) (Shamsudduha et al. 2012). Corroborating the above observations, comparison of field measured groundwater level fluctuation of decadal mean (2001–2010) to 2011 by Indian government authorities, in general, suggests groundwater decline in northern, northwestern, and eastern India and rise in southern and western India for most seasons (CGWB 2012b). They reported a declining water level trend for pre-monsoon during 2007 to 2012 with >55% of measured wells ($n = 11{,}024$) having groundwater level drop of ≥ 1 m/year (MoWR 2013).

The fertile alluvial plains of the IGB basin are extremely conducive for irrigational activities. Consequently, the IGB plains have been one of the cradles

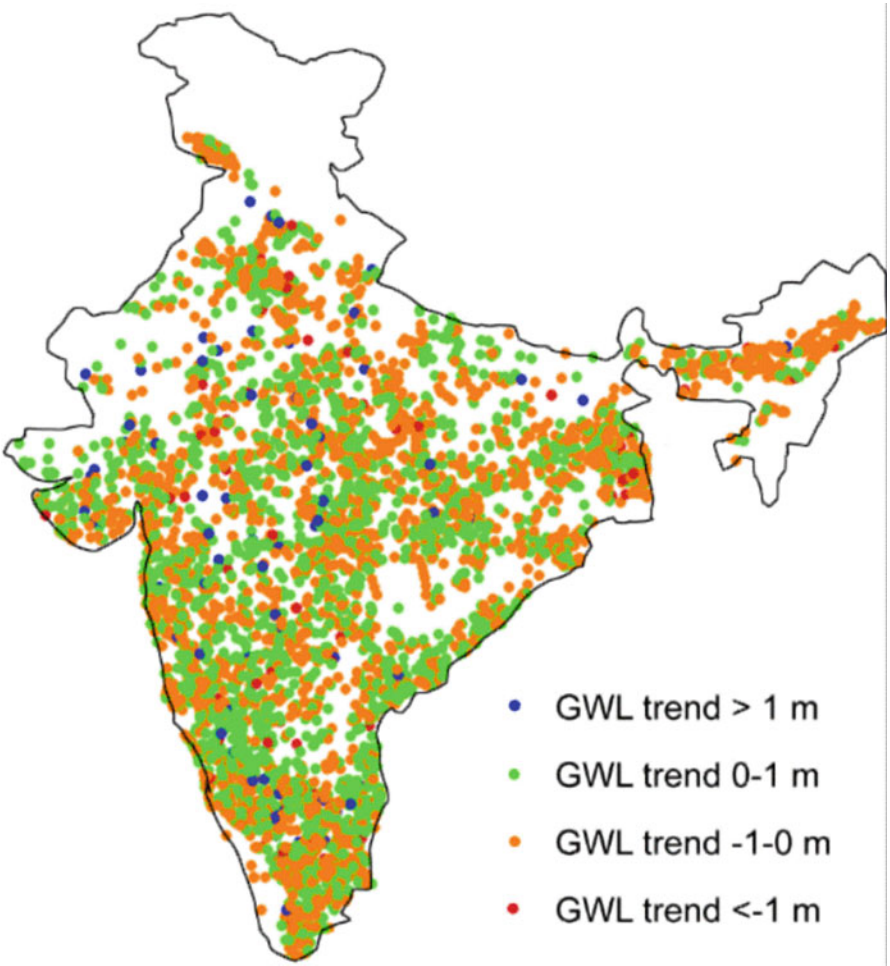


Fig. 3 Maps of in situ groundwater level trends in 2005–2013

of human civilization, and presently it is known as one of the most densely populated parts in the world. The rapidly accelerating groundwater demands in these areas are directly proportional to the increasing population, introduction of water-intensive crops (e.g., boro rice), and changes in cropping pattern (e.g., replacing food crop by cash crop) (FAO 2013) and coincide with the areas showing highest GWS depletion. Most of Bangladesh (percentage of gross irrigated area to gross cropped area, >60%; FAO 2013) and Indian states such as Punjab (98%), Haryana (85%), Uttar Pradesh (76%), Bihar (61%), and West Bengal (56%) are all located in these depletion zones (MoA 2012). More than 4 m groundwater decline have been observed during the last decade in Indian states of Delhi, Haryana, Punjab, Rajasthan, and West Bengal (CGWB 2014a). The drastic groundwater level depletion in Ganges basin has been

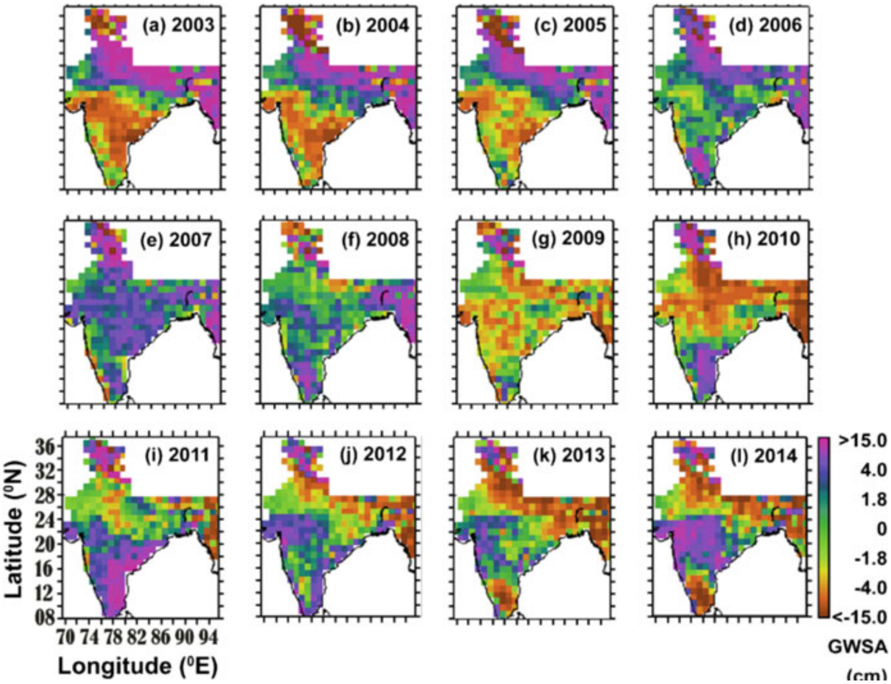


Fig. 4 Maps of the annual mean groundwater storage (GWS) anomalies (cm)

found to be linked with surface water quantity reduction in Ganges river during recent summers (Mukherjee et al. 2018).

3.2 Groundwater Storage Replenishments and Policy Interventions

Despite rapid GWS depletion in northern and eastern parts, GWSA replenishments have been observed in southern, central, and western parts of India (Figs. 4, 5, and 6). In situ estimates show groundwater level replenishing trend in Andhra Pradesh, Maharashtra, Gujarat, Tamil Nadu, and Chhattisgarh between 2005 and 2013. The estimates are consistent with published reports of CGWB (CGWB 2013, 2014b). Based on the satellite-based estimates, it has been found that several districts of the western, central, and southern study regions have been subjected to GWS replenishments. The reasons for the replenishment are investigated in detail in Bhanja et al. (2017b). Reasons include reduction in irrigation-linked groundwater withdrawal, change in agricultural practice, increasing artificial recharge, surface water irrigation increase, etc. (Bhanja et al. 2017b, and references therein).

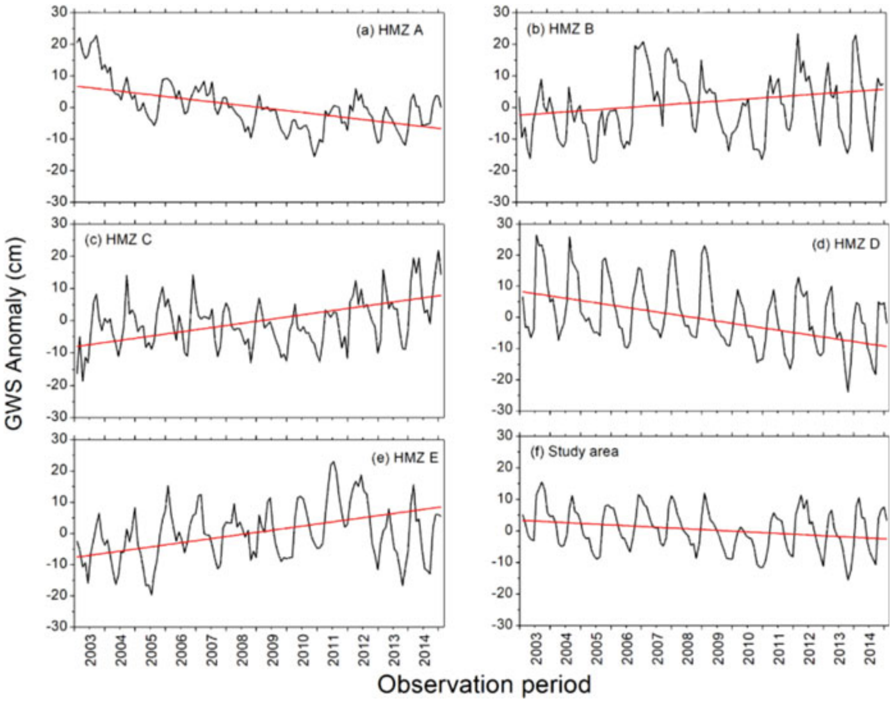


Fig. 5 Time series of GWS anomaly in (**a**) northern (HMZ A), (**b**) western (HMZ B), (**c**) central (HMZ C), (**d**) eastern (HMZ D), (**e**) southern (HMZ E), and (**f**) the entire study area

Uncontrolled withdrawal for increasing irrigation of water-intensive cropping practice (e.g., boro rice paddy) has been leading to one of the most critical groundwater depletion in human history. Recent shift in Indian government policies on groundwater withdrawal and incorporation of management strategies are facilitating increasing groundwater storage. Policies such as inhibition of subsidized electricity for irrigation, creation of large-scale recharge systems in crystalline aquifers (e.g., ~700 million USD allocated to the Tapi river Mega Recharge Project), targeted artificial recharge of 85 BCM/year in ~0.5 million km^2 through creation of ~10 million structures, and increased recharge as a function of the interlinking of river catchments (such as the Narmada-Sabarmati interlinking) have been implemented. Based on these, we hypothesize to have probably started replenishing the groundwater storage, as evident in GWL and GWS trends in parts of India (Bhanja et al. 2017b).

The potential implications of groundwater management policies are studied using the longterm (between 1996 and 2014), groundwater level information from the Indian states of Gujarat and Andhra Pradesh. The GWS were characterized as trends and cycles using the Hodrick-Prescott (HP) filter approach. The result suggests reducing groundwater trends from 1996 to 2002–2003 in Gujarat, at a rate of 5.81 ± 0.38 km^3/year (linear trend), and trend reversals to increasing GWS have been observed at a rate of 2.04 ± 0.20 km^3/year between 2002–2003 and 2014. A

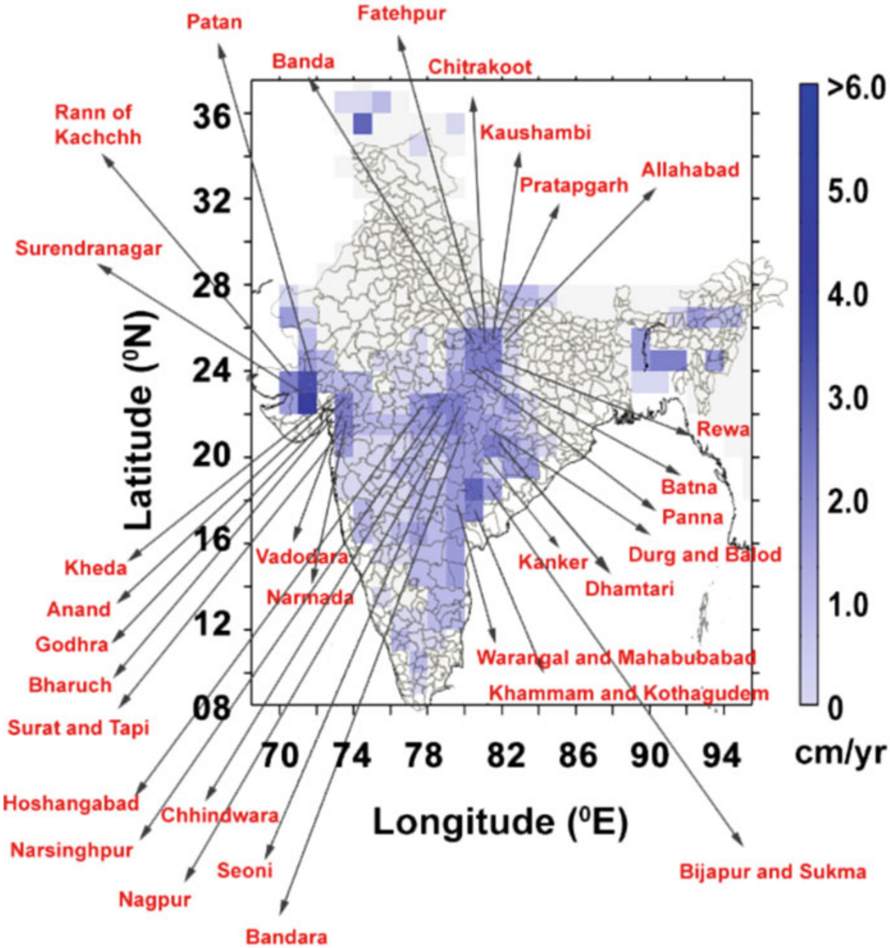


Fig. 6 District-wide groundwater replenishment from satellite-based observations. Districts with more than 2 cm/year are marked here

declining GWS trend has been observed in Andhra Pradesh (0.92 ± 0.12 km^3/year) in 1996–2003. Similar to Gujarat, the GWS trend has been following increasing trend in 2003–2014, at a rate of 0.76 ± 0.08 km^3/year. The trend reversals are found to be associated with implementation of several groundwater policy modifications in these two states (Bhanja et al. 2017b). In the same time period (i.e., 1996–2014), no distinct changes in HP trends of precipitation have been found in the two states (Fig. 3b and d), hence reducing possibilities of influence of precipitation on the groundwater storage trends.

A net decrease in agricultural power supply from 16 to 10 billion units in 2001–2006 resulted in 20–30% decrease in groundwater withdrawal in Gujarat.

Results of our analyses show electricity usage for groundwater irrigation (P value <0.05) was found to have negative influence on GWS anomaly in Gujarat, indicating the decrease in electricity usage facilitating reduction in groundwater pumping from 2002, possibly resulting to GWS replenishment in Gujarat. In Andhra Pradesh, UN FAO conducts program for farmers, associated with groundwater sustainable management training practice in 2004–2008. Another scheme named APWELL was associated with large-scale groundwater development in Andhra Pradesh (Bhanja et al. 2017b). An overall enhancement in surface water irrigation is observed 1996 onward (~20% increase in surface water irrigation have been recorded in 2003–2014 comparing the 2002 level), thus possibly inducing the increased non-meteoric recharge.

4 Summary and Conclusion

Over the past decade, the issue of diminishing groundwater resources in India has garnered significant concern worldwide. Several studies have shown the rapid depletion of groundwater storage as a consequence of intensifying crop irrigation and rapid urbanization. Our studies have identified replenishment of groundwater storage at regional scale in parts of southern and western India. In recent times, large parts of the country experience severe water crisis during every summer. Pervasive, unregulated groundwater withdrawal for enhancing irrigation of water-intensive cultivation is linked to one of the most severe groundwater depletion in the world and may be ascribed as "largest groundwater abstraction in human history."

Our study shows that a recent crucial shift in the Indian groundwater management policies for water utilization might be associated with the aquifer replenishment by increasing storage in western and southern India. We observed, in parts of western (Gujarat) and southern (Andhra Pradesh) India, groundwater storage had been decreasing at rates of -5.81 ± 0.38 km^3/year and -0.92 ± 0.12 km^3/year in 1996 to 2001–2002, respectively. Consequently, the groundwater storage has been found to increase at rates of 2.04 ± 0.20 km^3/year in Gujarat and 0.76 ± 0.08 km^3/year in Andhra Pradesh, respectively, during 2002–2003 to 2014.

The groundwater replenishment is probably caused by a combination of government policy changes and the grassroots efforts of local communities, who have undertaken several projects over the last several years in the form of efficient groundwater management and utilization policies. Recent changes in Indian government's policies on groundwater management processes, such as inhibition of subsidized electricity for irrigation, distinct electricity distribution for agriculture (e.g., Jyotigram Yojana), creation of large-scale recharge systems in crystalline aquifers (e.g., the Tapi river Mega Recharge Project), artificial recharge of 85 Billion cubic meter/year in approximately 0.5 million km^2 by creation of ~10 million structures (e.g., Pradhan Mantri Krishi Sinchayee Yojana), and increasing recharge by interlinking of rivers (e.g., Narmada-Sabarmati interlinking), are worth to be noted. The sustainable policy implementation is possibly starting to replenish the aquifers in the form of increasing groundwater storage in the future. Hence, the results of our study illustrate a potentially optimistic scenario, where under conducive groundwater management policies India can transform from a "groundwater-scarce" to a "groundwater-sufficient" country.

Acknowledgments Thanks are extended to the scientists of Central Groundwater Board for valuable suggestions and also the research scholars of IIT Kharagpur for their support. We would also like to thank Matthew Rodell (NASA GSFC), Yoshihide Wada (IIASA), Dipankar Saha (CGWB) and Amarjit Singh.

References

Bates B, Kundzewicz Z, Wu S, Palutikof J (2008) Climate change and water. Technical paper of the Intergovernmental panel on climate change. Geneva, Switzerland. ISBN: 978-92-9169-123-4

Bhanja S, Mukherjee A, Rodell M, Velicogna I, Pangaluru K, Famiglietti J (2014) Regional groundwater storage changes in the Indian Sub-Continent: the role of anthropogenic activities. In: American Geophysical Union, Fall Meeting, GC21B-0533

Bhanja SN, Mukherjee A, Saha D, Velicogna I, Famiglietti JS (2016) Validation of GRACE based groundwater storage anomaly using in-situ groundwater level measurements in India. J Hydrol 543:729–738

Bhanja SN, Rodell M, Li B, Saha D, Mukherjee A (2017a) Spatio-temporal variability of groundwater storage in India. J Hydrol 544:428–437

Bhanja SN, Mukherjee A, Rodell M, Wada Y, Chattopadhyay S, Velicogna I, Pangaluru K, Famiglietti JS (2017b) Groundwater rejuvenation in parts of India influenced by water-policy change implementation. Nat Sci Rep 7(1):7453

Central Ground Water Board (2012a) Ground water year book – India 2011–12. Ministry of Water Resources River Development and Ganga Rejuvenation, Govt of India, p 42. Available at www.cgwb.gov.in

Central Ground Water Board (2012b) Aquifer systems of India. Ministry of Water Resources River Development and Ganga Rejuvenation, Govt of India, p 92. Available at www.cgwb.gov.in

Central Ground Water Board (2013) Master plan for artificial recharge to ground water in India. Ministry of Water Resources River Development and Ganga Rejuvenation, Govt of India, p 225. Available at www.cgwb.gov.in

Central Ground Water Board (2014a) Ground water year book – India 2013–14. Ministry of Water Resources River Development and Ganga Rejuvenation, Govt of India, p 76. Available at www.cgwb.gov.in

Central Ground Water Board (2014b) Dynamic groundwater resources. Ministry of Water Resources River Development and Ganga Rejuvenation, Govt of India, p 283. Available at www.cgwb.gov.in

Central Water Commission (2010) Water and related statistics. Ministry of Water Resources River Development and Ganga Rejuvenation, Govt of India, p 253

Cheng M, Tapley BD (2004) Variations in the Earth's oblateness during the past 28 yrs. J Geophys Res 109:B09402. https://doi.org/10.1029/2004JB003028

Davis JC (2002) Statistics and data analysis in geology, 3rd edn. Wiley, New York, p 656

Famiglietti JS, Rodell M (2013) Water in the balance. Science 340(6138):1300–1301. https://doi.org/10.1126/science.1236460

FAO (2013) FAO Statistical year book 2013: World Food and Agriculture, p 289. Available at: http://www.fao.org/docrep/018/i3107e/i3107e00.htm

Feng W, Zhong M, Lemoine JM, Biancale R, Hsu HT, Xia J (2013) Evaluation of groundwater depletion in North China using the Gravity Recovery and Climate Experiment (GRACE) data and ground-based measurements. Water Res Res 49(4):2110–2118

Flechtner F (2007) AOD1B product description document for product releases 01 to 04 (Rev. 3.1, April 13, 2007). GRACE Project Document, pp 327–750

Geruo A, Wahr J, Zhong S (2013) Computations of the viscoelastic response of a 3-D compressible earth to surface loading: an application to glacial isostatic adjustment in Antarctica and Canada. Geophys J Int 192(2):557–572

MacDonald AM, Bonsor HC, Ahmed KM, Burgess WG, Basharat M, Calow RC, Dixit A, Foster SSD, Gopal K, Lapworth DJ, Lark RM (2016) Groundwater quality and depletion in the Indo-Gangetic Basin mapped from in situ observations. Nat Geosci 9(10):762–766

Maxwell RM, Miller NL (2005) Development of a coupled land surface and groundwater model. J Hydrol 6:233–247

Ministry of Agriculture (2012) State of Indian agriculture 2011–12. Govt of India. Available at: http://www.indiaenvironmentportal.org.in/files/file/State%20of%20Indian%20Agriculture%202011-12.pdf

Ministry of Water Resources (2013) Press release. 29 April, 2013

Mukherjee A, Saha D, Harvey CF, Taylor RG, Ahmed KM, Bhanja SN (2015) Groundwater systems of the Indian Sub-Continent. J Hydrol Reg Stud 4:1–14

Mukherjee A, Bhanja SN, Wada Y (2018) Groundwater depletion causing reduction of baseflow triggering Ganges river summer drying. Sci Rep 8(1):12049

Panda DK, Wahr J (2016) Spatiotemporal evolution of water storage changes in India from the updated GRACE-derived gravity records. Water Resour Res:51. https://doi.org/10.1002/2015WR017797

Reager JT, Famiglietti JS (2013) Characteristic mega basin water storage behavior using GRACE. Water Resour Res 49(6):3314–3329

Richey AS, Thomas BF, Lo M, Famiglietti JS, Reager JT, Voss K, Swenson S, Rodell M (2015) Quantifying renewable groundwater stress with GRACE. Wat Resour Res 51:5217–5238. https://doi.org/10.1002/2015WR017349

Rodell M, Houser PR, Jambor UEA, Gottschalck J, Mitchell K, Meng CJ, Arsenault K, Cosgrove B, Radakovich J, Bosilovich M, Entin JK (2004) The global land data assimilation system. Bull Am Meteorol Soc 85(3):381–394

Rodell M, Velicogna I, Famiglietti JS (2009) Satellite-based estimates of groundwater depletion in India. Nature 460:999–1002

Sacks WJ, Cook BI, Buenning N, Levis S, Helkowski JH (2009) Effects of global irrigation on the near-surface climate. Clim Dyn 33:159–175. https://doi.org/10.1007/s00382-008-0445-z

Shamsudduha M, Taylor RG, Longuevergne L (2012) Monitoring groundwater storage changes in the highly seasonal humid tropics: validation of GRACE measurements in the Bengal Basin. Water Resour Res 48. https://doi.org/10.1029/2011WR010993

Swenson SC, Chambers DP, Wahr J (2008) Estimating geocenter variations from a combination of GRACE and ocean model output. J Geophys Res Solid Earth 113(B8):B08410. https://doi.org/10.1029/2007JB005338

Tapley BD, Bettadpur S, Ries JC, Thompson PF, Watkins MM (2004) GRACE measurements of mass variability in the Earth system. Science 305:503–505

Tiwari VM, Wahr J, Swenson S (2009) Dwindling groundwater resources in northern India, from satellite gravity observations. Geophys Res Lett. https://doi.org/10.1029/2009GL039401

Voss KA, Famiglietti JS, Lo M, Linage C de, Rodell M, Swenson SC (2013) Groundwater depletion in the Middle East from GRACE with implications for transboundary water management in the Tigris-Euphrates-Western Iran region. Water Resour Res:49

Wahr JM (2007) Time-variable gravity from satellites. Treatise Geophys 3:213–237

Watkins MM, Wiese DN, Yuan DN, Boening C, Landerer FW (2015) Improved methods for observing Earth's time variable mass distribution with GRACE using spherical cap mascons. J Geophys Res. https://doi.org/10.1002/2014JB011547

Abhijit Mukherjee is a PhD graduate from the University of Kentucky, USA, and he completed his postdoctoral work at the University of Texas at Austin, USA. He also served as the physical hydrogeologist at the Alberta Geological Survey in Canada. He is currently an associate professor at the Department of Geology and Geophysics and research coordinator of School of Environmental Science and Engineering at the Indian Institute of Technology Kharagpur (IIT Kharagpur), India. His main research areas are physical, chemical and isotope hydrogeology, including modelling and contaminant transport, as well as water resource management and the effects of climate change on the hydrosphere. Prof. Mukherjee has over 20 years of teaching and research experience. He leads several international groundwater research consortiums and has researched in several countries, with emphasis on basin-scale hydrogeology. Among many awards and recognitions, in 2016, he was conferred the National Geoscience Award by the president of India. He served as an associate editor of several journals, including the *Journal of Hydrology*, *Applied Geochemistry*, *Groundwater for Sustainable Development*, *Frontiers in Environmental Science* and *Journal of Earth System Science*.

Soumendra Nath Bhanja obtained his PhD from the Indian Institute of Technology, Kharagpur. He is currently working as a postdoctoral fellow at Athabasca University, Canada. He has also worked at the NASA Goddard Space Flight Center being a recipient of Fulbright scholarship. His main research areas include regional-scale groundwater recharge and storage quantification, sediment-water interaction modelling, water resource management and aerosol optical, physical and radiative properties. He is a member of the American Geophysical Union (AGU), Geological Society of America (GSA), International Association of Hydrogeologists (IAH) and Indian Science Congress Association. He has won many awards and recognitions such as National Postdoctoral Fellowship, Fulbright scholarship, CSIR Shyama Prasad Mukherjee Fellowship and Shastri Indo-Canadian Institute's Student Mobility Grant. He has published in well-reputed scientific journals, and his research has been highlighted in several national and international news agencies including coverage in NASA's "Image of the Day".

Hydropower: The Way Ahead

Chetan Pandit and C. D. Thatte

1 Terminology

For about the past 30 years, HP development in India is facing an ill-advised opposition and consequent slow down on two planes. One, HP versus other sources, mainly coal. The murmurs of a “thermal lobby” are too strong to be ignored. Two, conventional energy sources, e.g., hydro, fossil fuels, and nuclear on one hand versus the non-conventional basket comprising solar, wind, ocean waves, etc., on the other. The focus of this paper is to explain the debate that surrounds HP; to explain why HP is a must and why it is facing opposition, unraveling the objections against it; and finally to recommend what needs to be done to reinstate HP. To understand the debate that surrounds the need and feasibility of HP vis-à-vis other energy sources, it would be useful to have clarity on many terms that are used to describe certain attributes of electricity generation and supply.

Conventional Electromechanical generators, and coal-based steam engines, or hydroturbines to drive the generators all date back to approximately the 1880s. For a long time, the fossil fuels comprising coal, oil, gas, and the flowing water were the only sources of energy to drive the generators. The first nuclear reactor was commissioned in 1942. The fossil fuels, flowing water, and nuclear fission are considered as conventional sources. The wind, solar, tidal, geothermal, and biomass energy sources are of much more recent times; some are still under development, and they are considered as non-conventional sources.

Chetan Pandit (✉)
Former Member, Central Water Commission, Government of India, New Delhi, India
e-mail: cmpandit@gmail.com

C. D. Thatte
Former Secretary, Ministry of Water Resources (now Ministry of Water Resources River Development and Ganga Rejuvenation), Government of India, New Delhi, India

© Springer Nature Singapore Pte Ltd. 2019

A. Singh et al. (eds.), *Water Governance: Challenges and Prospects*, Springer Water,
https://doi.org/10.1007/978-981-13-2700-1_12

Renewable Mankind started energy generation with a certain stock of coal, oil, gas, and uranium. As we use it up, the stocks are not regenerated. Therefore, these are called nonrenewables. In contrast to this, hydropower, solar, wind, and tidal sources are regenerated in short term and are called renewables. Strictly speaking, the geothermal source is not renewable but is practically inexhaustible and therefore is counted as renewable.

Sustainable In 1987 the United Nations World Commission on Environment and Development released the report "Our Common Future," now popularly known as Brundtland Report, after Gro Harlem Burndtland who was the chairperson of the Commission. The report suggested the idea of sustainable development (SD) as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

It was soon realized that this very laudable definition had many flaws. Any consumption of nonrenewable resources, no matter how miniscule, would someday result in that resource being exhausted and denied to the future generations and therefore must be seen as "not SD." Such perception did not suit the developed nations, who are the largest per capita consumers of natural resources. This also amounted to restrictions on the growth of developing nations, in the name of environment. And it was also pointed out that, when we are not able to fulfill the demands of even the present generation, where is the question of meeting the demands of the future generations?

The original definition of SD thus now stands discarded. Now, SD means development that is economically feasible, socially acceptable, and environmentally conservative. This vague definition however enables the activists to declare anything they do not like as unsustainable. Wind energy, once their darling, has now fallen out of their favor and is considered by them not SD. In environmental discourses, hydropower is branded as not SD. The fact remains that hydropower is 100% renewable, causes no pollution, and is decidedly SD.

Grid Quality Large energy generation plants do not supply electricity to a captive group of consumers. Instead, they feed electricity into a distribution network called a grid, and consumers draw from the grid. The advantage is that the supply to a consumer is not tied up with a particular generation plant being operational. However, to feed to the grid, the voltage, the frequency, and some other parameters of the electricity need to be within a tight range. Such electricity is called grid quality electricity. Small generation plants, typically within a few 100 KW range, may not be able to generate electricity that conforms to grid quality parameters. Such plants supply to only a small group of consumers and are called isolated plants. These attributes are summarized in Table 1.

Table 1 Comparison of different energy sources

Source	Conventional	Renewable	Sustainable	Grid quality
Coal, oil	Yes	No	No	Yes
Gas turbine	Yes	No	No	Yes
Hydro	Yes	Yes	Yes	Yes
Nuclear	Yes	No	Yes	Yes
Wind	No	Yes	Yes	Possible
Solar	No	Yes	Yes	Possible
Tidal	No	Yes	Yes	Yes

2 India's Energy Requirement Projections and Supply Options

Agriculture, industry, services, infrastructure, and all sectors of economy require electricity. With the given land resources remaining constant but land use changing very rapidly and with population continuing to increase but rapidly migrating, India is shifting from a predominantly rural and agriculture-based economy to urban habitats and industry-/service-based economy. Responding to these changes, the demand for electricity will continue to increase, and the estimated demand forecast for the year 2021–2022 is 1,904,861 MU[1] of energy, and 283,470 MW of peak power[2].

The conventional options for grid quality electricity are fossil fuel-based thermal power, hydropower, nuclear fission power, and gas turbines. Figure 1 shows India's current energy mix. More than two-thirds of the energy comes from thermal, i.e., from burning fossil fuels.

For the 12th and 13th plan, the Central Electricity Authority (CEA) projects a conventional capacity addition of 158,890 MW[3]. Its source-wise breakup is shown in Table 2. It is obvious that this is not what is desirable. It is what the CEA thinks is feasible. Thus, a large target for coal seems to be a fait accompli, because of expected impediments in the path of nuclear and hydro and limitations of wind and solar. This assessment was dated January 2012. In the 8 years since, there has been very little progress on installation of hydro/nuclear schemes. It is certain that the stated targets for hydro and nuclear energies are already jeopardized.

With growing concern about global warming and climate change, it is necessary to shift to non-fossil fuel-based, "low-carbon" energy sources. Also, with stress on "sustainable development," nations are attempting to move toward renewable energy. Solar and wind energy, being available over a part of a day only, were earlier not considered as suitable for absorption in the power grid, and their cost was

[1]MU, Millions Units, is the unit for measurement of electricity. 1 Unit = 1000 W × 1 Hour.

[2]Power Capacity Addition in India, Performance and Challenges. Sudhir Vadehra, The Journal of Governance, Vol 12, January 2016.

[3]National Electricity Plan, Central Electricity Authority, January 2012.

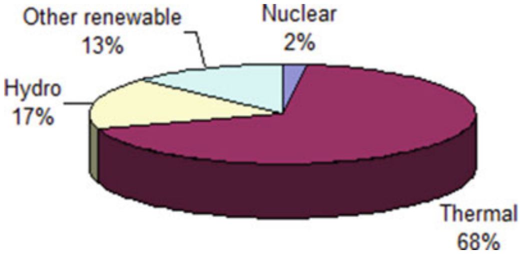


Fig. 1 India's current energy mix

Table 2 12th and 13th plan targets

Source	Target (MW)	% share
Coal	115,800	72.9%
Gas	1086	0.68%
Nuclear	20,800	13.08%
Hydro	21,204	13.34%
Total conventional	158,890	
Renewables	49,000	

also relatively very high. But recent developments in technology have reportedly brought down the cost of solar energy and have enabled consideration of solar and wind energy sources also as eligible grid contributors. HP is, of course, renewable, and a zero-carbon, grid quality source. Therefore, in the next decade or so, hydro (all sizes), wind, and solar should be the preferred options for capacity addition.

About HP, the plan says "India's hydroelectric resources are estimated to be 84 GW at a 60% load factor. Low carbon growth Strategy would ensure clean hydropower is used to its maximum potential for meeting peak loads and all new projects must be designed with this objective in mind. However, the full development of India's hydro-electric potential, while technically feasible, faces issues of water rights, resettlement of project affected persons and environmental concerns – issues that must be resolved."

Since HP faces all these concerns, and since wind and solar seems to be very environment-friendly, can India's future needs of electricity be met by renewable energy sources? This, in fact is the title of an analytical paper by Prof. S. P. Sukhatme[4] of IIT, Bombay. In the conclusions he writes "Meeting an annual requirement of electrical energy is necessary but is not enough. It is also necessary to meet the daily need for electricity on a continuous round-the-clock basis all over the country. Because of the intermittent nature of both solar and wind energy, there is a serious mismatch between diurnal variation of the supply and the diurnal variation of the demand. Thus, many technical challenges exist and these problems will have to be successfully resolved if matching is to be achieved and renewable energy sources alone can electricity needs in the future."

[4]"Can India's future needs of electricity be met by renewable energy sources? A revised assessment" Current Science, 25th November 2012.

Here is what ecology.com[5] says about the future of wind and solar. "The sun also provides enough energy that can be stored for use long after the sun sets and even during extended cloudy periods. But making it available is much easier said than done. It would be cost prohibitive to make solar energy mainstream for major world consumption in the near future. . . . According to the European Photovoltaic Industry Association, solar power could provide . . . 26 percent of global energy needs by 2040."

A more detailed discussion on shortcomings of solar and wind will be a digression. Suffice to say that no one expects wind and solar to replace a significant part of other sources of energy in foreseeable future. Solar and wind sources are not competitors for hydropower. Hydropower is as clean and as renewable as the solar and wind, and there are some other advantages that are unique to hydropower which makes hydropower an irreplaceable part of the energy mix.

3 Understanding Hydropower

Since the present paper is about understanding HP, it would be useful to appraise its basic engineering concepts. HP plants that generate some significant quantum of energy come in three different types/locations, each having its own plus and minus points.

3.1 Storage-Based

Water is stored in a reservoir created by construction of a dam across a river. The powerhouse is typically located at the toe of the dam, and after driving the turbines, the water rejoins the river within a short distance downstream of the dam (Fig. 2). The powerhouse can be located on surface at the dam's toe or can be placed in an underground cavern. If the riverbed downstream has substantial level drops, then an underground powerhouse can use these to increase the hydraulic head and thus increase the potential installed capacity.

3.2 Run of the River

Water is diverted from the river by construction of a barrage or a small dam across the river. The diverted water is allowed to flow in a channel or a conduit at a gentle slope for some distance, while the riverbed drops more steeply, thereby creating a

[5] http://www.ecology.com/2011/09/06/fossil-fuels-renewable-energy-resources/

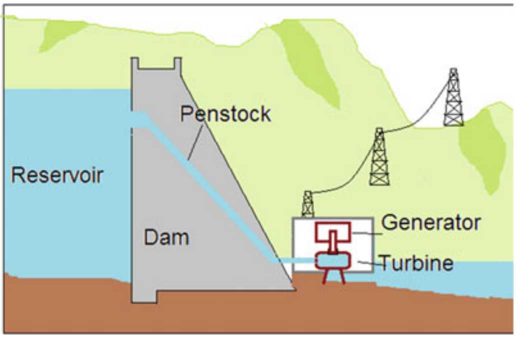


Fig. 2 Storage-type HPP

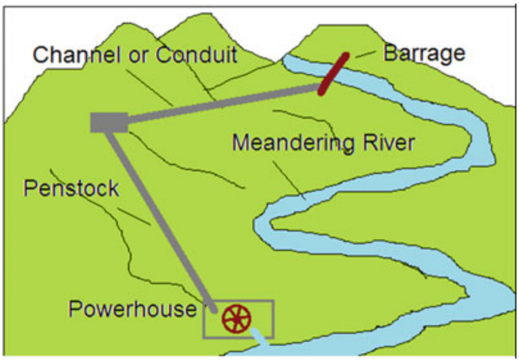


Fig. 3 RoR-Type HPP

level difference between the diverted water and the riverbed. In this type, the powerhouse is located a considerable distance away from the diversion point and can even be in another basin (Fig. 3).

3.3 Canal Head Regulator or Canal Falls

Most dams provide for head-regulators for main canal outlets. A hydropower plant can be placed in the canal, where the water is released from the dam. The canal head powerhouse in Sardar Sarovar Project has an installed capacity of 250 MW, larger than the total capacity of many small hydropower projects. The bed slope of a canal is usually flatter than the slope of the landscape through which the canal passes, thereby gradually increasing the level difference between the canal and the surrounding land. For structural reasons, it becomes necessary to construct a fall in the canal bed at suitable intervals and locations, to reduce the cost of canal construction. A long canal may have several such falls in quick succession along its course. Instead of allowing the water to merely drop down, a powerhouse can be installed to utilize the head for generation of electricity by passing the flow through a turbine.

4 Main Advantages of Hydropower

4.1 For Meeting the Peak Load Demand

The demand curve for electricity during a 24-h day cycle usually has two peaks, one during the morning hours and the second during the evening when, respectively, the day's 1st work shift starts and when the lighting load for the night takes shape with the 2nd work shift. The fossil fuel-based thermal plants and the nuclear plants are unable to respond quickly to the load changes as it takes some time for the boiler to generate more steam to obtain more power from the turbine. Neither the burning of the fuel nor heating of water can be quickly stepped up or stepped down in response to changes in demand in power load, unless thermal efficiency is sacrificed. Therefore, these plants are run to supply approximately an average of daily load barring the peaks, constituting what is termed as the base load. Hydropower plants and gas turbines on the other hand can respond very quickly to changes in load with tap like open/close operation possible for both resources. Therefore, as the demand increases over and above the base load, hydropower plants or gas turbines are brought in to supply the peak load. Wind and sun energy constitute intermittently available resources and hence can't generate energy on demand.

4.2 Frequency Control and Grid Management

If additional power is not fed into the supply grid within minutes to match the peak load, the frequency of the AC supply drops. If the drop is below an acceptable limit, then the load has to be cut to limit it to generation or else there could be a collapse of the distribution system. This power shading disrupts processes at user's end and compels the user to invest in portable or fixed oil-based generators, lead-acid battery-based inverters, and UPS for the critical equipment. It all leads to a waste of precious resources. The captive diesel generators are also a major source of air pollution in cities. Therefore, sufficient hydropower capacity is essential for frequency control and grid stabilization.

4.3 Cost

Sunlight and wind resources are abundant and freely available, but utilizing them for generating electricity costs sizeable finance. As of 2018, the cost of hydropower at the scale of its potential for development and use is undoubtedly the most economic source of renewable energy.

4.4 Multipurpose

Most hydropower dams serve multiple purposes of flood control and water storage for irrigation and hence impart flexibility in energy generation and utilization to suit the needs according to the variability in rainfall pattern and economic activities in the areas being served.

4.5 As a Way to Store Energy

During off-peak hours, there may be excess electricity in the grid, from thermal or nuclear sources. If there was a way to store it, then it would be available for use during peak hours. But storing large quantity of energy is a challenge. Rechargeable batteries are good enough to store standby power of a few units only. A special type of hydropower project, known as “pumped storage project,” offers a way to store large quantum of energy. The pumped storage scheme is like a routine hydropower project, but the turbine is designed to operate also as a pump, and the generator is designed to operate as an electric motor. Such machines are called reversible machines.

Excess thermal energy during off-peak hours is used to run the turbine-generator combine in the reverse mode, and the water is pumped from storage at a lower level to one at higher level, thereby storing the energy. During peak hours the water pumped earlier to a height is released through the turbine to generate hydropower to generate energy. It may be reiterated that pumped storage schemes are not a primary source of electricity but only a way to the excess electricity in the grid, generated from other sources in off-peak hours, store for use in peak hours of demand.

4.6 Reduce Fuel Import Bills

Inadequate peak generation capacity results in load shedding during peak hours. The consumers protect themselves against such load shedding by use of captive diesel generator sets. The total capacity of such generation is presently estimated at 90,000 MW[6] which is about half of total installed capacity in the country. The diesel gen-set capacity is estimated to be growing at the rate of 5000–8000 MW per year. The diesel electricity is no doubt very expensive, at about Rs.14 per unit. This makes Indian services/products more expensive, and India loses out to foreign competitors. It also adds hugely to the nation’s fuel import bill. Development of hydropower can hugely reduce fuel import bills.

[6]http://indianexpress.com/article/india/india-others/gensets-add-up-to-under-half-of-installed-power-capacity/

5 Hydropower Potential in the Country

The HP potential of the country has been estimated at 148,701 MW. Table 3 indicates it in different river basins/river systems[7].

A watt (W) is a unit of *power*, i.e., the *rate* at which energy is produced or consumed. The energy is the rate of production or consumption, multiplied by time. 1000 W power produced or consumed over 1 h is identified as one unit of electricity. The potential of a source and also the planned installed capacity of a project are expressed in units of kilowatts (KW = 1000 W) or megawatts (MW = 1000,000 W), and are used to identify the rated capacity of the machines. However, when comparing the energy expected to be generated by a power plant, it is necessary to take into account the number of hours for which a plant is likely to generate during 1 year.

A 1 KW plant running 24 h a day for all 365 days will generate $1 \times 24 \times 365 = 8760$ units of energy in a year. In practice, however, a power plant doesn't run at full capacity for all the 8760 h in a year. There would be shutdowns for maintenance or there could be shortage of fuel, etc. The ratio of actual energy generated to theoretical maximum that can be generated is called plant load factor (PLF). Thermal power plants can be run at a very high PLF of 90%. Hydropower plants can also be run at a high PLF, but, as explained in the foregoing, these are usually deployed to supply peak demand, and their typical PLF is 60%, although like thermal plants it can be very high.

A solar panel can generate electricity at its rated capacity say only for 8 h, in a day, which is 33% of total time. Further, it doesn't generate 8 h a day around the year. During monsoons there is cloud cover, and the output of solar panels is much less than rated capacity. The typical PLF for a solar power plant is 15%, with a maximum of 20%. A 1 KW hydropower plant running at 60% PLF will generate $1 \times 24 \times 365 \times 0.6 = 5265$ units of energy. A solar plant of the same installed

Table 3 River basin-wise potential (MW)

	Total capacity	Capacity developed		Under construction		Balance potential as per present assessment	
Basin/river system	Total MW	MW	%	MW	%	MW	%
Indus	33,832	10,779.3	32.6	4581	13.9	17,667.7	53.5
Ganga	20,711	4987.2	24.6	1136	5.6	14,128.6	69.8
Central Indian Rivers	4152	3147.5	81.4	400	10.3	320.5	8.3
West Flowing Rivers	9430	5660.7	62.9	100	1.1	3236.3	36.0
East Flowing Rivers	14,511	7783.2	56.5	470	3.4	5521.9	40.1
Brahmaputra	66,065	1847.0	2.8	5565	8.5	57,988.0	88.7
Total	148,701	34,204.9	23.5	12,252	8.4	98,863.0	68.0

[7]http://www.india-wris.nrsc.gov.in/wrpinfo/index.php?title=Hydro_Electric_Projects

capacity will generate $1 \times 24 \times 365 \times 0.2 = 1752$ units of energy. What it means is, for the same installed capacity, the actual energy generated by the solar plant will be one third to one fourth of that generated by the hydropower plant. Alternatively, to generate the same quantum of energy, the installed capacity of the solar plant will have to be three to four times that of hydropower plant.

6 Arguments Against Hydropower

Immediately after independence, India took up construction of many large multipurpose river valley projects, many of which had a hydropower component. The HP capacity and also its share in the total energy mix increased from 34.86% during the first plan period to 45.68% during the third plan period[8]. However, starting from about 1985, a climate of hostility toward hydropower projects seems to have been carefully nurtured by interested parties. Meanwhile thermal power plants went ahead full steam. As such, the share of hydropower in the total energy mix fell to 18% in 2014. Table 4 shows installed capacity at the end of various plan periods[9]. The 3rd column of the table shows growth in % over the previous value. During 1956–1961 the hydropower capacity grew by 80%. By 1974–1979 the growth had slowed down to 55%, and by 1997–1902 it was only 21%.

Opposition to the 240 MW "Silent Valley" HP project in the state of Kerala was one of the earliest cases of organized protests against HP. The project was approved in 1978 and was finally abandoned in 1984, ostensibly to save rain-tree forests in the

Table 4 Growth of hydropower

Plan	Capacity MW	% growth
1951–1956	1061	
1956–1961	1917	80%
1961–1966	4124	
1966–1969	5907	
1969–1974	6966	
1974–1979	10,833	55%
1979-1980	11,384	
1980–1985	14,460	
1985–1990	18,307	
1990–1992	19,194	
1992–1997	21,658	
1997–1902	26,269	21%

[8]The Hydro Power Development in India – Challenges and Way Forward, M M Madan. http://inae.in/wp-content/themes/inae-theme/pdf/hydro_power_development.pdf

[9]http://www.eai.in/ref/ae/hyd/hyd.html

submergence. Notwithstanding the name of the river – SILENT – it was said that the protests made a lot of noise and were successful. Nobody seems to have assessed how far the forests were conserved. The 1980s saw emergence of organized protests against the 1000 MW Tehri Project on Bhagirathi River and 1450 MW Sardar Sarovar Project on Narmada River, supposedly to avoid displacement and submergence. PILs were filed against both these projects, and the work remained suspended for several years. Amidst development of the best ever R&R packages, both the projects made halting progress. Objections against both projects were rejected finally by the Supreme Court, but the opponents of HP had "tasted blood," and from then onward practically every project has faced organized opposition and PILs. Now there are activist groups and individuals for whom protesting against any and every hydropower project is a full-time activity.

Initially the target of such opposition used to be multipurpose dams that store waters used for HP generation. But presently, the run-of-the-river schemes are also targeted. Some of the popular arguments aired by opponents of hydropower are now dealt with. These arguments can be divided into two groups. The first group comprises arguments that are, to some extent, reasoned, but their demerits have been exaggerated and merits discounted. The second group largely comprises myths, and/or convoluted/invented arguments.

6.1 Relatively Reasoned Arguments

The water storage for HP projects causes (i) submergence of land; some of which could be forest land; (ii) displacement of people living on these lands; (iii) a discontinuity in the river flow adversely affecting aquatic ecology in such discontinuities; (iv) prevention of certain migratory species of fish from crossing a dam; (v) an interception of the flow of sediment/nutrients in the river from upstream to downstream; (vi) limited service life of reservoir because of sedimentation; and (vii) a risk of flooding in downstream due to release of a very large volume of water from the reservoir, and in rare instances, due to dam break.

Here, one must try to understand the psyche of opponents of HP. It flows mainly from opposition to dams/high dams, which have been main instruments for HP generation world-over. Very good work has been done by ICOLD, IHA, ICID, and other global professional organizations led mainly by developing countries to counter the opposition to dams, during the last three to four decades. The "World Commission on Dams" was the last unsuccessful attempt by opponents. Fortunately, it was thwarted successfully.

6.1.1 Submergence

It is necessary to project this issue in proper perspective. Any infrastructure development project whether a dam, a road, or a building, whatever, calls for acquisition

Table 5 Submergence in Narmada project

Project	Area (Ha)
Bargi	26,800
Indira Sagar	91,348
Omkareshwar	9336
Maheshwar	4856
Sardar Sarovar	37,690
Total	170,030 Ha

of land along with the biomass grown on it, for the structure itself, the ancillary works, the quarries, and facilities. Yes, for a dam some concentrated areas are submerged and/or its nearby land use undergoes change due to a project. But it has always some compensatory trade-offs. One must realize that the submerged area constitutes a small fraction of the total area of the basin, whereas the benefitted area is several times larger. Also the benefit-cost analysis most of the times shows that B/C ratio is significantly high.

It is well known that a lot of noise was made about submergence in the Narmada Basin projects. Table 5 shows the area submerged by the five main projects in the basin. The total submerged area is 170,030 Ha, or 1700 km^2. The catchment area of Narmada Basin is 98,796 km^2. Thus, the area submerged by the five manmade lakes on mainstream Narmada is just 1.7% of the catchment area. For this, these projects provide 3470 MW of hydropower while irrigating 13 times larger 22 lakh Ha of land. As far as submergence/acquisition of forest is concerned, well laid out procedures have been developed/adopted to replace them with appropriate mix of plantations, located either in the project area or elsewhere as needed. Test-tube forestry also is now deployed to replace a specific variety of biomass going under submergence.

6.1.2 Displacement

The perception that only the dams displace people and also the perception that those displaced are happily settled people in their homesteads, are both incorrect. With continued unabated population rise and repeated subdivisions of land with each generation, the agriculture in plains has already reached the limit of supporting livelihoods per hectare of agricultural land, and a large number of rural populations are migrating to the city in search of livelihood opportunities in manufacturing and in services sector. This too is displacement, forced by lack of development. Entire villages have been displaced for protection of tiger core area in various sanctuaries. But no NGO has ever come forward to speak for these other displaced people, no PILs have been filed, and no stay orders sought.

Commenting on the displacement of tribal people in the PIL filed by the Narmada Bachao Andolan against Sardar Sarovar dam, the Honb'le Supreme Court in their judgment of 18-10-2002 noted that:

> The tribal who are affected are in indigent circumstances and who have been deprived of modern fruits of development such as tap water, education, road, electricity, convenient medical facilities etc. The majority of the project affected families are involved in rain-fed agriculture activities for their own sustenance. There is partial employment in forestry sector. Since the area is hilly with difficult terrain, they are wholly dependent on vagaries of monsoon and normally only a single crop is raised by them.

When people shift to cities in search of livelihoods, displaced by circumstances, it is without an organized support system for the displaced family. There is no rehab package, no house ready for occupying, no policy to provide any employment, and no transfer allowance, nothing. The rehab package for those displaced for wildlife protection is inferior to the rehab package for those displaced for construction of dams. The rehab package for those displaced due to construction of a dam has evolved and adopted after decades of analysis, and its content is such that the displaced people are invariably better off than what they were before displacement.

6.2 Myths About HP

The rest of the objections against dams or hydropower mostly arise out of ignorance.

6.2.1 Reservoir-Induced Seismicity (RIS)

This phenomenon has been variously described in publications as reservoir-associated seismicity (RAS) or reservoir-triggered seismicity (RTS). Large reservoirs created by construction of dams have been attributed through more than half a century to have triggered earthquakes. However, the fact is, there is no instance of a large tectonic earthquake that has been conclusively proved to have been caused by a reservoir. Here is what the Seismology Research Center[10] says about RIS.

> Reservoir induced seismicity is a transitory phenomenon which will occur either immediately after filling of the reservoir, or after a delay of few years. If there is a delay, this depends on the permeability of the rock beneath the reservoir. Once stress and pore pressure fields have stabilized at new values, reservoir induced seismicity will cease. Earthquake hazard will then revert to similar levels that would have existed if the reservoir had not been filled.

Nevertheless, people citing this objection do not appreciate that such local seismic potential never exceeds the native proneness to tectonic earthquake events for which the dam structure is designed.

---

[10] http://www.src.com.au/earthquakes/seismology-101/dams-earthquakes/

6.2.2 Dams Cause Floods

On the contrary, dams constitute the most reliable and long-proven flood control measure adopted by the world over. Upon receiving a flood forecast, a filled reservoir can be appropriately emptied by releasing the stored water over a period of time, to absorb the incoming flood and reduce flood intensity in the downstream area. Starting with Damodar Valley dams, thousands of dams constructed during the past 60 years provided ample proof of improved flood management due to construction of large dams.

6.2.3 Sedimentation Limits Reservoir Life

The argument that a reservoir has a limited "life" because the sediment accumulating in the reservoir will one day completely fill it up with sediment is theoretical. The time (number of years) it takes to fill the reservoir with sediment so as to impair hydropower generation is called its service life. Projects are planned to maximize the service life by (i) soil conservation measures in the catchment area to reduce the generating of sediment, (ii) by providing outlets to flush the sediment downstream, and (iii) by judicious operation of reservoirs to maximize flushing. As a result of all these measures, the service life is very long, typically in excess of 100 years. For example, Bhakra reservoir has a gross storage capacity of 9340 million cubic meters (MCM). The average sedimentation rate over a 32-year data has been estimated as 20.84 MCM by hydrographic surveys[11]. Thus, it will take 448 years for the Bhakra lake to get filled with silt. This takes the probable date of silting up well beyond the upper limit of planning. No human endeavor indeed is planned to last that long.

6.2.4 Dam Break Flood

Due to acts of commission and/or omission, accidents can result in a breach of dam. The argument is that such failure can release a huge flood wave in downstream area that can damage life and property. Every human endeavor has a risk of failure. Ships sink, aircrafts crash, and even the space shuttle, designed and engineered with a care unparalleled in other spheres of scientific work, can (and did) explode mid-flight; trains collide, buildings collapse, patients die on operation table, etc. The risk of failure is inherent to any human activity. It is more so when it is used to manage highly varying natural resources like water, land, and biomass. A fail-proof structure is itself a myth. The correct question to ask is – what is the probability of a dam break? And the answer is, for a well-engineered structure, it is very, very low. Dams are designed and built with adequate safety factors.

---

[11]SK Jain, Pratap Singh and SM Seth in Journal of Hydrologic Sciences, April 2002 http://hydrologie.org/hsj/470/hysj_47_02_0203.pdf

To grasp the risk of dam failure and fatalities, compare the accident statistics of dams and civil aviation. During the 15-year period from 2000 to 2014, there were 16 dam failures where fatalities occurred, and the total number of deaths was 653 (source: Wikipedia). In the same period, there were 218 air crashes with 7045 deaths[12]. Still, good engineering calls for a Disaster Management Plan, comprising an emergency action plan to be in place, before commissioning a dam.

6.2.5 Submergence of Archeological and Other Heritage Sites

The case for a hydropower project is too strong to negate because some ancient archeological heritage site is likely to be submerged/displaced by/due to a reservoir. It is always possible to shift such a heritage to a suitable location for preserving it for posterity. There are scores of instances where it has been achieved. The best instance is that of Aswan high dam on the Nile which had threatened the temple of Isis at Philae, dating back to 380 to 362 BC. The entire temple complex was dismantled piece by piece and reassembled/rebuilt at the river of Nile in the Island of Agilkia, situated on a higher ground some 500 m away.

6.2.6 We Worship Our Rivers, So Don't Spoil Them; Don't Silence Them

This is again just a specious argument. A question that is never answered is: Really do we worship our rivers? If we really did, we would not throw all the filth in the rivers and reduce them to stinking drains. In any case, construction of a dam for a HP project in no way insults the river, which is meant for the human welfare.

6.2.7 Environmental Flow

The argument is dams reduce the flow downstream, affecting aquatic ecology. The environmental flows debate is too complex to be addressed in this paper. Very briefly, hydropower does not consume water. After driving the turbines, the water is released back in the river. It is the consumptive use of water, mostly for irrigation and some for domestic use, industry, etc. that reduces the flow in the river. And there is absolutely no way to grow enough food for India's population, without using the water for irrigation. Whether this is water diverted from the river, or it is rainwater captured before it even reaches the river, or ground water, the net impact on the river is the same.

[12]http://www.airfleets.net/crash/stat_year.htm

7 Then, What Really Ails the HP Sector?

Despite all its advantages and importance, the hydropower generation is neglected and seems to be losing the battle to the sector's opponents. There are some very strong reasons for this situation, and this last section attempts their analysis to correct the balance in the narrative, once more. The issue is simple. On HP, the government seems to have lost the plot, story, and thread; government functionaries seem not sure about what to do and are seen floundering around. The following cases provide some pointers to the prevailing confusion.

First and foremost, a complete lack of clarity and resolve pervades governance. The hydropower sector is a part of the government's proclaimed energy mix. At national level, the government projects a potential of 148,701 MW for hydro installation; in Arunachal Pradesh even strategic reasons are cited for setting up infrastructure; the government sets up several PSUs for development of HP potential and invites the private sector to participate. However it is difficult to identify one major decision in the past two decades for enabling hydropower installation. On the contrary, to satisfy a motley crowd of activists in environmental and social sectors, new rules, regulations, and procedures are introduced frequently to make construction of HP projects increasingly difficult. The government obviously needs to firm up its mind about trade-offs in securing HP generation.

At present it seems the three concerned Union Ministries, of Power (MoP), Water Resources (MoWR), and the Environment and Forests (MoEF) don't see eye to eye on developing hydropower. The following examples are eye openers, if necessary.

7.1 Dibang Project

In 2008, the then Prime Minister Man Mohan Singh laid the foundation stone of the 3000 MW Dibang project in Arunachal Pradesh. Five years later in 2013, the MoEF rejected the project application for environmental clearance (EC). The project promoter (NHPC) resubmitted the application in 2014, which was granted in June 2015. It was however challenged in the National Green Tribunal (NGT) by the activists in July 2015. The NGT raised a procedural issue whether – while granting the EC the provisions of a MoEF order of 28.5.2013[13] were or were not complied. For the past 1 year, the MoEF has not been able to say before the NGT whether or not the order of 28.5.2013 is complied. Eight years after the foundation stone-laying ceremony, nobody seems sure whether the project will at all proceed or will be rejected.

[13] http://www.moef.nic.in/sites/default/files/om_ia_120813.pdf

7.2 HP in Uttarakhand

On August 13, 2013, the Hon'ble Supreme Court *suo moto* took note of voices raised by the activists and the media that the hydel projects in Uttarakhand had aggravated the damage caused by the very high floods in June 2013, and ordered stoppage of work on 24 ongoing projects, directing the MoEF to constitute an expert body (EB) to review the problems and submit a report in two months. MoEF took 2 months to constitute the so-desired expert body. But instead of experts, the EB (chair and members) was packed with the same environmental activists who had publicly opposed these projects. The EB members from CWC and CEA projected severe differences with these activists in the EB. They then resigned from the EB and submitted their independent report.

The developments thereafter are unclear. For a while, it appeared that MoEF was not inclined to clear the projects, though MoWR remained either neutral or willing. Then the scenario got inverted. Now the MoWR seemingly is opposing the projects, while MoEF is inclined to allow at least six of them to proceed. As of October 2018, it is not clear whether the MoP has taken any stand on these issues, and if so, what. During the hearing before the Supreme Court in April 2016, the internal differences within the Government were brought out by the advocate representing the activists. Faced with this situation, different ministries saying different things, the Supreme Court directed that there must be a unified stand (of the GoI) on the issue and all (related) Ministries must file their affidavits to make their stand clear. The situation looks obviously ridiculous.

7.3 E Flows

In 2016, the MoWR constituted a committee to take a view on how much E-flow is necessary in the rivers, even though deciding it was in the domain of MoEF. The MoWR had thereafter issued stipulations for EF, including what they called "maintenance of the latitudinal and longitudinal connectivity," which remains undefined. MoWR has also issued formal orders that no dam or barrage be designed unless their directions on EF are complied with.

7.4 Usual Debate: Surface Water Versus Ground Water

About a year back, the MoWR had appointed a committee to study and advice it on restructuring of its own apex organizations, CWC and CGWB. Ostensibly, it was considered necessary as the structure of these organizations was not relevant enough to the changed context of the water sector. But the committee meant to advice on administrative restructuring of the organizations took upon itself to advice the

MoWR on reforming the water sector. Despite not having a single WR engineer as a member (the committee was packed with opponents of large WRD projects), the committee has submitted a report that effectively puts a stop to river infrastructure. While the committee thought they are addressing the water management issues, recommendations against river infrastructure will put a stop to HP also.

For the purpose of present discussion, the issue is not whether the projects in Arunachal or in Uttarakhand, or anywhere else, should or should not be implemented. The issue is the governance structure itself seems to be not sure what is needed. Different ministries say different things, and they say different things at different times. On river valley projects in general, and hydropower in particular, the government seems to have lost the plot, the story, and the thread altogether.

8 Conclusions

Finally, the question is what's next? Can the HP sector be revived? If yes, how? At present, (i) commissioning of new HP projects, (ii) installation of new generating units, or even (iii) starting an otherwise needed HP project seems impossible. The opponents are too many, not only from outside the government but from within also, and the outsider opponents (activists) seem to have made in-roads in the decision-making process, via various committees. The present laws/rules seem to be against HP development altogether. Friends of the sector are too few and do not have the support of the present governance structure. Therefore, in the "business-as-usual" scenario, any addition to the presently installed capacity of HP seems out of question. Table 3 indicated the HP potential in the country. The last column of the table showed balance potential waiting to be developed, as 98,863 MW. If one more column was to be added to this table, "realistic balance potential," then the entry in that column would be "nil," or "close to nil." If the hydropower sector is to be revived, the following actions are necessary from today rather than from tomorrow.

8.1 Lack of Policy Coherence

Decide Once for All, Whether Hydropower Is Required or Is Not Required The arguments against hydropower are all known. Details such as exact number of trees to be cut for a given project will become known only after the EIA is done. But surely it is known that any large hydropower project in Arunachal Pradesh or in Western Ghats will need cutting of tens of thousands of trees. If these impacts are not acceptable, then the GoI should boldly remove addition to HP from the country's future energy mix. If it is to be retained, then the GoI needs to take MoEF on board and reign in the activism; MoEF has laid down guidelines for Compensatory Afforestation. Insistence on following them should help clearance of project specific deforestation. The absurd situation where the government bases its energy projections based on 148,701 MW of HP and the legal support to environmental activism results in scraping HP project after project must be brought to an end by judicious governance.

8.2 Mainstream Integrity and Transparent Policies and Practices: Accept that Some Adverse Environmental Impacts Are Unavoidable

A position that hydropower project (or any large infrastructure) will be allowed only if it causes no harm to the environment needs to be discarded at the earliest. Any large infrastructure project necessarily causes a mix of some beneficial and some adverse impacts on the environment. The Environmental Impact Assessment (EIA) ought to comprise a study to assess both, the adverse impacts, and also the beneficial impacts. Only then can a balance be achieved. Secondly, the EIA must address a study of the status: (i) "before and after" the project fructifies and also (ii) scenario of "with and without" the project. It is well-known that social/environmental cost of not doing a project in a developing country or one with emerging economy, is more than that of doing it. Secondly, the BC ratio must account for balance of +ve and -ve impacts, failing which India will either continue to remain condemned to be an energy deficit nation, or miserably fail on their commitment to reducing GHG emissions, while also incurring huge fuel import bills.

8.3 Compare Environmental Impacts of Alternatives

This is the single most important requirement that will go a long way in correct evaluation of HP status. The present environmental thinking compares the benefits of a project with environmental impacts. This is not correct, as it ignores the consequences of not approving the project. The question "whether to allow cutting of say 324,000 trees for a 3000 MW capacity power plant?" (as in case of Dibang project) may invariably get the answer "no" because 324,000 trees are a physical object, and cutting them results in a visible loss, whereas 3000 MW of power is an abstract, intangible, and sacrificing it does not result in a visible loss. What is not appreciated is, if the said HP project is scrapped, the nation is not likely to scale down its installed capacity needs by 3000 MW. The energy demand projections remain the same, and the reduction of 3000 MW from HP sector will have to be made good by, very likely, thermal sector. Once this is appreciated, the question becomes different. "To generate 3000 MW power (say at 80% PLF), whether to allow 1-time cutting of 324,000 trees, or to allow 15 million T of GHG emissions every year, forever" (GHG emissions assumed at 0.71 Kg/KWh.). Put thus, the one-time cutting of 324,000 trees seems more acceptable compared to perpetual emission of 15 million T of GHG every year. But deforestation can and should be certainly replaced by compensatory afforestation at another needy site.

Pointing out the replacement source of energy if the project is not approved, and evaluating its environmental impacts too, ought to be made obligatory in the EIA of not only hydro but all electricity projects, so that the decision leads to the option with least "environmental costs."

Equity in Environmental Impacts If a HP project in Arunachal Pradesh or in Western Ghats is rejected to save the environment in Arunachal/Western Ghats and is replaced by thermal generation in – say – Vidarbha region of Maharashtra, then it amounts to taking away a significant quantity of water from the farmers of Vidarbha and subjecting those people to increased atmospheric pollution. How does one justify subjecting the people at one place to death from Asthma or COPD (Chronic Obstructive Pulmonary Disease), or to water scarcity, so as to enable people at another place to retain their forests?

8.4 Legislative Changes

The present situation where any citizen can file a PIL against any project, at any time, also needs to be addressed. Such consideration is necessary not only for HP sector but is required for all infrastructure projects. While retaining the rights of the citizens to judicial review, limitations have to be defined to such a right. PIL against a development project should be permitted only in the most pressing circumstances, and not as a matter of routine, and that too when sufficient evidence exists to question the project. The following restrictions may be considered:

- MoEF should evolve norms of acceptable environmental costs per MW.
- PIL against the project should be admitted only if these norms are exceeded, or, if there is *Prima-facie* evidence of any other environmental costs.
- If a project is challenged on the grounds that it will cause certain environmental damage, the legal system presently puts the onus on the project promoter to prove that it will not cause the said damage. This enables PILs to be filed merely on a doubt that a certain damage may take place. Instead, the burden of proof should be on the petitioner to prove that the alleged damage will take place.
- If a PIL is admitted, the court must conduct a quick preliminary hearing to determine whether the objections raised and if sustained would call for scrapping the project or only a remedial action. If remedial action is sufficient, then no stay order to stop the work should be allowed. Stay order should be allowed only if scrapping the project seems imminent.
- A PIL infringes on the right of public at large, to obtain the benefits of the project. Presently the PIL is a zero-cost game. This must change. If the petition is found to be frivolous and unfounded, then exemplary costs should be imposed on the petitioner.

- The time limit for filing a PIL needs to be reduced to about 6 months after the public hearing. The mandatory public hearing places in public domain the DPR, the EIA, and all other information required for filing the PIL. Therefore, there is no need for a prospective petitioner to wait till the EC is accorded. As soon as the public hearing is held, the prospective petitioner may scrutinize the records and file the PIL, if so deemed fit. After 6 months from the date of public hearing, no PIL be entertained.
- All PILs against infrastructure are to be heard and decided by fast-track courts.

Indeed, there is no reason why HP sector in the energy-development nexus should not be revived. Actions on the aforesaid conclusions hopefully will bring back the developments in the energy sector to an even keel, so that India regains its capacity to march ahead with confidence.

Chetan Pandit graduated in civil engineering from Indian Institute of Technology, Delhi and then obtained M.Tech. in Hydrology from Galway, Ireland. He joined “Central Water Engineering Services” and worked for over 35 years in the Central Water Commission and other organizations under Government of India. His significant assignments include Member-Secretary, Upper Yamuna River Board; Chief Engineer, National Water Academy; and Executive Member, Narmada Control Authority. He is a former Member (WP&P) of CWC.

His core interests are hydrology and flood forecasting. However, he is known more for his contribution to policy analysis, on which he has authored many papers and is also a regular speaker in seminars and conferences, in India and abroad. He continues as visiting faculty at NWA. Presently he is working as a consultant to the government of Goa for Mahadayi River Dispute and is also a member of the Ministry of Environment and Forest Expert Appraisal Committee for River Valley and Hydro Power Projects.

C. D. Thatte 82, obtained his PhD in civil engineering (hydraulic modelling) from MSU, Baroda, starting as BE civil, Pune University (1956). He is a former Chairman CWC; Secretary Ministry of Water Resources, Government of India; and Secretary General International Commission on Irrigation and Drainage. In recent past, he worked as (1) a member of the Planning Commission Working Group on Irrigation; (2) a member of Working Group on India’s Water Resources for 11th plan; (3) chairman of Research Council of CWRDM, Calicut, for Government of Kerala; (4) chairman of the QuinQuennial Review Team for the WTC (ICAR Eastern Region); (5) RBA formation for Maharashtra Krishna Basin and Restructuring Maharashtra’s WR institutes; (6) chairman of ICOLD’s Committee, Dams and Water Transfer; (7) member secretary of the Task Force on Interlinking of Rivers, (8) chairman of several central-/state-level committees in WR/dam safety field; (9) SC Empowered Committee on safety of Mullaiperiyar Dam (Tamil Nadu-Kerala); and (10) DS of Lower Subansiri Project. He has also served as GoI expert advisor for Indus basin problems with Pakistan. Presently he guides conferences, symposia and training programmes related with IWRDM in the country, in particular of NWA and CWPRS. He is active in the international field and participates and shares his experiences in events round the world. During the last 14 years since retirement from ICID, he has contributed by way of papers, talks and participation in panels on policy subjects like international waters, sustainable development, Country Policy Support Programme, IWRM, water and energy, water and food, water and dams, dam safety, etc. Recently, he extensively commented on Western Ghats Ecology Experts Panel Report improving it significantly. He has authored more than 140 papers/articles/reviews, etc.

Resilience Building in Flood-Prone Areas: From Flood Protection to Flood Management

N. Choudhury

1 Introduction

Floods are a recurrent natural phenomenon in India. In 1980, the *Rashtriya Barh Ayog* estimated that around 40 million hectares in the country was prone to floods. In recent years, the estimate has been revised upwards to 50 million hectares (GoI 2011: 18). Floods have an adverse impact on the life and livelihoods of the riparian population. Between 1953 and 2011, there is not a single year when the country has not recorded damages from floods. Floods in India are an annual phenomenon. On an average (median), around 6.7 million hectares would be affected by floods every year, and the (median) loss due to floods is around Rs 15 billion (i.e. Rs 24 billion at 1993–1994 prices). The brunt of the floods is disproportionately more in the rural areas. This can be gauged from tracing out the impact of floods on agriculture—the lifeline in the rural areas. During 1953–2011, the cropped area affected by floods annually would be around 50% of the total affected area. During the same period, annual crop loss would be as high as 52% of the total losses emanating from flood (Figs. 1 and 2). Apart from the loss of crop and property, floods would also result in human and cattle mortality every year. This would be around 62,400 and 1,430, respectively, every year (CWC 2013a).

Since the first 5-year plan period, the government of India has undertaken various structural interventions towards flood control. Between 1953 and 2010, on an average every year, the damage from flood (at 2010–2011 prices) would hover around Rs 69 billion (GoI 2011: 170). But while the expenditure on flood control has increased over the years, so has the total loss resulting from floods (Fig. 3).[1] This

[1]Ideally one expects a negative relationship between expenditure on flood protection and damage from floods, as the flood protection mechanism is expected to reduce the flood damage. However, in India the correlation between the two is strongly positive (r = .56).

N. Choudhury (✉)
School of Habitat Studies, Tata Institute of Social Sciences, Mumbai, India

© Springer Nature Singapore Pte Ltd. 2019

A. Singh et al. (eds.), *Water Governance: Challenges and Prospects*, Springer Water,
https://doi.org/10.1007/978-981-13-2700-1_13

Fig. 1 Damage to crops from floods

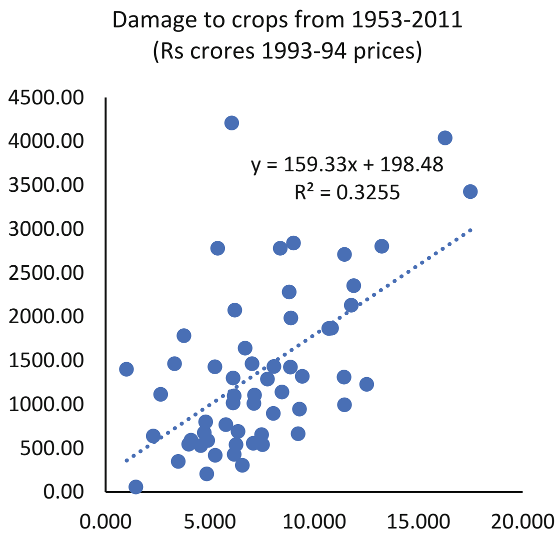
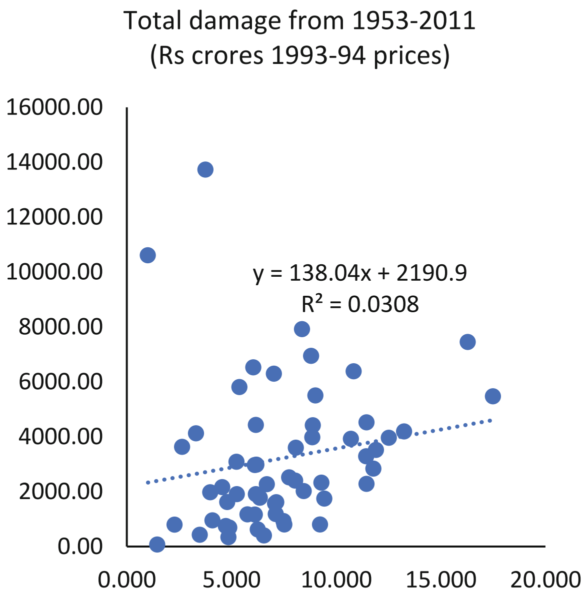


Fig. 2 Total damage from floods



indicates that increased expenditure on flood control could not reduce the losses emanating out of the disaster. Between 1953 and 2011, the total losses from floods was around Rs 1,830 billion (at 1993–1994 prices) (CWC 2013b), while the total expenditure towards flood control was around Rs 323 billion (at market prices) (Planning Commission 2013: 181). The 12th 5-year plan articulates the need for a "paradigm shift" from engineering centric structural intervention to

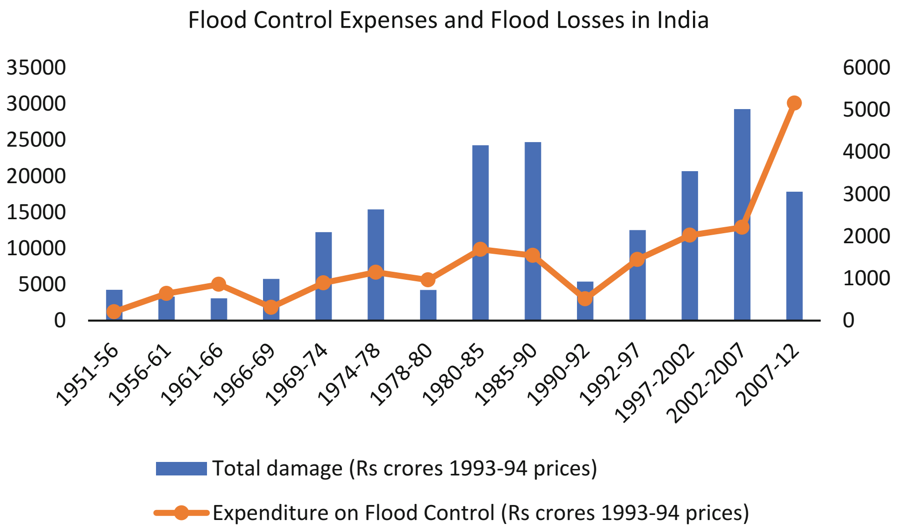


Fig. 3 Flood control expenses and flood losses in India

multidisciplinary, participation-oriented "non-structural mechanisms for flood management" (Planning Commission 2013: 145).

Based on an analysis of two clusters of villages located on the floodplains of Brahmaputra and Barak River, this article argues that the discourse around flood protection needs to be shifted to flood governance. Under flood governance, the focus should be towards building resilience among the riverine populations, who face multiple water hazards such as fluvial floods, pluvial floods, flash floods and river bank erosion (WMO 2017). A cluster of interventions—structural and nonstructural—needs to be undertaken with the aim to build resilience among the riverine population. Here the community—the households residing in the floodplains and their life and livelihoods—would be the focus of interventions. The article further argues that resilience building could take place through multiple sets of interventions, which analytically could be clustered under the following broad goals: (1) reducing vulnerability, (2) enhancing access to various developmental services, and (3) maximizing productivity.

2 Methodology and Description of the Study Area

The study focuses on two clusters of villages in Assam, one of the four chronically flood-prone states in the country (GoI 1981). The first cluster is located in the Dhemaji district in upper Assam, and the second cluster is located in Cachar district in Barak Valley of Assam. The cluster of villages was purposively chosen with the help of key informants.[2] The criteria for choosing a cluster was that the same is subjected to flood and related hazards (like waterlogging and river bank erosion) on a recurrent basis. A concurrent mix method approach (Creswell 2009) was followed for this study. The author visited each of the villages in the cluster and undertook a focus group discussion (FGD) at the village level. A structured set of questions was prepared in advance to guide the interaction. The questions were pertaining to the type of hazards and the frequency, duration and effect on the life and livelihood of the riverine population. The FGDs also aimed to brainstorm on the kind of resources at various levels (individual, household, village/community and macro level) that would make them more resilient to flood hazards. The primary, mostly qualitative data was simultaneously triangulated through an analysis of the village-level data collected from the Census 2011 dataset.

The Dhemaji cluster is dominated by the tribal (*Mishing*) population, whereas the Cachar cluster (alternatively referred to as Barak cluster) is dominated by scheduled caste Bengali-speaking Hindus (*Kaibarta* and *Namasudra* caste). The villages in the Dhemaji cluster are located beside the two rivers, R. Lali and R. Boro Suti, tributaries of the R. Siang. The villages in the Cachar cluster are located inside a *haor*. *Haors* are low-lying lands located in the floodplains, usually beside a large river, which also act as a retention basin, with a recurrent inundation period of 6–7 months in a year.

3 Nature of Water Hazards

In both the clusters, the larger rivers, R. Lali (a tributary of R. Siang) in Dhemaji and R. Surma (a distributary of Barak), have embankments. The habitations located inside the embankments face the brunt of bank erosion and floods. In villages located outside the embankment in the Dhemaji cluster, the floods take place due to the backflow of the R. Lali into the R. Boro Suti (which is connected to R. Lali). Some areas suffer from flash floods resulting from the small channels that come down from the neighbouring hills of Arunachal Pradesh. Apart from this, those villages that are inside the embankment are also exposed to river bank erosion. For villages in the Cachar cluster, flooding is largely due to the lack of drainage, given the bowl-shaped topography of the area. The *haor* is adjoining to R. Surma. Two rivers (R. Larang/ Kankra Khal and R. Harang), which originate from the North Cachar hills, flow through the *haor* and fall into R. Surma. There are regulators close to their confluence, but these regulators are either dysfunctional or are operated in an ad hoc manner. As a result, the backflow of R. Surma, when the river is in spate, and/or

[2]The civil society organizations, Centre for Microfinance and Livelihoods in Guwahati and Deshbandhu Club in Cachar, have been actively working in Dhemaji and Cachar, respectively. They helped the author to identify the village cluster.

sudden rainfall in the North Cachar hills flood the *haor* region. In both the clusters, there would be multiple bouts of flooding within a season. The season would run from May till October.

4 Physiography and Demography of the Clusters

The Dhemaji cluster consists of 12 villages located in the eastern part of the Dhemaji district (details in Table 1).

The district lies between three big rivers: Siang (in the east), Subansiri (in the west) and Brahmaputra (in the south). Apart from these, numerous rivers run through the district from north to south. As a result, the district is extremely flood-prone and the life and livelihoods of the people inhabiting these areas are affected every year. The cluster is located in the Janai subdivision and Murkongselek block of the Dhemaji district. The cluster is a set of 12 contiguous villages located close to R. Lali, a tributary of R. Siang. Another river, Boro Suti, also passes through the village cluster. The villages are dominated by the Mishing people, and the villages come under the governance of the Mishing Autonomous Council. As per Census 2011, around 79% of the population belong to the Scheduled Tribe (Mishing) community.

The remoteness of the villages can be gauged from the fact that, on an average, the distance between the villages and the nearest town is around 56 km. The roads connecting the villages are in dismal state. As in most parts of the flood-prone areas in Bihar, Uttar Pradesh, Bengal and Assam, the embankment becomes the road, and sometimes the road acts as an embankment. As a result, the condition of either (road/embankment) is poor, which then escalates the vulnerability of the people who are located just outside the embankment/road. On certain stretches, the road/embankment is not amenable even for a two-wheeler. As witnessed in most of the flood-

Table 1 List of villages for the Dhemaji and Cachar cluster

Cachar cluster	Dhemaji cluster
Khelma Part I	Ngabang Gamsuk
Khelma Part II	No.1 Gali Ghat
Khelma Part III	No.2 Gali Ghat
Khelma Part IV	Naharbijuli
Khelma Part V	Jiadhal Galighat-Lakhi Pathar Asomiya
Khelma Part VI	Mudai
Khelma Part VII	Debera Chapori
Saidpur Part I	Charaibari Kampung
Salimabad	Galighat Machkhuwa
Chandinagar Part III	Bhalukaguri-Haripur Deori
Chandinagar Part IV	Nalani Pam
Chandinagar Part VI	Kerker

prone areas in the Ganga-Brahmaputra-Barak basin, the biggest communication bottleneck arises from the dearth of roads that connect the village to the nearest motorable highway. Given that rivers crisscross the area, boats often become the most reliable, yet grossly inadequate, mode of transportation.

Few villages within the Dhemaji cluster are affected by flood and erosion because there are certain stretches where there is no embankment or there is a breach in the embankment or the embankment regulator is dysfunctional. It could also be because the village is located between the embankment and the river. These villages face bank erosion and there is always a looming threat of flood. The remoteness of the location coupled with the enhanced vulnerability from flooding and erosion has resulted in outmigration in the village clusters. As a result, the villages have a much smaller population compared to a usual Assam village.

As per Census 2011, on an average, there are around 45 households in a village within the cluster.[3] The population density hovers around 291 person per sq km of land, which is much less than the Assam average of 397 person per sq km. During our fieldwork in these villages, we came to know that people have migrated semi-permanently to the nearby sand bars, locally referred to as *char*/*chapori* (Munmuni *Chapori* in this particular case). Here, they have constructed temporary houses and have collectively divided the land to practise agriculture. This migration—akin to the concept of “environmental refugee”—has thrown a dual challenge. First, the nature of the *char* is changing from being *common* grazing land to *private* habitation land. Second, this change in the nature of land from de jure common to de facto private is becoming a source of conflict between the inland villages and the riverine flood-prone and erosion-prone villages. While the flood-prone villages would like to have some tenurial security on the land where they have now resettled, the inland villages would like to ensure that the land continues to remain common grazing land where they can graze their livestock.

The Cachar cluster consists of 19 contiguous habitations spread over 12 revenue villages, 4 Gram Panchayats and 2 blocks (Kalain and Katigorah) in Cachar district (see Table 1). These villages are located on low-lying wetlands, *haor*, prone to frequent flooding and extended periods of waterlogging. The habitations mostly consist of Bengali Hindus who have migrated from Bangladesh (erstwhile East Pakistan). The migration has come in waves. The first wave of immigrants came in the early 1950s, the second wave came in the mid-1960s (post-Indo-Pak War) and the third in the early 1970s (Bangladesh independence). Over the years, some of the inhabitants got statutory ownership of land (*patta*), some got land in the area as a resettlement compensation from the government of Assam and some continue to live on the land, but they are yet to get a *patta*. In their colloquial parlance, the people in the area refer to the habitations as *colonies*. There is one village (Jabda) in the cluster, referred by the people as the original habitation, which predates the advent of the refugee population. More than 60% of the population consists of scheduled caste

[3]However the data from Census 2011 should be taken more as an indicative measure as we found anomalies between the Census data and our ground-truthing done in the village site.

Hindus, mostly from the *Kaibarta* and *Namasudra* community. The villages are large (around 338 households in a village) and densely populated. The average population density in these villages is of the order of 679 people per sq km (with high intervillage variation ranging from 1441 person per sq km to as low as 289 person per sq km).

5 Livelihoods and Floods

Agriculture is the most important livelihood in the cluster of villages in Dhemaji. According to Census 2011, around 92% of the working population, categorized as main workers, are engaged in cultivation, and around 1% are engaged in agriculture labour. Among the marginal workers (i.e. who work on a profession for less than 6 months a year), around 80% are engaged in agriculture. Around 73% of the marginal workers were female.

The single most important crop in the area is paddy. The paddy, locally referred to as boro paddy, is cultivated in the post-flood months from November to December till May to June. Despite the importance of the crop in the area, its production is not stable. This is because the crop remains vulnerable to early flooding, monsoon showers or hailstorms. The crop diversity in the cluster is low as intensification in the post-flood month is limited owing to limited irrigation coverage in the cluster.

The only other important livelihood activity in the Dhemaji cluster is weaving. This is a traditional occupation undertaken by the women in the Mishing villages. However, limited space for locating the weaving infrastructure on account of flooding in the flood months, traditional and inefficient technology, limited marketing facility and product diversity constrain their livelihood (Hamid 2018). Despite this Phansalkar et al. (2016) note that this is the first livelihood activity that the household takes up once the flood months are over. Women in every Mishing household engage in this activity.

In the Cachar cluster, the livelihood basket would comprise of capture fishery (during the flood months), paddy (post-flood months) and migration. Fisheries are the most important livelihood activity in the villages in the Cachar cluster. Around 14,000 hectares of land in the district (around 45% of the total waterbodies area in the district) is classified as low-lying flood-prone areas (Bhalerao et al. 2015). These low-lying bowl-shaped perennially waterlogged areas are locally referred to as *haor*. During the flood months, as the backwaters of river Barak and its smaller tributaries inundate the *haor*, the entire region resembles a large lake full of fishes that come into the *haor* along with the floodwater. As a result, capture fishery becomes the only possible livelihood option in the area. The social composition of the people living inside the *haor* area makes this activity akin to what the weaving is to the Mishing community in Dhemaji.

The dominant caste group in these villages belongs to the *Kaibarta* clan. This community (*Kaibarta*) is known to engage in capture fisheries as part of their caste occupation. A senior professional from the district fisheries department told this author that a *Kaibarta* kid grows up in water from their childhood. At the same time, few people in the village practise input-intensive culture fisheries. Even those (usually the resourceful in the village) who practise culture fisheries practise low input-intensive fisheries. Hence, the fish productivity is low in the district at around 0.8 tonnes/hectare.[4] The district currently experiences a 30% deficit in fish consumption, catered to by fish brought in from Andhra Pradesh, and 30% deficit in seed production.[5] While lack of quality seed, non-availability of fish feed and lack of awareness among the fishermen about scientific fish farming are seen as major reasons behind low uptake of culture fisheries and high uptake of capture fisheries,[6] the overall hazard environment, to a large extent, determines the choice of livelihood.

Borrowing Jodha et al.'s (2012) work on risk minimization and loss minimization, one can say that the livelihood practices pertaining to fisheries are akin to adaptation strategies undertaken by the villagers in the face of an increasingly uncertain and risky environment. The cause of risk is the advent of floods. The floodwater brings in fishes which can be captured and consumed or sold in nearby markets, thus providing nutrition and a steady, albeit low, income to the households, with very little investment (boat and net). At the same time, culture fishery is a risky proposition for the people. The ponds do not have high bunds and the floodwater tends to wash out the fishes from the *private* pond and put it inside the *common* floodwater. Once the fish moves out of the farm pond, the owner of the fish ponds cannot exclude the non-owners from harvesting the same. The flood changes the nature of the good (fish/fisheries) from private good to a common pool resource (Ostrom and Ostrom 2012).

The agriculture landscape in the cluster villages is dominated by monocrop boro paddy that is cultivated in the months of December to May. But given the lack of irrigation in the area, the yield of boro paddy remains low, at around 1.8 tonnes per hectare (Bhalerao et al. 2015). Importantly, the production is not stable, as the crop is vulnerable to the early showers and hailstorms that usually take place in the month of April to May. In 2016, the standing crop of paddy went to waste due to early showers in all the villages in the cluster. The area is so primitive in terms of irrigation that one still comes across manual irrigation methods like *Dhenkuli*, an ancient way of irrigating land (Plate 1). Lack of irrigation also constrains the extension of the cropping season and agriculture intensification. According to the Census 2011, around a quarter of cultivable land (585 hectares out of 1500 hectares) remains fallow.

According to the Census 2011, around 36% of the people are engaged in works, apart from agriculture or household industry. The percentage goes up to 56%, 62% and 66% in some of the villages within the cluster. Given the recurrent floods and hence limited on-site resources, migration becomes a coping strategy. Migration to

[4]Based on Bhalerao et al. (2015) and the production data shared by the district fisheries officer in Cachar.

[5]Based on the interview in the district fisheries office in Cachar.

[6]Based on the interview and document shared by the district fisheries office in Cachar.

Plate 1 Primitive manual irrigation method in Cachar, Assam

nearby states of Mizoram, Meghalaya and Arunachal Pradesh is rampant. Industrial mining and construction activities attract many young people to these areas. Some young people also migrate to far-off urban centres like Guwahati, Bangalore, Kerala and Chennai.

6 Education in Flood-Prone Areas

The literacy rate in the Dhemaji cluster is around 53%, and the female literacy rate hovers around 44%, worse than the state figures of 73% and 67%, respectively, and all-India average (at 74% and 65%, respectively). The low literacy rate in the area can be partially attributed to the natural hazards like floods and erosion and its impact. From middle school onwards, the average distance that a child has to travel to reach a school would be around 5 km or more. Given that the area is flood-prone, with dismal road infrastructure and insufficient boat infrastructure, access to school, even if it is 5 km away, becomes extremely difficult. During outfield research in the village cluster, the respondents—particularly women respondents—have highlighted the lack of adequate transport mechanism during the flood months.

Even if the student goes to the school, the mother suffers from angst, as the mode of travel—an overcrowded small boat—is dangerous.

Boats are the most important mode of transport during flood months. They are an important and scarce resource and are subject to multiple claims. The male in the family might want to take it to catch fish and earn a living for the family, while the female in the family would want it to be used to send the children to the school and for her to fetch water from distant sources that are not yet submerged. In such cases of multiple claims, as expected, the need to earn a livelihood gains more importance, and the boat is used to catch fish. The children either drop out or take a gingerly ride to the school on a hired boat that is small and overcrowded.

The general educational status in the Cachar cluster is worse than in other parts of Assam. The overall literacy rate (63%) and the female literacy rate (59%) in the cluster villages were worse than the state average (72% and 66%, respectively). Within the 16 habitations that comprise the cluster, there were 7 pre-primary schools, 12 primary schools, 7 middle schools, 2 secondary schools and 2 senior secondary schools. The nearest college is more than 10 kilometres away. However, the numbers of schools are not a reflection of important qualitative parameters like the access to schools, particularly in the flood season, and the quality of education. The approach roads in these villages have been elevated, and the houses have also been elevated through earth filling (as reported by a respondent, by using the resources of Indira Awaas Yojana), but the land on which the schools are located has not been elevated. As a result, some of the schools in the area are prone to periodic inundation, children find the approach to schools difficult and conducting classes gets affected.

In an earlier regional study on chronically flood-prone areas of Uttar Pradesh, Bihar, Bengal and Assam, the author has found that often access to schools, even if it is within a few kilometres, becomes extremely difficult due to the unavailability of roads, or as schools are submerged if located on lowlands, or because they have turned into temporary relief camps if located on uplands. In the last case, by the time the relief camp is closed, the school is in no shape for conducting classes due to unthinkable hygiene and sanitation issues. As a result, classes became infrequent, and often in some of the flood-prone areas, there seems to be a *flood vacation* (Phansalkar et al. 2016).

7 Drinking Water, Sanitation and Health Issues in the Study Area

The cluster of villages in Cachar suffers from water scarcity. It is ironical that the areas otherwise identified as water abundant also suffer from water scarcity. The scarcity has a quantity and quality dimension, along with a seasonality component. Some of the habitations within the Cachar cluster have piped water supply. According to Census 2011, around 39% of the households had access to tap water supply. This is much higher than the average of 7% in Assam and at the all-India level (31%).

Plate 2 People in the *haor* area dig holes in the ground to source drinking water in Cachar, Assam

Table 2 Sources for drinking water

Source type	Dhemaji cluster	Barak cluster	Assam	India
Tap water	0	39	7	31
Dug well	1	7	19	14
Handpump	49	3	53	44
Tube well/borehole	11	5	8	8
Surface water bodies	37	43	9	2
Other sources	1	2	3	2

Source: Indian Census (2011)

However, during fieldwork, this author found that due to lack of availability of diesel (most of the water supply schemes are river-lifts powered by diesel engine), proper operation, maintenance and repair of the pipe infrastructure and weak management institutions (water supply committees at village level), most of these schemes remain dysfunctional for most of the time. As a result, most of the households have to depend on surface water bodies like rivers, ponds or open wells for sourcing their drinking water (Plate 2). Census 2011 figures show that around 50% of the households within the village cluster depend on these surface sources for drinking water (see Table 2). Only 10% of the household have a drinking water source within their premises (see Table 3), a figure much lower than the Assam and India average (50% and 35%, respectively). These figures, though dismal, do not

Table 3 Location of the source of drinking water

	Dhemaji cluster	Barak cluster	Assam	India
Within premises	16	10	50	35
Near premises	48	69	29	43
Away from the premises	36	21	20	22

Source: Indian Census (2011)

Plate 3 Make shift toilets in the *haor* area in Cachar, Assam

provide insight on the dimension of seasonality. Being located with the *haor*, the habitations experience prolonged period of inundation. During this period, many of the handpumps and wells are subjected to submergence, and people have to depend on surface water bodies for their water.

In the Dhemaji cluster, around 37% of the households depend on surface water bodies, and some 49% depend on the handpump (Table 2). Iron contamination was an oft-cited problem reported by the villagers in this cluster. Only 16% of the households had the source of the water within the premises, and for more than a third of the household, water had to be sourced from outside the premises (Table 3). Like in most part of the country, this task would mostly be done by the women in the household.

The grave implication on public health emanating from drinking water practices becomes clear once the sanitation practices prevalent in the area is taken into consideration. Like in most of the recurrent/chronic flood-prone areas in Uttar Pradesh, Bihar and Assam (Phansalkar et al. 2016), the sanitation situation in the cluster of villages in Cachar is dismal. The usual practice is to construct a temporary sanitation structure made of bamboo and ragged cloths or practise open defecation (Plate 3). Sometimes this set of structures is located very close to the river (right on the river bank). The location choice is guided by easy access to water supply. Thus the river water, on which a substantial proportion of people depend for their drinking source, is prone to contamination.

According to Census 2011, around 35% of the households in the cluster have no sanitation facility, and around 35–40% of the people have these makeshift arrangements. The situation further deteriorates during floods, when the makeshift toilet arrangements are prone to submergence or collapse. Hence open defecation is widely practised in the area.[7] As far as sanitation facility is concerned, according to the Census 2011 figures, around 93% of the households in the Dhemaji cluster have no latrine facility within the premises. Around 90% of the household do not have any bathroom facility within their premises, and another 10% have some ragtag arrangement. Based on fieldwork,[8] this author's observation is broadly in line with the Census figures. In a larger regional study that span over Uttar Pradesh, Bihar, West Bengal and Assam, similar problems pertaining to drinking water and sanitation were observed[9] (Phansalkar et al. 2016).

The drinking water and sanitation practice together pose a significant public health challenge. The problem further intensifies when one realizes that due to the topography in the area, drainage is a big problem. According to Census 2011, around 70% of the households had no drainage, and the remaining 30% had open drainage. This lack of drainage results in stagnant water, and hence the shallow unconfined aquifers, from where drinking water is sourced, are prone to contamination.

While the public health challenge stares stark in this area, the health infrastructure is poor. According to the Census 2011, there are no community health centres, primary health centres, primary health subcentres and maternity and child welfare centres in any of the 12 villages in the Cachar cluster. On an average, a person has to travel 5–10 km to access these healthcare units. The nearest hospital is around 10 km away from a village in the cluster. The ICDS centres are present in 5 of the 12 villages, and each village has an Anganwadi centre and ASHA. There is no veterinary hospital in any of the villages in the cluster. On an average, the nearest veterinary hospital/paramedical staff would be 10 km away from the village. Given the poor status of road in these areas (Plate 4), access to essential services becomes extremely difficult in these areas.

In Dhemaji cluster, there is no community health centre (minimum distance that one needs to travel to reach a community health centre is more than 10 km), no primary health centre, no primary health subcentre and no maternity and child welfare centre (Census 2011). The nearest hospital is more than 10 km away. There is rampant livestock mortality during flood and post-flood months. But the cluster has no veterinary hospital, the nearest is more than 10 km away. There are ICDS centres in two (out of 12) villages, Anganwadi centre in nine villages and ASHA in two villages.

[7]The fieldwork was conducted in 2016–2017.

[8]The fieldwork was conducted in 2016 and 2017.

[9]In another study spanning over more than 100 flood-prone villages in UP, Bihar, West Bengal and Assam, it was found that conventional drinking water and sanitation facilities, even if constructed, did not take the flood/waterlogging into consideration, and hence they were prone to inundation during floods. The adverse effect of this mostly fell on the women (Phansalkar et al. 2016).

Plate 4 Approach Road to a village in Dhemaji, Assam

8 Resilience Building in Flood-Prone Areas

In the preceding sections, this article characterizes the drudgery that exists in the life of the flood-affected populations. One can gauge it at the macro level from the historical data on the annual losses from floods. A micro-level portrayal of the same can be seen in the two clusters of villages in two different regions of Assam. While the government has continued to spend on structural interventions for flood protection and one sees the remnants of the same in different parts of the recurrent or chronically flood-prone regions of the country, the story of misery from floods seems to have remained unchanged over the years.

In the two village clusters we studied, one comes across instances of river training and bank strengthening through reinforced concrete cement porcupines and embankments. But despite such interventions, the misery in the life and livelihoods of the people from flooding, waterlogging and bank erosion seems to continue. The usual flood protection solutions take more of a “flood-resistant” approach—floods are natural hazards, and the endeavour is to stop floods once and for all. If one follows this discourse, the structural interventions, like embankment construction, river training and dredging, bank strengthening and dam reservoirs, become the most important set of interventions.

But if history has taught us anything, it is this: despite this spending over the years, the miseries of the people residing in the densely populated flood-prone areas of Ganga-Brahmaputra-Barak basin have continued. It seems at the policy level, at least in the water sector, the country has reached a point of inflexion, where it has articulated the need to break away from the past. The 12th 5-year plan document had argued for a paradigm shift (Shah 2013).

In the context of flood management, the paradigm shift would take place if the discourse and the accompanying interventions move away from "flood protection" and move towards "flood governance through resilience building". The former sees flood as an extreme natural water event which needs to be *tamed* by training the river. Stopping floods through taming and training becomes an end in itself and structural interventions a mean to the end. The latter looks at flood as an extreme water event which is partly natural and partly anthropogenic. In this paradigm, floods can result from high-intensity precipitation or a cloud burst, but the intensity of the event is enhanced manifold through human interventions, like rampant deforestation in the upstream areas, blockage of drainage lines due to construction activities and lack of operation, maintenance and management of structures like embankments and regulators and sluice gates. The flood governance through resilience building is also anthropocentric to the extent that it keeps the life and livelihoods of the flood-prone riparian population at the foci of any interventions. The goal is to build resilience among the riparian population through a plethora of structural and nonstructural multisectoral interventions. A paradigmatic shift in the discourse of flood management requires something akin to a Flood-Prone Area Initiative where multiple departments work together with the overarching goal of improving the life and livelihoods of the riparian population through resilience building.

The analytical framework for operationalizing the new paradigm of flood governance through resilience building encompasses clustering of interventions under three interrelated broad categories: (1) reducing vulnerability, (2) enhancing access to services and (3) maximizing productivity.

9 Reducing Vulnerability

Vulnerability is defined as a combination of exposure to a natural hazard (like floods) and the fluctuation or disturbance or damage caused by the hazard (Cutter et al. 2008). A set of interventions that either reduces the exposure or the damage due to the advent of a hazard would reduce vulnerability and would contribute to resilience building. A plethora of interventions at various levels (individual, household, river and region) would contribute to vulnerability reduction among the flood-prone riverine population.

It is important to undertake Strategic Environmental Assessment of a plethora of "developmental" activities in upstream regions (like in Arunachal Pradesh and Sikkim) and in regions such as North West Bengal and Brahmaputra Valley in Assam. These "developmental" activities result in deforestation, enhance erosion, increase surface run-off, reduce infiltration and enhance the probability of flash floods in downstream areas. The Himalayan rivers carry a lot of sediments, and dredging, though extremely resource intensive, would result in the removal of sediment and enhance the channel capacity. Bank strengthening through RCC

Plate 5 RCC porcupines for bank strengthening on R. Lali

porcupines (Plate 5) might also be useful. At the village level, setting up of community-based advanced warning systems, as promoted in parts of Assam, would ensure timely evacuation and reduce the loss.

Promoting participatory embankment management would ensure that the embankments are better managed. Similarly, elevated platforms in villages with adequate drinking water and sanitation facility would have an enormous impact in terms of providing the people a safe and hygienic evacuation land. At the household level, provision of stilted house, as seen among the Mishing community in upper Assam, elevated handpump with iron filters and elevated toilets would reduce the loss in terms of health hazards emanating from otherwise poor water and sanitation situation in the flood-prone and flood-affected villages.

10 Enhancing Access to Services

One important constraint faced in the above cluster of villages and also in the larger flood-prone region of Uttar Pradesh, Bihar, West Bengal and Assam is the lack of access to government services. Because of the remoteness of the areas, access to government services remains difficult in the non-flood months and mostly remains absent in the flood months, apart from sporadic availability of relief. A change in the status quo can only be brought about through infrastructural development. Hence a critical intervention in the remote flood-prone areas would be construction, repair and maintenance of roads, bridges and culverts.

One of the most important resources in flood-prone areas is boats. As shared earlier, often they are inadequate compared to their demand. Large-scale provision of boats at the village and household level in flood-prone villages will enhance the mobility of the people and would link them to the development service of the state during and post-floods. Access to education and health services would experience a quantum fillip as a result of the same.

11 Maximizing Productivity

A social-ecological system is seen to be resilient if it has the capacity to absorb the impact of the stressor and can bounce back and continue to perform at the level at which it was performing before the stressor manifested. In cases where the autarkic situation is characterized by low level of performance, resilience would imply not just a bounce back but bouncing forward. The absorption and bouncing back capacity can be enhanced by maximizing productivity through optimal utilization of the available resource. Hence building resilience in the flood-prone areas would essentially mean access to resources and optimal utilization of the resources to maximize the income.

Here again a plethora of interventions are required to be undertaken. Much of the land in the flood-prone area remains fallow for a prolonged period of time because of waterlogging (Plate 6). While land is an asset, such waterlogged land becomes a liability. But if one could promote livelihood intervention in these waterlogged lands, the character of the resource can change again. Hence promotion of culture fisheries through deepening of such waterlogged land coupled with bunding up to a height such that the floodwater cannot enter would contribute to income enhancement. In some of the areas, paddy and fish combination could be explored. In some other areas, integrated agroforestry and livestock development (like fishery and duckery) could be explored. Similarly, in Assam, improved access to solar-powered or electric-powered irrigation could enhance agriculture intensification. In Assam, promotion of short duration boro paddy would have an immense impact on the food security among the riverine population.

Plate 6 Waterlogged lands result in land remaining fallow

12 Conclusion and Way Forward: Need for a Flood-Prone Area Initiative

The discourse pertaining to flood management needs to move from flood protection to flood governance through resilience building. As the previous section explains, resilience building can take place through a plethora of interventions—a mixture of structural and nonstructural—that aim towards reducing vulnerability, enhancing access to services and maximizing productivity. These interventions—when undertaken in an integrated fashion and in a sustained fashion—would ensure increased robustness, introduce redundancy, enhance resourcefulness and bring in an element of rapidity, the key four elements that contribute to resilience building in any system (Tierney and Bruneau 2007). But integrated action would also require integration across multiple government departments and participation of government and nongovernment actors. The riparian population, who are exposed to multiple hazards, also needs to be an active contributor, rather than being a passive recipient, in the resilience building process. Promotion of interventions like participatory embankment management could entail such government-nongovernment participation. It seems that flood management needs to be move out being a one-department program to being a multisectoral programme, undertaken on a mission mode. Something akin to a Flood-Prone Area Initiative programme is the need of the hour.

Acknowledgements The author acknowledges the generous support of the Tata Trusts for supporting the field research for this study. The author would also like to thank the Centre for Microfinance and Livelihoods, Guwahati, Assam, and Deshbandhu Club, Cachar, Assam, for facilitating the field research.

References

Bhalerao AK, Kumar B, Singha AK, Jat PC, Bordoloi R, Deka BC (2015) Cachar district inventory of Agriculture. ICAR-Agricultural Technology Application Research Institute, Umiam, Meghalaya, India

Cutter SL, Barnes L, Berry M, Burton C, Evans E, Tate E, Webb J (2008) A place-based model for understanding community resilience to natural disasters. Glob Environ Chang 18:598–606

Central Water Commission (2013a) Financial aspects of flood control. Anti-Sea Erosion and Drainage Projects. Financial Performance Unit, Information System Organization, Central Water Commission

Central Water Commission (2013b) Water and related statistics. Water Resource Information System Directorate Water Planning and Project Wing, Central Water Commission

Creswell JW (2009) Research design qualitative, quantitative, and mixed methods approaches. Sage, Los Angeles/London/New Delhi/Singapore

Govt of India (2011) Report of working group on flood management and region specific issues for XII plan. Planning Commission, New Delhi

Govt of India (1981) Report on development of chronically flood affected areas. National Committee on the Development of Backward Areas, Planning Commission, New Delhi

Hamid A (2018) Mising weavers intertwine technology with traditional skills, Village Square. Available at: https://www.villagesquare.in/2017/12/15/mising-weavers-intertwine-technology-traditional-skills/

Jodha NS, Singh NP, Bantilan MCS (2012) Enhancing farmers' adaptation to climate change in arid and semi-arid agriculture of India: evidences from indigenous practices. Working Paper Series no. 32. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh, India, p 28

Ostrom V, Ostrom E (2012) Public goods and public choices. Workshop in Political Theory and Policy Analysis, Indiana University. Available at: http://johannes.lecture.ub.ac.id/files/2012/02/Public-Goods-and-Public-Choices.pdf

Phansalkar S, Choudhury N, Sabri TA, Kher V, Hazarika M (2016) Development profile in flood prone areas. Tata Trusts: Bombay House, Mumbai

Planning Commission, Government of India (2013) Twelfth five year plan. Sage Publications India, New Delhi

Shah M (2013) Water: towards a paradigm shift in the twelfth plan. Econ Polit Wkly 48(3):40–52

Tierney K, Bruneau M (2007) Conceptualizing and Measuring Resilience A Key to Disaster Loss Reduction. TR NEWS 250 MAY–JUN, 14–17. http://onlinepubs.trb.org/onlinepubs/trnews/trnews250_p14-17.pdf

World Meteorological Organization (2017) Selecting measures and designing strategies for integrated flood management: a guidance document. WMO, Geneva. Available at: www.floodmanagement.info/publications/guidance%2020selecting%20measures%20and%20designing%20strategies_e_web.pdf

Nirmalya Choudhury is a faculty in Tata Institute of Social Sciences, Mumbai. He has completed his doctoral work at Technical University Berlin, a postgraduate diploma in forest management at IIFM Bhopal and a postgraduate degree in economics at Calcutta University. In the past, he has worked with multiple research institutions and philanthropic agencies like the International Water Management Institute, Council for Energy Environment and Water, and the Tata Trusts. He has worked on water, environment and energy issues, and his work is published in international and national journals. In the last 2 years, he has been part of a research project on recurrent flood-prone areas in India.

Integrated Development of Reservoirs and Unified Control for Efficient Flood Moderation in Ganga Basin

N. N. Rai and J. Chandrashekhar Iyer

1 Introduction

Ganga is one of the largest and complex river networks traversing 11 states of India. These states are Uttarakhand, Himachal Pradesh, Haryana, Rajasthan, Delhi, Madhya Pradesh, Uttar Pradesh, Bihar, Jharkhand, Chhattisgarh and West Bengal. The origin of the river (named as Bhagirathi) is at Gangotri Glacier at 4000 m above mean sea level (MSL) in the lap of Himalaya in Uttarkashi district of Uttarakhand. River Alaknanda rises from the confluence of Satopanth and Bhagirathi Kharak glaciers at an elevation of about 5000 m, in Chamoli district of Uttarakhand. At Devprayag the confluence of the Bhagirathi and Alaknanda rivers is located. Henceforth the river is known as the Ganga which traverses about 2525 km till it debouches in the Bay of Bengal at a place called Ganga Sagar in South West Bengal. The Ganga flows about 1450 km in Uttarakhand and Uttar Pradesh, then about 110 km in Uttar Pradesh-Bihar border, for a distance of about 445 km in Bihar and Jharkhand and finally 520 km in West Bengal. A number of tributaries join the Ganga in its long journey, such as Ramganga, Yamuna, Tons, Gomti, Ghaghara, Son, Gandak, Kosi, Damodar and other small streams. The total drainage area of the Ganga River at Farakka Barrage including the drainage area in Nepal and China estimated works out to about 9, 31,000 km^2. The drainage area map of Ganga basin up to Farakka Barrage is presented in Fig. 1. The drainage area of river Ganga and some of its major tributaries are presented in Table 1.

The landfall of southwest monsoon takes place at the southern part of West Bengal around the first week of June, and then it advances in upstream direction,

N. N. Rai (✉)
Director, Central Water Commission, Ministry of Water Resources River Development and Ganga Rejuvenation, Government of India, New Delhi, India

J. Chandrashekhar Iyer
Commissioner, Ministry of Water Resources River Development and Ganga Rejuvenation, Government of India, New Delhi, India

© Springer Nature Singapore Pte Ltd. 2019

A. Singh et al. (eds.), *Water Governance: Challenges and Prospects*, Springer Water,
https://doi.org/10.1007/978-981-13-2700-1_14

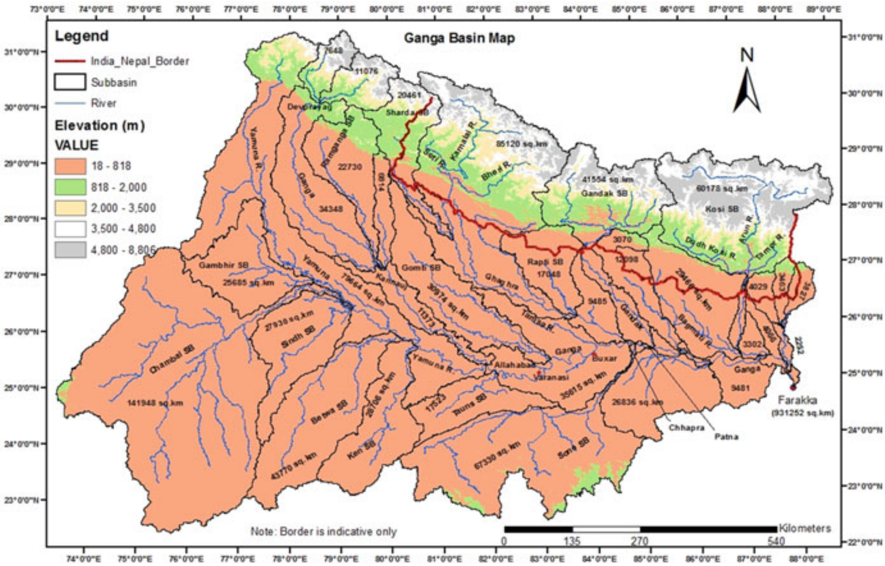


Fig. 1 Drainage area map of river Ganga at Farakka Barrage

Table 1 Drainage area of some of the rivers of Ganga basin

River	Drainage area (km^2)
Ganga at Allahabad	93,989
Yamuna at Allahabad	3,47,703
Tons	17,523
Ghaghara	1,32,114
Gandak	41,554
Son	67,330
Kosi	60,178
Bagmati	29,466
Tributaries of Yamuna	
Gambhir	25,685
Chambal	1,41,948
Sindh	27,930
Betwa	43,770
Ken	28,706

and by end of July, the monsoon reaches the western part of the basin. The mean annual rainfall in the basin is about 1,170 mm. About 88% of the annual rainfall is received during the period of June to October. The bulk of the remaining 12% occurs mostly in the periods of March to May and November to December. During monsoon, cyclonic disturbances cause heavy spells of rainfall in the Ganga River Basin. Cyclonic disturbances are commonly formed in the Bay of Bengal between June and September. Subsequent to their formation, they generally move west-northwest till they reach central India maintaining their strength. Due to strong

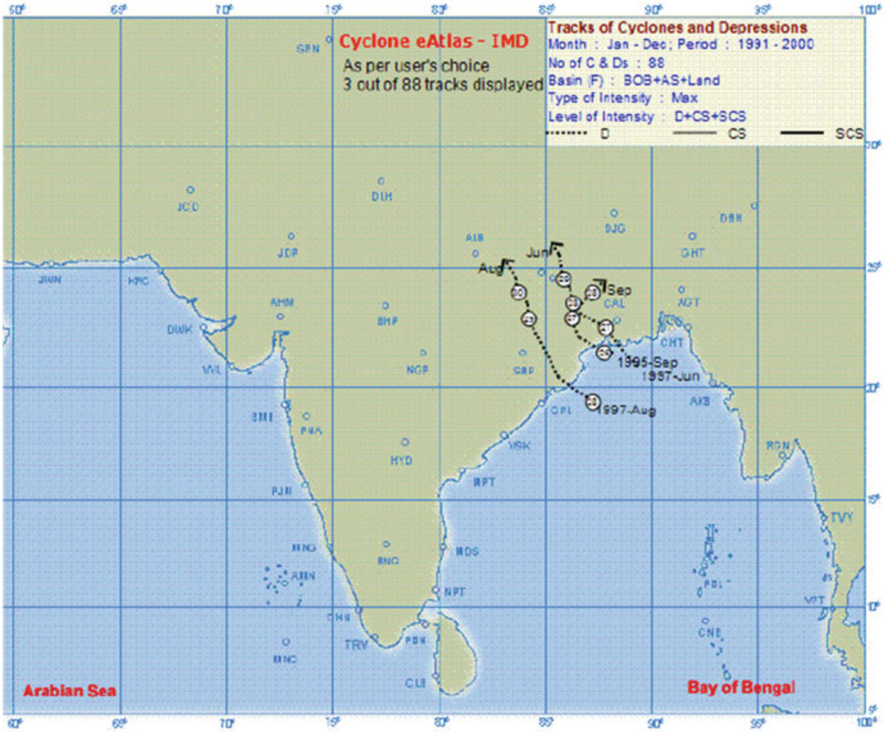


Fig. 2 Ganga River Basin severe rainstorm producing tracks of cyclonic disturbances (1991–2000). *(Source: Cyclone eAtlas – IMD)*

convergence in the southwestern sector, heavy rainfall occurs during the monsoon depressions. The part of the basin which comes in the track of southwest monsoon depressions receives very heavy rainfall. The part of the basin with Himalayan topography also plays an important role in facilitating significant rainfall during the southwest monsoon season. The main synoptic situations of the southwest monsoon system that generates heavy rainfall across the basin are monsoon depression formation and their subsequent movement. Some of the severe rainstorm producing tracks of cyclonic disturbances is presented in Fig. 2.

The August 2016 floods in the Gangetic plains were also due to low pressure depression formations. As per IMD two low pressure systems were active during the period 1st to 10th August which affected the areas of Gangetic West Bengal, Jharkhand, Madhya Pradesh and East Rajasthan. Consequent to these two low pressure systems, heavy to very heavy rainfall occurred in the sub-catchments of Koel, Rihand, Son, Tons, Ken, Betwa, Urmil, lower Chambal, Kali Sindh, Gambhir, Yamuna and Ganga downstream of Dalmau sub-catchments.

Meanwhile a slow-moving deep depression also formed in Gangetic West Bengal and adjoining Bangladesh on 16th August 2016 and moved very slowly westwards after intensifying from 16th to 21st August 2016. It finally weakened in East

Rajasthan. Rainfall of heavy to very heavy intensity at a few places with extremely heavy rainfall at isolated places were witnessed in the basins of Koel, Rihand, Son, Tons, Ken, Betwa, Urmil, lower Chambal, Kali Sindh, Gambhir, Yamuna and Ganga downstream of Dalmau sub-catchments.

2 Flood Management: A State Subject

Unlike irrigation, the subject of flood control is not in the preview of the three legislative lists included in the Constitution of India. However, the two measures, namely, drainage and embankments, are included in Entry 17 of List II (State List) as quoted below:

> Water, that is to say, water supplies, irrigation and canals, drainage and embankments, water storage and water power subject to the provision of entry 56 of List I. (Union List)

Entry 56 of List I (Union List) reads as follows:

> Regulation and development of inter-State rivers and river valleys to the extent to which such regulation and development under the control of the Union is declared by Parliament by law to be expedient in the public interest.

It is apparent that the states are primarily responsible for flood control. Some states are proactive and have enacted laws with provisions to address the issues. However, there exists a significant provision that the powers be exercised are subject to Entry 56 of Union List.

3 Floods in Ganga Basin

The management of the recurrent floods in Ganga River is a formidable challenge for the central and state governments. The state government plans, investigates, formulates and implements the schemes related to flood management. The union government only provides assistance, which are technical and advisory in nature and are catalytic and promotional. About 242 lakh hectare area is marked as flood prone in Ganga basin, as reported by the 12th Plan Working Group based on the inputs from the states.

The country has witnessed several flood events in the recent past when the wrath of the river in spate has left behind a trail of destruction spread across many states. *There are several structural and nonstructural measures in flood management.* Nevertheless, reservoirs along the river basin are central to the issue of flood management as they are able to moderate the intensity as well as the primary timing of the flood. The reservoirs are even more effective in managing floods if, in addition to the incidental moderation of floods, specific flood volume as earmarked can be stored as has been done in DVC dams. At present, out of 80 odd large dams (height > 100 m and capacity > 1 km^3), only 10 dams have dedicated flood cushion.

The August 2016 floods in the Gangetic plains is fresh in our minds that brings to the fore several intricate issues pertaining to management of a river basin reeling under floods. A study initiated recently post August 2016 floods in Bihar at the instance of Ministry of Water Resources, River Development and Ganga Rejuvenation by the Central Water Commission to holistically understand the flood peak formation phenomenon in river Ganga and to estimate the flood storage requirements in the Ganga basin has interesting revelations that are briefly discussed in this paper. The other structural and nonstructural possibilities in flood management, sediment issues, etc. are not dealt in this paper to ensure focus on the significance of flood storages in the basin and surrounding issues.

3.1 Flood Peak Pattern Analysis of Ganga River System

The vast historical data available on Ganga river system has been examined, and an attempt has been made to understand the flood peak formation phenomenon in the main stem of river Ganga between Allahabad and Patna for which the annual flood peak patterns of different contributing rivers have been plotted in Fig. 3. The flood peak data of river Ganga and its tributaries for more than 50 years has been used. From the flood peak pattern plot and date of occurrence of flood peak at respective locations, the study concludes that the flood peaks in the main stem of river Ganga, i.e. at Varanasi and Gandhi Ghat, Patna, is being governed by the flood peaks in river Yamuna at Pratappur. Further, the second most important contributor in flood peak of river Ganga at Patna is Son river system.

It is seen that in Ghaghara river system, most of the flows get spread out in vast territory of UP and Bihar creating huge floods. Thus Ghaghara's contribution in flood peaks in the main stem of river Ganga is of the order of about 8000 to 10000 cumec. One of the important revelations is that the concurrent occurrence of Kosi flood peak with Ganga flood peaks is very rare. However, the huge discharge in Kosi river results in flooding within its drainage area in Bihar.

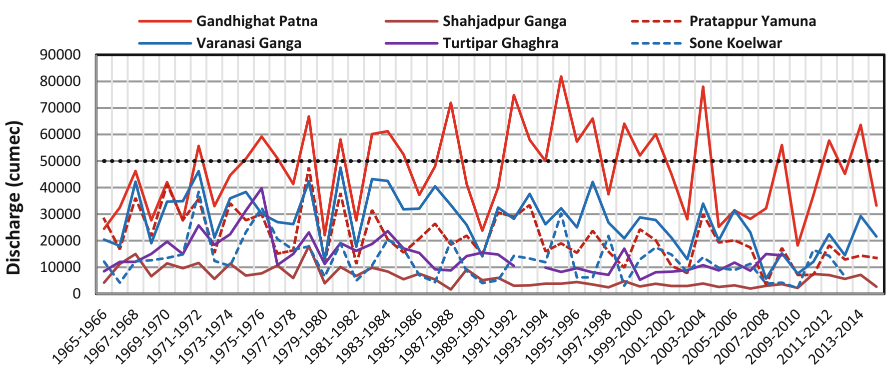


Fig. 3 Annual flood peak pattern in river Ganga and its tributaries. *(Source: CWC (2016) Flood Storage Estimate for Ganga Basin)*

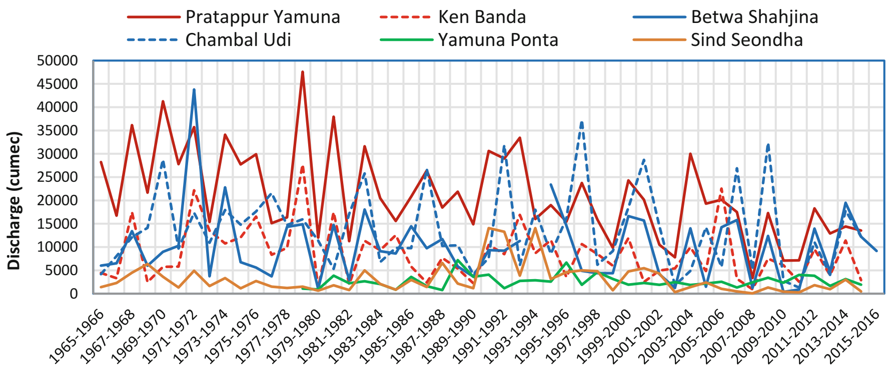


Fig. 4 Annual flood peak pattern in river Yamuna and its tributaries. *(Source: CWC (2016) Flood Storage Estimate for Ganga Basin)*

The flood peak pattern analysis carried out for the Yamuna river system as presented in Fig. 4 reveals that majority of the flood peak occurrences in Yamuna are due to significant contributions from its tributaries, viz. Chambal, Betwa and Ken.

In Chambal River, the major storage projects, viz. Gandhi Sagar and Ranapratap Sagar, were commissioned way back in the year 1970. As can be seen from the annual flood peak pattern, numbers of flood peaks with a significant discharge of more than 20,000 cumec have continued even after the year 1970. As per the study, some significant additional flood storage is essential on river Chambal, and some dedicated flood cushion in existing projects coupled with inflow forecast may help further mitigation of flood peaks.

As on date, there is no storage project on the river Ken, and the contribution of river Ken during the major flood events is more than 10,000 cumec; the study concludes that significant flood storage is essential on river Ken. Similarly, provision of dedicated flood cushion coupled with inflow forecast in the existing projects on river Betwa and additional storage will help in mitigating the flood peaks of river Betwa.

3.2 Flood Storage Estimate for Ganga Basin

As a sequel to the flood peak pattern analysis, flood storage estimate study for the entire Ganga basin too has valuable findings. It is worth mentioning here that the drainage area of river Ganga at Gandhi Ghat, Patna, is about 7, 25,000 km^2. Considering the possibilities of storage on Yamuna river system, viz. Ken, Betwa, Sind, Chambal, etc. and Himalayan part of Yamuna, Tons, Son and Ghaghara, the total drainage area which can be tapped is about 2,70,000 km^2 only. About 4, 55,000 km^2 (i.e. about 63% of the drainage area) shall remain untapped due to topographical constraints. This contribution from untapped catchment may vary from 30,000 cumec to 40,000 cumec in a flood scenario of above 65000 cumec.

From the data of flood peaks at Gandhi Ghat, Patna, Hathidah and Farakka on the main stem of river Ganga, it has been found that the magnitude of flood peak at Gandhi Ghat, Patna, is maximum in almost all the flood events that have occurred so far. Flood peak at Hathidah and Farakka is lesser in comparison to Patna due to the attenuation of flood peak by Mokama Taal and spillage of water in flood plains. To illustrate, daily discharge pattern of four worst flood events of years 1987, 1991, 1994, 2003 and 2016 each of them having peak discharge of more than 70,000 cumec has been picked up and analysed to estimate flood storage requirement. In the analysis the flood volume has been estimated considering a target to curtail the flood peak at Patna by about 20,000 to 25,000 cumec. Accordingly, for the flood events with peak flow below 75000 cumec, the volume has been estimated above 50,000 cumec discharge. For the flood events with peak flow above 75000 cumec, the volume has been estimated above 55,000 cumec discharge. The study reveals that:

- For September 1987 flood, maximum recorded peak was 71900 cumec, and flood volume above 50,000 cumec was about 4.8 BCM.
- For September 1991 flood, maximum recorded peak was 72608 cumec, and flood volume above 50,000 cumec was about 11.9 BCM.
- For August 1994 flood, maximum recorded peak was 81839 cumec, and flood volume above 55,000 cumec was about 10.9 BCM.
- For September 2003 flood, maximum recorded peak was 78000 cumec, and flood volume above 55,000 cumec was about 16.8 BCM.
- For August–September 2016 flood, the flood volume at Patna above 55000 cumec was about 12 BCM.

As stated above, the maximum influence on Ganga flood is mainly from Yamuna and Son river systems, considering that a total flood storage of about 12 BCM in Yamuna, Son and Ghaghara subbasins may be beneficial in moderating the floods in the main stem of river Ganga between Allahabad, Patna, and downstream of Patna. In order to mitigate the flood peaks at Patna by 20,000 cumec to 25,000 cumec, flood storage estimates for Chambal, Betwa and Ken river systems as per the study work out to 3.0 BCM, 2.5 BCM and 2.0 BCM, respectively. The estimate for Son river system is projected as 2.5 BCM. In the drainage area of Ghaghara, Gandak and Kosi river systems, the flood storage of 3.0 BCM, 2.3 BCM and 3.25 BCM, respectively, has been estimated.

As per the study, efforts should be made to ensure some dynamic flood cushion supported with inflow forecast in existing projects, viz. Gandhi Sagar in Chambal subbasin, Bansagar and Rihand in Son subbasin and Rajghat and Matatila in Betwa basin. The major projects being considered on Ghaghara river system are Pancheshwar multipurpose project on Sharda, Karnali (Chisapani) multipurpose project on Karnali (Ghaghara) and Namure multipurpose project on river West Rapti which are at different stages of preparation in association with the Government of Nepal. Similarly, on the Kosi river system, Saptakosi and Sunkosi multipurpose projects, Bagmati multipurpose project and Kamla Dam project are being investigated jointly with the Government of Nepal. Substantial moderation of floods in Uttar Pradesh and Bihar can be expected from these projects.

4 Discussion

The paper focuses on appreciation of two key aspects relating to flood moderation in Ganga basin. One is the flood peak pattern analysis, and the other is the estimate of flood storage requirement in different subbasins of Ganga river system. There is no doubt that the flood flows have to be managed effectively by the state and central government to mitigate the adverse flood impacts. We need to remind ourselves that floods per se do not understand man-made state boundaries. Floods have been inflicting damages to almost all the states in Ganga basin. While tackling floods in a large basin like Ganga, the cooperation and synergy among the riparian states on the issue of tackling flood are very vital in the interest of all. Integrated development and operation of the reservoirs in a river basin world over has significantly helped in efficient flood moderation.

With water being in the State List of the Constitution, the primary responsibility of flood control lies with the states. The state government controls and manages schemes by thorough planning, investigation, formulation and implementation. Assistance rendered by the union government is technical, advisory, catalytic and promotional in nature. As the priority of the projects differ from state to state, it is obvious that they may not agree to an integrated planning approach.

From the study outcome above, it is seen that large storage volumes are needed, supported with reliable inflow forecast network for moderating floods in a large basin like Ganga implying huge financial implications. These reservoirs in all likelihood would be interstate projects requiring consensus among the party states, and hence agreement on cost-benefit sharing would be vital. Difference of opinion between two states is enough to jeopardize the entire project. Above all, the proposed projects have to be environmentally sound and socially acceptable. River Ganga is a holy river, worshipped, revered and regarded as lifeline of the region. Any interference in the river environment and its regime will not be taken lightly by the people, and therefore building storages would require serious consideration and consultation of all stakeholders on all issues at the planning and developmental stage itself.

On the operational front, the best practices calls for all the major reservoirs (from storage volume consideration) to ideally come under integrated operation to ensure that the flood waters are efficiently routed and regulated. Further, for real-time integrated operation, a robust state-of-the-art data acquisition, storage and retrieval and transmission system to and from the centralized control and command centre are paramount. However, with water being in state domain, the control over releases from reservoirs remains with the state governments. Further, with increasing water conflicts among stakeholders in the basin, integrated operation would have to negotiate many hurdles. The issues on transboundary rivers too pose multiplicity of challenges. Confidence and consensus building through participatory approach is therefore important, and sincere efforts should continue diligently.

Acknowledgements The authors expressed their sincere thanks to the Central Water Commission for providing the data to carry out the flood storage analysis as well to prepare the figures. The authors expressed their sincere thanks to their colleagues for their fruitful inputs. The views expressed are purely personal and not necessarily the views of the organization.

Reference

CWC (2016) Flood storage estimate for Ganga Basin. Available at: www.cwc.gov.in

Nitya Nand Rai is a graduate in civil engineering and masters in hydrology from Indian Institute of Technology, Roorkee. He is recipient of the Merit Award of Central Water Commission (CWC) and Vice Chancellor Gold Medal of Avadh University. He has over 23 years of experience with CWC, and he is currently working as the Director of Hydrology. He has carried out hydrologic and hydrodynamic modelling for more than 80 river valley projects for water availability study, design flood estimation, dam break studies, glacial lake outburst flood studies, back water studies, reservoir sedimentation profile studies, surge analysis, reservoir and channel routing studies. He is one of the few experts who have evolved the methodology for glacial lake outburst flood estimation and carried out a number of studies including a very detailed analysis of Uttarakhand flood of June 2013, Jammu & Kashmir flood of September 2014 and flood storage estimate of Ganges and Brahmaputra Basins. He is also representing CWC in Expert Appraisal Committee of River Valley Projects constituted by MoEF&CC, Government of India for Environmental Clearance of River Valley Projects. He has delivered a number of lectures at Indian Institute of Technology, NIH, NHPC, CBIP, NTPC and Water Resources Departments of State Governments. He has authored more than 26 technical papers in various journals and at national and international conferences.

J. Chandrashekhar Iyer is currently the Commissioner (Flood Management), Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India. He acquired Master of Technology in civil engineering from the Indian Institute of Technology, Madras, Chennai, in 1986. On NORAD Fellowship, he pursued Master of Science in hydropower development from the Norwegian University of Science and Technology, Trondheim. An officer of Central Water Engineering Service of the Government of India, he has over 32 years of progressively responsible professional experience, working in various capacities in the water resources sector. He has been actively associated with many prestigious water resources projects in India and abroad. He has served in Ethiopia as an ITEC water expert from the Government of India. He represents the Government of India in various committees and has to his credit around 25 papers published in conferences/journals.

Flood Management Strategy for Brahmaputra Basin Through Storage

N. N. Rai and T. S. Mehra

1 Introduction

Brahmaputra River originates as Yarlung Tsangpo River from Mansarovar near Mt. Kailash in the Himalayas, flows via Tibet, China, India, and Bangladesh into Bay of Bengal. The total length of the river is about 2900 km. The drainage basin of the Brahmaputra extends to an area of about 580,000 sq.km, from 82°E to 97° 50′ E longitudes and 25° 10′–31° 30′ N latitudes. The basin spans over an area of 293,000 sq.km (50.51%) in Tibet (China), 45,000 sq.km (7.75%) in Bhutan, 194,413 sq.km (33.52%) in India, and 47,000 sq.km (8.1%) in Bangladesh. The mighty Brahmaputra and its tributaries flow above the danger level across Assam almost every year and affect more than one lakh people inundating human habitations and farm land in several districts of Assam and Arunachal Pradesh of North Eastern (NE) region of India.

Brahmaputra water is the prime resource endowed to this region, which has the potential to bring all the desired growth and prosperity to the region. If left unmanaged, it will become the biggest bottleneck against development due to recurring floods as this also gives sense of insecurity for sustainability of infrastructure and ultimately results in reluctance of investor to put his money for development in such region. Accordingly, flood is a major concern for the overall development of NE region. Besides, Assam suffers an average loss of more than Rs 200 crore every year due to floods; it loses large swathes of land to river bank erosion, and recovering such lost land has become a challenging task for the state. The above problem can be

N. N. Rai (✉)
Director, Central Water Commission, Ministry of Water Resources River Development and Ganga Rejuvenation, Government of India, New Delhi, India

T. S. Mehra
Commissioner, Ministry of Water Resources River Development and Ganga Rejuvenation, Government of India, New Delhi, India

© Springer Nature Singapore Pte Ltd. 2019

A. Singh et al. (eds.), *Water Governance: Challenges and Prospects*, Springer Water,
https://doi.org/10.1007/978-981-13-2700-1_15

solved effectively to a great extent through an appropriate flood management approach, where flood peaks of Brahmaputra are curtailed through storage of flood water in different subbasins of Brahmaputra. About six to seven judiciously located storage projects leading to about 14 billion cubic meters (BCM) of storage can turn around the biggest bottleneck of recurrent floods into a great opportunity of cheap and reliable nonpolluting power with an efficient navigation round the year approaching all the way across the region. All over the world including India, the storage projects are playing key role to moderate the flood peaks and are bringing relief from devastation and fury of floods.

In India, Bhakra Nangal dam in Sutlej basin, Bargi dam in Narmada basin, and a number of storage projects in Damodar valley and Tehri dam in Ganga basin are some live examples, which are efficiently controlling the floods in their region. Similarly, in Murray-Darling basin (Australia), Yellow River basin (China), Brantas River basin (Indonesia), and many other basins in all over the world, basin authorities are relying on flood management mainly with the help of large storage projects. The present paper discusses the flood wave formation phenomena in Brahmaputra and measures required to mitigate the flood in Brahmaputra.

2 Formation of Flood Waves in Brahmaputra Basin

In order to understand the flooding scenario in Brahmaputra River, it is essential to visualize the rainfall scenario in Brahmaputra basin. The same is shown in Fig. 1, where it can be seen that the average annual rainfall in Siang River upstream of great bend is less than 500 mm.

The same scenario is also in Lohit basin where the rainfall in Chinese catchment of Lohit River is less than 500 mm. The average annual rainfall in Siang valley downstream of Great Bend and up to Pasighat is of the order of 3500 mm. The rainfall in lower region of Dibang and Lohit basins is more than 4000 mm. There are certain pockets in Siang, Dibang, and Lohit basins where annual rainfall is even of the order of 5500 mm. Similarly in some pockets of Subansiri basin, the annual rainfall is more than 3000 mm. In the catchment of Brahmaputra plain, the average annual rainfall is of the order of 2400 mm.

Apart from the rainfall scenario a comparison of flood peaks observed in Siang River at Tuting and Brahmaputra River at Guwahati is given in Table 1.

From the above rainfall scenario and flood peak data of Tuting and Guwahati, it can be said that the flood or high discharge in Brahmaputra basin is basically due to very high rainfall in the Indian catchment of the basin. This may further get worsen due to climate change leading to more erratic and intense rainfall pattern, resulting in increase in the intensity of floods.

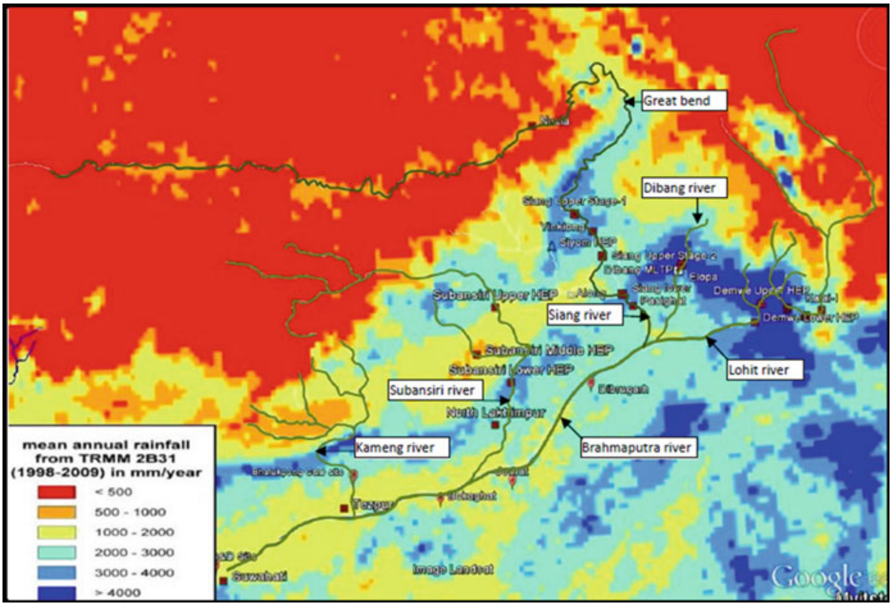


Fig. 1 Rainfall scenario in Brahmaputra basin. (*Source*: CWC (2013) Flood Storage Estimate for Brahmaputra Basin)

Table 1 Observed flood peaks in Siang and Brahmaputra rivers

Siang at Tuting (about 25 km d/s of India-China Border)		Brahmaputra at Guwahati	
Date	Observed flood peak (cumec)	Date	Observed flood peak (cumec)
08/09/2007	12,180	12/9/2007	44,508
01/09/2008	13,485	4/9/2008	49,659
01/07/2009	9230	24/08/2009	36,138
05/09/2010	11,300	19/09/2010	39,469

3 Flood Storage Requirement in Brahmaputra Basin

In addition to all nonstructural measures, it is essential to adopt all possible and effective structural measures for integrated flood management so as to tackle the problem of floods in Brahmaputra basin. The catchment area of Brahmaputra at Guwahati is about 417,000 sq.km in which the catchment area of Siang alone is about 251,521 sq.km. The catchment area of Lohit near Parsuram Kund is about 21,000 sq.km, while Subansiri at Gerukamukh is about 26,000 sq.km. Due to natural topography and availability of limited storage sites, it is possible to construct storage projects on Siang, Dibang, Lohit, and Subansiri rivers at those sites only. Further, a

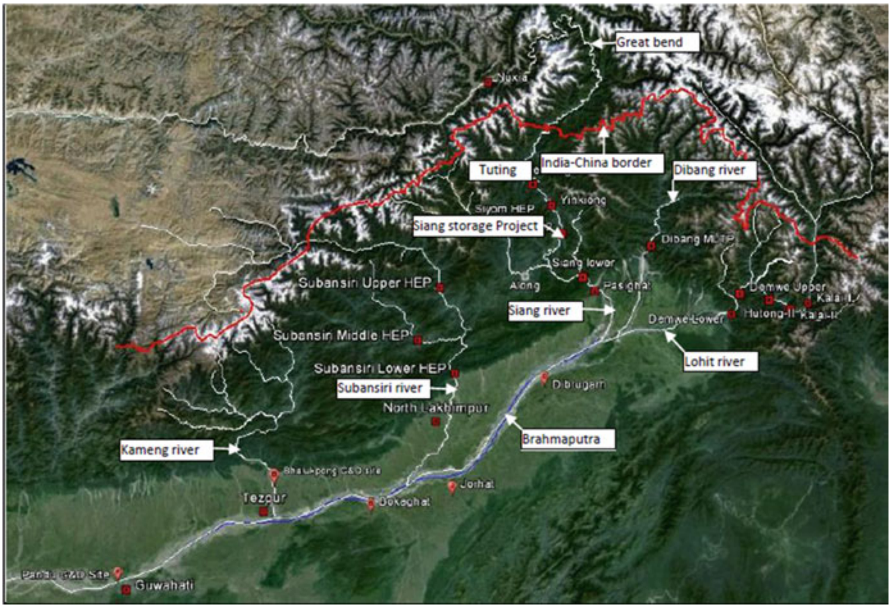


Fig. 2 Major river valley projects in Brahmaputra basin. (*Source*: CWC. (2013) Flood Storage Estimate for Brahmaputra Basin)

large catchment area of about 108,669 sq.km up to Guwahati lies in plain, where no storage project is possible. It has been estimated that from the unregulated catchment of Brahmaputra plain, a flood discharge of about 22,000 to 25,000 cumec is expected during the flood events of 100-year return period. However with judicious storage of flood waters in Siang, Dibang, Lohit, and Subansiri rivers at identified locations, the flood peak of Brahmaputra can be mitigated to safer levels. The adequate flood storages can be provided in Upper Siang storage project in Siang subbasin, Dibang multipurpose project in Dibang subbasin, and Subansiri lower, Kamla, and Subansiri upper projects in Subansiri subbasin. In Lohit subbasin, the storage available between operating level during monsoon and Full Reservoir Level (FRL) of Demwe lower, Demwe upper, Hutong-II, Kalai-II, and Kalai-I can be used to meet the flood storage requirements. The location of these projects is shown in Fig. 2.

In order to estimate the flood storage requirement in Brahmaputra basin, a Committee under Chairmanship of Member (D&R), CWC with experts from NHPC, CEA, Brahmaputra Board, Government of Arunachal Pradesh, and Government of Assam, was constituted by MoWR in July 2013. The Committee after detailed analysis and several deliberations identified that the major contributor of flood in Brahmaputra is Siang. The other rivers which contribute significantly in Brahmaputra flood peak formation are Dibang, Lohit, and Subansiri. In order to mitigate the Brahmaputra flood fury, the Committee estimated a flood storage requirement of 9.2 BCM in Siang, 0.6 BCM in Dibang, 1.61 BCM in Lohit, and 1.91 BCM in Subansiri subbasins.

4 Benefits of Storage Projects

4.1 Flood Mitigation

Efficient management of water resources potential including sustainable flood management in Brahmaputra basin may be achieved by ensuring the availability of the required quantity of water at the required point of time. This may be made possible through storing flood water during flood season by moderating the flood peaks and releasing it at an appropriate time of requirement. With aforesaid proposed flood storage projects, it will be possible to reduce the 100-year flood peak at Guwahati from 62,000 cumec to about 42,000 cumec. The 25-year return period flood of about 55,000 cumec will be possible to reduce below 40,000 cumec. Depending upon the contribution from the unregulated catchment, the proposed flood storage scenario will result in to reduction in water level at Guwahati by about 1.1 m–1.5 m. This will bring a major relief from floods and recurrent flood damages. Apart from the floods on account of rainfall occurrences, floods from glacial lake outburst and breaching of landslide dams will also be effectively attenuated by proposed reservoirs, thus effectively mitigating their downstream impact. The benefits of flood moderation besides water security and better navigability during lean period would also be available up to Bangladesh which is a lower riparian country.

Through these storage projects in upper reaches of the Brahmaputra basin, the flood levels in the main stem of Brahmaputra River will be reduced considerably. This will also facilitate removal of flood congestion and consequent reduction in flooding in the drainage area of the tributaries joining Brahmaputra River in downstream areas. One of such prominent area besides other areas where relief due to removal of flood congestion would be available is Bodoland Territorial Council area in Assam.

4.2 Hydropower Generation

The maximum flood storage is essential in Siang subbasin where the proposed Upper Siang Storage Project with installed capacity of 10,000 MW shall generate about 48,000 million unit of electricity annually even during the dry years.

Apart from the flood mitigation, these storage projects will help in overall development of NE region's economy through hydropower generation, major employment generation, industrialization, education, better medical facilities, etc. Large reservoirs will also provide the huge employment generation through tourism and fisheries for the local people. Other benefits are better navigability of Brahmaputra, water sports, and enhanced river flows during lean period resulting in better river ecosystem besides adding the effectiveness to anti-erosion/flood management and infrastructural works in Brahmaputra basin.

4.3 Water Security Aspects of Brahmaputra

Being a snow fed, Siang River is the major contributor of non-monsoon (November to April) flow of river Brahmaputra. The contribution of non-monsoon flow in Brahmaputra by Siang during November to April is about 22 BCM, out of which about 18 BCM is contributed from the drainage area in China. The possibility of diversion of Siang water by China has been raised by media from time to time. Also, as apprehended, the climatic change is reducing the size of glaciers which may also result in reduction of availability of water during non-monsoon period. Considering the possibility of reduction of Siang water in future, the Siang storage project will also ensure the non-monsoon water security in Brahmaputra basin besides becoming a safeguard to power projects and providing protection to ecology and environment.

5 Need of an Empowered Basin Authority for Brahmaputra Basin

Integrated water resources management (IWRM) of any basin for its overall development including integrated flood management may be achieved if there exists a well-structured and appropriately empowered authority at basin level. In Brahmaputra basin, there exists an autonomous body, namely, Brahmaputra Board at Guwahati, Assam, since 1982, with certain limitations on its mandate. Presently, the Board is certainly not a regulatory authority. However, Brahmaputra Board may be revamped appropriately as a basin authority and may be made responsible for Brahmaputra basin's water resources management with the mandate of all activities of water resources including management of floods and regulation of reservoirs, etc. As the effectiveness of flood storage can only be ensured by integrated operation of the proposed reservoirs in Brahmaputra basin, hence, whenever projects come into existence, a Reservoir Regulation Committee within the basin authority comprising of all stakeholders for coordinated operation of reservoirs during monsoon shall be essential to ensure optimum flood moderation benefits adding to integrated flood management. The advice given by the Committee should be binding to all the project owners of the basin.

Further, policy for operation of multipurpose reservoirs is needed for reducing the impact of flood cushion requirement vis-à-vis power generation from the project. For coordinating large reservoirs in real time, comprehensive data collection and decision support system will be required to be set up. Land use planning and flood plain zoning in unregulated catchment of Brahmaputra will further enhance the effectiveness of integrated flood management approach.

6 Conclusion

As already discussed, all over the world including India, the storage projects are playing key role to moderate the flood peaks and are bringing relief from devastation and fury of floods. Most of the basin authorities all over the world are relying on integrated flood management mainly with the help of large storage projects. Brahmaputra basin is also not exception to that, and strategic storage projects in the basin are essentially required for integrated flood management. Flood storage projects can be provided only in North Brahmaputra where storage sites are available in Subansiri, Siang, Dibang, and Lohit subbasins. The major contribution of flood in Brahmaputra is from the Siang River. With the proposed flood storage provisions, it will be possible to mitigate the Brahmaputra floods substantially. The proposed storage will provide a major relief to frequently affected flood areas in the basin with average annual saving of more than Rs.200 crore from flood damages in Assam. These projects will also provide effective relief from flooding in Arunachal Pradesh. Apart from the flood mitigation benefits, the Government of Arunachal Pradesh will get renewable energy and other benefits from all these projects. Hence, management of Brahmaputra waters through construction of strategic storage projects with stakeholder's active participation and integrated management of floods could be a key to overall development of NE region.

Acknowledgments The authors expressed their sincere thanks to the Chairman Central Water Commission for providing the data on which the figures have been prepared, to carry out the flood storage analysis. The authors expressed their sincere thanks to their colleagues for their comments and cooperation. The views expressed in the paper are purely personal and not necessarily the views of the organization.

Reference

CWC (2013) Flood storage estimate for Brahmaputra basin. Available at: http://cwc.gov.in/main/downloads/Final%20approved%20SOP_May_03052017.pdf

Nitya Nand Rai is a graduate in civil engineering and masters in hydrology from IIT Roorkee. He is recipient of the Merit Award of Central Water Commission (CWC) and Vice Chancellor Gold Medal of Avadh University. He has over 23 years of experience with CWC and he is currently working as the Director of Hydrology. He has carried out hydrologic and hydrodynamic modelling for more than 80 river valley projects for water availability study, design flood estimation, dam break studies, glacial lake outburst flood studies, back water studies, reservoir sedimentation profile studies, surge analysis, reservoir and channel routing studies. He is one of the few experts who have evolved the methodology for glacial lake outburst flood estimation and carried out a number of studies including a very detailed analysis of Uttarakhand flood of June 2013, Jammu & Kashmir flood of September 2014 and flood storage estimate of Ganges and Brahmaputra Basins. He is also representing CWC in Expert Appraisal Committee of River Valley Projects constituted by MoEF&CC, Government of India for Environmental Clearance of River Valley Projects. He has delivered a number of lectures at Indian Institute of Technology, Rookee, NIH, NHPC, CBIP, NTPC and Water Resources Departments of State Governments. He has authored more than 26 technical papers in various journals and at national and international conferences.

T. S. Mehra is a graduate in civil engineering. He obtained his master's in water resource development with specialization in hydropower developments and its apertinent structures from Indian Institute of Technology, Roorkee. He has over 29 years of experience with Central Water Commission (CWC) and Ministry of Water Resources, River Development and Ganga Rejuvenation both under Government of India. Presently, he is working as the Commissioner, Brahmaputra and Barak (B&B) in the Ministry. In CWC, he handled the works related to design of multipurpose mega projects like Indirasagar, Omkareshwar, Bargi Diversion, etc. He also handled the work from conceptualization to execution of a project of de-silting of water bodies for Border Security Force at Tekanpur, Gwalior. In the Ministry, he is dealing with various international issues of transboundary rivers with Bangladesh, Bhutan and China for more than 9 years. He is also having exposure of successful implementation of Ganga Water Treaty 1996 between India and Bangladesh for about 6 years. As commissioner (B&B), in addition to bilateral issues of water resource sector with Bhutan and China, he is also dealing with the technical issues of Brahmaputra Board, besides general issues of water resources development including hydropower development in North East India.

Governance in the Water Sector

Vidyanand Ranade

1 Introduction

Water is a prime natural resource, fundamental to life, livelihood, food and water security and sustainable development. It is characterized by spatial and temporal variation, variability from year to year, which is likely to get further distorted in the future due to effects of global warming and climate change, but still on an average its availability would be finite at any given place. It is a dynamic and reusable resource but is vulnerable to pollution. However, nature has provided two stabilizing factors to this dynamic resource, viz. temporary storage in the form of snow in temperate regions and as groundwater in most of the river basins. Any type of water resource development infrastructure planned for human use has to be designed duly taking into consideration all these characteristics. Rapid growth in demand for water as a result of rise in population and increased rate of urbanization and industrialization has been posing serious challenges to food security, water security and access to adequate safe drinking water. Release of untreated or partially treated effluent generated after non-irrigation use of water into natural streams has added new dimension to this issue. Time has come to take a holistic and interdisciplinary approach towards water-related problems, by resorting to 'Integrated Water Resource Development and Management' (IWRDM). Planning, development and management of surface and groundwater resource need to be governed by rational perspectives in an integrated and environmentally sound basis. When development and management of water resource fall short in meeting growing needs of water, issue of governance of development and management of infrastructure starts getting prominence as a soft option.

V. Ranade (✉)
Former Secretary, Irrigation Department, Government of Maharashtra, Mumbai, India

© Springer Nature Singapore Pte Ltd. 2019

A. Singh et al. (eds.), *Water Governance: Challenges and Prospects*, Springer Water,
https://doi.org/10.1007/978-981-13-2700-1_16

2 Historical Review of Water Resource Development in the Peninsular India

Eight to nine centuries before, irrigation facilities were provided to grow three crops in a year in the fertile delta region of most of the East flowing rivers in the Peninsular India, by constructing masonry weirs and diverting the perennial river flow. These schemes were constructed by the then rulers but were managed mostly by the beneficiaries. Some of these schemes were modernized during British Regime. Another development during the last three centuries was in the form of construction of small earthen dams, planned and constructed on the basis of time tested technique, to store water to deliver it to the paddy crop during water-stress period and ensure good land productivity. All along East coast from Odisha to Tamil Nadu state, about 1 Million such small tanks were financed by the big landlords (Malgujars) and the then rulers, with active contribution from the beneficiaries. Management of these schemes was done entirely by the beneficiaries. 'Phad system' which consisted of diverting river flow by means of a series of small weirs one below the other to irrigate crops was in vogue on some rivers in the Tapi basin for the last two to three centuries. Schemes were financed by the then rulers but were managed entirely by the beneficiaries.

In the pre-independence period, five large masonry dams were constructed in high rainfall zone in Sahyadri ranges in the Maharashtra State to store monsoon runoff and to convey it to drought-prone area towards East (intra-basin water transfer) to grow seasonal and perennial crops. Seven medium earthen dams were constructed in eastern part of the state, for achieving crop diversification (from paddy crop). Irrigation management of these relatively large schemes was, however, done by the government machinery. Some small earthen dams were constructed in the drought-prone zone, purely as famine protection works during scarcity years.

3 Emerging Trends in Water Resource Development Activities in the Maharashtra State, During Post-independence Period

To tide over food grain shortage faced by the country in the 1950s, several major irrigation projects were taken up in hand in most of the states in the country. Many major irrigation projects which ensured intra-basin transfer of water were also taken up in Maharashtra State. With the limited 3.5-month monsoon season and about 35–40% area of the state being drought prone and having no perennial rivers, all projects consisted of storing monsoon runoff to use the stored water all the year round. In order to extend irrigation benefits to the rain-fed cultivation bypassed by major dams (more than 10,000 ha irrigation potential), many medium-sized dams (2000–10,000 ha) were also taken up, and later on priority shifted to taking up minor dams (250 ha–2000 ha). With the result, more than 40% of the 4500 large dams (dam of height more than 15 m or storage more than 3 Mcum) in the country are in the Maharashtra State. On considerations of equity in dispersal of irrigation benefits in the basins, projects to irrigate land below 250 ha each were concurrently taken up. The mosaic of large to very small schemes ensured optimum development of water resources and equitable allocation of irrigation benefits in the river basins. On consideration of social equity, many large-sized lift irrigation schemes were also taken up by government to provide irrigation facilities to the parched lands on the plateau where conventional irrigation by gravity canals was not possible and GW availability was poor.

In more than 90% area of the state, availability of groundwater is limited and confined to shallow (less than 25–30 m deep) disconnected GW aquifers in the residual soils, decomposed strata and basaltic rock flows below. Every year, rainwater seeps below ground and gets stored in decomposed strata and in cracks, crevices and joints between two flows of rocks, and hence availability of GW is finite and limited. Reduction in family landholding size (due to partition of land) to about one third of what it was at the time of independence, induced rain-fed farmers to exploit GW to increase land productivity of the reduced landholdings to meet family needs for survival. Coupled with the availability of electricity in the rural area, pace of GW exploitation increased rapidly during the last 30–40 years, and with the result, some watersheds in the drought-prone areas became critical or over-exploited. With the availability of drilling rigs and deep well multistage submersible pumps, indiscriminate drilling of bore wells up to 200–300 m depth to exploit deep GW aquifers (aptly called as mining of water) to grow high-value cash crops was also started in the state from the 1980s. Over-exploitation of GW by shallow wells necessitated introduction of 'drip irrigation' on large scale on private wells where water shortage was acutely felt. Use of polyhouses and shed nets was also on the rise to grow vegetables, floriculture and other high-value crops.

Concept of 'watershed development' was introduced and successfully experimented in the 1970s and 1980s in the state by some enlightened social workers. Looking to the potential of this scheme in the comprehensive development of rural area through local water conservation works, government took a conscious decision in the 1990s to take up these schemes as government schemes. Watershed development schemes help in meeting basic needs of rural population, viz. water, food and fodder, fuel and livelihood security, through increased land productivity and employment generation brought about by conservation and harvesting of rainwater to augment GW recharge to provide protective irrigation to seasonal crops. It meets developmental needs of the disadvantaged section of the society by bringing social justice and equity in the water sector. Biomeasures (growing trees and pastures in the watershed) meet fodder needs of cattle and fuel needs for cooking and thus help in preventing degradation of the environment. Cooperation of the beneficiaries in operation of the scheme for equitable sharing of all the common benefits is the key to success of these schemes.

4 Demand and Supply Dynamics

Historically, as the size of human settlements started increasing, demand for water also increased but could then be met with by simple human interventions. With the industrialization and consequent urbanization in the eighteenth century, water demand increased appreciably, and it became location specific, requiring large-sized well-designed complex WRD infrastructures. With the increase in population of the world, the water demand increased further in the twentieth century. Growing concern about disforestation for bringing more land under cultivation put restrictions on the availability of agricultural land for food production. Choice then available to increase land productivity for ensuring food security to the teeming millions of the world was to develop additional water resource structures to provide more and more irrigation facilities. As a result of this situation, even if population of the world increased by three times during the twentieth century, water demand increased by seven times in the same period. To meet rapidly increasing demand for water all over the world, a number of large dams in the world increased from 5000 in 1950 to 48,000 in the year 2000 (pccweb99.tempdomainname.com). As long as water resource availability in a country/river basin was much more than the water demand and adequate finances and technology were available to develop appropriate infrastructure, it was possible to match rising demand with the supply.

In the developing countries and countries with emerging economy, severity of the problem of matching supply with the demand increased because of higher rate of population rise, increasing rate of industrialization and urbanization, inadequacy of finances for construction of WRD infrastructure and inherent inadequacy in availability of water resources in the river basins. Increased demand for non-irrigation purposes curtailed availability of water for irrigation, giving rise to urban-rural conflicts. Partial treatment of industrial effluent and practically nontreatment of city effluent resulted in pollution of long stretches of rivers on downstream of these locations. Use of such polluted water by lifting it for irrigation on both banks of rivers by the needy cultivators not only contaminated the agricultural produce and polluted groundwater, but it became a health hazard for the affected population.

5 Water Resource Availability and Scope of Development

In any river basin, natural availability of water resource and the limits put by the scope of structural interventions to make it available for human use decide the limits of water-related development in the basin. It also requires some regulatory mechanism in implementation of ongoing schemes so as to get early benefits from the scarce financial resources available with the developing countries and countries with emerging economies. Hard option to expand scope of development in water-short basins would be to explore possibilities of inter-basin water transfer from adjoining or distant water-surplus river basins, which is generally a costly alternative and involves social problems associated with such transfer of water. Other alternatives for water-short basins would be to plan such developmental activities in the basin which would not require high consumption of water. Soft option would be to carry out performance review/evaluation of all completed WRD schemes, with a view to exploring possibilities of introducing structural modifications and to implement them in a phased manner to improve water availability from the same structure. Lastly, very vital soft option would be to review present set-up of operation and management of all WRD schemes for all its competing uses of water and take nonstructural measures to improve their performance and water-use efficiency. Even if it is less cost intensive when compared with above alternatives, it calls for reorganization of water management set-up and involvement of beneficiaries in the management of water. All the activities stated above fall within the ambit of 'water governance'.

6 Water Governance

Water governance plays a very important role both in the development and management of water resources and more so in the river basins where natural availability of water resource is less in relation to water demand for people in the basin. In what manner Maharashtra State in the Peninsular India is trying to handle the problem of matching the supply with the dynamics of various competing demands on water by appropriate governance is explained below.

6.1 Governance in Implementation of WRD Projects

Paucity of financial resources is a chronic problem and major constraint with developing/emerging economies. With the limited funds, planning should aim at creating maximum storage of water together with infrastructure for water use, from the investment made. Instead of completing ongoing projects expeditiously to get early benefits, elected representatives of people clamour for taking up more and more new WRD schemes in their constituencies (their appeals are many times responded favourably), thereby resulting in thin spreading of financial resources and delay in completion of in-progress schemes in advanced stage of completion. Sometimes new projects are investigated, approved and included in the budget as special case, or scope of existing projects is changed, as per their demand. With the result projects in advanced stage of completion languish for years, cost of their balance work continues to increase due to inflation, and benefits from investment get deferred.

With a view to controlling/improving this situation, the Government of Maharashtra passed an act in the year 2005, to constitute an independent 'Maharashtra

Water Resource Regulatory Authority'. It was supposed to monitor preparation of Integrated State Water Plan consisting of basin-wise WRD plans by the Irrigation Development Corporations for the respective river basins and get them approved from the State Water Council (chaired by the Chief Minister) within a year and a half from its formation. As per provisions in the Act, new projects were to be taken up only out of the approved ISWP/basin-wise plans. However, ISWP could not be approved even after 10 years from formation of MWRRA, but many new projects were approved by the Water Resources Department (WRD) of GoM with the connivance of MWRRA, and same were included in the budget, defeating the very purpose of instituting a regulatory mechanism. Powers given by the Act to MWRRA to approve allocation of water for industries were withdrawn by the GoM and were given to a Committee of Ministers. MWRRA has, however, given some good decisions to resolve conflicts in allocation and use of stored water in water-short basins. MWRRA has also finalized the complex issue of tariff structure for use of water for various purposes, after holding several public consultations. Maharashtra is the first state in the country which has instituted a regulating authority in the water sector. There is scope to improve its performance by following provisions of the MWRRA Act strictly.

WRD of GoM should strictly ensure that first priority of allocation of funds should be given to projects in advanced stage of construction, even by deferring projects in the initial stage of construction. Stage-wise completion of major projects should be planned so as to accrue early benefits of storage and creation of irrigation potential from lesser investment. More expenditure should be incurred towards available soft options which would improve performance of completed projects.

6.2 Governance in Operation, Maintenance and Management of Irrigation

Any hydraulic structure requires routine periodical maintenance to get sustained performance over years. Since such structure has to face and negotiate the effects of unpredictable precipitation pattern, occasionally it gets damaged due to high floods and requires special repairs to spillways. Maharashtra State has set up Dam Safety Organisation which carries out periodical inspection of major dams, monitors results of routine pre- and post-monsoon inspections of smaller structures carried out by the management staff and publishes annual reports. It is experienced that due to financial constraints, more funds are allocated for construction activities, and routine maintenance of dams and canal network gets neglected. However, funds are usually allocated for special repairs. Lack of adequate and timely maintenance impairs performance of schemes in the long run.

6.3 Performance Evaluation of Completed Projects

There is no mechanism to evaluate performance of works after 5/10/20 years after their completion. Irrigation structures are planned and designed on the basis of some assumptions about availability of yield with certain dependability (75%–50% from major to minor dams) from its catchment and use of stored water for various purposes. Actual availability is seen to be many times less than the designed one, but water demand is always on the increase and is dynamic in nature for the competing water demands. Actual cropping pattern may be much different from the designed one. Water demand for non-irrigation use usually increases affecting availability of water for irrigation. Hence it is necessary to review performance of every completed project periodically, take possible structural/nonstructural measures to improve its performance and revise its actual potential. If utilization of stored water is poor for irrigation use, dialogue should be established with the water users, and actions should be taken to increase use of water. Results of such review give good guidelines for planning and implementation of new projects.

6.4 Management of Irrigation

Irrigation management of all projects in the state used to be done by canal management staff of WRD. After taking up several pilot projects to explore mechanism of transfer of irrigation management to water users and after holding discussions with many NGOs and elected representatives of people, GoM formulated and passed Maharashtra Management of Irrigation Systems by Farmers Act (MMISF Act) in the year 2005, for transfer of irrigation management of surface irrigation schemes to Water Users Associations (WUA). Each WUA gets canal water on volumetric basis at specified rates for each season. They have to operate and maintain distribution system in their jurisdiction, and members are free to grow any crop by making conjunctive use of groundwater. It is expected that there is good incentive for the water users to get more crop, cash and jobs per drop of water by making more efficient use of water. It was seen that some improvements in the water distribution network of projects would have to be carried out to enable transfer irrigation management to WUAs. Substantial funds would be required for these works. With the result, transfer of irrigation management to WUAs was seen to be a slow process, but water-use efficiency is expected to improve appreciably (Naik and Karlo 2000).

6.5 Introducing Micro Irrigation System (MIS) on Surface Irrigation Projects

MWRRA has recently issued notification to introduce on pilot basis, adoption of MIS (drip irrigation) for perennial crops in the command area of eight major projects in the state. It is planned to complete this transformation on the selected eight projects up to the year 2018. To enable introduction of MIS, it would be necessary to construct a balancing pond at the head of jurisdiction of WUAs to enable the change to introduce MIS, and it would be essential to provide some subsidy to the water users for capital investment for MIS equipment. There would be appreciable saving in water use on this account. On considerations of equity, water so saved is proposed to be delivered to irrigate seasonal crops in the tail reach of the canal. Learning from this experience, it is proposed to introduce MIS to irrigate perennial crops on all major projects in the state. This is a proactive step taken by MWRRA to improve water-use efficiency on surface irrigation schemes.

6.6 Treatment of Generated Effluent and Its Reuse for Irrigation

Nontreatment or partial treatment of effluent and releasing it into natural streams has been degrading natural and man-made ecosystems (reservoirs). There is no mechanism to enforce the polluters (urban water users, i.e. municipal corporations) to treat all the effluent prior to its release in rivers. Maharashtra Pollution Control Board falls short in ensuring full treatment of industrial effluent prior to its release in rivers. Implementation of 'zero effluent policy' for industrial effluent would appreciably mitigate the situation. Unless fool-proof governance mechanism (duly supported by enabling Acts and rules) is introduced, situation of degradation of all aquatic ecosystems would deteriorate further to the detriment of people.

7 Governance in Groundwater Management

Implementation of GW Acts and rules to control and regulate use of GW has always been a difficult problem to handle, in most of the countries all over the world. GoM has passed enabling Acts to regulate exploitation of GW, but its implementation is poor. GW is a cheap and fairly dependable (except during severe drought years) and good source for drinking purposes in rural area. It gets undermined if new wells are taken around the drinking water wells. GW from deep aquifers can also be a reliable source for drinking water. Quest to grow cash crops by digging and drilling wells to exploit shallow and deep GW aquifers has been seriously affecting source of drinking water. In effect, costly and unreliable measure of providing drinking water by means of water tankers is hence becoming practice per force. Strict implementation of recently passed Ground Water Regulation and Control Act by GoM would be a right step for good governance of GW.

7.1 Governance in Demand Management

Telescopic water rates should be charged for urban use of water to induce municipal corporations to introduce metered supply and to take measures to identify sources of leakage in the underground distribution network and rectify it.

Water rates should be used as an economic instrument for industrial use of water, so as to induce recycling of water, with ultimate aim of achieving 'zero effluent'. Demand of water for irrigation use should be controlled by entrusting irrigation management to WUAs and by introducing MIS on surface irrigation schemes, as explained in paragraphs above.

8 Conclusions

Governance in water sector on the lines as suggested above is possible only if relevant Acts and rules are strictly followed by the government machinery. NGOs working in water sector have important role to play in educating water users about their rights and duties and make them 'water literate' in the real sense. Pressure imposed by water literate stake holders and by the enlightened media can certainly keep check on the aberrations in rigid implementations of Acts and rules by the functionaries of concerned departments and on deviations because of political expediencies.

Acknowledgements The author extends his thanks to his erstwhile Irrigation Department in the Government of Maharashtra for their valuable comments and suggestions.

References

Naik G, Karlo AH (2000) A methodology for assessing impact of irrigation management transfer from farmers' perspective. Water Policy 2(6):445–460
pccweb99.tempdomainname.com

Governance in the Water Sector

World Commission on Dams and Development Report 2000
Maharashtra Water Resource Regulatory Authority Act (MWRRA Act) 2005
Maharashtra Management of Irrigation Systems by Farmers Act (MMISF Act) 2005
The Maharashtra Groundwater (Development and Management) Act 2009 (Act No.XXVI of 2013)

Vidyanand Ranade is a graduate in civil engineering from Pune University. He is the former Secretary of Irrigation Department, Government of Maharashtra. During his long tenure in Irrigation Department, Government of Maharashtra, he was involved in and supervised construction and operation of dams of several irrigation projects in the state. Postretirement, he is involved as a consultant to many international organizations like National Irrigation Administration in Philippines and World Bank in Gujarat State, India, Indonesia and in Ethiopia. He is widely travelled and presented papers in many international conferences throughout the world. He has delivered more than 350 lectures on various technical subjects. He has authored two books on reservoirs and environment and watershed development. He has published 45 articles on various facets of water. He is member of nine professional organizations.

Financing Aspects of Sustainable Water Management in India

D. T. V. Raghu Rama Swamy

1 Introduction

It is anticipated that with increasing population, India would need about 380 million tonnes of food production from the current levels of approximately 260 million tonnes. Meeting this demand would imply a significant increase in availability of land under cultivation, productivity, and water. In relation to the rainfed agriculture, irrigated agriculture is reported to be more productive (the latter contributes to nearly two-fifths of food supply from one-fifth of the land available) (Venkateswarlu and Prasad 2012). Food production can be sustainably improved by taking various initiatives such as conserving moisture content in the soil, adopting rainwater harvesting techniques, augmented with supplemental irrigation at relevant stages of crop growth. Thus, expansion of irrigation wherever feasible and modernization of existing irrigation systems along with other supply and demand side management initiatives for appropriate utilization of limited land and water resources are required to be undertaken in the near term. Irrigation also provides a defense against droughts, which are predicted to occur more frequently. In India more than INR 4820 billion have already been spent over the last 65 years or so far for creation of irrigation potential of about 42 million hectare (mha) through major and medium irrigation. It is estimated that another INR 7200 billion would be needed at present-day costs to create remaining potential. Under a business as usual approach, this may take another 20–25 years to create the balance irrigation potential. In India provision of formal irrigation water supply services is mainly with the government agencies, which often fail to provide either reliable and timely services in equitable manner to many stakeholders (especially the poor) or services provided is of poor quality.

D. T. V. Raghu Rama Swamy (✉)
Faculty of Architecture, Building and Planning, The University of Melbourne, Melbourne, Australia
e-mail: dtvraghu@unimelb.edu.au

© Springer Nature Singapore Pte Ltd. 2019

A. Singh et al. (eds.), *Water Governance: Challenges and Prospects*, Springer Water,
https://doi.org/10.1007/978-981-13-2700-1_17

Water charges and cost recovery of investments on irrigation and drainage (I&D) works have been a debatable issue for many decades. The inability of I&D projects to generate adequate revenues has always been a question mark on project's viability, especially when it comes to minimal charges that are being charged for irrigation water and due to the fact that only a fraction of farming community ends up bearing the burden. For instance, expense accumulation rates are almost negligible despite water charges being much lower than operations and maintenance (O&M) expenditure in a few projects. Not able to cover the running expenses poses serious questions for both project proponents and eventually users/other stakeholders. This essentially requires governments to fund projects out of budget and general tax revenues.

Water charges are solicited from users primarily to address two main aspects – first to recoup invested amounts (either capital expenditure or the operating expenditure or both) and second to incentivize users to utilize water efficiently (appropriate quantum per unit of output or produce) to generate greater net economic returns per unit of water. In order to ensure overall development and flow of funds, economic principles dictate that the cost and pricing waters should match with each other.

Economists and planners usually recommend that subsidies incurred in different sectors of the economy should be explicit. Subsidies for irrigation water or power are both direct and indirect and are sometimes disguised in budget allocations. This exerts undue pressure on the government on account of uneconomic water rates and cheap power, especially if compounded with concessional credit for irrigation works. In India, during the last decade, there has been a little progress in appropriation of the volumetric pricing of water through participatory irrigation management. A few states/projects have adopted volumetric pricing to a limited scale. However there is need to encourage this as, with volumetric water pricing, amounts to be paid depend on the quantum of water conveyed and consumed. Financial principles prescribe that price ought to be fixed equivalent to the expenditure incurred for delivering water; this would mean that there is a need for an accurate assessment of water consumption through use of meters. The advantage of this fundamental principle is that it urges users to measure and consume exactly as much as they need. However, there are multiple challenges in implementing such a system ranging from willingness and ability to pay, reasonableness of investments, and recurrent expenses and equity in provision of water.

2 I&D Sector Financing, Water Pricing, and Allocation

2.1 Financing of I&D Sector Projects

Countries, particularly in Asia, have invested billions of dollars of nonrenewable resources on development of water system potential. Many have received financial assistance from donors to meet the burgeoning investment needs. While basic infrastructure has been created, still a large extent needs to be accomplished to become more efficient/productive that needs further capital investments.

Financing of irrigation and drainage projects is conventionally undertaken through budgetary resources and with assistance of multilateral and bilateral funding sources. Over the years, various national 5-year plans and state budgets allocated monies for development of this sector. However, as the magnitude is huge, coupled with a need for improving the sector performance, external borrowings were sought to be utilized. Multilateral organizations such as the IBRD[1] and Asian Development Bank and bilateral entities such as JICA[2] and GiZ[3] participated in Indian I&D sector. These agencies typically provide sovereign guaranteed long-term loans (say for 20–30 years) at low rates that are used for a specific project or a group of projects. This assistance, in some instances, is provided along with technical grants that could be used for capacity building of implementing agencies and to prepare project documents (detailed project reports, environmental and social safeguards compliance, setting up of project monitoring units, etc.). However, accessing such loans is through national-level agreements, in which states have limited say. Some loan conditions may have provisions for policy and institutional improvements that state governments need to adhere to. Usually national budget support and monies from external borrowings cover a part or full capital expenditure, while operations and maintenance (O&M) is sought to be managed by state or implementing agency. As O&M expenses are also of huge magnitude, there has been a continued stress on finances of these agencies.

The quantum of funds required for meeting the O&M expenditure is increasing, while there is increasing attention to recovery of capital expenditure invested for development of projects. With the sources of funds becoming scarcer by the day, as more and more new projects seek assistance from the same sources (domestic and international), there seems to be a perceived shortage of funds for new projects. Hence, the need for finding methods to recoup the investments made in the sector is increasingly felt. Project proponents and policy makers including different nations are recognizing that the past projects have not paid off in financial terms, though economic benefits are positive, due to problematic and inefficient use of current water systems. Continued financial support to this sector is sought to be augmented by two other sources – collecting user charges from those who consume water and soliciting private sector participation in a few projects. Revenue collection from user charges depends on number of users brought into this ambit and rates that are proposed to be charged. Given the holdings size in India, as conventionally water has been provided free/accessed free of cost, there is a challenge to get these farmers to adopt system of user charges.

[1]International Bank for Reconstruction and Development.

[2]Japan International Cooperation Agency.

[3]Deutsche Gesellschaft fur Internationale Zusammenarbeit GmbH (German aid agency).

2.2 Public-Private Partnerships Experience

Government departments and other project proponents have been exploring public-private partnerships (PPPs) as a means to improve efficiency in general but also raise finances in particular in infrastructure sectors. PPP frameworks in irrigation sector are quite nascent and have not really taken off similar to the trend witnessed in transport sector. In this format, it is anticipated that private sector puts in varied amounts in capital expenditure and O&M expenses, manages the project, and recoups its investment through a variety of means including user charges, grants/payments from government, utilizing ancillary facilities such as land, putting project resources to other uses, etc. National Water Policies also consider PPP as one of the options for raising finances for I&D projects. Internationally, PPPs are used in service-oriented frameworks for improving efficiency and occasional infusion of investments. The success of international PPP projects is witnessed in situations where the public sector contributed significantly to the capital costs, and the private sector is made responsible for O&M expenditure and delivering water supply systems. However, the demographic profile of farmers in India is different, with a significant number of farmers having landholdings that are categorized as small (0.5–2 ha), with consequent lower ability to pay for input costs. It is imperative for the state to bridge the gap between the expenditure and the revenues that accrue from user charges. Lack of a robust revenue model, hence presence of a secure payment guarantee, is sought by most private sector organizations, and the same need to be configured by the project proponents to mitigate the risks. Despite provision in the National Water Policy and number of enabling initiatives undertaken by the government, unlike other sectors, there are very few reported PPP projects in Indian irrigation sector currently, as private organizations perceive lack of crucial conducive framework and a robust revenue model to make investment decisions. Numerous challenges faced by water resources sector in India further complicate the situation. Most of Indian PPP projects, specifically in the highway sector, have been implemented under a build, operate, and transfer (BOT) concession model, but given the sectoral differences, the same model does not appear to be applicable in irrigation sector. On the contrary, the circumstances seem favorable for service contracts with private sector role restricted to delivering high performance standards.

2.3 Water Pricing and Allocation

Recovery of monies, either partially or fully, for expenditure incurred by government has been a topic of debate and contention for a while. Irrigation user charges in Indian context would need to address issues that spread across demographic, regional, social, and economic realms (Sangal 1991; Rao 1991; Planning Commission 1992). Various countries have practiced different mechanisms of charging and collecting monies from irrigation users (Wichelns 2010; William 2005;

Sampath 1992). The modalities adopted by different countries include one or more of the following:

1. Volumetric assessment of demand is a common method, while there are instances of quantum of water being converted to time – minutes of supply from streams (as from a supply) as noticed in Israel and Peru (volumetric pricing principles are adopted with a low base that increases with consumption of larger quantum of water).
2. The user charges are determined based on multiple parameters such as the type of crop, season, and water consumption rate per area. Most nations charge a higher user fee when the water is provided through capacity works in relation to water being drawn directly from streams. The charges are based on the input power costs in many systems, indicating higher charges for lift systems than the systems based on gravity.
3. Extra land tax in light of expanded increased advantage from giving water irrigation systems.
4. The increased land value of surrounding areas, due to provision of irrigation, is sought to be captured through levy of betterment levies in some instances.
5. A flat, periodic (typically annual) irrigation cess (calculated on the basis of irrigable landholding) is levied, irrespective of consumption of water.
6. Levy of a maintenance cess on an annual basis that aims to recover the O&M costs incurred.

In India, all open water system frameworks are controlled by the government, and there is no immediate direct equation between user charges and investments made/being made. The water rates vary from state to state, often decided by political exigencies. It is increasingly acknowledged that water rates that are being charged are sponsored and are significantly less than even the recurring O&M costs (Kulkarni 2007). The most widespread practice in India with respect to charging of irrigation water is based on area. The considerations forming the basis for water charges include source (surface water, groundwater), supply type (gravity, lift), season (rainy, winter, and summer), type of crop (food grain, cash crops), duration of crop growing season (seasonal, two seasonal, and perennials), method of irrigation (drip, sprinkler), land classification (like wet and dry lands), and scale of the project (major, medium, and minor).

The National Water Policy of India (as set out in 2002 and reiterated in 2012) emphasizes that principles of equity and social justice need to be adhered while allocating water for irrigation purposes and that pricing of water needs to factor the quantum consumed (volumetric basis). Now many states have adopted participatory irrigation management (PIM) approach, where irrigation water is supplied to the Water User Associations (WUAs). Irrigation commission (1972) recommended that the water rates should be 5–12% of the total value of farms' produce, lower for food crops and higher for cash crops. Vaidyanathan Committee (1992) recommended "a two-part tariff comprising a fixed charge applicable to entire command area as a membership charge, a variable charge based on area irrigated to recover annual O & M cost, and 1% interest on the capital cost." Full cost recuperation was recommended to be a definitive objective. Some of the suggestions have been executed by a few state governments. The volumetric pricing of water system is one among others that has been implemented to a limited extent in a few projects.

In India, support to water sector comprises subsidizing energy that farmers use to pump groundwater. Institutional, political, and organizational structures have been so developed that within a broad-based democracy, politicians risk losing voting support if they introduce policies that significantly alters prevailing systems. With subsidies being used as incentives, indirect result is of indiscriminate overpumping of groundwater, putting undue strain on aquifers and creating issues for downstream users.

Assessing exact quantum of water that is being supplied and consumed is critical for adopting volumetric pricing strategies. While this is apparent in the developed world, where there are large farm sizes and modernized water system frameworks, it is much harder in developing nations. Farm sizes can be as little as a fourth of a hectare, water system is frequently decentralized, and water reaches cultivator fields by means of gravity through little, sporadic trench. Unlike in developing nations, such infrastructures are seldom constructed, and end users are not accustomed to paying for resources.

Water rates of minor water system activities ought to be to such an extent that they can completely cover O&M charges. One of the approaches to reduce user charges is to minimize capital cost based on efficient construction and its consequent operations and maintenance.

River Valley Division Council had approved the draft finalized by Water Resources Planning, Management and Evaluation Sectional Committee which formed the basis of standards promulgated by the Bureau of Indian Standards. The guidelines for fixing irrigation water rates, laid down in this Indian standard, are based on the recommendations of the following commissions and the National Water Policy, 1987:

(a) Maharashtra State Irrigation Commission 1962.
(b) Irrigation Commission 1972.
(c) National Commission on Agriculture 1976.
(d) 10th Finance Commission 1994
(e) Vaidyanathan Committee Report 1992.

Guidelines to frame uniform water rates in the country need to account for cropping pattern and geographical, seasonal, and systemic differences. Some of the features of water pricing practices prevailing in India include the following:

1. In some states water rates on lift irrigation schemes are lower than corresponding rates for flow irrigation schemes. However, in some states it is the reverse. For example, in Gujarat water rates for lift irrigation schemes on canals are half and on rivers one-third of the flow irrigation rates. In Maharashtra water rates on private lift irrigation schemes on storage reservoirs or between a dam and pickup weir are half of the water rates for flow irrigation (More 2016). UP is a similar example.

2. In Haryana, if water from any state irrigation work is lifted by any cultivator at his cost, he is charged half of the flow irrigation rates (Hellegers and Perry 2007). No water cess or irrigation cess is levied.
3. In Kerala the water rates on lift irrigation schemes are 50% more than flow irrigation schemes. Similarly in Goa, Daman and Diu water rates on lift irrigation schemes are higher compared to gravity flow schemes.
4. Maharashtra has levied additional rates on irrigated areas in the past. These are state government charges (1989) for (1) local cess on water rates at Rs. 0.20/ha, (2) additional charge known as education cess which varies from Rs. 40/ha for groundnut to Rs. 190/ha for sugar cane, and (3) employment guarantee cess at Rs. 25/ha on all irrigated agricultural land.

3 Financial Analysis for Development of Irrigation Project

The need for user charges emanates from the fact that there is a continuous decline of share of financial resources earmarked for I&D sector. India set its first priority to irrigation since 1st 5-year plan after independence in 1947 due to growing concerns on food stress and started planned development with the provision of about INR 3760 million, which was around 22.54% of all sectors. Plan expenditure on irrigation and flood control has increased tremendously over the next 65 years, and provision for irrigation and drainage sector rose to about INR 2117 billion during the 11th 5-year plan (2007–2012), amounting to a total expenditure of around INR4820 billion up to end of 11th plan (March 2012) (GoI 2014, 2015). However, there was a gradual shift in the emphasis to other dominant sectors, and by the end of 10th 5-year plan, share of irrigation and flood control reduced to 6.28%. During 12th 5-year plan (2012–2017), an outlay of INR4220 billion[4] has been made for irrigation and flood control sector, which is almost double of expenditure made during 11th plan period (GoI 2013).

In fact, one of the key reform areas that the government had prioritized in its budget 2016–2017 was the agriculture and farming sector. The government is looking to double farmer income by 2022 and recognizes that interventions in the farming sector need to be reoriented to optimally utilize water resources with improved service delivery. A dedicated irrigation fund of Rs. 200 million has been announced in the budget to bring about 2.85 million hectares under irrigation and for sustainable groundwater management. It is increasingly being thought that government sector alone may not be able to fill in these gaps related to financial and operation and management resources. With increasing strain on public finances, user charges could alleviate a certain portion of investments required.

[4]Source: 12th Five Year Plan (2012–2017) – Faster, More Inclusive and Sustainable Growth, Planning commission, Government of India.

To assess the extent of user charges that are required to be paid for an investment decision, financials of a typical irrigation project are considered, on a standardize basis. The data from Nira-Deoghar, a project in Maharashtra, is taken as an illustration, based on scoping study on PPPs in the irrigation sector in India conducted by ADB (Varma et al. 2010).

3.1 Project Description

Nira-Deoghar irrigation project is spread across three districts of Maharashtra – Pune, Satara, and Sangli, located about 90 km south of Pune near Deoghar village. This project on Nira River consists of 59 meters high and 2320 meters long dam with total capacity of 337 million cubic meters. This project was approved in 1984 with an estimated cost of INR 615 million, which escalated to INR 9100 million by 2000–2001. Ninety-five percent of construction has been completed since many years.

The project was proposed to be offered to the private sector on a BOT basis by the project proponent, the Maharashtra Krishna Valley Development Corporation (MKVDC). As a first step, expression of interest was invited from the private parties by MKVDC. The project structure envisaged that the private sector would manage the project for a designated lease period and hand the project back on completion of the period to the water resources department. MKVDC proposed multiple revenue streams to the private sector for recouping the money invested by them, including levying user charges for water consumption, allowing development of fisheries and tourism facilities. The private sector developer/consortium was also provided with option to engage in contract farming with landowners in the command area.

Nira-Deoghar is a brownfield project, and the scope of work includes redevelopment including building an earthen dam (of 2330 m length, 58.525 m height), a masonry gated spillway of 70 m, and right and left bank lined canals and canals for lift irrigation (208 km and 21 km respectively). On completion, it is envisaged that the project could serve an area under irrigation of 43,050 ha (CCA).

3.2 Financial Assumptions

The financial assessment is undertaken based on the report prepared by MKVDC that set out the capital. Costs were reviewed in 2007–2008. Total project cost including financing charges and interest during construction has been estimated to be Rs. 19395.7 million. The financial assumptions for the project include those set out in Table 1.

Table 1 Financial assumptions for the project

Item	Value
Construction period (years)	7
Model period (years)	55
Inflation (%)	5
Pre-op expenses as a % of capital cost	0.5
Contingency (as a % of capital cost)	3
Inflows (receipts and recoveries) (Rs. million)	13

3.3 Debt and Equity

The debt equity ratio assumed for the project is 70:30; based on the estimated project cost of Rs. 19395.7 million, the debt is estimated to be Rs. 13,577 million, and the rest Rs. 5818.7 million is assumed to be contributed as equity. It is assumed for the base case that there is no grant for the project. As the project is expected to have a life of nearly 100 years, the loan tenure is assumed at 30 years. The loans are expected to be given at an interest rate of 12%.

3.4 O&M Expenses

The estimation of O&M expenses is based on the following assumptions (item, norm, cost per annum):

- Dams and canals – 1% of capital costs increased by 3% p.a. – Rs. 134.8 million.
- O&M costs for CAD – Rs. 1000 per ha – Rs. 43.1 million.
- Technical investigations, surveys, and improvements, research – 0.1% of capital cost – Rs. 14.9 million.
- Direction and administration – 20% of total O&M costs – Rs. 48.2 million.

The total annual O&M costs are estimated to be about Rs. 240.9 million.

3.5 Revenues

Various possibilities of revenues for the project include (i) water charges (assumed at Rs. 1100[5] per ha – the collection efficiency is assumed to be 40% in first year with gradual increase to 75% in fifth year and remaining constant subsequently) (ii) income from development of fisheries (at Rs. 8682 per ha of the 792.5 ha of total area. Half of the revenues from this source are expected to be retained by private

[5]It is weighted average of the user charges set by the concerned government agency for different crops for this particular project.

Table 2 Revenue projections for initial years (*INR million*)

Year	8th	9th	10th	11th
Water charges	18.9	23.7	31.3	36.5
Fisheries	3.40	3.50	3.60	3.80
Sale of surplus available water	20.0	20.9	21.9	22.9
Tourism	39.5	40.7	41.9	43.2
Total	81.9	88.8	98.7	106.3

sector), (iii) tourism activities (entry tickets, boating, and miscellaneous charges), and (iv) sale of surplus water (at INR 6.6/cum[6] for 3.03 MCM surplus water available for drinking).

The revenue projections for select years are presented in Table 2.

3.6 Viability Assessment

The financial assessments (internal rate of return (IRR) and net present value (NPV)) of the project are calculated based on the above assumptions for different periods (20, 25, 30, 40, 50, and 55 years). The project indicates a negative IRR of all different time periods. The project NPV is also negative for all project periods with the values Rs. (10.3) million for 20- and 25-year period and Rs. (10.4) million for subsequent time periods.

Typically private sector requires a project IRR of around 15% to be considered as viable. The analysis for this project indicates that the calculated values fall short of private sector requirements by a huge margin. A review of the year-on-year cash flow indicates that the income from all streams is lesser than the debt service requirements (i.e., the sum of annual interest and principal payments). This indicates that the debt-bearing ability of the project is insignificant. There is a need to infuse equity over multiple years to make the project viable.

The primary source of revenues is the water charges from the farmers, which are much lower than required purely for financial viability (for the purposes of illustration, assuming all other factors remain undisturbed). In order to reach the private sector threshold of project IRR, the user charges would need to be increased to an unrealistic level of Rs. 150,000 per hectare.

As the project is nonviable at these assumptions, a few other commercial activities need to be added to improve the financial viability. Some of them include allocating additional land for commercial use, exploring options of constructing toll roads along the canal, and increasing the tourism-related activities. These are very project-specific options, and implementation needs further assessment.

[6]Based on estimation for another major irrigation project.

A review of the financial of Nira-Deoghar project indicates that with the water charges in vogue, the income generated is not adequate to meet even the operations and maintenance expenditure. The revenues of irrigation projects, hence, would need to be augmented with either substantial grants or needs to be provided with additional sources of revenues. These could be in form of commercial activities, tourism, fishing, contract farming, etc. However, these are very specific to the project under consideration and cannot be generalized. Moreover, as most irrigation projects are likely to be based away from urban centers, getting enough footfalls for these projects would be a challenge. Even with augmenting the project revenue sources, large projects might have cash flow shortages to service debt.

It would become imperative for the public sector to substantially finance the irrigation projects, both for the capital expenditure and for the O&M expenditure. Private sector role would primarily to improve the service delivery standards and to improve operational efficiencies. To attract significant private sector interest and to mitigate the risks perceived, the public sector project proponents would need to configure a project that reduces the financial commitment while focusing on service delivery standards. Equitable commercial structuring in form of payment guarantee mechanisms would go a long way to sooth the private sector concerns. The scope and rewards should also consider capacity of farmers to adopt more efficient farming practices while encouraging them to pay for input water in a sustainable manner.

4 Conclusions and Way Forward

Financing for sustainable water management has been a complex issue with no immediate solution being apparent. Given the scale and nature of investments, the role of public sector will continue for foreseeable future, albeit with certain improvements in institutional, governance, and implementation capacity. There were anecdotal statements made that a few states would need to spend budgetary amounts (as expended at current levels) for another decade or so to finish ongoing projects. On top of this, fresh investments would be required. As availability of long-term external borrowing is becoming competitive, government agencies are looking for other options for bridging the gap with PPP projects and levying user charges. Given the sheer economics of a typical project, there has not been a visible success in PPP model. User charges are very low to even cover O&M expenses fully. Adding other sources of revenue is very context specific and cannot be seen as a scalable option. Agencies are now reconfiguring PPP models to reflect service obligations, with most of capital and O&M expenditure being borne by government. User pay principle has been a point of contention due to holding pattern, social practices, and ability to pay. While a number of experts have suggested that this needs to be adopted, in practice only a few states took initial steps toward the same.

It is imperative for government to be involved in user charges pricing due to the following reasons:

1. The current market characteristics could not be categorized as entirely in the nature of "free market" as there is no established framework of robust private property rights. In the absence of free market conditions, it is not prudent to let the private players entirely decide the allotment of surface water systems and their improvement. Establishing such a framework would entail more structured property rights regime (clearly articulating the type, quantity, quality, geographical limits, and period/time of application). The property rights transferability (market for trading, its robustness, and ease of transactions) needs to be addressed. Other factors that determine the free market regime in terms of competition (for both supply and demand) and externalities need to be factored.
2. Irrigation water projects have the potential of economies of scale that could be captured by the public sector/government. Such economies of scale are possible in most of the components, such as capacity, transmission, and dispersion of water. Public involvement would portray and protect the public good nature/collective good nature of irrigation water.
3. The public sector can better manage the externalities that could arise over time, vis-a-vis the private sector particularly those relating to administration issues.
4. The fourth reason why public sector involvement is necessary is to ensure social equity and associated targets (wage redistribution, nourishment independence, and practical irrigation production).

The political will for developing an equitable water pricing system seem to be lacking, although almost all official committee reports have recommended promotion of such practices. Over the period, various public functionaries and policy makers (Sampath 1992; Koppen 2006; Kulkarni 2007) have provided suggestions for improvements in pricing framework. Some of the suggestions include:

1. One of the primary objectives of pricing of water should be to make the users realize the scarcity of this resource and improve the motivation to put the same to effective, unwasteful use (Ahmadi 2015). The extent of recovery to compensate for the O&M costs and part of fixed costs is driven by project-specific conditions. This condition should ideally be reached over a period of time without hampering the existing service delivery standards. Given the large number of smaller farmers, the rates should be so set that usage of ground and surface water is balanced and the interests of this group are not significantly affected.
2. Volumetric pricing has advantages over the flat rate water charges that are currently being used. Volumetric pricing can promote the usage of appropriate quantity of water and make the users aware of the value of the resource and encourage them to adopt more efficient irrigation practices. The volumetric pricing need not be uniform across a geographical region but could be customized for the project under consideration. However, the principles of pricing need to be transparent and properly communicated to the users, so as to avoid unfair

comparisons. A corollary of this arrangement is to set up infrastructure/metering systems to measure the quantum being consumed.
3. The water markets should be made more robust and liquid to enable transactions of water rights in a manner that does not constrain the supply of water for immediate needs.
4. Adoption of user pay principles. Attain an equitable position that provides for a commensurate price that meets costs incurred. Different accounting and assessment principles were suggested (Dinar 1997) – aggregate basis or average costs, etc.
5. Review and design subsidies to water system that are region specific and based on cropping patterns and yields.
6. Ring fence the O&M activities and the related expenditure, and aim for recovery of this expenditure from the sale of water. The implementing and governing agency capacities and institutional structures should be appropriately restructured.
7. To make a meaningful impact on water rate changes, users ought to be consulted while framing guidelines and in the institutional system being formulated.

Acknowledgments This work is based on a study carried out by Asian Development Bank (ADB). The authors extend thanks to Shri H Verma and other colleagues in ADB during preparation of this manuscript.

References

Ahmadi SAY (2015) Design and evaluation of irrigation water pricing policies for enhanced water use efficiency. J Water Res Plan Manag 142:5001–5011
Dinar YT (1997) The relative efficiency and implementation costs of alternative methods for pricing irrigation water. World Bank Econ Rev, 11(2), 243–262. FAO'S AQUASTAT data. Available at: http://www.fao.org/nr/water/aquastat/main/index.stm
Government of India (2013) Planning commission, twelfth five year plan (2012–2017) – faster, more inclusive and sustainable growth
Government of India (2014) Central ground water board, ground water year book of 2014. Available at: www.cgwb.gov.in
Government of India (2015) Central water commission water and related statistics 2015
Hellegers PJGJ, Perry CP (2007) Water pricing in Haryana, India. In: Berkoff FM (ed) Irrigation water pricing. CAB International, pp 192–207
Koppen TS (2006) Is India ripe for integrated water resources management? Fitting water policy to national. Econ Polit Wkly 41(31):3413–3421
Kulkarni SA (2007) Volumetric pricing of irrigation water in India: experiences and lessons learned. In: International Commission on Irrigation and Drainage (ICID), New Delhi
More DM (2016) Traditional water management practices of Maharashtra, President, Maharashtra Irrigation Collaboration, paper presented during India Irrigation Forum, New Delhi
Planning Commission, Government of India (1992) Pricing of irrigation water. New Delhi
Rao KP (1991) On irrigation water pricing in India. Int J Water Resour Dev:274–280
Sampath RK (1992) Issues in irrigation pricing in developing countries. World Dev 20(7):967–977
Sangal SP (1991) Pricing of irrigation waters in India. Economic & Political Weekly

Varma HK, Raghu RS, Dhingra DTV, Amarjit S (2010) Exploring public private partnership in the irrigation sector in India, Asian Development Bank 2012 water pricing and allocation. International Water Management Institute (IWMI)
Venkateswarlu B, Prasad JVNS (2012) Carrying capacity of Indian agriculture: issues related to rain fed agriculture. Central Research Institute for Dryland Agriculture, Hyderabad
Wichelns D (2010) Agricultural water pricing: United States. Indiana: Organisation for Economic Co-operation and Development
William EK (2005) Cost recovery and water pricing for irrigation and drainage projects. The International Bank for Reconstruction and Development/The World Bank, Washington, DC

D. T. V. Raghu Rama Swamy is a senior lecturer in the Faculty of Architecture, Building and Planning at the University of Melbourne. His research focuses on public-private partnerships, infrastructure development, financing and delivery of urban services. Previously, as the professor and director at RICS School of Built Environment, he had set up the School of Infrastructure and designed the MBA programme in infrastructure management. Earlier, he was the CEO of Infrastructure Development Corporation (Karnataka) Limited. He has over 23 years of experience in infrastructure consulting practice, academics, research and capacity building. Few of his important publications are, *Exploring Public-Private Partnership in the Irrigation and Drainage Sector in India* (Asian Development Bank, 2013), book chapter in *Healthy Future Cities* (China Architecture and Building Press, 2017) and several journal articles.

Civil Society in the Water Sector

Avinash C. Tyagi

1 Introduction

Often water governance debates are centred around either institutional reforms within the state or the scope and constraints of implementing market solutions. Considering the nature of the water development issues which touch all sections of the society, all spheres of development and stakeholders that are often unrepresented, there is a need to examine the role civil society organizations can play in improving water governance. This article presents Indian scenario of the civil society's contributions in water sector in order to understand what gaps do exist in making optimal use of the civil society in development and management in the water sector in India.

According to the Johns Hopkins University's Centre for Civil Society Studies[1], which quantifies the contributions of civil society, 75% of civil society actors spend their time delivering social services, education, health and others to vulnerable populations. This is a segment that shows its greatest impact in communities.

The engagement of civil society and other stakeholders in the run up to adoption of Agenda 2030 for Sustainable Development by the UN General Assembly in September 2015 served to greatly enrich the debates and build global awareness. It is fully recognized that sustainable development goals (SDGs)[2], which aim at tackling the world's biggest problems, starting from eradicating poverty to reducing

[1]Lester M. Salamon, S. WojciechSokolowski, Megan A. Haddock, and Helen S. Tice, (2012) 'The State of Global Civil Society and Volunteering: Latest findings from the implementation of the UN Non-profit Handbook'. Working Paper No. 49, Baltimore, Johns Hopkins Centre for Civil Society Studies.

[2]United Nations, 2015, 'Transforming our world: the 2030 Agenda for Sustainable Development', Resolution A/RES/70/1 adopted by General Assembly on 25 September 2015.

A. C. Tyagi (✉)
Former Secretary General, International Commission on Irrigation and Drainage, New Delhi, India

© Springer Nature Singapore Pte Ltd. 2019

A. Singh et al. (eds.), *Water Governance: Challenges and Prospects*, Springer Water,
https://doi.org/10.1007/978-981-13-2700-1_18

inequality or tackling water scarcity, require greater participation of various stakeholders. Civil society organizations (CSOs), which work outside the spheres of the state and businesses, can play a vital role in tackling the challenges presented in achieving SDG 6 on clean water and sanitation.

Participatory approach, involving users, planners and policy-makers at all levels of management of water, is anchored in the Dublin Principles[3] for Integrated Water Resources Management. This participatory approach involves raising awareness of the importance of water among the entire spectrum of stakeholders: from policy-makers to the general public. It requires decisions to be taken at the lowest appropriate level, with full public consultation and involvement of users in the planning and implementation of water projects.

Growing conflicts due to water scarcity in India and their social, political and economic impacts on various development sectors require an ever-increasing assignation of various stakeholders. Civil society at large can play an important role in shaping water resource management solutions suited to particular conditions. In particular, civil society can help ensure equity among the multiple users and uses of water. Civil society has the ability to stimulate and support governments in creating opportunities for and ensuring effectiveness of dialogue with all stakeholders by ensuring educated participation of stakeholders in decision-making.

2 Civil Society in Water Sector in India

The phrase ‘civil society’ in India[4], which gained general currency since the beginning of the 1990s, collectively defines individual and organizational initiatives for public good. It is also known as the social sector, the non-profit sector or the ‘third’ sector. In India the term covers (1) community-based organizations (CBOs), (2) mass organizations, (3) religious organizations, (4) voluntary development organizations (VDOs), (5) social movements, (6) corporate philanthropy, (7) consumer groups, (8) cultural associations, (9) professional associations and (10) economic associations.

The UN defines NGOs as: ‘any non-profit, voluntary citizens’ group, which is organized on a local, national or international level task-oriented and driven by people with a common interest’ NGOs perform a variety of service and humanitarian functions, bring citizen concerns to governments, advocate and monitor policies and encourage political participation through provision of information. Some are organized around specific issues, such as human rights, environment or health. They provide analysis and expertise, serve as early warning mechanisms and help monitor and implement international agreements. Their relationship with offices and

[3]The Dublin Statement on Water and Sustainable Development, 1992.

[4]Tandon, R. (2002a), Voluntary Action, Civil Society and the State, New Delhi: Mosaic Books.

agencies of the United Nations system differs depending on their goals, their venue and the mandate of a particular institution.

Since the 1980s, civil society groups have come to be more popularly known as NGOs, and they have become more focussed in their actions. In the water sector and perhaps in other sectors as well, the voluntary movement can be broadly categorized into three major groups: development NGOs, advocacy NGOs and the activists.

The traditional development NGOs work in a village or a group of villages and demonstrate various means of water conservation practices, etc. These NGOs engage themselves in a variety of rural development and social issues, and their entry point may or may not be water. Although there are thousands of such organizations active at the village level, the two important names that come to the mind are the *Tarun Bharat Sangh* and the *Ralegaon Siddhi* experiment that have resulted in rural transformation through better watershed development. The experiences of Tarun Bharat Sangh are presented elsewhere in this volume.

The second group of NGOs advocate with the government or with industry or petition the courts for improvement in the sector based on research in a particular issue. A well-known example of an NGO of this type in the environment field which is active in water sector is the Centre for Science and Environment (CSE). For example, CSE picked up samples of well water and then submitted the results of the chemical analysis to a court because the organization had not been able to get the factory to change its polluting practices in any other way. Professional associations, such as the Institution of Engineers or Indian Association of Hydrologists, can play a role in bringing science to the policy and decision-makers.

The third group can be said to include community of volunteers who see themselves as advocates of certain cause also called activists. Of course, all NGOs undertake a certain amount of activism to get their points across – petition the bureaucrats and alert the media whenever they find something wrong and so on. But this third group of NGOs see activism as their primary means of reaching their goals, because they do not believe they can get the authorities to move in any other way.

Perhaps the most-known example of an NGO in this category in the water sector is the *Narmada Bachao Andolan* (NBA), an organization that opposed the construction of a series of large dams in the Narmada river valley of central India. They oppose the dam construction ostensibly for the reason that it entails displacement of people upstream of the dam. The members of this NBA adopted confrontational approach on the construction of Sardar Sarovar project in Gujarat delaying the entire development process. They ended up creating a make-belief atmosphere that all large dams worsen water scarcity for the majority of the people in the long run rather than solve the scarcity problem. The conduct of NBA has resulted in creating a trust gap between the government and NGOs in water sector in India.

There is a strong view in the development sector that some of the NGOs belonging to this activist category fail to take a holistic development approach and focus on narrow perspective and take a piecemeal approach focussing on a limited aspect of development. So much so that often they allow themselves to be a prey to an unscientific approach. For example, the debate on environmental flows in India is presently mired in emotional rhetoric and is largely devoid of scientific reasoning.

Realizing the need for bridging some of these gaps between development facts and fictions, the Ministry of Water Resources had encouraged setting up of a few civil society organizations in water sector such as the Indian Network on Participatory Irrigation Management (INPIM), the Indian Water Partnership (IWP) and the Indian Water Resources Society (IWRS).

The Indian Water Resources Society (IWRS) was founded in 1980 with the main objective of advancement of knowledge in technical and policy aspects of water resources development and management. IWRS, acting as a think-tank, was intended to serve as a platform for free and frank discussions among those concerned with water-related issues and facilitate co-operation among the civil society with the government agencies instead of confrontation. Concerned with the rise in the misinformation campaign unleashed by misplaced activism, IWRS has been advocating for open and informed debate based on the scientific facts rather than relying on unintended myths. They have intended to be a source of scientific information on seemingly complex issues. IWRS advocates for peoples' informed participation for which they initiated celebration of the Water Resources Day since 1988, which was subsequently adopted by UN as World Water Day, observed on 22nd of March every year. Unfortunately, IWRS has failed to live up to its mission of providing a multi-stakeholders' platform and organize open debates. One of the major causes for the failure of IWRS lies in its management structure as it has been headed and managed by the same people who are incharge of the sector in the government.

Established in 2001, IWP is a non-profit organization that promotes IWRM. Largely supported by the Global Water Partnership, IWP networks with other NGOs active in water sector in the country by hand-holding them and also to make them allies in advocacy, influence state policies and reinforce knowledge sharing, communications and capacity building at the grass-roots level.

3 Civil Society Organizations in Water Sector at International Level

The United Nations Conference on Environment and Development (UNCED, 1992) gave a call for broadest public participation in poverty eradication and sustainable development. Civil society is increasingly seen as a key player in this process, complementing the work of state actors and intergovernmental organizations.

Civil society movement within the water sector at the international level came to the forefront with the setting up of a network of institutions from around the world as Global Water Partnership (GWP) in 1996 to foster integrated water resource management (IWRM), an approach that has its origins in the guiding principles for action in the Dublin Statement issued at the International Conference on Water and the Environment (ICWE) in January 1992. GWP network is open to all organizations involved in water resources management: government institutions, professional associations, research institutions, non-governmental organizations and the private sector. It has helped establish Country Water Partnerships as well as some regional and area-level partnerships.

In the same year, the World Water Council was formed as an international multi-stakeholder platform to promote awareness, build political commitment and trigger action on critical water issues at all levels and to facilitate the efficient conservation, protection, development, planning, management and use of water in all its dimensions on an environmentally sustainable basis for the benefit of all life on earth. The World Water Forums organized every 3 years is the flagship activity of the Council. Indian linkages with these international civil society movements have been weak at almost all levels: at the government, the institution, the civil society or the individual level.

4 Civil Society Interventions in India

In a large developing country like India, despite best efforts by the government, numerous gaps in the development process do remain – sometimes intentional, sometimes due to lack of funds, often due to lack of coordination among various institutions and sometimes due to lack of awareness. NGOs play an important role in filling these gaps. In the last 20 years or so, a very large number of NGOs in India have been active in the development process especially in the area of environmental safeguards.

In the context of water sector, the focus has specially been on ensuring access to and control of people (including the most marginalized sections) over water. Here, normative issues of social justice, equity, participation, sustainability, etc. become important along with ensuring accountability of state in its functioning in the water sector. Empowering the NGOs and engaging them constructively for the overall benefit of the society are marred by controversies with questions of accountability, legitimacy and most importantly transparency.

It is important as well as necessary to understand the developmental role played by the civil society organizations, especially their role in governance including the scope and constraints of NGOs as civil society actors in governance, as well as to learn from success stories of working with government as service providers and indirectly influencing public policies including learning from the past experience the scope and constraints of influencing public polices through confrontational politics to bring in structural changes.

Before involving NGOs in government-led development activities, it is important to understand why do NGOs work with the government and what are the motive and the logic behind such collaboration. An understanding of the core values that define the work of NGOs and how these values are different from those in the spheres of government is crucial. Strategies of such organizations could be manifold ranging from collaboration to working as development appendages of the government along with occasional confrontations on specific issues. At the same time, it is also important to be aware of the external factors like donor funding that influence policy and the responses from civil society. At the same time, it is important to evolve parameters of ‘success’ such as equity, gender relations and efficiency of delivery and how NGO strategies do strengthen peoples’ abilities to access and manage water better. Care needs to be taken to avoid a situation where NGOs are getting so close to the government that their credentials for independence and autonomy are lost or weakened as a result.

Civil society interventions cover the entire spectrum of interventions such as bridging the gap between science and policy and local sustainable solution in WASH, encouraging water harvesting, capacity building in use of new technology and seeking legal intervention to assert societal right above the private and individual profiteering. Two of these are briefly described in the Appendix. More than organizational interventions, these initiatives raise fundamental questions on the current water development paradigm. Most of the interventions by NGOs have worked at a micro-level: in a village, in a watershed or in a small basin. Without sustained support and participation of the larger communities, it is difficult to upscale these initiatives.

Traditional development NGOs working at the grass-roots level are multifaceted and engage the locals in various facets of development whether it is health, family planning, women’s issues, water management or micro-financing. Many times, the local functionaries do not have adequate technical information to convince for change in a particular behaviour or to convince the stakeholders. Even the advocacy NGOs sometimes get swayed by popular perceptions. Professional scientific NGOs need to play the role of bringing knowledge to the public domain and orient the debate on scientific facts. They should provide the scientific basis to the efforts of ground-level NGOs. Professional NGOs who confine themselves to bringing out technical papers should address the needs of development NGOs and keep the public and policy debates on scientific track. Government and CSR funding are called for to support professional organization willing to take this responsibility.

It is important to recognize that successful intervention from NGO requires a dedicated leadership and the support of its stakeholders – users, local water management authority, community-based organizations (CBOs), volunteers, etc., and sustained financial mechanism and hydrologically sound activities – to operate and sustain itself. However, the causes of successes and failures are not adequately identified, fully examined or adequately documented. The possibilities of upscaling such community-based initiatives – either as larger projects or through greater number of such projects – have not been adequately explored. There is a strong case for intervention in upscaling such NGO initiatives by making suitable policy interventions, providing adequate legal framework, establishing support mechanism or undertaking capacity development to ensure that they are economically feasible and environmentally sustainable.

5 Conclusions

It is important to accept the gaps that exist in the delivery of water-related services and identify the character of the space for civil society action to bridge that gap. Water sector governance will be served positively if the influence, effectiveness and pitfalls of the activities (related to public advocacy) of voluntary organizations and social movements at different levels in the country are acknowledged and analysed.

The increasing water-related conflicts between various sections of society and the emotional nature of the limited debate that takes place are indicators of the gap between science and society on one hand and science and policy on the other. There is a need to bridge this gap without further delay to resolve the conflicts in an amicable fashion for achieving sustainable development objectives.

In order to unleash the vast potential coiled up in the civil society organizations engaged in water-related activities, the government needs to undertake the following steps to get their positive and constructive support:

(a) Create enabling environment for capacity development of the grass-roots level NGOs through a consortium of knowledge base professional NGOs.
(b) Support professional civil society organizations such as the India Water Partnership to be able to provide multidisciplinary perspectives and create an independent evaluation mechanism.
(c) Analyse and understand the reasons and obstacles in scaling up the successful NGO initiatives.
(d) Recognize that such reasons may vary from region to region and the culture of cooperatives and the past history of success (or failure) and accordingly adapt.

The guiding principles of responsive governance are accountability, transparency and participation, and the key attribute and criteria of its success is the process. Responsive governance for development, particularly in water sector, requires empowered government-citizen relationship where accountability of the officials is towards citizens and stakeholders. Unfortunately, there is no formal platform or mechanism for developing such a relationship with stakeholders in the water sector. There is a need to develop a relationship of mutual respect shifted even more towards one of cooperation, complement and mutual empowerment.

In order to empower the stakeholders in settling their conflicts, taking appropriate decision on sustainable development in the most equitable manner, the government should consider enabling water sector NGOs financially and technically. There is a need for developing a strategy for making efforts of thousands of NGOs engaged in water sector more meaningful and effective.

Acknowledgements The author is thankful to the management of International Commission on Irrigation and Drainage, New Delhi for permission to publish this article. Thanks are also due to my colleagues in the Ministry of Water Resources, Government of India, World Water Council and in Global Water Partnership who shared their experiences while working with civil society organizations.

Appendix

Community Mobilization and Safe Water Access: One Drop Project, India

One Drop project in Orissa, India, implemented over 4 years (2011–2014), attempts to carry out sustainable solutions to the problem of poverty through a WASH program designed and implemented by *Gram Vikas* through access to toilet, a bathing room and water availability 24/7. It draws inspiration from circus creativity by developing artistic activities firmly rooted in local culture to raise collective awareness, educate and mobilize the populations around WASH issues in order to inspire people and enable the process of social change. It involves more than 58,000 people of both genders, all ages and castes.

The behavioural change activities helped to raise communities' awareness and understanding of the impacts of poor hygiene and generated a sense of empowerment for villagers who feel they are no longer beneficiaries but real participants in the project. Following the workshops, an improvement of the sanitation and hygiene behaviours could be witnessed in several villages where, for instance, women were no longer using the local stream to bathe and toilet use had increased. The entertaining nature of the artistic activities ensures the participation of all categories of people, effectively breaking the caste, class and gender divide. Finally, conflicts over water have decreased in some villages, demonstrating how social arts can generate engagement and alleviate social disparities.

Protection of Bangalore Lakes for Posterity: Environmental Support Group

Bangalore currently draws about 1400 million litres per day (MLD) of water from river Cauvery and meets just over half the city's needs. The rest of the city's water needs are drawn from fast-depleting groundwater resources, the quality of which is also deteriorating. The current metropolitan area of Bangalore (approx. 1400 sq. km.) had over 600 such lakes till about two decades ago, and these provided water for drinking, irrigation, horticulture and industrial activity. In addition, they served as important wetland habitats, especially to migratory waterfowl. Urbanization has caused serious damage to these lake systems in recent decades and contributed to deterioration and dislocation of lake communities that protected and maintained these commons. Today, with less than 450 lakes struggling to survive, contamination and encroachment are rampant leaving them in various stages of deterioration with debilitating impact on groundwater resources.

The Environment Support Group (ESG) has been addressing the issue for about a decade. ESG organized local communities and ran a series of campaigns for conservation of lake systems. The basic intention was to ensure that lakes remained as commons and that they were functional ecosystems that provided a variety of livelihood, cultural and social services. Law and policy was evolving to support the concept of lakes as commons.

The theme of reclaiming the commons evolved as an idea in peoples' minds, and they began to see that a possible privatization of lakes would result in the exclusion of their access to them. Starting with small numbers of supportive people, the momentum grew, resulting in significantly large protests in 2007 and 2008 against lake privatization. The positive outcome of this was also that local communities began to step forward to secure their lakes which were being encroached and polluted.

ESG then moved the Karnataka High Court in a Public Interest Litigation (Writ Petition 817/2008) which resulted in two major reliefs: a status quo was ordered on the ongoing privatization of lakes and a committee involving nine agencies of the government officiated by a sitting Judge of the Court was constituted to develop a comprehensive plan and strategy to protect and conserve Bangalore's lakes for posterity. The Court-Appointed Committee commenced its work in December 2010. As key petitioner and initiator of the idea, ESG was asked to assist the Committee in formulating the report. This was achieved in February 2011, and every public agency of the Committee arraigned for the tasks subscribed to the proposal. Under the direction of the Court on 3 March 2011, this document has become binding on the government.

Er. Avinash C. Tyagi a 1973 graduate from the University of Roorkee, India, and a postgraduate from the Indian Institute of Technology (IIT) Delhi, has vast experience in dealing with various facets of water resources management starting from hydrologic observation to disaster risk management to interstate water dispute resolution to contributing to the national and international policy-making. He served as Commissioner of policy planning in Ministry of Water Resources River Development and Ganga Rejuvenation in India before leading water and climate wing at World Meteorological Organization (WMO) as Director. He was instrumental in reviving the International Commission on Irrigation and Drainage (ICID), an international professional non-governmental organization, as its Secretary General. A leader in true sense, both at WMO and ICID, he introduced and successfully implemented a host of internationally acclaimed initiatives. He, through his interaction with water, climate and disaster managers from various member countries of WMO and ICID, gained an intimate knowledge of issues related to water resources, climate change and disaster management in developing countries around the world and helped them through transfer of technology and capacity development. He interacted with policy-makers and ministers of many member countries. Er. Tyagi is an ardent advocate of multidisciplinary collaboration for resolving complex development challenges and in continuing dialogue among various stakeholders and community participation in the water sector.

Capacity Development for Sustainable Water Resources Management in India

E. J. James and Thomas J. Menachery

1 Introduction

1.1 Sustainable Development

Capacity building has gained considerable importance and also attained new dimensions and dynamism in the context of sustainable development. Several discussions and debates took place on the theme 'development versus environment' since the Stockholm Conference in 1972, in which the then Prime Minister of India gave a thought-provoking talk on 'Man and Environment'. There has been a general recognition that development and conservation have to go hand in hand for the existence of humanity, since the annunciation of World Conservation Strategy (IUCN et al. 1980). Towing in the same line, an attempt was made to define sustainable development as the one which takes into account the requirements of future while meeting the needs of the present (UN 1983). Ever since, there has been an emphasis on the 'ecosystem' or 'holistic' approach for attaining sustainable development of natural resources (CBD 2004). Though there have been several theoretical works available on ecosystem approach, there are only limited practical lessons and best practices to share the success stories of ecosystem approach. There are certain limitations in understanding and appreciating linkages in ecosystem approach. In this context, capacity building, keeping in view the sustainability considerations, gains importance.

E. J. James
Former Director, Water Institute, Karunya Institute of Technology and Sciences
(Deemed University), Coimbatore, India

T. J. Menachery (✉)
ICFAI Business School, Hyderabad, India

© Springer Nature Singapore Pte Ltd. 2019

A. Singh et al. (eds.), *Water Governance: Challenges and Prospects*, Springer Water,
https://doi.org/10.1007/978-981-13-2700-1_19

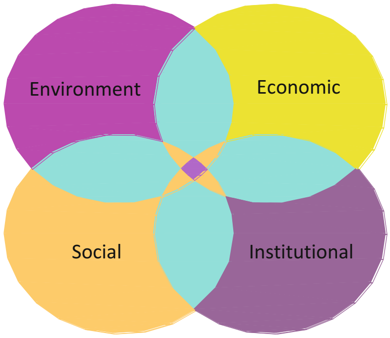


Fig. 1 Factors influencing sustainable development

1.2 Integrated Water Resources Management

Integrated Water Resources Management (IWRM) aims at sustainable development, mainly through systematic allocation and monitoring of the available water resources in a unit like basin or watershed (James 2014). In the context of sustainability, social, economic, environmental and institutional factors are equally important (Fig. 1).

The Dublin Conference (Young et al. 1994; ASCE/UNESCO 1998) highlighted the principles of IWRM: (1) finite nature of fresh water, (2) participatory approach for water resources development, (3) place of women in water management and (4) economic importance associated with water. These principles were reflected in Agenda 21 of Rio Conference (UN 1992). It is also worthwhile to note that food security, health security, energy security and ultimately economic and social security depend on water security to a great extent.

1.3 Global Water Crisis

The importance of development of capacity in the area of water management was well recognized in the context of present crisis and problems associated with governance of water. It is disturbing to note that water-use pattern is changing very fast, and the growth rate of water use is considerably more than the rate of population increase during the past ten decades (UN-Water 2015). More than 50 countries on five continents are said to be at the risk of conflict over water. With the declaration of Millennium Development Goals (MDG) and the recognition of the importance of attaining these goals, a renewed vigour in capacity development is noticed (WHO 2012).

1.4 Water Management Issues in India

Strategies for capacity development in India have to consider the national, state and local level conditions and also the experience gained by India and other countries, particularly by other developing countries. A large and geographically and climatologically diverse country like India faces several challenges in managing its water resources. The variability in rainfall in space and time and water to meet the requirements of a growing population is to be appropriately addressed (CWC 2003, 2004), apart from the limitations associated with lack of stakeholder participation and the enthusiasm of government departments to be the provider and not the facilitator. The need for organizational and procedural shifts has not been well recognized. Most of the projects, particularly large and medium ones, are neither properly maintained nor operated, partly because of lack of revenue. Sanitation facilities in the country call for considerable improvement as also the sewage treatment in both urban and rural areas (Arghyam 2007; CPCB 1989). Several pockets in the country are facing severe water quality problems associated with fluoride and arsenic (James 2014). All these call for a paradigm shift in water management practices, which is possible only through capacity development and awareness creation.

1.5 Capacity Building: Concept, Dimensions, Strategies and Evaluation Techniques

1.5.1 Definition and Concept

The United Nations Development Programme (UNDP) has been involved in preparing guidelines for 'institution building' since the early 1970s, and this initiative can be considered as the forerunner of the present concept of capacity development. Capacity development in a broader sense may be defined as the exercise through which the stakeholders gain capacities to realize their social and economic goals. This can be achieved through enhancement of know-how and skills and finally the improvement of systems and institutions (UNISDR 2009). In the 1990s, the term 'community capacity building' became popular. Overall capacity building strengthens all levels of society to smoothly function and achieve the development objectives within a timeframe (UNESCO 2006). From this, it is implied that capacity concerns not just with skills and knowledge but in a larger perspective with relationships, values and attitudes and many other factors (Morgan et al. 2005). However, one of the definitions given by the World Bank (2005b) in the context of African countries highlights the essence of capacity development – it concerns with the ability of key players of a society to achieve the social and economic goals on their own. According to Kaplan (2000), a renowned NGO scholar, the different elements of organizational capacity building encompass evolving of a conceptual framework, encouraging an organizational approach and formulating a vision, mission and structure for the organization. It also calls for equipping with appropriate skills and acquiring required resources.

There is often a misconception about 'capacity building'; it is often considered as a task just confining to building local skills. The term is frequently used and even misused so much so that its real meaning has been lost. In the areas of water supply and sanitation at the local level, capacity building may mean the activity which equips the community to undertake the governance and provision of service in a sustainable manner (UNDP 1996). The process of capacity building should mainly aim at increasing the availability of resources and at changing the power relationships among parties involved. The community may be a panchayat or a village-level committee.

Very often capacity building concentrates on a single-sector player or an organization in a particular area without taking into account the overall system or context within which the organization functions. Therefore, there is a need to properly interpret the term 'capacity'. Morgan et al. (2005) recognized that the individual makes the primary building block which makes the organization to perform when the capacities and competencies of individuals are synthesized and synergized within their organizations. However, any organization can function smoothly only within the overall system or context within which it operates. In this background, the all-embracing institutional, social, economic or even environmental context has to be properly realized for the groups/institutions to efficiently function within the larger perspective.

1.5.2 Elements of Capacity Building

Three fundamental requirements for capacity development in a comprehensive manner are (1) creation of an enabling environment with the formulation of necessary policies and legal framework, (2) institution building with stress on community participation and (3) human resources development and strengthening of managerial systems (UNDP 1996). An ideal capacity development process is supposed to have three levels: (1) the overall system or context for the stakeholders to operate within; (2) various endogenous dimensions of development of organization and human resources within the areas of water and sanitation covering public and private domain, communities involved or even civil society; and (3) level at which the strategy is evolved (Fig. 2). The existing capacity is the product of the system or context which facilitates change and also acts as a hurdle to change. The context analysis should consider, among other things, (1) structural factors, history of state formation, natural and human resources and globalization trends; (2) institutional factors, norms for exertion of power and authority, socially embedded norms,

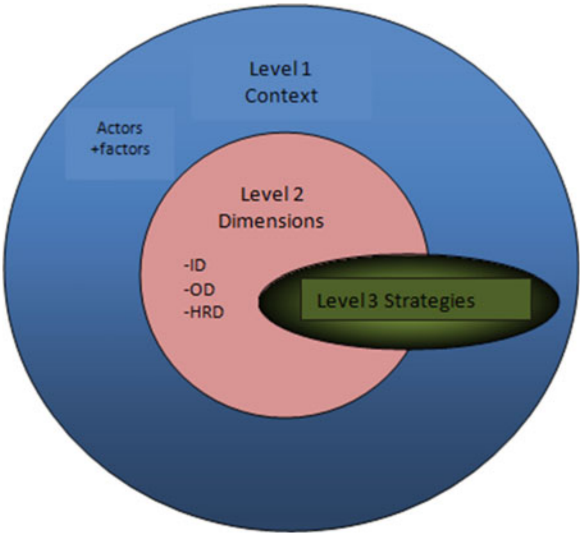


Fig. 2 Holistic approach to capacity building: three basic levels or spheres

practices on governing reciprocity and exchanges and also consideration of existing legal framework and other regulations and broader sector development process which may cover, for instance, policies of the government and other factors like market sector changes and role of donors; and (3) stakeholders in the areas of water and sanitation sector covering public and private sector, community or even civil society.

Whether it is in the area of water or sanitation, capacity development generally has three phases or levels dealing with institutional, organizational and manpower developed. The development of the institution may consider strategic harmonization among various organizations working in the sector leading to collective policy development for third parties, operational harmonization among different organizations involved in the individual programme or collective programme development, learning capacity by sharing information and experience of the organizations in the network leading to a learning process capable of influencing the policy and implementation process and external influence on third parties to defend certain interests, to help in defining the policies and to vouch for human rights. Organizational development mainly deals with improving the strength and attainment of sustainability to achieve the objectives and fulfil the mission. Some of the important components to be specifically addressed are ability to learn management and technical skills as also to understand the social and cultural background of the stakeholders. The HR development aims at the enhancement and sustenance of manpower and quality to be maintained by the organization. It focuses on the knowledge, skills, attitudes and motivation of the personnel working in the organization. As part of capacity development, each person has to be equipped with the ability to change the vision and values depending on requirement and also acquire correct perspective, skills and attitudes. In fact, human resources development can be broadly classified into (1) management, (2) technical and (3) attitudinal or motivational aspects.

1.5.3 Strategies

The strategies for capacity development cover a large canvass including defining the goal and preparation of plans to achieve the goals; chalking out inputs, outputs, outcome, targets and indicators; and monitoring and evaluating techniques. All possible alternatives have to be studied in developing a strategy, and funds are to be found to actually build capacity. According to Beyer (2002), choices in capacity building are dependent on different accomplishments pertaining to availability of data and know-how as well as attitude and degree of skills and consequently on different tools and activities envisaged. Some of the most employed instruments and activities are listed below:

- Management of data and information resorting to websites and information desks – relevant modern tools like cloud computing, internet of things and geographic information system to be made use of depending on necessity
- Input from persons from outside having expertise and experience
- Initial learning process to be enriched by coaching exercises
- Research to be encouraged by establishing research centres and centres of excellence
- Training – academic and practical courses, workshops, seminars and on-the-job training to become part of the routine
- Networking by making use of all relevant conventional and modern tools and techniques
- Education – professional, graduate, postgraduate and doctoral levels as well as other formal and informal education systems
- Development of innovative models for achieving management and business goals
- Providing and acquiring necessary funds for the purposes of training and skill enhancement

The formulation and development of strategies are to be anchored on the community within the system with focus on cooperation from all those involved. This is a process where diverse stakeholders work together to achieve common objectives through participatory learning and action plans (Beyer 2002).

The relevance of capacity building may be now revisited in the background of the statements made above. Capacity building is considered as a prerequisite in the development sector for poverty alleviation. The relevance of capacity development for improvement of sector is still debated. Though there is a global realization that capacity building is central to development, people are finding it difficult to explain what exactly capacity building is and what it consists of.

1.5.4 Threshold Levels

There are several conceptual frameworks available for determining the threshold of capacity building, for costing of the activities as well as for monitoring and evaluation. The threshold concept developed by Len Abram (UNDP 1996a) is highlighted

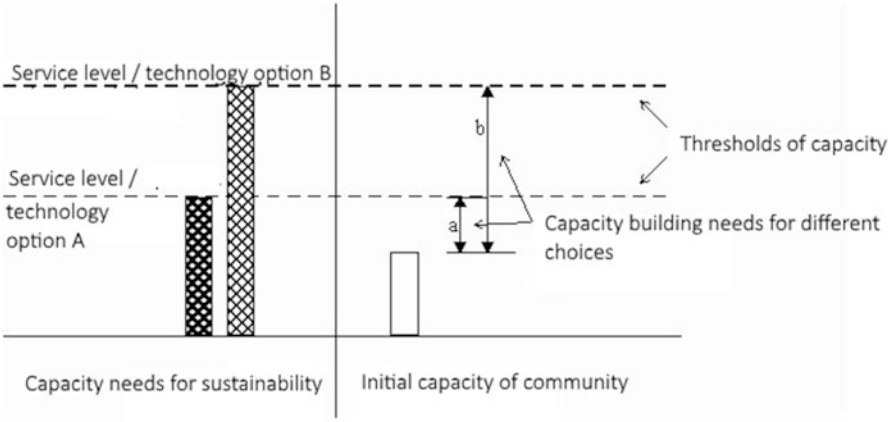


Fig. 3 Threshold levels of capacity building for sustainability

herein. For the sustainability of any given service in a particular area, it is always necessary to predetermine the details of different components for developing the capacity in the required area. The thresholds for sustainability of a service are arrived at from this information as given in Fig. 3. The existing level of capacity in the community is a yardstick to estimate the degree of capacity to be built. The future requirements of services and technologies are to be projected based on this benchmark. If already existing capacity is less than the threshold, their capacity may have to be enhanced to bring to the threshold level. If threshold values are attained in all respects except in community acceptance, the project may not be sustainable since the revenue cannot be collected for the services rendered by the scheme.

The existing capacity of the community has to be assessed through a participatory approach. Thereafter, the service-level options and technology choices can be established to identify the thresholds which the community must meet in each area to attain sustainability (Fig. 4).

Wherever the special skills to identify the threshold values do not exist, external agencies may be approached to impart the skills. The capacity building requirements can thus be clearly earmarked with predetermined performance criteria and the activities costed with some degree of accuracy. The concept of thresholds and the clear definition of the tasks required within a programme make the evaluation of the performance of capacity building and training agencies much easier. The failure of the system may be due to institutional or economic factors and generally not due to technical factors. The system requires systematic operation and maintenance which call for necessary finance, efficient administration and total support of the entire stakeholder community. It is required that all categories of services rise up to the threshold value for sustainability; if one area lags behind, others may also get affected since they are interconnected.

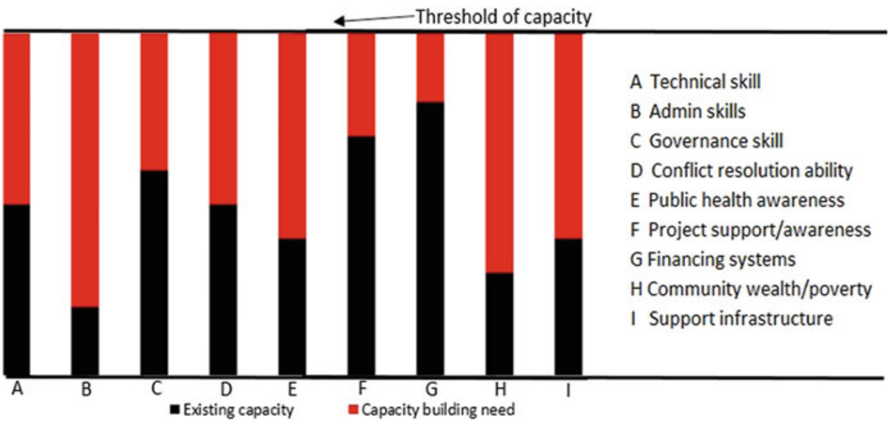


Fig. 4 Thresholds to be met by the community for sustainability

1.5.5 Lessons Learnt

The efforts taken in capacity development should be brought to the notice of others involved in such exercises. Very often, the best practices evolved, and unsuccessful case studies are not available in literature (WWF 2005); the lessons learnt should be publicized for the use of others taking up similar exercises. There are also not much works highlighting the context analysis, and the main reasons attributed to the absence of such works are lack of bottom-up approach, limitations of funds to take up such exercise and above all the inability to understand the overall spectrum of capacity development. Moreover, Morgan et al. (2005) argue that most of the assessments of capacity are at the organizational level, and the assessment techniques do not take into account the nature of capacity built; different actors and interrelationship among them and the system as a whole are not covered in these studies. Political environment exerts great influence on the governance factor in capacity building. Capacity development calls for shift in attitudes, identities, responsibilities and authorities at individual to institutional and structural levels. In some cases, conflict of interest among groups may lead to pressures and vested interests, and perverse incentives prevail, thus ending up in capacity destruction. There is a need to assess the political influence and interference and take care of these factors while formulating the capacity building strategy. Studies show that in several countries including India, political interference affects the development initiatives (UNDP 1996; UNESCO-IHE 2005). The challenges of capacity building differ from sector to sector and country to country. However, the donors have realized that traditional tools like conventional training and providing technical support may not help in achieving the goals of building sustained sector capacity (World Bank 2005a).

The guiding principles in sustainable capacity building were formulated by IRC based on the lessons learnt from past experiences and are presented in the draft baseline document of the World Water Forum (WWF 2005). These guidelines include allocation of sufficient funds, need to customize capacity building approaches, emphasis on country-led capacity development planning with local ownership, activities built into larger and broader strategic frameworks, vision as a continuous process, need for coherent and coordinated approach, promotion of change of attitudes, appropriate systems in place for information sharing and knowledge management and availability of appropriate tools for monitoring and evaluation.

1.5.6 Capacity Building in the Water Sector: Initiatives in India

Water management encompasses several stakeholders, which include different ministries and departments of the Government of India (GoI), several departments/organizations of the state government, Panchayati Raj Institutions (PRI), local self-governments (LSG), industries, research organizations, academic institutions, non-governmental organizations (NGO) and people themselves. Though water is included in the State List of the Constitution, there is a provision for regulation and development of interstate rivers by the GoI. The National Water Policy (2012) gives a broader perspective of most of the water-related matters. The Ministry of Water Resources River Development and Ganga Rejuvenation (MoWRRD&GR) of GoI has several functions directly or indirectly related to capacity building. There are several commissions, boards, authorities and research organizations in the Ministry which deal with capacity building in their spheres of activity.

Some of the ongoing or completed water projects of GoI/state governments with a strong component of capacity building are development of information system, hydrology project, groundwater management and regulation, R&D initiatives, river basin organization/authority, accelerated irrigation benefit programme and Command Area Development Authority (CADA). A few of the weaknesses identified, having an impact on capacity building, are the following: (1) there is no mechanism for effective coordination among various departments/agencies; (2) the organizations under the concerned ministry comprise mainly of engineers and scientists, and there is no in-house system to address environmental, social and other related aspects; (3) the public interaction and participatory approach in planning and decision making process is relatively poor; (4) most of the organizations are advisory in nature and therefore not adequate to address policies and programmes for future challenges; (5) capacity building and collaborative international partnerships for sharing knowledge and expertise are not adequately addressed; (6) due to lack of state-of-the-art laboratories in most part of the country, water quality monitoring is not satisfactorily carried out; and (7) policies with regard to human resources management require changes (MoWR 2011) .

The National Water Policy (2012) has emphasized the need for institutional capacity building. A discussion paper of TERI (2014) on the policy statements highlights that by its very nature, water requires active cooperation at individual and community user levels. The importance of local culture and practices on water management has been brought to light in the paper as also the role of community institutions and PRIs.

The MoWRRD&GR came out with the functions of the National Water Mission (NWM) aiming at water conservation, wastage minimization and the need for ensuring equitable distribution of water both across and within the states through IWRM (CWC 2014). Out of the five goals of the mission, one is to improve water-use efficiency by 20%. Strategies for achieving this goal have several components dealing with capacity building. The NWM forms part of India's Intended Nationally Determined Contribution to bring down the greenhouse gases and predicted impact of climate change.

In the context of operation and maintenance of drinking water supply schemes, the guidelines of CWC (2014) envisioned the need for public-private partnership (PPP). The guidelines also mention about the need for empowering PRIs and creating public awareness, efficient use of media, participation of women, water conservation and saving techniques and measures to motivate people, communities and governments for achieving better efficiency in operation and water management as such. The need for a policy for zoning the basins according to the type of industries and quantity of water consumed/discharged has been recognized. The requirement for constituting water conservation groups in industries is also brought to light.

India has forged partnerships with Water and Sanitation Programme – South Asia – which programme of the World Bank is funded by several external agencies. This has considerably helped in capacity development in the area of water resources projects. The decentralized drinking water and sanitation programme entrusts the community with the management of water supply schemes; this is expected to shift the role of state government from the provider to facilitator. The programme also envisages empowerment of PRIs and system design based on the willingness of consumers to pay for a particular level of service. Sector reform project for water supply and Total Sanitation Campaign (TSC) were launched in 1999 and have been successful to a great extent. There have been also several attempts to revive the traditional practices for sustaining local-level water resources. Attempts like *Neeru Meeru* and *Pani Roko Abhiyan* are worth mentioning. The cardinal principles identified by the Ministry of Rural Development of the Government of India in the water and sanitation sector are awareness generation, transparency, community participation and social auditing (WWF 2002).

One of the well-thought-out programmes of MoWRRD&GR in the area of capacity building was the CADA initiatives implemented in different states (MoWR 2013). The functions of water and land management institutions in the states include capacity building for micro-level water management; institutional strengthening of water user associations; serve as nodal institute for information transfer, education, communication and demonstration on optimal use of land and water; promotion of mass awareness; performance evaluation and benchmarking of completed projects; studies on water-use efficiency; and filling up of gaps in the area of research in water sector.

The PRIs and NGOs implementing different projects have contributed considerably to capacity building for local water resources development and management.

Artificial recharge propagated by the Central Ground Water Board and the construction of cost-effective rain water harvesting structures initiated by different state governments have been successful to a great extent. Many of the projects had capacity building components which helped in conserving several of the aquatic ecosystems facing degradation, such as Chilika and Loktak wetlands. More concerted efforts are called for to fill up the gaps in capacity building in the water sector. The success stories and case studies have to be documented for helping future capacity building initiatives.

1.5.7 Identifying the Gaps and Way Forward

In the background of the reviews already available and the experiences of experts and agencies from within the country and abroad, a general picture on the shortcomings of capacity development projects in the country has emerged. All these identified shortcomings may not be important or relevant for all projects or programmes in one particular sector or region.

The publications of UNESCO-IHE (2005) and UNDP (1996) pointed out that in countries like India political influence has been found to be the limiting factor in developing sufficient capacity. The other countries bracketed with India are Kenya and Nigeria.

In most of the developing countries including India, the projects dealing with water and sanitation are often administered by the government departments. Societies are registered at times in the country to implement the major projects. But most of these societies formed to have more functional freedom are managed by senior officers of the government, and these bodies often function like the government departments.

The government generally plays the role of a provider and not of a facilitator in the water sector of the country. The present top-driven approach has to give way for stakeholder participation for better efficiency.

Most of the government departments involved in the water sector in the country are dominated by engineering professionals who are not sufficiently exposed to social or environmental sciences. The water resources/irrigation departments of the states have often emerged out of the public works departments (PWD), and in some states these departments are still attached to the PWD. The engineers in these departments often lack the soft skills to deal with the stakeholders in the field. The scientists working in the R&D institutions and the laboratories in the country dealing with water and sanitation problems are also not often sufficiently exposed to the field conditions.

There is no mechanism for effective coordination among various departments/agencies of the government. The interaction of government departments/agencies with the private institutions, NGOs and other stakeholders in the water sector is also minimal. Several of the water conflicts could not be resolved due to the lack of proper communication and interaction among all concerned in the sector. Problems requiring technical solutions or consensus among different stakeholder communities are politicized and precipitated.

The MoWRRD&GR itself has admitted that adequate attention has not been given to capacity building in the sector and also to international collaborative partnerships for sharing of knowledge and expertise.

The need for a policy to address different aspects related to human resources management has been recognized by the MoWRRD&RG. There are only a few universities/institutions in the country which conduct interdisciplinary programmes in the area of water. Only two or three universities conduct postgraduate programmes in IWRM. Subjects related to water resources are not given sufficient importance in the schools, colleges and poly-techniques.

Some of the PRIs and LSGs have been keen to take up projects in the area of water resources. However, they do not have necessary knowledge base and skill to implement the projects. The PRIs and LSGs are in an advantageous position to plan for local water resources projects since they are fully aware of the local environment and can motivate the stakeholders.

In many cases, funds are not available to take up new projects, and in the existing projects, revenue generated is not even sufficient to meet the operation and maintenance cost. In the absence of awareness, motivation, participation and incentives, the stakeholders are reluctant to pay for the level of services provided.

An earnest attempt has not been made to explore the possibilities of PPP in the water sector. However, some progress has already been made recently in this direction (WSP 2011).

The full potential of NGOs has to be utilized in the water resources development sector. There are a few NGOs with sufficient levels of capacity and experience in implementing innovative projects in the field. Others can be trained to take up such projects.

The thresholds of capacity development are often determined at the pre-project stage through a participatory rural appraisal (PRA) or any other suitable appraisals. This is not done in several projects, and it becomes difficult to know whether the output, outcome and targets are achieved. In the absence of predetermined threshold values and also indicators, it may not be very often possible to monitor and evaluate the performance of capacity building projects or programmes.

The capacity building activities in the water sector are not always a continuous process as required by the project (Lamoree and Jaokim 2002). Even in spite of the withdrawal strategies introduced in some projects, capacity building almost comes to a halt at the end of a major project. The capacity development initiatives in the country very often do not encompass the three important levels of development, namely, (1) the context in which all actors operate; (2) internal dimensions consisting of institutional, organizational and human resources dimensions; and (3) the strategy development.

The various aspects to be considered in the context of sustainable water resources management are given in Fig. 5; the capacity building for the management of water environment should cater to the requirements of all the aspects highlighted therein.

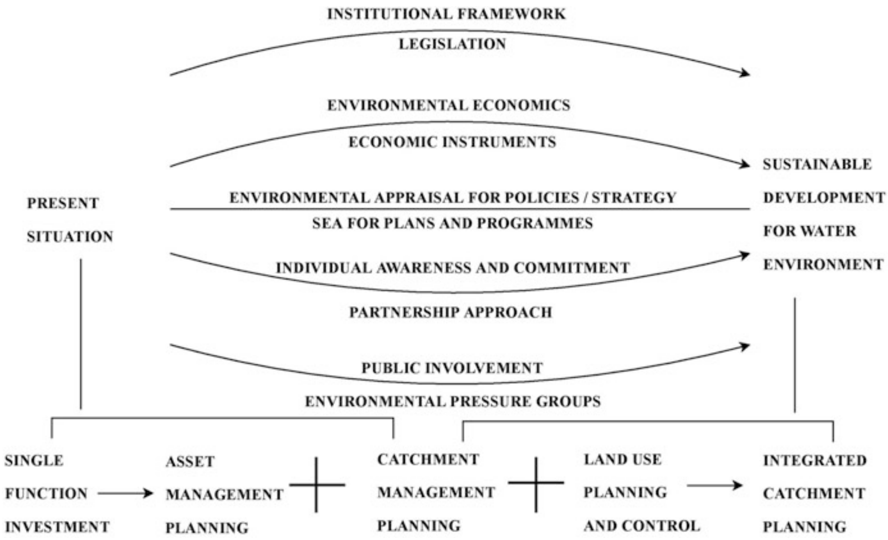


Fig. 5 Pathways to sustainable water environment posing challenges to capacity building

2 Conclusions

The concept of sustainable development in the context of global and national water crisis has been highlighted and the importance of IWRM brought to light. The relevance of capacity building in the context of sustainable development of water resources in India has been discussed. The need for capacity building from a holistic perspective has been stressed as also the need for continuity of different capacity building projects. The threshold approach to plan and monitor the capacity building services and activities has been presented.

A few areas requiring focus in the context of capacity building in the water sector of the country are participation of stakeholders; more representation for experts in the areas of social and environmental sciences in the relevant departments; coordination among departments/agencies; formulation of appropriate policies on human resources management; stress on subjects dealing with water in the school/college curricula; empowerment of PRIs, LSGs and NGOs; generation of more revenue and funds; initiating public-private partnerships; and inculcation of proper understanding on the concept and requirements of capacity building. The way forward conceptualized in the paper highlights the important areas to be considered while planning for capacity building in the water sector.

Acknowledgements The authors are indebted to their colleagues for their valuable suggestions. The opinions expressed in the paper are of authors personal and not of their respective department.

References

Arghyam (2007) Urban waters, background material for second annual conference, Bangalore. Available at: www. arghyam.org

ASCE/UNESCO (1998) Sustainability criteria for water resources systems. ASCE, Reston

Beyer W (2002) Developing a capacity building strategy for forest certification through the RAAKS methodology, STOAS International, EC-BMZ-DFID

CBD (2004) The ecosystem approach, secretariat of the convention on biological diversity. CBD, Montreal, pp 3–4

CPCB (1989) Status of water supply and wastewater generation, collection, treatment and disposal in class-II towns, Control of Urban Pollution Series: CUPS/31/ 1989–90, Central Pollution Control Board, New Delhi

CWC (2003) Pocket book on water data, information system organization, Central Water Commission, New Delhi. Available at: www.cwc.gov.in

CWC (2004) Water and related statistics, information system organization, Central Water Commission, New Delhi. Available at: www.cwc.gov.in

CWC (2014) Guidelines for improving water use efficiency in irrigation, domestic and industrial sectors, Performance Overview and Management Improvement Organization, Central Water Commission, New Delhi. Available at: www.cwc.gov.in

IUCNUNEPWWF (1980) The World Conservation Strategy, International Union for the Conservation of Nature, Geneva

James EJ (2014) Integrated water resources management for facing the challenges in India's water sector. In: Proceedings of the international symposium on integrated water resource management (IWRM 2014), CWRDM, Special Volume, Excel India Publishes. pp 12–45

Kaplan A (2000) Capacity building: shifting the paradigms of Practice, Development in Practice. 3/4. 10 (10th Anniversary Issue), pp 517–526

Lamoree G, Jaokim H (2002) Institutional capacity building within the water resources sector of developing countries. Part 1: a framework for analysis. Water Int 27(4):542–549

Ministry of Water Resources, Government of India (2012). National Water Policy 2012

Morgan P, Land T, Baser H (2005) Study on capacity, change and performance, Interim Report, Discussion Paper No. 59a, European Center for Development Policy Management, Brussels, Belgium

MoWR (2011) Strategic plan for Ministry of Water Resources, Ministry of Water Resources, Government of India, New Delhi. Available at: www.mowr.gov.in

MoWR (2013) Guidelines on command area development and water management programme, Ministry of Water Resources, Government of India, New Delhi. Available at: www.mowr.gov.in

TERI (2014) Perspectives on a water resource policy for India. Discussion Paper, Vijay Kumar S, Bharath GK (eds), The Energy and Resources Institute, New Delhi

UN (1983) Process of preparation of the environmental perspective to the year 2000 and beyond, UN General Assembly Resolution 38/161

UN (1992) Earth summit, Agenda 21: the United Nations programme of action from Rio, United Nations, New York, USA

UNDP (1996) Capacity building as knowledge management: purpose, definition and instruments, In: Alaerts GJ, Hartvelt FJA, Patroni FM (eds) Water sector capacity building: concepts and instruments, Second UNDP Conference on Capacity Building, Rotterdam

UNDP (1996a) Capacity building for water supply and sanitation development at local level – the threshold concept, Paper by Len Abrams, Second UNDP Symposium on Water Sector Capacity Building, Delft, The Netherlands

UNESCO (2006) Compendium of basic terminologies in governance and public administration, United Nations Economic and Social Council, New York

UNESCO-IHE (2005) Professional capacity needs assessment to achieve United Nations Millennium Development Goals on water and sanitation, UNESCO-IHE, Delft

UNSIDR (2009) Terminology, https://www.unisdr.org/we/inform/terminology. United Nations Office for Disaster Risk Reduction, Geneva

UN-Water (2015) United Nations World Water Development Report, Water for a Sustainable World, United Nations Educational, Scientific and Cultural Organization, Paris. pp 37–67

WHO (2012) Global costs and benefits of drinking water supply and sanitation interventions to reach the MDG target and universal coverage, WHO Press, World Health Organization, Geneva, Switzerland, p 5

World Bank (2005a) India's water economy, bracing for a turbulent future, Washington, DC. USA

World Bank (2005b) Capacity building in Africa, an OED evaluation of World Bank Support, Washington DC, USA

WSP (2011) Trends in private sector participation in the Indian water sector: a critical review. Field Note, Water and Sanitation Programme, New Delhi

WWF (2002) Indian reform initiatives in water sector, Keynote Address (M. Venkaiah Naidu), World Water Forum, World Bank, Washington, DC, pp 1–16

WWF (2005) Cross-cutting perspective C: capacity building and social learning, Draft Baseline Document for the Fourth World Water Forum

Young CJ, Dooge CIJ, Rodda JC (1994) Global water resources issues. Cambridge University Press, Cambridge, p 39

E. J. James graduated in civil engineering from the National Institute of Technology, Karnataka (erstwhile KREC) and also obtained MTech from the same institute. He completed his PhD at the University of Calcutta and postdoctoral work at the Institute of Ecology and Hydrology, Wallingford, UK. He is a former scientist G and executive director of the Center for Water Resources Development and Management (CWRDM) at Calicut. Since 2008, he has been working in the Karunya Institute of Technology and Sciences (deemed university), Coimbatore, in different capacities, as Director of the Water Institute, Director of the School of Civil Engineering, Dean of Research, Dean of the School of Agriculture and Biosciences, Pro-Vice Chancellor and Vice Chancellor. Presently, he is Professor Emeritus and Director of Research and Consultancy at the KITS. He has carried out more than 80 funded research projects and has more than 100 publications. He has served as a consultant to several agencies like the World Bank, UNDP, UNEP, JICA, Wetlands International South Asia, India-Canada Environmental Facility, etc. He served as the chairman of the Research Council of CWRDM and also as the chairman of the Steering Committee of the National Wetland Atlas of MoEF&CC and SAC. He was earlier a member of the Central Wetland Regulatory Authority.

Thomas J. Menachery received his PhD in business administration from Loyola Institute of Business Administration, University of Madras in 2014. During the research, he was an Audi fellow at the Catholic University of Eichstätt-Ingolstadt, Germany. After completing the dissertation, he worked with Mahindra Consulting Engineers in management consulting projects for clients such as UNIDO and CDC. Thereafter, he worked with NIT Calicut as a faculty member in the School of Management Studies. Presently, he is an Assistant Professor at the Department of Human Resources, ICFAI Business School, IFHE, Hyderabad. His research interests include strategic human resource management and performance management.

Research and Development in the Water Sector in India

Sharad K. Jain and M. K. Sinha

1 Present Challenges in Water Sector

India has the twin challenges of meeting its water needs along with sustaining pace of development. It has more than 18% of the world's population and 15% of livestock but has only 4% of world's renewable water resources with 2.4% of world's land area. On an average, India receives an annual precipitation of about 4000 billion cubic metre (BCM), which can be said to be its basic water resource. Out of this, after accounting for the natural evapotranspiration, about 1869 billion cubic metre (BCM) is the average annual natural flow through rivers and aquifers. Due to topographical and other constraints and spatio-temporal variations in resources, it is estimated that only about 1123 BCM (690 BCM from surface water and 433 BCM from groundwater) is utilizable. Utilizable quantities of water are further limited owing to uneven distribution over time and space. Variabilities may further increase substantially due to climate changes, leading to water crisis and possible water-related disasters, i.e. floods, increased erosion, higher frequency of droughts, etc. Further, competing demands for this limited resource for various uses – drinking water, sanitation, irrigation and industry, to name a few – underline importance of research and development to meet these challenges in an equitable and judicious manner on sustainable basis.

As per the international norms (Falkenmark and Widstrand 1992), a country is categorized as "water stressed" when per capita per year freshwater availability is less than 1700 m^3 and "water scarce" if it is less than 1000 m^3. India's current average per capita water availability is 1413 cubic metre per year for its present population of 132 million, which is expected to reduce to 1154 cubic metre in the

S. K. Jain (✉)
Director, National Institute of Hydrology, Roorkee, Uttarakhand, India

M. K. Sinha
Member, Narmada Control Authority, Indore, Madhya Pradesh, India

© Springer Nature Singapore Pte Ltd. 2019

A. Singh et al. (eds.), *Water Governance: Challenges and Prospects*, Springer Water,
https://doi.org/10.1007/978-981-13-2700-1_20

year 2050 with the projected population of 1620 million. Note that the average value does not reflect the real water stress in many parts of the country since nearly two-thirds of our water resources are confined to Ganga-Brahmaputra-Barak (GBB) basins. Clearly, India is heading towards water scarcity. The scarcity of water availability poses several challenges since water is an economic resource also in addition to being vital for life, living and livelihood.

Another challenge is ensuring food and energy security, which is integral to and dependent upon water security. The National Commission on Integrated Water Resources Development (NCIWRD), in its report in 1999, had assessed that India would need about 450 million tonnes (MT) of food grains annually for its projected stabilized population of 1.70 billion by 2070. Increasing food grains from present level of about 280 MT to the level of food security of 450 MT would require not only higher water use efficiency but also higher food productivity, i.e. "more crop per drop". Similarly, ensuring energy security would require substantial development of hydropower generation.

Climate change adds to these existing challenges. Preliminary estimates indicate almost same amount of rainfall in fewer number of days, implying more extreme events and larger dry spells. India has also committed itself to Sustainable Development Goals by 2030 in line with the United Nations resolution. Ensuring proper water and sanitation to all by 2030 in India is itself a herculean task by any means.

2 Research and Development Needs

The challenges in water sector, enumerated above, can be mitigated only through sustained research and development. The wide reach of water sector cutting across all sections of society demands multidisciplinary research and development. In this context, a number of recommendations were advanced by Jain et al. (2007) and the *Sub-committee on Technology Interventions in the Water Sector* (2014), constituted by the Scientific Advisory Council to the Prime Minister (SAC to PM). Most important research needs in the present context have been categorized under broad themes and are discussed next.

1. *Systematic collection of data and their analysis* – Water resource management requires, inter alia, databases of key hydrometeorological data. Preferably these databases should be shareable and available online. To measure the variable, there is a need to develop robust and cost-effective sensors. We also need to strengthen data collection networks for rainfall, streamflow and other variables such evapotranspiration and soil moisture. Development of methodologies for integrated assessment of water resources in a river basin under the various scenarios of land-use land-cover change and climate change along with their temporal and spatial variation requires urgent attention.
2. *Integrated water resource management* – A range of activities need to be undertaken under this broad theme so that the best practices for water resources development and management can be followed in India.

3. *Increasing water use efficiency* – This is an important research need of India since our present level of water use efficiency in irrigation, water supply, industries, etc. is very low even when compared to developing countries. Extensive research is needed in all water uses to reduce water footprints and make available water for further developments and environmental needs. This calls for research in irrigation application methods; increasing utilization of green water (soil moisture), efficient water distribution and reducing non-revenue water; flow measurements and water metering; improving industrial processes and technologies; reduce, recycle and reuse; etc.
4. *Integrated water resources management* Next important research need is achieving integrated water resource management (IWRM). This calls for models and other tools for optimal allocation of water, real-time estimation of demands, water accounting/budgeting and development of SCADA (supervisory control and data acquisition) and decision support systems. This would ensure equitable and judicious water allocation and management fulfilling the larger needs of the society.
5. *Climate change impacts assessment* – Climate-resilient water management requires projection of climate change impacts at river basin scale. This calls for research in downscaling of climate change models, projecting likely impacts at river basin scales and evolving mitigation strategies.
6. *Rehabilitation of Hydro-infrastructure* – Another area of research is in the field of rehabilitation techniques for dams, canal and other water resources structures. Considerable resources go in development of water resources structures, and it makes techno-economic sense to maintain these structures and rehabilitate them whenever and wherever found necessary. This would require newer investigation methods, instrumentation technologies, research and development in repair materials and their applications without disrupting operation of dams and canals such as underwater repairs, etc.
7. *Water quality and environment* – "Water, water everywhere but not a drop to drink" was a rhyme for a mariner, but now it is becoming more and more applicable all over India with most of rivers, water bodies (ponds/lakes) and groundwater becoming highly polluted. While emphasizing the need to prevent pollution, it is urgent to take up research to develop technologies of water purification at community level; in situ purification of rivers, ponds, lakes and groundwater; cost-effective removal of fluoride and arsenic contamination; etc. to increase availability of fresh or potable water. Reverse osmosis, which is prevalent for household water purification, is not only costly but wastes almost four times the water it purifies. A challenge for Indian engineers is to design and develop engineered natural systems of sewage treatment which require land area and life cycle costs that are comparable to or lower than those for electromechanical systems.
8. *River rejuvenation* – Many of our rivers are dying, and there is an urgent need to rejuvenate them and sustain aquatic ecosystem. There is a need to be innovative in the planning and design of water resource structures so that hydrologic (longitudinal and latitudinal) connectivity, environmental flow, flood plain

retention, groundwater recharge, etc. can be achieved without compromising developmental needs. This would require research in assessing ecosystem needs, environmental flow, silt management, river training and bank protection, analysing surface and ground water interactions to augment ground water recharge as well as base flow, etc.

9. *Managing water-related disasters* – Hydrologic extremes continue to hit India year after year. This calls for a need to develop methodologies for (a) long-range forecasts for planning purposes (e.g. frequencies and magnitudes of floods and droughts, water availability and demands, etc.); (b) real-time short-term forecasting of associated variables, e.g. rainfall, river stage, stream flow, urban and riverine floods, etc.; and (c) integrated real-time multi-reservoir operation, by making use of forecasts for irrigation, flood control, hydropower generation and municipal and industrial supplies.
10. *Water policy research* – Government of India had formulated a National Water Policy in 1987 which was subsequently revised in 2002 and 2012. We also have a National Environmental Policy (2006) and hydropower development policy. The Ministry of Water Resources, river development and ganga rejuvenation has prepared a draft National Water Framework Bill. Keeping in view these developments, there is a need for more research on water policy and legislation-related issues. Institutes such as Centre for Policy Research and IWMI-TATA water policy research programs are active in this field. However, efforts need to be scaled up. We also need more active interface between policy scientists, practitioners, hydrologists and decision-makers. There is an urgent need to initiate research on water policies and their impacts. Evidence-based water policies will certainly facilitate better water management.

3 Current State of R&D in the Water Sector

Indian researchers have done commendable work in the field of hydraulics, hydrology, sediment transport, and irrigation water management. The R&D work on design of unlined channels in alluvial soils by Kennedy, Lacey and many other eminent irrigation engineers; and the theory of design of weirs on permeable foundations by Dr. Khosla and his team got worldwide appreciation. In recent decades, a large number of technical papers are being published by Indian experts in international journals and conferences. Books and technical reports published by Indians have created a major impact in the field of water resources. Over the past 100 years or so, a wide network of organizations involved in R&D in water sector, such as Central Water and Power Research Station, Pune; National Institute of Hydrology, Roorkee; Indian Institute of Tropical Meteorology (IITM), Pune; National Environmental Engineering Research Institute (NEERI), Nagpur; Indian Institute of Remote Sensing (Dehradun); GB Pant Institute of Himalayan Environment & Development (GBPIHED), Almora; State Irrigation Research Institutes; IITs/NITs; other central and state universities; and some private universities/colleges, have evolved.

Table 1 Major central ministries who fund R&D in water sector

Ministry/Department	Areas covered
Ministry of Water Resources, River Development and Ganga Rejuvenation	All area in water resources planning and management
	Hydrologic modelling, irrigation and drainage, flood management, surface and ground water, climate change, water quality, cryosphere
Department of Science and Technology (DST)	All the above areas
Ministry of Earth Sciences	All the above areas plus hydrometeorology
Ministry of Agriculture/Indian Council of Agricultural Research (ICAR)	Water and soil management in agriculture, watershed development
Ministry of Environment and Forests& Climate Change	Environmental, water quality and climate change issues
Department of Space (ISRO)/National Remote Sensing Centre	Application of remote sending data to water resources
Council of Scientific and Industrial Research (CSIR)	Water quality, purification
Ministry of Power	Hydropower development
Ministry of Drinking Water and Sanitation	Rural drinking water
Ministry of Urban Development	Urban drinking water, industrial water use
Ministry of Home Affairs/National Disaster Management Authority	Management of water-related disaster (flood)

In India, R&D activities in almost all sectors and more so in the water sector are chiefly funded by the central/state government. A number of ministries/departments provide funds for R&D either by running research institutes or through sponsored research projects. Many ministries provide financial assistance to promote research in the field of water resources through grants to academicians in the universities/IITs/IISc/NITs, R&D institutions and NGOs. To that end, research proposals are invited, reviewed, and approved based on merit. Among the ministries and departments, Department of Science and Technology (DST) is the largest extramural R&D funding body. In the field of water, the other major ministries are Ministry of Water Resources, RD&GR (MoWR, RD & GR), Ministry of Earth Science (MOES), Ministry of Agriculture (MOA) and Ministry of Environment, Forest and Climate Change (MOEF&CC). Table 1 lists the major central ministries who provide R&D support in water sector and the areas covered by them.

The Ministry of Water Resources, River Development and Ganga Rejuvenation (MoWR, RD & GR) has constituted three Indian national committees which are the Indian National Committee on Surface Water (INCSW), Indian National Committee on Ground Water (INCGW) and Indian National Committee on Climate Change (INCCC) to review and promote research in respective aspects of water. DST processes research projects through Science and Engineering Research Board (SERB) and Water Technology Initiative (WTI). For the Ministry of Earth Sciences, the Project Appraisal and Monitoring Committee (PAMC) for Hydrology and Cryosphere mainly processes the research proposal concerning water sector. The

Indian Space Research Organisation (ISRO) undertakes research through its institutes, namely, SAC, (Ahmedabad), NRSC (Hyderabad), Indian Institute of Remote Sensing (Dehradun), CAZRI (Jodhpur) and others. Mandal and Priti (2015) found that of all the extramural research funding for the 10-year period (till 2012), only 1.97% of the fund was allocated for water research. Clearly the investment on R&D in water sector is very small.

Irrigation/water resource research and training institutes have been working for quite some time and doing appreciable work in some States, e.g. UP (Irrigation Research Institute), Gujarat (Gujarat Engineering Research Institute), Maharashtra (Maharashtra Engineering Research Institute), Kerala (Centre for Water Resources Development and Management), etc. However, such institutes in many states are deteriorating with time. There are some state S&T councils, but their involvement in water R&D is not much and varies considerably.

Many states have set up water and land management institutes, and these are known as WALMI/WALAMTARI/NERIWALM, etc. Many WALMIs are doing good work in their focus areas and are conducting training courses. Some important research outcomes have been reported by the institutions under ICAR, particularly Water Technology Centre. Similarly, good works have also been reported by some agricultural universities in the country. There are some notable contributions from individual water users (e.g., Mr. Anna Hazare); many farmers in water-scarce areas have adopted innovative techniques for water conservation as well as efficient use of water. These efforts need to be appropriately recognized and multiplied.

4 Some Major Schemes on R&D in Water

The Ministry of Water Resources, River Development and Ganga Rejuvenation (MoWR, RD & GR) implements a scheme on “R&D in water sector”, which funds the research activities of the three apex R&D institutions of the Ministry, namely, the National Institute of Hydrology, Central Water and Power Research Station and Central Soils and Material Research Station, and funds sponsored research works in the water sector through the three Indian national committees, viz. INCSW, INCGW and INCCC. In addition, under the National Hydrology Project, being implemented with the assistance of World Bank, a research component in the form of purpose-driven studies has been launched with the aim of solving real-life problems. Such studies would be able to galvanize the state government organizations dealing with water resources in taking up and working on research projects.

To actively associate academic institutions in studies related to impact of climate change on water resources in some river basins, MoWR, RD & GR has established six “professorial chairs” in selected IITs/NITs. Water Technology Initiative is a programme of the DST which started in 2007 with the aim to promote R&D activities to provide safe drinking water at affordable cost and adequate quantity. It also promotes related activities such as human and institutional capacity building by fellowships, training of water managers, promoting, etc. Many water-related

R&D projects have been completed under the Natural Resources Data Management System (NRDMS) programme of DST. It was launched with the aim to demonstrate and promote the use of spatial data technologies for local level planning under diverse topographic conditions and promotes S&T inputs for formulating policies related to spatial data technologies.

Indian scientists are also working with groups from other countries on many bilateral research projects. For example, MOES is partnering with NERC of the UK in supporting R&D projects in the field of hydrology and meteorology. DST and the US government jointly fund the Indo-US Science and Technology Forum (IUSSTF) which supports bilateral academic activities. Similar R&D activities are undertaken with many other countries. The Council of Scientific and Industrial Research (CSIR) has established a large network of publicly funded research organization. CSIR has identified drinking water and water treatment as its niche research areas.

5 Critical Review of R&D in Water Sector in India

Before embarking on critical review of water sector R&D in India, it will help to carry a strength, weakness, opportunity and threats (SWOT) analysis, as shown in Table 2.

Water sector in India is at very low level of development marred by poor efficiency, inadequate database and the lack of evidence-based policy formulation and decision-making, implying vast opportunities for research and development. This is the region that a large number of foreign institutions are interested in carrying out research on water-related issues of India. Though outside initiatives are generally welcome, sometimes there may be conflict of national interests. And therefore, there is a need to promote R&D culture among Indian institutes and universities. It can be seen from the SWOT analysis that there is a need to make research career as a better option. The recent initiatives undertaken by the government in promoting research with more incentives including Flexible Complementing Scheme have started yielding positive results, but a lot still remains to be done. There is an urgent need to professionalize research activities with little interference from bureaucrats and finance. Uncertainties are inherent in research and expecting well-determined outcome before sanctioning a research project is too much. Too many questioning and very restrictive work culture prohibit creativity and innovation resulting into scientists stopping application of their minds. Flexibility in operation is the least which should be ensured to promote R&D.

A reason hindering research in water sector is the presence of high subsidy. Since water charges are highly subsidized, there is hardly any incentive for the users to be water savvy. Technological developments are driven by economics, and the absence of economics virtually eliminates the importance of R&D in water sector. Even though water subsidy has a social and livelihood aspects, the driving force for research and development gets missing. Thus, there is an urgent need to evolve economic-based water policies to drive research in water sector and mitigate present and future challenges.

Table 2 SWOT analysis of R&D in water sector in India

Strengths	Weaknesses
Very good research work has been carried out in the past, resulting in strong legacy	Engineering−/science-oriented research with weak social science component
Highly qualified manpower	Small number of scientists compared to the size of the country and extent of problems
Adequate infrastructure and groups in many institutes which can be replicated	Vast challenges
Excellent opportunities for research and innovations	Bureaucratic processes and delays
	Less incentives and opportunities to choose R&D as career
	Poor linkages of Indian R&D institutes with industries and foreign counterparts
	Lack of strong scientific leadership – Role models
Opportunity	**Threats**
Indian R&D institutes can give much needed scientific orientation/inputs	Better career options in other fields
With support from the government, reasonable global leadership can be provided	Inadequate funding for R&D projects
	Bureaucratic delays in sanctioning of research projects

6 Disconnect Between Laboratory and Field and Science and Decision-Making

The proverbial gap between laboratory and field and science and decision-making is too evident in water sector in India. In water sector, Government is the dominant employer. Due to various reasons, very few new major development projects are coming up. Further, due to poor career advancement opportunities, aging, negative peer pressure, bureaucratic rule/precedence based procedures, etc., people in Central/State Governments are seldom keen in taking up new challenges, innovation and implementing new developments. There does not appear to be much keenness to try new ideas and take risks since rewards are few or non-existent but risks are typically large. As a result, R&D developments remain in technical journals and conference/seminar proceedings with little developments on the ground. Many such departments have research institutes and design offices which also act as interface between the R&D and academic world, but officers are seldom enthusiastic about postings to these places.

Establishing linkages between industries and research institutes can facilitate implementation of new technologies on ground. Research scientists, even in government sector, should be permitted to take up industry-sponsored research, rising above the vigilance syndrome of promoting a particular industry.

Information is power, and well-informed citizens hold the key to steering developments. Unfortunately there is no proper exchange of information in the water sector regarding current status and developments taking place from people dealing with the issues. As a result, unconnected people raise irrelevant issues distracting the focus needed in the water sector. Being a democratic set-up, decision-makers get swayed by conjectures rather than evidence-based scientific research. There is a need to authorize water professionals and researchers to present correct perspectives on water-related issues so that people at large and decision-makers, in particular, get benefitted from evidence-based scientific research.

7 Physical and Financial Resources

India lacks significantly on availability of physical and financial resources for R&D in water sector. And the prime reason is too much dependence on government funding caused by poor linkages with industries. A review of data shows that the expenditure on R&D in many developing countries as a percentage of GDP generally varies in the range 1.6–3.5%. In Israel, it was about 4.27% and the figure for India was 0.87% in 2009. This clearly shows that a significant increase in R&D outlay is necessary for India to catch up with developing countries. More than budgetary outlays, functional flexibility is necessary to boost research activities. As a result even limited budgetary outlays are not fully utilized. There is a need to ensure faster approvals after peer reviews with little or no interference from bureaucrats and finance.

The recent government policies to promote and incentivize research appear promising, but due to poor implementation, these policies have little impact on the ground. For example, Flexible Complementing Scheme (FCS) assures time-bound promotion, but meeting of Assessment Boards for promotions under FCS seldom takes place in time resulting into delayed promotions with consequential loss. Further, the highest position to which a bright researcher can rise is at relatively much lower rank in the government set-up, and this is yet another disincentive for young generation to enter in R&D sector.

8 Suggested Way Forward

The following suggestions are made to boost R&D in water sector:

1. Water cuts across all sectors so research in water sector should be multidisciplinary. There must be intra- and inter-institutional linkages between scientists in addition to strong industry linkages to promote multidisciplinary research in water sector. This would enable comprehensive and holistic approach towards water issues.

2. There is a need to synergize developments in allied sectors, like instruments, sensors and geospatial IT technologies with water sector. Scientists should be given adequate exposure to these developments as well.
3. There should be strong linkages between academic institutions and government and industrial research institutes so that basic research as well as applied research for optimum solutions to real-life problems is taken up in a balanced manner.
4. Regular interactions between academia, applied researchers and working professionals should be ensured to identify research needs, field constraints and priorities.
5. R&D set-up in India needs to be revamped and energized. We need to create conducive environment through functional autonomy and positive work culture which encourages people to excel.
6. Scientists and faculty of academic/research institutes should be encouraged to take more industry-sponsored research projects to make research more practical. They need to address the existing challenges by using the information available and provide solutions.
7. Scientists should also be encouraged to network with foreign institutions and avail sabbatical leaves to upgrade their skills.
8. There is urgent need to increase investment in water-related R&D. Currently R&D funding is project based with typical duration of 2–3 years. Effective technology development and implementation/testing require support over a long period of time.
9. A vision/ plan needs to be developed with aim to take up R&D for the next 15–20 years. More studies on social aspects of water management, e.g. governance and conflict resolutions, should be included.
10. India requires multidisciplinary centres of excellence to tackle big issues like water system response to climate change, forecasting of intense precipitation and floods and medium-range weather forecasts for improved management of water in agriculture and water contamination.
11. Indian research organizations should be benchmarked with global reputed water research institutes to promote centres of excellence and competitiveness.
12. Promote multidisciplinary masters programmes in water resources in academic institutes.

Acknowledgement The authors extend their thanks to their colleagues for their valuable inputs during the course of preparing the manuscript. The views expressed are of authors personal and not of the department.

References

Falkenmark M, Widstrand C (1992) Population and water resources: a delicate balance. Popul Bull 47:1–36

Jain SK, Agarwal PK, Singh VP (2007) Hydrology and water resources of India. Springer, Dordrecht ISBN 978-1-4020-5179-1

Mandal K, Priti (2015) Water R&D in India: Trends and intervention. ISTIP Policy Bulletin No. 10, CSIR-NISTADS

Sub-committee – SAC to PM (2014) Technology interventions in the water sector. Scientific Advisory Council to the Prime Minister, Government of India, New Delhi. Available at: http://tenet.res.in/Publications/Presentations/pdfs/SAC-PM_report_on_water.pdf

Sharad K. Jain is currently the Director, National Institute of Hydrology, Roorkee, where he is working since 1982. He was a postdoctoral fellow in Japan; visiting professor in LSU, USA (2002); and NEEPCO Chair Professor at IIT Roorkee (2009–2012). His research interests include surface water hydrology, water resources planning and management, impact of climate change, application of emerging techniques and water policy and governance. Dr. Jain has co-authored the following four books: (a) *Water Resources Systems Planning and Management*, Elsevier; (b) *Hydrology and Water Resources of India*, Springer; (c) *Risk and Reliability Analysis*, ASCE, USA; and (d) *Water Resources Systems*, Institution of Engineers. He has written 35 book chapters and 235 technical papers. His group has developed a software package for reservoirs analysis and has set up an experimental basin in Upper Ganga Basin. He is the chairman of Expert Appraisal Committee (river valley and hydro), MOEF&CC and member of Project Appraisal and Monitoring Committee (hydrol and cryosphere), MoES; WRD1:1 of BIS; sub-committee on Interlinking of Rivers, MOWR; and expert committee on Spatial Data (of DST). He was also a member of the Task Force on Water, Scientific Advisory Council to Prime Minister (2013–2014). Dr. Jain is a member of the International Board of Advisors, *Journal of Hydrologic Engineering*, ASCE and Editorial Board of *Hydrological Processes* Journal (Wiley-Blackwell). He is also a consultant to International Atomic Energy Agency, Vienna.

Mukesh Kumar Sinha graduated in civil engineering from Indian Institute of Technology, Delhi in 1986 and did his master's in rock mechanics (IIT Delhi) and in engineering hydrology from University College, Galway, Ireland, and PhD in disaster management planning. He joined Central Water Commission in 1988, and since then, he is associated with planning, design and detailed engineering of several water resources and hydropower projects. He was Member Secretary of Indian National Committee on Hydraulic Research as well as that of the National Committee on Seismic Design Parameters for River Valley Projects. He was one of the authors of the CBIP Publication on *Repair, Renovation and Life Extension of Hydro Power Projects* and the BMTPC Publication on *Vulnerability Atlas of India*.
He was also Member (civil) as well as Member (environment and rehabilitation) of Narmada Control Authority for ensuring compliance of NWDT Award. He worked as Director of Central Water and Power Research Station, Pune, and Advisor (coordination and monitoring) of National Water Mission launched as part of National Action Plan for Climate Change in respect of water conservation and efficient use of water. He is president of Indian Society for Hydraulics and chairman of Technical Committee TC113/SC1 of International Standardisation Organisation (ISO).

Crafting a Paradigm Shift in Water

Mihir Shah

1 Introduction

India is now the fastest-growing economy in the world. A process of economic reforms over the last 30 years has prepared the ground for this transition. However, it has not been adequately recognised that this growth process will become completely unsustainable unless a paradigm shift is initiated in the water sector in India. This paper describes a key episode in India's attempt at a paradigm shift in water. The 12th Five-Year Plan adopted a unique process designed to fundamentally alter the principles, approach and strategies of water management in India. This paradigm shift was the outcome of a new and inclusive process of plan formulation, which saw the coming together of practitioners and professionals from government, academia, industry and civil society to draft the 12th Plan proposals on water.

2 Demand and Supply of Water in India

Estimates of India's water budget, i.e. annual flow of water available for human use after allowing for evapotranspiration and minimum required ecological flow, vary considerably. The water budget derived from the Ministry of Water Resources estimates (summarised in the first column in Fig. 1) shows utilisable water of 1123 BCM against current water use of 634 BCM suggesting more than adequate availability at the aggregate level given current requirements. This is based on the Central Water Commission's estimate of India's water resource potential as 1869 billion cubic metres (BCM). The Standing Sub-committee of the Ministry of Water

This is a modified and updated version of a paper that first appeared in the *Economic and Political Weekly*, January 19, 2013

M. Shah (✉)
Distinguished Visiting Professor, Shiv Nadar University, New Delhi, India

© Springer Nature Singapore Pte Ltd. 2019

A. Singh et al. (eds.), *Water Governance: Challenges and Prospects*, Springer Water,
https://doi.org/10.1007/978-981-13-2700-1_21

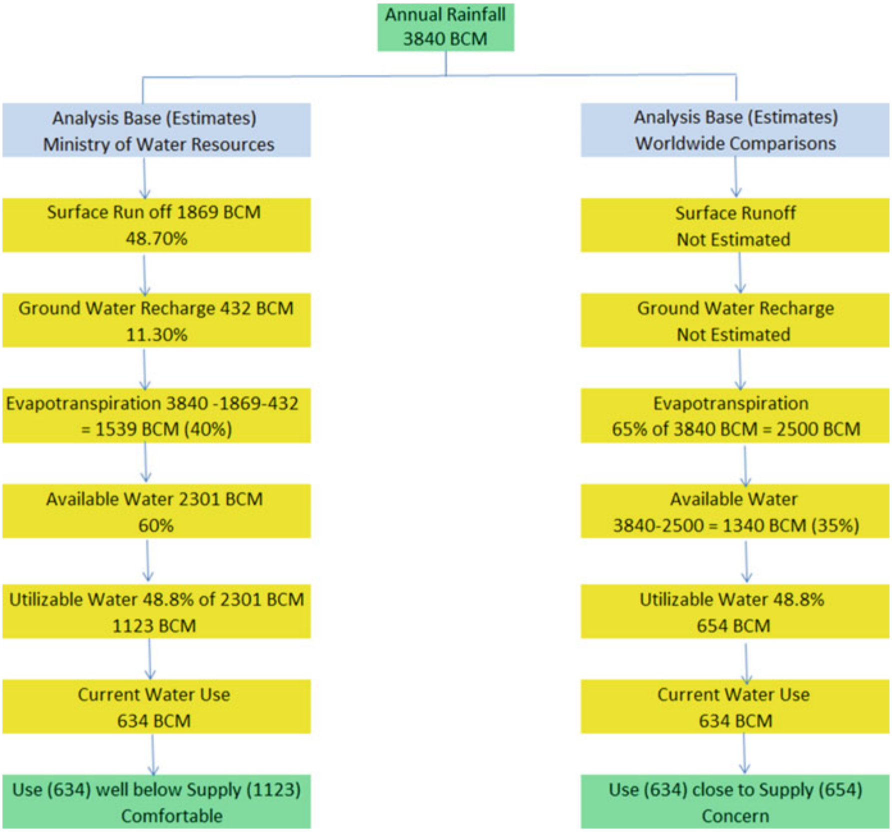


Fig. 1 An estimate of water resources in India

Resources estimates total water demand rising to 1093 BCM in 2025, thus reaffirming a comfortable scenario. However, more recent calculations based on higher estimates of the amount of water lost to the atmosphere by evapotranspiration are less comforting. Narasimhan (2008) has recalculated India's water budget, using an evapotranspiration rate of 65% which compares with worldwide figures ranging from 60% to 90% instead of the 40% rate assumed in the official estimates. The result also summarised in Fig. 1 is sobering. After allowing the same 48.8% for ecological flows, his estimate of water utilisable for human use comes to only 654 BCM, which is very close to the current actual water-use estimate of 634 BCM. The 2030 Water Resources Group (2009) estimates that if the current pattern of demand continues, about half of the demand for water will be unmet by 2030. The estimate of water resource presented by Narasimhan and Gaur (2009) is given in Fig. 1.

In addition to the fact that aggregate estimates suffer from data infirmities and arbitrary assumptions and are still being debated and contested, it is also important to emphasise that in a country of such immense physiographic, hydrogeological and demographic diversity and also vastly different levels of economic development (hence water use), water balances for the country as a whole are of limited value since they hide the existence of areas of acute water shortage or even problems of quality.

What is required is a much more disaggregated picture, accurately reflecting the challenge faced by each region. The exact level at which regions need to be defined would depend on the purposes of the exercise, as also unifying features of the region, such as basin and aquifer boundaries.

3 Sources of Water in India

Around 80% of India's water is consumed by the irrigation sector. For the first two decades after independence, this water was mainly supplied through large and medium irrigation dams constructed on our major river systems. However, over the last four decades, it is groundwater that has been the main source of water.

Figure 2 summarises sources of water for irrigation in India and shows how groundwater, especially irrigation largely carried out through tube wells, has become the main source in recent decades. The annual extraction of groundwater in India (210 billion cubic metres) is by far the highest in the world. As shown in Fig. 2, groundwater today provides more than 60% of net irrigated area. The area irrigated by canals and tanks has actually undergone a decline even in absolute terms since the 1990s.

What is truly alarming, however, is the fact that we are now facing a serious crisis of groundwater. Water tables are falling and water quality issues have increasingly come to the fore. As we drill deeper for water, our groundwater gets contaminated with fluoride, arsenic, mercury and even uranium.

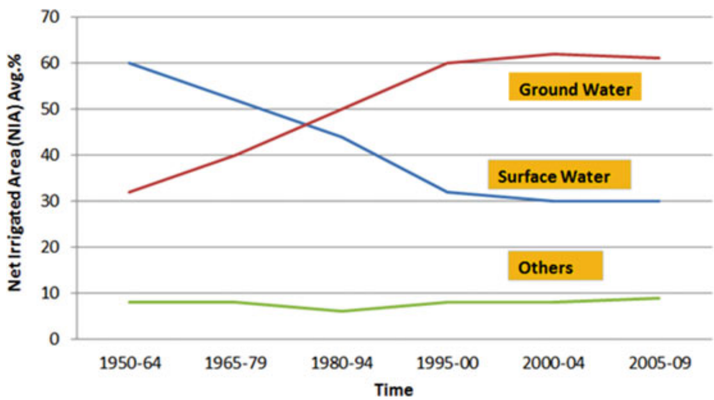


Fig. 2 Net area irrigated over the years by different sources, 1950–2010 in percentage

4 Features, Dimensions and Principles of the Present Paradigm

India has, in recent years, been suffering successive droughts causing great misery to millions of people, even resulting in suicides of the farmers. The epicentre of the present drought is Maharashtra, the State with the highest number of dams in India. Intervening in a debate in the State Assembly on July 21, 2015, the Chief Minister of Maharashtra remarked that the State has 40% of the country's large dams, "but 82 per cent area of the state is rainfed. Till the time you don't give water to a farmer's fields, you can't save him from suicide. We have moved away from our vision of watershed and conservation. We did not think about hydrology, geology and topography of a region before pushing large dams everywhere. We pushed large dams, not irrigation. But this has to change".

It is our contention that without a fundamental change in the prevailing paradigm of water in India, we cannot overcome the kind of paradox Maharashtra and many other States face in India. Before suggesting the changes required, let us first summarise the key *features*, *dimensions* and *principles* that characterise the existing paradigm, each of which needs to undergo urgent transformation:

(a) *Command-and-control*: Whether it be rivers or groundwater, the dominant paradigm is of command-and-control. There is no understanding of river systems or their interconnections with the health of catchment areas or groundwater.
(b) *Bureaucratic governance*: Large, centralised, decaying bureaucracies are charged with administering water throughout the length and breadth of India.
(c) *No reference to hydrological entities such as aquifers or river systems*: When I joined the planning commission in 2009, the word aquifer could hardly be found within government discourse, and the integrity of river systems is still not understood.
(d) *Uni-disciplinarity*: Since the goal is command-and-control through dam construction and groundwater extraction, the only disciplines evoked are engineering and hydrogeology, that too in their narrowest versions. Water cannot be understood with this narrow disciplinary focus.
(e) *Uni-dimensionality*: Since the focus is extraction and development, all dimensions of water, other than economic resource use, are ignored. These various other dimensions are however of critical importance to the primary stakeholders of water in India.
(f) *Water in silos*: We have divided water into silos of groundwater and surface water, as also irrigation and domestic use, with little dialogue across silos, leading to "hydro-schizophrenia" (Jarvis et al. 2005) where the left hand of drinking water does not know what the right hand of irrigation is doing and the

left foot of surface water does not know what the right foot of groundwater is doing.

(g) *Instrumental view of water, especially rivers*: The way we look at our rivers is, as water resources to be exploited, ignoring completely the numerous ecosystem services provided by living river systems, as also the intrinsic value of rivers for our people and other forms of life.

(h) *Supply-side focus*: The entire focus has been on augmenting supplies, with little attention being paid on demand management of water.

(i) *No reference to sustainability*: In the preoccupation with extraction and development, there has generally been an absence of considerations of sustainability, endangering the future of both groundwater and river flows.

(j) *Discrimination and lack of equity in access to water*: Historical forms of discrimination, combined with the impact of growing economic inequalities in the country, to create severe discrimination in access to water on grounds of caste, class, gender, location and community.

(k) *Lack of transparency and access to water information*: Over the years, there has been needless secrecy in access to water data, and information for researchers and stakeholders that has only meant that the quality of water management has suffered and conflicts have got exacerbated.

(l) *British common law*: The legal framework governing water belongs to the nineteenth century British common law, which legitimises and perpetuates inequity in access to water by giving unlimited powers of drawal of water to owners of land.

The 12th Plan faced a challenge of how to move forward. It was clear that business as usual would not do. New ideas needed to be desperately put into place for which the best scholars and practitioners had to come together. Thus, a new architecture of plan formulation was designed. The Working Groups for the 12th Plan in the water sector were, for the first time in the history of the Planning Commission, all chaired by renowned experts from outside government. Secretaries of concerned departments were designated co-chairs. There was initially great resistance to this move both within and outside government, with both sides showing great reluctance to work with each other. However, it was impressed upon them that only their working together could provide the solutions the country so desperately needed, given the emerging crisis that they all acknowledged. What was also clear was the need to arrive at a workable consensus on each issue, even where there were major disagreements. Over the course of several months in 2011–2012, a new path was charted out, giving rise to a tenfold paradigm shift in water resource management in India. This paper outlines the main features of this change.[1]

[1]The 12th Plan and this paper derive in large part from the insights contained in the reports of these Working Groups, which are all available on the website of the Planning Commission.

5 Paradigm Shift in the 12th Plan

5.1 Large Irrigation Reform[2]

Given the emerging limits to further development in the major and medium irrigation (MMI) sector, the 12th Plan proposes a move away from a narrowly engineering-construction-centric approach to a more multidisciplinary, participatory management perspective, with central emphasis on command area development and a sustained effort at improving water-use efficiency, which continues to languish at a very low level. Given that nearly 80% of our water resources are consumed by irrigation, an increase in water-use efficiency of irrigation projects by the 12th Plan goal of 20% will have a major impact on the overall availability of water not only for agriculture but also for other sectors of the economy.

Huge public investments over the last 60 years have meant that the irrigation potential created through MMI projects has increased nearly fivefold from 9.72 mha in the pre-plan period to around 46 mha by the 11th Plan. The problem is that during the same period, the utilisation of this potential has failed to keep pace. From being almost equal in the pre-plan period, the gap between the two has only grown wider over the years. The 12th Plan believes that improved utilisation of these capacities can dramatically add to irrigated area and also lead to a major improvement in water-use efficiency.

The key bottleneck so far has been that capacities of irrigation departments in many States to deliver quality services have failed to keep up with growing MMI investments. While States compete for capital investments in new MMI projects, they do little to manage them efficiently. In 2005, the World Bank estimated that to minimise deferred maintenance on Indian MMI systems, we need to spend Rs. 19,000 crore on annual maintenance, which is nearly 20 times more than what States actually spend. State irrigation departments are content to generate enough revenue to meet their establishment costs, which many do from the water charges they recover by selling a small proportion of MMI water to industries. But this just covers salaries and leaves little or nothing for regular maintenance and upkeep of systems, especially canals and distribution systems. This has an adverse impact on irrigation.

This is closely linked to the fact that in many States the irrigation service fee (ISF) to be collected from farmers has been abolished or is as low as 2–8% of dues. In this way, the accountability loop between farmers and irrigation departments is broken. Wherever ISF gets regularly collected, irrigation staff shows greater accountability and responsiveness to farmers. There is greater contact between the two, there is greater oversight of water distribution and farmers expect at least a minimal level of service if an ISF is demanded of them. When governments abolish ISF or fix it at a token rate or fail to undertake regular collection, farmers forfeit their right to demand service, and irrigation staff can afford to neglect service provision. The 13th Finance

[2]The 12th Plan Working Group on MMI was chaired by Tushaar Shah.

Commission took note of this and recommended a grant of Rs. 5000 crore over 4 years for providing central assistance to each State, linked to outcomes in terms of ISF collection, MMI performance and impacts. However, this incentive grant appears too small to nudge States to take up an aggressive irrigation reform agenda.

A substantial National Irrigation Management Fund (NIMF) was, therefore, proposed to incentivise States to make the required paradigm shift. The NIMF would be a non-lapsable fund that reimburses to State irrigation departments a matching contribution of their ISF collection from farmers on a 1:1 ratio. In order to generate competition among MMI staff across commands, States would allocate the central grant to MMI systems in proportion to their respective ISF collection. To encourage participatory irrigation management (PIM), the NIMF would provide a bonus on that portion of each State's ISF collection, which has been collected through Water User Associations (WUAs). And this will be on condition that WUAs and their federations are allowed to retain definite proportions of the ISF, which would not only enable them to undertake repair and maintenance of distribution systems but also increase their stakes in water management. Similarly, to encourage volumetric water deliveries, NIMF would provide an additional bonus on that portion of a State's ISF collection which accrues through volumetric water supply to WUAs at the outlet level. The clear understanding is that empowering WUAs is the key to making the process of pricing of water and ISF collection more transparent and participatory. These proposals are based on experience on the ground over the last few years in Andhra Pradesh, Gujarat, Maharashtra and Karnataka.

To enable irrigation departments to effectively play their new role in irrigation management transfer, their human resource profile needs to be broadened to include disciplines such as social mobilisation, management, agronomy, etc. Capacities of civil engineers need to be reoriented to move them away from a narrow construction outlook towards management roles (as being done by their counterparts throughout the world). These partnerships would need to be developed with national institutes of eminence to establish centres of excellence in irrigation management to undertake research, education and training for senior MMI managers in performance management through planning, budgeting and monitoring systems. Another set of partnerships would help build management information systems for MMI schemes with the specific purpose of generating real-time information on the working and performance of these systems to enable their benchmarking.

Our huge investments in irrigation have yielded much less than what they should have mainly because command area development (CAD) has been consistently neglected and divorced from building of irrigation capacities. The 12th Plan stipulates that all irrigation project proposals (major, medium or small) will henceforth include CAD works from the very beginning as an integral part of the project. Thus, each proposal will plan for irrigation water from the reservoir to the farm gate and not just the outlet as at present. No investment clearance will be provided to any irrigation project devoid of CAD integration. There will be pari passu action in each irrigation command wherein works in the distributary network and software activities of CAD will be undertaken simultaneously with head works and main canal work, leading to a seamless integration of work in the head-reaches and tail-end of the command. Recognition of potential creation at the outlet of distributary will be discontinued. Potential creation will be recognised only after complete hydraulic connectivity is achieved from reservoir to farm gate. In this manner, creation of irrigation capacities will be better matched by their utilisation, farmers will truly benefit from these investments and water-use efficiency will improve.

5.2 Participatory Aquifer Management[3]

Since groundwater accounts for nearly two-thirds of India's irrigation and 80% of domestic water needs, the 12th Plan advocates the adoption of a participatory approach to sustainable management of groundwater based on aquifer mapping that takes into account the common pool resource (CPR) nature of groundwater. As the work of Elinor Ostrom (1990) shows, the first design principle in the management of a CPR is the clear delineation and demarcation of its boundaries. And an understanding of its essential features, which in the case of groundwater includes its storage and transmission characteristics.

It is this understanding that underpins the comprehensive programme for the mapping of India's aquifers initiated during the 12th Plan. The aquifer mapping programme is not an academic exercise and must seamlessly flow into a participatory groundwater management endeavour. This demands strong partnerships among government departments, research institutes, gram panchayats/urban local bodies, industrial units, civil society organisations and the local community. The interface of civil society and research institutes with government will be encouraged across all aspects of the programme, ranging from mapping India's aquifers, large-scale capacity building of professionals at different levels, action-research interface with implementation programmes and development of social regulation norms around groundwater.

The challenge of groundwater management arises from the fact that a fugitive, common pool resource is currently being extracted by individuals, millions of farmers in particular, with no effective mechanism to ensure that the rate of extraction is sustainable. Over the last few years, innovative approaches across the country have blazed a trail on how this paradox might be resolved. This requires an understanding of the following aspects:

[3]The 12th Plan Working Group on groundwater management was chaired by Himanshu Kulkarni.

- Relationship between surface hydrologic units (watersheds and river basins) and hydrogeological units, i.e. aquifer.
- The broad lithological setup constituting the aquifer with some idea about the geometry of the aquifer – extent and thickness.
- Identification of groundwater recharge areas, resulting in protection and augmentation strategies.
- Groundwater balance and crop water budgeting at the scale of a village or watershed.
- Groundwater assessment at the level of each individual aquifer in terms of groundwater storage and transmission characteristics, including the aquifer storage capacity.
- Regulatory options at community level, including drilling depth (or whether to drill tube wells or bore wells at all), distances between wells (especially with regard to drinking water sources), cropping pattern that ensures sustainability of the resource (aquifer) and not just the source (well/tube well) and comprehensive plan for participatory groundwater management based on aquifer understanding, bearing in mind principles of equitable distribution of groundwater across all stakeholders.

Each of these is the central foci of the National Aquifer Management Programme launched in the 12th Plan.

5.3 Breaking the Groundwater-Energy Nexus

The current regime of power subsidies for agriculture has had a major role to play in deteriorating water tables in most parts of India. These very same power subsidies fuelled the Green Revolution, but given the emerging stresses on groundwater, an imaginative way needs to be found, which breaks the groundwater-energy nexus, without hurting farmer interests. The single most effective solution found by States has been the physical segregation of power feeders to provide 24×7 electricity to rural habitations and nonfarm users, with separate feeders giving three-phase predictable supply to agriculture, which is rationed in terms of total time, at a flat tariff. This provides requisite power to schools, hospitals and the nonfarm economy while allowing rationed supply of power to agriculture, which can be at off-peak hours. For example, the Government of Gujarat invested US $1250 million during 2003–2006 to separate 800,000 tube wells from other rural connections and imposed an 8-h/day power ration but of high quality and full voltage. This was combined with a massive watershed development programme for groundwater recharge. The net result has been [a] halving of the power subsidy, [b] stabilised groundwater draft and [c] improved power supply in the rural economy. Combined with other measures such as high-voltage distribution system (HVDS), specially designed transformers and energy-efficient pumpsets, this could be a better way of delivering power subsidies that cut energy losses and stabilise the water table at the same time. Major investments are proposed in this direction in the 12th Plan.

5.4 *Watershed Restoration and Groundwater Recharge*[4]

Even while emphasising the need to improve the efficiency and sustainability of our irrigation systems, the 12th Plan is fully cognisant of the fact that the demands of national food security necessitate a major breakthrough in the productivity of our rainfed areas (Shah et al. 1998). A primary requirement for this is a massive programme for watershed restoration and groundwater recharge. The 12th Plan proposes to move in this direction by transforming MGNREGA into our largest watershed programme, giving renewed energy to the reformed Integrated Watershed Management Programme (IWMP) launched in the 11th Plan and launching a completely revamped programme on repair, renovation and restoration (RRR) of water bodies.

Given the massive investments government is making on MGNREGA and its central thrust on water conservation and drought-proofing, the programme offers the best bet to undertake watershed restoration and groundwater recharge at a large scale. The new MGNREGA Guidelines (MoRD 2012a) issued by the Ministry of Rural Development in 2012 herald the beginning of MGNREGA 2.0, which envisions a programme whose success will, in itself, pave the way for its downscaling. A large proportion of MGNREGA workers are small and marginal farmers, the productivity of whose lands has been so decimated over the years, that they have been compelled to work under MGNREGA. The real success of MGNREGA lies in creating the foundational water infrastructure that enables raising the agricultural productivity of millions of these farmers. They will then be able to return once again to farming and will no longer need to depend on MGNREGA for their survival.

MGNREGA 2.0 has expanded the list of permissible works to include many activities that build on watershed restoration to attain livelihood security. The aim is to convert the programme into a productivity-enhancing instrument based on a watershed approach. This derives from many such experiences scattered across the country that have brought about remarkable transformation.[5] Planning and implementation of works by gram panchayats (GPs) will be facilitated by multidisciplinary cluster facilitation teams that will operate at the milli-watershed/aquifer levels but with full accountability to GPs.

[4]Deep Joshi chaired the 12th Plan Working Group on Watershed Management.

[5]See Reports of the National Consortium of Civil Society Organisations on MGNREGA as also Shah (ed) (2012).

New guidelines were also issued for the IWMP in 2012 (MoRD 2012b). The 11th Plan proposed a radically new approach based on the suggestions of the Technical Committee on Watershed Programmes in India (Parthasarathy Committee). However, in a comprehensive review of the programme carried out by the Ministry of Rural Development in 2012, it emerged that a number of practical impediments were coming in the way of putting the new paradigm of watershed management into practice on the ground and the pace of the programme was found to be less than satisfactory. A Committee with Member, Planning Commission (Rural Development) as chair revised the guidelines to provide necessary flexibility and momentum to the programme, even while strengthening its innovative features. One of the key deficiencies of the programme was found to be the shortage of funds to deploy high-quality professional human resources for both social and technical aspects for which a special allocation was proposed. A new national strategy for capacity building was unveiled, since this was a key requirement of the programme that needed much greater direction and momentum. A separate provision was also made for institution building to ensure sustainability of benefits beyond the project period. All reviews of the watershed programme show that the best work has been done by civil society organisations. The new guidelines seek to provide further scope and facilitation for civil society participation in the programme. A major concern, especially in tribal areas, is the procedural complexities of work in ridge areas that fall within forest lands. The new guidelines proffer a framework within which this work can be facilitated.

There is a rich historical tradition of local water harvesting in India from the *ahar-pyne* system in Bihar, the *tankas* of Rajasthan, the Himalayan *dharas* and the *talabs* in Bundelkhand to the *eries* of Tamil Nadu. According to the fourth Minor Irrigation Census (2006–2007), there are 5.56 lakh water bodies in the country, out of which 3.02 lakh are publicly owned. Tragically, many of these water bodies have been languishing in a state of disrepair and disuse. A scheme for the repair, renovation and restoration of these water bodies was launched in 2005. The 12th Plan proposes a major overhaul of this scheme. The major change is not merely to place greater emphasis on the physical repair and desilting of the water body itself but to address the two major challenges that limit their potential benefits to users – restoring the health of their catchment areas that would reduce the rate of siltation and prolong their life and developing the command areas that are served by these water bodies. Thus, to realise its full potential, the RRR scheme must combine work that is generally done in separate silos of watershed treatment and command area development. It needs also to absorb the central lesson of both these schemes, which is that not merely engineering but institution building must equally take centre stage. This would enable stakeholders to fully participate in the planning and implementation of the scheme and feel a full sense of ownership over the work done and assets created/restored. Without such participation and ownership, the outcomes will be necessarily short-lived and unsustainable. During the 12th Plan, RRR would cover all water bodies with ayacuts of 20–2000 ha.

5.5 Industrial Water[6]

As the economy industrialises, it is extremely important that industry adopts the best international practices to improve water-use efficiency. This can be broadly done in two ways:

- Reducing the consumption of fresh water through alternative water-efficient technologies or processes in various manufacturing activities.
- Reusing and recycling the waste water from such water-intensive activities and making the reclaimed water available for use in the secondary activities within or outside the industry.

Such an approach is extremely important to reduce the water footprint of Indian industry, both in terms of fresh water used, as also polluted wastewater released untreated into the environment. The urgency of this issue is because water conflicts are increasingly arising across the length and breadth of India between competing users and uses. And industry, as a relatively new user of water, needs to recognise that economising on the use of water is now an essential ingredient in ensuring sustainability of its operations and may be in its own enlightened self-interest.

The first step in this direction will be to make comprehensive water audits a recurring feature of industrial activity so that we know what is being used by the industrial sector at present and so that changes can be monitored and the most cost-effective basket of water efficiency technologies and processes designed and implemented to reduce water demand and increase industrial value added per unit of water consumed. The water audit will consider both quantity and quality aspects as the need to reduce polluting discharges to the aquatic environment or to sewage systems is often the key driver to water saving. The starting point will be large units in water-intensive industries such as paper and pulp, textiles, food, leather (tanning), metal (surface treatment), chemical/pharmaceutical, oil/gas and mining.

It is proposed to make it mandatory for companies to include every year in their annual report, details of their water footprint for the year. This would include the following:

- The volume of fresh water (source-wise) used by them in their various production activities (activity-wise).
- The volume of water used by them that was reused or recycled (again activity-wise).
- A commitment with a timeline that the company would reduce its water footprint by a definite amount (to be specified) within a definite period of time (to be specified).

[6]This section partly draws upon a working paper *Developing a Water Conservation Strategy for Industry* prepared for the Planning Commission by the Centre for Energy, Environment and Water.

The second step would be to examine the measures to levy charges for water use and incentivise water conservation. Currently, the Water (Prevention and Control of Pollution) Cess Act 1977 is the only instrument to impose cess on discharge of effluent water from industrial units. This charge is based on the quantum of discharge from the industry and is used to augment the resources of the Central and State Pollution Boards. The charges imposed through the water cess are not enough of a disincentive for industries to reduce their water footprint. It is important to examine this Act and other provisions and options to increase the charges imposed on water use and effluents substantially. This is particularly important where industries use groundwater and do not pay municipalities, water utilities or even irrigation departments for water use. The importance of water pricing as an instrument for change is critical.

The third step would be to publicly validate the water audit of industries so that this builds experience and confidence on the best practices. This water reduction commitment of each industry will be tracked for compliance and enforcement through environmental regulatory institutions. In order to more credibly move industry along this path, Central and State governments need to set an example by undertaking their own audits of water use in their premises and setting targets for ensuring less water use and changes in technology and behaviour that will reduce waste. It is also very important to develop a forum which would:

- Provide information on industry-specific good practices in wise water use.
- Undertake to develop expertise in water audits and water-use advisory services.
- Provide details of “exemplar” case studies that are relevant to the different industrial sectors operating in India.
- Provide a “gateway” for accessing information about water-saving and water efficiency technologies in rainwater harvesting, recycling and reuse, water-conserving devices and support to helping behaviour change.

Once such systems are in place, there is enough experience from across the world to show that significant economies can be effected in water use. Reported water savings range from 15% to 90% of current water use, depending on the industrial subsector considered, the individual process investigated or the combination of water-saving measures analysed, with the most commonly found figures being within the 30–70% range.

5.6 Renewed Focus on Non-structural Mechanisms for Flood Management[7]

In addressing the problem of floods, the central focus over the years has been on engineering/structural solutions. Apart from the massive investments in large dams,

[7]Nirmal Sengupta chaired the 12th Plan Working Group on Flood Management.

India has already constructed over 35,000 km of embankments. But these are rapidly reaching their limits. Recent studies show, for example, that “the existing storage infrastructure in Peninsular Rivers is mostly designed to smooth out the southwest monsoon flows in, say, 9 out of 10 years. There may still be the 1 in 10 year flood, for which, however, there is no economic justification to invest in substantial additional infrastructure. Instead, better weather and flood forecasting is required, along with flood insurance and possibly the designation of flood diversion areas, whereby farmers are asked to temporarily (and against compensation) set aside embanked land to accommodate flood overflow for the Ganges system, out of 250 BCM of potentially utilisable water, about 37 BCM are presently captured, and a total of at most 50 BCM would be captured if all possible dams under consideration were to be built. These would add little in the way of irrigation or flood prevention benefits. Tributaries at risk are already fully embanked, and floods have occurred not because water has flown over the embankments, but because embankments have been repeatedly breached as a result of poor maintenance (e.g., Kosi in Bihar) or inappropriate dam management (e.g., Hirakud in Orissa)” (Ackerman 2011).

Evidence from floods in the Ghaggar-Hakra River basin, both in 1993 and 2010, clearly shows the damage caused in Punjab and Haryana by breaches in embankments and unused, poorly designed and maintained canals, as also because settlements have been encouraged on flood plains and drainage lines. In 2008, a breach in an upstream embankment of the Kosi led to the nearly thousand deaths and the displacement of around 3.35 million people (Government of Bihar 2008). In North Bihar, despite the continued construction of embankments, the flood-prone area has increased 200 per cent since independence, at times because embankments end up obstructing natural drainages and impede the natural building up of river deltas and flood plains.

In acknowledgment of the limits to further possibilities of building large storages and embankments, some State governments (such as Bihar) have decided to broaden their strategy of tackling floods by placing greater emphasis on rehabilitation of traditional, natural drainage systems, leveraging the funds available under MGNREGA (Samaj Pragati Sahayog and Megh-Pyne Abhiyan 2012). Since this involves a process of complex social mobilisation and social engineering, civil society organisations will work in close partnership with the State government in this endeavour. The 12th Plan strongly endorses such a paradigm shift in flood management away from building more and more embankments and towards a “room for the river” kind of approach (Government of Netherland 2007; ClimateWire 2012).

Indeed, an attempt must be made, as far as practicable, to convert adversity into opportunity. Part of the waterlogged area could be used for construction of small multipurpose farm ponds. The mud of the ponds would be raised on the side as embankments on which crops like banana, papaya, mango, pigeon pea and cashew nut can be grown. The pond water will be used to irrigate the non-waterlogged, upland area. Experiments have shown that in waterlogged areas, cultivation of water chestnut (*Trapabi spinosa*) can be quite profitable. Research and field level trials have identified extra-tall varieties of paddy that can grow fast and can tolerate waterlogging. Waterlogging is often aggravated by the mismanagement of rainwater in the upper catchment. In situ rainwater conservation in the upper catchment and intensification of the use of groundwater through shallow tube wells are possible interventions to mitigate the problem. Through integrated management of land, water and nutrients, agricultural productivity of these uplands could be stabilised and enhanced, which would, in turn, have a positive impact on the waterlogged lowlands.

In addition, far greater priority must be given to non-structural measures such as the efficient management of flood plains, flood plain zoning, disaster preparedness and response planning, flood forecasting and warning along with disaster relief, flood fighting including public health measures and flood insurance. Many reservoirs were initially constructed without any flood cushion but with development and population growth, habitations have come up very close to the downstream of these reservoirs and operation of such reservoirs needs to be done carefully. The existing flood forecasting network of Central Water Commission (CWC) is not sufficient to cover the entire country adequately. We need to draw up a concrete plan for extension of CWC's flood forecasting network in consultation with the State governments and IMD to cover class A, B-1, B-2 and C- cities located near rivers under the network of automatic data collection, transmission and flood information dissemination. At present, the CWC provides inflow forecast to 28 reservoirs in the country. This needs to be extended to an additional 160 reservoirs, which will cover 80–90% of the total live storage capacity.

Moreover, a majority of the flood warning systems in India are not timely, primarily due to poor transmission. Delays cause enormous damage to property and lives every year. Models used for flood forecasting and its influence zones are not rigorous enough due to lack of integration of hydrology and the weather forecasting systems. The lead time for flood forecasting can be improved through the use of hydraulic and hydrologic models which are linked to the weather forecasting system, the real-time data acquisition system and the reservoir operation system. It is possible to improve the current forecasting methods by using satellite-based information for better estimates of rainfall and snowmelt.

In order to support the manifold paradigm shift in water management described above, two major enabling initiatives were undertaken in the 12th Plan. These are in the area of water database development and management and in fashioning a new legal and institutional architecture.

5.7 Water Database Development and Management[8]

As part of the preparation for the 12th Plan, the Planning Commission decided to constitute, for the first time, a Working Group to carry out a comprehensive and

[8] A. Vaidyanathan chaired the 12th Plan Working Group on Water Database Development and Management.

critical review of the present system for collection and dissemination of water-related data, identify deficiencies in the data being generated and used for planning and policy and suggest a programme of action to overcome them. The Working Group highlights serious gaps and inadequacies in the scope, coverage and quality of data currently used for assessing India's potential and utilisable water resources from different sources, their actual utilisation for, and impact on, various end uses. It also spells out a concrete programme for phased action to improve physical facilities, methodologies and mechanisms to generate more comprehensive, detailed and reliable data and outlines changes needed in institutional arrangements for collection validation and dissemination of data and for facilitating intensive analysis through research.

Data improvement is a national effort of the Central and the State government agencies that requires active involvement of specialised government agencies and scholars in universities, research institutions and non-governmental organisations in a way that fragmentation of focus and effort is minimised. This calls for a common agreed framework of concepts. It is, therefore, suggested by the Working Group that the Central government take the lead in creating appropriate institutional arrangements to ensure independent and professional conduct of the surveys, providing financial and technical support to the States, ensuring that all agencies follow prescribed protocols to transmit data to the central pool and to work out:

(a) The strategy, modalities and funding for building a comprehensive, technical and scientific data base on potential and utilisable water from different sources.
(b) Details of the scope, content, methodology and mechanisms of the surveys to assess performance and impact of programmes through sample surveys of users and specific projects.
(c) The design of an integrated and digitised National Water Resources Information System by suitably expanding, reorganising and equipping the existing Water Resource Information System in the Central Water Commission.

The bulk of the expenditure on the programmes for data improvement needs to be for expanding and upgrading facilities for assessment of resource potential and utilisation. Sample surveys to assess actual performance and impact of schemes at the ground level will be a small but critical component. Altogether this small investment in improving information and knowledge will provide huge returns in terms of improving efficiency and sustainability of water use.

5.8 New Institutional Framework

5.8.1 State-Level Regulators[9]

The 12th Plan recognises the need to evolve an institutional framework backed by a legal regime that facilitates setting up of regulatory bodies that would enable

[9]Subodh Wagle chaired the 12th Plan Sub-Group on Water Regulators.

resolution of water conflicts. To protect the right to drinking water for all, there is no alternative to entitlements and appropriate pricing of water. This demands a transparent and participatory process of determination of entitlements and prices. Again to ensure sustainability and meet environmental needs, a regulatory authority is a must in each State.

Since the water sector is a natural monopoly, international experience clearly indicates that it is regulators who provide the cutting-edge that is otherwise missing in a non-competitive environment. Regulators have contributed to major improvements in water-use efficiency, water quality and provision of environmental services.[10] And given the impact that their operations can have on public health and the environment, the water and wastewater industry have to be highly regulated to protect customer interests. The water quality, environment and health standards set by the regulator have a bearing on tariffs. The final call on tariffs would, of course, be a political one but the regulators have a crucial role in advising governments on the objective basis for tariff determination (somewhat akin to what the CACP does for agriculture pricing). The basic requirements of drinking water and of the environment need to be determined and ensured in a transparent manner and kept as a "reserve" (as it is called, e.g. in South Africa).[11] The determination of this level requires an independent regulator who can transparently, accountably and in a participatory manner conduct the processes and procedures required for this.

As part of the 12th Plan, a Model Bill for State Water Regulatory System has been drafted.[12] This draft is based on a thorough study of latest international thinking on regulation as also the experience of the Maharashtra Water Resources Regulatory Authority (MWRRA). The draft bill tries to resolve the conflicting demands of autonomy and accountability brought into sharp relief by the Maharashtra experience. It does so by proposing a regulatory system with interrelated but separate institutions that handle distinct governance functions. The bill proposes a separation of the authority to make "political" or "normative" decisions and the authority to make "technical" or "predominantly non-normative" decisions. Thus, the State Water Regulatory and Development Council (SC) is expected to ensure accountability by providing the "normative" or "political" framework for the techno-economic regulatory decisions of the State Independent Water Expert Authority

---

[10]Thus, for example, while Scottish Water is a state monopoly, the legal and regulatory framework within which it functions ensures that efficiencies are achieved, quality standards adhered to and expectations of consumers satisfied.

[11]In South Africa, the "Reserve" constitutes an attempt to quantify an amount of minimum flow in the country's rivers and impoundments reserved for the maintenance of basic ecological functions (such as habitat for fish and plants) and to ensure that the South African population is guaranteed a minimum of 25 litres per capita per day for domestic purposes. Thus categories of use that are perhaps not sufficiently defended vocally are nevertheless declared to be non-negotiable in the public interest. The Reserve is an attempt to decide what level of loss is acceptable rather than an attempt to determine what "the environment" needs.

[12]The draft model bill is available on the website of the Planning Commission.

(SIWEA). The SIWEA will, in turn, be accountable to technical experts through the mechanism of regular peer reviews.

The model bill incorporates the principle of subsidiarity by laying out water governance at four levels: (i) State, (ii) river basin, (iii) subbasin and (iv) local. At all these four levels of governance, institutions with different structure, compositions, functions, authorities and roles are provided for in the bill. The apprehension that such decentralisation might prove dysfunctional or suboptimal, especially because of the lack of capabilities and understanding, is sought to be taken care of through the concept of phased institutional transition by providing stepwise, gate-protected processes for gradual introduction of the decentralised institutional structure.

The bill also builds in enough flexibility in its design to take care of differences across States through a modular structure, from which modules based on the state-specific situation, requirements, priorities of water sector governance and other factors could be selected by the State government while preparing and enacting their final draft of the bill.

5.9 New Legal Framework

5.9.1 Groundwater (Cullet 2012)

Sustainable and equitable management of groundwater based on aquifer management requires a new legal framework to support efforts in this direction. Since the 1970s, the Government of India has put forward several model bills to regulate groundwater for adoption by the States. But these model bills only introduce a limited regulatory framework and amount to little more than "grandfathering" existing uses. What is remarkable is that some of the most important legal principles governing groundwater even today were laid down in British common law as early as the middle of the nineteenth century and have not been updated since.

Existing rules of access to and control over groundwater are still based on the common law doctrine of absolute dominion. This gives the landowner the right to take substantially as much groundwater as desired from wells dug on own land. Landowners do not own groundwater but enjoy access as part and parcel of their ownership rights to the land above.[13] Contrary to established hydrogeology, a

[13] "The person who owns the surface may dig therein, and apply all that is there found to his own purposes at his free will and pleasure; and that if, in the exercise of such right, he intercepts or drains off the water collected from underground springs in his neighbour's well, this inconvenience to his neighbour falls within the description of damnum absque injuria [damage without injury], which cannot become the ground of an action" *Acton v Blundell*(1843) 12 Meeson and Welsby 324 (Court of Exchequer Chamber,1 January 1843).This was confirmed in *Chasemore v Richards* (footnote 21), which found that the right of the owner of a mill using spring water had no action against other landowners abstracting groundwater to the extent of affecting his own use of the water. This was because the judges determined that such a right would "interfere with, if not prevent, the draining of land by the owner".

distinction is also made between "defined" and "undefined channels": "Groundwater that percolates through underground strata, which has no certain course, no defined limits, but which oozes through the soil in every direction in which the rain penetrates is not subject to the same rules as flowing water in streams or rivers".[14] On the other hand, where groundwater was found to flow in defined channels, case law says that rules applicable to surface water would also apply. This has been interpreted (Katiyar 2010) to mean that the right of the landowner would then be limited to the use and consumption for household and drinking purpose, for watering their cattle and even for irrigating their land or for purposes of manufacture provided that the use is reasonable, it is required for their purposes as owners of the land and it does not destroy or render useless or materially diminish or affect the application of the water by riparian owners below the stream in the exercise either of their natural right or right of easement, if any.

A lot of legal hermeneutics was devoted over the years to clearly spelling out the distinction between defined and undefined channels of groundwater.[15] This differentiation is completely meaningless in scientific hydrogeological terms since groundwater occurs in aquifers, which do not necessarily take the form of "channels" like streams and rivers. Aquifers are rocks or rock material possessing the capacity to store water in different openings and transmit water from one point in the aquifer to another, due to the interconnectedness between these openings. Hence, the question of water flowing through streams generally does not arise.[16]

Indeed, water flowing underneath any parcel of land may or may not be generated as recharge on that specific parcel. Recharge areas for most aquifers are only a small part of the land that overlies the entire aquifer. Hence, in many cases, water flowing underneath any parcel of land will have infiltrated the land and recharged the aquifer from another parcel, often lying at a distance. When many users simultaneously pump groundwater, complex interference results between different foci of pumping, a common feature in many parts of India, where wells are located quite close to one another. In such situations, natural groundwater flow is changed and groundwater moves depending upon the distribution of pumped water levels in different parts of the aquifer, again making it difficult to create rules based on defined streams of water akin to surface water movement.

What is worse, the present legal framework only considers the interests of landowners, completely overlooking the hugely important fact that groundwater

[14]*George Chasemore v Henry Richards* (1859) VII House of Lords Cases 349 (House of Lords, 27 July 1859)

[15]Thus, for example, in the words of Justice Seshagiri Aiyar "It must have a fairly defined course. It must move. Its water must be capable of identification. It need not always be confined within banks. It need not have a continuous flow. Its width need not be of particular dimensions" Unde Rajah Raja Sri Raja Velugoti Sri Rajagopala Krishna Yachendrala Varu Bahadur, K.C.I.E. Maharajah of Venkatagiri v Secretary of State for India in Council (1915) 28 MLJ 98 (High Court of Madras, 19 October 1914).

[16]Except in case of carbonate rocks which have large openings on account of the phenomenon called karst

serves the basic needs of life of so many people who do not own land. New developments in jurisprudence have created both the basis and the necessity to redefine the legal framework for groundwater. These include the following:

- New water law principles (for instance, the public trust doctrine enunciated by the Supreme Court),[17] which suggest that water, and groundwater specifically, is a public trust and that the State at all levels (from the panchayat to the State government) is the custodian of the resource.[18]
- Environmental law principles (for instance, the precautionary principle).
- Decentralisation principles embodied in the 73rd and 74th amendments to the Constitution.
- Changes in irrigation law focusing on participatory irrigation management over for the past 15 years and implemented in a number of States.[19]
- The fundamental right to water that has been a part of Indian law for the past two decades.[20]
- Protection principles, such as the prevention and precautionary principles, most recently statutorily recognised in the National Green Tribunal Act, 2010 (Section 20).

Keeping these in mind, the 12th Plan proposed a new *Model Bill for the Protection, Conservation, Management and Regulation of Groundwater*.[21] It is based on the idea that while protection of groundwater is key to the long-term sustainability of the resource, this must be considered in a framework in which livelihoods and basic drinking water needs are of central importance. The overall objectives of the Model Bill are to:

- Regulate iniquitous groundwater use and distribution to ensure that the safe and secure drinking water/domestic needs of every person and irrigation needs of small and marginal farmers can be met.
- Regulate overextraction of groundwater in order to ensure the sustainability of groundwater resources and equity of their use and distribution and to ensure fulfilment of ecosystem needs.
- Promote and protect community-based, participatory mechanisms of groundwater management that are adapted to specific locations.

---

[17] *MC Mehta v Kamal Nath*(1997) 1 SCC 388 (Supreme Court, 1996); *State of West Bengal v Kesoram Industries* (2004) 10 SCC 201 (Supreme Court, 2004)

[18] This applies to groundwater as a resource (aquifer) and not to mechanisms (wells/tube wells) for abstracting it. The Model Bill is built around the need to regulate unreasonable use of sources of groundwater that threaten the aquifer to ensure that the resource (aquifer) itself is protected and can provide a sustainable basis for meeting the basic needs of every person for decades to come.

[19] For example, the Andhra Pradesh Farmers' Management of Irrigation Systems Act, 1997; Gujarat Water Users' Participatory Irrigation Management Act, 2007; Maharashtra Management of Irrigation Systems by the Farmers Act, 2005; and Tamil Nadu Farmers Management of Irrigation Systems Act, 2000

[20] For example, *Subhash Kumar v State of Bihar,* AIR 1991 SC 420 (Supreme Court, 1991)

[21] The draft is available on the website of the Planning Commission.

- Prevent and mitigate contamination of groundwater resources.
- Promote and protect good conservation, recharge and management practices.
- Protect areas of land that are crucial for sustainable management of groundwater and ensure that high groundwater-consuming activities are not located in areas unable to support them.

Putting in place this multifaceted paradigm shift in the 12th Plan was a massive challenge of initiating change that was in many respects long overdue but was being resisted by a range of players within the system. There was, in the process, a complete change in the principles and approaches animating water management in India across various sectors – a move away from a narrow engineering-construction perspective towards a more multidisciplinary understanding of water with central emphasis on the goal of resilient ecosystems, a focus on the principle of subsidiarity, incentivisation of participatory approaches, modern data management systems, innovations in technology and path-breaking legal changes that recognise the common pool nature of water and are based on the most updated scientific knowledge. What is more, this shift in perspectives was backed by a completely new and vastly enlarged package of incentives and financial and technical support, whether in the Nirmal Bharat Abhiyan, National Irrigation Management Fund, National Aquifer Management Programme, Integrated Watershed Management Programme or the RRR scheme.

What gives hope is the fact that the process of hammering agreement on change was deeply inclusive with buy-in from key implementers, especially the State governments. They were a central part of fashioning this change, and the most innovative ideas sketched out in this paper are based on examples of best practice from the States. There is also the fact that the emerging water crisis is forcing the pace of change from below, with a range of stakeholders no longer willing to countenance business as usual. Even so, the road ahead is a long and difficult one of confronting the recalcitrance of entrenched attitudes and vested interests. The same preparedness of civil society, academia and government of closely working together that transformed the 12th Plan agenda will now be required in its implementation, with close involvement of local communities, if success is to be achieved on this path.

6 Developments After the 12th Plan[22]

In a remarkable tribute to continuity of governance in India, in September 2015, I was asked by the newly elected government at the centre to chair a committee for restructuring the CWC and CGWB, as also a committee to draft a Model Groundwater Bill and a National Water Framework Law. This provided a welcome

[22]This section draws upon the *Report of the Committee on Restructuring CWC and CGWB* that I submitted to the Government of India in July 2016.

opportunity to carry forward the paradigm shift in water initiated in the 12th Plan. In its review of work since the 12th Plan, the Committee found that the National Aquifer Management Programme (NAQUIM) initiated is the largest such programme ever initiated in human history. Nothing of this scale has been attempted before: the term scale is used in two senses – one, the *extensiveness* of scale, and, two, the *fineness* of scale (resolution of the maps). Tragically, so far the programme has failed to take off with the requisite momentum. The major reason for this is the huge lack of capacities in the CGWB and the state ground water boards. The institutional mandate of CGWB should be strengthened to enable it to perform its role as the manager of groundwater resource, including hiring from the fields of community institutions, participatory management of resource, political economy and economics, water markets, regulatory systems, alternative uses, opportunity cost of groundwater extraction, energy management and so on.

We also noted that for some time now, policy-makers and scholars alike have emphasised the need to integrate our interventions on surface and groundwater given that the ultimate source of all water on land is precipitation as rain, snow or hail. The need to focus on river basins as the appropriate unit of intervention is evident in the watershed programmes initiated by the government over the last 40 years. River Basin Organisations have also been set up. However, it remains true that progress on integrating surface and groundwater has been slow in actual work done on the ground. In recognition of this fact, the recent National Water Framework Law (NWFL) drafted by the Ministry of Water Resources, River Development and Ganga Rejuvenation has placed special emphasis on integrated river basin development and management, as also on river rejuvenation as central pillars of national policy.

The draft bill emphasises the integral relationship between surface and groundwater. The NWFL recognises that "water in all its forms constitutes a hydrological unity, so that human interventions in any one form are likely to have effects on others; and that "ground water and surface water interact throughout all landscapes from the mountains to the oceans". This is evident in the fact that "overextraction of groundwater in the immediate vicinity of a river and destruction of catchment areas and river flood plains have very negatively impacted river flows in India; such a decrease in river flows, in turn, negatively impacts groundwater recharge in riparian aquifers in the vicinity of the river".

And because "the fall in water tables and water quality, as also the drying up of rivers, has serious negative impacts on drinking water and livelihood security of the people of India, as also the prospects for economic growth and human development in the country", it is vitally important that "each river basin, including associated aquifers, needs to be considered as the basic hydrological unit for planning, development and management of water, empowered with adequate authority to do the same".

The NWFL places central emphasis on river rejuvenation and enjoins the appropriate government to "strive towards rejuvenating river systems with community participation, ensuring:

(a) "Aviral Dhara" – Continuous flow in time and space including maintenance of connectivity of flow in each river system
(b) "Nirmal Dhara" – Unpolluted flow so that the quality of river waters is not adversely affected by human activities
(c) "Swachh Kinara" – Clean and aesthetic river banks".

The CWC and CGWB were created in a very different era, with a mandate appropriate for that era. The challenge today is for us to restructure these agencies so that they can:

(a) Work on the new mandate that the nation has placed before them.
(b) Work in a manner that overcomes the schism between groundwater and surface water.
(c) Work with greater presence on the ground at the river basin level.

The committee on restructuring CWC and CGWB has proposed that a National Water Commission be created that unifies these two apex bodies. Both the CWC and CGWB have useful and formidable capabilities for water resource exploration, assessment and monitoring and planning of infrastructure projects; these must be preserved, nurtured and built upon. These capabilities are no doubt important even today and will remain so in future, too. However, technologies available today are so advanced that these tasks can be performed better and in more cost-effective manner than is being done now. The need of the hour is to significantly enhance the effectiveness of assessment, monitoring and planning capabilities and their effective deployment.

The CGWB grew out of a small organisation with a narrow, specific purpose, viz., drill exploration wells to assess groundwater resource. The CWC even today views itself as "an apex *technical* organisation in the field of water resources development". Neither agency ever viewed itself as a water governance organisation. In the new water resource governance scenario facing the country, we need to envisage a high-level central organisation that is forward-looking, strategic, agile and transdisciplinary in its skill set. This has to be conceived of as an action organisation rather than merely an assessment and monitoring organisation, although these too will remain aspects of its mandate.

It is true that all the action in the water sector lies with the State governments. Yet a well-designed central organisation can deploy and use funds as well as scientific and knowledge resources to influence and support what States do in water governance. This organisation should have a compact leadership with a broad range of expertise related to water. Moreover, it has to have a culture of cross-disciplinary teamwork rather than different disciplines operating in silos. The need of the hour is a new organisational culture, new skill mix and new operating style.

Both CWC and CGWB are weighed down by their highly specialised but narrow-based skill structure. These are massive organisations using up huge resources and energies in managing themselves. Their functioning is also mired by a highly dysfunctional organisation culture. There is literally a quagmire of hundreds of different designations, which has nightmarish consequences for framing recruitment rules, career progression ladder, promotions, seniority, pay scales, etc.[23] All these limitations constrain the capacity of these agencies to rise to meet major new challenges facing India's water economy. The larger water governance challenge requires a new-age, modern, agile and compact apex organisation that is untrammelled by the burden of the irksome internal management complexities of these unwieldy bureaucracies.

What is more, the organisation needs to view both groundwater and surface water in an integrated, holistic manner. CWC and CGWB cannot continue to work in their current independent, isolated fashion. The one issue that brings out the need to unify the two bodies more than any other is the drying up of India's rivers. The single most important factor explaining the drying up of post-monsoon flows in India's peninsular rivers is the overextraction of groundwater. The drying up of base flows of groundwater has converted so many of our "gaining" rivers into "losing" rivers. If river rejuvenation is, indeed, the key national mandate assigned to the Ministry of Water Resources, then this cannot be done without hydrologists and hydrogeologists working together, along with social scientists, agronomists and other stakeholders.

Both the CWC and CGWB are lacking in the capacities essential for them to respond to the needs of the water sector in twenty-first century India. Civil engineers (the main discipline overwhelmingly present in the CWC) and hydrogeologists (the main discipline in the CGWB) are crucial for effective water management. But alone they cannot be expected to shoulder the entire burden of the new mandate. There is an acute lack of professionals from a large number of disciplines, without which these bodies will continue to underperform. These disciplines include, most importantly, the social sciences and management, without which we cannot expect programmes such as Participatory Irrigation Management and Participatory Groundwater Management to succeed; Agronomy, without which crop water budgeting cannot happen and water-use efficiency will not improve; Ecological Economics, without which we will not gain an accurate understanding of the value of ecosystem services, which need to be protected in river systems; and River Ecology, which is essential to the central mandate of river rejuvenation.

It is, therefore, imperative that:

(a) A brand new National Water Commission (NWC) be established as the nation's apex facilitation organisation dealing with water policy, data and governance.
(b) NWC should be an adjunct office of the Ministry of Water Resources, river development and ganga rejuvenation, functioning with both full autonomy and requisite accountability.
(c) NWC should be headed by a chief National Water Commissioner, a senior administrator with a stable tenure and with strong background in public and development administration, and should have full-time commissioners

[23]For example, CGWB has as many as 125 different designations (Scientific-71, Engineering-20, Ministerial/Administrative-34). Rampant increase in court cases and representations related to seniority, promotions, FCS, etc. bears testimony to the fact that there is a link between number of designations and court cases/representations.

representing hydrology (present chair, CWC), hydrogeology (present chair, CGWB), hydrometeorology, river ecology, ecological economics, agronomy (with focus on soil and water) and participatory resource planning and management.

(d) NWC should have strong regional presence in all the major river basins of India.

(e) NWC should build, institutionalise and appropriately manage an architecture of partnerships with knowledge institutions and practitioners in the water space, in areas where in-house expertise may be lacking.

The key mandate and functions that the National Water Commission needs to pursue has the following building blocks:

(i) Enable and incentivise state governments to implement all irrigation projects in reform mode, with an overarching goal of *har khet ko paani* and improved water resource management and water-use efficiency, not just construction of large-scale reservoirs, as the main objective.

(ii) Lead the national aquifer mapping and groundwater management programme.

(iii) Insulate the agrarian economy and livelihood system from pernicious impacts of drought, flood and climate change and move towards sustainable water security.

(iv) Develop a nationwide, location-specific programme for rejuvenation of India's rivers to effectively implement the triple mandate of *nirmal dhara*, *aviral dhara* and *swachh kinara*.

(v) Create an effective promotional and regulatory mechanism that finds the right balance between the needs of development and environment, protecting ecological integrity of nation's rivers, lakes, wetlands and aquifers, as well as coastal systems.

(vi) Promote cost-effective programmes for appropriate treatment, recycling and reuse of urban and industrial waste water.

(vii) Develop and implement practical programmes for controlling point and non-point pollution of water bodies, the wetlands and aquifer systems.

(viii) Create a transparent, accessible and user-friendly system of data management on water that citizens can fruitfully use while devising solutions to their water problems.

(ix) Operate as a world-class knowledge institution available, on demand, for advice to the state governments and other stakeholders, including appraisal of projects, dam safety and interstate and international issues relating to water.

(x) Create world-class institutions for broad-based capacity building of water professionals and knowledge management in water.

7 New Paradigm of Water in India: Features, Principles, Dimensions

From the above discussion, we get a clear idea of the fundamental change we need to effect in the paradigm of water in India, if we are to meet the challenge of sustainable and equitable access to water and livelihood security for the Indian people. The new paradigm would need to have the following features, principles and dimensions:

(a) *Weaving Our Interventions into the Contours of Nature*: Rather than command-and-control, our attempt needs to be to fully appreciate and apprehend the enormous diversity that characterises this nation and plan our interventions in full cognisance and understanding of this diversity, making them as location-specific as possible, to avoid the pitfalls of indiscriminate centralised planning. Watersheds, aquifers and river systems would be the cornerstones of such planning.
(b) *Governance Based on Partnerships*: Rather than making governance the sole responsibility of governments, we need to craft a carefully designed architecture of partnerships, where all primary stakeholders get deeply involved in the collective Endeavour of participatory water governance.
(c) *Multidisciplinarity*: We must acknowledge that we cannot understand water other than in a deeply multidisciplinary perspective. This involves not just engineering and hydrogeology but also river ecology, agronomy, soil science, the various social sciences and management, among others.
(d) *Multidimensionality*: We must adopt the perspective proposed in the current draft of the National Water Framework law, which states that: "water is the common heritage of the people of India; is essential for the sustenance of life in all its forms; an integral part of the ecological system, sustaining and being sustained by it; a basic requirement for livelihoods; a cleaning agent; a necessary input for economic activity such as agriculture, industry, and commerce; a means of transportation; a means of recreation; an inseparable part of a people's landscape, society, history and culture; and in many cultures, a sacred substance, being venerated in some as a divinity".
(e) *Breaking the Silos*: The proposed NWC will hopefully help in our being able to take an integrated view of water, so that the current hydro-schizophrenia can be overcome, ensuring protection of watersheds, river systems and endangered aquifers.
(f) *Demand Management and Sustainability as a Central Focus*: Rather than seeking to endlessly augment supplies of water, the focus must shift to effectively managing demand so that we recognise the finite nature of the resource and that sustainable use will be impossible without this shift. The supply-side thrust is a vicious infinite regress with no end in sight other than depletion of quantities and quality.
(g) *Emphasis on Equity in Access to Water*: We need to centrally emphasise the imperative to end discrimination in access to water on grounds of caste, class, gender, location and community, as emphasised in the National Water Framework law.
(h) *Transparency and Easy Access to Water Information*: The issue here is not just access to information which should have transparency but also availability of information in a manner and form that is useful to and useable by primary

stakeholders. The aim must be to proactively proffer water solutions to problems people face.

(i) *National Water Framework Law*: The draft NWFL provides an essential corrective to British common law by building upon the public trust doctrine enunciated by the supreme court, whereby the state at all levels holds natural resources in trust for the community. This would ensure that no one's use of water would be able to deprive anyone of their right to water for life as defined under the NWFL.

It is my considered view that only through this comprehensive shift in the paradigm of water in India can we come to grips with and find sustainable and equitable solutions to the grave crisis of water facing the country. The changes being proposed are so fundamental that even this primary step of disbanding the CWC and CGWB and setting up the NWC is itself a huge challenge and is being fiercely resisted even though it is the result of a vast consultative process, which included all relevant stakeholders of India's water sector, from within and outside government. Within the CWC and CGWB there were concerns whether the restructuring suggested would end up undermining them. Such concerns were only natural as prospects of change always generate apprehension. As a committee, we made a concerted effort to engage both the CWC and CGWB in an intensive and prolonged dialogue to allay these apprehensions. It is our considered view that the thousands of professionals in both the CWC and CGWB will get an even better chance to improve their technical capabilities and career prospects within the NWC.

There has also been widespread support in favour of this change.[24] And many young and dynamic officers of the CWC, who see these changes as being in the right direction, are working with a truly extraordinary team of senior-most officers in the Ministry of Water Resources to carefully think through the next steps in implementing these recommendations. This is the first time ever that the Ministry of Water Resources has shown itself open to fundamental reform.[25] The response so far from the Prime Minister's Office has also been positive. It, of course, remains to be seen how far the government finally goes in acting upon these long-overdue reforms, which should really have been initiated at least two decades ago.

Acknowledgements The author is grateful to the members of the Working Groups on Water in the 12th Plan, the members of the Committee on Restructuring CWC and CGWB and of the Committee to draft the Model Groundwater Bill and the National Water Framework Law, the members and officers of the Planning Commission and the Ministry of Water Resources, all of whom greatly contributed to enhancing my understanding of the water sector in India.

[24] See, among many examples, this editorial in *The Economic Times* (September 3, 2016) http://blogs.economictimes.indiatimes.com/et-editorials/mihir-shah-report-brims-with-sense/ and this article in the *Hindustan Times* "Water: The resource that will determine our future" (March 25, 2017), which states "Rigorously researched and closely argued, this report displays a deep familiarity with social and economic life across India, and offers a set of forward-looking recommendations as well".

[25] Even as Member, Planning Commission, from 2009 to 2014, I faced fierce resistance from the Ministry of Water Resources when I proposed the paradigm shift.

References

Ackerman R (2011) New directions for water management in Indian agriculture. Glob J Emerg Mark Econ https://doi.org/10.1177/097491011200400205

ClimateWire (2012) How the Dutch make "Room for the River" by redesigning cities. Available at: http://www.scientificamerican.com/article.cfm?id=how-the-dutch-make-room-for-the-river, January 20

Cullet P (2012) The groundwater model bill – rethinking regulation for the primary source of water. Econ Polit Wkly 47(45):40–47

Government of Bihar (2008) Kosi flood: assessment report. World Bank, global facility for disaster reduction and recovery

Government of Netherlands (2007) Spatial planning key decision: room for the river. Available at: www.ruimtevoorderivier.nl/media/21963/pkb%204%20approved %20decision%20h01-h086.pdf

Jarvis T, Giordano M, Puri S, Matsumoto K, Wolf A (2005) International borders, ground water flow and Hydroschizophrenia. Ground Water 43(5):764

Katiyar BB (2010) Law of easements and licences. Universal Law Publishing, New Delhi

MoRD (2012a) Report of the Mihir Shah Committee on operational guidelines for MGNREGA, Ministry of Rural Development, Government of India

MoRD (2012b) Report of the Mihir Shah Committee on common guidelines for watershed development projects, Ministry of Rural Development, Government of India

Narasimhan TN (2008) A note on India's water budget and evapotranspiration. J Earth Syst Sci 117:**237**

Narasimhan TN, Gaur VK (2009) A framework for India water policy. National institute for advanced studies Bangalore. Available at: http://eprints.nias.res.in/235/1/R4-09.pdf

Ostrom E (1990) Governing the commons – the evolution of institutions for collective action. Cambridge University Press, Cambridge

Sahayog SP, Abhiyan MP (2012) Leveraging MGNREGA for flood control: a case for policy reform in Bihar, National Consortium of Civil Society Organizations on MGNREGA

Shah M (ed) (2012) MGNREGA Sameeksha (2012) an anthology of research studies on the Mahatma Gandhi National Rural Employment Guarantee Act (2006–2012). Ministry of Rural Development, Government of India

Shah M, Banerji D, Vijayshankar PS, Ambasta P (1998) India's drylands – tribal societies and development through environmental regeneration. Oxford University Press, New Delhi ISBN: 978-0195642315

Water Resources Group-2030 (2009) Charting our water future. Available at: https://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/sustainability/pdfs/charting%20our%20water%20future/charting_our_water_future_full_report_.ashx

Mihir Shah graduated in economics from St. Stephen's College, Delhi University, and completed postgraduation at Delhi School of Economics and PhD at the Centre for Development Studies, Kerala. In 1990, he formed Samaj Pragati Sahayog (SPS), which has now presence in 72 of India's most backward districts. He is the first president of the Bharat Rural Livelihoods Foundation. From 2009 to 2014, he was Member, Planning Commission (now NITI Aayog), Government of India, holding the portfolios of Water Resources, Rural Development and Panchayati Raj. He was chiefly responsible for drafting the paradigm shift in the management of water resources enunciated in the 12th Five-Year Plan and also initiated a makeover of MGNREGA, the largest employment programme in human history. In 2015, he chaired the Committee on Restructuring the Central Water Commission and Central Ground Water Board.
Dr. Shah is a founding signatory of the Geneva Actions on Human Water Security, 2017. He is Distinguished Visiting Professor of Shiv Nadar University and a Member of the International Steering Committee of the CGIAR Research Program on Water, Land and Ecosystems (WLE). He remained a prolific writer and contributed in almost all pre-eminent journals and addressed audiences world over.