Water Resources Development and Management

Girish Chadha
Ashwin B. Pandya *Editors*

Water Governance and Management in India

Issues and Perspectives, Volume 2

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Introduction

The editors are happy to continue the dialogue that was started with the first volume of the book. It has indeed been an enriching experience in expanding the coverage on the issue of water governance and management in the second volume. The two volumes together present a rainbow of aspects that influence water resources development, governance and its management. We have been fortunate enough to have yet another set of enlightened authors to do justice to the additional aspects covered in the second volume.

The authors touch upon several administrative, planning, environmental and financial aspects of water governance in the seven chapters, often highlighting specific areas that require attention.

In the first chapter, Himanshu Kulkarni et al. take up the issue of community-based groundwater management model, suggesting that participation of people should remain the backbone in this pursuit.

India's groundwater usage is the largest in the world. Nearly, all sectors, especially rural domestic water and water in agriculture, have large-scale dependencies on groundwater resources. Groundwater exploitation, without due consideration to the concept of aquifers as common pool resources, has led to the dual problem of groundwater depletion and contamination, besides depletion in river flows. Competition over groundwater resources has slowly emerged as a complex problem across India's diverse aquifer typology, sometimes leading to conflict. The rise in the number of wells across the small land holdings in India has meant that groundwater extraction occurs at high granularity, making it difficult for large-scale data and information to capture the reality of problems of the ground.

The authors feel that the existing groundwater governance mechanisms, mainly in the form of institutional frameworks including legislation, are not robust enough. These mechanisms, they feel, limit the impacts of processes such as participatory groundwater management. Given the enormity of the problem in India, and the size of the country too, the authors argue that the one-size-fits-all approach of groundwater management and governance would become irrelevant under the country's aquifer and socio-economic diversity.

Rather than making governance the sole responsibility of governments, a carefully designed architecture of partnerships should be crafted, where all primary stakeholders get deeply involved in the collective endeavour of participatory water governance. In the country, participatory management of water resources has been attempted, often with resounding success, in small measures.

Framing groundwater governance as the governance of aquifers is also important so as to instil confidence and belief in managing groundwater resources as common pool resources. In doing so, groundwater management must become inclusive of the need to shift the focus of plans and practices from 'sources' of groundwater to the 'resource'. Creating a proactive policy environment that embraces community participation in developing the understanding on groundwater and generating knowledge on aquifers, communities and ecosystems is most important. Such an environment will enable the agencies of governance such as Panchayati Raj Institutions to take improved decisions and undertake actions that will lead to sustainable, efficient and equitable usage of groundwater.

In the second chapter, Singh and Mahanta bring out the fact about 30% of India's population lives in cities and urban areas that are expected to double in population by 2050. Currently, five of the world's 20 largest cities under water stress are in India, with Delhi being second on the list, they point out, adding that with a growing economy and fast changing lifestyles, the pressure on already strained water resources is escalating. Urban hubs are likely to witness severe water shortages in the future, which could risk urban growth in India and reduce quality of life for urban citizens.

The authors urge leaders to rethink their institutional approach to water management, building a strong case for adoption of a circular economy model, to begin with, in wastewater.

The authors state that demand management concepts are very important in view of increasing stress on available fresh water resources in India. They present several strategies covering doorstep metering and revenue generation based on consumption, rehabilitating conveyance infrastructure for better and assured delivery and maintenance measures for maintaining the system like pressure leakage control, mains replacement, retrofitting the plumbing, legislation promoting the sustainable revenue models and also reuse/recycle policies. Being an upcoming sector key to economic growth, the sustainable urban water management has strong implications to growth of economic activities and improvement in quality of life across the board.

In the third chapter, Bathla et al. analyse the relative efficiency of public investment in irrigation across major states in India from 1981–1982 to 2015–2016. There has been a sizeable increase in public expenditure on irrigation and improvement in capital intensity in the last one decade even though there is declining trend vis-à-vis earlier plan periods as a percentage of overall pie, the authors note.

Also, an upturn in capital and revenue expenditure has not been commensurate with an increase in irrigation intensity, reflecting considerable inefficiencies. On average, public canals operated at about 59 per cent technical efficiency in recent years, although levels vary widely. The inefficiency is largely due to capital expenditure, which needs to be utilized properly through faster completion of projects, the authors argue. The magnitude of the capital needed for implementation and management versus the inputs generated at the Centre and state level too have a mismatch. Relative influence of Centre in project implementation is also governed by the relative shares of capital being infused in the projects. Low-efficiency scores may also suggest that public irrigation is not well placed, suggesting need for better management. Public policy should focus more on outcomes rather than on outlays, suggest the authors.

Khurana and Sen highlight the twin challenges of water quantity and quality in the fourth chapter. Challenges of quality are yet to be addressed in a holistic way for generating better and efficient utilization of the available resources. Improving water quality is going to need a basket of options ranging from policy-level interventions and implementation, real-time data that informs decision making, preventive and mitigation technologies, enforcement and public awareness, participation and oversight. The best way would be to prevent pollution from taking place and using technologies that either do not pollute or are able to treat the effluents, so that there is no toxic discharge. This cannot happen overnight, but an implementable action plan could make this a reality. Agricultural pollution will need to be addressed through minimizing chemical input use and the scaled-up adoption of integrated pest management and organic farming. Financial instruments will be needed for this.

The authors highlight the fact that the issue of water quality has now reached dangerous levels and needs a completely new perspective to address it. Any effort on this front requires serious commitment and a long-term vision and plan.

They posit that addressing industrial pollution will require shifting from concentration-based standards to pollution load-based standards. The practice of following of concentration-based standards in India is unable to keep an effective check on the polluting industries. A common data grid of the water quality monitoring sites of various agencies that monitor water quality like the Central Water Commission, Central Ground Water Board, Central and State Pollution Control Boards, Water Provisioning Department and Utilities need to be integrated so as to provide a robust system of data and information to help water utilities, citizens and government take measures for addressing pollution and define management actions. Excellent examples are available for reuse of wastewater, but adoption by the communities remains a challenge. Community awareness coupled with adequate monitoring and supply re-allocation measures can help, the authors note.

In the fifth chapter, Kumar et al. make a strong case for providing space to wetlands in water management plans, pointing out the merit of looking at wetlands as nature-based solutions. The authors underline that wetlands, as ecosystems at the interface of land and water, have a significant role in ensuring water & climate security in India given their role in the water cycle and multiple hydrological functions. The rapid loss of natural wetlands is as much a threat to water and climate security as is an environmental crisis.

Integration of wetlands in water management plans in also not about pitting grey and green infrastructure, but achieving complementarities and synergies. While making water infrastructure decisions, a beginning can be made by examining whether green infrastructure solutions such as wetlands can deliver the desired water resource outcome, and then filling the gap that may still exist by a grey-green combination, the authors suggest.

A harmonized understanding of wetlands and their hydrological functions in a landscape is the foundation step. The science-base on wetlands will need to graduate from being dominated by describing ecosystem structures and processes to providing quantitative assessments of hydrological functions, in usable forms and terms suited to water sector policy-makers. Wetlands managers will also need to have the capacity to describe water regime requirements of wetlands to perform these functions while acknowledging that climate change may render historical regime information insufficient to inform about the future course of actions. For water managers, the role of wetlands will need to evolve beyond just an allocation decision, to understanding water as it moves in a landscape, and the role wetlands play in influencing this movement. A natural convergence point is to plan at a catchment scale, wherein the landscape and water interactions can be assessed and planned for meaningfully, the authors state.

In the sixth chapter, Pandya brings out the role that data plays in establishing efficient planning and implementation as well as operational strategies for the water sector in general. Generally, at the planning level, resource availability data is of prime concern. However, for efficient management in real time, it is necessary to harness the usage data at the same level of frequency and accuracy as the resource data, he stresses.

Collection and processing of data also assumes prime importance for resource allocation amongst competing political and administrative entities and is the key parameter upon which the entire adjudication process relies. But, he feels that this underlying importance is not well appreciated by the planning and economic communities in general, and accordingly, the field remains rather neglected. The neglect leads to gaps in the data and knowledge base. Multiple jurisdictions and domains delineated by the federal structure of the Constitution and governance of the country affect a unified data strategy. Lack of such strategy will lead to wrong priorities in planning and deployment. The chapter describes data requirements, provisions enabling collection and processing and status of availability. New technologies and approaches available for handling constraints generated out of multiple jurisdictions and conflict of interests are also highlighted.

Pandya also underlines the fact that transboundary water management is highly reliant upon sound data availability, while warning that progress in equitable development will get seriously hampered if sound data management policies are not adopted across the board and data driven negotiations are not established.

In the last chapter, Srinivas and Prajapati are of the opinion that India's federal governance for long-term water security has not received its due attention. The discourse about federal governance is generally dominated by that of fiscal federalism. The limited work about federal water governance is restricted to interstate river water disputes and their resolution. Poor indicators of national water resources governance do not inspire confidence about its long-term security.

The chapter posits that this is an outcome of the federal constituents—the states and the Union Territories—assuming exclusive powers over water governance. They pursue inward and territorialized strategies for water resources management. This, at times, leads to non-optimal solutions and stresses on the internal relations amongst the federal constituents. The Centre has to play an anchoring role and work with states towards pursuing these goals.

The chapter takes a closer look at the historical changes in budgetary allocations of the Centre and select states for water resources governance and highlights the issues of consistency in funding and coordinating mechanisms required for achieving an optimal solution. The structural and institutional elements of federal water governance have not received adequate attention. The existing provisions are not only under-nurtured, but also inadequate to pursue India's development goals and address the new and emerging challenges of water governance towards long-term water security and sustainability goals.

The authors insist that it is imperative to build a 'new federal consensus' about Centre-states' roles in water governance. There is a need to engage in a political process to elevate the debate of federal water governance to the goals of addressing the 'whole' and emphasize partnership building between Centre-states for the purpose. At the same time, the chapter calls for strengthening the Centre's by provision of additional set of political and institutional processes.

Through the chapters, the multi-dimensionality of water management and development sector as also uni-dimensionality of the individual stakeholders pertaining to one field comes through. This is where participative management with an overarching outlook comes in. India's Water Policy (2012) did recognize this issue by declaring water a common pool resource.

As water availability and its management spans over a large set of sectors, each requiring a special branch of knowledge, coordination between them is a challenging task. However, we all have to live in a collective society where the right of existence has been made equal. While advocating the ideal regime for a specific sector, one should not lose sight of other sectors that may also be competing for the same ideal. Each sector may require making sacrifices to allow others also to have the same opportunity.

The development process is always a transformative one. Development consumes or deploys a set of resources and produces the outputs in form of products, which are further traded or consumed for livelihood sustenance or economic prosperity. The dialogue, therefore, happens between the static model of no change from what is given by nature to a dynamic model where the interventions to meet demands may make changes to the natural regimes.

In case of water, this has been happening since the dawn of human civilization. Development so far has been on the basis of deployment of water as a resource to produce food, fibre, energy, transportation, recreation and also as a medium to convey the wastes. The thoughts provided by our authors also grapple with the same duality of approaches.

All have recognized the adversity in form of temporal and spatial availability of water resources through the country. The skew makes floods and droughts to exist simultaneously in the country in different regions and sometimes within the same region in different seasons or years. Given these complexities, strategies are, therefore, needed towards sustainable development and management regime for water security to be achieved.

The Indian water sector is almost exclusively dominated by the government at the state level or at the Union level. The government is present at every stage of water development, financing, implementation and distribution and finally even in revenue generation through service charges. This necessitates a multiple role of an enterprise with an economic goal out of resource management and a welfare entity, which would like to provide a resource on an equitable basis without consideration of economic status or capacities to pay. Governance in this context does not fully have a techno-economic context but also includes a fair amount of political and social bearings with ample dose of welfare thrown in. This makes the definition of various practices for governance difficult.

Due to various socio-political contexts, the national-level view of water governance is subservient to the state or regional level ones even though the Constitutional arrangement does not build this hierarchy. This leads to difficulties in dealing with issues like large river rejuvenation, development of hydropower as an eminent green source of energy and catering to the diverse needs of agriculture as the views of the Centre and various states do not often converge. At the local level, the issues of capacities dominate. For water management at the local bodies level, the lack of capacities and also finances provide a big challenge. We have a strong growth record of urbanization. However, the systems to manage the new areas falling under urban context lag the actual developments. How to make the entire process participative across the social and economic status boundaries is also still a challenge.

The governance regime in the country is also heavily influenced by ideologies and advocacy pressures. However, water being a physical resource governed by the climate, topography, geology and material sciences, and its management is also influenced by the same factors in all the fields.

In addition, water usage is also influenced by the economy and financial aspirations of the end users. When we think in compartments based on our own area of expertise or concern, some of the factors land up getting relegated to background or neglected in the solutions being propagated. This requires adjustments. There is a struggle between what we would like to have as an ideal versus what can be achieved in the light of demands of other associated sectors. Therefore, the approach is to find an optimal situation which is not ideal for any individual sector but allows all of them to survive at the same time. The key lies in negotiations between sectors on the basis of an information base, which is capable to indicate the levels of comfort of various competing demands and where the expansion in any one field of demands will make others uncomfortable.

The more we look at it, the more we realize the importance of information about availability and use of water for forming a holistic idea before we start promising and distributing the resource. Importance of unbiased data on all these aspects becomes an essential part of governance and management. States have a prime focus on development and bringing improvements in their asset base for better coverage. At times, this desire may not result into a balanced development covering all political entities sharing the same resource. In such contexts, it is necessary to know the actual state of affairs at the ground level. Data, therefore, has a large role to play in quantifying the priorities and stresses that these may be undergoing. For effective governance at every level, one has to look into data collection, processing and analyses capabilities for a better future.

India is a diverse country as far as geostrategic context is concerned. Many river basins also cross our national boundaries, and India finds itself in the roles of an upper, middle and lower riparian country. This requires a fair amount of hydro-diplomacy while dealing with the neighbours. At this level, the dialogue becomes more complex as other areas of economy, socio-political setup and strategic relationships also have to be heeded.

India has been somewhat fortunate in having good relations with some of its immediate neighbours. For instance, with Bhutan, it has been able to devise a 'win-win' situation in terms of hydropower generation and mutual economic prosperity. India also has to share disasters like cyclones and floods with some neighbours. Mutual sharing of disaster warning and management exercises provides with ample opportunities to build cooperation and collaboration.

Internally, the water governance regime is distributed between states with federalism playing an important part. The interstate basins too provide a great challenge in governance. The political boundaries versus basin boundaries and water availability to various political units are a cause of great political and social turmoil in many parts of the country. Capacities also vary between the co-basin states.

Commonly, the availability of resource and potential to use are quite often located in different states and regions. Negotiations regarding financing the developments and compensation towards sacrificing some of the lands required for water projects have been important issues that need to be resolved. Water governance at Union level requires an in-depth assessment and quantification of the problems at hand, while at state level, governance should comprise willingness to negotiate in a sound and rational manner for an optimum solution rather than taking an exclusivist approach generated out of a sense of sovereignty. The states with lower capacities in financial and expertise terms may need to be helped for matching up with their better placed counterparts. This remains true for development initiatives as well as disasters like floods and droughts.

Issues pertaining to water management cannot always be made to fully fit into a framework of legalities. There is a fair amount of give-and-take while keeping in view the essential principles of science and technology. Resolving the differences is an exercise in which the scientific solutions supported by the legal base are important. Herein lies the role of governance, especially at the Union level, where the states can find a platform to settle their differences away from the pushes and pulls of local exclusivist influences.

When it comes to financing, being a developing country, India has great demands on its available resources, in which the water sector also has to compete. The share of finances of the states under their own budgets is considerably higher than the finances at the Union level. However, the Union has the responsibility to ensure that the last-mile shortages in finances do not deprive beneficiaries of water programmes from the intended benefits. Implementation of projects are affected by a large number of factors, especially land availability and interaction with other utilities as well as acceptance of proposed developmental plans by the beneficiaries as well as displaced persons. A coordinated governance regime is required in which better consultative processes on the investment plans of individual states are discussed and dovetailed into the national-level financial perspectives.

Together in both the volumes, we have covered governance issues at state and Federal levels, utilization and deployment of water resources for various purposes like hydropower, rejuvenation and drinking water supply, investments for development of irrigation and water supply. We also covered issues arising out of environment-related disasters like droughts and floods and issues of wetlands and river rejuvenation, groundwater management. Water availability being stochastic in nature, the role of data management in planning for water resources is also covered in the volumes.

It is hoped that through the two volumes, a strong narrative on some of the several issues related to water governance and management will emerge to foster further dialogue, research and policy review. It is also expected that the two volumes are able to deliver mature and diverse views on the many issues related to water governance and management.

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February 2021

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Contents

Catalysing Groundwater Governance Through People's Participation and Institutional Reform

Himanshu Kulkarni, Dhaval Joshi, Uma Aslekar and Siddharth Patil

Abstract India's groundwater usage is the largest in the world. Nearly, all sectors, especially rural domestic water and water in agriculture, have large-scale dependencies on groundwater resources. Groundwater exploitation, without due consideration to the concept of aquifers as common pool resources, has led to the dual problem of groundwater depletion and contamination. Groundwater depletion has also led to depletion in river flow. Competition over groundwater resources has slowly emerged as a complex problem across India's diverse aquifer typology, sometimes leading to conflict. The rise in the number of wells across the small land holdings in India has meant that groundwater extraction occurs at high granularity, making it difficult for large-scale data and information to capture the reality of problems of the ground. The social, economic and environmental consequences of groundwater over-extraction in India is as much related to the variability in the transmission and storage properties of different aquifers as it is about the diversity in the social context of people who use groundwater resources. Community-based norms on managing groundwater resources have been one of the emergent areas of responding to the crisis of groundwater management in the field. Policy, on the other hand, has been toying with conventional regulatory responses, mainly through groundwater legislation. The gap between the policy and practice of groundwater management is quite wide and requires a combination of groundwater management and governance. Institutionalizing the integration of groundwater management and governance, although seemingly challenging, has become crucial in addressing India's groundwater crises. Combining demystified science, people's participation and institutional reform to bring to the fore the concept of aquifers as common pool resources can form a solid foundation for catalysing groundwater governance in India.

Keywords Aquifer typology · People's participation · Community-based norms · Institutions

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1 Introduction

India's new government recently merged the two most important ministries—the Ministry of Drinking Water and Sanitation and the Ministry of Water Resources—dealing with water and constituted the Ministry of *Jal Shakti*. It is an interesting move, keeping in mind the constantly shifting dependencies in the water sector and the recent spate of droughts that many regions of India have experienced. Nearly, 1 billion Indians use groundwater every day, whether in agriculture, for drinking water supplies or in the context of urban and industrial water supplies (based on recent data, mainly Ministry of Drinking Water and Sanitation 2018; Ministry of Agriculture 2014; NIUA 2011). Groundwater, in particular, has received much attention, both in practice, through the focus on water conservation and recharge programmes, and in public policy, through the national aquifer mapping programme and through the more recent policy reform suggested for India's two large institutions—the Central Water Commission and the Central Ground Water Board (Jain 2017; Committee on restructuring the CWC and CGWB 2016). Moreover, the focus of managing groundwater has also figured strongly in a report on the strategic management of the programme called Prime Minister's Krishi Sichayee Yojana—PMKSY—and the work on solar power for improved management of groundwater resources from different parts of India (Shah et al. 2016; Bassi 2018).

The crisis surrounding groundwater is already hitting India hard. And it is here to stay! India became the largest extractor of groundwater in the world in the 1980s (Shah 2009). The fact, of course, became evident only after data on groundwater over-extraction emerged in the late 1990s and towards the beginning of the twenty-first century. India's groundwater extraction continued to grow through the 1980s and is still in the acceleration mode. The trend and pattern of India's groundwater extraction presents a temporal and spatial paradox. Growing dependencies in agriculture, from as less as 30% at the time of India's independence to as much as 70% after the turn of the century (Vijay Shankar et al. 2011; Ministry of Agriculture 2013), has meant that agricultural demand for groundwater is competing with groundwater sources that provide 98% of India's rural drinking water supplies (Ministry of Drinking Water and Sanitation 2018). India's towns and cities are not behind in their access to groundwater supplies. More than half of India's urban water supply comes from groundwater through formal and informal systems (Narain and Pandey 2012), while sample studies across industries show that 55% of industrial water use is based on groundwater, either as a stand-alone source or as a source that supplements surface water supplies (Perveen et al. 2012).

Such large-scale, unprecedented dependency on groundwater created a crisis surrounding groundwater resources. With the largest groundwater-depleted region of the world—the Indo-Gangetic Plains—reported through a variety of publications (Macdonald et al. 2016; Mukherjee et al. 2015), the groundwater revolution in India has been scripted by millions of farmers and ordinary citizens, essentially to bridge the gap between public water supply and the rapidly growing demand. This gap was filled by groundwater resources tapped largely through individual investments and technology innovations, both of which require a separate chapter, beyond the scope of this one. Despite more than 5000 large dams, their distribution networks and centralized water supply systems to many towns and cities, groundwater usage continues to grow in myriad ways through the farms of India's hinterlands and the by-lanes of its towns and cities. The consequences, simply put, are in the form of profound impacts of severe depletion of groundwater resources, serious effects on groundwater quality leading to groundwater contamination and ungauged effects on river flow through base flow depletion. However, what is even more intriguing is the degree of neglect by water practice and policy despite a growing dependency and deepening crisis surrounding India's aquifers and its river systems. Moreover, public water supply delivery still remains aloof of this paradox on groundwater, implying the need for a serious relook into the questions surrounding groundwater governance in India's diverse groundwater setting.

Understanding the intricate linkages between the science of groundwater and the societal aspects of the resource has become very relevant to the field of global water management (Burke and Moench 2000). The contextual diversity of India's groundwater resources cannot be complete without understanding the complex dynamics between the large-scale consumptive and productive anthropogenic demands and the subtle services that groundwater provides to the environment. The tacit competition between the demands for life (drinking water and sanitation), livelihoods and food security (agriculture), production services (industry) and ecosystem services (base flows and springs that sustain natural flows and stocks in the environment) deserves more attention than it is getting today. Adding to this is the dimension of community-managed systems of water such as the traditional concepts of water–users associations and even the more recent but eroded systems of equitable water distribution called the Pani Panchayats (Deshpande and Reddy 1990), both of which are based on the principles of managing and governing water as common pool resources.

India's groundwater footprint is quite unique and requires a different paradigm of management and governance. While synthesis of the problem of groundwater depletion and contamination is quite elaborately discussed, the specific subject of groundwater governance is actually a more recent development that needs deeper insights from the ground. Globally too, groundwater governance is being synthesized through many lenses, including that of regulation and participation (Molle and Closas 2017), also providing the opportunity to look at a fairly new topic through varied prisms. It has become necessary to revisit the subject of groundwater governance, particularly in India, because of the fuzziness between groundwater management and governance. Moreover, the need for participatory science and decentralized science-based decision-making form the two pillars on which groundwater governance thinking must move forward in India (Joshi et al. 2019). This paper delves into the dichotomy of groundwater management and governance and the need to bridge the gap between these two for groundwater governance to become an effective tool in the complex world of managing India's aquifers as common pool resources. The paper largely bears reference to groundwater governance for rural India and has major implications for agriculture and rural drinking water in India.

2 Aquifers as Common Pool Resources: Current Context

India is one of the most hydrogeologically diverse regions of the world. Two distinctly different aquifer settings dominate India's aquifer setting. Nearly, 1 million km^2 of India's surface area is underlain by unconsolidated, river and wind-blown deposits, while 1.5 million km^2 of its area is underlain by crystalline rocks—ancient igneous and metamorphic—rocks, also called 'hard-rocks'. Together, these two hydrogeologically different aquifer systems underlie 70% of India's area and constitute the two dominant regions of large-scale groundwater overexploitation. More than 80% of the region of groundwater exploitation in India is underlain by these two aquifer systems (Kulkarni et al. 2015; CGWB 2017). Moreover, it is interesting to note how rural and urban habitations in India are distributed across its diverse aquifer settings (Fig. 1).

The great dependency of India's major sectors on groundwater and the emerging crises of depletion and contamination has meant growing competition and potential conflicts over groundwater resources (Kulkarni and Vijay Shankar 2014). Such competition is evident within each sector (farmer versus farmer) but is clearly emerging in the form of inter-sectoral competition (agriculture versus urban demands), leading to conflict. Many villages face acute drinking water scarcity, especially during summers, as a consequence of large-scale groundwater irrigation throughout the year. Not many of these conflicts are reported except the one about a beverage company and a village panchayat (ELRS 2012).

India has the largest number of wells in the world. There are an estimated 29 million irrigation wells today across the country (5th Minor Irrigation Census, Government of India). However, Shah (2009) had estimated 30 million irrigation wells in India. While one can continue to argue about the actual numbers, it is interesting to note how, in the last couple of decades, the rise in bore wells and tube wells have enabled easy access to many users from greater and greater depths. For instance, during the two decades from 1986 to 2006, the number of dug wells in the Malwa region of Madhya Pradesh increased by one and a half times, while the number of deep tube wells increased by thirteen times (Kulkarni et al. 2015), clearly indicating that not only has the well-density significantly risen, but the competition over chasing groundwater from greater depths has also gone up significantly. In other words, groundwater users are competing for water in different aquifers, both through putting more sources on their lands but also ensuring that the deepest wells in a region are also on their land.

India's average landholding is estimated to be of the order of just over a hectare. The highly granular nature of groundwater usage across India's diverse aquifer typology creates a variety of tensions. The mismatch of hydrogeological boundaries (aquifers) and political–administrative boundaries (e.g. land-holds, villages, talukas or blocks, districts, states) is evident in myriad forms. However, this mismatch has resulted in tensions across the entire typology of India's aquifer systems, many examples of which are available in Kulkarni and Patil (2017). Conflicts over groundwater are a result of early competition (Kulkarni and Vijay Shankar 2014).

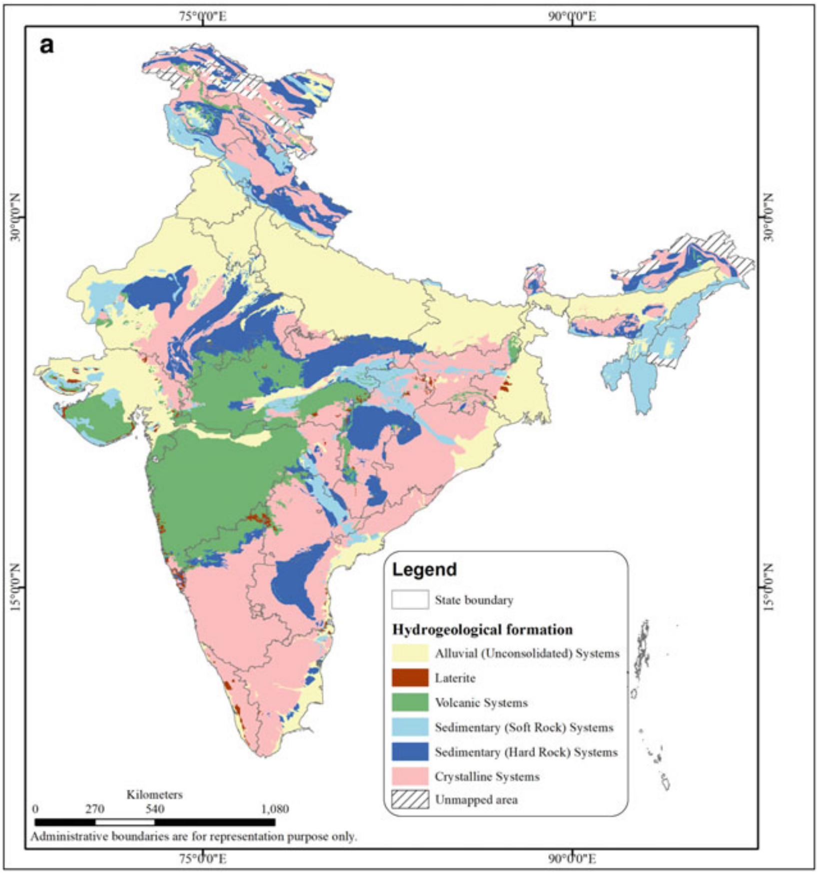

Fig. 1 Generalized aquifer settings in India (**a**)—modified after COMMAN, 2005 and updated significantly by ACWADAM recently—and the distribution of rural and urban habitations based on these aquifer settings (**b**). *Note* Himalayan and sub-Himalayan region has been consolidated as 'Mountain' in Fig. 1b

Users having a common goal of water usage, e.g. agriculture or industry, readily accept and live with competition for long periods.

Social, political and even legal battles ensue because of the domain of allocations made possible through quantitative estimation of stock and flow of surface water (Kulkarni and Patil). Surface water is commonly sourced, accessed and distributed through 'public' systems of water supply. Hence, conflict and contestation take on the shape of a variety of responses ranging from protests to protracted legal battles over such water. Administrative (land) boundaries complicate matters further, leading to a variety of transboundary disputes. On the other hand, groundwater in India, and perhaps from many other parts of the world, is sourced in a dispersed and fragmented manner. Boundaries, quantities and interdependencies are less visible or measurable as compared to surface water resources, resulting in

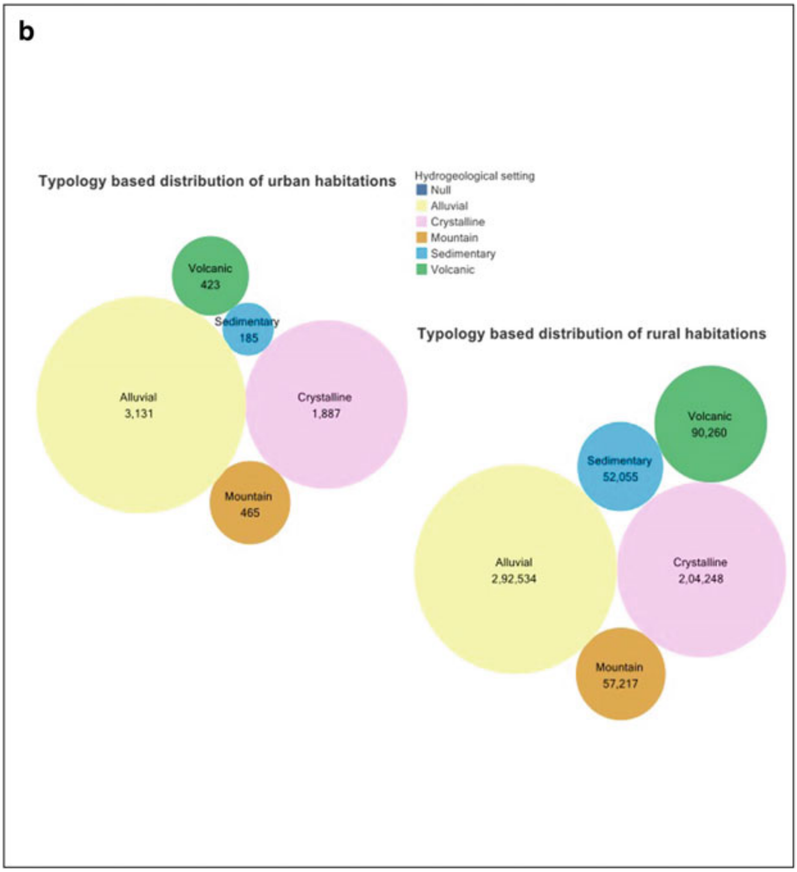

Fig. 1 (continued)

groundwater resources being subjected to intense and intricate competition between users and uses before conflicts become open (Kulkarni and Vijay Shankar 2014). Moreover, individual access and complex distribution systems from multiple sources lead to failure of sources that in turn causes severe water stress. Social and economic drivers often lead to haphazard access and distribution patterns of groundwater in India's large agrarian landscape. Often, understanding of groundwater—particularly aquifers—is neglected in creating improved access and distribution. In pursuing improved access, the number of sources (wells) increases at the expense of an intense competition between users and types of usage over a common resource (aquifer). On the other hand, competitive extraction and falling water levels leads to a marginalization and shutting out of the lower castes, typically marginal farmers and the landless, from well-ownership altogether (Dubash 2002).

Groundwater overexploitation maybe defined as a situation in which, for some years, average abstraction rate from aquifers is greater than of closer to the average recharge rate (Custodio 2002). Large-scale, granular groundwater access in India has led to serious impacts of groundwater depletion and contamination. While alarm bells rang louder when global estimates, including particularly the estimates on groundwater depletion and contamination in the Indo-Gangetic region were presented by international researchers (Rodell et al. 2009; MacDonald et al. 2016), the latest figures presented in CGWB's periodic assessments clearly state the glaring facts. Some 32% of India's sub-district administrative units—blocks and talukas—have become unsafe (semi-critical, critical or overexploited) or have high levels of salinity (CGWB 2017). What is even more glaring are the degrees of contamination of groundwater by fluoride and arsenic. The Ministry of Drinking Water Supply and Sanitation (2018) reports that we have problems of high Fluoride in 203 districts, Ironin 206 districts and Arsenic in 35 districts. Fluorosis is estimated to afflict 65 million and Arsenicosis around 10 million people in India.

Apart from the above, one of the largest knowledge gaps in India pertains to the environmental role of groundwater. Large-scale inclusion of groundwater in both, global development reporting and the ecosystem debates is relatively recent (CGIAR 2015; WWAP 2012). Groundwater resources are as important in ecosystems as they are in providing services to anthropogenic needs such as domestic, agricultural and industrial water supplies. Aquifers are relevant to both ecosystems such as forests and wetlands and their ecosystem services. Forests and wetlands have figured in discussion on ecosystem and ecosystem services for a long time now. Groundwater, only recently and not as much! As aquifers are 'developed' and then subsequently over-extracted, one of the first visible impacts is often in the form of base flow depletion, with streams and rivers drying up (Macdonald et al. 1995). The stocks and flows in aquifers, determined primarily by their transmission and flow characteristics, provide a variety of services to both human and ecosystem needs as aquifers also support a variety of habitats, primarily through seeps, springs and base flow contribution to river flows. In a monsoonal climate, such as in India, base flow from groundwater is a relatively small but seasonally significant flow that keeps streams and rivers flowing during the dry periods of the annual hydrologic cycle.

There are clear social, economic and environmental consequences of groundwater depletion and contamination, leading to serious forms of morbidity and even mortality. The proliferation of wells in India is a classic example of how increased individual access to groundwater has often defeated the goal of managing aquifers as a common pool resource. Community wells have given way to individual access such as is evident in some programmes of the Government of Maharashtra, for instance, where the slogan of 'whoever asks for a well or a farm pond, will be given one (by the State)'. Consequently, the concept of 'water resources held in trust' by the community has been replaced by a competitive and conflict-ridden arena of sourcing, access and distribution of groundwater resources. The crisis of groundwater in India can be addressed only through a return to the principles of common pool resources, principles that not only address converting competition to co-operation but also help in bringing communities closer to their aquifers.

Having said that, it is also important to recognize that aquifers in India are as diverse as the social milieu that define groundwater usage. The social milieu is

Table 1 Estimated percentage of areas in each broad type of aquifer system, which is under some degree of groundwater exploitation

Aquifer typology	Area (km^2)	Percentage of total area which is in the three categories of groundwater exploitation (%)
Alluvial (unconsolidated) systems	931,832	18
Mountain systems	525,067	0
Volcanic systems	525,036	7
Sedimentary (soft rock) systems	85,436	0
Sedimentary (hard rock) systems	194,798	2
Crystalline (basement) systems	1,023,639	10
Total	3,285,808	38

Note Aquifer typology is based on Kulkarni (2005), Kulkarni et al. (2015) and estimates of groundwater exploitation are based on CGWB (2017)

defined not only by the social and economic context of a region—which again is often rooted in the culture of a region—but also on the system of aquifers and their status of exploitation and contamination. Aquifer systems are defined primarily by the geology of a region and by the properties of rock types that govern the accumulation and movement of groundwater in aquifers. The storage capacity of an aquifer, known as storativity and the capacity of the aquifer to transmit groundwater, known as transmissivity are called aquifer characteristics. Both these vary, depending upon how different geological formations constitute aquifers. Table 1 shows the distribution of India's broad aquifer systems and the percentage of the areas underlain by aquifers under various degrees of exploitation, in each of these aquifer systems.

3 Groundwater Management and Governance: The Practice and Policy Dilemma

Civilizations in different parts of the world have been depending on groundwater resources for many centuries. The legacy of groundwater usage until the nineteenth century involved a combination of widespread access from shallow sources such a community dug wells, springs and qantas followed by inventions that involved human and animal traction (after Moench et al. 2013), through technologies such as the Persian Wheel. One can therefore presume that such systems must have included a strong component of governance by the social and political systems prevalent at different periods in history. The unprecedented growth of groundwater dependency across the world, and especially in Asia, is often cited as a revolution by millions of users, especially farmers (Fornés et al. 2007; Shah 2009), who, largely with their own investments created access to groundwater for irrigation. This growth has fuelled the improved security of water supplies, both for domestic and agricultural needs across the world. At the same time, it has clearly brought about a shift from community-governed systems of shared sources and resources to individual, access-driven competition around such resources, especially aquifers.

India's annual groundwater extraction is estimated to have increased ten times since India became independent (estimated from Shah 2005). India's groundwater trajectory, as a consequence of the almost invisible transition from a dominantly surface water dependency in agriculture to an unprecedented dependency on groundwater for agriculture and domestic water supplies, both in rural and urban settings, has led to a set of serious consequences, the main ones being:

1. The shift, during the last century, from a community resource to a fragmented resource accessed by millions. The division of the resource (aquifers) through such millions of sources (especially wells) has come into conflict with the fundamental principles of managing aquifers as a common pool resource.
2. The competition between various users and types of use has led to critical levels of groundwater depletion that is often coterminous with serious issues of groundwater contamination.
3. Nearly, the entire drinking water supply in rural India is met from groundwater. While the average annual demand for drinking water in a typical India village is negligibly small when compared to the demand for irrigation, the competition between these two demands has surely seen only one winner—irrigation. Drinking water security is seriously endangered in very many villages of India.
4. Groundwater is largely invisible and requires an understanding that is based on carefully collected, analysed and interpreted data. While available data on groundwater in India is sufficient to be indicative of a variety of problems, the data is not representative enough to stimulate robust decision-making at appropriate scales.
5. Lastly, conservation and recharge efforts are becoming increasingly popular across India; while many such efforts are genuine, their overall benefits to the management and governance of groundwater remains limited, especially with regard to the free riding (of such benefits) through unsustainable groundwater usage.

A variety of responses have emerged in developing examples and demonstration of sustainable groundwater management in India. The Hivre Bazar experiment from Maharashtra has been a torch-bearer of combining supply- and demand-side reforms through decentralized institutions of governance (Gram Panchayat) in a drought-prone, hard-rock aquifer system in India (Singh 2012). Apart from this experience, whether it is the scaled approach of using a hydrological water balance to develop crop-water budgets under the Andhra Pradesh Farmers Managed Groundwater Systems (APFAMGS) (Das and Burke 2013) or the intensively engaging programme of developing a social protocol integrating hydrogeology and people's participation under the Participatory Groundwater Management Programme (PGWM) in a variety of locations across five or six different states, there are certain common features that have emerged through such efforts (Ghose et al. 2018). These features, among many nuanced aspects of hydrological and socio-economic importance, broadly include the following:

1. Demystified understanding of hydrological units such as watersheds and hydrogeological units such as aquifers.
2. A systematic quantification of (ground)water usage that is indicative of various demands over water, means of supply and their numbers and availability of water, often according the various seasons during a year.
3. Participatory systems of data collection, collation and analyses.
4. Decision support based on basic inferential aspects of analysed data, such as the developing of a groundwater management protocol that is customized to local conditions.
5. Participatory action, often at the community level such as the implementation of systematic conservation and recharge measures, efficient application of water, changes in cropping systems and protection of drinking water sources.

Hence, the success of many of these initiatives has depended on how each of the above have evolved with regard to the local context and the nature of organizations and collaborations that have provided knowledge and facilitation support to the local rural communities. These organizations have been in the form of Civil Society Organisations, Government Departments or even local leadership that have anchored external inputs to raise and nurture community-level systems of decision-making on groundwater management. However, one of the important questions that is raised with regard to such initiatives on community based, participatory groundwater management, is that of why have these initiatives remained 'islands of success' without being replicated or scaled out to other, even neighbouring locations. Moreover, after an initial phase of success, participatory processes of groundwater management cannot often be sustained in time.

With this background, it is important to examine the challenges posed to such strategic approaches—management objectives around certain key hydrogeological paradigms (called protocol) and their impacts of groundwater management that have precluded the scaling out in both space and time (Table 2).

Most efforts in India on coming to terms with the groundwater crises focus on bringing communities together to develop and act upon a set of supply and demand management actions. These efforts try to integrate aquifer understanding with community participation to achieve improved levels of efficiency and equity in groundwater usage (Ghose et al. 2018). However, as may be seen from the table above, the challenges are mainly in the form of a variety of externalities that have solutions largely in the 'policy' arena. Moreover, it is easier to develop social norms around groundwater such as a village-level groundwater management protocol but it is well-nigh impossible to both, sustain the protocol and gain formal acceptance to the social norm through existing institutional mechanisms.

Hence, the large gap between the practice of participatory groundwater management and current policies dealing with water forms the major stumbling block in achieving any form of scaled response to the crises of groundwater depletion and contamination in India.

Table 2 Synthesis of protocols and impacts of community-based groundwater management in India and the main sets of challenges to sustain these impacts

Broad protocol of groundwater management	Impact through key measures of success	Hurdles or challenges in sustaining the impact or measure of success
Conservation and recharge including managed aquifer recharge	Ensuring optimum recharge and protecting catchments from degradation, which in turns ensures both groundwater level and groundwater quality maintenance in aquifers	Operation and maintenance of conservation measures are not sustained, encroachment and land-use/land-cover changes on natural and conserved recharge areas; government programmes also provide farm-level conservation that takes priority over community level conservation and recharge efforts
Measure of using and managing sources through efficient use of wells and springs	Efficient extraction and application of groundwater leading to improved productivity of sources	Competition cannot be avoided in the absence of any legislation; competition includes community drinking water wells versus individual wells; competition leads inefficient extraction rates that affects the status of aquifers; policy externality often brings incentives and subsidy through individual wells
Regulating withdrawal rates of groundwater using energy as an instrument of regulating pumps	Sustained rates of pumping leading to improved efficiencies in pumping, extraction and wells	Energy as an externality is a key factor (Shah et al. 2012)—individual connections on wells often conflicts with groundwater-based Water User Groups; energy is often used as a political instrument where free and unlimited power become instruments of gaining votes before elections
Protection zones including protecting drinking water sources by controlling source-to-source interference and regulating the depth of wells	Drinking water secured from competitive extraction and drilling	Schizophrenia of digging and drilling—maximizing sources—especially during a drought; the disconnect between land-rights and groundwater leads to multiplication of sources as land ownership changes with land division; droughts leading to schizophrenia of drilling; uncontrolled water markets where groundwater from farmland is transported to towns, cities and industries

(continued)

Table 2 (continued)

Broad protocol of groundwater management	Impact through key measures of success	Hurdles or challenges in sustaining the impact or measure of success
Regulating groundwater extraction by managing crop-water budgets	Efficient demand management of groundwater in agriculture based on simple but effective groundwater balances	Uncertain crop markets make the choice of sustainable agriculture difficult; iniquity in land holding, and the decentralized political economy imply that practices of groundwater management and conducive policies to sustain them are seldom in resonance
Comprehensive management of groundwater using a combination of the above measures and integrating these with water user co-operatives	Integrated groundwater management that is inclusive of efficient and equitable access and distribution of groundwater as a CPR	Market as an externality with consequences for labour, returns and water conservation forms the main hurdle; the absence of pro-active legislation and incentives form the main challenges in scaling up practices of aquifer-based, participatory groundwater management

4 The Dichotomy of Groundwater Management and Governance

Groundwater governance is defined in multiple ways. Groundwater governance is the art of co-ordination between administrative action and decision-making at different jurisdictional levels, at the same time being a process involving groundwater management through the application of responsibility, participation, information, transparency, custom and rule of law (Varady et al. 2013). On the other hand, groundwater governance is better thought of as the governance of aquifers given their vulnerabilities and importance in providing essential reserve supplies of water (https://www.oecd.org/cfe/regional-policy/8-Tour-de-table-Andrew-Ross.pdf). While defining a framework of groundwater governance in the USA, Megdal et al. (2015) highlight three problems as priorities within this framework—water quality and contamination, conflicts between users and declining groundwater levels.

Currently, the lack of robust groundwater governance mechanisms, mainly in the form of institutional frameworks including legislation, limits the impacts of processes such as participatory groundwater management. In a recent publication on the challenges and prospects of water governance in India, Singh et al. (2019) define water governance as the set of rules, practices and processes through which decisions for the management of water resources and services are taken and implemented. Often, water governance becomes a paradigm that must be developed centrally. In other words, it becomes synonymous with policy making.

However, given the granular nature of the problem itself, setting down a centralized process of governance will only widen the divide between groundwater management and governance. South Asia's groundwater problem, for instance, requires groundwater governance that deals with a clear integration of conjunctive management of rain-surface water-groundwater, addressing the energy-irrigation nexus, participatory groundwater recharge, conveying water through pipes rather than channels, but most significantly dealing with externality (Shah 2009).

The paradox of pushing for participatory forms of groundwater management in India while attempting to deal with governance through stringent instruments of legislation represents a clear dichotomy between thinking on groundwater management and governance. Table 3 highlights the differential context of groundwater management and governance and attempts to identify gaps that require a fresh approach from the current paradigms of water governance, based on experiences on PGWM by ACWADAM in Maharashtra (Aslekar et al. 2013; Rangan 2016). Hence, the meaning and relevance of groundwater governance in India can be culled out as the process that enables institutional support to help sustain aquifer-based, decentralized participatory groundwater management bearing in mind the objectives of efficiency, equity and sustainability.

While developing the framework for institutions around groundwater management and governance, one fundamental question that arises out of the current dichotomy between groundwater management and governance is: 'Why legislate if people participate in the management of groundwater'? There are two fundamental reasons for an institutional reform on groundwater in India, including a large overhaul to legislation. But before getting to this point, it is important to answer the question of why legislation, as part of the larger institutional reform, is necessary. Firstly, the quantitative and qualitative change in the significance of groundwater resources and the growing dependency of India's population on these resources requires an institutional overhaul, including major changes in water laws in India. The regulatory framework governing groundwater has not been updated since the nineteenth century and is based on a mistaken understanding of hydrogeology and the present legal regime gives precedence to individual interests of landowners precluding the basis for aquifer-wide protection measures (Cullet 2019).

A new paradigm to overcome the gaps between the practice of participatory groundwater management and policies of water governance is to bring these two as close to each other as possible. 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. Such partnerships are even more relevant when we think about participatory groundwater governance because the concept of command-and-control regulation and established institutions of governance become irrelevant when millions of users now control the usage of groundwater. Rather than disciplining the users through formal processes of regulation, it is more sensible to gain their confidence through a variety of participative

Table 3 Narrowing the gap between management and governance—a broad-based template for actions

Broad parameters for sustainable groundwater management	Major challenges in developing and/or sustaining the parameter of management	The most important element that defines groundwater governance in addressing the challenge
Efficient groundwater usage defined by optimal extraction for different uses	Inherent complexity of groundwater settings, lack of data and information, the externality of energy and the poor understanding of energy-groundwater relationships	Information and data at appropriate scales, a finer understanding of groundwater and energy and defining groundwater efficiency as a measure of aquifer productivity rather than water productivity
Equitable distribution leading to fair and just supply of groundwater	The complicity of land and water rights; priorities of groundwater usage—economic (irrigation) returns take precedence over social (drinking water) and ecological (base flows) returns	Political commitment along with robust legal provisions that enable a protection of social water right over economic ones
Community-level decision through formal institutions	Breakdown of co-ordination among stakeholders; weak decision support due to lack of data, facilitation and conflict resolution	Institutional support—decentralized support by public agencies dealing with groundwater and legislation that mainly addresses externalities of free riding the benefits of community-led decentralized decisionsby formal governance institutions
Sustainable economic returns while ensuring environment security	Misplaced subsidy, uncertain markets and skewed returns (crops requiring more water generally fetch higher and steady returns)	Reforms in markets and market support, especially to farmers

processes leading to collective decision-making in managing and governing groundwater resources.

5 Institutions: Towards Integration of Groundwater Management and Governance

Ostrom (1990) "design principles" in the management of common pool resources such as aquifers make a clear reference to resource pool, the local scale of operation and sustained co-operation among users of the resource. The design principles are:

1. Clearly defined contents and boundaries of the resource and exclusion of external untitled parties;
2. The appropriation and provision of common resources that are adapted to local conditions;
3. Collective-choice arrangements that allow most resource appropriators to participate in the decision-making process;
4. Effective monitoring by monitors who are part of or accountable to the appropriators;
5. A scale of graduated sanctions for resource appropriators who violate community rules;
6. Mechanisms of conflict resolution that are cheap and of easy access;
7. Self-determination of the community recognized by higher-level authorities; and
8. In the case of larger common pool resources, organization in the form of multiple layers of nested enterprises, with small local CPRs at the base level.

The design principles can be further broken down into primary and secondary factors while understanding community groundwater management in India. At the same time, it becomes important to note the common features of experiences in both Community Management Responses to groundwater in rural India (COMMAN 2005) and the evolving experience in Participatory Groundwater Management (PGWM) from different parts of India (ACWADAM 2014; Ghose et al. 2018). These are listed below:

- Both community approaches and PGWM empower communities to make informed choices around the question of rural water security.
- Groundwater management is not necessarily interpreted in terms of developing locally agreed controls.
- Symptoms and responses to groundwater problems, especially depletion, vary despite underlying common causes.
- Measures to augment groundwater are more acceptable than those to conserve it.
- Hydrogeological advice may help assess the risk of losing conservation gains.
- The limitations of state's interventions for regulating groundwater use through punitive measures can be circumvented to a large extent by enabling communities to make informed choices—such as instances of banning and regulating the depth of new borewells, shifts in cropping pattern, sharing of borewells, etc.
- The incongruence between scales of groundwater management and aquifer dynamics along with the issue of exclusion of certain stakeholders from the management group are the central challenges to the development of community-based organizations for groundwater management.
- The heterogeneity of communities remains a big challenge in achieving success in participatory, community-driven groundwater management, especially in regional aquifer systems.
- Dealing with large externalities such as urbanization, energy incentives and land-use changes is the biggest challenge for efforts in community-based groundwater management, not to mention the difficulty in incentivizing peoples' participation on groundwater management, through public policy instruments.

Whether it is dealing with externality or with the limitations resulting from lack of information (on the scale of aquifers) or proceeding beyond supply-side management into the domain of demand-side groundwater management, the conceptual framework of robust institutions, and therefore, the broader reference to groundwater governance become significant. In moving forward, it is important to couple participatory forms of groundwater management with decentralized groundwater governance in India. In doing so, it is important to remember that transdisciplinary, demystified science should become the basis for participatory decision-making leading to developing an institutional system of groundwater governance based on a relevant protocol of groundwater management. The process itself could be based on four basic steps:

1. Mapping of aquifers leading to participatory responses that include direct, indirect and community instruments of management.
2. Special emphasis on securing rural drinking water supply, in terms of assured quantity and potable quality of water.
3. Management plan will depend upon the groundwater setting, aquifer geometry, state of groundwater usage including agriculture/industry/rural–urban interface and other such factors.
4. A legislative framework that goes beyond a typical command-and-control legislation to a more reformed legislative instrument that compliments and protects the socially accepted norms of participatory groundwater management.

In a recent attempt to reform India's water sector, the Mihir Shah Committee (Shah 2016) has recommended the constitution of the National Water Commission, which builds enduring partnerships between government, academia and civil society and functions through a decentralized, transdisciplinary river-basin structure. The main purpose behind the recommendations in the report is to reform India's Water Governance. As part of the same report, it becomes relevant to summarize the reform included specifically for the groundwater sector. The main suggestions for groundwater governance deal with reforming the topmost groundwater institution in the country—the Central Ground Water Board (CGWB). These suggestions are summarized as:

- India must engage with the issues of groundwater depletion and contamination by looking beyond groundwater assessment and permits. This can be done by strengthening the institutional architecture on water in general and groundwater in particular, the latter through a major reform within the CGWB and all the state groundwater departments/directorates without whom the CGWB simply cannot function.
- At the topmost echelons in the institutional structure of the country, the reform must include bringing in an interdisciplinary approach to groundwater institutions through:
  - Expansion and enrichment of the human resource profile of the CGWB and all other such organizations involved in groundwater governance.

- Revive and reform State groundwater departments/directorates and make them more accountable to catalyse decentralized groundwater management and governance.
- Aquifer mapping to groundwater management—enduring partnerships with academic and research institutions, as also civil society organizations.
- Build capacity on the equitable, efficient and sustainable management of aquifers in India.
- A deeper knowledge of grass-roots realities on groundwater in different parts of the country will be possible for policy makers and people in governance only through a deeper engagement with communities, themselves a diverse set of stakeholders in groundwater management and governance.

A one-size-fits-all approach of groundwater management and governance becomes irrelevant under India's aquifer and socio-economic diversity. Table 4 provides a synthesis of the relevance of individual elements of the protocol of groundwater management to the six broad aquifer settings in India. The synthesis uses their hydrogeological features, the main threats to the aquifer systems and the most relevant protocols that will require to be prioritized through a potential groundwater governance lens.

6 Conclusion

The consequences of unrecognized large-scale groundwater dependency are evident in the form of aquifer depletion, groundwater contamination and drying up of rivers. Restoring aquifers requires a strategic combination of managing groundwater resources while establishing a robust system of decentralized groundwater governance (Kulkarni et al. 2015; Joshi et al. 2019). The process of ensuring a seamless integration of efficient and equitable groundwater management to sustainable groundwater governance must firstly include demystified science leading to the development of knowledge, data, skills and understanding of groundwater resources at any given location. Such understanding will lead to the decision support to a variety of stakeholders, especially when the stakeholders participate in the building up of the knowledge and understanding on groundwater.

Based on such decision-making, co-operation between stakeholders can evolve and must be supported through robust systems of governance that include socially normative regulation backed by formal legislation, which together will define the institutional structure of groundwater governance in India.

Framing groundwater governance as the governance of aquifers is important so as to instil confidence and belief in managing groundwater resources as Common Pool Resources (CPR). In doing so, groundwater management must become inclusive of the need to shift the focus of plans and practices from 'sources' of groundwater to the 'resource'. Lastly, creating a pro-active policy environment that embraces community participation in developing the understanding on groundwater

Table 4 Broad canvass of groundwater management protocols across India's diverse aquifer typology

Aquifer typology	Hydrogeological character and situational elements including potential threats	Relevance of specific elements of groundwater protocol in prioritizing mechanisms of groundwater governance
Himalayan mountain system	Springs and streams fed by glaciers, snow melt and rain along with discharges from low storage, moderately transmissive aquifers. Estimates indicate the presence of 2 million springs that support at least 60% of the population. Increasing urban pressures leading to a competition between wells, bore holes and spring water, sometimes from the same aquifer. Evidence of long-term decrease in precipitation, changing land-use and land-cover and changes in ecosystem elements like wetlands are leading to depleting water sources, especially springs	Springshed management, including protection of recharge areas as part of conservation; protecting and managing the springs themselves from competition by wells in the same aquifer; Spring-water management planned on the basis of spring-discharge and variability in this discharge; Spring-water distribution is possible largely through gravity-based systems, with exogenous energy being reserved only for lifting naturally available spring water and not for extraction from the aquifer; Protecting a spring source from interference with artificially created sources like wells (many of which have extraction devices like energized pumps) is necessary; crop water budgeting in mountain agriculture can be planned on spring-discharge seasonal variabilities in discharge; groundwater user groups can be designed around both, individual springs or a cluster of springs as a comprehensive strategy of groundwater governance
Alluvial system	Large storage, transmissive aquifers that are either heavily depleted due to over-extraction or are still in a state of reasonable balance. Springs, seeps, wetlands, lakes are coming under pressure from intense competition with tube well drilling. Major challenges in groundwater quality, including arsenic and even radioactive elements. Groundwater access is challenged in some areas by flood-proneness	Recharge activities should be based upon the geometry and situation of aquifers; natural recharge areas may be distant from the areas where extraction takes place; generally, well yields are high and reasonably consistent in an area, so, the focus should be on avoiding undesired competition through lateral interference of wells; controlling heavy duty individual irrigation wells becomes a priority through managing energy inputs; crop water budgeting may be effective if groundwater balances at the scales of villages are attempted (and even if these are not representative of aquifer-level groundwater balances); water user groups or co-operatives have to be a larger scales or clusters for sharing both controls and benefits

(continued)

Table 4 (continued)

<table>
<tr><th>Aquifer typology</th><th>Hydrogeological character and situational elements including potential threats</th><th>Relevance of specific elements of groundwater protocol in prioritizing mechanisms of groundwater governance</th></tr>
<tr><td>Sedimentary systems (hard and soft)</td><td>Pockets in different parts of India. Local and regional aquifers with variable rates of extraction and depletion. Larger issues around the close coherence of sedimentary aquifers with forests, tribal hinterlands and potential mineral resource hot-spots. Industries around mining centres and associated urbanization lead to tension between sectoral groundwater usage. Increasing impacts of deforestation, mining, tourism and industrialization, affecting both, the quantities and quality of groundwater resources</td><td>The most diverse range of aquifer properties implies the application of strategic conservation and recharge; managing energy through a systematically developed range of pumping systems that can sustain highly variable well yields; hence protecting the lower ranges of well yields is important; a combination of well interference zones along with depths of drilling becomes significant; given the variability in scales, groundwater balances and crop water budgeting needs to be undertaken at multiple scales ranging from villages, aquifers to larger watersheds; groundwater user co-operatives need to be integrated through an integration of more local village-level user groups</td></tr>
<tr><td>Volcanic system</td><td>Most heterogeneous aquifers in India. Host to the largest numbers of traditional large-diameter dug wells. Springs at the source regions of many major rivers. Competition dynamics between large dams and wells and between different kinds of wells
Increasing impacts of intensive agriculture including high water demand crops, effects of deforestation and tourism on aquifers. Significant reduction in base flows to rivers</td><td rowspan="2">Integrated watershed management is one of the best instruments for managing groundwater recharge and initiating conservation in the hard-rock aquifers of India; efficient management of the shallow aquifers through traditional large-diameter wells forms the backbone of managing hard-rock aquifers; reviving shallow unconfined aquifers and efficient pumping of dug wells using energy more efficiently; highly variable well yields imply a common rate of extraction, preferably at the lower end of the well-yield range in hard rocks along with a control on the depth of wells and bore holes; this will reduce competition but also reduce vertical interference between aquifers while ensuring protection of drinking water; crop water budgeting on the basis of aquifer-level groundwater balances are desired while aggregating water user groups into a larger federation of such co-operatives</td></tr>
<tr><td>Crystalline system</td><td>Intense competition over depths of wells—mainly through bore holes. Aquifers are largely local, but deep and extensive weathering of crystalline basements has produced some regional aquifer systems. Intensive use for agriculture and also in rapidly urbanizing centres. Large volumes are extracted in many parts. Urbanization and deforestation are the major threats</td></tr>
</table>

and generating knowledge on aquifers, communities and ecosystems is most important. Such an environment will enable the agencies of governance such as PRIs to take improved decisions and undertake actions that will lead to sustainable, efficient and equitable usage of groundwater.

Finally, on a more practical front, enabling reforms in key areas of groundwater management and governance is the most fundamental step in ensuring sustainable groundwater management. Participatory processes of management can lead to a socially normative protocol where community decisions are documented and accepted through institutional instruments such as resolutions of the village gram-sabhas (local instruments of governance under the gram panchayats—village levels elected democratic institutions of governance vested under the Constitution of India). Such social norms have a significant weight as they evolve through a continuous dialogue that is the hallmark of democratic decision-making. At the same time, it is difficult to say whether such norms are safe enough from 'free riding' through an externality such as large-scale drilling and extraction in neighbouring villages. Conventional legislation usually adopts a command-and-control approach to law making and implementation and may often become counter-productive to producing social norms. Moreover, states in India develop their own groundwater legislation. Hence, the tendency of legislation is to be constituted by a reasonable broad set of legal provisions and rules.

The concept of decentralized governance, given that the actual decision-making on groundwater will be vested at the village or sub-district levels, becomes quite relevant to India's atomistic groundwater problem. Reconciling legislation to the nuances of a decentralized normative framework will be challenging. Hence, a new approach to developing legislation on groundwater could actually include protecting the social processes developed under a participatory, decentralized normative frame. Moreover, it could further link up to protecting not just aquifers but also the larger ecosystem, thereby also demanding a strong overlap with other legislation such as legislation in agriculture, urban development and even on forests and the environment.

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Sustainable Urban Water Management Strategies

Kulwant Singh and Sajib Mahanta

Abstract India is suffering a very significant water crisis with economic growth, livelihoods, human well-being, as well as ecological sustainability at stake. The macro-water availability and numbers are unsettling; India is home to ~17% of world's population but has only 4% of the world's freshwater resources. Evidence also suggests that, 11 out of 20 largest cities in India face an extreme risk of water stress and the per capita water supply is considerably lower than the per capita demand. A closer look at cropping patterns in the Indian states also reveals a frightening inefficiency and suboptimal planning that is causing most water-related problems, including depletion of the groundwater tables at an alarming rate. The bigger issue here is that the scarcity of water resources has many cascading effects including desertification, risk to biodiversity, industry, energy sector and risk of exceeding the carrying capacity of urban hubs. With a country generating 140 BCM of wastewater annually, mismanagement of wastewater which also contaminates groundwater, lack of liquid waste management, poor sanitation conditions and poor hygiene habits has contributed to a major portion of population suffering from water-borne diseases (*Strategy for New India @ 75* (NITI Aayog 2018), p. 102, https://niti.gov.in/writereaddata/files/Strategy_for_New_India.pdf). Water scarcity can seem difficult to full grasp, given the dichotomous ways in which water is affecting habitations. To tackle the complex water challenge facing India, it is imperative to take a holistic view of water, starting with the hydrological system, the interactions of this system with climate change on the one hand, and with human factors across agriculture, industrial and energy production activity on the other. Thus, this chapter identifies the issues and challenges in managing water sustainably, explores the various Government initiatives on water management and recommends a holistic strategy for water demand management.

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1 Context Setting

Water not only has a basic function in maintaining the integrity of the natural environment but is also a key driver of health, gender equality, resilience, inclusive cities, life below water, terrestrial ecosystems and peaceful and inclusive societies, which in turn are indicators of Socio-economic development. Thus, the sustainable management of water is extremely vital and increasingly considered as a requisite for India's growth and ecosystem sustainability. India is home to ~17% of the world's population but has only 4% of the world's freshwater resources. Its per capita water availability is around 1100 cubic meter (m^3), which is well below the internationally recognized threshold of water stress of 1700 m^3 per person per year, and precariously close to the threshold for water scarcity of 1000 m^3 per person per year. According to a Water Risk Filter assessment by WWF, nearly one-third of the 100 cities in the world which are susceptible to 'water risk'—which range from droughts to floods—are in India. Evidence also suggests that, 11 out of 20 largest cities in India face an extreme risk of water stress. This data is based on the sub-national Water Stress Index, formulated by London-based risk analytics firm Verisk Maplecroft. According to the index, Delhi, Chennai, Bengaluru, Hyderabad, Nashik, Jaipur, Ahmedabad and Indore are among the cities facing 'extreme risk'. After accounting for all the loss, the water supply is only 25 L/day per capita which is considerably lower than the demand of 210 L/day per capita.

The annual utilizable water resources in the country are 690 billion cubic meter (BCM) from surface sources and 447 BCM from groundwater. In spite of possessing surface water resources, India is highly dependent on groundwater resources for day-to-day survival. Presently, India is facing the challenge to fulfill its demand through its existing but depleting resources. To supplement its present resources, the country has to find unconventional solutions involving recycling and reuse of water and rainwater harvesting. It is estimated that 214 BCM of surplus monsoon runoff can be conserved in groundwater reservoirs. In view of the limited availability of water resources and rising demand for water, sustainable management of water resources has assumed critical importance.[1]

Water is a life shaping resource. However, water as a public good is not used very efficiently. Adding to it, the infrastructure development and well-regulated demand interventions have also not kept pace with the population and economic growth. Thus, the increased scarcity of water is affecting the broad spectrum of economic, social and developmental activities of the country. Paradoxically, India is also one of the major net exporters of virtual water (the amount of water required

[1]ibid.

to produce the products that is exported from India) and has one of the most water-intense economies. Despite the challenges in managing water resources, India is one of the largest water users per unit of gross domestic product (GDP). This suggests that the lack of governance of water resources accounts for much of India's water woes.

It not only affects GDP directly in the form of loss of productivity of agriculture, industrial and service sectors but also decreases the ability of the human resources to think, invent and produce which indirectly hampers the growth of the country. Currently, nearly 820 million people in 12 major river basins of India are facing high-to-extreme water-stress situation. Out of these, 495 million people alone belong to Ganga river basin which generates nearly 40% of the country's GDP. The scarcity of water resources also has many cascading effects including desertification, risk to biodiversity, industry, energy sector and risk of exceeding the carrying capacity of the urban hubs.[2] Therefore, to ensure sustainable water management, there is a need for the country to take measures not only for better outcomes but also make efforts involved for achieving these outcomes.

2 Government Efforts: Jal Shakti Abhiyan (JSA)

Water in India is a State subject, and its optimal utilization and management lies within the domain of the States. In July 2019, the central government picked up the challenge of water management and conservation by launching a campaign called Jal Shakti Abhiyan for water conservation and water security in 1592 water-stressed blocks in 256 districts. The Jal Shakti Abhiyan is a time-bound mission-mode water conservation campaign, and the programme has the capacity to change the overall scenario prevailing in the water sector of India. During the campaign, officers, ground and surface water experts and scientists from the Government of India are working together with state and district officials in India's most water-stressed districts[3] for water conservation and water resource management by focusing on accelerated implementation of a five target intervention. The JSA aims at making water conservation a Jan Andolan (people's movement) through asset creation and extensive communication.

Intervention Areas for JSA Include

1. Water conservation and rainwater harvesting
2. Renovation of traditional and other water bodies/tanks

[2]Amitabh Kant, CEO, NITI Aayog, Composite Water Management Index, August 2019.

[3]Water-stressed districts: Districts with critical or over-exploited groundwater levels as per the Central Ground Water Board (CGWB) 2017. For states without critical and over-exploited groundwater levels, districts with the least availability of groundwater in comparison with the rest of the districts in the state have been selected.

3. Reuse and recharge structures
4. Watershed development
5. Intensive afforestation.

Special Intervention Areas Include

a. Development of Block and District Water Conservation Plans (To be integrated with the District Irrigation Plans)
b. Krishi Vigyan Kendra Melas to promote efficient water use for irrigation (Per Drop More Crop) and better choice of crops for water conservation
c. Urban Wastewater Reuse—In urban areas, plans/approvals with time-bound targets to be developed for wastewater treatment and reuse for industrial and agriculture purposes. Under the JSA special intervention areas, the municipalities will be directed to pass by-laws for separate treatment of greywater and blackwater
d. Scientists and IITs to be mobilized at the national level to support the teams
e. Creation and development of 3D Village Contour Maps and made accessible for efficient planning of interventions.

On the other hand, the Jal Shakti Ministry [earlier called the Ministry of Water Resources, River Development and Ganga Rejuvenation (MoWR)] recommends an approach that is not a prescriptive model but a process that invites existing cities and emerging ones to adjust their current planning and management practices, given their own priorities, in a hydrological, environmental and socioeconomic context. One of the key components of such an approach is participation of the relevant stakeholders including the public, private and social sectors. Although there can be many stakeholders involved in the both the service and value chain, but an agreement needs to be reached with the representatives of local government who shall remain the main convener to implement things at the grassroots level. The development practices often promote a silo mentality, and the participation of the key stakeholders is essential in order to: break "silos" between different sectors and activities; reach a common understanding and vision of challenges and activities. This will in turn induce behavior change and realistic water demand management.

3 Risk of Exceeding the Carrying Capacity of Urban Hubs[4]

About 30% of people in India live in cities and urban areas that are expected to double in population by 2050. With a growing economy and fast changing lifestyles, the pressure on already strained water resources is escalating. Urban hubs are likely to witness severe water shortages in the future, which could risk urban

[4]Composite Water Management Index, NITI Aayog, August 2019, p. 16.

growth in India and reduce quality of life for urban citizens. India's urban population is expected to reach 600 million by 2030,[5] and fulfilling its water needs will be a great challenge. Estimates suggest that the demand–supply gap for the domestic sector will stand at ~50 BCM in 2030, with the future demand expected to double by that time.[6] The present situation is also not ideal as five of the world's 20 largest cities under water stress are in India, with Delhi being second on the list.[7]

As of 2014, no major city in India supplied 24 × 7 water to its entire urban population,[8] and only 35% of urban households in India had piped water supply in their dwelling as the primary source to support drinking water needs, while others rely on piped water to plot/yard, tube wells and public taps amongst other sources.[9] These water delivery challenges will further exacerbate as migration to major urban cities in search of better livelihood opportunities continues, and additional stress is put on the already insufficient water resources and inadequate infrastructure. As of 2015, India treated only 30% of the wastewater generated in the country.[10] Lack of adequate infrastructure in cities to handle their own wastewater will also severely add to the water management woes. Industrial growth in and around cities will be severely compromised as companies will move their operations to more water-secure locations. All these challenges can together create serious water scarcity conditions for urban dwellers where their basic water needs are not met.

Box 1: Implications for Urban Planning

A strong focus on urban regional water planning can help mitigate water risks in urban settlements. An integrated approach to land-use planning and zoning, which includes water as a key aspect, is the only way to ensure sustainable urban development where cities do not run out of water in the long run. State and city governments should consider water resource availability in the region while creating city plans and providing permits for new establishments and restrict any development activities that are not sustainable in terms of water management. The central and state governments can also encourage such a shift in urban development through policies and tight monitoring. The American Planning

[5]"World Urbanization Prospects 2018—Population Division", United Nations, accessed May 6, 2019, https://population.un.org/wup/Download/.

[6]Charting Our Water Future (McKinsey and WRG 2009), p. 9, https://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/sustainability/pdfs/charting%20our%20water%20future/charting_our_water_future_full_report_.ashx.

[7]McDonald et al. (2014).

[8]"24 × 7 Water Supply: FAQs", World Bank, accessed May 16, 2019, https://www.worldbank.org/en/country/india/brief/faqs-24x7-watersupply.

[9]National Sample Survey Office, Drinking Water, Sanitation, Hygiene and Housing Condition in India: NSS 69th Round (Ministry of Statistics and Programme Implementation, 2014), p. 82, https://mospi.nic.in/sites/default/files/publication_reports/nss_rep_556_14aug14.pdf.

[10]Suresh Kumar Rohilla et al., Urban Water Sustainability (Centre for Science and Environment, 2017), p. 16. https://cdn.cseindia.org/attachments/0.84020200_1505207729_Urban-water-sustainability-report.pdf.

Association (APA) in the United States has introduced water-related policy guidelines in its charter to promote sustainable development in cities that treats water as a critical and essential element in infrastructure planning. As a part of the initiative, APA has also committed to collaborate and work with federal agencies, organizations and programmes to address present and future water issues, enhance technical skills of planners to enable them serve as water experts and help advance legislations that support integrated approach to water management.[11]

4 Economic Risks of Water Scarcity

Water is essential for the production of most physical goods (directly) and services (indirectly). Water scarcity poses a serious threat to sustainable economic activity in India and can hamper national growth. As the water crisis worsens, production capacity utilization and new investments in capacity may both decline, threatening the livelihoods of millions, and commodity prices could rise steeply for consumers due to production shortages (Veolia). Such circumstances can lead to economic instability and disrupt growth. Given below are the key risks that lie ahead in India's case.

4.1 Risk to Sustainable Industrial Activity

Water shortages in the country may hamper industrial operations and other economic activity that may lead to muted economic growth. Industrial activity accounts for ~30% of GDP contribution at the national level[12] and holds significant importance in India's economy. Estimates suggest that industrial water demand will quadruple between 2005 and 2030[13] highlighting the significant rise in demand by the sector over time. Additionally, a recent study reports that industries will need to draw three times the water compared to their actual consumption by 2030 due to water efficiency

[11]"APA Policy Guide on Water", American Planning Association, accessed May 16, 2019, https://www.planning.org/policy/guides/adopted/water/.

[12]Ministry of Finance, Contribution of Various Sectors to GDP (Press Information Bureau, 2018), https://pib.nic.in/newsite/PrintRelease.aspx?relid=186413; Central Statistics Office, Key Economic Indicators (Ministry of Statistics & Programme Implementation, 2019), https://eaindustry.nic.in/key_economic_indicators/Key_Economic_Indicators.pdf.

[13]Charting Our Water Future (McKinsey and WRG 2009), p. 55, https://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/sustainability/pdfs/charting%20our%20water%20future/charting_our_water_future_full_report_.ashx.

challenges.[14] Water shortage will drive up the cost of water and lead to a disproportionate impact on the Small-to-Medium Enterprise (SME) and Micro, Small and Medium Enterprise (MSME) segment. The industrial developments especially at the small and medium level interspersed with the dwelling units also provide a challenge to the management of water quality as the industrial wastewater mixes with the urban sewage making the resulting mix difficult to treat at reasonable costs.

Worst affected industries are likely to include water-intensive ones such as food and beverages, textiles and paper and paper products. Amongst these, the textiles industry alone contributes 4% toward India's GDP, 14% to national industrial production, and accounts for 17% of the country's foreign exchange earnings.[15] Water shortages have already impacted the production processes in several industries in the recent years. These impacts have ranged from industries operating at reduced capacity, to temporary shutdown of operations, and even curtailment of expansion projects. In 2016, a steel plant in Vishakhapatnam, Andhra Pradesh was forced to operate on reduced capacity due to lower water availability.

Box 2: Implications of Water Usage in Industry[16]

Industrial water quotas, tradable permits and water availability linked licenses can help in optimizing water usage in scarce regions and minimize the water supply deficit. Industrial water use can be optimized by giving permits that put caps on water consumption by each user, while industrial zoning can restrict water-intensive industries from setting up in water-scarce regions. This will help promote water efficiency amongst both small and large industries. Additionally, a tradable water permit system can be developed, where water entitlements and allocations are provided to industrial units annually, and they can freely trade their water quotas to maximize outputs and income by optimizing water use. The water market system in Australia's Murray–Darling Basin is one successful example, which supports water trading worth AUD 2 billion annually. It allows buying and selling of water entitlements and allocations amongst different users based on their own preferences and creates incentives for water to be moved to higher-value uses.[17]

[14]"Investments worth $291 bn needed to plug water demand–supply gap in India: Study", ASSOCHAM India, accessed May 16, 2019, https://assocham.org/newsdetail.php?id=6357.

[15]WWF-India and Accenture Services, Water Stewardship for Industries: The Need for a Paradigm Shift in India (WWF-India, 2013), p. 18, https://www.indiaenvironmentportal.org.in/files/file/water%20stewardship%20for%20industries_0.pdf.

[16]Composite Water Management Index, NITI Aayog, August 2019.

[17]"Water Markets and Trade", Murray-Darling Basin Authority, accessed May 5, 2019, https://www.mdba.gov.au/managing-water/watermarkets-and-trade.

Box 3: Pricing Water-Israel Model

Pricing water to reflect irrigation costs as well as water scarcity can be an effective model for water conservation in agriculture, as demonstrated by Israel' water pricing example. The water prices in Israel are set by the National Water Authority and account for delivery costs (infrastructure investment, O&M expenditure, treatment cost) as well as social costs (groundwater extraction fee tied to water availability) to signal the true price of water. Water tariffs are also differentiated based on the water type utilized (freshwater, brackish and effluent) to reflect the scarcity of each of these resources. Through this water pricing approach, Israel has been able to reduce agricultural consumption of freshwater resources from 80% to ~30%, given the higher water charges for use of such resources. This has also allowed Israel to reduce pressure on its freshwater resources and sustainably meet the increasing water demand of its urban population, which has increased 10 times since 1948.[18]

5 Water Demand Management Strategy for Indian Cities

As mentioned above, the issues in the water sector are rooted in its wasteful use, characterized by poor management systems, improper economic incentives, under-investment, failure to apply existing technologies, and a traditional mind-set focused almost exclusively on supply side interventions, developing new supplies rather than conservation and use efficiency. In today's scenario, the rising level of competition for water is directly contributing to a global water shortage. Despite impressive progress in reducing poverty and hunger and improving health of people during the past couple of decades, humanity still faces enormous socioeconomic and sustainability challenges. Ensuring the sustainable provision of equitable access to sufficient good quality water for people, productivity and the environment is a necessary condition. Progress is being made in ensuring clean water supply and safe sanitation for the poorest and the destitute. However, this progress is not fast enough to meet the goals of the world expressed through the United Nations Sustainable Development Goals (SDGs), particularly with respect to the need for improved safe water and sanitation (SDG 6). This growing water scarcity and the uncertainties as a result of climate change reinforce the need to adapt both water policies and land planning policies that have a positive and lasting impact on water management practices. For the past fifteen years, water demand

[18]Yoav Kislev, The Water Economy of Israel (Taub Centre, 2011), https://taubcenter.org.il/wpcontent/files_mf/thewatereconomyofisrael.pdf.

Table 1 Major River Basins in India

S. No.	Major river basin	Origin	Catchment area (km^2)	Surface water—average annual potential in river (BCM)	Total replenishable groundwater resources (BCM)
1	Indus	Mansarovar (Tibet)	453931.87	73.31	26.49
2	Ganga	Gangotri (Uttar Pradesh)	861,452+	525.02	170.99
3	Brahmaputra	Kailash range (Tibet)	194,413+	585.6	26.55
4	Barak		41,723+		8.52
5	Sabarmati	Aravalli Hills (Rajasthan)	21,674	3.81	
6	Mahi	Dhar (Madhya Pradesh)	34,842	11.02	
7	Narmada	Amarkantak (Madhya Pradesh)	98,796	45.64	10.83
8	Tapi	Betul (Madhya Pradesh)	65,145	14.88	8.27
9	Brahmani	Ranchi (Jharkhand)	39,033	28.48	4.05
10	Mahanadi	Nazri Town (Madhya Pradesh)	141,589	66.88	16.46
11	Godavari	Nashik (Maharashtra)	312,812	110.54	40.65
12	Krishna	Mahabaleshwar (Maharashtra)	258,948	78.12	26.41
13	Pennar	Kolar (Karnataka)	55,213	6.32	4.93
14	Gauvery	Coorg (Karnataka)	81,155	21.36	12.3
Total			2,528,084	1570.98	356.45

Source Water Resource Information System

management (WDM) has been emerging as a key issue of sustainable development in India and many developing countries. This comprises a set of measures intended to increase the technical, social, economic, environmental and institutional efficiency of the various water uses.

5.1 Water Scenario in India

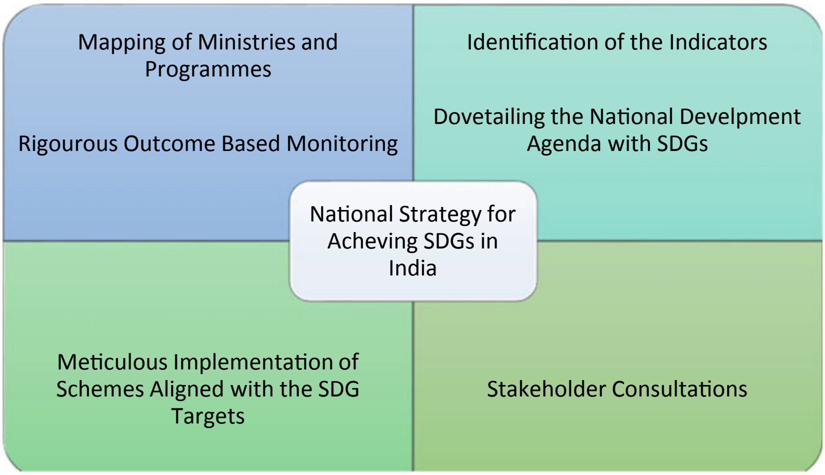
India, with its high population and high-dependence on monsoon, creates great susceptibility to hydrological shocks by any global standards. 22 out of 32 major cities in the country *face acute shortage of water supply* every day (India Water Portal). About 90% of rivers in India flow during four months and over 50% of rain pour in just 15 days, resulting in floods in many parts of the country. India, with its huge potential for rainwater harvesting, could enhance its water storage, which is currently 209 m^3 per capita (AQUASTAT Data). The surface water in India consists of twenty-two major river basins (CWC 2011). Of these twenty-two river basins, there are thirteen major river basins that are spread over 81% of the geographical area comprising a catchment area of 2.6 million km^2 (Table 1) (Water Resource Information System).

The National Commission for Integrated Water Resources Development (NCIWRD) has projected the demand for water for the years 2025 and 2050. By the year 2050, the total demand for water is expected to be 973 billion cubic meter (BCM) according to the low demand scenario and 1180 BCM according to the high demand scenario (NCIWRD). Due to the rainfall pattern and low surface storage, about 63% of India's irrigated agriculture and 85% of drinking water supplies are dependent on groundwater. In the last few decades, India has witnessed an intense groundwater withdrawal and exploitation for agriculture, industrialization and city-development. One of the underlying reasons for excessive use of groundwater is the legal framework governing access to the groundwater resource, which gave the landowners the right to access groundwater from below their land without regard to the migrating nature of the resource.

According to a report published by NITI Aayog, India is facing the worst water crisis in its history, and 21 Indian cities will run out of groundwater by 2020. It also highlighted the need for urgent and improved management of water resources. With nearly 600 million Indians facing high-to-extreme water stress—where more than 40% of the annually available surface water is used every year—and about 200,000 people dying every year due to inadequate access to safe water, the situation is likely to worsen as the demand for water will exceed the supply by 2050 (Composite Water Management Index CWMI Report 2018).

In the context of the water sector, NITI Aayog has come out with a Composite Water Management Index (CWMI), as a major step toward creating a culture of data-based decision-making for policy makers in India. This index is an attempt to nudge the States toward more efficient utilization and better management of water with a primary focus on reuse and recycling. This also gives an insight on how several States have progressed in the water sector over 2015/16 and 2016/17.

1. National Strategy for Achieving SDGs in India



Source I NITI Aayog 2018

5.2 Non-revenue Water

In order to limit the extent of non-revenue water (NRW) and also account for the per capita water consumption with relation to the demand, a network of piped water systems must be established at all levels. NRW comprises apparent losses due to leakages in the transmission and distribution networks as well as losses due to illegal water connections, water theft and metering inaccuracies. In an analytical study conducted by the Delhi Committee of the Associated Chambers of Commerce and Industry of India (ASSOCHAM), it has been revealed that distribution losses are primarily due to leakages in a network of nearly 9000 km-long water supply lines and because of theft committed through unauthorized connections. Pointing out that this figure was quite high even in comparison with the 10–20% losses seen in the developing countries, the study stated that the percentage of unaccounted-for-water calculated from the difference between water produced and pumped was also very high at between 35 and 40% (ASSOCHAM). The current gap between supply and demand of water is nearly 1300 million liters of water. A transition from supply side management to demand management is therefore crucial for sustainable use of water resources.

6 Water Demand Management Concept

Necessity of Sustainable Water Demand Management (SWDM) is immensely higher in the rapidly urbanized mega-cities of India where groundwater depletion and water deficit are taking place at an alarming rate. In 2014, closely 3.9 billion people, or 54% of the global population lived in cities, and as mentioned above, by 2050, two-thirds of the global population will be living in cities, which will generate 55% additional water demand in the world (Arfanuzzaman and Rahman 2017). A common characteristic of water demand in urban areas worldwide is its relentless rise over many years and projections of continuous growth over coming decades. The chief influencing factors are population growth, together with changes in lifestyle and consumption pattern, demographic structure and the possible effects of climate change. Water demand management can be hard to define; more an issue of policy than of technology, it is about managing and moderating our demands for good quality freshwater. It is less a matter of piping and pumps and more a tool for changing the ways we use water and the rates at which we use it. In practice, WDM comes down to three key goals: economic efficiency, social equity and sustainability.

1. ***Economic efficiency***

There are many ways to improve the efficiency of water use, for example, by reducing losses in the distribution system, by reducing the amount or the quality of water needed to perform a task and by changing the timing of water use. Reducing the amount of water used is an obvious benefit, but reducing the quality of water used is almost as important. Lower quality, less costly water can safely be used for many purposes, from irrigation to industrial uses. It may be water that has not been treated to the point where it is potable water, or it may be reused water, like “grey water”. Policies that encourage the use of lower quality water may require changing the way a task is performed, and of course it is essential to ensure that there are no negative effects on health or the environment. The timing of water use can also affect efficiency. Irrigating crops at night instead of during the heat of the day reduces losses from evaporation. Using water at off-peak times for other purposes reduces strain on the water delivery system. Equally important, the system needs to be able to cope with water shortages to have the ability to continue to supply the basic needs of the population during times of drought or seasonal water shortages.

2. ***Social equity***

Any strategy for the implementation of WDM must take into account the goal of social equity and inclusion. A key element is the sensitive issue of water pricing, and ensuring that poverty is not a barrier to reasonable access to clean water. Responses to the needs of the poor will vary depending on the surroundings: The needs of the poor in urban situations are quite different from those in rural areas, where both demand and supply of water as a resource are guided by different factors. The situation of poor women and children requires that policy makers find ways to provide for at least minimum supply of clean water. Women are frequently the "water managers" in the household, and difficulties in their efforts to ensure the family's water supply can become a barrier to opportunities for education and employment. Control of the water supply has traditionally been a source of power in many societies. Policy makers and practitioners need to be aware of the sensitivities of local custom, as well as traditional water rights, when attempting to implement WDM strategies. Policy makers are also advised to look through the lens of gender equity to achieve equality amongst the end users. Community participation in water management decision-making helps to ensure that the benefits of WDM are understood and are widely accepted, which greatly increases the likelihood of success.

3. *Environmental sustainability*

No other region of the world has so many people striving so hard for economic growth with so little water than the Asian region. While an average individual uses only about 10 L of water per day, it is obvious that as populations grow and lifestyles change that traditional water supply systems cannot cope with the demands of modern life. The problem is not that India is inefficient in its use of water, but rather that it has to be even more efficient if the region's development is to be sustainable. It is important to note that some water must be left in natural watercourses (whether on the surface or underground) to protect the natural environment and to permit the environment to continue to provide services such as waste purification, habitat protection and flood control.

At the same time, there is rapidly growing evidence of the effects that climate change has on water availability. The region is particularly vulnerable and can expect increased temperatures and reduced rainfall, according to the 2007 report of the Intergovernmental Panel on Climate Change (IPCC). In the past, water management has generally been based on the assumption that climatic conditions would remain more or less the same. Based on the IPCC evaluations, Governments need to be prepared to re-evaluate their policies and institutions for the management of water resources. WDM is an effective strategy for adaptation to the current challenge of water scarcity, and will become more so as climate change further reduces the availability of water and land, and brings more heat waves and frequent dust storms. Policies based on WDM strategies contribute to preparedness and social resilience in the face of the challenges that lie ahead for the Governments and people of the region.

6.1 Water Demand Management Strategy

The strategy proposed here should be considered as a draft strategy which will require the support and "buy-in" of both the water utility as well as the different funding organizations involved in the upgradation of the water supply in India. For this reason, the WDM strategy has been restricted to key focus areas which are essential to the efficient and effective management of any water supply system. Wherever possible, specific recommendations have been suggested which will help to improve the situation and must be implemented at some stage if any meaningful progress is to be achieved. The WDM strategy suggested for the Indian cities is considered to be both practical and methodical, concentrating on key essential issues. Some of the key aspects that should be considered while designing a demand-based strategy for sustainable water usage are:

District Metered Areas (DMAs)
DMAs are a pre-requisite for efficient management of any distribution system. It enables the operational staff to monitor and manage the water usage and losses for each separate zone. The international norm for the size of zone (according to the code of practice of various countries) is between 2000 and 4000 properties/households. However, at this stage, no minimum or maximum size of zone is specified for Indian cities as this will vary from city to city.

Bulk Management Meters
Proper bulk metering is essential for efficient management and water balance calculations in a water distribution system. It should be noted that the team responsible for the installation of any meters should develop its own standards in line with the current Indian legislation in this regard (https://www.Pacificwater.org).

Domestic Consumer Meters
In most Indian cities, there are no domestic consumer meters in the water supply system. All accounts sent to individual domestic consumers are therefore based on a flat rate tariff. This form of billing often results in very high wastage and/or leakage at the consumer level since there is no financial incentive to save water. Flat rate tariffs should therefore be discouraged if possible and replaced eventually by a block or step-tariff which is based on genuine metered consumption. It appears, however, that domestic metering has been implemented in several parts of India with varying degrees of success. While such metering would normally be the ideal solution to customer leakage control, it may be premature to propose full domestic metering in many Indian cities due to the expense involved with installing, servicing and reading the meters.

Pressure Management
Pressure management can be used to control customer demand and reduce leakage in water supply systems. Under certain circumstances it is the most cost-effective form of leakage control that can be implemented. However, for many small- and medium-sized cities, it is not considered appropriate at this time since only a few

receive continuous pressure (let alone high pressure), and the scope for pressure management is therefore very limited.

Mains Replacement Programme
Mains replacement is often the most expensive measure that can be undertaken to reduce leakage and is usually only undertaken as a last resort. It is therefore important that any mains replacement is properly coordinated and motivated to avoid wasting the limited funds available to improve the system. Mains replacement is normally based on the frequency of bursts occurring from a specific length of pipe, and it is, therefore, important to record the frequency of bursts for each main section of pipe in the system. It should be noted that most water supply systems are designed to last up to 50 years which in turn suggests an annual replacement of 2% of the total asset value. Very few water utilities worldwide allocate 2% per year to the maintenance with the result that many systems are gradually deteriorating.

Active and Passive Leakage Control
Passive leakage as the name suggests is a passive or reactive approach to leakage control whereby a water utility/concerned governing body will send out a leak repair team only when a leak is reported to the utility by a member of the public. Active leakage control is a pro-active approach whereby water utility personnel, armed with leak detection equipment, actively searches for unreported leaks in the water distribution system.

Planned Maintenance
It appears that relatively little planned maintenance takes place in most Indian cities and as a result many of the valves are in poor condition. All valves have a limited life, and without regular maintenance, they deteriorate quickly causing leakage and water loss. For example, in the city of Indore, at least 50% of the valves inspected were leaking to some degree (UN-Habitat Report 2006).

Payment for Water and Illegal Use
It is often not politically acceptable to simply remove illegal connections, and in most cities, the approach of legalizing such connections is preferable. It should be noted that illegal connections are often made with sub-standard fittings with the result that they leak badly and more water is often lost through the leakage than is used by the resident using the illegal connection. When legalizing such connections, it is therefore important to make a proper connection using proper fittings, in this manner, the consumer is added to the billing data base, and the leaking connection is replaced with a proper connection. Political support is required to address illegal connections, and the governing bodies must develop a proper strategy to this issue which is fully sanctioned by the Government agencies.

Capacity Building and Public Involvement
There is a general lack of capacity within the water utility with regard to WDM and water use efficiency. In addition, there is little capacity with regard to metering, maintenance, GIS and various other issues required to run a water utility efficiently. For this reason, it is necessary to provide support and training in various key areas.

It is also important that the consumers are informed on how they can save water at household level. They should be encouraged to inform the public works department or the concerned municipality whenever they see a leakage or wastage.

Pilot Projects
Before embarking on any large-scale projects to improve a water reticulation network, it is often appropriate to undertake a small-scale project or pilot project to assess whether or not the proposed procedures are viable. Pilot projects can be used to improve virtually any aspect of a water utility's business ranging from metering to leak location to tariff structures. While some recommendations are made with regard to possible pilot projects, the list is far from complete, and the water utility management should add to the list or delete items as appropriate.

Legislation
Legislation is required to support the process of WDM and encourage the use of water use efficiency in Indian cities. Such legislation can be in the form of regional laws or local bye-laws. Such legislation also requires maximum support from the municipal officers as well as all political leaders if it is to be implemented successfully. There should be both incentives for adopting water efficient practices as well as penalties for wasting. Proper legislation is therefore important to facilitate water use efficiency.

Rainwater Water Harvesting for Water Conservation
Efforts should be made in promoting and implementing the harvesting of rainwater from roof tops in order to recharge the groundwater. Although the success of the efforts made by several Indian cities is commendable, the results are difficult to quantify. The publicity accompanying these efforts has created a greater awareness for water conservation throughout the country.

Sewage Reuse
The scope for reuse of treated sewage is becoming a key issue in most large cities in India. The scope for using treated sewage for either industrial or agricultural purposes is enormous and should not be overlooked. It is recommended that a scoping exercise is undertaken to assess the possibilities for sewage treatment options and assess its benefits along with possible revenue generation from its reuse. The possibility of groundwater contamination, especially in areas where tube wells are used, should be taken into account when assessing sewage reuse. For instance, in the city of Indore, it is estimated that it costs between 7 and 15 rupees/kl to supply treated water and that the cost of treating the sewage to a level suitable for discharge into the local stream is approximately 1 rupee per kl of water (UN-Habitat Report (2006)). Clearly, the volume of sewage is likely to increase significantly, and the possibility of increasing the capacity of the sewage treatment works is a distinct possibility.

Retrofit Internal Plumbing
Retrofitting is the repair and/or replacement of various household fittings that can attribute to high water loss or usage. General retrofitting of leaking plumbing fittings is usually more successful in public buildings and schools than in private

homes. In this regard, the main focus of this task should be addressed at reducing the consumption and losses at public buildings. The potential for household retrofitting projects as a pilot project should be investigated.

Box 4: Singapore: An Exemplary Case of Urban Water Management
Singapore is a city state with an area of about 700 km^2. It currently consumes about 1.36 billion liters of water per day (Cecilia Tortajada 2007). It is a water-scarce country and thus used to import its entitlement of water from the neighboring state of Johor, Malaysia, under the long-term agreements signed in 1961 and 1962. Under these agreements, Singapore can transfer water from Johor for a price of 1 cent per 1000 gallons. The water from Johor was imported through three large pipelines across a 2-km course way that separates the two countries. In August 1965, Singapore became an independent country, and the long-term water security was an important consideration for this newly independent nation. Accordingly, Singapore made a special effort to register the Separation Agreement in the United Nations Charter Secretariat Office in June 1966. Singapore has developed a new plan for increasing water security and self-sufficiency during the post 2011-period, with increasingly more efficient water management, including formulation and implementation of new water-related policies, heavy investments in desalination and extensive reuse of wastewater, catchment management and other similar actions. Institutionally, Public Utilities Board (PUB) currently manages the entire water cycle of Singapore. Earlier, PUB was responsible for managing potable water, electricity and gas. In April 1, 2001, the responsibilities for sewerage and drainage were transferred to PUB from the Ministry of the Environment. This transfer allowed PUB to develop and implement a holistic policy, which included protection and expansion of water sources, storm water management, desalination, demand management, community-driven programs, catchment management, public education and awareness programs. The country is now fully sewered to collect all wastewater and has constructed separate drainage and sewerage systems to facilitate wastewater reuse on an extensive scale.

Overall Approach

One of the reasons as to why Singapore has been very successful in managing its water and wastewater is because of its concurrent emphasis on **demand management**, wastewater and stormwater management, institutional effectiveness and creating an enabling environment, which includes a strong political will, effective legal and regulatory frameworks and an experienced and motivated workforce. The Singapore example indicates that it is not unrealistic to expect the existence of an efficient water management institution in a country, in the midst of other similar mediocre management institutions, be they for energy, agriculture or industry. Water management institution in a country can only be as efficient as its management of other development sectors. The current implicit global assumption that water management institutions can be improved unilaterally when other development sectors remain somewhat inefficient is simply not a viable proposition.

7 Water Auditing: An Integral Element of a Demand Management Strategy

A water audit is an accounting of all of the water in a water system resulting in a quantified understanding of the integrity of the water system and its operations. It is the first step in formulating an economically sound plan to address water losses. A preliminary water audit begins with the following information and simple calculations:

1. Determine the amount of water added to the system, typically for a one-year period,
2. Determine authorized consumption (billed + unbilled) and
3. Calculate water losses (water losses = system input − authorized consumption)
   (a) Estimate apparent losses (unauthorized consumption + customer meter inaccuracies + billing errors and adjustments)
   (b) Calculate real losses (real losses = water losses − apparent losses).

These steps are an example of a top-down approach of an audit, which starts at the "top" with existing information and records. Water systems are dynamic, and the water audit process and calculation of the water balance, when routinely performed, is a useful guide for a system's water loss control program. Water systems audit can get started using the data that is readily available, identify any data gaps and then work toward improving the data. After performing an initial top-down audit, it may become evident that some of the numbers are rough estimates. The next action in the audit process is to improve any initial estimates and begin reducing non-revenue water losses.

A bottom-up audit is often implemented after several top-down audits have been completed and can better quantify loss volumes that were not revealed by the top-down audit. A bottom-up audit helps in finding apparent and real losses and begins by looking at components or discrete areas in the utility's operations. A bottom-up audit assesses and verifies the accuracy of the water loss data associated with individual components of the water system.

Additional data collection can occur during the audit or intervention phase and may include the following:

- Locating leaks and losses can be accomplished through an examination of billing records, flow monitoring, visual inspection or leak detection equipment (e.g., acoustic, thermal, electromagnetic and tracer). Through an examination of billing records, a water system may identify sudden changes in water usage at particular locations in the water system, which could indicate the need to investigate further for possible leaks or theft. Flow monitoring can be conducted by examining individual customer meter records, metered districts or through placement of temporary meters in suspect locations. These temporary meters clamp onto pipes and do not sacrifice the integrity of the pipelines.

- Condition assessment tools include traditional external visual inspections (e.g., periodic walk over and opportunistic inspections of exposed mains), internal visual inspection technologies (e.g., closed circuit television (CCTV) camera inspections), pit depth measurements, destructive testing (e.g., test coupons) and non-destructive testing (e.g., ultrasonic testing).
- Hydraulic modeling can be used to predict locations of leaks in a water system based on physical and operating data of the water system. Calibration of these models to actual field data is essential to obtain realistic and usable results.

8 Conclusion: Transitioning Toward a Circular Economy Approach

The middle-class population is expected to grow from 1.8 billion to 3.2 billion people in the world by 2020 and then to 4.9 billion people by 2030 (Veolia). This growth is aggravated by the impacts of climate change and leading to unsustainable pressures on existing resources. Our current linear “take make-dispose” economic model needs to change for a more circular one and relieve the escalating pressures on our resources—energy, materials, food and water. A circular economy creates value for local communities and municipalities, which must seize their opportunity to organize local closed loops for water, material and energy recovery. As hosts of industries, households and public infrastructure, cities have the unique opportunity to lead the effort of integrating and linking these desired closed loops. Beyond its necessary preservation, water, as a carrier of materials and energy, is critical to the circular economy actually taking shape. Knowing this, the water community has a central role to play in transitioning the world out of the linear consumption of resources toward their circular use. Success in the development of a circular economy dynamic will require individuals, organizations and companies to go beyond their traditional silo mentality and develop more partnerships and interactions. For a smooth transition from a liner to a circular economy, the focus should be on holistic ideas and approaches. Narrow sectorial approaches isn’t going to give us the intended results.

Many experts have claimed that wasteful treatment of water results from dysfunctional political or economic systems and ill-defined markets. But the real issue is that water has been pushed into a linear model in which it becomes successively more polluted as it travels through the system, rendering its use in future as nearly impossible. This practice transforms our most valuable and universal resource into a worthless trickle, creating high costs for subsequent users and society at large. Since the linear model is economically and environmentally unsustainable, we must instead view water as part of a circular economy, where it retains full value after each use and eventually returns to the system. And rather than focus solely on purification, we should attempt to prevent contamination or create a system in which water circulates in closed loops, allowing repeated use. These shifts will require radical solutions grounded in a complete mind-set change, but they must happen immediately, given the urgency of the situation.

Water is a renewable resource, but it is very unequally distributed and increasingly scarce as a result of urbanization and climate change. Based on the recommendations and best case examples, a comprehensive suite of solutions exists to respond to these challenges, ranging from integrated water resource management to wastewater reuse. Only less than 5% of all water is reused globally, but recycled wastewater is the only resource that grows with the needs. Reusing wastewater increases the productivity of the abstracted water, typically in agriculture, enabling to grow "more crops per drop". Reusing water may also mean mining waste and turning it into a new source of materials or energy as is the case with the methanization of waste and wastewater streams from the food and beverage industry, or the material recovery out of mining industry. Innovators, responsible operators and committed system developers are spearheading the creation of new technological solutions, pilot cases and initiatives to improve water management. Many of the technologies are already generating profits or will soon be. Equally important, leaders should also rethink their institutional approach to water management. Many of their solutions are only being applied at small scale, however, and this must change over the next ten years to meet the water resource challenge.

Finally, the following five ideas are recommended for a smooth transition to a circular economy model:

Product-design partnerships: Even in 2020, there is minimum dialogue between producers and wastewater operators. As the cost of treatment mounts, pressure will increase on producers to reduce contamination, especially as new technologies make it easier to identify their source.

Resource-positive utilities: Wastewater utilities are ubiquitous, visible and largely similar. They could soon become energy positive due to technical advances related to sludge methanization, waste-heat recovery, potassium hydroxide reduction or on-site distributed power generation.

Management for yield: Water is a powerful driver of yield in almost any industrial process and the extraction of raw materials. Improved site-level water management can increase beverage yields by 5% and oil-well productivity by 20%, largely benefitting the bottom line (Ellen MacArthur Foundation Report 2015). It can also convey many other advantages, such as reduced heat or nutrient loss during processing. Taken together, these advantages can turn water into a major value driver.

Basin management: Floodplain protection is a viable method for reducing the risk of flooding and preventing freshwater contamination. But attempts to improve basin management often fail because they require sophisticated multiparty contracts and a deep knowledge of hydrology and engineering.

Local organic nutrient cycles: Most communities are struggling to handle low-quality sludge and fragmented, contaminated streams of organic waste coming from households and businesses. Simultaneously, agriculture experts are exploring new sources for nutrients, since mineral fertilizer will soon be in short supply. If we aggregate local organic waste flows, we could help communities deal with their problem while also creating vibrant local markets for fertilizer components.

Each of these players represents a new way of looking at water and represents a huge business opportunity. They provide the industry with a chance to reposition itself and develop a new generation of designers, power engineers, yield managers or ecosystem-services marketers. The shift to a circular water economy holds much promise. It would replace scarcity with abundance and greatly reduce the resources needed to run our global water infrastructure.

At some point, a circular water economy might even eliminate rapidly growing cleanup costs because no harmful substances would ever be added to the water supply. Since water is the single most important shared resource across all supply chains, and wastewater is the largest untapped waste category—as big as all solid-waste categories taken together—it is the natural starting point for the circular revolution.

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Estimating Efficiency of Public Investment in Irrigation at the State Level in India

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Abstract An attempt is made to measure the relative efficiency of public investment in irrigation across major states in India from 1981–82 to 2015–16. We find a sizeable increase in public expenditure on irrigation and improvement in capital intensity in the last one decade. However, agriculture continues to receive a low priority in the public policy vis-à-vis its importance in the national economy. Also, an upturn in capital and revenue expenditure does not commensurate with an increase in the irrigation intensity, reflecting considerable inefficiencies. On an average, public canals have operated at about 59% technical efficiency in recent years, although levels vary widely from 9.6% in Andhra Pradesh to 100% each in Jammu and Kashmir, Madhya Pradesh and West Bengal. The inefficiency is largely due to capital expenditure, which needs to be utilised properly through faster completion of projects. Low efficiency scores may also suggest that public irrigation is not well placed, suggesting need for its better management and to explore potential for other sources of irrigation.

Keywords Public irrigation expenditure · Investment · Agriculture orientation index · Technical efficiency · Canal irrigated area

1 Introduction

Irrigation has played a significant role in the development of agriculture in India. It has acted as a catalyst in encouraging the use of improved seeds and fertilisers and increasing private investment in agriculture. The government has always put intensive focus on the development of networks of canals across states through

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higher investments (Easter and Liu 2005). An increased public investment in irrigation infrastructure has a '*crowding in*' effect on private (farm household) investment in irrigation, which in turn helps to accelerate agricultural productivity and reduce rural poverty (Hussain and Hanjra 2004; Bhattarai and Narayanamoorthy 2003; Gulati and Bathla 2001; Bathla et al. 2020). However, concerns have been raised about the efficacy of public investment in major and medium irrigation projects, and returns obtained thereof vary across geographical locations. Poor operation and maintenance of irrigation systems have affected water use efficiency, which is perceptible from low utilisation of irrigation potential created along with safety risks due to recurrent dam failures and hence floods and loss of lives.

Recovery of cost of investment, time overruns, non-completion of projects and escalation of cost, poor operation and maintenance, environmental externalities have become serious concerns (GoI 1992; Gulati et al. 1994; Easter and Liu 2005; Gulati and Banerjee 2017). The Central Water Commission reports 5264 large dams in operation across the country, each having more than 25 years of age. Initiative for completing the last mile projects started with the launch of Accelerated Irrigation Benefits Programme in 1996, first as a loan-based scheme transforming to a grant-based scheme in 2008. The scheme yielded good benefits in setting up canal networks upto minor canals level. From 2015–16, completion of major and medium irrigation/multipurpose irrigation projects (including management of dams to avert flood) is tried through Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)—*Har Khet KoPani*. Neglect of operation and maintenance of irrigation dams, persistent leakages, poor management practices have always been attributed to lack of sufficient funds resulting from low pricing of water (GoI 1992). A dedicated Long Term Irrigation Fund (LTIF) is therefore created under NABARD from 2016–17 with an initial corpus of Rs. 20,000 crore to bridge the fund requirements for completion of irrigation projects, including command area development works.

In this context, this chapter examines whether it is the failure of the public policy in resource allocation towards irrigation across the states or the states are inefficient in utilising the available resources. This issue is addressed by quantifying the priority of the respective state governments towards agriculture and measuring the relative efficiency of public investment in irrigation. The efficiency is measured through technical efficiency scores obtained through the Data Envelopment Analysis (DEA).

The chapter is structured as follows. Following introduction, Sect. 2 explains the database and methodological approach. Section 3 sets the stage for measurement of efficiency in public irrigation investment by delineating the temporal and spatial trends in public expenditure and capital intensity. It also underscores the priority accorded to agriculture sector in the public policy by estimating an agriculture orientation index at state level. Section 4 presents results on technical efficiency of public irrigation investments at the sub-national level. The last section provides conclusion and policy implications for the management of public canals.

2 Data Base and Methodology

The trends in public expenditure in agriculture and irrigation are analysed for the period 1981–82 to 2015–16 across 20 major Indian states. The Finance Accounts published by the Comptroller and Auditor General of India (CAG), Government of India (GoI), provide detailed account of government expenditure under the revenue and capital heads of social and economic services. The capital expenditure represents investment or gross capital formation[1] on different economic activities. The expenditure on irrigation head includes (a) minor irrigation (b) medium irrigation (c) major irrigation (d) command area development, and (e) flood control. Expenditure on agriculture and allied head includes twelve categories; major ones are crop husbandry, animal husbandry, soil conservation, research and extension, food-storage-warehousing, and fishery and forestry.

Data on gross state domestic product, net sown area, and irrigated area were compiled from the National Accounts Statistics, Ministry of Statistics and Programme Implementation, Government of India (GoI) and Ministry of Agriculture and Farmers' Welfare (MOA&FW), GoI. Public expenditure on agriculture and irrigation, compiled from the Finance Accounts, GoI, are converted into 2011–12 prices using gross state domestic product (GSDP) deflators. For maintaining consistency in expenditure data analysis, information pertaining to the newly formed states of Telangana, Chhattisgarh, Jharkhand and Uttarakhand (available from 2000–01) was merged with their respective parent states of Andhra Pradesh, Madhya Pradesh, Bihar, and Uttar Pradesh. The 20 selected states cover about 90% of the net sown area and agricultural income.

An agricultural orientation index (AOI) was developed to analyse the priority of the state governments in allocation of resources towards agriculture and irrigation. The AOI is defined as the share of agriculture and irrigation in total public expenditure divided by the share of agriculture in GSDP. According to Syed and Miyazako (2013), this index is an indicator of the degree to which the share of agriculture–irrigation in public expenditure commensurate with the weight of the sector in GDP. Efficiency of public expenditure on irrigation was analysed through Data Envelopment Analysis (DEA). DEA has been widely used in the literature for estimating technical efficiency of various economic activities (Ray 2004; Watkins et al. 2014).

The percentage area irrigated by canal in total net irrigated area is taken as an outcome variable while public expenditure on capital and revenue accounts on major–medium–minor irrigation and command area development (excluding expenditure on flood control) as two input variables. Public investment (capital expenditure) in irrigation is taken as a stock variable, estimated by taking the accumulated expenditure in 1981 and accounting for 10% depreciation each year.

[1]Capital expenditure is given in gross terms and includes the government's investment in financial stocks. Hence, it may be an over-estimation of actual investment in the respective heads/services. This is the major data limitation.

Both input-oriented and output-oriented models are estimated under the assumption of variable returns to scale. The estimates on slack inputs are computed to identify the inputs whose utilisation can be improved to enhance the overall efficiency.

3 Public Expenditure on Irrigation and Capital Intensity

This section analyses the temporal and spatial trends in public expenditure on agriculture and irrigation. On an average, 25% of total expenditure was allocated to irrigation and flood control followed by agriculture and allied activities at 19.2%. Although the amount spent on these heads has more than doubled during the 2000s, it is alarming to notice that the share of agriculture, irrigation–flood control in total expenditure has fallen substantially. It could be due to low growth in capital expenditure (investment) for irrigation schemes and agriculture and, increase in the revenue expenditure which is on day-to-day expenses and on farm subsidies.

Table 1 and Fig. 1 reveal public expenditure on agriculture, and allied activities has increased from Rs. 141 billion in triennium ending (TE) 1983–84 to Rs. 852 billion in TE 2015–16 growing at an annual rate of 4.92% at 2011–12 prices. In contrast, irrigation and flood control expenditure has stepped up from Rs. 240 billion in TE 1983–84 to Rs. 738 billion by TE 2015–16 and grew at a modest rate of 3.88% over time. It is also clear that most of the southern states, which are relatively developed, have taken a lead in allocating more outlays towards both investments and input subsidies. Taking only capital expenditure (i.e. investment) into consideration, large variations in agriculture and irrigation are visible across the states, showing a higher annual rate of growth (near 7%) in Andhra Pradesh, Gujarat, Karnataka, Maharashtra, and Tamil Nadu. The rate of growth has jumped during the 2000s in almost all to the tune of more than 10%. Three states viz. Haryana, Punjab, Rajasthan, and Uttar Pradesh continued to lag. The reasons for this are not merely in financial aspects but also lie in the situation of the states, for example, Andhra Pradesh, Karnataka, and Maharashtra settled the inter-state disputes on Krishna in 1979–80, similarly Gujarat could settle Narmada dispute and was then free to take up the stalled schemes. On the other hand, Haryana and Rajasthan suffer from supply crunch of water as the water available through Indus system is tightly allocated, and the additional allocations are under severe disputes. Uttar Pradesh has a historical advantage of establishing irrigation systems since the last century and the balance resource uses are difficult to harness in the absence of international cooperation with the neighbouring countries.

In the face of large inter-state variations in public expenditure on agriculture and allied activities and irrigation, we estimate the same on per hectare (ha) basis. Taking all states together, per ha investment in agriculture has increased from Rs. 63 in TE 1983–84 to Rs. 516 in TE 2015–16 (Table 2). Among the states, J&K, Kerala, Maharashtra, Tamil Nadu, and Uttarakhand have invested more than Rs. 1000 per ha in recent years. In case of irrigation stock (excluding expenditure on flood control), Table 3 shows that per ha investment has increased from Rs. 14,397

Table 1 Annual rate of growth in public investment during 1981–82 to 2015–16

States	Public investment (agriculture, irrigation, and flood control)			
	1981–82 to 1990–91	1991–92 to 2000–01	2001–02 to 2015–16	1981–82 to 2015–16
Andhra Pradesh and Telangana	2.08	1.30	10.49	7.74
Assam	−0.10	−1.16	15.86	1.26
Bihar and Jharkhand	−0.12	5.67	7.19	1.37
Bihar	−0.12	4.96	8.90	0.11
Gujarat	1.43	9.64	12.54	6.48
Haryana	−8.79	19.84	0.01	0.01
Himachal Pradesh	5.22	4.81	7.33	4.95
Jammu and Kashmir	−3.83	–	13.50	–
Karnataka	1.83	2.42	4.24	6.72
Kerala	−4.31	−0.45	6.19	−0.06
Madhya Pradesh	1.04	−6.73	8.91	2.74
Maharashtra	3.41	2.74	4.17	5.98
Madhya Pradesh and Chhattisgarh	1.04	−6.06	8.32	4.21
Odisha	−1.57	5.51	9.68	2.43
Punjab	–	–	–	–
Rajasthan	0.95	0.78	0.57	1.30
Tamil Nadu	−2.01	10.16	8.66	6.16
Uttar Pradesh and Uttarakhand	0.43	13.12	4.65	3.69
Uttar Pradesh	0.43	13.06	3.23	3.02
West Bengal	3.19	2.82	15.57	4.82
All states	0.40	4.51	6.98	4.80

Note '−' not estimated due to negative entries under capital expenditure
Source Based on Finance Accounts (GoI)

in TE 1983–84 to Rs. 19,299 in TE 2015–16. The southern states have much higher investments in irrigation compared to the northern states. Clearly, the developed states spent more which is obvious due to higher economic growth in these states and hence better spending power. Each state had invested in irrigation during 1980s which significantly fell down in subsequent decades and somewhat recovered during the 2000s. The lagging states where per ha investment continues to be low include Rajasthan, Assam, Bihar, Haryana, Punjab, Kerala, Madhya Pradesh, Uttar Pradesh, and West Bengal. It is obvious that investments are much higher in major–medium irrigation systems (Rs. 14,665/ha) compared to minor irrigation (Rs. 4251/ha), except in Assam and other hilly areas where possibility of large dams is remote. Further, asset formation is negligible under the command area development category of irrigation expenditure.

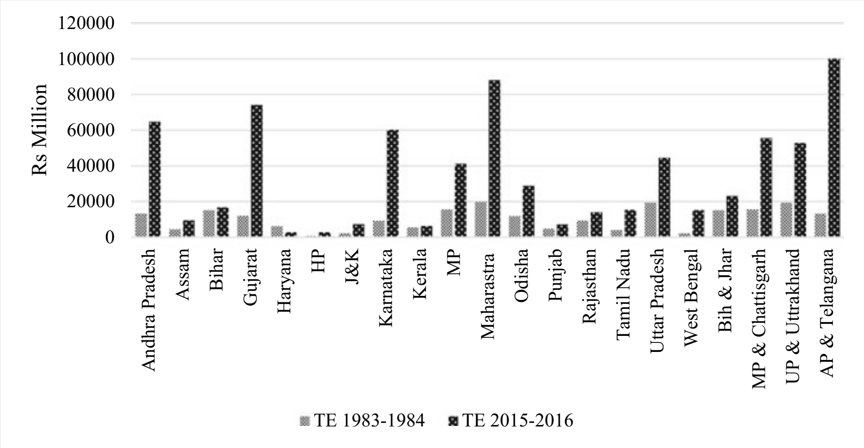

Fig. 1 Public investment in agriculture and irrigation, Rs. million, 2011–12 prices. *Source* Based on Finance Accounts (GoI)

The analysis shows that the magnitude of expenditure on agriculture and irrigation has significantly increased in every state from early 2000. A consistent increase in expenditure is identified in less developed agriculturally dependent states, which is a welcoming policy initiative by the respective governments. However, an important concern is that the capital intensity has not increased in a significant manner. Table 4 corroborates it by eliciting the share of capital expenditure in total (capital + revenue) expenditure on agriculture and irrigation heads. Taking all 20 states together, from TE 1983–84 to TE 2015–16, the percentage share of capital expenditure in total expenditure on agriculture has increased from 6.26% to 8.57% and on irrigation from 61.09 to 65.58%. On excluding flood control expenditure in total irrigation, the capital intensity continues to be almost 60% in recent period. The share of investment went down to 47% during mid 1990s and 54% in early 2000s and revived subsequently.

Capital deepening on irrigation is visible only in Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Odisha, and Tamil Nadu. A lesser share of investment indicates that government expenditure is incurred more towards day-to-day administrative expenditure including subsidies. Lower share of capital expenditure in total expenditure may also imply mounting bureaucracy and inefficiency, especially on major and medium canal irrigation systems. According to Chandrasekhar and Ghosh (2002), a consistent cut in expenditure on capital account during the 1990s and a concomitant hike in current expenditure were possibly to achieve targeted fiscal deficit, which might have affected investments in key sectors. Although one may see some recovery in spending during the last one decade, capital intensity has hardly changed in each state with a few exceptions. As such, the share of capital expenditure in development expenditure remains low at 15% which persists at the sectoral level as well.

Table 2 Public investment in agriculture and allied activities (Rs./ha) at 2011–12 prices

States	TE 1983–84	TE 1993–94	TE 2003–04	TE 2012–13	TE 2015–16
Andhra Pradesh	12.20	43.94	35.10	36.00	48.12
Assam	148.11	42.65	4.06	49.06	75.96
Bihar	70.54	17.91	11.52	135.58	651.53
Gujarat	155.76	202.04	196.96	553.81	738.85
Haryana	60.68	46.40	−824.34	2622.22	−1401.32
Himachal Pradesh	589.94	566.24	558.75	1288.16	672.73
Jammu and Kashmir	354.83	1834.40	2540.51	6953.91	6259.03
Karnataka	20.71	37.97	34.57	166.07	197.45
Kerala	302.21	526.52	321.92	1507.61	1574.29
Madhya Pradesh	56.34	52.19	38.00	150.18	83.03
Maharashtra	50.85	376.20	340.05	782.49	1317.16
Odisha	122.85	127.56	166.50	205.16	434.51
Punjab	−6.92	−323.25	−572.89	27.10	181.45
Rajasthan	23.89	43.48	33.24	136.90	213.92
Tamil Nadu	262.13	225.42	346.45	1346.03	1522.36
Uttar Pradesh	−29.03	32.95	636.42	−43.51	689.81
West Bengal	99.02	56.37	41.69	317.49	1040.12
Chhattisgarh	–	–	84.04	164.85	126.02
Jharkhand	–	–	2.53	254.64	458.65
Uttarakhand	–	–	55.86	2508.99	3744.02
Bihar and Jharkhand	70.54	17.91	8.14	160.25	607.30
MP and Chhattisgarh	56.34	52.19	39.55	153.66	93.05
UP and Uttarakhand	−29.03	33.30	584.54	59.80	812.43
AP and Telangana	12.20	43.94	35.10	36.00	70.23
All 20 states	63.33	115.05	154.00	406.36	544.91

Note '–' not estimated due to negative entries under capital expenditure
Source Based on Finance Accounts, GoI

Further, among various types of irrigation expenditures, the maximum share is occupied by medium and major irrigation systems. On an average, this head of expenditure constitutes a sizeable share (40%) in total irrigation expenditure, which may be due to AIBP providing grant-based funds and also provision of PM package for distressed areas. The state governments have allocated outlays with a completion target by June 2020. In phase—II probably starting from 2020, nearly seven hundred more dams will be added to the list for implementation across 18 states.

The analysis further shows that the government in less developed states spends more on minor irrigation having 27.68% share in total irrigation expenditure during

Table 3 Public investment in irrigation (Rs./ha) 2011–12 prices

States	Major and medium irrigation			Minor irrigation			Command area development			Irrigation		
	TE 1983–84	TE 2003–04	TE 2015–16	TE 1983–84	TE 2003–04	TE 2015–16	TE 1983–84	TE 2003–04	TE 2015–16	TE 1983–84	TE 2003–04	TE 2015–16
Andhra Pradesh and Telangana	16,254	10,633	43,878	1655	1432.49	5044.15	373.47	139.37	34.68	18,282.72	12,204.94	48,956.49
Assam	6808	1989	1324	9109	3605.55	9126.35	926.09	215.25	93.87	16,842.48	5810.74	10,544.23
Bihar-Jharkhand	21,895	5983	9258	2415	490.67	2084.3	4.56	0.12	17.75	24,314.49	6473.05	11,359.54
Bihar	21,895	7899	8054	2415	578.34	1369.83	4.56	0.18	0.03	24,314.49	8477.76	9423.85
Gujarat	11,830	11,179	27,457	459	999.05	4666.58	0.29	0.01	0	12,290.26	12,177.57	32,123.78
Haryana	16,663	8255	12,025	1595	1556.15	202.2	0	0	0	18,258	9811.42	12,227.29
Himachal Pradesh	2227	1640	6555	6523	5604.66	12,980.6	73.79	379.44	1140.27	8824.29	7624.09	20,675.96
Jammu and Kashmir	17,253	4222	5342	7141	1101.4	11,748.23	0	0	2284.35	24,394.36	5323.45	19,374.3
Karnataka	10,938	14,094	26,087	1546	1077.87	4407.77	0	0.11	167.24	12,483.76	15,171.78	30,661.76
Kerala	24,209	8619	4736	1626	958.06	1824.25	0	0	0	25,835.66	9577.75	6560.24
Madhya Pradesh	7450	3814	9299	2821	1106.67	2774.82	150.3	46.44	217.1	10,422.13	4966.97	12,290.44
Maharashtra	11,134	10,177	25,561	1423	1353.43	2711.78	4.65	0.55	0.08	12,562.06	11,530.94	28,272.33
MP-Chhattisgarh	7451	2748	8477	2821	875.95	4209.38	150.3	32.66	277.66	10,422.13	3656.6	12,964.45
Odisha	17,481	10,027	18,316	2559	1047.03	4486.87	0.21	0.07	0.01	20,041.46	11,074.07	22,802.62
Punjab	12,930.16	9219.72	4601.81	1036.78	374.32	481.98	1.41	658.28	1498.59	13,968.35	10,252.32	6582.38
Rajasthan	6207.2	3616.92	2375.63	740.86	486.75	820.42	456.84	718.05	343.75	7404.9	4821.72	3539.8
Tamil Nadu	6956.73	4741.25	7442.78	154.81	435.41	1381.48	156.19	5.98	343.63	462.52	4967.66	9136.82
UP and Uttarakhand	11,450.15	4146.01	7207.85	3407.61	348.02	1774.05	45.42	1.63	0.23	14,903.17	4495.66	8982.13
Uttar Pradesh	11,450.15	4554.82	6685.13	3407.61	373.58	1365.77	45.42	1.81	0.24	14,903.17	4930.22	8051.14

(continued)

Table 3 (continued)

States	Major and medium irrigation			Minor irrigation			Command area development			Irrigation		
	TE	TE	TE	TE	TE	TE	TE	TE	TE	TE	TE	TE
	1983–84	2003–04	2015–16	1983–84	2003–04	2015–16	1983–84	2003–04	2015–16	1983–84	2003–04	2015–16
West Bengal	3337.6	1621.8	1299.52	62.83	382.26	1528.09	68.33	70.42	104.71	3462.44	2074.27	2932.28
All 20 states	12,479.79	6657.77	14,512.55	2598.86	1220.01	3936.08	135.01	114.75	313.49	14,889.31	7982.28	18,760.63

Note Irrigation investment measured in stock; public investment in irrigation excludes flood control. Major and medium irrigation categories are clubbed as expenditure on major irrigation is given from 2010

Source Based on Finance Accounts, GoI

Table 4 Capital intensity of public expenditure in agriculture and irrigation (share of capital expenditure in total expenditure)

States	Agriculture and allied activities			Irrigation (excluding flood control)		
	TE 1983–84	TE 2003–04	TE 2015–16	TE 1983–84	TE 2003–04	TE 2015–16
Andhra Pradesh and Telangana	1.61	2.18	1.0.1	56.71	43.71	62.69
Assam	5.73	0.15	0.7	83.14	55.74	63.21
Bihar	6.8	1.48	10.93	74.94	49.17	54.62
Gujarat	24.42	13.2	17.24	52.94	43.62	88.34
Haryana	2.94	−2131.22	−78.17	52.09	35.43	36.21
Himachal Pradesh	8.61	3.79	2.78	60.02	40.98	31.04
Jammu and Kashmir	6.4	15.59	26.49	63.21	27.62	37.39
Karnataka	2.88	1.7	2.04	56.83	90.3	87.82
Kerala	11.18	5.52	8.12	73.67	49.07	35.32
Madhya Pradesh	6.46	2.98	2.16	80.13	77.16	86.41
Maharashtra	3.44	12.56	22.99	62.64	63.75	74.09
Odisha	11.57	8.72	10.43	86.34	73.12	64.83
Punjab	−9.51	472.13	3.15	57.97	41.56	25.03
Rajasthan	7.95	4.73	10.44	56.57	39.76	40.84
Tamil Nadu	12.62	7.93	10.56	38.96	36.63	40.83
Uttar Pradesh	−8.41	28.37	20.32	51.65	33.13	40.42
West Bengal	9.97	2.39	20.52	27.98	20	38.94
Chhattisgarh	–	3.16	1.07	–	72.11	78.41
Jharkhand	–	0.08	5.55	–	84.57	62.8
Uttarakhand	–	0.65	17.98	–	21.77	54.18
Bihar and Jharkhand	6.8	0.75	9.6	74.94	60.51	58.26
Madhya Pradesh and Chhattisgarh	6.46	2.96	1.62	80.13	75.69	84.33
Uttar Pradesh and Uttarakhand	−8.41	24.25	20.28	51.65	32.39	41.58
All 20 states	6.26	7.21	8.8	61.09	54.12	65.38

Note Public investment in irrigation excludes flood control
Source Based on Finance Accounts, GoI

TE 2015–16 compared to 4.81 and 16.64% in the middle and high per capita income states.[2] States spend substantially on flood control which is visible from its high proportion in total irrigation expenditure at 62.8%. This may have also cut

[2]Based on average per capita income from 2000–01 to 2013–14, the low-income states are Bihar, Uttar Pradesh, Assam, Jammu and Kashmir, and Madhya Pradesh. The medium-income states are Odisha, Rajasthan, West Bengal, Andhra Pradesh, and Karnataka. The high-income states are Punjab, Himachal Pradesh, Tamil Nadu, Kerala, Gujarat, Haryana, and Maharashtra.

down spending on irrigation. The annual rate of growth in minor irrigation is much higher at 11.95% compared to that in the major–medium irrigation systems at 5.75%. An increasing investment in minor irrigation, mainly tanks and tube wells can be explained by long gestation periods in the construction of canal network and perhaps growing inefficiency in it. It is an important step, especially knowing that the marginal efficiency of capital in minor irrigation is much higher than that in major–medium irrigation.

Large inter-state differences in public investment in agriculture and irrigation are identified. There have been historical reasons and agroclimatic factors behind putting more outlays into major and medium irrigation systems in the northern states (mainly Punjab and Haryana) compared to other parts of India (Bathla et al. 2020). Such biases have remained for a longer period in the country and appear to continue.

Which state invests more in agriculture? As shown in Table 5, Gujarat, Karnataka, Maharashtra, MP-Chhattisgarh, and AP-Telangana have occupied a relatively higher share of public investment in agriculture–irrigation between 10 and 20% in recent years. Surprisingly, Punjab hardly invests in surface irrigation.[3] The investment share is also lower in the hilly states, which is expected. The budgetary allocations towards agriculture and irrigation are largely determined by the size of government spending, availability of funds, revenue deficit, and factors from the demand side. It is crucial for the government to increase investments in Bihar, Assam, Odisha, Tamil Nadu, and West Bengal, which will also induce private investment in due course owing to a complementarity relation between the two investments.

Going by a sizeable increase in absolute expenditure in agriculture and irrigation, it is imperative to analyse the extent to which states have shown priority towards the agricultural sector over the period. This is evaluated by constructing an agriculture orientation index (AOI), based on the share of public expenditure in agriculture and irrigation sector vis-à-vis its weight in the national income. As shown in Table 6, the AOI has improved in many states with little increase at the aggregate national level. The AOI was 0.60 in TE 1983–84 declined to 0.48 in TE 2003–04 and increased to 0.61 by 2015–16. A significant increase in AOI is witnessed only from mid 2000s (TE 2012–13) in Gujarat, Himachal Pradesh, Karnataka, Kerala, Punjab, Chhattisgarh, and Uttarakhand but weakens in Haryana, Madhya Pradesh, Maharashtra, Rajasthan, Uttar Pradesh, West Bengal, and Jharkhand. The AOI has moderately increased in Assam and Bihar. A low index in most of the low-income states having high incidence of rural poverty and low land and labour productivity is worrisome. It calls for increased budgetary outlays towards agriculture and irrigation to invigorate the rate of growth of agriculture.

[3]This may also be as the Indus system has covered almost all the eligible areas by late 1970s, and the dominance of private tubewells has come up through introduction of paddy and free power against paid canal water.

Table 5 Percentage share of each state in public investments in agriculture and irrigation

States	Public investment (agriculture and irrigation)				
	TE 1983–84	TE 1993–94	TE 2003–04	TE 2012–13	TE 2015–16
Andhra Pradesh and Telangana	8.51	12.23	10.37	19.76	17.53
Assam	2.91	2.70	0.93	1.62	1.74
Gujarat	7.77	9.67	7.02	10.87	13.27
Haryana	3.99	2.46	1.32	3.39	0.39
Himachal Pradesh	0.49	0.51	0.53	0.72	0.51
Jammu and Kashmir	1.46	1.35	1.16	1.81	1.31
Karnataka	5.87	11.49	14.18	10.40	10.83
Kerala	3.55	3.17	1.47	1.19	1.11
Maharashtra	12.69	17.34	23.83	18.68	15.74
Odisha	7.59	5.86	4.25	3.63	5.03
Punjab	3.11	3.78	1.41	0.90	1.24
Rajasthan	6.00	6.88	4.69	1.97	2.53
Tamil Nadu	2.59	2.23	2.85	3.83	2.79
West Bengal	1.45	1.65	1.09	1.36	2.69
Bihar-Jharkhand	9.70	4.24	4.59	4.37	4.10
MP-Chhattisgarh	9.99	8.62	9.13	10.25	9.91
Uttar Pradesh-Uttarakhand	12.33	5.82	11.16	5.25	9.28
All 20 states	100.00	100.00	100.00	100.00	100.00

Note Public investment in irrigation includes flood control
Source Based on Finance Accounts (GoI)

4 Measuring the Efficiency of Public Irrigation Expenditure

Public investments in agriculture and irrigation have shown signs of recovery since 2003–04, though their share in total public expenditure as well as GSDPA has continued to be almost the same, indicating low priority in the annual budgets. A higher income going back to investments is indicative of an increase in the availability of irrigation water and also its access, which in turn can contribute to agriculture productivity growth. However, the outcome in terms of area irrigated by canals in each state is not promising with a few exceptions. Till date hardly 46% of net sown area (NSA) (141 million ha) is irrigated at the national level with Punjab, Haryana, Uttar Pradesh, and Bihar having more than 70% area under irrigation (Fig. 2). This indicates a low dependence of farmers on surface irrigation water, which seems plausible due to a negligible increase in the share of irrigated area by surface water bodies over time. The net irrigated area by tubewells is almost double as compared to that of area irrigated by canals. The area irrigated through tubewells has increased by 2.5% per year, whereas the same under canal irrigation has hardly

Table 6 Agricultural orientation index (AOI) of public spending on agriculture and irrigation

States	TE 1983–84	TE 1993–94	TE 2003–04	TE 2012–13	TE 2015–16
Andhra Pradesh	0.46	0.51	0.49	0.90	0.85
Assam	0.55	0.40	0.26	0.37	0.38
Bihar	0.28	0.19	0.17	0.29	0.30
Gujarat	0.76	0.80	0.76	0.69	0.90
Haryana	0.51	0.44	0.34	0.52	0.34
Himachal Pradesh	0.57	0.54	0.41	0.54	0.57
Jammu and Kashmir	0.58	0.46	0.39	0.47	0.47
Karnataka	0.65	0.65	0.84	1.01	1.49
Kerala	0.44	0.45	0.35	0.52	0.63
Madhya Pradesh	0.75	0.54	0.48	0.56	0.44
Maharashtra	1.43	1.43	1.30	1.12	1.15
Odisha	0.54	0.50	0.41	0.79	0.73
Punjab	0.40	0.28	0.17	0.22	0.43
Rajasthan	0.52	0.46	0.36	0.30	0.25
Tamil Nadu	0.59	0.73	0.67	0.50	0.64
Uttar Pradesh	0.50	0.38	0.31	0.23	0.27
West Bengal	0.43	0.33	0.19	0.18	0.18
Chhattisgarh	–	–	0.63	0.78	1.26
Jharkhand	–	–	0.53	0.40	0.41
Uttarakhand	–	–	0.58	0.86	0.95
Bihar-Jharkhand	0.28	0.19	0.25	0.32	0.33
Madhya Pradesh-Chhattisgarh	0.75	0.54	0.53	0.61	0.60
Uttar Pradesh-Uttarakhand	0.50	0.38	0.33	0.27	0.31
All 20 states	0.60	0.52	0.48	0.54	0.59

Note AOI = Share of public expenditure in agriculture and irrigation in total public expenditure/share of GSDPA/GDP. Irrigation expenditure excludes flood control
Source Based on Finance Accounts and NAS (GoI)

seen an increase of 0.6% per year. It reflects an increased pressure on groundwater for irrigational purposes. Among the states, Jammu and Kashmir, Assam, Chhattisgarh, Andhra Pradesh, Kerala, Tamil Nadu, and Gujarat have relatively more area irrigated by surface bodies than by the groundwater. A much higher dependence on groundwater in other states can largely be attributed to subsidised electricity and diesel, along with a considerable time lag and excessive cost of completion of canal networks.

The scenario also indicates that the year-on-year sizeable investments being incurred on major–medium irrigation systems as well as generation and distribution of rural energy have not resulted in a commensurate increase in irrigation intensity, which in some ways reflective of inefficiency in public investments. As shown in

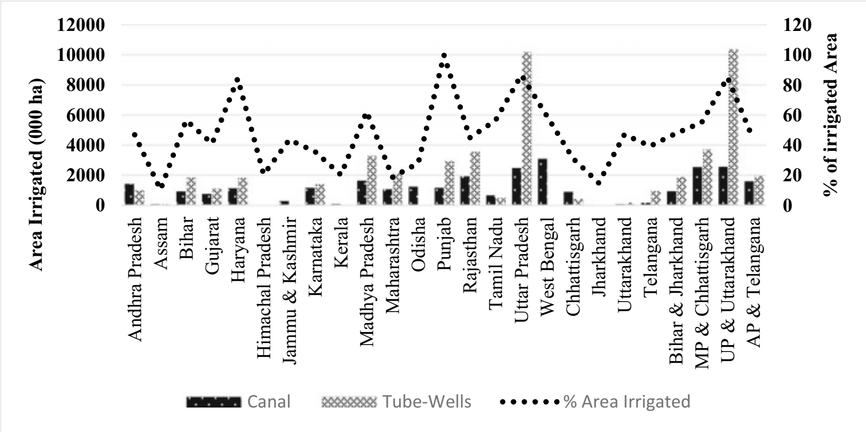

Fig. 2 State-wise net irrigated area by sources and % share in NSA (2014–15). *Note* Data on area under canal irrigation are not available for Odisha and West Bengal. Also, area irrigated by other sources in these states is for 2013–14

Table 7, the percentage share of net area irrigated by canals in total has consistently decreased from 36.6 to 25.9% during 1981–82 to 2015–16 with only exception of Andhra Pradesh, Bihar, Odisha, and Assam where signs of recovery were visible from early 2000. In a few states viz. Gujarat, Himachal Pradesh, Madhya Pradesh, Karnataka, Maharashtra, Punjab, Rajasthan, and West Bengal, the status continues to be unaltered since 2000. A very low (below 25%) and unchanged share of CIA in NSA in most of the states validates that public irrigation investments have not effectively translated into physical outcomes.

We quantify the technical efficiency (TE) of public irrigation expenditure to evaluate the extent of inefficiency in investment (capital expenditure) as well as in day-to-day expenses (revenue expenditure), either because of subsidies on irrigation, cost escalation, and delays.The efficiency of public expenditure is defined when the government, using its given resources, produces a maximum possible benefit for the population—i.e. produces more output while spending less on inputs, otherwise termed inefficient, i.e. produces fewer output and use of more inputs (Mohanty and Bhanumurthy 2018). A case of overcapitalization and/or underutilization in canal irrigation can help in drawing implications for good governance and institutional reforms.

TE is estimated at four different points of time using four years averages of variables from 1982–83 to 1985–86; 1992–93 to 1995–96; 2002–03 to 2005–05, and 2012–13 to 2015–16. To reiterate, the percentage area irrigated by canal in total net irrigated area is taken as an outcome variable while public expenditure on capital and revenue accounts on major–medium–minor irrigation and command area development (excluding expenditure on flood control) as two input variables. Public investment (capital expenditure) in irrigation is taken as a stock variable. Both input-oriented and output-oriented models are estimated under the assumption

Table 7 % Share of canal irrigated area (CIA) in net irrigated area (NIA) and net sown area (NSA) (four year's average)

States	% Share of CIAin NIA				% Share of CIA/NSA			
	1982–86	1992–96	2002–06	2012–16	1982–86	1992–96	2002–06	2012–16
Andhra Pradesh and Telangana	49.56	40.85	33.81	30.91	16.52	15.62	12.87	13.57
Assam	63.33	63.29	23.57	25.83	13.44	13.13	1.20	2.81
Bihar	37.53	28.68	27.05	31.23	12.53	13.80	15.53	17.59
Gujarat	19.55	20.38	18.28	18.21	4.36	5.90	6.26	7.48
Haryana	54.13	51.23	47.23	41.12	33.24	38.70	39.67	35.19
Himachal Pradesh	5.03	4.98	3.43	3.58	0.82	0.88	0.69	0.73
Jammu and Kashmir	93.93	93.16	92.13	87.78	40.47	41.76	38.18	38.30
Karnataka	41.94	40.61	32.97	33.75	6.49	8.76	8.62	11.98
Kerala	37.59	31.88	26.91	20.83	4.66	4.82	4.84	4.10
Madhya Pradesh	43.23	32.51	17.07	17.07	6.42	8.99	6.27	10.22
Maharashtra	31.64	19.74	33.89	33.29	3.35	2.84	5.90	6.23
Odisha	59.73	45.38	63.30	66.00	15.72	15.07	18.22	18.54
Punjab	39.76	37.16	26.93	27.71	34.23	34.66	26.03	27.62
Rajasthan	33.27	29.95	24.73	24.70	6.80	8.58	8.84	10.68
Tamil Nadu	32.96	29.77	25.87	23.75	14.60	14.36	13.25	13.58
Uttar Pradesh	33.33	27.38	20.53	17.90	19.34	18.28	16.11	15.24
West Bengal	36.94	37.52	21.98	21.72	13.19	13.11	12.49	12.86
Chhattisgarh	–	–	69.54	60.60	–	–	16.83	18.90
Jharkhand	–	–	14.88	3.04	–	–	1.51	0.46
Uttarakhand	–	–	27.39	24.67	–	–	12.33	11.66
Bihar-Jharkhand	37.53	28.68	26.54	29.37	12.53	13.80	12.60	14.03
Madhya Pradesh-Chhattisgarh	43.23	32.51	26.26	23.04	6.42	8.99	8.84	12.24
Uttar Pradesh-Uttarakhand	33.33	27.38	20.70	18.05	19.34	18.28	15.95	15.10
All 20 states	36.60	33.11	27.88	25.94	10.73	12.11	11.59	12.56

Table 8 Technical efficiency in public Investment in irrigation (input-oriented index)

States	1982–83 to 1985–86	1992–93 to 1995–96	2002–03 to 2005–06	2012–13 to 2015–16
Andhra Pradesh	0.47	0.317	0.162	0.096
Assam	1.00	1.00	0.783	0.454
Gujarat	0.393	0.329	0.159	0.477
Haryana	0.512	0.43	0.21	0.273
Himachal Pradesh	0.629	0.48	0.258	0.16
J&K	1.00	1.000	1.00	1.00
Karnataka	0.518	0.48	0.917	0.781
Kerala	0.354	0.397	0.362	0.443
Maharashtra	0.508	0.358	0.256	0.405
Odisha	0.962	0.605	1.00	0.724
Punjab	0.486	0.435	0.328	0.426
Rajasthan	0.797	0.761	0.365	0.948
Tamil Nadu	1.00	1.00	0.324	0.548
West Bengal	0.932	1.00	0.713	1.00
Bihar	0.404	0.401	0.408	0.571
Madhya Pradesh	1.00	1.00	1.00	1.00
Uttar Pradesh	0.352	0.308	0.35	0.398
Chhattisgarh	–	–	1.00	1.00
Jharkhand	–	–	1.00	0.618
Uttarakhand	–	–	1.00	0.534
Average	0.666	0.606	0.580	0.593

of variable returns to scale. Under input-oriented index, it is assumed that inputs (expenditures) are reduced keeping the output (% share of canal irrigated area) constant. In contrast, output-oriented index presumes that output (% share of canal irrigated area) increases while keeping the inputs (expenditure) constant. The estimates on slack are also computed which enable to examine the inefficiency in the outcome variable due to the inputs used, i.e. capital and revenue expenditures on irrigation.

Tables 8 and 9 present results obtained from both models along with the rate of change in TE in each state. Figure 3a, b depicts TE scores based on input-oriented model from 1982–83 to 2015–16 and then for the first and the last period under study. This is followed by results based on the output-oriented model in Fig. 4a, b.

The input-oriented model indicates that on an average for 20 major states, canals operate at about 59% efficiency, although levels vary widely, from 10 and 16% in Andhra Pradesh and Himachal Pradesh to 100% each in J&K, Madhya Pradesh, and West Bengal. The latter two states along with Rajasthan, Odisha, and Karnataka found to be more efficient in spending on canal irrigation compared to Andhra

Pradesh, Himachal Pradesh, Uttar Pradesh, Kerala, Maharashtra, and Assam. The results also indicate that several states are at the low end of efficiency scale (below national average) such as Haryana, Himachal Pradesh, Punjab, Kerala, Maharashtra, and Uttar Pradesh. It implies that the potential for easier gains through technical efficiency tends to be higher in these states. At the other end of the scale, the above-mentioned states have operated at relatively higher levels of efficiency, suggesting little scope for improvement.

The sub-period analysis shows that an increase in efficiency is achieved mainly in Kerala, Gujarat, Bihar, Karnataka, Odisha, Rajasthan, Madhya Pradesh, and West Bengal. The deterioration in efficiency is visible in Assam, Himachal Pradesh, Uttar Pradesh–Uttarakhand, and Andhra Pradesh–Telangana. This implies lack of efficiency gains due to inappropriate use of technology or combination of inputs or higher expenditure than required. The result for Andhra Pradesh–Telangana combined should be taken cautiously. Since the inception of the state Telangana, considerable initiatives have been taken to make irrigation water available to farmers under the Pradhaan Mantri Krishi Sinchai Yozna. Perhaps a disaggregated analysis of the two states can show higher level of efficiency in Telangana.

The result from output-oriented model (output, i.e. % share of canal irrigated area increases while keeping the inputs, i.e. capital and revenue expenditures constant) is fairly similar to the first approach. The all India average TE score is slightly lower at 0.52 compared to the input model at 0.59. While the ranking of states in terms of scores remains unchanged, the values of indexes in some of the states are slightly different compared to the values obtained in the first model. There is enough potential to improve efficiency through expenditure in most of the states (average 52% from the efficiency frontier) with a few exceptions. A sub-period analysis of TE performance again provides mixed results. J&K, Madhya Pradesh and West Bengal are among the top in experiencing technical efficiency throughout. The turnaround is found in Assam and Uttarakhand with a significant deterioration in efficiency change. Gujarat, Maharashtra, Rajasthan, and Bihar registered a spectacular performance over the years. These results have implications for good governance and the fact that public policy should focus more on outcomes rather than on outlays.

Finally, results on slacks from output-oriented model are given in Table 10. The slack inputs are indicative of the excess inputs. It is calculated as the difference between actual input consumed minus the target input a state/institution should have consumed. An efficient unit will have zero input–output slacks. The results show that the inefficiency is more due to capital expenditure which has also increased over the period. On an average, a state utilises the capital and revenue expenditures efficiently, but the capital is being used in excess in some of the states. Based on recent years analysis, if a state aspires to be efficient, it should reduce about Rs. 5905 per ha of capital expenditure and Rs. 499 per ha of revenue expenditure. Among the states, Gujarat, Karnataka, Maharashtra, Andhra Pradesh, Himachal Pradesh, Tamil Nadu, Bihar, and Uttar Pradesh can easily reduce expenditure by avoiding delays in the completion of projects and maintaining day-to-day expenses.

Table 9 Technical efficiency in public investment in irrigation (output-oriented index)

States	1982–83 to 1985–86	1992–93 to 1995–96	2002–03 to 2005–06	2012–13 to 2015–16
Andhra Pradesh	0.644	0.513	0.359	0.318
Assam	1.000	1.000	0.575	0.368
Gujarat	0.316	0.266	0.130	0.289
Haryana	0.692	0.582	0.543	0.566
Himachal Pradesh	0.039	0.143	0.035	0.045
J&K	1.000	1.000	1.000	1.000
Karnataka	0.681	0.600	0.826	0.611
Kerala	0.531	0.437	0.332	0.314
Maharashtra	0.364	0.247	0.373	0.502
Odisha	0.995	0.676	1.000	0.940
Punjab	0.644	0.498	0.377	0.418
Rajasthan	0.691	0.673	0.283	0.409
Tamil Nadu	1.000	1.000	0.332	0.338
West Bengal	0.947	1.000	0.322	1.000
Bihar	0.532	0.384	0.365	0.480
Madhya Pradesh	1.000	1.000	1.000	1.000
Uttar Pradesh	0.489	0.410	0.251	0.268
Chhattisgarh	–	–	1.000	1.000
Jharkhand	–	–	1.000	0.048
Uttarakhand	–	–	1.000	0.411
Average	0.680	0.614	0.555	0.516

5 Key Findings and Implications

In India, agriculture and irrigation are state subjects. There are historical and political reasons behind a faster development of irrigation and adoption of high yielding variety technology in north and north west states. These together with biases in the sectoral policies may explain persisting inter-state disparities in public expenditure on agriculture and irrigation to date. The northern states have reaped the benefits of massive investments in canal networks and agricultural growth, compared to the eastern and rain-fed states which remained neglected for long. Concerted efforts to scale up investments in these agriculturally low per capita income along with dedicated expenditure towards completion of existing irrigation projects are welcoming steps to accelerate agricultural growth and productivity.

This chapter examined whether it is the failure of the public policy on resource allocation on irrigation across the states or the states are inefficient in utilising the available resources. This issue is addressed by quantifying the priority of respective state governments towards agriculture and measuring the relative efficiency of

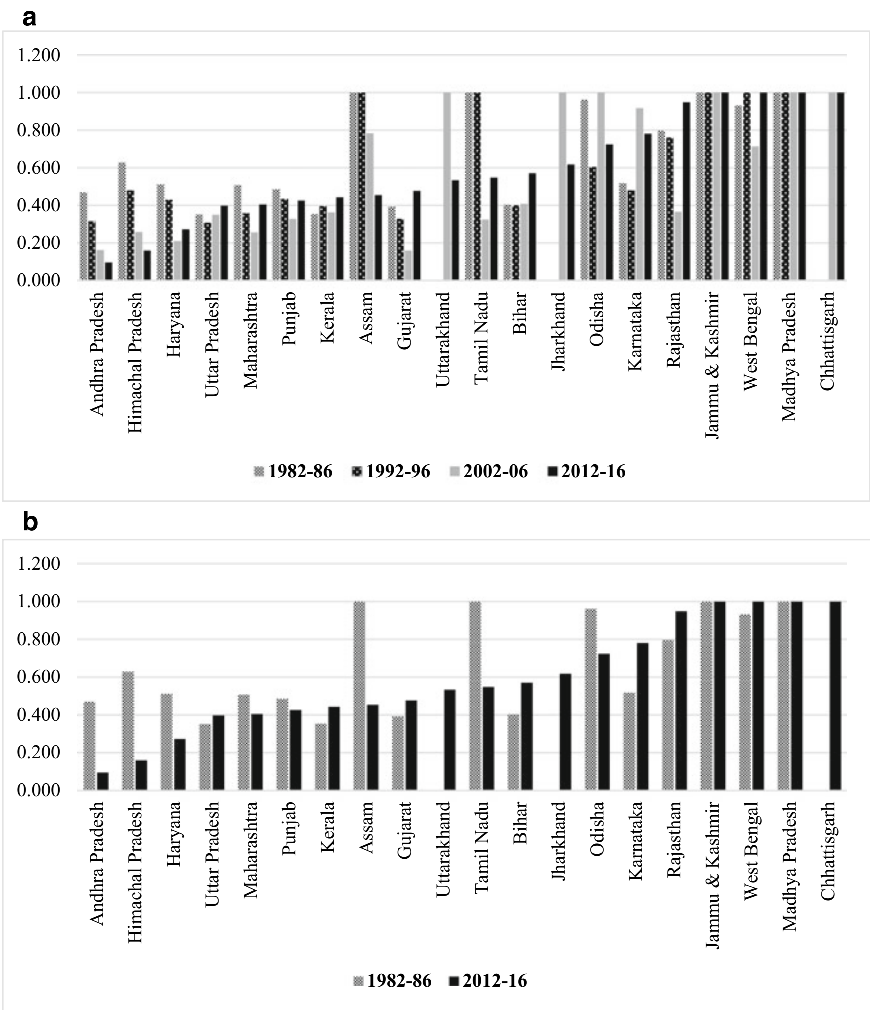

Fig. 3 **a** Technical efficiency in public expenditure in irrigation (input-oriented index) (TE 1982–2016). **b** Technical efficiency in public expenditure in irrigation (input-oriented index) (TE 1982–1986 and 2015–16)

public spending on irrigation. The efficiency is measured through technical efficiency scores based on the Data Envelope Analysis approach. The analysis is carried out at 2011–12 prices across 20 major Indian states from 1981–81 to 2015–16 and in different time periods to appraise the improvements therein.

We find a considerable increase in public expenditure on agriculture and minor, medium, and major irrigation during 2000s compared to the preceding decades. The per hectare public irrigation capital stock significantly increased from Rs. 1688 in TE 1983–84 to Rs. 18239 in TE 2015–16. High per capita income states spent more

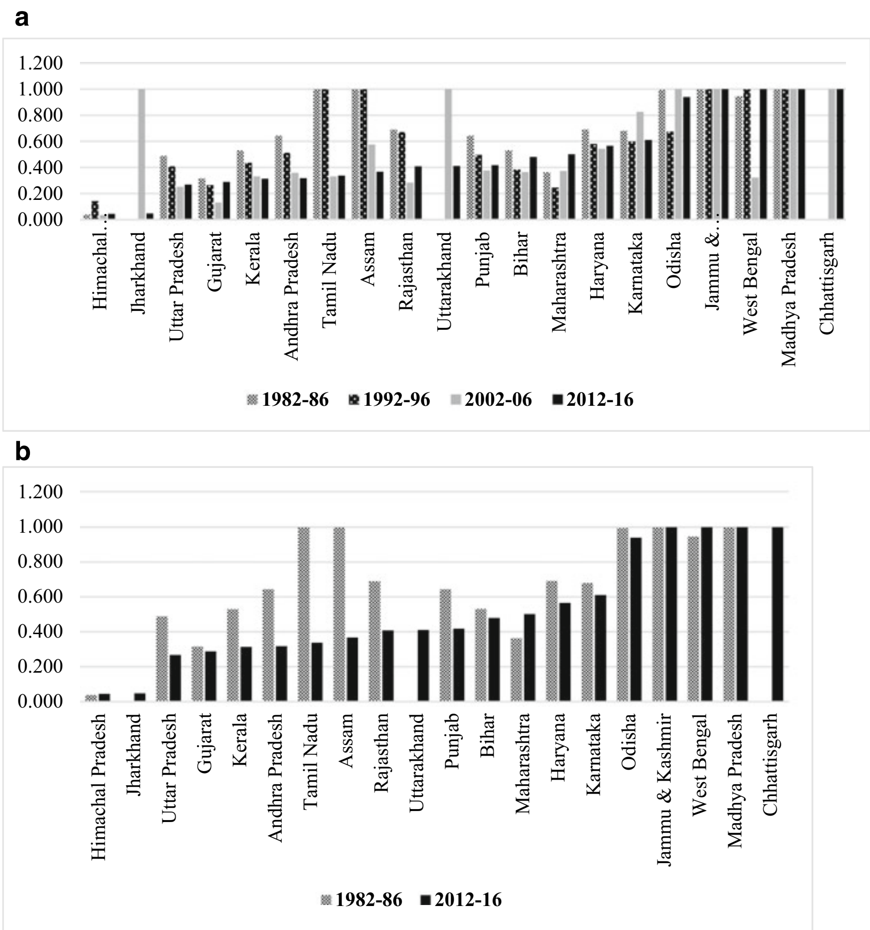

Fig. 4 **a** Technical efficiency in public expenditure in irrigation (output-oriented index) (TE 1982–2016). **b** Technical efficiency in public expenditure in irrigation (output-oriented index) (TE 1982–86 and 2012–16). *Source* Based on data given in Finance Accounts (GoI)

which is obvious due to their higher economic growth and hence better spending power. Nevertheless, each state has accorded a low priority to agriculture and irrigation in their public expenditure policy. Not only the share of public expenditure in this sector in total expenditure has declined from 13 to 5.4%, its share with respect to national income has also remained constant. The Agriculture Orientation Index of public spending verifies it—0.58 in TE 1983–84, declined to 0.49 in TE 2003–04 and then back to the same level by 2015–16. The AOI showed a slight upturn from mid-2000s in Andhra Pradesh, Bihar, Chhattisgarh, J&K, Karnataka, Kerala, Odisha, and Uttarakhand but weakens in Gujarat, Jharkhand, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh, and West

Table 10 Input slacks of capital stock and revenue expenditure per ha (output-oriented model)

States	1982–83 to 1985–86		1992–93 to 1995–96		2002–03 to 2005–06		2012–13 to 2015–16	
	Capital stock	Revenue expenditure	Capital stock	Revenue expenditure	Capital stock	Revenue expenditure	Capital stock	Revenue expenditure
Andhra Pradesh	0	0	449	0	7664	37	29,303	3124
Assam	0	0	0	0	0	0	983	0
Gujarat	0	78	0	0	7016	287	22,840	0
Haryana	0	247	0	43	3604	0	0	122
Himachal Pradesh	0	0	0	0	0	0	2138	513
J&K	0	0	0	0	0	0	0	0
Karnataka	0	0	0	0	8124	0	23,388	0
Kerala	6072	0	2281	0	0	0	0	549
Maharashtra	0	0	0	0	2345	0	22,649	0
Odisha	1917	0	1893	0	0	0	10,414	0
Punjab	0	0	0	0	1078	0	0	666
Rajasthan	0	0	0	0	0	0	0	45
Tamil Nadu	0	0	0	0	0	0	3103	0
West Bengal	0	0	0	0	0	0	0	0
Bihar	3064	0	2366	0	0	0	3284	0
Madhya Pradesh	0	0	0	0	0	0	0	0
Uttar Pradesh	0	76	0	154	0	0	0	968

(continued)

Table 10 (continued)

States	1982–83 to 1985–86		1992–93 to 1995–96		2002–03 to 2005–06		2012–13 to 2015–16	
	Capital stock	Revenue expenditure	Capital stock	Revenue expenditure	Capital stock	Revenue expenditure	Capital stock	Revenue expenditure
Chhattisgarh					0	0	0	0
Jharkhand					0	0	0	981
Uttarakhand					0	0	0	3020
Average	650	24	411	12	1492	16	5905	499

Source Based on Finance Accounts (GoI)

Bengal. A low AOI in the poorer states indicates that an increased public investment in agriculture and irrigation is necessary to accelerate production. Concomitantly, growing investments are not commensurate with the outcomes, seen through less than 50% of net area irrigated, stagnancy in area irrigated by public canals and large gaps in irrigation potential created and utilised. The empirical results confirm large inefficiency in public irrigation expenditure across the board. The canals operate at about 59% efficiency, although levels vary widely, from 9.6% in Andhra Pradesh to 100% each in J&K, West Bengal, and Madhya Pradesh. There is ample scope to improve efficiency in the public irrigation system though a few states viz. Rajasthan and Odisha have demonstrated improvements since 2000. Our results on slack indicate that the inefficiency is more due to capital expenditure (i.e. investment) which should reduce by about Rs. 5905 per ha through timely completion of projects. The inefficiency is much lower on account of revenue expenditure at Rs. 499 per ha, suggesting a check on day-to-day expenses. Low (technical) efficiency scores suggest that public irrigation is not well placed, suggesting to explore potential for other sources of irrigation.

These results have implications for good governance and the fact that public policy should focus more on outcomes rather than on outlays. Several studies confirm that better irrigation governance can significantly improve the performance of public irrigation system and hence agriculture productivity (Lio and Liu 2008; Kannan et al. 2019). Appropriate measures have to be taken to complete the irrigation projects, divert resources towards minor and micro irrigation and bring institutions for proper and timely delivery and distribution of water. Among many reasons for poor performance of canal irrigation system, lack of funds for proper maintenance has been considered as an important problem. It has supposedly been arisen due to low user charges and poor collection mechanism resulting in low recovery rate. Between TE 1985–86 and TE 2015–16, the operational expenditure on major and medium irrigation schemes has increased by two and half times. Receipt from these has also increased during this period. Although the increase in receipts in absolute value is less than the operational expenditure, the rate of increase in receipts is found to be much higher. Consequently, the recovery rate, though low, has improved from 15.11% in 1985–86 to 21.63% in 2015–16 which should be further improvised.

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Tackling Water Quality Issues

Indira Khurana and Romit Sen

Abstract For India, the challenges are twofold: One is to address the growing water shortage, and the other is to address quality issues. Ample evidence points toward increasing deterioration of water quality. Both surface and groundwater sources are contaminated through point and nonpoint pollution sources, and biological and chemical pollutants. Consuming contaminated water has health implications which can be inter-generational. Improving water quality is going to need a basket of options ranging from policy-level interventions and its implementation, real-time data that informs decision making, preventive and mitigative technologies, enforcement and public awareness, participation and oversight.

Keywords Water quality · Water pollution · Surface water · Groundwater · Health · Community

1 Introduction

Water pollution is the contamination of water bodies (lakes, rivers, oceans, aquifers and groundwater) and occurs when pollutants are directly or indirectly discharged into water bodies without adequate treatment to remove harmful compounds. Scientifically, it is defined as an alteration in the physical, chemical and biological parameters of water, which may cause harmful effects on living organisms.

Sources of surface water pollution are generally grouped into two categories based on their origin: point sources and nonpoint sources. Point sources of water pollution refer to contaminants that enter a water body from a single, identifiable source, such as a pipe. Examples of sources in this category include discharges from

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a sewage treatment plant, a factory or a city storm drain. Nonpoint source pollution refers to diffuse contamination that does not originate from a single discrete source. It is often the cumulative effect of small amounts of contaminants gathered from a large area. A common example is the leaching out of nitrogen compounds from agricultural lands.

Contaminated storm water washed off of parking lots, roads and highways, called urban runoff, is sometimes included under the category of nonpoint pollution. However, when this runoff is channeled into storm drain systems and discharged through pipes to local surface waters, it can be considered as a point source.

Pollutants causing water pollution can also be broadly classified as pollution due to poverty—lack of sanitation infrastructure, for example—and pollution due to prosperity, as countries industrialize and empty the waste into water resources, both surface and ground.

Interactions between groundwater and surface water are complex. Consequently, groundwater pollution, sometimes referred to as groundwater contamination, is not as easily classified as surface water pollution. By its very nature, groundwater aquifers are susceptible to contamination from sources that may not directly affect surface water bodies, and the distinction of point versus nonpoint source may be irrelevant. A spill or ongoing releases of chemical contaminants into soil (located away from a surface water body) may not create point source or nonpoint source pollution, but can contaminate the aquifer below, defined as a toxin plume. The movement of the plume, called a plume front, may be analyzed through a hydrological transport model or groundwater model. Analysis of groundwater contamination may focus on the soil characteristics and site geology, hydrogeology, hydrology and the nature of the contaminants.

2 Global Water Quality Crisis

In 2019, the World Bank released a worrisome report: *Quality Unknown: The Invisible Water Crisis.*[1]

The book informed that:

- Water quality is a problem that is growing in complexity as prosperity expands and new contaminants emerge.
- The increasing range of pollutants varies by sector, geography and development level.
- There are still deep uncertainties about safe levels and the size and type of impacts on humans and ecosystems.
- Not only is there no silver bullet solution to solve the water quality problem, but even coming up with a typology of appropriate responses is challenging.

[1]Quality Unknown: The Invisible Water Crisis, Damania, Richard, Sébastien Desbureaux, Aude-Sophie Rodella, Jason Russ, and Esha Zaveri, Washington, DC.

- There are three approaches available to policy makers: a passive approach of inaction, a proactive approach of prevention and a reactive approach that treats contaminants.

Policy inaction is common in low-income countries or where there is uncertainty about the effects of pollutants. Responses to perceived hazards are then left to individuals, who may, for instance, relocate to a safer area or circumvent the effects through private avoidance actions. Where regulatory capacities are higher, policy makers can be proactive and seek to prevent or reduce pollution at the source. Alternatively, they may be reactive and attempt to treat the toxic discharges, typically through investments in various types of water treatment facilities.

3 India's Water Pollution Story

With 70% of its surface water resources and a growing percentage of its groundwater reserves contaminated by biological, toxic, organic and inorganic pollutants, water pollution is a serious problem in India. As a result of the pollution, many water sources have been rendered unsafe for human consumption and even for irrigation and industrial needs.[2]

The causes of water pollution in the country are either natural like inland and coastal salinity; geogenic contamination due to the presence of arsenic, fluoride, iron and nitrates; and anthropogenic, such as disposal of untreated industrial and domestic effluents or runoff from agricultural fields.

3.1 Agricultural Pollution

Excessive use of fertilizers and pesticides in agricultural activities to enhance productivity due to rapid population increase and development of technology threatens the groundwater and surface water on a large scale. Agriculture is the largest user of freshwater in India. Except for water lost through evapotranspiration, agricultural water is recycled back to surface water and/or groundwater. Unfortunately, agriculture is the cause and victim of water pollution. It is a cause through its discharge of pollutants to surface and/or groundwater, and through salinization and water logging of irrigated land. It is a victim through use of wastewater and polluted surface and groundwater, for example, the use of raw sewage and industrial effluent water.

[2]Murty and Kumar (2011).

3.2 Sewage Pollution

Discharge of untreated sewage in water bodies is one of the major sources of water pollution. The urban population in India jumped from 25.8 million in 1901 to about 387 million (estimated) in 2011.[3] This has thrown up two major problems—shortage of water and generation of sewage. In view of the population increase, demand of freshwater for all uses will increase and so will the amount of sewage.

An estimated 62,000 million liters per day (MLD) sewage is generated in urban areas, while the treatment capacity across India is only 23,277 MLD or 37% of sewage generated.[4] Thus, there exists a large gap between generation and treatment of wastewater in India. The Central Pollution Control Board (CPCB) carried out an inventorization of sewage treatment plants (STPs) located in India in the year 2014–15 and found that out of 816 STPs, 522 are operational, 79 are non-operational, 145 are under construction and 70 are proposed for construction.[5]

Projected wastewater from India's towns and cities may cross 120,000 MLD by 2051, while rural India will also generate not less than 50,000 MLD.[6] Where will all this sewage go? Unless sustainable technologies and systems to treat this sewage are found, effects on water quality and health of the people will be disastrous. Wastewater management plans will need to address this increasing pace of wastewater generation.

3.3 Centralized Versus Decentralized Wastewater Treatment

Wastewater treatment systems can be centralized where large volumes of water are treated in sewage treatment plants involving a network of pipes, major excavations and big manholes. On the other hand, there can be onsite decentralized treatment systems where wastewater from a single household or a colony is treated with small excavations and reusing the effluent.[7]

Centralized sewage treatment plants come with their own set of costs and challenges. These are cost intensive and involve transport of waste to centralized systems for treatment. This involves the creation of infrastructure and the use of energy for pumping over long distances.

Often this is because of the operation and maintenance cost and high energy cost. Even if plan funds are available for setting up the large STPs, there is dearth of funds for its high maintenance and energy cost. This may be a major reason why even the existing treatment capacity is not effectively utilized, and operation and

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[3]Census of India, 2011, Ministry of Home Affairs, Government of India.

[4]Handbook of Urban Statistics, 2016, Ministry of Urban Development, Government of India.

[5]Inventorization of Sewage Treatment Plants, 2015, Central Pollution Control Board.

[6]Kamyotra and Bhardwaj (2011).

[7]Guidelines for Decentralized Wastewater Treatment; (2012); Ministry of Urban Development, Government of India.

maintenance of existing plants and sewage pumping stations is not satisfactory. Moreover, nearly 39% plants are not conforming to the general standards prescribed under the Environmental (Protection) Rules for discharge into streams as per the CPCB's survey.[8] Thus, across towns and cities, the existing treatment capacity remains underutilized, resulting in the discharge of untreated sewage.

Decentralized treatment systems correspond to systems which ensure collection, treatment and reuse or disposal of the waste generated from a/few confined areas. Rather than setting up one 500 MLD plant, for example, it is more economical and efficient to set up 10–20 small, decentralized plants. This will require lesser capital cost for setting up of equivalent capacity small, decentralized wastewater treatment plants, with lower maintenance cost and energy requirements, and make it a preferred choice which also makes available treated water for reuse, resulting in reduced water requirements.

Decentralized wastewater treatment systems generally have 2 units, one primary treatment and the other secondary treatment. Primary wastewater treatment refers to the water treatment involving settlement where heavy solids converted to flocs get settled at the bottom of the tank and other particles like grease and oil can float to the surface. The settled and floating materials are removed to get partially treated water. Secondary treatment is done to get a better-quality effluent by removing dissolved and suspended solids.[9]

The conventional approach to wastewater treatment in India has been focused on centralized sewage treatment plant (STP) models, resulting in operation and maintenance problems and underutilization, plus lesser reuse of treated water and pumping back over a longer distance of treated water. However, looking at challenge of operation and maintenance, cost and efficiency, high energy use and great risk of damages in case of an accident, there is merit in exploring the use of decentralized systems and having the advantage of reuse of treated water in the areas where the wastewater was collected.

The benefits of decentralized systems include almost no use of power, low maintenance and minimal expenses setting up a network of pipelines. Given that these are locally managed systems, users should be able to bear the O&M costs of plants, such as cost recovery by selling the treated water.[10]

3.4 Industrial Pollution

Following are some of the examples of industrial pollution in India: In Kochi, the Kadambrayar acts as the main source of water for several industrial units, InfoPark,

[8]See Footnote 5.

[9]Arora et al. (2016).

[10]Starkl Markus; Centralized Versus Decentralized Systems: Which is Which For You?: University of Natural Resources and Life Sciences, Vienna.

Smart City and Cochin Special Economic Zone. Used as a source for dumping waste without proper cleaning drives, the river is fast getting polluted. The growth of water hyacinths and other weeds is affecting water flow. Environment activist Purushan Eloor worries that unless the river is taken care of, it will dry forcing the industries to shut down and the residents to leave, turning Kakkanad into a ghost town.

The Brahmapuram waste treatment plant is also a threat to the water body as it is not fully functional yet and waste is being dumped straight into the river. A massive cleaning drive, under the instruction of then district collector K. Mohammed and Y. Safirulla, was held from May to November 2017 using the CSR funds of the companies working in the vicinity.

Increasing salinity due to increasing salinity ingress is another issue of the Kadambrayar River. KINFRA had to stop pumping of this river's water to the InfoPark because of this. Following complaints, the Pollution Control Board plans to conduct pollution tests on the river.[11]

In Tirupur, people are paying the price of the cloth industry. The success story of Tirupur as a successful textile town in Tamil Nadu began in the 1980s, when over time, it became a successful cotton knitwear and hosiery export hub. While the city contributed to global export earnings and generated jobs, the environmental degradation costs have been high. The city's dyeing and bleaching units have turned the Noyyal River into a toxic sewer and destroyed vast areas of agricultural land the river once sustained.

Residents and farmers claim that in utter violation of the Madras High Court orders, the unit owners discharge toxic effluents directly into the river clandestinely. Even though effluent treatment plants have been set up, the problems are far from over. Farmers claim that fertile land located within 2 km along the river on either side has been rendered useless, disrupting livelihoods and families. Groundwater is affected too.[12]

Industrial production is another significant cause of pollution. The discharge of industrial effluents and hazardous waste has severely polluted freshwater sources. It has led to severe degradation of the quality of surface water and groundwater sources. The impacts of industrial pollution on human health and environment have not been studied as extensively as domestic sewage-based irrigation practices. The effluents discharged from the industrial units have percolated into the underground aquifers. Large concentrations of heavy metals, biochemical oxygen demand (BOD) and chemical oxygen demand (COD), have been reported in groundwater in places situated around the industrial estates. The discharge of effluents from the industries has severely polluted rivers, lakes and surface water reservoirs. The people living around the industrial estates are facing acute shortage of drinking water due to degradation of quality of surface water and groundwater. Many people

[11] https://www.newindianexpress.com/cities/kochi/2020/feb/11/waste-dumping-salinity-leave-kadambrayar-high-and-dry-2101688.html. Last accessed on April 13, 2020.

[12] https://thewire.in/environment/australian-open-tiruppur-dyeing-bleaching-groundwater-contamination-agriculture-noyyal-river. Last accessed on February 12, 2020.

living in these polluted sites have been found to use contaminated water for drinking purposes in the absence of any other viable drinking water source and are facing severe health impacts.

Industries consume large quantities of freshwater resources and pollute it to a large extent. The overall annual consumption of water and discharge of wastewater in the industrial sector is 40.01 billion cubic meters and 30.72 billion cubic meters, respectively.[13] The overall ratio of wastewater discharged to the freshwater consumption is 0.77. Industries in India are thus discharging 0.77 m^3 of wastewater for every cubic meter of water being consumed.[14]

There are many industrial units that are diluting the effluents in order to follow the legal norms for discharge of effluents. The concentration-based standards for the disposal of effluents are being followed in India.[15] Therefore, industrial units like distilleries and pulp and paper mills discharging effluents with high BOD loadings are able to meet the legal standards for the discharge of effluents by diluting it with large quantities of water.

The pollution loading is the product of BOD and volume of the waste. The dilution of wastes increases the volume of the waste and decreases the BOD by the same amount, and hence, the pollution loadings remain the same.[16] Following the concentration-based standards for effluent disposal does not provide any incentives to a polluting industrial unit to reduce pollution loads or to reduce water consumption.[17] The industries are therefore not only putting pressure on the local water resources, but also the wastewater being discharged by the industrial units is polluting environment and is posing a serious threat to the health of the people living in the surrounding areas. The poor implementation of legislations and the failure of regulatory authorities in checking water pollution and exploitation of water resources by the industrial sectors have led to indiscriminate pollution of surface water and groundwater by the industrial units. Table 1 presents a sample of the different polluted industries and their impacts on drinking water quality and human health.

The small-scale industries are more polluting as compared to the large-scale industries as these industries lack infrastructure and treatment facilities. The small-scale industries like textile mills, pulp and paper mills, tanneries and pharmaceutical industries have severely polluted environment and freshwater resources. The total share of small-scale industries in the wastewater generation is 40%.[18]

The direct disposal of effluents from industrial units of all sizes and capacities on the land results in its leaching into the underground aquifers, thereby contaminating groundwater sources. The impacts of industrial pollution on drinking water quality

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[13]CSE (2004).

[14]CSE (2004).

[15]CSE (2004).

[16]Babu and Seth (2007).

[17]CSE (2004).

[18]CPCB (2001).

Table 1 Pollutants found in rivers and groundwater from some polluting industries and their impact on human health

S. No.	Types of industries	Polluted areas	River pollution	Groundwater pollution	Health impacts
1	Chemical manufacturing	Daurala (U.P.), Ankleshwar, Vapi, Nandesari and Bharuch (Gujarat), Bicchri (Rajasthan), Mahad (Maharashtra), Angul, Talcher (Orissa), Singrauli (U. P.), Kolhapur (Maharashtra), Hyderabad (A. P.), Eloor (Kerala)	Dumping of untreated effluents has severely polluted Amlakhadi, Kolak, Damanganga, Mini, Mahi, Periyar, Nakkavagu and Manjira rivers	Arsenic, lead, aluminum, cyanide, nitrates, fluorides, chlorides, mercury, chromium, nickel found in groundwater. Dirty, dark water rendered useless	Nervous breakdown, skin ailments, enteric fever, digestive disorders, cancer, children born with physical and mental defects
2	Pulp and paper mills	Jaibheem Nagar (U.P.), Ankleshwar (Gujarat), Patancheru (A. P.), Bharuch (Gujarat), Bhadravathi (Karnataka), Kala Amb (H. P.), Kashipur, Lalkuan, Pantnagar, Kichha and Bazpur (Uttarakhand)	Severe contamination of Kali, Amlakhadi, Kolak, Nakkavagu, Bhadra, Manjira, Markanda, Kosi, Ramganga, Dhella, Bahella, Kichha and Pilakhar rivers	Iron, chromium, cadmium, mercury, lead, manganese, zinc, nitrates, fluorides and pesticides found in groundwater	Skin diseases, gastric disorders, cancer, kidney problems
3	Tanneries	Kanpur (U.P.), Ranipet and Vellore (T.N.), Dindigul (T.N.)	Ganga, Palar, Ponnai rivers severely polluted	Hexavalent chromium, mercury, arsenic, pesticides found in groundwater	Lung cancer, gastrointestinal disorders, damage to kidneys and liver, prostate cancer, soft tissue sarcoma, testicular cancer and bladder cancer

(continued)

Table 1 (continued)

S. No.	Types of industries	Polluted areas	River pollution	Groundwater pollution	Health impacts
4	Dye industry	Lali village (Gujarat), Nandesari (Gujarat), Ankleshwar and Vapi (Gujarat), Bhilwara (Rajasthan), Raigad (Maharashtra), Pali (Rajasthan), Ludhiana (Punjab), Pali (Rajasthan), Panipat (Haryana), Bicchri (Rajasthan), Patancheru (A. P.), Tirupur (T. N.), Surat (Gujarat), Sanganer (Rajasthan)	Khari, Amlakhadi, Kolak, Bhilkhadi, Damanganga, Kothari, Patalganga, Mulla, Jajori and Bandi rivers severely polluted	Mercury, lead, chromium, iron, zinc, fluorides, chlorides, sodium and T. D.S. found in large concentrations in groundwater	Cancer, digestive disorders, waterborne diseases like jaundice, diarrhea and skin lesions
5	Distilleries	Daurala (U.P.), Jaibheem Nagar (U.P.), Sitamarhi (Bihar), Nagda–Ratlam (M.P.), Kashipur (Uttarakhand)	Kali and Manusmara rivers turned dark red or black, unfit for drinking. Terai rivers like Kosi, Ramganga, Dhella, Bahella, Kichha and Pilakhar became unfit for human consumption	Heavy metals like arsenic, lead, aluminum, cyanide, cadmium and chromium found in groundwater. Very high levels of BOD and COD reported	Nervous breakdown, cardiac disorders, gastrointestinal disorders, cancer, skin diseases, reproductive disorders, skeletal deformities in children
6	Pharmaceuticals	Vapi (Gujarat), Nagda–Ratlam (M.P.), Ankleshwar (Gujarat), Nandesari (Gujarat), Durgapur (West Bengal), Bharuch (Gujarat)	Severe pollution of Amlakhadi, Kolak, Mini, Mahi and Damodar rivers	Lead, zinc, mercury, nitrates, chlorides found in groundwater	Cancer, kidney problems, skin ailments, digestive disorders and respiratory disorders

(continued)

Table 1 (continued)

S. No.	Types of industries	Polluted areas	River pollution	Groundwater pollution	Health impacts
7	Pesticides	Ankleshwar and Panali (Gujarat), Vapi (Gujarat), Hyderabad (A. P.), Nandesari (Gujarat), Raigad (Maharashtra), Bharuch (Gujarat)	Kolak, Bhilkhadi, Damanganga, Mini, Mahi, Nakkavagu, Manjira, Patalganga and Mulla rivers severely polluted	Groundwater heavily colored. Nitrates, fluorides, chlorides and the presence of heavy metals like chromium, lead, zinc, mercury, arsenic and nickel reported	Cancer, kidney problems, digestive disorders
8	Fertilizers	Ankleshwar (Gujarat), Ernakulam (Kerala), Bharuch (Gujarat), Raigad (Maharashtra)	Amlakhadi, Kolak, Periyar, Patalganga and Mulla rivers severely polluted	Nitrates, fluorides and heavy metals like mercury, chromium, lead found in groundwater	Cancer, gastroenteritis, waterborne diseases like jaundice, diarrhea
9	Soft drinks	Chennai (T.N.) and Palakkad (Kerala)	N.A	The presence of ions of calcium, magnesium, sodium. Groundwater turned yellow, unfit for potable and non-potable uses	N.A
10	Ferro alloys	Bhadravathi (Karnataka), Durgapur (West Bengal), Cuncolim (Goa)	Severe pollution of Bhadra and Damodar rivers	Zinc, iron, manganese and pesticides found in groundwater	Sporadic fever, kidney damage, growth retardation and injury to central nervous system
11	Electroplating	Ludhiana, Jalandhar, Hoshiarpur, Amritsar, Gurdaspur and Harike (Punjab)	Effluents containing heavy metals and phenols have contaminated Satluj River	Hexavalent chromium, nickel, lead, cadmium, arsenic, cyanides found in groundwater	Cancer, neurological disorders, liver- and kidney-related diseases, congenital defects, miscarriages, mutations in DNA

(continued)

Table 1 (continued)

S. No.	Types of industries	Polluted areas	River pollution	Groundwater pollution	Health impacts
12	Steel manufacturing units	Haryana, Bhadravathi (Karnataka), Durgapur (West Bengal), Cuncolim (Goa)	Severe pollution of Bhadra and Damodar rivers	Zinc, iron, manganese, chromium found in groundwater	Kidney damage, growth retardation, injury to central nervous system
13	Aluminum manufacturing units	Haryana, Angul and Talcher (Orissa), Singrauli (U. P.), Korba (Chhattisgarh)	Brahmani and Mahanadi rivers severely polluted	Heavy metals like iron, aluminum, lead, titanium, arsenic, chromium, cadmium, zinc and the presence of fluorides reported. Numerous borewells rendered useless	Skeletal disorders, digestive disorders, gastric ulcer and skin diseases
14	Chromite mining	Sukinda (Orissa)	The presence of hexavalent chromium and heavy metals has severely polluted Damsala and Brahmani rivers	Hexavalent chromium and nickel in large concentrations found in groundwater	Gastrointestinal bleeding, infertility, birth defects
15	Coal mining	Jharia (Jharkhand), Angul and Talcher (Orissa), Durgapur (West Bengal), Singrauli (U. P.), Korba (Chhattisgarh)	The presence of arsenic in Damodar River, turned black. Brahmani and Mahanadi rivers also severely polluted	Heavy metals like cadmium, arsenic, copper, lead, chromium, zinc and the presence of fluorides in groundwater. Numerous wells and borewells rendered useless	Arsenicosis, digestive disorders

Source Industrial water pollution and its impact on health, Nishtha Gupta, TERI University, and Indira Khurana, WaterAid, 2011 are much evident in Patancheru as a result of toxic wastes discharged from pharmaceutical industries.[19] Similarly, people living in Kanpur, Ranipet and Vellore are suffering from acute shortage of drinking water and are facing severe health impacts due to pollution from tanneries. The discharge from chromite mines in Orissa has severely polluted surface water and underground aquifers, and people are using mine discharge for drinking purposes.

4 Surface Water Pollution

The Sabarmati River water quality was analyzed upstream and downstream of Ahmedabad to assess the impact of the city in the river water quality using monthly data from April 2011 to March 2017. Analysis of the data revealed that the river is in keeping with the norms when it enters Ahmedabad, but the river is dead downstream. The impact of this pollution by the city is borne by the residents in the peri-urban areas.[20] This is an example of just one river.

In 2018, the Central Water Commission brought out a report sharing the findings of water quality vis-à-vis toxic metals in 16 river basins of India. Toxic metals found in these river basins included cadmium, chromium, copper, iron, lead and nickel. Table 2 highlights some of the toxic metals found in rivers and their possible health impacts.

Table 2 Number of rivers where toxic metals are found beyond permissible limits and health implications

Toxic metal	Number of rivers with toxic metals beyond permissible levels	Health implications
Cadmium	25	Cardiovascular disease, kidney failure, lung damage and cancer, high blood pressure
Chromium (VI)	21	Rash, stomach ulcers, respiratory problems, lower immune system, kidney and liver damage, lung cancer, genetic alterations
Copper	10	Wilson's disease and stomach ailments
Iron	137	Hemochromatosis
Lead	69	Hematopoiesis, lung damage, miscarriage, respiratory illnesses
Nickel	25	Skin rashes, respiratory illness, cancer

Source Status of Trace and Toxic Metals in Indian Rivers, 2018, Central Water Commission

[19]Babu and Yadav (2007).

[20]Bansal and Parathasarathy (2020).

5 Snapshot of What Ails the River Ganga

Great civilizations have been known to flourish along rivers. Abuse of these rivers is a form of self-destruction since if a river dies, civilizations have known to perish.

Between September 2019 and January 2020, a Ganga Sadbhavana (Goodwill) Yatra was undertaken by the Jan Jal Jodo Abhiyan, a campaign of academics, scientists, civil society and activists. The Yatra traveled across the five states through which the Ganga flows: Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and West Bengal.

The *White Paper on the Ganga* that emerged from the Yatra threw up disturbing information as indicated below.

The river was adversely affected across all five states through which it flows. Road broadening, encroachment, blasting and sand mining had affected river flow. In several places, it had stopped flowing altogether. Pollution from industry, agriculture and sewage had turned this vibrant river system into a receptacle of waste, far beyond the river's carrying capacity, and in spite of holding the river in high regard.

In Uttarakhand, considerable soil erosion was taking place due to Char Dham construction activities being undertaken that too without requisite precautionary measures. Areas around Haridwar were being exploited due to mining, affecting the river. In Uttar Pradesh, the river was being heavily polluted due to agricultural and industrial pollutants. Considerable investments were made to clean up the ghats or build new ones, with little positive impact on the river per se. In Bihar, dredging was affecting the river and leading to ecological migration. Pollution due to industry and agriculture and sewage disposal had affected several tributaries and the main river itself. In Jharkhand, the factories were dissolving effluent ashes in hot water which was finding its way into the river and affecting the biodiversity and water quality. In West Bengal, in addition to severe erosion pollution levels were high.

More the investment into cleaning the Ganga, more was the deterioration. The Ganga continued to be in 'ICU,' undergoing 'treatment' from doctors who were unable to comprehend the treatment that was required. In spite of being on her deathbed, the Ganga continued to be eyed for economic gain.

The Yatra corroborated evidence that the health of the people along the Ganga was closely linked to the health of the river. Medical evidence reveals an alarming rise in the incidence of cancer amongst those living in the Ganga river basin. Studies conducted by the National Cancer Registry Program informed that people living alongside the Ganga in Uttar Pradesh, Bihar and West Bengal are more prone to cancer than anywhere else in the country. Thus, the health of a river is also linked to our health, the balance between surface and groundwater and hence to sustainability of water resources and to other vibrant living ecosystems.

A report commissioned by the NGT after the Ardh Kumbh pointed out that large amount of untreated sewage had leaked into the river and the groundwater. The plastic lining to be used in septic tanks to prevent leaching was missing. The report blamed the Kumbh Mela authorities to be uncooperative and attempting to hoodwink the cleaning of waste. This hoodwinking was also evident during the Yatra when non-functional STPs were reported as functional.[21]

In Bihar, Ganga and its tributaries such as Punpun, Ghagra, Gandak and Kosi cover major agricultural areas of Bihar. Scientific evidence indicates that due to the presence of bacteriophages in the river water, the wastes would remain normal and healthy for long durations of time. This unfortunately has changed due to river pollution caused by agricultural industrial wastewater and sewage that flows into the river. In a study, 34 samples collected from where the river enters the state (Chausa) and where it leaves the state (Bhagalpur) reveal that the river contains extremely high levels of fecal coliform which has also made the water alkaline. The study confirmed that in addition to industrial pollution, fecal coliform also contributes for almost 50% of the contamination in the Ganga water.[22]

6 Groundwater Contamination

Groundwater is a critical source of drinking water, especially in rural India. During the 1980s–1990s, over-extraction resulted in depletion of groundwater. What was more disturbing was that by then, 80% of drinking water sources were groundwater-dependent. As a result, habitations and villages that were covered with a safe water supply by the government started slipping back.

Water quality also started becoming a problem, and drinking water problems began to emerge in new areas. The problems were chemical in nature, best pointed out in the case of West Bengal. Endowed with 1650 mm of rainfall and several rivers, West Bengal was earlier using surface water and shallow ponds as drinking water sources. As the state shifted to groundwater sources, reports of arsenic contamination began coming in from the right bank of the Ganga. Similarly, over-extraction of groundwater has also resulted in increase in fluoride concentration in the states of Andhra Pradesh, Assam, Gujarat, Karnataka, Madhya Pradesh and Rajasthan.

Other contaminants include excess iron, nitrates and brackishness, the latter especially in coastal areas. Increase in brackishness in coastal areas has been the result of groundwater extraction through deep tube wells for drinking and irrigation purposes, leading to salinity ingress where seawater seeps in. The occurrence of inland salinity is due to over-extraction of groundwater and less recharge of aquifers.

Thus, the problems that emerged from groundwater use were not limited to depleting sources, but also contaminants that did not need to be dealt with before.

[21] Indira Khurana, November 2019. https://www.indiawaterreview.in/Story/GuestColumns/time-to-rebuild-gangahuman-relationship-that-looks-beyond-economic-gains/2429/5. Last accessed on April 01, 2020.

[22] Ghosh and Kumar (2020).

As of now, the scenario is fearful and alarming. There is a variety of problems that relate to quantity as well as quality. Eighty per cent of our drinking water needs are met by groundwater, which is depleting at an alarming rate, compounded with large-scale contamination.

Compared to surface water pollution, groundwater pollution due to anthropogenic sources is a far serious problem. In case of surface water sources, water remains in contact with oxidizing agents of atmosphere and has potential to improve quality over long flow distances in case of rivers and streams, provided there is water in the surface water body. In addition, capture and treatment of surface water sources are relatively easy. In case of ground water, the pollutants do not have potential to dilute due to relatively small and slow intermixing. Unlike surface water, the connectivity amongst aquifers is also not fully mapped, thereby making difficult to contain such pollution in a specific area. The greatest problem is the granularity of utilization through numerous dug wells in formal and informal sector where each one will require a treatment facility.

Other quality issues facing rural include excessive fluoride in groundwater in 20 states, which cause deformities in bones and teeth. Arsenic is found in seven states of India, namely West Bengal, Jharkhand, Uttar Pradesh, Assam, Manipur and Chhattisgarh. Harmful effects of arsenic consumption include bladder, lung, liver and skin cancer, heart disease, strokes and diabetes.

Unconfined aquifers are tapped extensively for water supply across the country. The chemical parameters are TDS, fluoride and chloride. Arsenic, nitrate and iron are the main constituents defining the quality of water in unconfined aquifers. The following were tested in the unconfined aquifers (Table 3):

- Electrical conductivity or salinity: Salinity always exists in groundwater in varying amounts.
- Chloride
- Fluoride (>1.5 mg/l)
- Iron (>1.0 mg/l)
- Arsenic (>0.01 mg/l)
- Nitrate (>45 mg/l).

Table 4 informs which states have more than permissible levels of four parameters.

7 Interlinking Pollution Between Surface Water and Groundwater

While surface water and groundwater behave differently, there are several examples of how the pollution of one leads to pollution and contamination of the other, some of which are given below.

Table 3 Number of districts with excessive levels of electrical conductivity, fluoride, arsenic, nitrate, iron and chloride

No.	State	EC > 3000 mS/cm	Fluoride > 01 mg/l	Arsenic between 0.1 and 0.5 mg/l	Nitrate > 45 mg/l	Iron > 01 mg/l	Chloride > 1000 mg/l
1	Andaman and Nicobar					01	
2	Andhra Pradesh	12	09	03	13	12	11
3	Arunachal Pradesh					02	
4	Assam		02	07		14	
5	Bihar	02	05	19	22	21	
6	Chhattisgarh	01	07	01	10	13	
7	Daman and Diu	01		01			
8	Delhi	05	05	02	8	03	03
9	Goa					02	
10	Gujarat	20	17	12	23	12	16
11	Haryana	09	10	06	11	14	04
12	Himachal Pradesh		01	01	3		
13	Jammu and Kashmir		03	03	05	05	
14	Jharkhand	01	06	01	13	09	01
15	Karnataka	11	17	02	22	17	05
16	Kerala		01		12	12	
17	Madhya Pradesh	08	10	08	35	10	01
18	Maharashtra	17	06		30	20	06
19	Manipur					03	
20	Meghalaya					03	
21	Odisha	07	13	01	28	28	02
22	Punjab	06	06	05	10	13	01
23	Rajasthan	29	29	01	32	21	16

(continued)

Table 3 (continued)

No.	State	EC > 3000 mS/cm	Fluoride > 01 mg/l	Arsenic between 0.1 and 0.5 mg/l	Nitrate > 45 mg/l	Iron > 01 mg/l	Chloride > 1000 mg/l
24	Tamil Nadu	14	08	09	15	03	07
25	Telangana	06	09	01	10	07	04
26	Tripura					03	
27	Uttar Pradesh	10	18	12	31	14	02
28	Uttarakhand		01		02		
29	West Bengal	07	04	09		15	
	Total						

Source CGWB, 2018. Ground water quality in shallow aquifers in India, table compiled by authors. Maps enclosed as Annex 1

Table 4 Locations having more than four parameters beyond permissible limits in 2015

No.	State	District
1	Andhra Pradesh	Prakasham and Kurnool
2	Haryana	Kaithal
3	Rajasthan	Ajmer, Hanumangarh, Jaipur

These four parameters are EC, fluoride, nitrate, iron and chloride
Source CGWB, 2018. Ground water quality in shallow aquifers in India. Table compiled by authors

(a) *Districts of Uttar Pradesh*
'It's acid and not water that is flowing in these rivers. It's making us very, very sick.' Around 150 villages in four districts of UP are situated along the Hindon, Krishna and Kali rivers. The water is so polluted that the people are suffering from deadly diseases such as skin disease, crookedness of hands and feet and cancer. These three rivers flow through the four districts: Muzaffarnagar, Meerut, Baghpat and Shamli. These rivers are heavily polluted due to untreated effluents released from factories and sewage. Factories include paper mills, slaughter houses and sugar mills. Heavy metals are also found in high quantity in these river waters. According to the villagers, their taps are near the rivers and so the contamination seeps into their supply. The area stinks because of the pollutants. Children are born with physical deformities. With the government in denial, remedial action seems difficult.[23]

(b) *West Bengal*
A study has revealed high level of toxins in drinking water in the Bengal basin. The paper, Wide exposure of persistent organic chemicals (PoPs) in natural waters and sediments of the densely populated Western Bengal Basin, India, by S Duttagupta, A Mukherjee and others from IIT Kharagpur, was published in Science for Total Environment in February 2020. This pollution is in addition to the arsenic found in several districts across West Bengal.

Hundreds of samples were tested and taken from groundwater and river water, which is used for drinking water supply, from the Farakka Barrage to the Sunderbans. The scale of the pollution found by the study is alarming. Highlights of the study included the following[24]:

[23]https://en.gaonconnection.com/its-acid-and-not-water-that-is-flowing-in-these-rivers-its-making-us-very-very-sick-2/. Last accessed on March 5, 2020.

[24]Science of the Total Environment, Volume 717 taken from https://www.sciencedirect.com/science/article/pii/S0048969720306975?via%3Dihub.

- Extensive pesticide residues detected in groundwater and river water of arsenic contaminated lower Gangetic basin.
- Malathion in the predominant detected pesticide, with concentrations up to 46 times higher than the permissible limit.
- Naphthalene and phenanthrene were the predominantly detected PAHs, mostly delineated in urban and peri-urban areas.
- Pesticides and PAHs detected in agricultural and rural areas are distinct form urban settings.
- Around 50% of the population—about 20 million people—are exposed to hazardous concentrations of pesticides and PAHs.

(c) *Ghaziabad, Uttar Pradesh*
A private laboratory has confirmed the presence of hexavalent chromium, a cancer-causing element that also affects the liver and kidneys in groundwater of Rajnagar area of Ghaziabad, U.P. In late 2019, several residents found the tap water to be of yellow color, following which they got the water tested from a private laboratory, which confirmed the presence of this deadly element. Subsequently, the Rajnagar Resident Welfare Association (RWA) wrote to the District Magistrate and to the UP Pollution Control Board. Meerut industrial area, close to Rajanagar has several chrome plating units.[25]

8 Is Water Safe to Drink?

Monitoring of water quality is thus a growing challenge because of the increasing number of chemicals used in our lives, agriculture and industry. In a country where groundwater is the major source of drinking water, health-related issues are cause for concern. In some cases, over-extraction of groundwater has led to tapping of aquifers containing fluoride and arsenic.

The Bureau of Indian Standards or BIS is a national standard body established for standardization, marking and quality certification of goods. In case of drinking water, the standard to be adopted is the BIS code IS: 10500 (2012).

This code includes a complex set of parameters such as color, taste, pH, turbidity, total dissolved solids, inorganic elements from aluminum to zinc, toxic substances such as cadmium, cyanide, lead and mercury, pesticides and other organic compounds, radioactive substances, E. coli and other biological contamination, and more. The code mentions a list of 64 items on which the drinking water has to comply on. While this is a long list, so is the list of pollutants and

[25]https://www.timesnownews.com/mirror-now/civic-issues/article/ghaziabad-residents-live-in-fear-as-cancer-causing-element-contaminates-groundwater/546882. Last accessed on Jan 15, 2020.

contaminant found in water, some of which—such as Uranium—are not even included in the BIS list.

As per the Jal Shakti Ministry's Web site, the National Rural Drinking Water Program defines drinking water to be contaminated; if the water is biologically contaminated, it contains chemical contamination exceeding permissible limits. The list of water quality parameters they adopt includes pH, arsenic, fluoride, total dissolved solids, E coli, nitrates, calcium, iron, magnesium, sulfate, alkalinity and turbidity. These standards are also not mandatory.[26] More importantly, the list does not include all contaminants found in water sources, even those listed in the IS10500 guidelines.

9 Uranium in Groundwater in Telangana

In October 2019, the Atomic Minerals Directorate (AMD) found dangerous levels of uranium concentration in the groundwater samples tested in the Lambapur–Peddagattu region of Nalgonda district in Telangana, known for its uranium deposits. These findings came at a time when concerns are already being raised around high levels of uranium in Tummalapalle, Kadapa district, Andhra Pradesh, where uranium is being mined.

The department tested the samples collected from 25 private tube wells/hand pumps, from November, 2018 to July, 2019, around Lambapur–Peddagattu region in Nalgonda district, as part of the environmental baseline data collection. It was found that uranium values in the sample locations vary from 1 to 2618 parts per billion (ppb).[27]

Uranium contamination in Punjab has been reported since the early 1990s, with little information on where it has come from. Uranium is also found in Rajasthan and Gujarat. Consumption of uranium causes kidney problems. While levels less than 60 ppb are the prescribed safety limit by the Atomic Energy Regulatory Board (AERB) Uranium, the element is not monitored under the Bureau of Indian Standard's drinking water specifications.

10 Jal Jeevan Mission Guidelines and Water Quality

In March 2017, the Government of India launched the National Water Quality Sub-Mission (NWQSM) under the National Rural Drinking Water Program to provide safe drinking water in identified quality-affected rural habitations by March

[26] https://nrdwp.gov.in/content/nwqsm. Last accessed on April 05, 2020.

[27] https://www.newindianexpress.com/states/telangana/2020/feb/07/uranium-levels-in-groundwater-found-to-be-high-in-telanganas-nalgonda-2100222.html. Last accessed on April 05, 2020.

Table 5 Number of habitations with contamination levels beyond permissible limits

States	Total	Fluoride	Arsenic	Iron	Salinity	Nitrate	Heavy metals
Andhra Pradesh	409	345	0	1	57	6	0
Arunachal Pradesh	409	345	0	1	57	6	0
Assam	10,917	283	4416	6211	0	0	7
Bihar	4211	898	871	2442	0	0	0
Chhattisgarh	1156	400	19	725	2	10	0
Haryana	125	118	0	0	7	0	0
Jammu And Kashmir	16	4	0	12	0	0	0
Jharkhand	2797	534	101	2,155	3	4	0
Karnataka	872	497	3	61	29	281	1
Kerala	361	34	0	199	96	32	0
Madhya Pradesh	181	166	0	5	10	0	0
Maharashtra	215	67	0	16	51	81	0
Meghalaya	32	0	0	32	0	0	0
Nagaland	30	0	0	30	0	0	0
Odisha	2976	104	0	2501	371	0	0
Punjab	3516	298	695	267	14	141	2101
Rajasthan	19,567	5939	0	5	12,587	1036	0
Tamil Nadu	169	0	0	152	17	0	0
Telangana	364	1	0	36	182	145	0
Tripura	2532	0	0	2,532	0	0	0
Uttar Pradesh	1379	179	748	362	80	10	0
Uttarakhand	15	0	0	12	0	3	0
West Bengal	17,389	1293	9756	5613	458	0	269
Total	69,258	11,160	16,609	23,398	13,964	1749	2378

Source Written reply to Rajya Sabha on Water Quality Affected Habitation in India, submitted on March 15, 2019, by Ministry of Drinking Water and Sanitation (https://data.gov.in/resources/state-and-district-wise-number-water-quality-affected-habitations-which-are-yet-be. Last accessed on April 04, 2020)

2021, with an outlay of Rs 25,000 crore. As per the plan, the NWQSM will end on March 31, 2021. Table 5 provides number of habitations affected by iron, arsenic, fluoride, salinity, nitrate and heavy metals.

11 The Jal Jeevan Mission[28]

With the launch of Jal Jeevan Mission (JJM), the government has set a target of providing Functional Household Tap Connection (FHTC) to every household by 2024. With respect to water quality, states have been advised to take up Community Water Purification Plant (CWPP) schemes in arsenic- and fluoride-affected habitations as an immediate (short-term) measure for providing 8–10 L per capita per day (lpcd) of safe water for drinking and cooking purpose only. These states have also been asked to plan for long-term measures in these habitations to provide FHTCs.

In case of piped water supply (surface water/ground water) which was approved under NWQSM, states have been asked to provide FHTCs at service level of 55 lpcd to every rural household by retrofitting and making it JJM compliant by 2021. In case of short-term measures (Community Water Purification Plant or CWPP) approved under NWQSM, states will take measures to provide FHTCs at service level of 55 lpcd to every rural household by 2021.

For the CWPP, the choice of technology has been left to states to decide. However, the states have to ensure that such CWPP systems have robust post-installation O&M systems and safe disposal of residue so that they continue to function as per prescribed standards. While there are a number of water treatment solutions available for different contaminants such as nanotechnology-based, reverse osmosis, capacitive deionization, adsorption and electrolytic de-fluoridation, the major considerations as outlined in the Jal Jeevan Mission guidelines for selecting a particular technology include (i) availability of filter media, (ii) reject management and (iii) cost-effectiveness of the solution.

The JJM guidelines also outline the mechanism for treating RO reject water which in the current scenario is disposed off, in either open drains or discarded nearby, creating a pool. The reject water is usually in large quantity based on the recovery ratio of the plant and is estimated to be around 60% of the feed water. In order to properly manage the reject water, the guidelines suggest that the reject needs to be stored separately in structures specifically constructed for this purpose and use it for non-potable, non-agricultural uses, i.e., washing of vehicles, agricultural equipment, house-washing, vessels and flushing/cleaning of nearby community toilets. The guidelines indicate that proper signage or warning against the use of the reject water for potable and agricultural uses should be put up on and around the stored RO reject water structures.

With respect to water quality monitoring, it is mandated that water quality laboratories will be set up at all levels—state, districts and blocks. These have to be accredited by NABL. There are just 2233 drinking water testing laboratories in the country, of which only 54 are NABL accredited. Of these, 19 are state laboratories while 35 are district laboratories.

While the scheme envisages ensuring potable drinking water in all 17.87 crore rural households in the country by 2024, the department also wants to empower the public to be able to ascertain the quality of water being provided.

[28]Jal Jeevan Mission Operational Guidelines, 2019, Ministry of Jal Shakti, Government of India.

12 National Green Tribunal Order on Regulating Use of RO-Based Drinking Water Systems[29]

The National Green Tribunal (NGT) on May 28, 2019, instructed the Ministry of Environment, Forest and Climate Change (MoEF&CC), Government of India, to notify prohibiting the use of drinking water through reverse osmosis (RO) systems in areas where the amount of total dissolved solids (TDS) was less than 500 milligram/litre (mg/l). It also asked the ministry to lay down the requirement for RO system manufacturers that the recovery of treated water is at least 60% and not more than 40% should go as waste. According to earlier standards issued by the Bureau of Industry Standards (BIS) in 2015, the water recovery by ROs had to be 20% only.

The order called for gradually increasing the recovery rate to 75% and for designing RO system in a way that treated water would have a minimum 150 mg/l TDS concentration. It also stressed on remineralization to compensate for loss of minerals during RO treatment. The order was based on petition filed by Sharad Tiwari, general secretary of a Delhi-based nonprofit, 'Friends,' who had pleaded that indiscriminate use of ROs was leading to huge wastage of water and that there are areas that do not require RO to be used for filtration.

However, the draft notification issued on by the MoEF&CC on February 3, 2020, does not mention such limits. Instead, it only mentioned that use of membrane-based water purification system, mainly RO purifiers, shall be prohibited where drinking water complies with the Bureau of Indian Standards (BIS). It is important to note that BIS does not have any minimum limit for TDS in treated water and was asked by the NGT to develop guidelines on the same.

13 Water Pollution Regulation in India

The Indian Constitution includes several laws for pollution regulation. The Water (Prevention and Control of Pollution Act), 1974, is an enabling statute in preventing and controlling water pollution. This Act prescribes general and industry-specific standards for the discharge of wastewater into water bodies and has given powers to the Water Boards to decide their own standards and regulations as per local needs.[30]

This Act led to establishment of Pollution Control Boards at the central and state levels for monitoring of pollution.[31] The Central Pollution Control Board (CPCB) and State Pollution Control Board (SPCB) are the regulatory authorities for monitoring pollution at the central and the state levels, respectively.

[29]Shagun Kapil, Centre's new draft for RO system not what NGT asked for (Feb 2020), and Banjot Kaur, Ban RO systems if dissolved solids are less than 500 mg/l (May 2019), Down to Earth.

[30]Goldar and Banerjee (2004).

[31]Puthucherril and Lekshmi (2004).

Water Cess (Prevention and Control of Pollution) Act, 1977, provides economic incentive to control pollution.[32] This act is a funding tool that provides powers to Pollution Control Boards to charge for water consumption in the industries. The cess being charged is used for the activities of the Pollution Control Board.[33]

The Environment Protection Act (1986) is umbrella legislation focusing on protection and improvement of the environment. This legislation extends to monitoring of water quality and controlling water pollution. Section 24(2) of this act allows the operation of Water Act, 1974.[34]

13.1 Central Water Commission

The Central Water Commission (CWC) is monitoring the water quality of rivers since late 1950 at 552 key locations covering all the major river basins of India. CWC maintains a three-tier laboratory system for analysis of the parameters[35]:

- *Level I* laboratories are located at 295 field water quality monitoring stations on major rivers of India where physical parameters such as temperature, color, odor electrical conductivity, total dissolved solids, pH and dissolved oxygen of river water are monitored.
- *Level II* laboratories located at 18 selected division offices to analyze 25 physicochemical characteristics and bacteriological parameters of river water.
- *Level III* laboratories, five in number, function at Varanasi, New Delhi, Guwahati, Hyderabad and Coimbatore, where 41 parameters including heavy metals/toxic parameters are analyzed.

13.2 Central Pollution Control Board

CPCB sets the standards for discharge of effluents, lays down ambient standards and coordinates the activities of SPCBs. It is responsible for undertaking surveys for monitoring of the polluted sites and for carrying out mitigation measures in polluted places. The CPCB plays a key role in regulating water pollution due to discharge of industrial effluents.[36]

The CPCB has established a network of monitoring stations on aquatic resources across the country. The network comprises 4022 stations in 28 states and six union

[32]Puthucherril and Lekshmi (2004).

[33]Maria (2003).

[34]Puthucherril and Lekshmi (2004).

[35]https://cwc.gov.in/water_quality.

[36]Maria (2003).

territories. The monitoring network covers rivers, lakes, tanks, ponds, creeks/marine/sea/coastal, canals, drains, groundwater, sewage treatment plants and water treatment plant (raw water).[37]

State Pollution Control Boards (*SPCBs*): The enforcement of the standards set by CPCB is decentralized at the state level. SPCBs have sufficient powers to punish the industries not complying with the standards for discharge of effluents. Fines of up to Rs. 10,000 and imprisonment for up to 3 months can be imposed on the polluting industrial units for not complying with the standards. SPCB also has the power to cut water supply of these polluting units and to charge water cess from the industries based on the volume of water consumed in the industries. However, the PCBs suffer from lack of staff and finances which impact their work. The cess for pollution which was meant to sustain the PCBs is abysmally low in the range of 30–60 paisa per kilo litre for polluting industries and is inadequate to sustain the Pollution Control Boards.[38]

13.3 Central Ground Water Board (CGWB)

The Central Ground Water Board (CGWB) has been monitoring the chemical quality of groundwater since 1974. Some 14,377 observation wells have been set up by CGWB all over the country to monitor groundwater quality. While the monitoring is significant, it needs to be analyzed and made easily available to all. Also, the data should be used for informing policy.

14 The Way Ahead

Reports indicate that almost 80% of surface water in India is contaminated and a growing percentage of groundwater reserves are contaminated with biological, toxic, organic and inorganic pollutants, due to deficiencies in wastewater treatment and over-extraction. Studies indicate high levels of chromium and other industrial pollutants in Ganga waters. Medical research informs that people living along the Ganga River are more prone to cancer because of the pollutants in the water.

The main source of pollution in addition to domestic sewage—a mere 26% of the 27,000 million liters of sewage generated per day is treated before being disposed in water bodies—is agricultural runoff and industrial production. Polluting industries such as distilleries, dye manufacturing, pharmaceuticals, pesticides,

[37]https://www.cpcbenvis.nic.in/water_pollution_main.html. Last accessed on April 01, 2020.

[38]Maria (2003).

fertilizers, soft drinks, ferro alloys, tanneries, chemical manufacturing and paper and pulp mills, electroplating, steel and aluminum manufacturing, and chromite and coal mining have polluted water resources with similar potential life-threatening repercussions. Reluctant to invest in wastewater treatment, some companies have also engaged in reverse pumping of polluted water into the ground.

As per the Jal Shakti Ministry's Web site, the National Rural Drinking Water Program defines drinking water to be contaminated if the water is biologically contaminated and contains chemical contamination exceeding permissible limits. The list of water quality (chemical) parameters adopted includes pH, arsenic, fluoride, total dissolved solids, E coli, nitrates, calcium, iron, magnesium, sulfate, alkalinity and turbidity. These standards are also not mandatory. More importantly, does this include the list of all poisons found in potable water sources?

Consumption of contaminated water has serious and often inter-generational effects. Groundwater is a critical source of drinking water, especially in rural India. Other quality issues already faced rural include excessive fluoride in groundwater in 20 states, which cause deformities in bones and teeth. Arsenic is found in seven states of India—Bihar, West Bengal, Jharkhand, Uttar Pradesh, Assam, Manipur and Chhattisgarh. Harmful effects of arsenic consumption include bladder, lung, liver and skin cancer, heart disease, strokes and diabetes.

According to estimates given by Indira Gandhi Institute of Developmental Research and United Nations Development Program (UNDP), industries will have to spend around 2–5% of their capital investment on pollution control considering a hypothetical situation when all the industries were complying with the existing pollution standards. According to these estimates, the annual operating costs will be between 15 and 20% of the investment made on the treatment facilities.

Clearly, water quality is a serious challenge facing the country today, with implications on human health and the economy. Addressing this will require serious commitment and a long-term vision and plan.

Tackling water pollution and addressing water quality-related challenges will need to be a mix of prevention, technology, removal, community participation and considerable resources—both human and financial. The legal framework and the implementation of laws will need to be strengthened as will real-time monitoring and subsequent action. Focus must be on prevention rather than treatment. Some suggestions are given below.

1. *Being proactive and preventing pollution*: To prevent water pollution, steps need to be taken to ensure that rivers and other water sources are not used as receptacles of human waste. First polluting water and then using technology to address it make little sense. The best way would be to prevent pollution from taking place and using technologies that either do not pollute or are able to treat the effluents, so that there is no toxic discharge. This cannot happen overnight, but an implementable action plan could make this a reality.
   In addition to preventive measures, steps need to be taken to revive rivers to make these flowing. Currently, the status of most rivers is dry or there is limited flow. This does not enable the existing pollutants to be diluted.

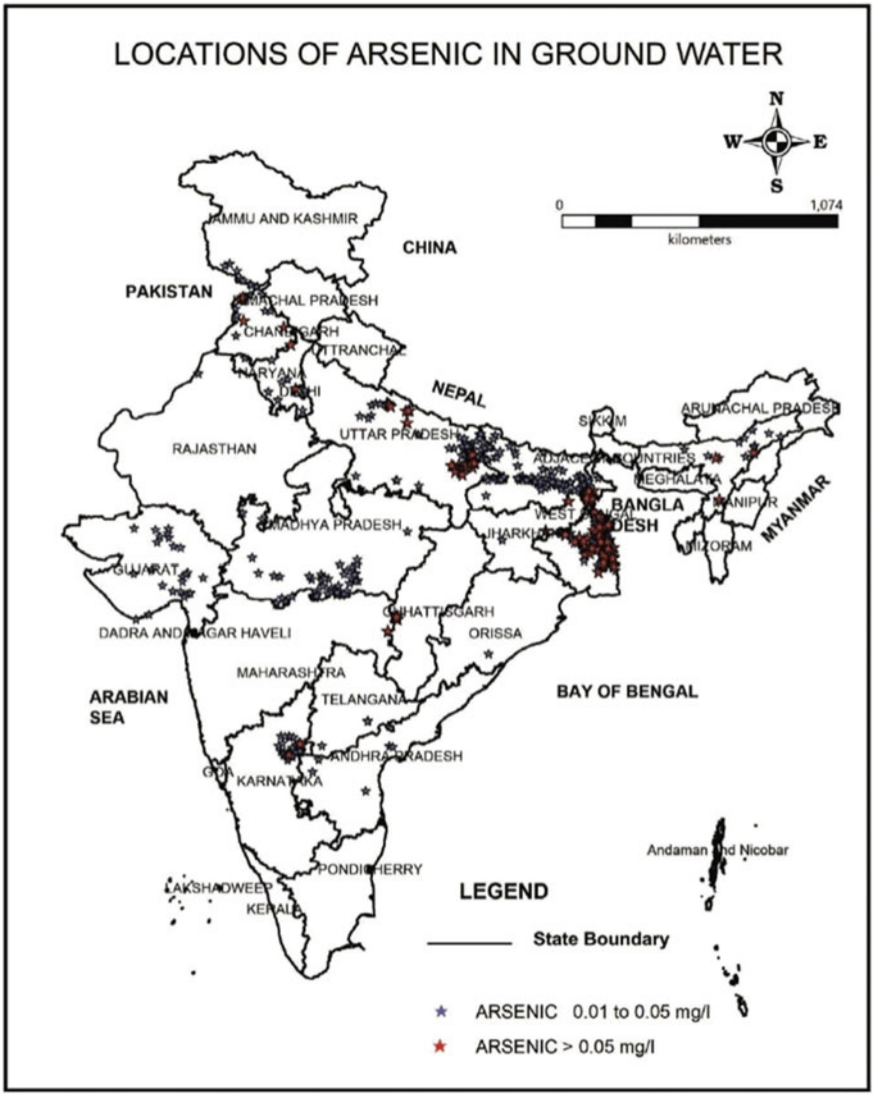
2. *Minimizing pollution loads*: Agricultural pollution will need to be addressed through minimizing chemical input use and the scaled-up adoption of integrated pest management and organic farming. Financial instruments will be needed for this.
   Addressing industrial pollution will require shifting from concentration-based standards to pollution load-based standards. The practice of following of concentration-based standards in India is unable to keep an effective check on the polluting industries. Adoption of practices like water treatment, effluent treatment, wastewater reuse, recycling of treated effluent and waste minimization will lead to effective management of water resources.[39] The industrial units should mandatorily meet most of their water requirements through technique of rainwater harvesting. There should be mandatory water recycling percentage being specified for different industries so that all industries recycle a specific proportion of the water consumed.
   The pollution due to sewage can be addressed through a judicious mix of centralized and decentralized sewage treatment plants and investment to further develop, promote and institutionalize decentralized waste water systems.
3. *Increase water quality monitoring*: There is an urgent need to increase water quality monitoring stations to get the real-time data on extent of water pollution and its impact of water quality. A common data grid of the water quality monitoring sites of various agencies that monitor water quality like the Central Water Commission, Central Ground Water Board, Central and State Pollution Control Boards, Water Provisioning Department and Utilities needs to be integrated so as to provide a robust system of data and information to help water utilities, citizens and government take measures for addressing pollution and define management actions.
   There should be a central repository of data on water pollution and quality. GIS can be used for data base management. Data should be shared with all concerned sectors and should also be on the public domain. A mechanism for incentives and punitive action will help in encouraging establishments who have taken measures to control water pollution and strengthen their efforts, while penalties can act as a deterrent.
4. *Low-cost technologies for water testing*: Most of the times, water quality measurements involve expensive, sophisticated tools and that are difficult to operate and maintain, and require substantial expertise in collecting, analyzing and managing the data. The existing methodology for water quality management is inadequate to identify the various sources of pollution and contamination of water. Development and promotion of low-cost technology options that reduce the cost and time water testing will help in management of water quality especially during times of natural calamities.

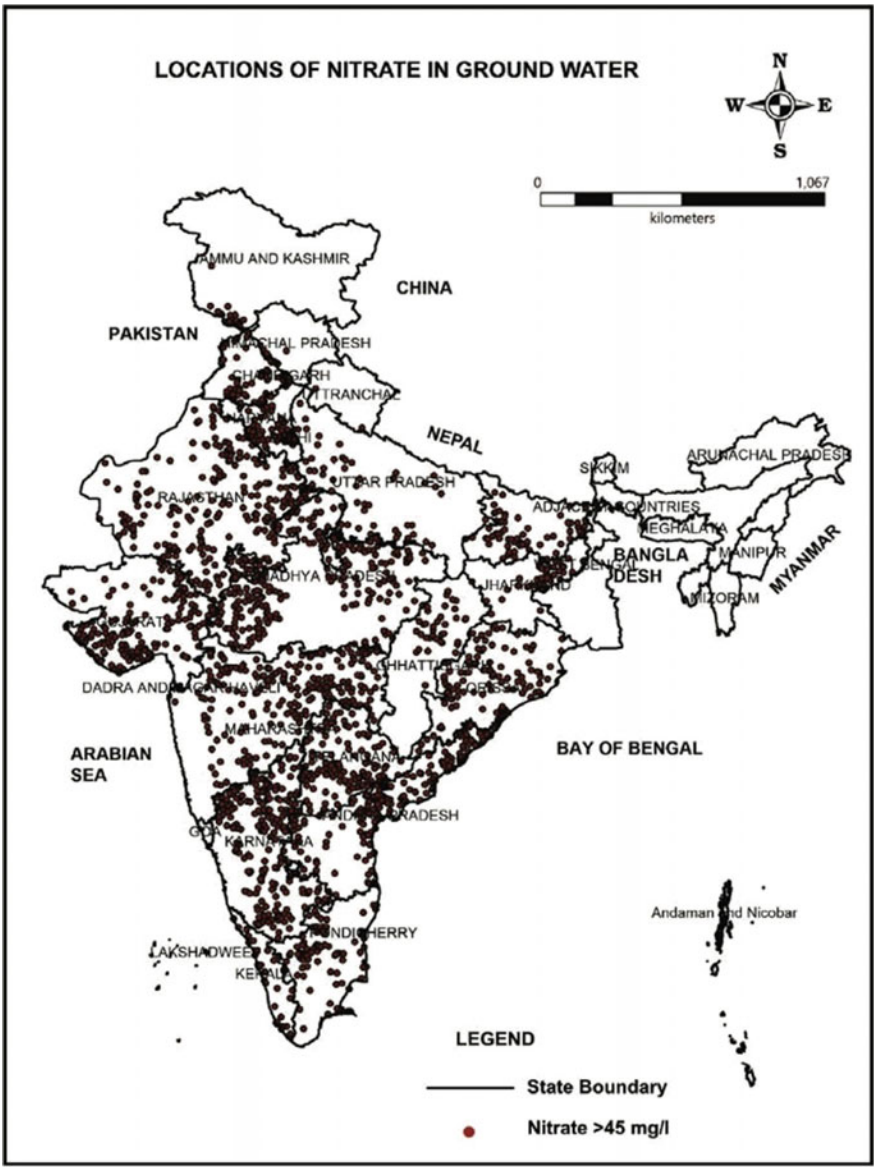
[39]CSE (2004).

5. *Promoting the use of treated wastewater*: It is estimated that the projected wastewater from India's towns and cities may cross 120,000 million liters per day (MLD) by 2051 and that rural India will also generate not less than 50,000 MLD in view of water supply designs for rural areas. While our current wastewater treatment capacity is less than 30%, there is a possibility of this figure increasing given the thrust on wastewater treatment infrastructure by the government in the past few years. While we take measures to increase the treatment capacity, it is important that the government gives attention to promote measures that enable to use treated wastewater for irrigation and non-potable use for our cities (horticulture and dust suppression) and industries (can be used for dust suppression and greening).
   In addition, to reduce the burden on freshwater sources, the option of dual water system is being worked out in several parts of the country. The success of this system lies in the fact that filtered purified water is used only for drinking purposes while other sources of water may be used for purposes other than drinking. This is also a cost-saving measure as resources spent on providing clean water are saved by using alternate sources.
6. *Promoting community involvement through water literacy*: Currently, there is little public pressure on addressing water pollution issues. Addressing water quality issues will not be possible without involving the community at large, including those who 'pollute.' Curriculum also does not address the issue. There is thus a need to engage the people through water literacy drives so that there is pressure to change the status quo.
   But first, the problem will need to be acknowledged. This in itself will be a big step in the right direction. All this, of course, will only be possible if there is strong and committed political leadership.

The issue of water quality has now reached dangerous levels and needs a completely new perspective to address it. Water poisoning needs to be addressed on a war footing and will require a mix of technological, financial, institutional and social measures. This will include rethinking development, adopting preventive approaches, polluter pays principle and giving a careful thought and a time-bound plan on how these are going to be addressed in the long run.

Annex 1: Groundwater Quality in Shallow Aquifers of India




LOCATIONS OF NITRATE IN GROUND WATER
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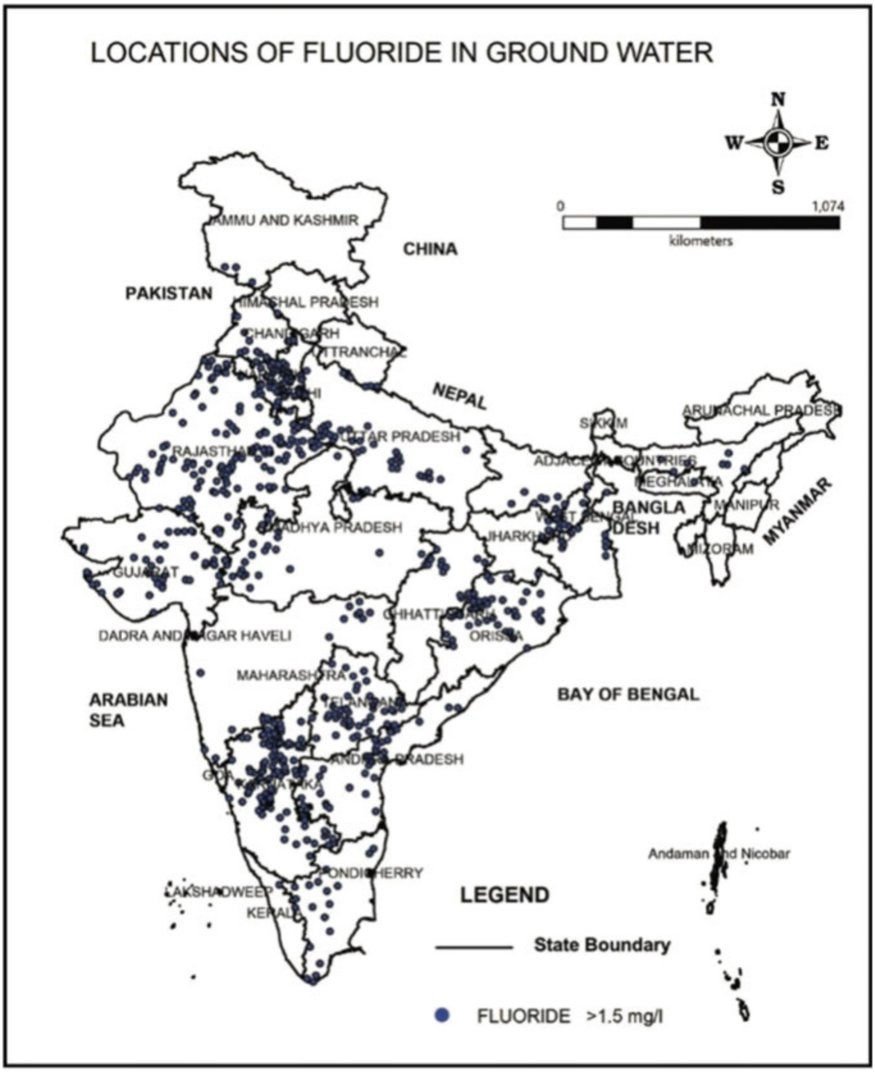
State Boundary
Nitrate >45 mg/l


LOCATIONS OF FLUORIDE IN GROUND WATER
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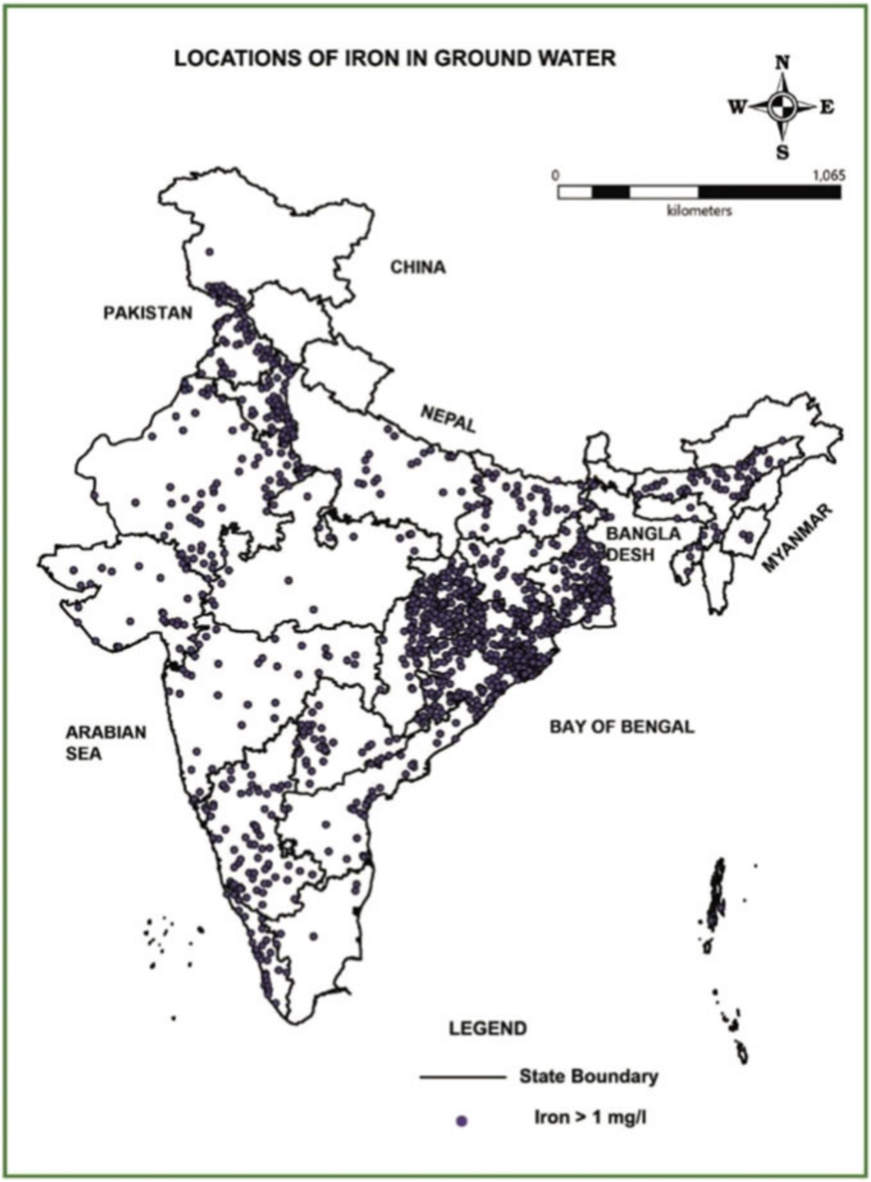
FLUORIDE >1.5 mg/l


LOCATIONS OF IRON IN GROUND WATER
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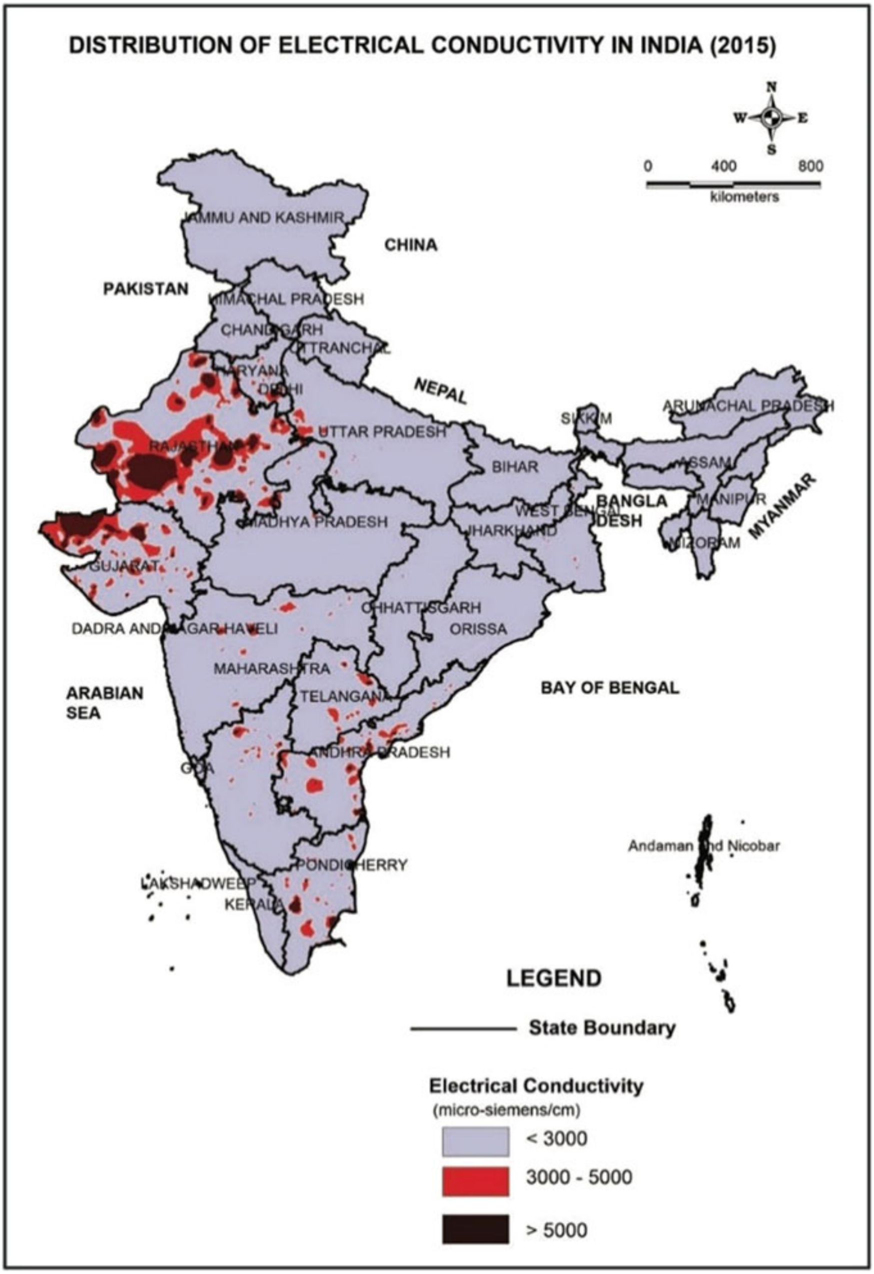
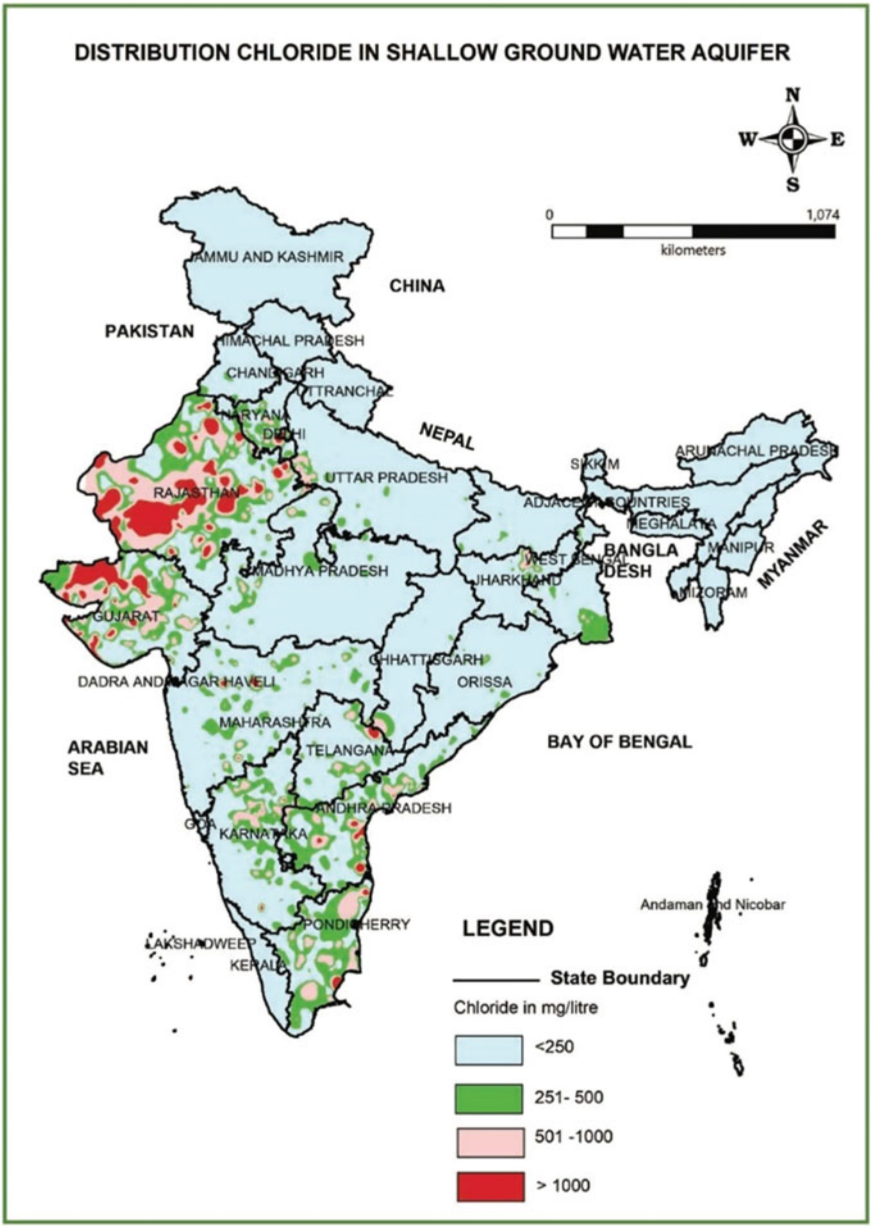
LEGEND
State Boundary
Iron > 1 mg/l



Source CGWB, 2018. Ground water quality in shallow aquifers in India.


DISTRIBUTION CHLORIDE IN SHALLOW GROUND WATER AQUIFER
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ARABIAN SEA
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UTTAR PRADESH
MADHYA PRADESH
JHARKHAND
ORISSA
MAHARASHTRA
TELANGANA
ANDHRA PRADESH
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GOA
KERALA
LAKSHADWEEP
Andaman and Nicobar
LEGEND
State Boundary
Chloride in mg/litre
<250
251- 500
501 -1000
> 1000

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Wetlands and Water Management: Finding a Common Ground

Ritesh Kumar, Harsh Ganapathi and Santosh Palmate

Abstract Wetlands, ecosystems at the interface of land and water, have a significant role in ensuring water and climate security of India given their role in the water cycle and multiple hydrological functions. The rapid loss of natural wetlands as has been experienced lately is as much a threat to water and climate security, as is an environmental crisis. The supply-side hydrology which characterized water sector for long has tended to overlook this role of wetlands, and at several instances, in an attempt to 'develop' these ecosystems, created several adverse ecological and socio-economic impacts. With broadening of thinking on water resources management from run-off to precipitation-based management incorporating land use, the role of ecosystems such as wetlands in building water system resilience becomes highly significant in Indian context. Forging 'natural infrastructure' of wetlands with the conventional 'physical infrastructure' of water resources can bring multiple advantages to the water sector and provide the required flexibility to address climate change-induced uncertainties and risks. Using catchment as a planning unit and a harmonized understanding of wetlands and their hydrological functions is the foundation step for collaboration between water and wetlands sectors. Communication between the two sectors can be bridged by wetlands managers articulating water needs and hydrological functions of wetlands in terms useful to water sector, and the latter, incorporating wetlands as nature-based solutions for meeting water management objectives.

Keywords Wetlands · Trend index · Nature-based solutions · Ecosystem services · Resilience

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Water Resources Development and Management,
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1 Introduction

Water challenges in India are deepening with intensifying impacts of climate change, reducing per capita water availability, equity concerns and growing water conflicts (World Bank 2005; Cronin et al. 2014; Jain 2019). The Government of India, of late, has rightly accorded high priority to water in its development agenda and has taken strategic steps such as consolidation of institutional landscape for water by creating Jal Shakti Ministry in 2019 (merging the erstwhile Ministry of Water Resources, River Development and Ganga Rejuvenation and Ministry of Drinking Water and Sanitation) and adopting a mission of 'water for all' (GoI 2020).

Wetlands, which form an integral part of water cycle and perform multiple hydrological functions, have a significant role in ensuring water and climate security of the country. Forging 'natural infrastructure' of wetlands (da Silva and Wheeler 2017) with the conventional 'physical infrastructure' of water resources can bring multiple advantages to the water sector, provided the role these ecosystems play in the hydrology of a landscape is systematically taken into account in policy and programming decisions.

This chapter looks into the interconnections between wetlands and water management and builds a case for integration of wetlands into water sector policies and programmes. It is argued that the rapid loss of natural wetlands is not just a crisis for environment, but also for water and climate security.

By transforming the available science on the role of wetlands into practical actions, the two sectors of wetlands and water which have historically pursued disparate trajectories can capitalize on mutually supportive outcomes towards building resilience. The arguments are presented in seven sections. The section following introduction looks into the scientific basis for integrating wetlands into water management and the enabling mechanisms thereof. The next two sections contain discussions on trajectories of water resources development and wetlands management and the extent to which sectoral coordination opportunities have been taken into account. Joined-up policy and programming opportunities, as well as science, policy and practice barriers limiting integration of wetlands in water resources management, are discussed in sections five and six. Section seven concludes with recommendations for the two sectors to collaborate for building water resilience. Throughout the discussions, the reference to water sector encompasses institutions, groups, agencies and organizations responsible for regulatory, operational and institutional aspects of water policy, programmes and regulation. Similarly, the reference to wetlands sector is to institutions, organizations, groups and agencies responsible for regulatory, operational and institutional aspects of wetlands policy, programmes and regulation.

2 The Need for Integrating Wetlands in Water Management

Wetland is a generic term used for aquatic ecosystems located at the interface of land and water and combining attributes of terrestrial as well as aquatic ecosystems (Keddy 2010). The Ramsar Convention (a multilateral environmental agreement on wetlands ratified by 171 countries, including India, which ratified the Convention in 1982) uses a broad definition of wetlands as ‘areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six metres’ (Ramsar 2016).

To ensure connectivity between different habitats, Article 2.1 of the Convention provides that riparian and coastal zones adjacent to the wetlands and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands may also be included within the boundary (Ramsar 2016). This broad-ranging definition thus covers a large category of inland aquatic systems (such as ponds, lakes, marshes, swamps and peatlands); coastal and nearshore marine ecosystems (such as coral reefs, mangroves, seagrass beds and estuaries); and human-made wetlands (such as rice–paddies, fish ponds and water storage areas as tanks, reservoirs and dams).

The term ‘water bodies’ is commonly used in the Indian water sector to distinguish water storage areas from flowing systems such as rivers (GoI 2018a). Wetlands are diverse, ranging from open-water-dominated systems (such as lakes, ponds or tanks), wherein evapotranspiration is not constrained by water availability, to those wherein water is at or frequently below the surface (such as swamps and marshes), and evapotranspiration is regulated by plant physiology (McCartney and Acreman 2009). Thus, all water bodies are wetlands, but not all wetlands are ‘water storage’ areas, in the sense used by the water sector.

India has a diverse wetland regime ranging from high-altitude lakes of the Himalayas, floodplains and marshes of the Gangetic–Brahmaputra alluvial plains, saline flats of Great Indian Desert, tank-studded Deccan Peninsula to extensive mangroves and coral reef areas bordering the country’s east and the west coastline (Kumar et al. 2017). As per the National Wetlands Atlas (SAC 2011), India has 15.26 million ha under wetlands, accounting for nearly 4.6% of her geographical area (Fig. 1). In terms of biogeographic zones, the coasts and the Deccan region have the maximum wetlands areas, the proportion of natural wetlands being higher in the former and human-made in the latter.

Wetlands, in their various occurrences, forms and characteristics, play an important role in functioning of the water cycle (Bullock and Acreman 2003). As water moves through the surface or underground, it passes through wetlands, which in turn regulate the quantity, quality and reliability of water. Wetlands provide vital water-related ecosystem services at different scales (e.g. clean water provision, wastewater treatment, groundwater replenishment) and, thereby, offer significant opportunities to address water management objectives with sustainable and, in

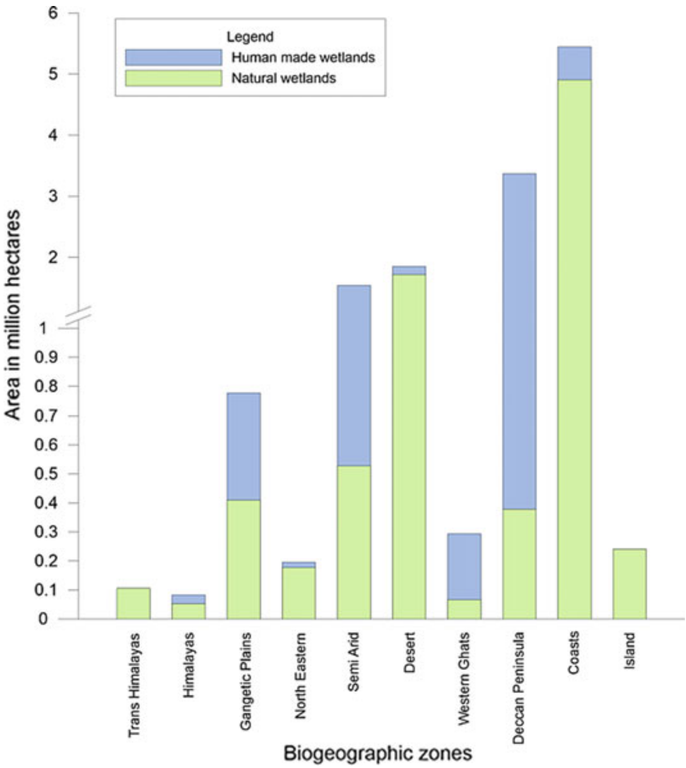

Fig. 1 Distribution of wetlands in different biogeographic zones of India. *Source* Authors, estimated from the data of National Wetlands Atlas (SAC 2011)

several instances, cost-effective solutions (UNEP 2014). The ecosystem services of wetlands can also complement human-made infrastructure to deliver water supply, sewage treatment and energy, thereby aptly being referred to as 'natural' or 'green infrastructure' or 'nature-based solutions' for water managers (UNEP 2014; Nesshöver et al. 2017).

The hydrological functions of wetlands can be elucidated by several examples. The high-altitude wetlands of Himalayas serve as headwaters of the 10 largest rivers of Asia, the basins of which support nearly one-fifth of the global population (Trisal and Kumar 2008). For several cities, wetlands were the primary source of water and continue to be so, as reflected in the moniker 'city of lakes' given to Bangalore (Nagendra 2010), Udaipur (Singh et al. 2018), Bhopal (Verma and Negandhi 2011) and many others. In some instances this water store can be highly significant, such as the water storage in Yamuna floodplains has been estimated to be equivalent to three-fourths of Delhi's water supply (Soni et al. 2009).

Wetlands have traditionally been the backbone of agriculture practised in the Ganga–Brahmaputra floodplains. The waste treatment capability of wetlands has been effectively used by the city of Kolkata which depends upon the East Kolkata Wetlands to treat nearly 65% of its wastewater, saving nearly Rs. 4600 million annually in terms of avoided treatment cost (WISA 2020). Wetlands act as major flood defence systems for cities such as Srinagar (Jammu and Kashmir) and Guwahati (Assam) (Kumar et al. 2017). In the hard rock Deccan Plains and arid regions of the country, there has been an age-old tradition of constructing tanks to store rainwater for use in irrigation and domestic water supply (Bhattacharya 2015). The value of coastal wetlands as a buffer against tropical storms has been brought out by several researchers (Das and Vincent 2009; Kathiresan 2010). Wetlands are also intricately interwoven with the rich cultural and religious tapestry of the country, and several wetlands are considered sacred (Singh 2013).

India's total annual utilizable water resources have been assessed to be 1123 km^3, of which 39% is accounted for by groundwater (MoWR 2010). The surface storage capacity of inland wetlands (projected from the wetland extent data from National Wetlands Atlas and assuming an average depth of 1 m) comes roughly to 60 km^3. The contribution of inland wetlands to groundwater recharge [estimated by the authors using National Wetlands Atlas data and recharge factors of Central Ground Water Board] comes to 51 km^3, of which 21 km^3 is from natural inland wetlands. While the contribution of wetlands to available water resources may appear small (for want of a more systematic assessment), their value lies in their availability as a diffuse resource in virtually all landscapes. Unlike large water storage structures, these systems do not require massive investments into infrastructure for accessing and distributing water, rather can be accessed with very nominal technology. The ability to support diverse life forms while also playing a crucial role in food and climate security makes them an incredible water resource.

Notwithstanding the high value of ecosystem services wetlands provide to society, they continue to be degraded, polluted, encroached upon and converted for alternate uses. A wetland area trend index constructed by the authors for Indian wetlands based on 237 published data points for 1980–2014 using wetland extent trends index method (Dixon et al. 2016) indicates an average decline in natural wetlands area by 41% and a near commensurate increase in area under human-made wetlands by 44% (Fig. 2). These trends are similar to those reported globally, wherein the natural wetlands have been on a decline, and the human-made wetlands are increasing (Gardner and Finlayson 2018). Such trends are worrying because natural wetlands are difficult to restore, and their functions cannot be totally replaced by human-made ones (Gardner and Finlayson 2018).

There is a considerable body of research that highlights the increasing vulnerability of landscapes, wherein natural wetlands have been degraded or lost (Dewan and Yamaguchi 2008; Acreman and Holden 2013; Marois and Mitsch 2015). This is especially true for major urban areas in India, wherein large swathes of wetlands have been converted to give way for housing and other infrastructure needs (Kumar and Kaul 2018). As a matter of fact, a positive relationship between an increase in the built-up area, increasing run-off, loss of wetlands and enhanced flood vulnerability has been observed for several cities, such as Mumbai (Zope et al. 2016), Bangalore (Ramachandra et al. 2019) and Chennai (Gupta and Nair 2011).

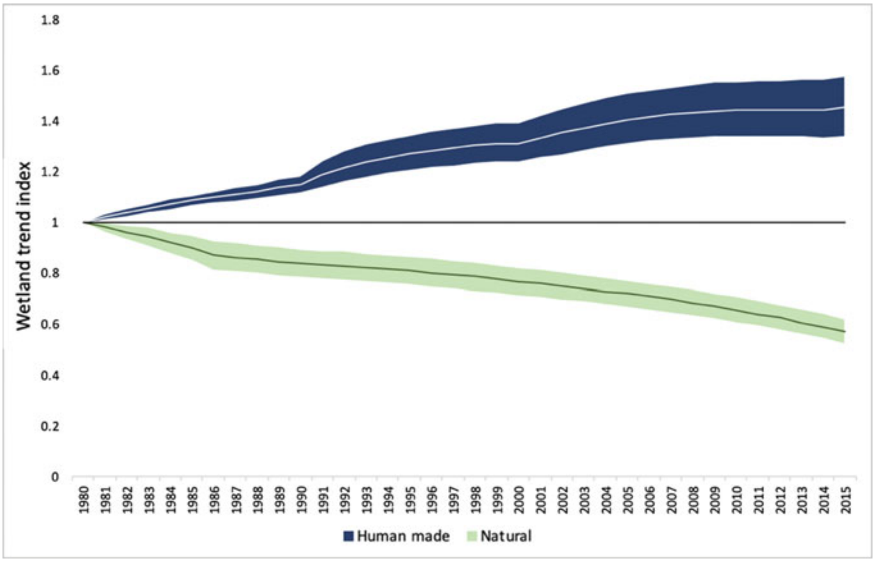

Fig. 2 Wetland area trend index for natural and human-made wetlands of India. *Source* Authors

Extensive urbanization of floodplains and conversion of wetlands were identified as critical anthropogenic drivers of extensive damage due to 2014 extreme flooding in Kashmir (Romshoo et al. 2018). With the capacity of treating sewage limited to only 31% of total generation (ENVIS 2019), pollution of wetlands is rampant. Wetlands are also degraded due to fragmentation of hydrological regimes, excessive siltation, encroachment, invasive species, unregulated tourism and overharvesting of wetland resources (MoEFCC 2019), although the intensity of drivers of change varies in different biogeographic zones.

Wetlands are managed for their wise use—sustainable utilization for the benefit of humankind in a way compatible with the maintenance of natural properties of the ecosystem (Finlayson et al. 2011). Wetlands evolve and function within physical templates set by water regimes and sediments (Ramsar 2010a). Treating water as a commodity and resource delivered through physical infrastructure as dams, pumps and pipes for various human usages (domestic, industrial or agricultural) obfuscates the fact that water is a component of healthy, functional ecosystems such as wetlands. Several water resource development projects have, thereby, led to degradation of wetlands by altering flow patterns, reducing water availability and deteriorating water quality, ultimately rendering the entire water management goal unsustainable. The delivery of hydrological functions is contingent on the availability of water of right quantity and quality and at the right time, thus necessitating that wetland functioning is integrated into water resources planning and decision-making processes (McCartney and Acreman 2009). Similarly, wetland managers need to articulate the water needs of wetlands to water managers and ways wetlands can help meet overall water resources management objectives.

The most significant body of work on wetlands and water is available within the Ramsar Convention. A number of resolutions have been adopted by Contracting Parties which have been summarized in four handbooks (Ramsar 2010a, b, c, d). A common element in all these guidelines is recognition of two important facts: (a) water resources management is dependent to a large degree on the hydrological functions of wetlands, and (b) wetland ecosystems need a certain amount of water allocated for maintenance of ecological character, in order to maintain these hydrological functions. The Ramsar guidelines on integration of wetlands in river basin management are structured around eight principles (sustainability such as a goal, clarity of process, equity in participation and decision-making, credibility of science, transparency in implementation, flexibility in management, accountability for decisions and cross-sectoral cooperation in policy development and implementation) and recommend a critical path approach to achieve the integration (Ramsar 2010d; Rebelo et al. 2013). The guidelines on allocation of water for wetlands stress upon an enabling policy environment, supported by appropriate legal arrangements and a framework for assessing the merits of different allocation options (Ramsar 2010a). Similarly, the guidelines for integrated management planning encourage site managers to take into account the role of wetlands in wider catchments while defining wise use strategies (Ramsar 2010e).

3 Water Resources Development Trajectories and Consequences for Wetlands

The centrality of water resources development in shaping up of Indian state is well recognized (Whitcombe 2005). Wetlands were accorded special status (referred as ‘anupa’, or incomparable lands) in religious texts (Rangarajan 2005), many wetlands species such as fish and lotus were considered sacred, and these ecosystems formed an essential source of water for domestic use and irrigation (Agrawal and Narain 1997; Bhattacharya 2015). With high temporal and spatial variability and heterogeneity in rainfall and availability of water resources, Indian society has adapted to the situation, by either living along the banks of rivers and wetlands, and carefully husbanding water resources (World Bank 2005). The agrarian society was mostly dependent on surface water storages within natural as well as human-made wetlands, and gravity flow irrigation to water crops. In the alluvial plains of the north, monsoon floodwaters were diverted and managed to enable riverine agriculture. The Deccan Plateau of peninsular India, which did not have an abundance of perennial rivers, had a long tradition of constructing tanks to conserve rainwater (Raju and Shah 2000; Van Meter et al. 2014). The cascading tank systems of southern India are an important reference point as multi-functional systems providing seasonal water storage, along with being centres of settlements and as providing social and cultural identity to the communities (Mosse 1997; Van Meter et al. 2014).

The beginning of the nineteenth century, however, marked colonial reconfiguration of irrigation regime by undertaking large canal projects driven by an ambition to commodify water and generate revenue (D'Souza 2002, 2006). Colonial water technologies such as weirs, dams and barrages were directed at providing perennial irrigation for settled agriculture, which was needed to address the food and development needs of a burgeoning population (World Bank 2005), but gradually led to reduced relevance of traditional water systems (D'Souza 2006). The water technologies were also directed at draining and reclaiming marshes and swamps for more productive and revenue-generating usages such as agriculture (Richards et al. 1985). Attempts to tame floods through embankments scarred the alluvial floodplains and the deltas (D'Souza 2003; Singh 2008), which when done counter to natural fluvial regimes, prevented the spread of fertile sediments into the floodplains and ultimately led to extended periods of water logging and converting landscapes from being flood-dependant to flood vulnerable (D'Souza 2003).

Post-independence, taming rivers and floods formed the cornerstone of water resources development. Colonial technologies were perpetuated in the form of dams and embankments. Large-scale water resources development projects backed by powerful state hydraulic bureaucracies stood robustly behind the construction of what the first Indian Prime Minister referred to as 'temples of modern India' (Morrison 2010; Swayamprakash 2014). Increased control over water resources entrenched the prominence of human-made wetlands, the reservoirs and barrages. In contrast, the natural wetlands were seen as unproductive wastelands, reclamation of which was incentivized by state, by means such as drainage programmes, especially in response to the great famines that the country faced in the 1950s.

The approach of 'developing' water resources was also applied to several wetlands. In the north-eastern state of Manipur, the solution to devastating floods of 1966 and the region's deprivation of power was seen in the form of regulating the Loktak, the largest floodplain wetland of the state (Meitei 2020) and converting it into a reservoir. The Ithai Barrage was constructed at the outflow to prevent depletion of water level in dry winters and water from the wetland diverted to produce 105 MW of hydropower through the Ithai multipurpose project of the National Hydroelectric Power Corporation. The vision to green the deserts of Rajasthan by diverting waters from River Sutlej and Beas through Indira Gandhi Canal was realized by constructing a diversion barrage at Harike over a large riverine marsh (Maitra 1987). The Quilon water supply scheme involved embanking the Sasthamcotta, a freshwater wetland linked with Kallada River, to supply water to Kollam City, an important centre of spices trade in Kerala (WISA 2017a). The planners of Kolkata saw the vast saline marshes on the eastern margins of the city as a safe place to discharge sewage and in the process laid the basis of world's most extensive sewage-fed fishery system (WISA 2020). The famed backwaters of Kerala, the Vembanad, were split by Thaneermukkom, a barrier to retain freshwater and enable its availability to Kuttanad, the rice bowl of Kerala. Kuttanad itself emerged out of polderization of floodplains (James et al. 1997).

The impact of water resources development projects, coupled with linked developmental changes in the catchments, has been highly adverse in many cases.

Harike has emerged as a large silt trap and, coupled with continued discharge of pollutants from upstream townships brought into Harike by Rivers Sutlej and Beas, has been perennially infested with water hyacinth (Singh et al. 2020). Regulation of water for hydropower in Loktak has converted a naturally pulsating wetland into a reservoir, causing loss of migratory fisheries and severe degradation of the habitat of globally endangered deer species, *Rucervus eldii*, which inhabits the wetland (Trisal and Manihar 2004; Tuboi et al. 2018). In Vembanad, the changes in hydrological regimes have led to a loss of migratory fish species, concentration of pollutants and reduced flood buffering capacity of the estuary (James et al. 1997; Kumar et al. 2013). As water abstraction has exceeded the availability in Sasthamcotta, the wetland has faced bouts of prolonged drying (WISA 2017a).

In the last six decades, India has become the largest groundwater user in the world, accounting for nearly 65% of the country's gross irrigated area, abstracted collectively from ~30 million wells, bore wells and tube wells (Kulkarni et al. 2015; Smilovic et al. 2015). This trend emerged in the sixties, wherein the use of mechanized pumping technologies made groundwater extraction in large quantities possible, also matching the advent of Green Revolution, which created a high water demand for irrigating the high yielding variety crops (Shah et al. 2012). Rapid expansion in groundwater use for irrigation and drinking water purposes has been encouraged by several factors such as flexibility and timeliness of water supply, the poor service delivery of public water supply systems, newer pump technologies increasing affordability of sinking and operating a tube well, and government electricity subsidies, which shielded farmers from full cost of pumping (The World Bank 2010; Shah et al. 2012). The current situation of groundwater is alarming, with falling water levels and reduced well yields in several parts of the country (Tiwari et al. 2009; GoI 2019a), mobilization of heavy metals from deep aquifers (Kulkarni et al. 2015), inequity of endowments and an invidious nexus of mutual dependence between water, food and energy (Shah et al. 2012; Kulkarni et al. 2015). The creation of a 'water-scavenging' irrigation economy (Narayanamoorthy 2007; Shah 2009) has also meant reduced relevance of gravity flow irrigation from surface storages such as wetlands (Shah 2012). For groundwater-dependent wetlands such as those prevalent in northern India, lowered water levels and fragmentation of river connectivity led to shrinkage in natural inundation regimes. The declining significance of tanks meant they were allowed to decay, silted and at many instances constructed upon (Narayanamoorthy 2007).

Water resources development efforts have singularly focused on freshwater, and thereby water and sediment regime needs of coastal ecosystems have been comprehensively compromised. In several mangrove areas, reduction in freshwater inflow has been identified as a significant causative factor for an increase in salinity resulting in reduced habitats of salinity-sensitive species and dominance of high salt-tolerant ones (Kathiresan 2010; Giri et al. 2014; Gnanappazham and Selvam 2014; Sathyanathan et al. 2014). Estuaries such as Ashtamudi (Kerala) are gradually progressing towards hypersaline conditions, with reduced productivity and a high degree of transformation in species assemblages (WISA 2017b). Shrinkage of deltas due to sediment deprivation has been observed as a significant challenge in almost all parts of the globe (Syvitski et al. 2009), such trends having been noted in the deltas of Ganga (Ramesh et al. 2019), Mahanadi (Bastia and Equeenuddin 2016), Godavari and Krishna (Nageswara Rao et al. 2010). The resulting shoreline erosion is one of the factors inducing investment into concrete shoreline protection measures, which have their adverse impacts on the coastal environment.

There has been a renewed interest in revitalizing tank systems to support local water security. In June 2005, a pilot scheme for the restoration of water bodies was initiated by the Ministry of Water Resources, which has since been upscaled into a full-fledged scheme by the title 'Repair, Renovation and Restoration (RRR) of Water Bodies' since the 12th National Plan period to create 2.1 million ha irrigation potential (GoI 2017). As per data retrieved on RRR dashboard at the time of writing this chapter, the programme had covered nearly 2300 water bodies in 12 states, restoring 1.09 km^3 water storage capacity at a total cost of Rs. 19.6 billion. A midterm analysis of Mission Kakatiya, a programme of Government of Telangana to restore over 40,000 derelict tanks in the states, has indicated a positive impact on water availability, groundwater recharge and farm economics (Shah et al. 2017), and also recognized as good practice by India's national policy think tank—NITI Aayog. Similar programmes have also been launched in several other Indian states.

In summary, the supply-side hydrology, which characterized water sector for a large part of the nineteenth and twentieth century, has tended to overlook the role of wetlands and, at several instances, in an attempt to 'develop' these ecosystems on the lines of other water resources projects, created several adverse ecological and socio-economic consequences. Growing neglect of wetlands is reflected in their extensive conversion, physical modification and pollution. However, the value of some wetlands such as tanks as freshwater stores is increasingly being realized in recent times, and efforts are underway for their revival. Some assessments even indicate the positive impacts on groundwater conditions in southern parts of the country in response to such measures (Bhanja et al. 2017), when implemented as a part of broader management measures.

4 Inclusion of Water Management Dimensions in Wetlands Management

Unlike the water sector, wetlands management is of recent vintage, emerging globally around the 1950s over concern for the declining population of water birds in Europe and North America (Gopal 2003). Designating wetlands of high ornithological values as protected areas under colonial laws, and post-independence, under Indian Wildlife Protection Act, 1972, was the primary approach for, as can be discerned from the closure of Vedanthangal, Keoladeo, Khijadiya and Ranganathittu bird sanctuaries or wilderness areas (Kumar 2019).

India's ratification of Ramsar Convention in 1982 and creation of the Ministry of Environment and Forest in 1985 (from a Federal Department of Environment in

1980) provided the necessary backdrop for the establishment of a national programme on wetlands, which was launched in 1986 for assisting state governments for implementing management plans for prioritized wetlands (MoEF 1992). Subsequently, separate programmes for urban wetlands and mangroves and coral reefs were carved out from the national programme to focus on the issues of urban pollution and increasing vulnerability of coastal wetlands (DasGupta and Shaw 2013). The national wetlands programme is currently known as the National Programme for Conservation of Aquatic Ecosystems (NPCA) and has subsumed the programme on urban wetlands (MoEFCC 2019). As of December 2019, over 250 wetlands have been covered under these national programmes, majority being protected areas, designated for biodiversity values, primarily water birds.

The science base on wetlands, as in Europe, emerged from surveys on wetlands biota. Bird-ringing programmes were initiated as early as the 1920s, highlighting the ornithological value of wetlands (Balachandran 1998). Towards the 1940s, ecologists deepened the science into examining the role of sediments and hydrological regimes in influencing vegetation and other biota (Michael 1980; Gopal 1998). Post-independence, with establishment of CIFRI and launch of International Biological Programme, more focus on ecosystem processes such as primary production and energy dynamics came in, and pollution garnered interests of researchers in the 1970s, concurrently with Government of India enacting the Water (Prevention and Control of Pollution) Act in 1974 and Central and State Pollution Control Boards being established. Long-term ecological studies in Keoladeo National Park (Bharatpur, Rajasthan) were perhaps one of the early ones to start quantitatively defining water regime requirement of wetlands, though the assessments were only based on habitats of select water bird species (Vijayan 1991).

Towards the 1990s, as the MoEFCC's national wetlands programme started gaining strength and increased emphasis was placed on integrated management plans taking into account their catchments, water balance studies began to be taken up (NIH 1999, 2000). This was also the period when the impact of water resources development projects and land use changes on wetlands started garnering the attention of researchers. In Keoladeo National Park, one of the prime water bird habitats in eastern Rajasthan, construction of Panchana Dam over Gambhir River upstream of the park, increasing demand of water for irrigation in the upstream reaches and increasing variability of rainfall exposed the wetland to risks of prolonged drying and depleting water bird population leading to an intense water conflict between allocation for wetland versus irrigation needs (Chauhan 2006). In Loktak, construction of Ithai Barrage was identified as a causative factor for wetland degradation, particularly habitat of globally endangered ungulate species, *Rucervus eldii* (Trisal and Manihar 2004). In Chilika, Odisha, changing hydrology due to reduced connection with the Bay of Bengal was pitted as a significant causative factor for the decline in fisheries and progression of the estuary towards a freshwater-dominated state (Kumar et al. 2020). Impact of freshwater flow reduction on mangrove species diversity in Sunderbans, West Bengal (Gopal and Chauhan 2006), and Pichavaram, Tamil Nadu (Sathyanathan et al. 2014), was also brought to fore. Elsewhere, the impacts of the transformation of wetlands by altering natural hydrological regimes were highlighted, for example, in Kolleru (Andhra Pradesh), wherein the natural flood buffering function was lost to aquaculture (Sellamuttu et al. 2012). During the late 1990s, projects on Chilika, Bhoj and several other urban wetlands were framed on Integrated Lake Basin Management Framework, which was also adopted as an implementation framework for restoration of urban lakes (Nakamura et al. 2007; MoEF 2008a).

Despite the emerging evidence base on the adverse impacts of hydrological transformation on wetlands, integration of wetlands into water resources planning and decision-making has hit several roadblocks. The assessment of environmental flows for Chilika stands out possibly as the only positive example, wherein operational rules of Naraj Barrage at the head of Chilika catchment were formulated considering freshwater needs of the lagoon, and a river basin-level monitoring of hydrological regimes has formed as part of wetland management strategies since 2000 (The World Bank 2005; Kumar and Pattnaik 2012). In the case of Loktak, despite over a decade of assessments and identification of a framework for revising operations of Ithai Barrage to secure Loktak ecosystem, implementation is yet to take place (WISA 2011). For Vembanad, many assessments have indicated options for revision of Thaneermukkom to benefit the wetland environment, as well as address needs of farmers and fishers, and actual change of barrage operation is yet to take place (Kumar et al. 2013).

The network of wetlands prioritized by states for conservation has often included hydraulic structures, as over time their biodiversity values were recognized beyond their role as a water resource. For example, the water bird diversity and numbers in Hirakud Reservoir at present are next only to Chilika (WISA and CDA 2015). Bird surveys in Pong Reservoir indicated that species diversity had considerably increased after the construction of the reservoir (Pandey 1993). The list of 37 wetlands designated by India as Wetlands of International Importance includes 17 reservoirs and barrages. The management arrangements of such hydraulic structures have had to make necessarily incorporation of ecosystem requirements (such as water needs for maintaining water bird habitats), which is an indication that cooperation between the two sectors is indeed possible.

In summary, wetlands conservation in India has been structured around a network of sites. Over time, the narrative has shifted from a concern for species, mainly water birds, to a role in maintaining water and food security and buffering extreme events such as floods. There has been considerable progress in recognizing the role of hydrology in wetland functioning and incorporating hydrological descriptions within wetland management plans. However, translating information on flows to achieving desired changes in water use and allocation practices within the river basin has been very difficult and, more often than not, highly contested.

5 Policy and Programming Synergies Between Wetlands and Water Management

Despite water and wetlands sectors having adopted different development trajectories, there also exist several policy and programming complementarities. The National Environment Policy of 2006 makes explicit recognition of wetlands as 'freshwater resources' and emphasizes integration of conservation and wise use of wetlands into river basin management involving all relevant stakeholders (MoEF 2006). India's National Wildlife Action Plan (2017–2031) identifies conservation of inland aquatic ecosystems as one of the 17 priority areas and envisages development of a national wetlands mission and a national wetlands biodiversity register (MoEFCC 2019). Mainstreaming the full range of wetlands ecosystem services into developmental planning is listed as the objective of the National Wetlands Programme (MoEFCC 2019). In 2017, the MoEFCC notified the Wetlands (Conservation and Management) Rules, 2017, under the Environment (Protection) Act, 1986, wherein state wetlands authorities have been constituted as nodal policy-making, programming and regulatory institutions for wetlands in the state. The structure of the authority includes representation from all sectors, including water resources, thus providing a platform for balancing diverse sectoral interests related to wetlands.

Likewise, integration of wetlands in river basin management has been identified as a strategy for the management of river systems (MoWR 2012). The National Water Policy recommends adoption of a basin approach for water resources management and identifies conservation of river corridors, water bodies and associated ecosystems as an essential action area (MoWR 2012). The guidelines on Integrated Water Resources Management issued in 2016 by the Central Water Commission recommend using water balance as a basis for planning at basin level and ensuring that upstream and downstream impacts are taken into account (GoI 2016). The National Action Plan for Climate Change includes wetland conservation and sustainable management in the National Water Mission and the Green India Mission (MoEF 2008b). The National Disaster Management Plan takes into account several non-structural measures for flood and cyclone risk reduction measures and makes direct reference to wetlands (NDMA 2019). The national indicator framework for monitoring implementation of Sustainable Development Goals provides a mapping of various sectoral programmes towards assessing country's progress on sustainable development goals (MoSPI 2015) and makes several references to integrated management of wetlands and water resources.

The nature of water sector challenges that India currently faces is complex—water demand outstrips supply in several basins, rampant aquifer depletion prevails, economic development driven by urbanization and industrialization is altering water use and efficiency by several proportions while creating water quality issues, and water conflicts have become more endemic (World Bank 2005, 2010; Molle et al. 2010; Cronin et al. 2014). Future climate change projections for the country indicate increasing variability of precipitation, run-off and extreme events, and several other changes further exacerbating water risks (GoI 2018b). The stationarity view that serves as the foundation of much of water resources planning, using assumption that hydrological variables can be described based on time-invariant probability distribution functions, is being increasingly challenged in the context of climate change-induced uncertainties and risks (Milly et al. 2008). A business-as-usual approach to water management, based on only conventional grey infrastructure solutions, will be highly insufficient in the current contexts.

The discourse on water has greatly matured, from a recognition as a vital resource and economic good as per Dublin Principles in 1992 to being the 'bloodstream of the biosphere' determining the sustainability of living systems (Ripl 2003). The water resources thinking has gradually broadened in the last four decades from run-off-based management to precipitation-based water management incorporating land use, focusing on multiple scales and integrating role of ecosystems in water resources management (Falkenmark and Rockström 2010). A widened green–blue approach to planning (partitioning rainfall into a green water resource as moisture in the unsaturated zone and a blue water resource in aquifers, wetlands and water impoundments such as dams, which subsequently generate flows, as green water flow from evaporation and transpiration and blue water flow including river and groundwater flows) and understanding their functions in the water cycle (regulation, production, carrier, maintaining ecosystem state) has been posited providing system view to build resilience against state shifts and tipping points which can be triggered through salinization, terrestrialization of aquatic habitats, desertification, basin closure, aquifer depletion, waterlogging and ecosystem collapse (Falkenmark and Rockström 2006; Falkenmark et al. 2019). In an era of increasing water variability and extreme events, it is argued that stationarity-based water allocation approaches may need to graduate to one that focuses on building resilience, especially preventing breaching of thresholds, which can shift water systems and society to alternate and often undesirable states (Boltz et al. 2019; Falkenmark et al. 2019; Rockström et al. 2014).

A major emphasis on water management in India has been on harnessing blue water, the run-off, using inflexible infrastructure managed often on rules determined on historical hydrological observations—which are found wanting in the face of extreme events and uncertainties imposed by climate change. A widened focus on building water system resilience considering the entire blue–green water interactions allows for addressing the inherent inflexibility of hard engineering infrastructure by bringing in the role of green infrastructure solutions which use natural or semi-natural systems to provide water resources management options (UNEP 2014). Nature-based solutions, which are inspired by nature, and use or even mimic natural processes to contribute to improved water management are at the heart of green infrastructure solutions (Nesshöver et al. 2017). These solutions include wetlands conservation and rejuvenation, and wetlands-based technologies such as constructed wetlands to address various water management issues. A preliminary mapping of suitability of wetlands solutions for different biogeographic zones of India is presented in Table 1.

Table 1 Potential for wetlands rejuvenation and conservation as green infrastructure solutions for water management issues in different biogeographic zones

Biogeographic zones	Water management issues					
	Water supply	Water purification	Erosion control	Flood control—riverine	Urban stormwater run-off	Coastal storm surges
Trans-Himalayas	+++					
Himalayas	+++	+	+		+	
Gangetic plains	+++	+++	+++	+++	+++	
Semi-arid	+++	+++	++	+++	+++	
Desert	+	++	+	+	+	
Western Ghats	+++	++	+	++	+	
Deccan Peninsula	+++	+++	+	++	+++	
Coasts	++	++	+++	+++	++	+++
Islands	+	+	++			+++

(+++ = highly relevant, ++ = relevant, + = somewhat relevant: the degree of relevance is based on the available knowledge on wetlands extent and wetlands function with respect to specific water management objective)

6 Some Integration Bottlenecks and Challenges

Integration of wetlands in water management plans cannot be treated as an additive process, wherein the policies and programmes of wetlands and water sector are simply joined together, but require a more sophisticated and nuanced, collaborative and beyond sectoral disciplinary approaches (Bracken and Oughton 2006). The issue at hand is not just about connecting two different policy areas at a single hydrological (catchment) or administrative (district) scale. Given the pervasive uncertainty (such as the manifestation of climate change on wetlands functioning as well as on extreme hydrological events, such as floods and droughts) and contested knowledge claims (such as increased need for hydrological regulation is required to address variability), the difficulty of joined-up management of wetlands and water cannot be overcome by policy and programme actors acting in isolation. The role of collaborative governance solutions is crucial for addressing challenges associated with building coherent conceptual and methodological narratives (such as wetlands degradation not just seen as tantamount to loss of critical ecosystem services, but reduced landscape resiliency to increasing water risks), and developing approaches for joint working that have potential to transform, rather than simply reaffirming segmented ways of research on natural systems and landscapes. We discuss in this section the science, policy and practice bottlenecks that hinder adoption of integration of wetlands in water management.

6.1 Multiplicity of Wetland Definitions and Management Approaches

There is a multiplicity of definition and interpretation of wetlands used by different ministries of the Government of India. The MoEFCC subscribes to the wider definition of wetlands as agreed to in the text of Ramsar Convention, yet operates multiple schemes to fund conservation of different wetland types. While the NPCA guidelines call for catchment scale planning for wetlands (MoEFCC 2019), the guidelines for management planning for protected area (Sawarkar 2005) used as a reference for wetlands designated as of location within the protected area network underplay the role of hydrological regimes and catchment scale processes. The Ministry of Jal Shakti on the other hand distinguishes between wetlands and water bodies. The National Water Policy of 2012 mentions wetlands only once, together with water bodies, with restoration efforts recommended to be directed to the latter (MoWR 2012). The manual prepared for census of water bodies uses a diffuse definition and indicates these entities to be any area of water, salty or fresh, large and small, distinct from one another in various ways (GoI 2018a). The minor irrigation census includes only those water bodies which are used for storing water or other purposes, and excludes lagoons, mangroves and other coastal systems (GoI 2018a). The Water Resources Information System of the MoWR includes information on water bodies and does not use the term wetlands at all. The Department of Land Resources of the Ministry of Rural Development in their inventory of wastelands includes several wetland categories (such as waterlogged and marshy land, land affected by salinity, sands coastal and snow glacier-dominated areas), but excludes water bodies (GoI 2019b).

6.2 Limited Effort to Translate Information on Wetlands Structure to Wetland Functions

For wetlands to be considered within water resources planning and decision-making, an inventory which renders an understanding of how wetlands function and deliver their hydrological functions may be more relevant, using approaches, such as hydro-geomorphic classification of wetlands (Brinson 1993). The classification used in wetlands inventories prepared by the MoEFCC is based on a mix of parameters, key being morphology, vegetation and inundation (Panigrahy et al. 2012; Garg 2015). This information is useful to give a broad understanding of wetlands structure and key influencing ecosystem processes. The inventory of water bodies under the irrigation census or water resources information system does not dwell much on types and instead looks at their use and water source. Inventory of water bodies prepared for use in water resources planning such as the minor irrigation census or river basin atlases tends to obfuscate wetlands types clubbing them into ecologically meaningless categories.

6.3 Simplistic Extrapolation of Wetland Functioning

The hydrological functions of wetlands are often communicated in generic terms based on simplistic extrapolation of site and wetlands-specific evidence into more generalized statements which give an impression that all wetlands perform similar hydrological functions in all landscape settings (this issue has been aptly highlighted in McCartney and Finlayson 2017). The ability of wetlands to moderate flow regimes is closely linked with soil condition, in particular, the extent of saturation and relative location within a landscape (Bullock and Acreman 2003). Wetlands located in highly saturated headwaters may become a source of floods, rather than acting as a sponge, as is widely believed (Acreman and Holden 2013). In similar lines, there are nonlinearities in storm surge buffering capacity of mangroves, and extreme events with very high water levels and wind speed may actually end up damaging and even destroying mangroves, thus rendering their coastal protection value less effective (Narayan et al. 2016). Knowledge of how wetlands function within a landscape and deliver their hydrological buffering services is crucial for managers and policy planners to pursue integrated approaches (Thorslund et al. 2017).

6.4 Wetlands as 'Water Users'

Evapotranspiration usually forms a significant component of water budget of wetlands, and from the water resource perspective, it is often considered as a 'water loss'. The subcommittee on surface water management in its report for formulation of National Water Mission places water use in wetlands to be amongst the highest amongst all options, compared with irrigated agriculture (GoI 2008). Such a fragmented view of water misses the point that water flowing through wetlands provides the wide-ranging ecosystem services such as food production and climate regulation, and thereby the disjunct between run-off and evapotranspiration is actually about the role of water in meeting human needs through built infrastructure and natural infrastructure. It is the complementarity and coupled nature of water whether it is available as a run-off, or moves through ecosystems in an evaporated form that enables delivery of different functions of the water system.

6.5 Capacity Gaps

Cooperation between water and wetland management sectors is often limited due to inability to describe, quantify and communicate interests, objectives and operational requirements. Wetland managers need a sufficient understanding of the technical and operational aspects of water resources management to understand the methods of articulating and quantifying the requirements of wetland ecosystems in metrics and parameters used by water managers. Further, they also need to know the mechanism of working with water managers to be able to define operating rules and flow regimes that represent the optimal allocation of water between multiple uses, including ecosystem maintenance. Similarly, water managers require a quantitative understanding of the hydrological services of wetlands and the water regime required to maintain these services. The training systems and institutions for water and wetlands hardly overlap, and thereby, siloed thinking on water and ecosystems prevails and is frequently contested upon in policy and programming decisions. With climate change as a pervasive issue across several sectors, conventional training may be insufficient. For wetlands managers, water allocation decisions for restoration determined using historical hydrological regimes may be rendered unfeasible objectives under climate change, and the emphasis on species-focused water allocation may need to include ecosystem functions and services (Capon et al. 2018).

6.6 From Balancing Water Uses Across Sectors to Addressing Water Risks

While the practice guidelines within wetlands are built around the assumption that integrated water resources management provides the necessary policy and programming platform, its realization in India has been contested given the wholesale reforms needed, especially demand management in informal arrangements (Shah and Koppen 2006). While the emphasis on integrated water resources management has been continued in water sector policies and programmes, full-scale realization may be distant, also given the complexities induced by climate change (Moomaw et al. 2018). Increasing variability in water availability and extreme events may need focusing on water risks and water system resilience building, rather than focusing on water allocation challenges.

7 In Conclusion

India's quest for sustainable development is closely hinged on achieving water system resilience. The historical divide between water and wetland sectors, if it has to be paraphrased, is one of viewing water more narrowly from where it can be used, against a fuller understanding on how water moves in a landscape and performs various developmental and ecological functions shaping resilience. Water resource challenges that India presently faces are not limited just to water allocation for various uses but are also about balancing water for food, development, nature and society. The current paradigms of managing water from where it is sourced (surface water or groundwater), where it is used (agriculture, water supply, hydropower and others), technology (dams, reservoirs, canals and tanks) and social equity (the share of accessible water to a particular societal group and geography), preclude a unified vision of water. Given the coupling between land use and water use decisions, the need to widen the scope of integrated water resources management to include land management aspects is pertinent. With wholesale reforms as required to realize integrated water resources management being a difficult terrain, a beginning can be made by thinking on specific issues and challenges, such as managing floods and droughts, or improving water use efficiency in food production.

Integration of wetlands in water management plans is also not about pitting grey and green infrastructure, but achieving complementarities and synergies. While making water infrastructure decisions, a beginning can be made by examining whether green infrastructure solutions such as wetlands can deliver the desired water resource outcome, and then filling the gap that may still exist by a grey-green combination. A harmonized understanding of wetlands and their hydrological functions in a landscape is the foundation step. The science base on wetlands will need to graduate from being dominated by describing ecosystem structures and processes to providing quantitative assessments of hydrological functions, in usable forms and terms suited to water sector policy-makers. Wetlands managers will also need to have the capacity to describe water regime requirements of wetlands to perform these functions while acknowledging that climate change may render historical regime information insufficient to inform about the future course of actions. For water managers, the role of wetlands will need to evolve beyond just an allocation decision, to understanding water as it moves in a landscape, and the role wetlands play in influencing this movement. A natural convergence point is to plan at a catchment scale, wherein the landscape and water interactions can be assessed and planned for meaningfully.

With water sector going through a significant reorganization, an important question to ask is whether wetland management will be better off if brought within administrative frame of the former? The answer, unfortunately, is not a black-and-white one. In case water sector continues its focus on water storages, such a move may be highly retrograde, as only few wetlands and a narrow set of ecosystem functions of wetlands are likely to be considered. On the other hand, when located within the stable of MoEFCC's programmes, wetlands become a silo of their own and get relegated to one of the several sectors that water planners need to consider and provide for in allocation decisions. The answer, perhaps, lies somewhere in between; placing wetlands in either sector does not matter, till the full ranges of ecosystem services and biodiversity values of wetlands are considered and secured in developmental planning and decision-making.

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Data Usage for Development, Management of Water Resources

Ashwin B. Pandya

Abstract Challenges in water development and management are many and well known. With population growth, urbanization and industrialization, the challenges in water management are getting more complex. Likely impacts of climate change would, undoubtedly, add to these complexities. Unlike other resources, water management poses additional challenge of randomness of occurrence and distribution in space and time. For a geographical and meteorologically diverse country like India, many issues and concerns cannot be handled properly unless efforts are backed by sound data and conclusions drawn there from. Generally, at the planning level, the resource availability of data is of prime concern. However, for efficient management in real time, it is necessary to harness the usage data at the same level of frequency and accuracy as the resource data. Collection and processing of data also assumes prime importance for resource allocation amongst competing political and administrative entities and is the key parameter upon which the entire adjudication process relies. However, this underlying importance is not appreciated by the planning and economic communities in general, and accordingly, the field is rather neglected. The neglect leads to gaps in the data and knowledge base. Multiple jurisdictions and domains delineated by the federal structure of the constitution and governance of the country affect a unified data strategy. Lack of such strategy will lead to wrong priorities in planning and deployment. The chapter describes data requirements, provisions enabling collection and processing and status of availability. New technologies and approaches available for handling constraints generated out of multiple jurisdictions and conflict of interests are also highlighted.

Keywords Develop and management of water resources · Water data scope · Data management strategies · Challenges of maintenance of national water data · Data-based judgements

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1 Introduction

Unlike any natural resource, water resources are finite though cyclic. The hydrological cycle continuously renews the available water and keeps on providing us with the much needed life giving resource time after time. The cycle is not uniform like that of diurnal time and has random variations within it; there is also a multitude of cycles. On the other hand, demands of life are largely constant at the unit level. We need fixed quantum of water at fixed points in time to sustain our food and energy security regimes. There is a need to realize that water is a physical resource and not an abstract resource like money. When we deal with a physical resource, our strategies have to be built on the foundations of data—of supplies and demands and their interplay with other physical resources like land, food and fibre. Whereas other resources are attributed monetary values and, thereby, provided with abstract formulations, water is traditionally not dealt in this manner. Being a common pool resource, it has to be allocated amongst various stakeholders in a rational manner, else, there can be societal imbalances and tensions. Quantification of such apportionments requires information about the temporal and spatial availability and utilization priorities. Such quantification cannot be made without support of data. However, the availabilities are random, being dependent upon climate phenomena, which are not fully understood, and the limitations of such knowledge have to be compensated by treatment of the same as a random resource.

When we are dealing with the random resource, we also realize that the randomness is not confined to time alone but across space as well. Not all areas of a region are equally well endowed with water. Some areas have in plenty and struggle with the problem of surplus, while other areas are not capable of maintaining the quality life as we all have collectively set as a standard. In such an inequitable availability regime, our constant endeavour is to provide an equitable supply regime for everyone as per their needs.

In order to solve this problem, we need to find trends and opportunities of harnessing the water supply so as to make it available for our sustenance and progress. Most of the processes of nature responsible for supply of water are too complex to model in a deterministic sense. Hence, there are no unique solutions that can be generated in mathematical terms. Granularity of water usage is also a challenge. Every agricultural field (some times even parts of the same field) is a unique response unit for water consumption. Similarly, each house hold and each industrial unit are also unique in this sense. Similarly, each parcel of land of a catchment area is a unique element having its own response characteristic towards generating the surplus out of the precipitation that it receives. The atmospheric process of precipitation is having its own complexity, which is well known.

Thus, we are required to resort to an observational approach where we observe the phenomena (in this case water availability and consumption) and attempt to find trends which can provide us clues about the match between demands and supplies. Observations result in data of diverse kinds. Each of the class of data has to be correlated with the other data sets so as to find the cause-and-effect relationships.

Water resource projects, which form the atom of the entire management chain, are costly and difficult to execute. The projects have to have a sound basis of planning so as to ensure that the economic resources that are being poured in provide the intended results. Also, being random in nature, we need to worry about the performance of the project on a hydrological cycle basis so as to ensure that the benefits being provided do not swing from one extreme to another but provide a stable supply regime for sustainability of the developments depending upon the water availability.

There is lot of discussion on the economic and social justifications and desirability of a particular type of intervention, especially in the policy and advocacy sphere where the interaction with other social sciences takes place. However, in most of such formulations, the underlying role of observational data and the scenarios generated out of them is missed. The appreciation of adequate time-length of observations and the diligence required for each observation is also missed. To complicate matters, the solutions are non-unique and a generous mix of projections can lead to multitude of conflicting interpretations of the same data. Such issues provide a nightmarish situation at the time of adjudication and allocations.

It is, therefore, necessary that the importance of sound quality assured data and processing methodologies resulting in rational solutions is appreciated not only by the scientists and engineers but all the communities in general. During the course of further discussions, we will attempt to understand this requirement and find solutions to them.

2 Data Typology Required for Water Management

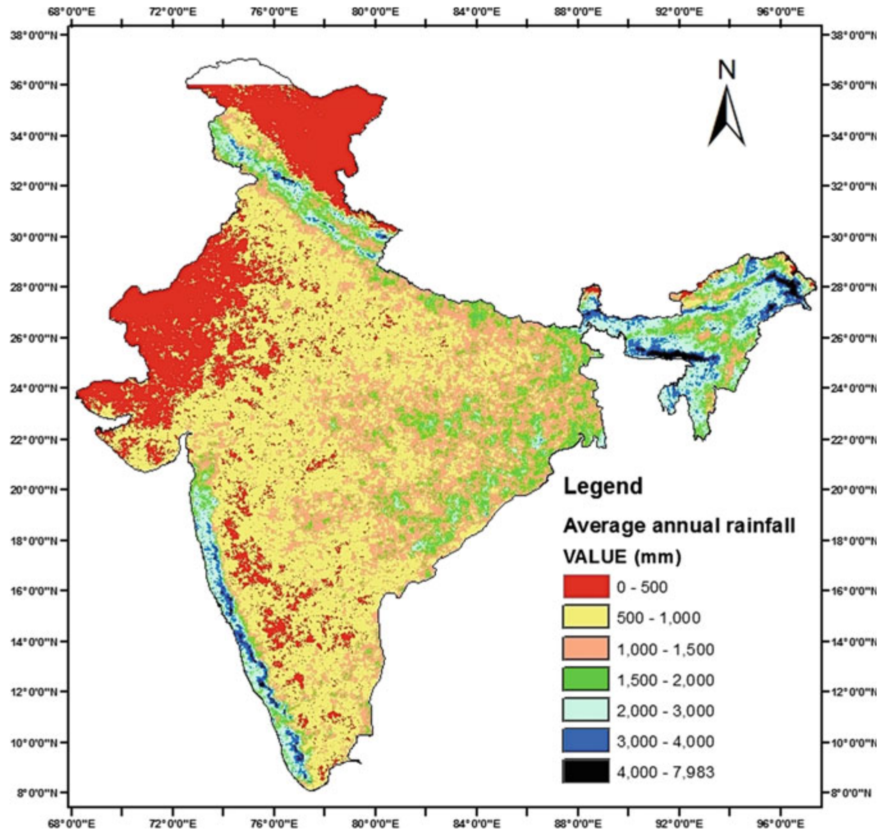
Water management is a multi-disciplinary field. It requires data from all associated fields of meteorology, hydrology, topography, geology, agronomy, regional economy, environment and habitats, land use patterns, etc. There are many other associated specialized fields like geotechnical engineering and specialized material and techniques which are needed to be explored for water management solutions. Each of the areas described above are specialisations in their own right, and water resources management touches them with various levels of depths. How various data types play a role in various areas of water management is described below.

2.1 Precipitation

The prime source of water on land is atmospheric precipitation of all types, i.e. rainfall and snowfall. The occurrence of precipitation is a meteorological process affected by the topography and global circulation patterns of the atmosphere. This being one of the basic natural process is highly complex, and discerning trends and patterns are of utmost importance in view of primacy of the data in determining water resources regime over a specific area. The precipitation is affected by the seasons and monsoon phenomena for Indian sub-continent. The patterns of rainfall vary greatly and accordingly the water availability across the country. The map below depicts the average annual rainfall patterns over the country. As can be seen that India has areas having highest rainfall in the world of the order of 15,000 mm and also areas having hardly 500 mm rainfall in the entire hydrological year.

The precipitation patterns vary over the season as well as across the years. Generally, it is observed that the precipitation occurs in the form of episodes separated by different random time intervals. This is due to essential convection patterns of the atmosphere which are governed by the monsoon phenomena. This leads to droughts and floods in the affected areas. It is, therefore, necessary to understand the patterns of the precipitation for any water management planning.

Generally, it is observed that the seasonal precipitation fluctuates randomly around a mean value established over long period of observations. This provides a dependable value providing an estimate of the chance of a specific precipitation value occurring over a time slot. However, for this purpose, it is necessary that the rainfall observations are collected over a long period of time which can take into account the variations in the atmospheric processes which may have very long cycles.



It is necessary to appreciate that the rainfall, though an aerial event, is measured as a point sample over large area. The conversion of the point values to the aerial estimates is a complex process. Many a times, it is observed that the point estimates are directly used for making assessments of precipitation available for an area. Such estimates have a strong probability of falling off the rational range over which reliable planning can be performed.

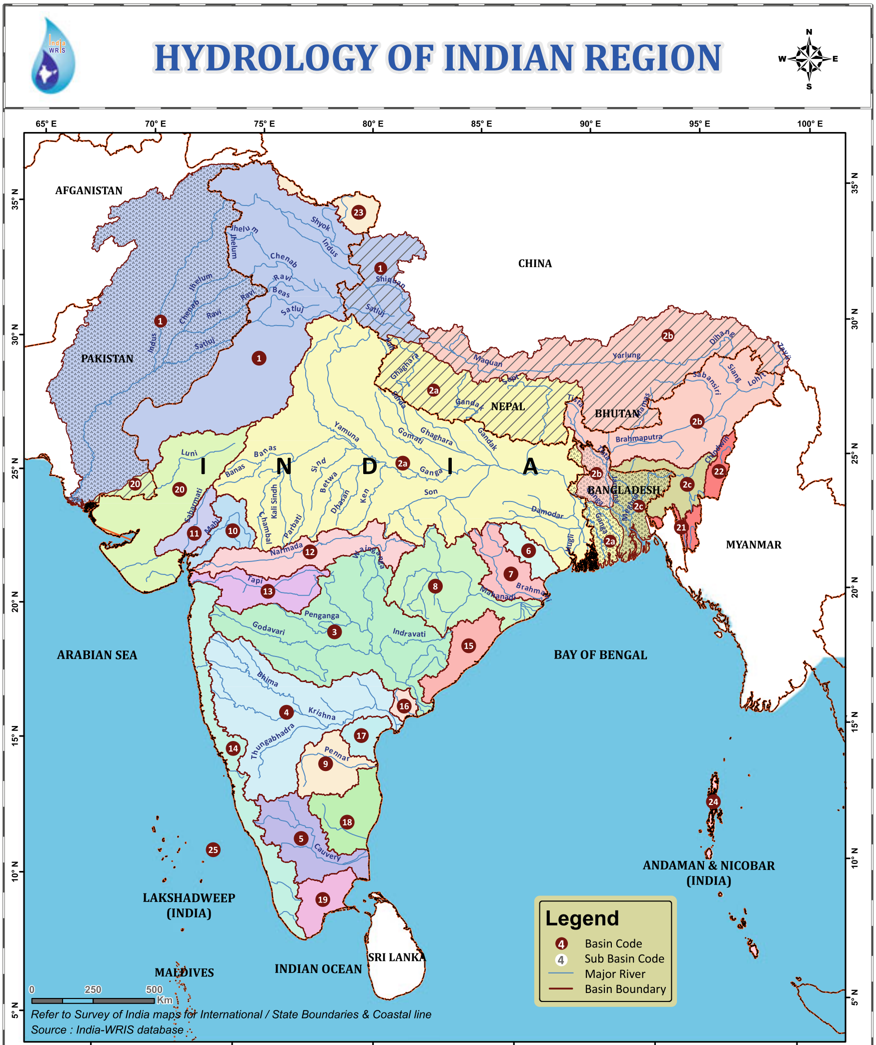
While cumulative precipitation over seasonal time periods is good for working out the yields, but the same is not adequate for flood risk and disaster management purposes. Much better sampling frequencies are required for assessing the flood risk in monsoon period. All these lead to requirements of sampling, transmission and processing turnarounds.

2.2 *Resource Yields*

Once the precipitation hits the ground, the resource yield in its utilizable form takes shape in form of surface water. Some of the surface water is absorbed by the ground and becomes groundwater in varying quantities depending upon the infiltration capacity of the ground and the rate at which the rainfall occurs. Since the opportunities of management and utilization of resource are different, they are treated as two different resources as far as technological and management regimes are concerned though they are dependent upon each other. In an overall water management scenario, they are like two verticals of a business where both may support each other, and the internal management and implementation mechanisms operate independently and come together at the time of finding final outcomes of the effort. Therefore, the policy planners have the tendency to lump them in one basket, and the operational strategies require them to operate in their own domains.

2.2.1 Surface Water

Surface water basically occurs in the form of flows in the natural rivers of different magnitude and order and eventually connects to the sea where the water which has not evaporated through evapo-transpiration process or consumptive evaporative processes of industries and other societal activities or has been regenerated out of surpluses of groundwater goes at the end of land phase of hydrological cycle. Flows are also generated out of snow melt which is another form of atmospheric precipitation. Being a largely tropical country, the contribution of snow melt in non-Himalayan basins is non-existent and even in Himalayan basins, varies greatly depending upon the topography and elevation ranges being drained. It is observed that the contribution of snow melt yield as a proportion to rainfall-based yield goes on decreasing along the river basin as we progress towards the alluvial reaches of the river.



Area of Trans -boundary Basins

Basin Name	Basin Area* (km²) India	Basin Area Upstream of India	Basin Area downstream of India	Total
Ganga	804032	180640	32036	**1016708**
Indus	453941	308597	28294	**790832**
Brahmaputra	186421	98201	596718	**881340**
Barak and others Basin	45622	-	52502	**98124**
WFR of Kutch and Saurashtra including Luni	184745	13056	-	**197801**

* Area calculated under India -WRIS

Flow measurement in various streams and channels is governed by various principles of hydraulics and hydrodynamics and is known as hydrometry. The hydrometry has been practiced since long in the country, and the status of the same is discussed subsequently.

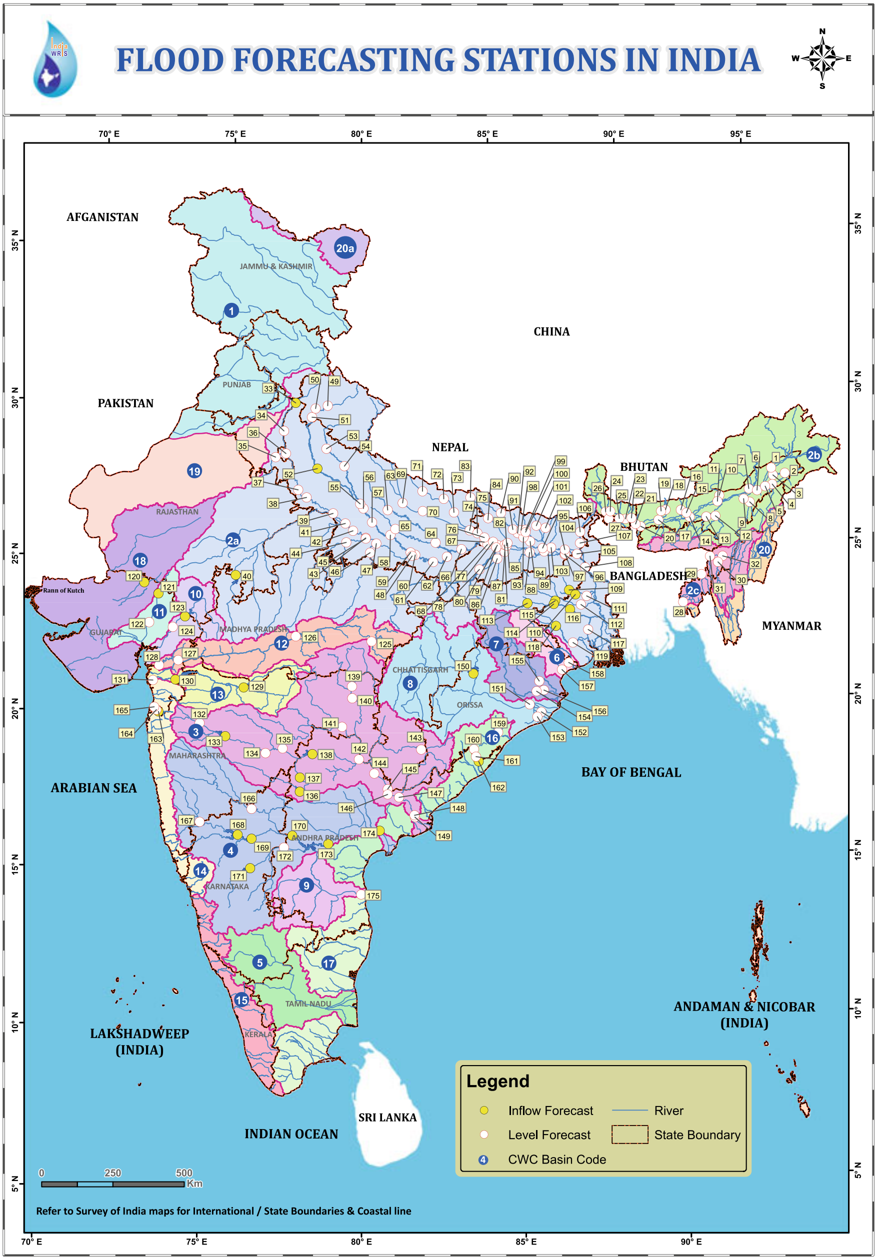
The surface flows are strongly affected by the precipitation phenomena and are also random in nature in line with the precipitation. It becomes necessary to have data lengths of appropriate lengths in order to arrive at a reasonable assessment of the yield again based on stochastic concepts as well as on the basis of hydro-meteorology of the basin. For the purpose of yield assessment, the volumes that are available in a given interval of time become quite relevant, and assessment of yields in intervals of week, 10 days, month or year is common. However, it is required to be understood that the longer the time interval, the anomalies within the intervals are levelled out, and any disaggregation of the data for planning at a smaller interval is fraught with risks of failure.

2.3 Disaster Preparedness and Management

Water is not merely associated with beneficial uses but also is a cause of disasters like floods and droughts. Especially, the floods which still occur regularly over the large parts of eastern and north eastern India require management in real time for generating advance warnings and putting relief measures in place.

Floods are primarily caused by the surface flows, and the occurrence is generally confined to the monsoon period of the year. Measurement and assessment techniques require extensive surface water flows data in real time so as to make a prediction about the eventuality of submergence and damage to land and people. Rainfall and surface flows data collected in real time in key catchments and streams provide most important measurements. While the yield assessment exercises require the measurement frequencies of once in a day, the floods management in real time often require measurements with frequencies of once an hour. Disaster management also requires additional data in terms of topography, facilities and land use for assessing the potential effects and also planning for the relief measures.

2.3.1 Regional Flood Management



Floods over large regions are a characteristic of Ganga basin as well as flood plain portions of middle and lower Brahmaputra valley. Other parts of the country especially the deltaic regions of Krishna, Godavari, Mahanadi and other large basins and some coastal areas prone to cyclonic storms also require regional flood management. Weather data and especially rainfall data collection in real time and its use for the simulation of the probable flood event is quite important. The data of releases from the reservoirs lying at the head of the catchment also assumes great importance. In case of low lying areas near the coast line require state of tides and seal levels at the time of flood as a crucial input for handling the inundation in the region. The data pertaining to water is of prime importance in flood management as it provides vital clues about the temporal and aerial spread of disaster and its relative magnitude. This input is very valuable for the disaster preparedness and management activities.

2.3.2 Urban and Peri-Urban Flood Management

Urban flooding has come up as a special disaster which has many similarities but crucial specialities which the conventional regional flood management does not have. With growing urbanization, the percentage of population residing in urban conglomerations is approaching 50%, and a very large segment of this population resides in vulnerable areas of slums and unauthorized colonies largely located in low lying areas and near the banks of rivers and drains.

In urban flooding scenario, the phenomena is much more of drainage congestion rather than the extreme flooding due to intense rainfall. Drainage capacity plays an important part in determining the flooding extents. The granularity of the rainfall data is very important as the aerial extent is generally limited, but the affected population is very high due to high population densities in urban areas. Many of our large cities namely, Mumbai, Chennai, Kolkata and Surat are lying in poorly draining coastal areas. In most of the cities, the real-time information about the carrying capacity of the natural drainage network is required to be assessed regularly for anticipating the flooding problems. Oftentimes, the developments obstruct the natural slopes in the catchment areas of the drains leading to flooding.

As witnessed in case of flooding episodes in Chennai and Surat, the operation of reservoirs lying on the upstream of the cities in the basin and coordination with the urban authorities is of great importance. Data flow mechanisms coupled with simulation models are important. Since natural extreme events are rare, the data collection and transmission systems are not well oiled and leave gaps in performance.

2.4 Utilization Planning

This is the most important aspect of water resources. Water, in its natural form, is not utilizable unless its flow is diverted or managed in order to meet the requirements of demanding sectors of agriculture, industry and life forms consumption including aquatic life. Generally, the interventions are planned in terms of projects of various sizes with smallest at field level and larger ones extending the management across millions and thousands of hectares.

We have already discussed the data requirements for yield assessment which are directly consumed here. However, apart from that, there are additional data requirements which are needed for planning a sustainable project. For any conservation project, the risk is posed by the floods and earthquakes. In case floods, the data related to past storms and flood wave generation characteristics of a catchment area is important inputs which determine the flood risk posed to the project at varying degrees of probability. Large structures are difficult to replace and also pose hazard to the downstream areas if the unregulated releases are made from them, and very low probabilities and consequent risks have to be provided for in terms of capacity. For small structures whose complete loss will not pose any significant hazard and the replacement of the same can be handled without very high investments can provide for relatively higher probability flood values which are lower in magnitude. Similar is the case for providing for the earthquake risks. For large projects having significant hazard potential, seismo-tectonic data is needed with geotechnical characteristics of the foundation and reservoir area for assessment of the risk at different probabilities as described in case floods.

For sizing the project, the demands and supplies have to be matched at appropriate probability level, and accordingly, the estimate of demands from the all sectors of the beneficiary region is required. This matching is of crucial importance for the success of the project and is often skewed due to various social pressures.

Project planning also involves data from a large number of associated domains, and being specialities themselves, we will focus on the data types directly associated with the water here.

2.5 Agricultural Water Consumption and Demands

Data from agricultural water requirements carries most weight not only in planning but also in real-time operation of the agriculture operations with success. Agriculture occupies largest share of consumptive demands for food and fibre security.

Consumption of the water by crops depends upon the type of crop and its variety, climatic conditions, input in the form of natural rainfall over the area, soil characteristics of the fields and also the methods of application of water to the crops. The data varies from field to field and even within the field if multiple crops are being grown.

These data sets are very important for handling the irrigation schemes in real time. The resilience of the particular type of intervention is measured by the capacity of the scheme to handle the shortfalls with minimal impact on crop growth. The data also determines one of the sides of the most important demand–supply equation. However, the data is very difficult to come by in view of the competing sectors and competing political and social entities demanding as large a share as possible so as to ensure the security of their investments.

2.6 Urban and Industrial Water Management

Urban water management requires the data on the similar pattern as that of agriculture water management above but also needs to concern about its chemical and biological composition. The quality assumes great importance. Unlike agricultural water management, where the beneficiary area can be tailored as per the resource availability, in case of urban water management, information about alternative or augmenting sources of water is needed.

It has been observed that the urban land use planning has the tendency to vary greatly and that impacts the consumptive demands by having greater population densities compared with the earlier plans. The actual demand that may be encountered keeping in view the trends in development on the ground is necessarily required as input for any development and management exercise.

Another major impact of the urban water management issue is the effect on the water quality through its effluents. It has been observed that about 80% of the supplied water is returned as poor quality water needing extensive biological and chemical treatment. The causes and impact is multi-dimensional and needs data pertaining to water usage in various areas, catchment areas of the sewage treatment plants, if any and also the type and nature of industries operating in the urban areas.

Many industries like thermal power generation, agro-processing industries including paper and pulp, chemical, drugs and fertilizer industries, cement manufacturing, coal processing and steel industries generate considerable of effluents which pose serious water quality hazards of the natural waters. Quality management requires data on the treatment methodologies employed and real-time performance of the same.

3 Status of Data Collection at Union and States Level

As per the constitution, the responsibilities for development and management of water resources rest with the states subject to the provisions of Entry 56 of List I by which the development and management of interstate river basins are entrusted to the union government. Since large parts of Indian peninsula are covered by basins which are interstate in nature, central government through its specialized agencies, namely Central Water Commission and Central Ground Water Board, collects and maintains such data as is essential for planning and management of interstate river basins and assessing the status of groundwater in various parts of country. Precipitation is of utmost importance, and historically, India Meteorological Department (1875 onwards) collects and processes data in addition to other climatic and lithosphere data. Historically, the longest length of data for water resources is available with these central agencies. Other key data like geological, soil characteristics and topographical information is collected and provided by Geological Survey of India (1851 onwards), National Bureau of Soil Survey and Land Use Planning and Survey of India (1767 onwards), respectively. Specific data on water resources is also collected, processed and managed by National Remote Sensing Center since 1969 onwards. Each of these agencies collect and provide extensive data sets which are very valuable for planning and managing water resources.

Apart from the systematic long-term data collection, State Governments and project developers and implementers especially in case of hydropower collect short-term data specific to the project sites. This data is primarily collected for the immediate project report preparation basis and is correlated with the other long-term data for planning.

3.1 Surface Water Data

3.1.1 Data Collected by CWC

1. Following hydrological data related to surface water is collected at CWC Hydrological Observation (HO) sites:
   (i) River water level (Gauge, *G*),
   (ii) River discharge (Discharge, *D*),
   (iii) Sediment flow (Silt, *S*) and
   (iv) Water quality (Quality, *Q*).
2. Besides hydrological observation, CWC also observes some selected sites, selected meteorological parameters such as rainfall, maximum–minimum temperature, humidity, pan-evaporation, solar radiation and wind velocity on some specific sites.

3. The general frequency of hydro-meteorological data collection is

(i)	Gauge water level (non monsoon)	– Daily at 08:00, 13:00 and 18:00 h
(ii)	Gauge water level (monsoon)	– Hourly
(iii)	Discharge	– Daily
(iv)	Sediment	– Daily
(v)	Water quality	– Ten-daily/monthly
(vi)	X-sections of the rivers	– Pre-monsoon and post-monsoon
(vii)	Meteorological data	– Daily/hourly

4. Thus, the hydro-meteorological information available with CWC is

(i) Daily discharge values (including velocity, manning's "*n*" values, rating curve, etc.) both observed and interpolated/extrapolated and any analysis or derivation of the values like yearly/monthly/ten-daily flows, etc.
(ii) Gauge values/water levels observed at uniform time interval or non-uniform time interval.
(iii) Suspended/bed sediment flow values including fine, medium and coarse sediment, both observed and interpolated/extrapolated. Any analysis or derivation of the values like yearly/monthly/ten-daily flows, etc.
(iv) Water quality parameters observed at site or analysed in the laboratories.
(v) Cross sections, longitudinal sections, other topographical information and river morphology-related data.
(vi) Reservoir water levels and live storage position
(vii) Meteorological data such as rainfall, maximum–minimum temperature, humidity, pan-evaporation, solar radiation and wind velocity.

3.1.2 Dissemination Policy for Hydro-Meteorological Data

From the point of view of data dissemination, the country can be divided into following three regions;

(i) Region-I: Indus basin and other rivers and their tributaries discharging into Pakistan;
(ii) Region-II: Ganga–Brahmaputra–Meghna basin and other rivers and their tributaries discharging into Bangladesh/Myanmar and
(iii) Region-III: Remaining other rivers and their tributaries.

The data of Region-I and II is classified except data mentioned under Para 3 below, whereas the data of Region-III is unclassified.

The reservoir water level, live storage position, water quality, groundwater and meteorological data for all regions are unclassified. Similarly, all metadata (information about data, sites, OWs, etc.) for all CWC HQ sites and CGWB OWs including yearly average data and historical important data (such as highest flood level, yearly flood peak, etc.) are also unclassified for all regions.

3.1.3 Flood Preparedness and Flood Forecasting Network

The flood season for Brahmaputra, Barak, Teesta, Jhelum and their tributaries starts on 1 May 2020, and for rest of the basins, it starts on 1 June. Flood preparedness meeting with Headquarter through Video Conferencing for B&BBO (whole basin jurisdiction), T&BDBO (for SID Gangtok and LBD, Jalpaiguri), IBO (for Jammu Division) has already been held on 22 April 2020, and for other organization, it will be held in the month of May. All the flood preparedness works for starting the Central Flood Control Room (CFCR) of DoWR, RD&GR and the Divisional Flood Control Rooms (DFCR) have been completed.

Water Management Information System (WIMS) software for Flood Data Entry has been readied, water level of FF stations, base stations, reservoirs will be fed by all the DFCR, and Daily Flood Bulletins will be shared with all stakeholders from 1st May onwards. The new Website which is being developed under WIMS is progressing. However, if the development is not fully done by 1st May, the old Website will be made operational till the new Website is fully operational satisfactorily. All social media platforms for flood related information viz. Facebook page (@CWCOfficial.FF), Twitter handle (@CWCOfficial_FF) are in all readiness. At regional level, organizations have been informed for use of WhatsApp Group for sharing the information between project authorities and State Government.

All the three-day advisories models have started functioning, and the Website is made operational for use by all stakeholders. Regional models are also being developed for use in respective organisations so that the regional models can be run from the divisions itself and forecasts are issued based on the consensus between statistical model and mathematical models.

M/s Google has targeted to increase the number of inundation alert areas to at least 3 times of the present area and cover at least 20 more FF stations during the year in various basins.

Work of issuing CAP alert being developed by NDMA in collaboration with Centre for Development of Telematics (C-DOT) will be done on experimental basis in the State of Tamil Nadu during this year for which necessary training has been imparted to incumbents in CFCR.

Details of state-wise/basin-wise/organisation-wise flood forecasting stations and telemetry stations is given in Tables 1 and 2.

Table 1 Basin-wise flood forecasting stations

S. No.	Major interstate river systems	FF stations as on date		
		Level	Inflow	Total
1	Indus and its tributaries	3	0	3
2	Ganga and its tributaries	94	39	133
3	Brahmaputra and its tributaries	39	5	44
4	Barak system	6	0	6
5	Subarnarekha (including Burhabalang)	4	3	7
6	Brahmani and Baitarni	3	2	5
7	East Flowing (Mahanadi to Pennar)	4	4	8
8	Narmada	4	6	10
9	Tapi	1	2	3
10	Mahi	1	4	5
11	Sabarmati	1	1	2
12	Mahanadi	3	3	6
13	Godavari	18	22	40
14	Krishna	5	17	22
15	West flowing rivers (Kutch and Saurashtra)	1	1	2
16	West flowing rivers (Tapi to Tadri)	2	1	3
17	Cauvery and its tributaries	3	9	12
18	Pennar	1	1	2
19	East flowing rivers (Pennar to Kanyakumari)	1	6	7
20	West flowing river (Tadri to Kanyakumari)	3	2	5
	Total	197	128	325

3.2 Groundwater Data

The CGWB is the principal agency responsible for assessment of groundwater potential and its exploitation in the country, as well tracking trends in its utilization. It has done a considerable amount work to develop, test and refine the conceptual framework and estimation procedures for this purpose. It has assessed the volume of renewable groundwater resources generated by direct recharge from rainfall and indirectly on account of lateral seepage from rivers, streams, water bodies and canals.

These estimates are based on field studies of recharge rates under different agroclimatic and geological conditions. In addition, the CGWB (along with the State Boards) monitors the behaviour of water levels in over 50,000 observation wells across seasons and over the years. Studies on a more limited scale are being done on the estimation of several other aspects (delineating and mapping of aquifer disposition, specific yield, extraction rate and groundwater quality) relevant for groundwater potential and use.

Table 2 State-wise flood forecasting stations

S. No.	Name of State/UT	Number of flood forecasting stations		
		Level	Inflow	Total
1	Andhra Pradesh	10	9	19
2	Arunachal Pradesh	3	0	3
3	Assam	30	0	30
4	Bihar	40	3	43
5	Chhattisgarh	1	2	3
6	Gujarat	6	7	13
7	Haryana	1	1	2
8	Himachal Pradesh	1	0	1
9	Jharkhand	2	15	17
10	Karnataka	1	14	15
11	Kerala	3	2	5
12	Madhya Pradesh	2	10	12
13	Maharashtra	8	13	21
14	Odisha	12	7	19
15	Rajasthan	2	11	13
16	Sikkim	3	5	8
17	Tamil Nadu	4	11	15
18	Telangana	5	7	12
19	Tripura	2	0	2
20	Uttar Pradesh	39	5	44
21	Uttarakhand	4	2	6
22	West Bengal	12	4	16
23	Daman and Diu	1	0	1
24	NCT of Delhi	2	0	2
25	Jammu and Kashmir	3	0	3
	Total	197	128	325

Based on these data, estimates of groundwater potential and utilization as well as secular trends in water-table levels are estimated and mapped at the block level.

Aquifer mapping is a process wherein a combination of geologic, geophysical, hydrologic and chemical field and laboratory analyses is applied to characterize the quantity, quality and sustainability of groundwater in aquifers. There has been a paradigm shift from “groundwater development” to “groundwater management”. An accurate and comprehensive micro-level picture of groundwater in India through aquifer mapping in different hydrogeological settings will enable robust groundwater management plans at the appropriate scale to be devised and implemented for this common pool resource.

The outputs and of aquifer mapping will be both scientific and social. Some of the scientific outputs include

Disposition of Water Bearing Formations: Surface outcrop, subsurface continuity in vertical and horizontal disposition, overlay of different litho units to form a group and aquifer system, e.g. alluvium—gravel, sand, silt and clay in different percentage underlain by compact sandstone,/shale, hard rock, etc.

Water Bearing Capacity Variation with depth: Changes in space and time, runoff zone, recharge zone, discharge zone and abstraction status.

Aquifer (Formation water) Quality: In-situ (depositional), anthropogenic, vertical zonation and blending/migration of pollutants in aquifers with time.

Strategies for Sustainable Management: Quantification of water within different layers (Aquifers-1, 2, 3, etc.), quality in each aquifer (group), demand–supply analysis, estimation of prevailing development status, precise assessment of functional wells for agriculture, industries, drinking water purposes (modified well census as village wise by public participation to be translated into aquifer wise and then administrative unit).

Identification of Clusters of Aquifers (layers): Vertical–horizontal flow of recharged water from source—rainfall, canal, applied irrigation, etc.

4 Role of Remote Sensing Applications for Water Resources Data Collection and Visualization

With the advent of satellite-based remote sensing methods, a new and promising mode of data collection and analysis has been available. With Indian space programme taking off from 70s, greater sophistication is being introduced in data collection for various natural resources fields. Incidentally, the water resources field has been an early mover in the area coupled with the crop assessment technologies. Key to the success of remote sensing-based methods lies in their ability to provide large regional data at varying degrees of resolution which are valuable in real-time assessment as well as planning. Many features like crop coverage, water stress amongst the crops on the ground, assessment of snow pack yield forecasting and flood disaster mapping and near real-time situation report are the valuable products provided for water resources management and planning in long term as well as in the immediate context. In addition, the land utilization and land cover mapping applications also provide very valuable information for realistic planning of the water resources projects.

Remote sensing has not remained confined to satellite-based data acquisition only. With the advent of drones and microlight aircrafts, the data collection at the local level has been revolutionized. Assessments at the field level for the precise information at sub-field level on crop conditions, reach of irrigation and status of conveyance networks have been successfully made. Drones are also efficient in carrying out topographic surveys and monitoring progress over widely spread construction sites and are capable of providing real-time information.

Processing and visualization and quantification of the data have been particularly benefitted by the Geographical Information Systems, and nowadays, RS-GIS has become inseparable twins for planning, especially the water resources planning. Migrating to aircraft and of late drone-based surveillance technologies using the similar principles as that of satellite-based remote sensing has enabled planning exercises to come down to much greater atomic levels almost to the individual fields and villages.

5 India Water Resources Information System

One of the biggest achievements of assembling of a wide variety of data sets on a single platform for water resources applications has been achieved jointly by National Remote Sensing Center and Central Water Commission in form of Water Resources Information System (WRIS) Portal available at https://indiawris.gov.in/wris/#/.

The portal has achieved integration of the resource data as well as the utilization data in a holistic manner. The remote sensing assessment has been capable of visualizing the various parameters like

- Status of water flows available at various locations subjects the classified data policy and locations of measurement stations
- Major and medium water resources project locations and their command areas across the country especially those covered by erstwhile Accelerated Irrigation Benefits Programme and now Pradhan Mantri Krishi Sinchai Yojana
- An inventory of water bodies above 0.1 ha surface area all across the country
- Land use and land cover information for the country
- Basin and sub-basin boundaries with watershed atlas for the country
- In all, there are 32 layers on the Web GIS platform covering associated information relevant to water resources assessment, planning and operations.

The portal is a very essential first step in the direction of integration of the water resources data across the sectors and platforms. However, as has been pointed out earlier, the information is dynamic. Many of the parameters like land use project command areas and other associated infrastructure information keep on varying with developments taking place over time.

Having created the base layers at great effort and cost by Central Water Commission and National Remote Sensing Center, the same is now required to be nurtured under the newly established National Water Informatics Center. The value of information lies in having a specific time period which can be considered reasonable for the planning and assessment purposes. Active cooperation of states is needed for upgrading the information about the utilization. With a large geographic area of the country, it is necessary to keep the spatial resolution of the database within limits so as to provide reasonable response times during Web operations. For this purpose, it is worthwhile to develop state-wise or basin-wise information systems in which data at a higher level of precision can be incorporated and exchanged across portals on a demand basis. A strategy to this effect is required to be put in place. Already, some of the progressive states have developed purpose-driven information systems, but the standardization of the data formats has not yet been taken up as the purpose being making the information available in intra-state context.

The information about water storage position in the country is a case in point about the diverse formats being followed by different agencies. In case of Central Water Commission, a Web-based data collection and presentation system has been developed which works on daily inputs. In case of different states, the information is updated frequently during monsoon periods, but the reporting is mostly manual and is published in different forms ranging from pdf files to Web pages, and the updation is not at regular intervals. Thus, it becomes difficult to integrate them. This leads to assessment of storage positions across the country in a non-uniform manner some parts of the country do not have adequate sized storage structures which can be incorporated in the national level assessment exercises carried out by CWC. Reservoir storage available at various points of time is a strong indicator of the success rates agricultural production as well as indication of drought conditions and possible drinking water shortages during summer months. It is, therefore, necessary that a comprehensive assessment at a much finer resolution is available.

A key integration with the crop forecasting applications described above is needed so as to find an estimate for water utilization from various projects. The work is easily said than done as there are a number of conceptual and practical constraints. However, in order to provide a comprehensive portal for water planning and assessment, the information is particularly needed.

As discussed above, the important aspect of efficient data interchange between the national level information systems and the state level information systems is the standardization of the data formats and storage policies so that automation is feasible. It is necessary to establish a mechanism of discussion and standardization so as to put the same into action. A standing conference and consulting mechanism under the aegis of National Water Resources Informatics Center or Central Water Commission is necessary for the purpose.

6 Role of Temporal and Spatial Variations and Data Collection/Reporting Policies

As discussed in the para above, the water being important for all activities of life, its usage is required to be assessed in all walks of life. In order to carry out the planning and assessment exercises, it is necessary to fulfil the following important sampling conditions, namely

- Matching element size of spatial distribution of usage and availability
- Uniform sampling rates of quanta and flux with respect to time
- Equitable standards of accuracy for the collected data.

The types of data required are already discussed in the paras above. All the data are required to match the above requirements in order to have a simulation setup which can answer the questions of planning and operational strategies required for a project at the atomic level and a basin at a macro scale.

It is necessary to note that the data pertaining to resource availability as well as utilization has many random components. These random components are not amenable to disaggregation if the time step is longer than desired. Any disaggregation will lead to non-unique distributions within the reported time step and thereby will lose validity for a deterministic planning exercise. For example, data reported as 10 daily average will not contain any information about the flash floods, and such determination will also not be feasible unless the observations are reported at hourly intervals. Non-consideration of this aspect leads to claims of adequate rainfall when viewed on a monthly basis, but in reality, the entire rainfall has occurred within a span of 24 h! These examples are generated almost every year across the peninsular India.

The spatial resolution of the observed data is also equally important. In India, the rainfall is generated out of monsoon systems which are having many components of cyclonic circulation. This leads to intense rain storms in limited areas with the balance areas not experiencing the same. The denser network will have greater chance of capturing such intense events whereas the densities have a decreasing trends with respect to past time periods. This phenomena is specially required to be understood in case of urban flooding where the spatial extent matching with the denser developments creates a greater disasters. The planners have to take these aspects into account.

These aspects are quite important as the water is a common pool resource and is required to be managed amongst all the stakeholders on a need basis rather than greed basis.

A common problem that occurs while apportioning water for agricultural uses out of a project is the tendency to view the availability at an annual scale, whereas the requirements at the field level are often weekly or 10 daily time steps. This is especially relevant for the projects who do not have adequate backing of a large storage at their respective heads from where the entire distribution is managed. Since the annual availability data does not provide adequate information for the seasonal variations, the operations of the project are frequently characterized with mismatch between real-time demands and supplies. Similar is the case even in other industrial and domestic or power generation areas where the demands often outstrip the supplies due to variable nature of the inflow patterns within the year. This situation is encountered in cases where the storage size is not adequate against the lean season demands. The mismatch can often result in non-utilization of the allocated quantum especially in monsoon season.

It is also observed that the resource data to be used for project planning needs to be statistically stationary. This stationarity will enable the planner to choose an adequate time interval using which a reasonably assured supply demand regime can be achieved. With the changes in utilization patterns across the basins much of which is not adequately reported, the availability data has a tendency to vary with time. In such a situation, it is observed that the time interval chosen for using the resource data should match with the demand patterns being used for the planning. This leads to conflict between the aspirations with which the project is being planned and the success rates after its implementation. The general tendency of the socio-political class is to promise as much as possible benefits without due regard to the availability aspects. In such an event, the search of an interval which satisfies demands at present level is started by selectively sampling the data and ignoring the inconvenient periods. In one of the major projects currently under implementation (names not given to avoid embarrassment), the resource data that was planned to use was pertaining to observation period of 12 years or older, whereas the demand scenario was for the periods of 10–20 years in future. Coupled with lack of balancing storage, the investment costs of pumping and operations were very high compared with a reasonable sized project which would obviously not have catered to such large demands, but the level of satisfaction out of investments and benefitted population would have been much higher.

7 Role of Data Collection and Interpretation in Transboundary Water Negotiations

In transboundary context, the basis of positions of the parties is required to be built on the data only. The interpretation of the data also poses challenges in adjudication due to differing stands taken by the parties based on their perceptions of interest. With the associated problems described above, the situation becomes quite complex. In case of such allocations, India has an Inter-State River Water Disputes Act (1956) as amended in 2002. The act provides for a judicial tribunal which is primarily comprised of eminent judges from supreme and high courts of India. The proceedings are also carried out following the judicial procedures with law professionals acting as primary interface between the tribunal and parties of dispute. The situation provides for judicial purity and soundness but has to negotiate the challenges of data management and interpretation as the outcome of allocation has to be based on the historical data and projection of the trends in future. A very complex situation arises when the main players being from judicial sector have to contend with the principles of hydrology and water management. A wise provision in form of assessors has been made in the act where senior water resources professionals are available for providing much needed disambiguation of the arguments and submittals made supporting them. It is important to note that the hydrological analysis relies on statistics and probability principles which do not necessarily lead to a deterministic solution. On the other hand, the desire of the litigants is to have a fixed allocation regime so that the planning and implementation decisions can be more precise. This poses great challenge in adjudicating the issue of allocation and more so in operationalizing the judgements. The following paras discuss a case history illustrating many of the points made above.

7.1 Data Availability Provisions for Disputes

A legal instrument in the form of Section 9(A) of the Inter-State River Water Disputes Act, 1956 (as amended up 2002) also empowers the Union Government to maintain a data bank and information system at the national level for each river basin, which shall include data regarding water resources, land, agriculture and matters relating thereto. Further, it stipulates that the State Government shall supply the data to the Union Government or to an agency appointed by the Union Government for the purpose, as and when required. The act also empowers the Union Government to verify the data supplied by the State Government and appoint any person or persons for the purpose and take such measures as it may consider necessary. The said sub-section further postulates that the person or persons so appointed shall have the powers to summon such records and information from the concerned State Government as is considered necessary to discharge their functions under this section. The Section 9(A) of the Inter-State River Water Disputes Act, 1956 (as amended up 2002), is reproduced hereunder.

"**9A. maintenance of date bank and information**—(1) The Central Government shall maintain a data bank and information system at the national level for each river basin which shall include data regarding water resources, land, agriculture, and matters relation thereto, as the Central Government may prescribe form time to time. The State Government shall supply the data to the Central Government or to an agency appointed by the Central Government for the purposes, as and when required.

(2) The Central Government shall have powers to verify the data supplied by the State Government, and appoint any person or persons for the purpose and take such measures as it may consider necessary. The person or persons so appointed shall have the powers to summon such records and information from the concerned State Government as are considered necessary to discharge their functions under this section."

Further, the National Water Informatics Centre (NWIC) has also been recently created by the Ministry of Water Resources, River Development and Ganga Rejuvenation at New Delhi, vide notification dated 28 March 2018. NWIC is supposed to be a repository of nation-wide water resources data and would be headed by a Joint Secretary level officer. In this backdrop, National Water Informatics Centre is expected to provide a "Single Window" source of updated and validated data on water resources and allied themes. It is further expected that the said Agency shall also provide value added products and services to all stake holders for its management and sustainable development.

It is, however, found with concern that position in respect of the availability of consistent and reliable data through a single window is far from satisfactory. In this regard, the observations of the Mahadayi Water Disputes Tribunal are quite relevant and are reproduced hereunder.

"1405. The experience of Mahadayi Water Disputes Tribunal is that there was no single source for supply of necessary data required for assessment of water availability. On the basis of information provided by the States of Goa, Karnataka and Maharashtra, the position in respect of source of related data is as under.

Observed gauge and discharge data.

a. Observed discharge data at Ganjim and Collem Gauging Stations for the period from 1979 to 2012 by Central Water Commission
b. Observed discharge data at Khadki, Daucond, Kudchire and Paikul for varying period from 2009 to 2013 by the Water Resources Department of the State of Goa
c. Observed discharge data at Chapoli for the period from 1985 to 1991 and from 2000 to 2013 by the Water Resources Department of the State of Karnataka
d. Observed discharge data at Virdi for the period from 1986 to 2004 and 2006 to 2011 by the Water Resources Department of the State of Maharashtra".

The Tribunal has also noted that the data in respect of rainfall, sediment, evaporation, infiltration, etc., was also not at all available through a "single window". The Tribunal has, further, expressed serious concern about the consistency of the data collected by various State Governments and made available to the Tribunal. Relevant observations of the Tribunal are reproduced hereunder.

"1406. On examination of the data provided by the party States, the Tribunal found serious issues relating to variations in the data of same station for the same period reported in documents filed by two States, or reported in two different documents of the same State, particularly in respect of rainfall data. Further, the Tribunal noticed that consistency of the data was a serious issue. It was found by the Tribunal that proper consistency checks were not carried out by any agency which led to varying conclusions about the quality of data."

The situation in respect of access to consistent water utilization data is more precarious. No reliable data is available even in case of actual water use for agriculture from various sources from year to year. Very high degree of inconsistency prevails in the information from different sources. Even the basic information about irrigated area varies from one source to other, say, the irrigated area as per the revenue record or the irrigated area as per the information available from Irrigation/ Water Resources Departments or the irrigated area assessed through remote sensing. Obviously, a lot more is required to be done to improve the position in respect of availability of water-related information/data.

7.2 Data Interpretation Challenges

It is, however, noted with concern that there are very few research outcome and findings of the studies which are applied to address the water challenges through improvement in planning process and efficient management. Although there are guidelines which prescribe procedures to be adopted for specific analysis, it is found that the recommendations of such guidelines (which are based on findings of research and studies) are rarely followed by the project authorities or even by the experts. These concerns have also been highlighted by the Mahadayi Water Disputes Tribunal in their Report. Relevant observations of the Tribunal along with their recommendations are reproduced hereunder.

"1410. However, the Tribunal found that none of the party States or the Experts who appeared as witnesses before the Tribunal, followed the procedure prescribed in the Guidelines. Most of the Experts considered hydrology as an in-exact science and chose to deviate from the Guidelines issued by the Ministry of Water Resources and adopted approach of their own likings.

This has led to considerable variation in the process of assessment of water availability and hence the ultimate results. Some notable variations/contradictions noted by the Tribunal are as under.

a. Length of data used for development of rainfall runoff relation varied from 10 to 34 years.
b. Length of data used for generation of time series of annual yield varied from 25 to 85 years.
c. An expert opined that out of 34 years of observed discharge data at Ganjim by CWC, the data of only 5 years was acceptable. He modified the data of 22 years and ignored the data of 7 years for the purpose of his analysis on one ground or the other.
d. Another expert opined that the observed discharge data of 34 years observed at Ganjim by CWC was consistent, but at the same time, he decided to ignore the data of 9 years for the purpose of development of Rainfall–Runoff relations. However, for the purpose of assessment of water availability at a project site, the Expert used the observed data of all the 34 years including those which were ignored by him for development of Rainfall–Runoff relations. The expert also opined that the data observed at Collem by CWC was not consistent and that he decided not to use the data in one of his Reports, but he used the data of Collem for estimation of yield at a proposed project site.
e. Even CWC opined that the data of Ganjim were consistent but the data of 9 out of 20 years were ignored by CWC for the purpose of development of Rainfall-Runoff relation.
f. Various Experts employed different methods for filling-in the missing rainfall data.

g. The Experts chose different methods for estimating the average rainfall—sometimes the Thiessen Polygon Method was used while on other occasions, Arithmetic Mean Method was used."

Obviously, the above scenario is not at all desirable, and unless necessary measures are taken, such scenario is bound to contribute considerably to (a) unrealistic plan leading to either unsustainable development or non-optimal benefits from the available resources and/or (b) conflicts amongst various stakeholders. Such selective use of data also has a potential of using specific information on selective basis as a tool of convenience to prove or disprove a particular line of pre-conceived thinking, which is very serious. The Mahadayi Water Disputes Tribunal has expressed their concerns on these aspects as well. Relevant extracts from their Report (MWDT 2018) are reproduced hereunder.

"1412. Although the sources of most of data collected by the party States were same i.e., CWC in respect of river flow data at Ganjim and Collem, and IMD in respect of rainfall data at various stations in and around the basin, each of the three States have projected different figures relating to availability of water in Mahadayi Basin with very large variations. The estimated water availability at 75% dependability for the entire Mahadayi basin, which were reported by the party States and the experts, varied from 208.73 to 145.05 tmc. One State would contend that Mahadayi Basin is a surplus basin whereas another State would contend that Mahadayi Basin is a deficient one. The result was that the Mahadayi Water Disputes Tribunal had to struggle a lot to arrive at an acceptable yield of Mahadayi Basin at 75% dependability, due to which, most of the time of the Tribunal was occupied only in determining the yield of Mahadayi Basin at 75% dependability.

1413. The situation is undoubtedly very serious. This is more so in view of the fact that the Hydrology Studies Organization of CWC is fully devoted to hydrological analysis and a premier research institute namely, National Institute of Hydrology is in existence since 1978 with main objective of undertaking, aiding, promoting and coordinating systematic and scientific work in all aspects of hydrology. As per the web-site of the National Institute of Hydrology, the Institute is well equipped to carry out computer, laboratory and field oriented studies. Further, the Tribunal is also informed that a Hydrology Project with assistance of the World Bank is being implemented by the Union Ministry of Water Resources since 1995, that the Phase-I and Phase-II of the said project have since been successfully implemented and that the Phase-III of the project is currently under implementation with objectives 'to improve the extent, quality and accessibility of water resources information, and to strengthen the capacity of water resources management institutions in India.'

1414. The Tribunal is baffled and also anguished that despite availability of considerable data, existence of expert organization and institutions and implementation of specific projects related to hydrological data, hydrological analysis and capacity building, the Tribunal had to struggle for arriving at an acceptable value of water availability at 75% dependability of the Mahadayi basin."

The status of research and studies in respect of related areas (other than hydrology and water availability) also indicates that the result outcome or the findings of the studies are rarely applied while planning water resources development projects and a lot more focus is called for. To illustrate, some specific areas are discussed hereunder.

8 Real-Time Management of Water Resources

One of the greatest challenges in water resources management is the real-time operations. As demonstrated above repeatedly, the operations of any water resources project be it a farm pond or a large reservoir catering to thousands of hectares of irrigated area or hundreds of MW of hydro power, the exercise remains that of matching a random supply with delivery of an average quantum of water in given period of time.

The prediction of yields and floods is a critical exercise in any water management scenario. Entire economies of the regions depend upon availability of specific amounts of water at specified periods of time. Water availability scenario depends upon many hydro-meteorological factors and also on the upstream utilization patterns for projects lying in the middle and lower basin areas. With the climate change, it has been predicted that for a monsoon fed country like India, the intensity and areal extent of rainfall events may face greater skew than what has been observed historically. This will lead to the situations described in the foregoing paragraph where the strategies have to be based on managing the extremes.

Yield forecasting plays an important role in planning operations in such a manner that the economic outputs from the project are optimized and have lesser risks. Crop planning generally has to take place by June so as to utilize the planting season. An estimate of the water that will potentially be available for the monsoon season becomes the greatest determining factor towards potential success of the venture on the part of the farmer. In many of the snow fed catchments in Himalayas, the remote sensing techniques provide reliable estimates of snow melt yields that may become available at the commencement of planting season. BBMB successfully uses such remote sensing-based yield forecasting models for their operations. Such predictions in most of our purely rain-fed basins is quite difficult. India Meteorological Department (IMD) provides various products of predictive rainfalls in meteorological divisions of the country which are of some help though much more needs to be done as far as supportive irrigation needs are concerned. The flows during the monsoon season are not only affected by the rainfall but are strongly affected by the basin utilization patterns which affect the yields for the downstream areas.

Increasing events of intense rainfalls followed by relative dry spells make the capture of yield and utilization quite difficult. Interconnection of reservoirs with short-term forecasts of yield into the parent reservoir and assessment of yields in the recipient reservoirs in real time can provide systems which can solve the conundrum.

For management of floods, the real-time data is an obligatory requirement. Wherever the stream is provided with reservoirs of adequate capacity, the issue of handling the flood safely through the reservoir while maintaining safety and integrity of the controlling structures is of utmost importance. The operations also provide the valuable insights about the flood situation downstream and disaster management operations planning. Critical issue in flood disaster management on the part of a water resources professional is to provide as long a warning time as possible for implementing the disaster management operations. Inundation assessments are another aspect of the assessment of damages that may have occurred and prioritization of areas for directing relief and rehabilitation operations.

Real-time data collection and transmission has become relatively easy with the advent of modern satellite-based telemetry and other telecommunication networks with improved transducers and measurement technologies. Starting in 1997, CWC has implemented a telemetry network which spans over almost the entire country and its neighbourhood wherever the bilateral arrangements exist.

In Himalayan regions, the dangers of flash floods occurring due to formation of land slide dams across streams and also the dangers of breaching of glacial lakes have been mounting from some time. Assessment of the volumes stored behind such landslide blockages or in the glacial lakes is of utmost importance for assessing the dam break floods. Remote sensing technologies with greater spatial resolutions coupled with digital terrain models have proved to be very good tools for disaster preparedness and management in the affected areas. Efficient predictions in case of Satluj (2004), Bhote Kosi Nepal (2014) and Zanskar basin (2015) have prevented loss of lives and damages to costly infrastructures, and the methodologies have shown maturity. Availability of real-time data coupled with a pre-computed simulation proves of great value.

9 Difficulties in Setting Up a Comprehensive Water-Related Database

A comprehensive database is the need of the hour for all the problems of allocation, planning, implementing and operating the projects. The question therefore arises that why such a database is not available so far. There are many reasons for persistence of this problem.

9.1 Lack of Appreciation for Linkages of Resource Availability and Utilization

Since water spans over a large domain of economy and natural resources management sector, the data collection and reporting generally pertains to the prime interest on the part of the agency engaged in the activity. A case in point is the urban water supply. Whereas the municipal and other local bodies agencies are quite concerned about the receipt of adequate water at all points of time, the information about the outflows returning back to the river is not of that level of concern. There are a number of parameters like quality and composition of the effluents which are quite important from a water manager's view as the same water has to be provided for another usage downstream. Similar is the case for other large industrial consumers like power generation utilities or mining and steel producing utilities.

Due to lack of manpower and lack of attention being bestowed on the minor irrigation projects, the information of individual minor irrigation project about its water utilization at regular intervals of time is normally not available or is available in a lump sum manner. However, with advent of a large number of minor irrigation projects in a catchment, the overall usage becomes comparable to that of a major project, but the data on consumptive usages as measured in case of a major project is not replicated for the individual minor project. In many cases, this has led to difficulties while negotiating about the water usages between states and also making real-time projections about availability and consequent planning for downstream areas in the basin.

9.2 Competitive Nature of Water Management at Interstate Level

Appreciation of the need for the collective responsibility and collaborative approach in an overall basin concept in view of increasing demands has been lacking amongst the stakeholders at various levels extending all the way to the states. The individual entities are more interested in ensuring a fixed quantum of the resource as an exclusive right or entitlement. Historically, the usages which were within the overall availability with some surplus have provided a sense of entitlement, but with the increasing demands, the surpluses have vanished, and shortages especially temporal nature of shortages have gone up. The agriculture being the largest user has a great role to play in this regard. The effects have been multi-fold. The first one being premium on the other hand, the random nature and increasing demands of a fixed quantity in line with the development aspirations make the same extremely difficult to manage such a regime. In this scenario, the individual entities are quite responsive about the requirements and actual resource availability but are not amenable to share the information about the actual consumption achieved. This leads to multiple data sets each reflecting the perception about ensuring the water availability and also to establish a case for assured availability of such nature that even in below average years also the entitlement is not encroached upon.

Utilization data is the big casualty in this case. Assessments are made at the time of project planning about the cropping patterns and requirements of irrigation water for various seasons. However, the changes in cropping patterns are rampant. There being a pricing skew in favour of water intensive crops, the availability of irrigation water leads to changes in cropping pattern thereby utilization from the projects. The projects also have a long gestation period before the full utilization comes into effect. Hence, the partially developed command area gets habituated with increased availability leading to increase of water intensive crops. The implementing agency is also interested in demonstrating the full use of the allocated quota of water for the project and by extension for the state which at times, lets such usage patterns grow. All these aspects affect the reporting of utilization data in a rational manner and on an equal level of accuracy comparable with the resource availability data. At the union level, the situation is difficult to handle due to lack of manpower and adequate spread in the field for making such assessments.

These aspects have contributed significantly towards lack of progress in establishment of a consistent data regime.

9.3 Multiplicity of Sources and Need for Appreciation Amongst Specialized Agencies About Requirements for Water Sector and Vice Versa

A comprehensive database for water management is an integration of multi-disciplinary databases from such sectors which are having an impact either on water availability or utilization. However, these sectors are disciplines in their own right and have priorities in their own areas of operation. Any database gets primarily established for catering to the needs of the sector. When such data is to be used for other purposes, it becomes necessary to transform some of the data elements into a form which can be consumed by the field of interest in this case water. In order to achieve this, the data products that are planned are required to be on a consultative basis. At present, the products are generated based on the convenience and perceptions within the field. Simultaneously, the data consumers within the water resources field have to devise ways in which the datasets available in the associated fields can be leveraged for the analysis and projections. Such convergence is especially needed for assessment of actual water consumption in irrigated areas by crops and assessments of field level efficiencies achieved in practice.

9.4 Deployment of Adequate Diligence for the Consistency of Data

All data collection for water resource management are local. The large number of local data observations has to be transformed into a global picture which can be deployed in global level assessments and projections. Water data is strongly affected by the physical parameters of the measurement sites and set-ups. Hydrometry which forms the backbone of water resources data is affected by the hydraulic conditions at the measurement site. The observed values are the end products of the water inputs of the entire upstream basin area and utilization spread over the same area. With the continual changes in land and water usages, the data collection points and the interpretation of the data have to modify itself for the consistency. Reassessment of the suitability of observation site from the hydraulic and hydrologic consistency is an exercise not carried out frequently. Instances of changes in data due to construction of a dam/barrage/bridge often vitiate the observations. Operation of such structures will completely disturb the level discharge relationships. Such data, if incorporated within the database without any reference to the changes, can lead to inconsistent results. Equal diligence is required for verifying the data which has been generated by agencies, which may have different focus. A good example being the reporting of the irrigated areas by groundwater and canals. The conclusions were based on the data collected by the authorities in charge of land revenue collection where the non-availability of data on canal irrigation was reported as 0 (zero) for the area. This has led to a lopsided conclusion about declining share of canals irrigated area over the period of time. This serves as a lesson for ensuring the consistency of data generated by different agencies before incorporating the same in the analysis. Another example is being a study where the sedimentation and implication about long-term silting of Ganga river were drawn based on a single sample collected at random time instant in a year. The sampling method is completely away from the actual reality of variation in sediment load in an alluvial river over the year and methodology established for integrating the variation of the sediment concentrations over a large flow cross section. These examples demonstrate the attention required to be paid to the diligence of collection and consistency in context of the conclusions to be drawn.

For ensuring the integrity of the data, technical auditing of the consistency of the methods used for collecting the data is necessary. The context in which the data has been collected and its use in the present scenario should be carefully analysed.

10 Leveraging New Technologies and Approaches

Efficient data management requires efficient collection and processing also. With the advent of sensor, telemetry and satellite as well as ground networks-based communication technologies, the collection of data over the wide geographic area has become relatively easy. The utilization of these technologies has seen steady progress across the country, and by now, a large part of the data collection network of CWC for hydrologic data has been automated. Similarly, the usage of remote sensing-based regional assessments has provided great help in yield forecasting and inundation mapping as well as presenting a realistic picture of project progress. Automation in water quality assessment through instrument assemblies is also gaining popularity.

While leveraging new technologies, it also becomes important to establish the correlation with the historical data so that the observations are on the basis of the same principles and assumptions as the original ones. If this link is broken, the disconnect between the two datasets leaves both of them unusable. In case of water, the historical continuity is very important to generate probabilistic models for planning and forecasting.

Selection of appropriate technologies for the data collection and processing is of utmost importance.

With the technology, comes the needs for capacity. Any technological solution adopted for data collection and processing, the capacity to maintain, troubleshoot and upgrade has to be built in. The capacities have to be built in right from the first level of operators to the top level consumers. With the advent of plug and play technologies with advances in self-diagnostic systems built in the sensors and data collection platforms, the field level maintenance exercises have become relatively easier with the detailed repairs relegated to offsite workshops.

11 Conclusions

1. In order to manage a random physical resource like water, an approach based on sound data is required. Hence, a well-thought out strategy for data collection, processing and use is a prime requirement.
2. Water being a ubiquitous resource, present in all the activities of civilization and environment, collection and processing of multiple domain data, is necessary to generate a holistic picture. The data collection fields span over climatic phenomena like precipitation, flows over or underground, intervention measures employed and utilization in various fields like agriculture, industry, human and animal consumption.
3. Contexts of data collection and management are also multifarious. Water is not only a life giving resource but also a factor causing disasters and disruptions. Data collection and processing strategies have to account for each such needs.
4. Demand and utilization assessment pose big challenges in data collection due to their wide spatial extent and divergences generated due to developmental needs of the society. Direct observation methods face field level implementation problems necessitating indirect assessments.

5. Status of data collection in the country is widely varying. While there are reasonably good assessments at resource availability level, matching precision and coverage is not found at utilization level. Multiple agencies are working in isolation leading to incompatible data sets and difficulties in national and regional level planning.
6. There is a strong impact of new technologies especially the remote sensing technologies on indirect data assessments, and such technologies need further development for reliably and unbiased assessment of utilization by agriculture and other spatially distributed consumers. Other new technologies of data communication and telemetry for ground-based point observations also need be promoted. Necessary capacities are required to be built in the line organizations for consuming and managing these new facilities.
7. Bringing historical data sets with new technology-based observations is the need of the hour to provide a continuous historical record with a common base line. Good initiatives like India-WRIS and crop forecasting systems developed with remote sensing techniques need be promoted.
8. Transboundary water management is highly reliant upon sound data availability. Interpretation exercises have to follow common well-established principles and practices. Production of a consistent, non-biased picture is the need of the hour. In the absence of sound analysis, adjudication becomes difficult and non-conclusive.
9. Even after efforts in this direction, a lot of ground needs to be covered in bringing about comprehensive database. Establishment of such database is constrained due to limitations imposed constitution and competitive race to capture resource, lack of adoption of new technologies and quality assurance of collected data.
10. Progress in equitable development will be seriously hampered if the sound data management policies are not adopted across the board and data-driven negotiations are not established.

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Whither India's Federal Governance for Long-Term Water Security?

Srinivas Chokkakula and Prakriti Prajapati

Abstract India's federal governance for long-term water security has not received its due attention. The discourse about federal governance is generally dominated by that of fiscal federalism. The limited work about federal water governance is restricted to interstate river water disputes and their resolution. Poor indicators of national water resources governance do not inspire confidence about its long-term security. The chapter posits that this is an outcome of the federal constituents—the states and the union territories—assuming exclusive powers over water governance. They pursue inward and territorialized strategies for water resources management, leading to conditions akin to a collective action problem to pursue national development and long-term security goals. It is long recognized that the Centre has to play an anchoring role and work with states towards pursuing these goals. Does it have the required leverage to influence states? This chapter, perhaps a first, is a modest effort to address this question. It takes a closer look at the historical changes in budgetary allocations of the Centre and selects states for water resources governance towards an empirical assessment of this leverage. The chapter concludes that the federal water governance in India is weakly structured and poorly nurtured to pursue its national development and long-term sustainability goals.

Keywords Federal water governance · Centre–state relations · Water federalism · India's national water security

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1 Introduction

India's federal water governance is defined by its distinct arrangements as laid out by the Constitution. Water governance is practised as an exclusive domain of states, though the states' powers are subject to the Centre's powers over interstate river regulation and development. The Centre's role remains critical for three broad reasons.

First, due to the states' presumed exclusive powers and dominant executive powers, India's long-term water security is determined by the cumulative outcome of the states' actions—their own strategies and approaches to water governance. The Centre must play an anchoring role to ensure long-term national water security.

Second, India's ambitious development goals are increasingly located into the realm of interstate river development and regulation: meeting irrigation development needs, river rejuvenation, inland navigation, interlinking of rivers, etc. These plans locate the Centre's role in an imagery of intricately woven interdependent hydro-geographies.

Third, the emerging conditions of 'water crisis' and new challenges in water governance, including climate change, raise questions about India's long-term water security. The 'crisis' is manifested and unravelled as inequities in access, competitive interests between sectors and states, depleting groundwater levels, deteriorating water quality, etc. Besides climate change, new and emerging challenges include disasters and degrading river ecosystems and ecologies. These conditions and challenges reiterate the Centre's key role in anchoring states' development interests towards the long-term water security interests of the country.

In contrast to assuming this central and vital role, the Centre has relegated itself to interstate river water dispute resolution—the record of which is not too inspiring. Yet, the national water policy discourse continues to assume Centre's leverage over states' approaches to water governance (NWP 1987, 2002, 2012). This is reflected in repeated instances of national policy-making without adequate attention to the means of implementing or 'giving effect' to these policies. The most visible means of making it possible, as the discourse goes, is through reworking fiscal transfers and using them as a leverage, especially through the specific-purpose intergovernmental financial transfers (IGFTs). The 15th Finance Commission (FC15)'s terms of reference (ToR) include the possibility of performance-linked IGFTs. Perhaps, the NITI Aayog's ranking of states' water governance performance through the Composite Water Management Index (CWMI) too reflects this thinking (NITI Aayog 2018, 2019).

This chapter attempts to carry out a reality check and to critically analyze the tenability of such assumptions. It seeks to examine the Centre's ability to influence states' water governance regime by looking at its historical role in water resources development and management in India vis-à-vis the states. Specifically, the chapter explores the budgetary allocations and fiscal transfers between the Centre and states to discuss the former's leverage in pursuing developmental and long-term water security goals.

With the help of the extent and nature of fiscal investment trends in water resources development, we argue that the emerging scenario does not bode well for the Centre to pursue these goals. This does not mean to imply for a 'stronger Centre', but for a stronger and robust federal governance of water resources.

The chapter is organized in the following manner. The section following the introduction elaborates on the critical need for a relook at the federal water governance arrangements with particular reference to emerging conditions and challenges to water governance to posit a possible 'federal anarchy'—an absence of robust and effective federal governance mechanisms—in water resources management.

In Sect. 2, we examine this condition by a deep engagement with the changing course of Centre–state relations in governing the country's water resources. It employs an unexplored dimension of looking at fiscal leverage of the Centre and analyzes the water resource management budgetary allocations of the Centre, and some select states to engage with the following questions.

(a) How do water resources management budgetary allocations of the Centre and states vary over time? What are the strategic priorities reflected by these allocations?
(b) How do the intergovernmental financial transfers (IGFTs) matter for states, in contrast to their own allocations? What kind of influence does the Centre bear over states to make them shift their strategies?
(c) What are the possible strategic directions for strengthening India's federal governance structure towards addressing its development and long-term water security goals?

Section 3 discusses the implications and future directions to strengthen federal water governance towards pursuing India's development and long-term water security goals.

2 Is India Water-Secure? The Role of Federal Water Governance

The idea of water security varies with the disciplinary specializations and practitioner interests. The conventional notion of water security, however, primarily emphasizes supply augmentation by building dams and other storage structures and corresponding distribution networks. Water-insecure countries face greater challenges compared to those early water-secure countries due to difficult hydrological conditions and greater responsibility towards social and environmental impacts (Grey and Sadoff 2007).

However, global assessments of water security suggest that the path of greater investments infrastructure does not necessarily ensure water security in its true sense. Investments made in pursuit of creation of physical infrastructure, if planned without adequate safeguards, may lead to short-term enhancement in water security, but often induce stress on river ecosystems and local biodiversity too. In turn, some of these stressors increase a country's vulnerability to new threats too. Countries with a history of high investments in water infrastructure do not necessarily show any enhanced resilience to threats to their river ecosystems–indicating the fragility of their water security. Lack of similar investments to address biodiversity and other threats has contributed to previously unrecognized threats (Vörösmarty et al. 2010).

It is now well recognized that the idea of water security extends beyond the conventional means of relying on building infrastructure for enhancing it. Instead, it needs to integrate other multiple dimensions associated with biodiversity, human health, equity, etc. (Palmer 2010). This growing understanding defines water security as 'an acceptable level of water-related risks to humans and ecosystems, coupled with the availability of water of sufficient quantity and quality to support livelihoods, national security, human health, and ecosystem services' (Bakker 2012: 914).

This expanded and multidimensional scope of water security warrants rethinking by nations about their respective water resources development strategies and governance arrangements. It may be particularly challenging in a country like India where water governance is not a federal subject but lies in the provincial domain. With the dominant executive power concentrated with the states, the country's national water security depends on its federal governance arrangements. We provide an assessment of India's current water security scenario below to discuss the role of federal governance and how it is placed to address these challenges.

2.1 How Water-Secure is India?

If the conventional notion of quantity-based assessment is considered, India may not sound as precarious as it is perceived. Falkenmark Stress Indicator projections made by Central Water Commission (CWC 2019) place India in 'water scarce' category in 2051; it will be 'water stressed' much later. This is, however, an indicator of per capita availability of water resources and not usable resources. It is not an indicator of the actual risk. The World Resources Institute's (WRI) Aqueduct Water Risk Atlas, a more comprehensive assessment, with a set of 13 indicators, puts India in 'extremely high' category (WRI 2019). In its most recent ranking, India is placed at 13th spot among countries most vulnerable to water risks.[1]

A more serious risk for India is attached to the quality of water and its access to the population. Depleting groundwater levels as well as polluted water bodies and rivers is exposing its populations to variety of contaminations with adverse impacts

[1]Some of these metrics cannot give an accurate sense of the risks. Due to the large size of India, and the extreme variations of topography, climate and water availability over space, the assessments of security need to be at a disaggregated scale. National-level assessments hide many vulnerabilities and also opportunities for addressing the risks.

on their health and productivity. The Central Ground Water Board's (CGWB) monitoring of groundwater quality shows 17% of the blocks, out of 6881 monitored across the country, are 'overexploited' (CGWB 2019). In some states like Punjab, these overexploited blocks exceed safe limits by 149%.

The National Water Quality Monitoring Programme of the Central Pollution Control Board (CPCB 2018) reports reduction of biological oxygen demand (BOD) levels in about 29% of the river stretches monitored (351 in number). These levels exceed the discharge standards for treated sewage into freshwater sources (30 mg/l of BOD). The extensive dependency on groundwater for drinking water and also the growing pollution loads in water and river bodies expose large proportion of India's populations to contaminants like fluoride, arsenic and heavy metals (Ayoob and Gupta 2006; Chakraborti et al. 2003). There is an emerging evidence of more perilous challenges. The history of long and extensive use of synthetic fertilizers by the Green Revolution apparently has led to widespread nitrate contamination of groundwater as well as surface waters.

Besides the issues with water quality, the states are engaged in a race for augmenting water resources—evident from the frequently emerging and recurring interstate river water disputes. These are on the rise, and the nature is shifting to water quality issues.

2.2 Failed Federal Governance?

The above outcomes at the national level do not inspire confidence about India's national water security in the long term. The situation poses several questions. One is do the sum of parts (states' contributions) make the whole (national water security)? Or is it different? Is there a greater whole?

Two is the federal government (Centre) in a position to steer the federal constituents (states) towards the whole? If the above-described indicators do not assure that the Centre can steer the states, does it indicate a failed federal governance?

Federal governance arrangements under the Indian Constitution put the primary onus for water governance on the states. Water is a state subject by virtue of Entry 17 of the State List, under the Seventh Schedule of the Constitution: 'Water, that is to say, water supplies, irrigation and canals, drainage and embankments, water storage and water power subject to the provisions of entry 56 of List I'. These powers of the states are subject to the powers of the Centre under the Entry 56 of the Union List: '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'. These are the often-cited provisions to describe the contours of water governance in India.

There is a direct but special provision by virtue of the Article 262. This may be considered within the scope of the Entry 56 but has special status. The Article is concerned about resolution of interstate river water disputes. This provides for barring the jurisdiction of the courts, including that of the Supreme Court.[2]

The public discourse and debates do not often go beyond these provisions while discussing federal governance of water in India. There are several other provisions through which the Centre works with states on water resources development.

The Wildlife (Protection) Act, 1972, Water (Prevention and Control of Pollution) Act, 1974, the Forest Conservation Act, 1980, and the Environment (Protection) Act, 1986, are some such acts that draw from various provisions of the Constitution and impact water resources development indirectly. There are also other provisions that are gaining significance with the changing development priorities. For instance, the Entry 24 in the Union List about inland waterways is now rigorously being pursued with the Inland Waterways Authority of India Act of 1985 and the National Waterways Act, 2016 (Chokkakula et al 2020).

However, these are often not taken into account while considering federal water governance arrangements, if any. Instead, the literature and discourse have settled to the following understanding:

(a) Water governance is primarily the states' domain, and water resources development strategies are set and pursued by state governments.
(b) The Centre's role is essentially restricted to interstate river water and largely focused on enabling interstate river water dispute resolution.
(c) The Centre's role extends to exercising influence through financial transfers. The Centre provides financial assistance to states through various forms of specific-purpose IGFTs, ostensibly to promote progressive policies and strategies in water governance. The IGFTs flow in various forms including Central Sector Schemes (CSs), Centrally Sponsored Schemes (CSSs) and National Projects (NPs).

In conversations about federal water governance, it is widely presumed as well as assumed that water is a state subject, even though subject to the union's powers under the Entry 56. The concentration of executive power with the states fortifies these notions. These conversations too invariably take place in the background of interstate river water disputes and their resolution. The episodes of dispute escalation often lead to an impasse or a stalemate, producing awkward situations. These conditions are most familiar in the long-running and intractable disputes like the Cauvery and Ravi–Beas. The Centre and other federal institutions—including the

[2]Article 262. Adjudication of disputes relating to waters of interstate 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 interstate river or river valley.

(2) Notwithstanding anything in this Constitution, Parliament may by 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).

Supreme Court—are often defied, and these lead to conditions of constitutional crises (Iyer 1994, 2002; Chokkakula 2014). The literature on these conditions is often listless and helpless. Nariman (2009) called these escalations 'a nightmare'. Others advised against interference by the Supreme Court, calling it as undermining federalism (D'Souza 2009).

The much-mentioned Entry 56 under the Union List is the central element in this role of the Centre in interstate river water governance. There exists a River Boards Act, 1956, essentially to facilitate cooperation and collaboration between states over interstate rivers. Here too, the Centre's role is a detached one. The act attaches the Centre with an advisory role in the act (Nariman 2009). Yet, interestingly, the act has never been put to use to create any river board since its inception. None of the existing river boards draw the force of the act (Doabia 2012). Several government reports termed the River Boards Act, 1956, as 'dead letter' (Sarkaria 1988, NCRWC 2002).

Further, the existing body of work and understanding has a major 'blind spot'. Despite the RBA 1956s 'disuse', the record of interstate cooperation over river waters is a compelling one (Chokkakula 2019). In contrast to nine river water disputes since independence, there are 139 interstate river water agreements—as compiled by CWC (2015). Most of these agreements are bilateral though, and there is no assessment available about how actively the Centre contributed to the materialization of these agreements or their endurance later. However, a quick perusal of these instances suggests there are instances of both: the agreements endured with or without the Centre's participation.[3]

This state of affairs raises doubts about the Centre's ability to pursue the larger national water security goals. Can the apparent minimalist role of the Centre be linked to the adverse trajectory indicated by the national-level indicators of water security? Does it suggest failed federal water governance?

2.3 *'Federal Anarchy' in Water Governance?*

This link between federal governance and deteriorating water security indicators has to be substantiated, though it is intuitively convincing. To rely entirely on the experiences of interstate river water disputes may not be sufficient. The element of politicization and territorialization of interstate river water disputes can make them an exception to assessments of federalism (see Chokkakula 2014; Iyer 2002).

[3]There are also instances where bilateral agreements needed Centre's intervention later. The instance of Vamsadhara dispute between the states of Andhra Pradesh and Odisha began with a bilateral agreement between the two in 1956 for construction and cost sharing of multiple projects on the river. In the later years, this arrangement drew on the Centre for technical support (via the CWC), as well as resolution of a dispute. In 2006, Odisha demanded setting up a tribunal to resolve a dispute arising out of a Andhra Pradesh's construction of a flood flow canal. The Vamsadhara tribunal set-up in 2010 gave its award 2017.

There are however strong assertions of neglected federal water governance, if not failed one. Iyer (2002) has argued that there has been a 'wilful abdication of its role' by the Centre. Chokkakula (2020) has argued that the Centre has 'lost ground' and is linked to Indian state's historical transformation trajectory. There are also equally strong assertions to the contrary that the federalism is undermined by various interventions of the Centre in water sector (Acharyulu 2019). It is important to take this debate beyond these assertions and probe for more compelling evidence —for or against federal governance. This is most critical, not just because the water security indicators are alarming, but also because of the vital significance of a strong and robust federal governance structures for pursuing long-term water security goals.

This is all the more important for at least couple of broad reasons. One is the limited role and the dominant executive power imply that the outcomes at the national level are essentially cumulative contributions of individual states—the 'sum of parts'. These 'parts' are often produced in the process of pursuing individual states' respective territorial visions for water resources development. These visions do not take into consideration the 'whole'—the national water security concerns. This, in a way, suggests a collective action problem producing the adverse outcomes at the national level—extending Hardin's (1968) logic, 'the tragedy of the commons'. In order to pursue the goals of the 'whole' of long-term water security at the national level, this problem of federal governance must be addressed.

Two is these conditions akin to 'federal anarchy' are also not helpful to pursue India's development goals in water sector. Its goals rely on the ambitious projects and programmes for river rejuvenation, inland navigation, inter-basin transfer and irrigation development, universal access to safe and secure drinking water—most in the realm of interstate river waters. The recent slew of legislations—Inland Waterways Act 2016, National River Ganga (Rejuvenation, Protection and Management) Bill, the Interstate River Water Disputes (Amendment) Bill, the River Basin Management Bill, or the Dam Safety Bill—are some steps in these directions. Success of these projects depends on close coordination and consensus building between states (Chokkakula 2019). This requires an active anchoring by Centre with the support of robust and resilient federal governance ecosystem.

The vacuum or the supposed 'federal anarchy' in water sector is obscured by the larger debates around fiscal federalism. Managing imbalances between states through the general-purpose IGFTs receives extensive attention in this debate.[4] The specific-purpose IGFTs are not as significant in comparison, but the Centre uses these as an effective channel for incentivizing progressive policies and priority

[4]IGFTs are of two types. General-purpose IGFTs provide general budgetary support to states: unconditional and mandated by law to offset the fiscal disadvantages arising from a lower revenue capacity and a higher unit cost of providing public services. Specific-purpose IGFTSs provide purpose-specific budgetary support, usually conditional and to incentivize undertaking certain programmes or projects. They often involve matching contributions from states (see Rao and Singh 1999).

programmes. There is, however, a limited understanding about the extent to which the Centre has been successful with this objective overall, much less so in water sector.

In the following section, we make a modest attempt at addressing this gap by looking at how IGFTs matter in federal water governance. The analysis serves two earlier alluded purposes: to extend our understanding into federal relations over water governance and to reconsider federal water governance towards pursuing long-term national water security goals.

3 Can the Centre Influence States to Address National Water Security Concerns?

This analysis looks deeper into the budgetary allocations and expenditures of the Centre and states in water sector over time. It searches for specific insights into how the Centre and the states are located with respect to each other to gauge the former's ability to influence the latter, as also states' responsiveness to the Centre in pursuing the larger national goals. This is a relatively unfamiliar and unexplored terrain. There are no earlier studies of this kind that can offer a framework for such an analysis. And, the water sector poses particular challenges. It is not easy to draw a line about what can be considered as water budgetary expenditure. Besides, the exercise of budgetary analysis accompanies complexities associated with the way the numbers are produced by each state, and meanings associated, which can also vary across states. The findings of the analysis are subject to these limitations. Yet, they present a useful and interesting picture.

3.1 Shifting Stakes and Stakeholders?

A quick look at the water resources versus other ministries' budgets puts the overall state of affairs with the Centre's own changing priorities in locating itself in water resources development and management. The Centre's allocations to the water and other proximate ministries over the last one decade can be seen in Fig. 1. Over time, the Department of Water Resources, River Development and Ganga Rejuvenation (DoWR)[5] has been allocated much less than the other ministries with proximate impacts over water use.

It is in fact declining in relative terms, and the growth in allocations for DoWR is insignificant compared to others. In the past decade, there has been a shift, of greater allocations to the Ministry of Agriculture and Farmers' Welfare (MoA) and

[5]Ministry of Jal Shakti (erstwhile Ministry of Water Resources, River Development and Ganga Rejuvenation or MoWR, DR&GR).

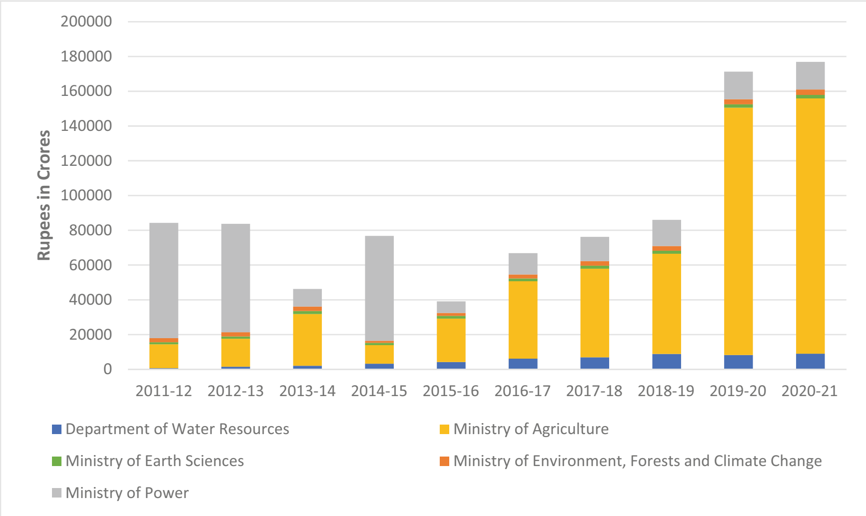

Fig. 1 Composition of central allocations across key environmental line ministries. *Source* Demands for grants of Central Government (of India), for respective years

the Ministry of Power (MoP). Both these ministries play a critical role in the water–food–energy nexus.

The trends may be useful to make the following conclusions. One is the declining allocations to DoWR may be reflective of the Centre's reducing role in comparison with the states' relatively increasing assertions with greater allocations. Two is the growing allocations to other ministries may be an indicator of shifting stakes in water governance. Considering their critical role in water–food–energy nexus, the other ministries' stature as stakeholders in pursuing the goals of security and sustainability must also be recognized.

3.2 Historical Spending on IFC: Declining Centre's and Increasing States' Shares[6]

India's primary strategy since independence involved large-scale investments into infrastructure for supply augmentation. Since the first Five-Year Plan (FYP), the emphasis has been on major and medium irrigation (MMI) projects. Several multipurpose projects were taken up in the first few plan periods, resulting in MMI expenditure dominating India's total water budget. This was followed by

[6]Throughout the analysis in this section, the category 'states' includes India's 28 states and 8 union territories.

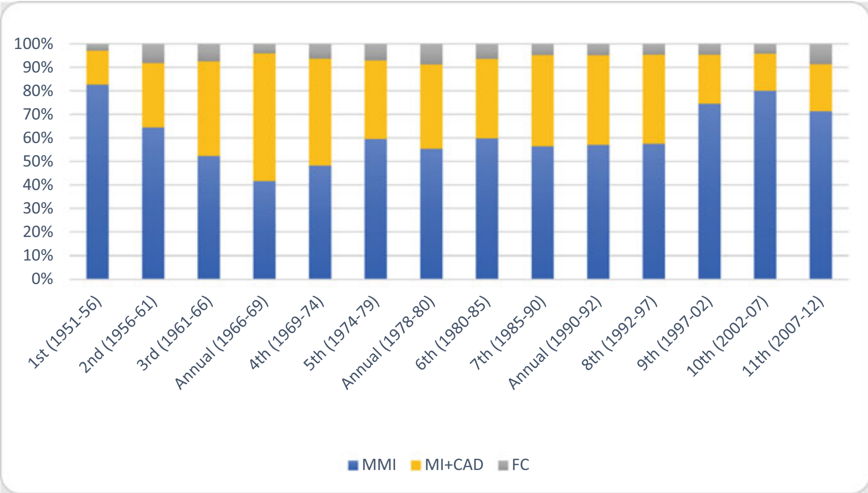

Fig. 2 Composition of the total expenditure on the water sector since 1951. *Source* Ministry of Water Resources (2011)

expenditure on minor irrigation (MI) and command area development (CAD), and flood control (FC) (see Fig. 2).

The Centre played an anchor as well as driver's role in initiating several of these multipurpose projects. This involved funding the schemes, often in the form of loans to state governments during the first FYP. The Centre also provided for initial investment required to kick-start agricultural and industrial development building on the irrigation and power generated by the MMI schemes. In the initial years, these were conceived as mega river valley development projects on interstate rivers such as Mahanadi, Krishna, Sutlej–Beas, Kosi, Chambal, Cauvery and Sone/ Rihand, along the lines of earlier successful projects like Damodar Valley Corporation, Tungabhadra project and Bhakra Nangal Dam.

The Centre's share in the total plan outlay was as high as 60%, and almost a fifth of this was spent for river valley projects 'on behalf of the states' as loans to be repaid later. The share of IFC in total plan outlay (expenditure incurred by both the Centre and states) declined since the first FYP, from 23% in the first FYP to 7% by the 11th FYP covering 2007-12 (Fig. 3). The cumulative share of states within the quantum corresponding to these shares, however, expanded from 40% in the first FYP to 96% by 2017. Centre's share declined proportionately during the period, from 60 to 4% of India's total (Centre + states) spending on IFC (Fig. 4).

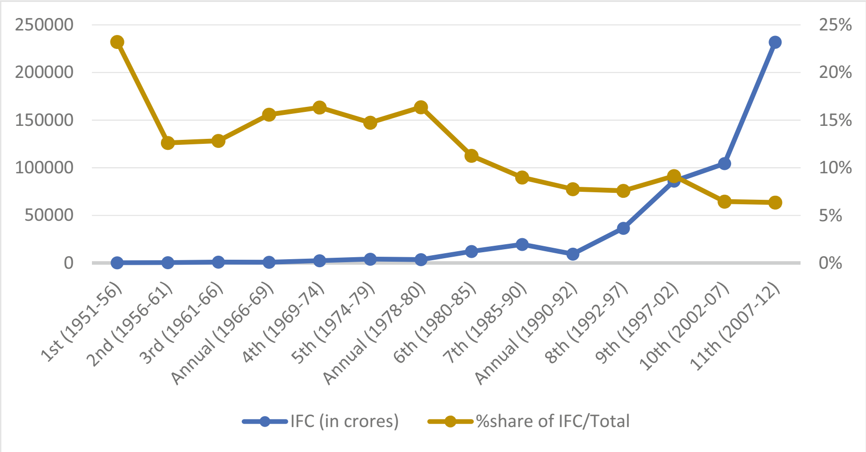

Fig. 3 Share of IFC in total plan expenditure (Centre and States, combined). *Source* Ministry of Water Resources 2011

3.3 *Are the Centre's Contributions to States' Water Budgets Significant Enough to Influence Them?*

The flow of financial resources to states happens through the Finance Commission's redistribution of tax collections. These IGFTs are of two types: general-purpose IGFTs and specific-purpose IGFTs. The former follows a particular formula, and there is not much room for reworking these transfers. The latter flows through the Central Sector Schemes (CSs) and Centrally Sponsored Schemes (CSSs). These schemes can be designed to nudge or influence states in a particular direction, as in the interest of changing states' strategies or choices to address the larger challenges liked to long-term water security and sustainability.

As seen, the Centre's contributions into the IFC component have fallen sharply after the first and second FYPs (Fig. 4). In the later years, the states' relative investments have risen sharply and significantly. Even the large CSS like the Accelerated Irrigation Benefit Programme (AIBP) in the later years (1996 onwards) constituting financial assistance to MMI projects also does not elevate the Centre's relative share in comparison. The more recent CSS (from 2015 onwards), the *Pradhan Mantri Krishi Sinchayee Yojana* (PMKSY), too is significantly large but has had no impact in improving the relative share of the Centre.

The PMKSY is a consolidated CSS and continues the trend of increasing Centre's share. In comparison with the earlier years of decline, the changed trajectory of the Centre's share in absolute terms can be seen in Fig. 5. Along with the CSS, the CS contributions are also on the rise. Yet, the total Centre's share remains low in comparison with states' contributions, as it is seen from Figs. 4 and 5.

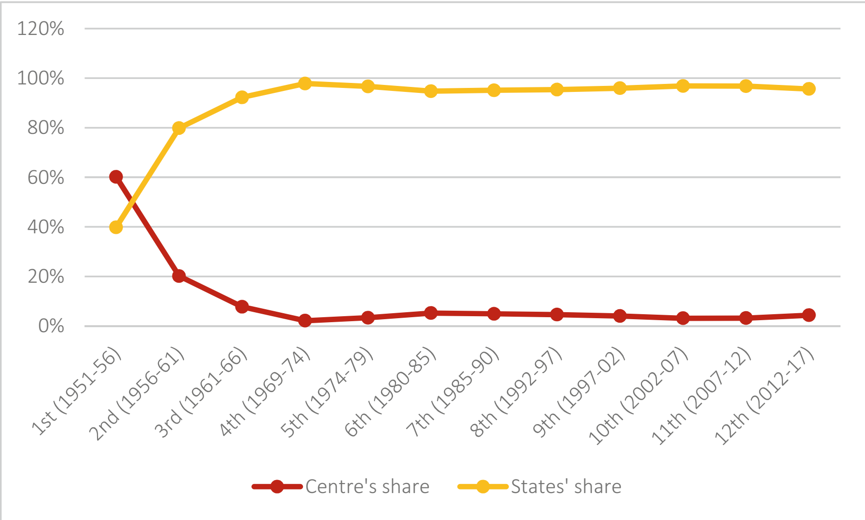

Fig. 4 Centre's and states' share in total plan outlay on IFC. *Source* NITI Aayog (respective FYP documents, 1951–2012); Ministry of Water Resources Outcome Budgets (2002, 2020)

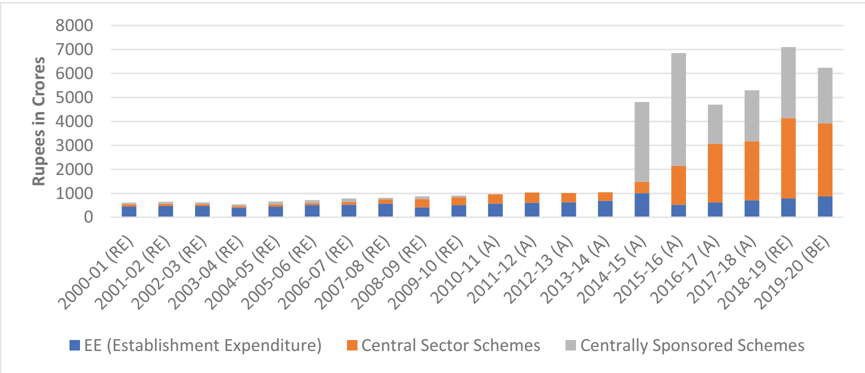

Fig. 5 Composition of central outlay on IFC. *Source* MoWR, RD&GR Outcome Budgets (2000–20)

This declining Centre's contributions need to be further contextualized in the states' own respective and territorial-level perceptions to gauge how these contributions matter to them. Water allocations of the states themselves are not that large when they are seen as parts of their overall budget outlays (see Fig. 6). Water allocations vary between 3 and 12% of the overall budget outlays. An allocation of about 12% of Karnataka may be an outlier for that year under consideration (2015–16); it is much lower for other years. Andhra Pradesh is likely the other outlier for the year under consideration and is not a representative year. The state was

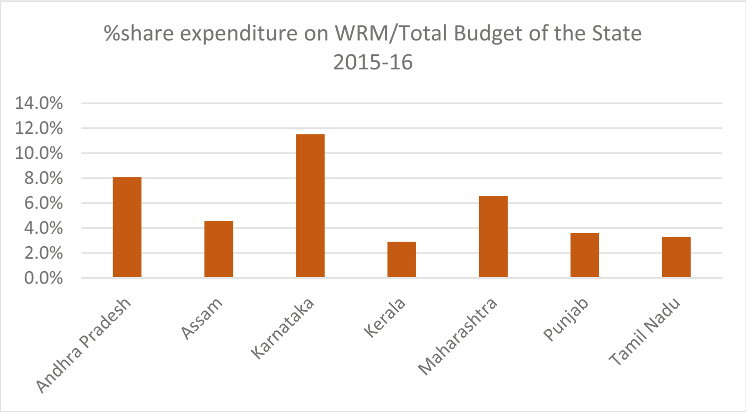

Fig. 6 States and their WRM budgets (2015–16 Actual Expenditure). *Source* State Governments' detailed demands for grants (department-wise) (2017a, b, c, d, e, f, g)

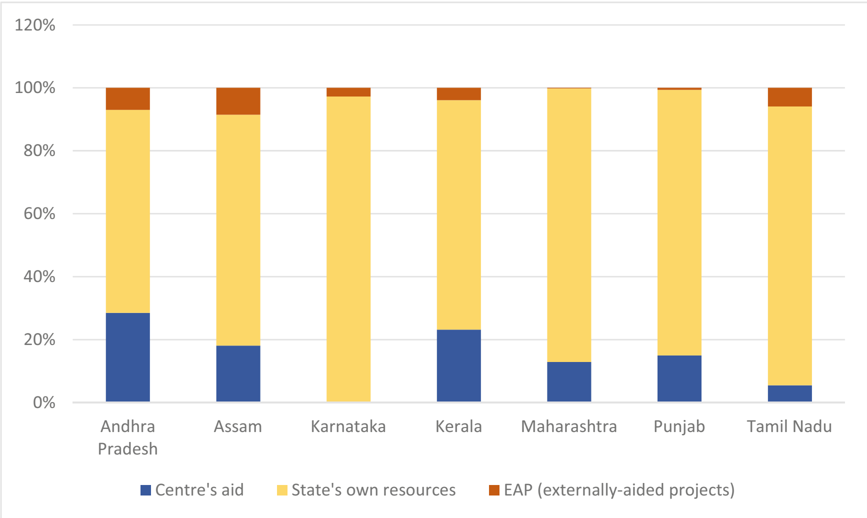

Fig. 7 States' water budget dependency (2015–16 Actuals). *Source* State Governments' detailed demands for grants (department-wise) (2017a, b, c, d, e, f, g)

bifurcated in 2014, and there may have been additional flow of resources from the Centre to cope with the bifurcation.

Figure 7 presents the disaggregated view of the Centre's contributions in the respective water budgets of the states. For the same year, the contributions vary with the sizes of the states. For smaller states like Punjab, Kerala and Assam, these are significant—15%, 18% and 23%, respectively. For larger states, these are really insignificant: varying between 0 and 13%. The question here is—are these contributions enough for the Centre to exercise influence over states to change their ways towards the greater goals of long-term water security?

The data presented here may not give a definitive response to the question. The Centre's contributions, at as much as 20% of water budgets of smaller states, may be important to affect some course-shift from the supply augmentation preferences towards more efficient usage and sustainable practices promoted by the Centre.

However, for larger states, though the Centre's contributions appear important enough at up to 13%, whether they are adequate to make the states change their course or water resources management strategies and preferences is an open question and cannot be responded with complete confidence.

Yet, it may be not entirely about how these contributions matter when it comes to states' strategic choices for water resources management. Water is an emotive subject and is closely connected with populations and constituencies. Water resources development and the conflicts around it are deeply politicized. The projects and strategies are driven by competitive politics, often leading to emergence and recurrence of interstate river water disputes. Water resources projects and strategies are more likely determined by constituencies and electoral outcomes (Chokkakula 2014). The Centre's intended influence over states with fiscal instruments has to negotiate this key element.

There can be other factors in this small versus large state's responses: the availability of land, climate suitability for agriculture, etc. While supplies may be adequate for hilly states due to well-spread rainfall, the same may not be true for inland areas like Deccan Plateau. Further, not all states are at the same level of development for variety of reasons. The context and conditions of the states matter. However, these aspects would need a different analytical frame and are beyond scope of this paper.

3.4 How is the Centre Using its Limited Influence?

Centre's financial contributions to states leave us with a rather equivocal and ambiguous assessment about its ability to influence states. This assessment, however, relies on not so reliable premise that the Centre's CSSs do indeed promote progressive policies. The primary flagship water sector CSS launched in the recent times is not under the Ministry of Jal Shakti (MoJS), but the Ministry of Agriculture and Farmers Welfare's (MoAFW), the *Pradhan Mantri Krishi Sinchayee Yojana* (PMKSY).[7] This is an interesting extension to the earlier observation about how other ministries play key roles in water resources management. The PMKSY is a consolidated programme of several components and aspires to promote Integrated Water Resources Management (IWRM) paradigm.

[7]Some components monitored by the Central Water Commission, Ministry of Jal Shakti.

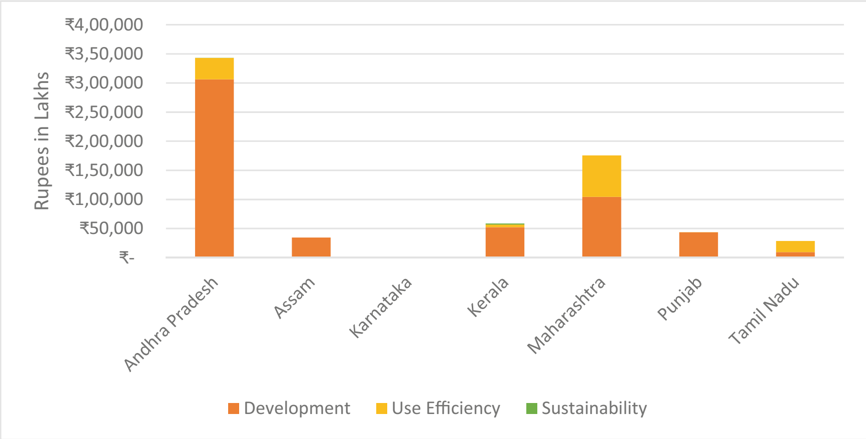

Fig. 8 Central transfers—disaggregated analysis. *Source* State Governments' detailed demands for grants (department-wise) (2017a, b, c, d, e, f, g)

Other similar CSSs such as the Ganga Action Plan (GAP—extended to National River Conservation Plan to include other rivers) are meant to promote water and river conservation. A closer look at support to states through the CSSs reveals some interesting insights.

These programmes do not appear much different from earlier ones in terms of the projects funded or their nature. The transfers continue to largely support supply augmentation strategies. Figure 8 presents the break-up of central transfers disaggregated in three categories: development (capital expenditure promoting supply augmentation); use efficiency (improving agriculture use efficiency); and sustainability (expenditure supporting essentially institutional reforms towards sustainable management of resources). The central transfers themselves seem to continue to favour supply augmentation. We cannot also miss the visibly prominent use efficiency projects' (or programmes') shares in large states like Maharashtra, Tamil Nadu and Andhra Pradesh.

This pattern does not differ much even with externally aided funding, often perceived as promoting progressive policies. This expenditure too follows similar pattern, with the category of development receiving much of the funding support. In spite of the strong voices of the international development agencies (IDAs) for broader shift towards IWRM, the translation of these into actual practice appears limited. It requires further exploration why it is the case, but these are indicative of the likely intransigent nature of states' preferences for supply augmentation strategies.

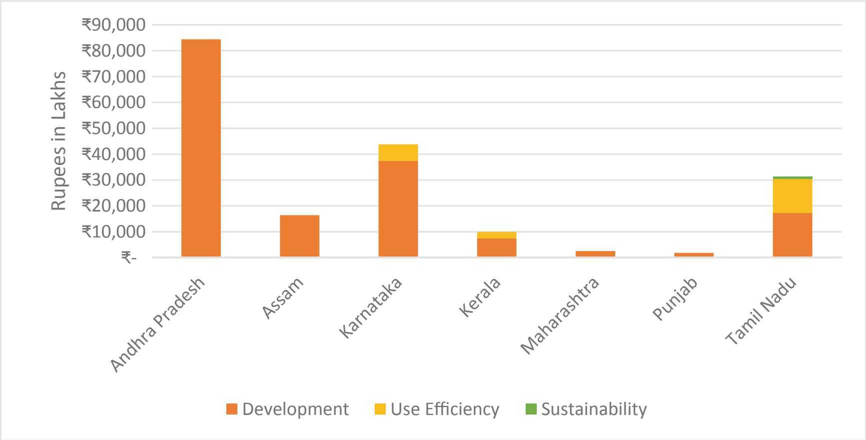

Fig. 9 External aid—disaggregated analysis. *Source* State Governments' detailed demands for grants (department-wise) (2017a, b, c, d, e, f, g)

3.5 States' Priorities and Preferences

The intransigence is evident from a similar disaggregated analysis of the states' own contributions to their respective water budgets (Fig. 9). Development category of expenditure allocations dominates. It most likely reflects the true preferences of the states. These are rather unequivocal in their proclivities towards development projects or programmes, essentially constituting supply augmentation. The states' budgetary expenditures do not show any recognizable allocations for use efficiency or sustainability. This can lead to the following surmises, but merit exploring further.

First, states' commitment for the broader course-shift towards IWRM is not yet established. Second, we cannot assert a similar commitment from external forces as well—including the Centre and the IDAs in translating their own committed course-shift towards progressive policies. Third, states' own political spaces do not allow negotiating the internally dominant supply augmentation preferences towards a course-shift (Fig. 10).

4 Concluding Discussion

We began with the question whether there is a condition akin to 'federal anarchy' to address the long-term water security and emerging challenges of water governance. An absence of robust federal water governance ecosystem may be contributing to the not so inspiring assessment of long term of water security in India. This is particularly critical in the background of the two typical characteristics of this

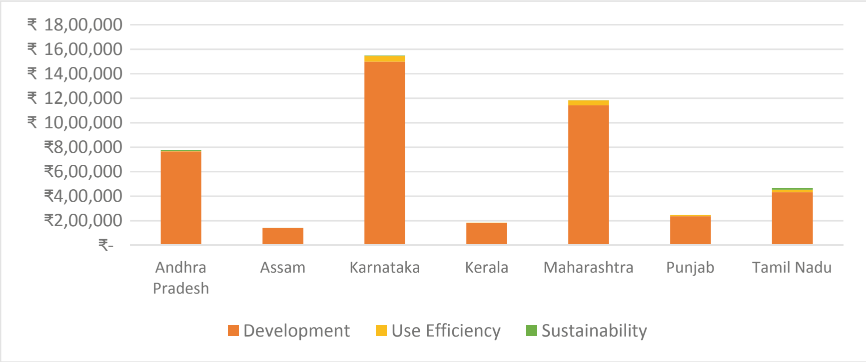

Fig. 10 State's expenditure preferences—disaggregated analysis. *Source* State Governments' detailed demands for grants (department-wise) (2017a, b, c, d, e, f, g)

space: (i) the assumptions and presumptions that water is an exclusively state subject and the associated extant and dominant executive powers with the states and (ii) the history of negligence of constitutional provisions under the Union List, especially the poor application of a credible role under the Entry 56 provisions.

There are earlier works that made similar arguments extending support to this plausible 'anarchy'. Iyer (1994, 2002) blamed the Centre for 'abdication of its role' (Chokkakula 2019) and argued that the Centre 'lost its ground' due to the particular political history of Indian state's historical transformation. For others, the Centre relied on non-statutory bodies such as the Planning Commission and the attached 'fiscal power' to engage with states (Swenden and Saxena 2017). While a great deal needs to be done, the lone intervention under the Entry 56 provisions, the RBA 1956, has also turned out a 'dead letter'. Further, since its inception, the RBA 1956 has not been modified or amended to address even its immediate concerns of interstate river water regulation and development.

The neglect of federal governance space appears to have gradually eroded the Centre's role, allowing the states' dominant executive powers reinforcing notions that water is an exclusively state subject. In order to assess the extent of erosion, and for an evidence-based argument, the chapter makes an initial assessment of the 'fiscal power' of the Centre in engaging with states for improved water governance or in support of the broader course-shift needed for pursuing the long-term security and sustainability goals, besides the immediate development goals that India has set itself. The analysis of budgetary allocations of the Centre, select states and their historical trends leads to the following findings.

First, the Centre's allocations have declined over years, and relatively the states' allocations have risen to a point that the former cannot claim significant influence over the latter's preferences and choices regarding water resources management. Even if we see a sharp rise of Centre's contributions in recent years, these are neither adequate, nor effective. Yet, we cannot make a sweeping statement to this effect across the board though, for these contributions appear to be significant enough for smaller states. Considering the political nature of states' choices and approaches, it is possible to argue that the Centre's contribution to state water resource management budgets is insignificant to influence change in their course or content of their strategies. The territorialized politics of water resources development in the states do not assure that even Centre's enhanced contributions can affect this change.

Secondly, there is no evidence to show that the Centre's (or the IDAs') or states' budgetary allocations reflect an ongoing larger course-shift from supply augmentation to the broader paradigm of IWRM or the goals of long-term water security. The Centre's equivocal translation of its espoused course-shift in the design and implementation of CSSs is a critical concern.

Thirdly, building on the above two findings, the Centre's role needs to be strengthened by supplementing it with additional set of political and institutional processes, besides a more effective legal element in the larger ecosystem of federal water governance.

Finally, in response to the question posed in the beginning, the structural and institutional elements of federal water governance have not received adequate attention. The existing provisions are not only under-nurtured, but also inadequate to pursue India's development goals and address the new and emerging challenges of water governance towards long-term water security and sustainability goals. It is imperative to build a 'new federal consensus' about Centre–state roles in water governance (Chokkakula 2019). There is a need to engage in a political process to elevate the debate of federal water governance to the goals of addressing the 'whole' and emphasize partnership building between Centre–states for the purpose.

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