Groundwater Resources and Sustainable Management Issues in India

Dipankar Saha, Sanjay Marwaha and Arunangshu Mukherjee

Abstract Groundwater is a critical component for socioeconomic development in India. The country exhibits wide spectrum on geology, climatic condition, and terrain, which is reflected in considerable variation in groundwater occurrence and movement. In addition, excessive withdrawal, in comparison with its annual replenishment, has created overexploitation of this precious natural resource, obliterating natural groundwater regime in large areas of the country. Besides, in many parts, the groundwater is contaminated both geogenically and anthropogenically. India as a country has established himself as the largest groundwater extractor in the world. The looming issues of overexploitation and deteriorating quality call for sustainable management of groundwater resource in long-term perspective. With the preamble on the review of the hydrogeology of the country, this paper summarizes 20 contributions that have been included in this volume. The papers are rich in their content and present a wide array of groundwater issues of the country, ranging from quality, conjunctive use of surface and groundwater, artificial recharge, community participation in its management, urban hydrogeology, coastal aquifer dynamics, mining hydrogeology, and application of state-of-the-art investigation techniques in groundwater survey and management. The aroma of the volume will enrich which are directly or indirectly linked with groundwater resource management of the country.

Keywords Groundwater · Sustainable management · India · Aquifer · Water level · Quality

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1 Introduction

Groundwater is extremely important for drinking water and food security, besides rendering a significant service toward human health and ecosystem (Gleeson et al. 2016). At many places, aquifers are the only source of available water for drinking and irrigation, rendering groundwater as the most abstracted raw material on the Earth (NGWA 2016). In the changing climate scenario, the role of groundwater is significant, due to its relative stability in terms of both quality and quantity. India, as a country, is tilted toward groundwater for its societal needs. With 243 km^3 extraction annually, India is the largest consumer of groundwater in the world, consuming more than the cumulative draft of second and third highest consumers, i.e., Republic of China and USA, respectively (NGWA 2016). Nearly 85% of rural drinking need, 62% of irrigation need, and more than 50% of urban water demand of the country are met up from aquifers.

India's groundwater story is unique and interwoven in its journey toward achieving food security. The country has witnessed atomistic groundwater development, through private participation, where the million of landowners drilled their own wells. At present, the number of wells used for irrigation in the country is pegged to be more than 25 million. Besides providing irrigation, the wells boast rural economy and employments.

Growing population, urbanization, industrialization, and overall development of infrastructural facilities with improved lifestyle have put water in a competitive sectoral demand more than other parts of the world. There is a radical reduction of per capita annual availability from 5177 to 1545 m^3 since India's independence. All global prediction say large part of India is going to be water scarce by the year 2030. Aquifers, being comparatively safer source of potable water and being distributed in all types of terrain and in agroclimatic zones, the pressure from increasing water demand will be mainly focus on groundwater development and management. Central Ground Water Board being the apex organization under Govt of India in the domain of groundwater exploration, monitoring, and management has a stupendous task in fostering sustainable development of this precious natural resource involving the stakeholders, planners, researchers, and implementing agencies in state level.

2 Groundwater Occurrence

India is a vast country having geographical area over 32.87 lakh km^2 and can be divided into three broad geomorphic divisions, the Peninsular India, the Indo-Ganga-Brahmaputra Plain, and the Extra Peninsular India. The Peninsular India and Extra Peninsular India predominantly represent hilly and undulating topography, interspersed with alluvial deposits of rivers. These two units are predominantly characterized by hardwork aquifers, where groundwater occurs within the top weathered zones (generally <30 m thick) and underlying fracture/joints generally confined within 200 m below ground. The fractured aquifers are highly heterogeneous and largely local to subregional in extent. In these areas, the recharge is mainly through point to local recharge. Groundwater remains in phreatic condition in the weathered zone, whereas groundwater remains semi-confined to confined in the fractures below. The groundwater in this hard rock terrain is comparatively younger in age. Indicating recharge in annual cycle (Saha et al. 2013). Whereas the Indo-Ganga-Brahmaputra Plain is underlain by thick unconsolidated deposits of Quaternary age holding some of the most potential aquifer systems in the world (Mukherjee et al. 2015b).

Beside the Indo-Ganga-Brahmaputra Plains, the wide costal tract in Bangal deltaic regions and along the East Coast is largely occupied by pile of thick unconsolidated sediments mainly of Quaternary age. In total, the unconsolidated deposits roughly occupy one-third of geographical area of the country. They are characterized by multilayered aquifers of regional to subregional extent which are reported down to several hundreds of meter below ground. These aquifers dominantly pose primary granular porosity, rendering substantial yield potential to the wells. The recharge is both through local or regional flows. Groundwater remains under varied condition, ranging from phreatic to semi-confined in shallow and middle depth (up to 100–120 m below ground in general), while under confined in deeper levels. The shallow and middle depth aquifers get modern recharge from rainfall, while deeper aquifers may contain relatively older water even up to several thousand years old (Saha et al. 2011).

2.1 Groundwater Regime

Groundwater levels in India vary considerably in response to various geologic, terrain, and climatic conditions and anthropogenic interventions. A simplified groundwater level map of premonsoon phreatic groundwater level data (CGWB 2016) shows four broad zones running across SE to NW of India (Fig. 1a). The trans-Himalayan foothill zone and the East Coast have nearly continuous band of <5 m depth to water level, apart from few isolated patches largely concentrated in the eastern half of India and in parts of Maharashtra coast. 5–10 m below ground level (bgl) occurs in large part of India, except in northwest states of Rajasthan and Punjab. This is followed by deeper levels of 10–20 mbgl, largely spotted by small pockets concentrated in the western part of the country. The deeper levels are recorded in arid parts of Rajasthan and central part of Punjab where levels are varying from 20 to 40 mbgl and even deeper. Apart from this, patches of deeper levels are also observed in parts of Gujarat, Haryana, Telangana, and Bundelkhand region of Uttar Pradesh and Madhya Pradesh. The perennial shallow groundwater levels (2–5 mbgl) are largely the regional discharge zones, either along the foothills of Himalaya or along the East Coast. Similarly, the deepest groundwater level zones are areas of negligible groundwater recharge in the arid parts of India.

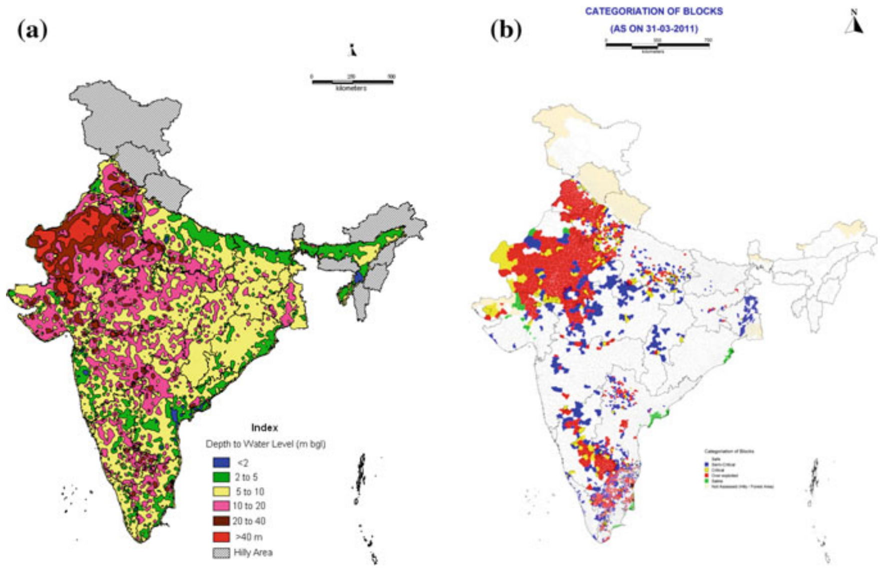

Fig. 1 **a** Depth to water level map of premonsoon 2016. **b** Categorization of assessment units based on SOD. Colors represent as (*Red* = OE, *Yellow* = Critical, *Blue* = Semi-critical, *Green* = Saline and *White* = Safe). *Source* CGWB

2.2 *Level of Groundwater Extraction*

The rainfall is the main source of recharge to aquifers in India. The ratio of groundwater recharge to draft in an annual scale provides the stage of groundwater development (S0D). SOD is considered in India as an earmark to assess the stress on the dynamic groundwater resource. The latest estimation of dynamic groundwater resources (CGWB 2016) has indicated the overall SOD of the country as 62%. The assessment unit, i.e., blocks (talukas, firkas in some states) are categorized based on their SOD as- "safe" (S0D < 70%), "semi-critical" (SOD 70–90%), "critical" (SOD 90–100%), and "overexploited" (SOD > 100%). The SOD is not uniform throughout the country due to obvious reasons that govern the aquifer potential, recharge capability, and extent of groundwater exploitation. Groundwater overexploitation is confined in 1071 units of the country and in another 914 significantly where level of exploitation has exceeded 70%. All these units are largely concentrated in the NW parts, as well as deep in Pennisular India. These areas are also characterized by deeper groundwater levels (Fig. 1b).

Groundwater overextraction has resulted in decline in water levels, dwindling well yields and drying up of dug wells. Besides, there is an overall increase of background salinity in groundwater. This is apart from the known ambient higher values of EC in arid regions of India, as well as in coastal tract. This has prompted to conclude that groundwater overextraction is deteriorating the ambient quality of groundwater also (Mukherjee et al. 2015b). Shift to drinking water abstraction from deeper zones might have triggered certain pollutants to enter into aquifer-based drinking water cycle (Saha et al. 2009; Mukherjee et al. 2015a).

The India's groundwater resource management is at crossroad, because of accelerated pace and skewed extraction leading to significant decline in groundwater level on the one hand and expanding areas under waterlogging and deteriorating water quality resulting in considerable reduction in availability of fresh and potable water. Strategies for better groundwater governance and management need to be developed through wide consultation among various stakeholders, academia, researchers, and state departments dealing with groundwater. To achieve this Central Ground Water Board, Ministry of Water Resources, River Development and Ganga Rejuvenation has organized a one-day thread-bearing discussions 'Bhujal Manthan' on August 21, 2015, at Kurukshetra University, Kurukshetra, Haryana. This volume derives some of the best papers presenting and deliberating in the workshop. The volume contains 22 papers which are grouped into the following four subthemes.

3 Layout of the Book

The articles selected from the Bhujal Manthan-2015 are broadly grouped into following four themes (i) groundwater quality, (ii) conjunctive use of surface and groundwater, (iii) management intervention for sustainable water, and (iv) groundwater problem and application of techniques.

3.1 Groundwater Quality

Qualitatively, groundwater is considered as a safer source in comparison with surface water. Mineralization of groundwater up to certain extent is considered to be good for human health and crops. By and large, the ambient quality of groundwater in India is still good and requires no external treatment before drinking, irrigation, and industrial uses. The quality of groundwater in the operational zone of open dug wells was found potable since ages. But due to various anthropogenic reasons, slowly this zone became contaminated with fecal collies, forced shifting of abstraction from deeper zones through mechanized wells, and hand pumps for drinking needs. Deeper zones hold groundwater with relatively more mineralization that under reducing condition may produce toxicity. Apart from geogenic contamination such as arsenic and fluoride, seawater intrusion in the costal tract, agricultural practice, urban wastewater and land fields, and liquid and solid disposed from industries and mines are the main source of contamination of groundwater (Banerjee et al. 2012).

During the recent years, much of the emphasis in groundwater for drinking use has shifted from problem of availability to issues of quality. The quality problems are broadly grouped into two: ‘geogenic’ and ‘anthropogenic.’ Geogenic pollution refers to naturally occurring elevated concentration of certain constituents in groundwater having adverse health effects. In India, contamination of fluoride and arsenic is geogenic in nature and affecting several parts of the country and has became major health concern and posses challenge for safe water supply (Bajerjee et al. 2012). Besides these, elevated levels of salinity, iron, manganese, uranium, radon, chromium selenium, and other traced elements reported at places may also be of geogenic origin. In India, approximately 40 million people are residing within the risk zone of arsenic contamination (Saha and Sahu 2015). The states from which arsenic contamination has been reported are West Bengal, Bihar, Uttar Pradesh, Jharkhand, Assam, Manipur, Punjab, Haryana, Chhattisgarh, and Karnataka. However, the elevated concentration is mostly confined in the Indo-Gangetic Plains (Saha 2009) CGWB has been advocating exploitation of arsenic safe deeper aquifers in the Indo-Gangetic Plains under regulated pumping. The other remedial measures include removing arsenic from groundwater after it is extracted and reducing the level within the aquifer itself through in situ treatment and through dilution of the contaminants by artificial recharge. Fluoride concentration has pan-India presence. Its concentration above maximum permissible limit of 1.5 mg/L has been reported in groundwater from parts of many states of India, namely Andhra Pradesh, Telangana, Assam, Bihar, Chhattisgarh, Delhi, Gujarat, Haryana, Jammu and Kashmir, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh, and West Bengal. Fluoride-contaminated areas are mostly characterized by the presence of crystalline basement, and volcanic and sedimentary rock areas particularly characterized by arid and semiarid climatic conditions. Dissolution and weathering of F^- bearing minerals, pulled by calcite precipitation, are considered to be the dominant mechanism responsible for groundwater fluoride (F^-) contamination. Long-term solution involves providing alternate source of potable water by construction of wells tapping fluoride-free aquifers, installation of community-based de-fluoridation plants, and surface water-based supply, wherever available.

Six papers have been incorporated under this theme and amply signify the importance of this issue. Out of that four papers discussed, the issues are related to elevated levels of fluoride and its mitigation and one deals with uranium contamination. The remaining paper discusses on deteriorating groundwater quality because of saline water ingress in East Coast area. Prof. **L. Elango and Jagadeshan** in their paper are of opinion that managed aquifer recharge can be an effective mean for dilution of fluoride concentration in groundwater. Through their experiment by dug well recharge, they have able to obtain desired results in a contaminated phreatic aquifer in hard rock areas of Dharmapuri district in Tamil Nadu state. **Dr. Santhil Kumar** and their co-authors in their study had shown the example of seawater ingress and deterioration of groundwater quality due to excessive pumping driven by urbanization in coastal Chennai area of Tamil Nadu state. Bromide has been used as an indicator to delineate the seawater–freshwater interface. **Sh. Supriya Bramha** has discussed the level of fluoride concentration in different aquifers and related issues in varied hydrogeological setup represented by hard rock and older alluvium in West Bengal. **Prof. H.K. Pandey** and co-authors discussed the petro-mineralogical and geochemical significance of fluoride contamination and its release mechanism in groundwater of hard rock aquifer from Sunbhadra district of Uttar Pradesh. In another study made by **Dr. P. Madhnure** and co-authors, the evolution of fluoride-rich groundwater has been dealt in detail in Cherlapalli water shed in Nalgonda district of Telangana state represented by hard rock aquifer. They are of opinion that fluoride enrichment is related to Ca^{+2} removal during rock–water interaction.

Uranium contamination of groundwater in southwest part of Punjab has been discussed by **Prof. K.P. Singh** along with his co-authors. They have opined that the genesis of uranium is not related to basement granite or the phosphate fertilizer. They have found uranium concentration in sediments of the area which may be one of the sources for its elevated concentration at places in groundwater.

3.2 Conjunctive Use of Surface and Groundwater

To improve the overall efficiency of water resource development and management, ‘conjunctive use’ has been considered as an affective tool. It is defined by Foster et al. (2010) as a situation where both groundwater and surface water are developed (or coexist and can be developed) to supply a given irrigation canal command—although not necessarily using both sources continuously over time nor providing each individual water user from both sources. Alternatively, FAO (1995) described conjunctive use as ‘use of surface water and groundwater consists of harmoniously combining the use of both sources of water in order to minimize the undesirable physical, environmental and economical effects of each solution and to optimize the water demand/supply balance.’ Because different stakeholders are involved in the conjunctive use of surface and groundwater resources, a conflict-resolution technique should be employed to resolve cross-interests. A major issue related to conjunctive use of surface and groundwater in efficient manner is to have some form of institutional arrangement and a supportive regulatory framework. The number of studies has been undertaken by institutions and government departments for establishing feasibility of conjunctive use in India. The studies have established that the isolated use of surface water ignoring groundwater in irrigation command area has resulted in various environmental problems such as waterlogging and salinity. Further, it is also felt that there is a need to adopt groundwater management which incorporates a groundwater simulation model as constraint in the management model which can be efficiently used in planning the conjunctive use of water. Such planning will need to be supported by a national policy and to occur within a framework that ensures sustainable use of the resources. This will require significant technical inputs, especially within the context of the need to assess the available consumptive pool.

Dr. D.K. Chadha, former Chairman, CGWB, in his contribution pointed toward decimal efforts being made toward the conjunctive use of surface and groundwater in the country and suggested means and ways of efficient conjunctive use. He strongly advocated implementation of its use in the areas where such studies have already been completed. **Prof. Shasank Shekhar** and co-authors advocated that the conjunctive use practice can prevent the rivers from getting dried up because of depleted contribution from aquifers. They have advocated that conjunctive use can provide the requisite environmental sustainability to the river ecosystem.

3.3 Management Interventions for Sustainable Use

Globally, irrigated agriculture is the largest consumer of groundwater resources. However, in many arid and semiarid areas, recharge from rainfall is limited and unconstrained use is causing serious aquifer depletion and environmental degradation. The interactions between irrigation, surface water, and groundwater resources are often very close, such that active cross-sector dialogue and integrated vision are needed to promote sustainable land and water management. Clear policy guidance and focused local action involving communities are required to make efficient use of groundwater in view of drought mitigation and climate change adaptation. Policies must be tailored to local hydrogeological settings and agroeconomic realities, and their implementation will require active involvement of the farming community.

Dr. Himanshu Kulkarni and co-authors in their paper discussed alternative way of calculating efficiency of groundwater in agriculture system. They presented an interesting case of groundwater efficiency assessment involving the inherent aquifer characteristics like specific yield which are often ignored. The paper illustrates two examples from the Deccan basalt aquifer system in western Maharashtra state, where use of specific yield parameter has helped in a robust understanding of groundwater use efficiency for its better management.,

Prof. Tushar Shah, Chairman of Task Force of Managed Aquifer Recharge Project of Gujarat State, from his experience and expertise has sketched the impact of groundwater overexploitation and possibilities of artificial recharge for water-stressed areas of Gujarat. He has opined that apart from hydrogeologists, water experts, economist, and social scientist can also made important contribution to water strategy formulation. **Dr. P.K. Gangopadhyay** and co-authors in their interesting article presented a case study of co-solving groundwater level depletion as well as flooding problem using managed aquifer recharge in the Ram Ganga subbasin of the Gangetic Plain through participatory mode. They use the terminology UTFI (underground taming of floodwater through irrigation) where floodwater is diverted into the de-saturated part of the aquifer below. This has double benefit of reducing the flood risk and enhancing the groundwater resource of the area.

The impact of artificial recharge on groundwater is presented by **Sh. Subburaj** and co-authors in the hard rock aquifer of Salem district of Tamil Nadu. They have shown the increase of sustainability of groundwater due to implementation of artificial recharge projects. The pumping hours by the farmers have increased, and also, there is rise in water level in the area. **Dr. S.S. Vittala** and co-authors presented the result of soil infiltration studies carried out in Ankasandra water shed in Tumkur district of Karnataka state. They found that lowest infiltration rate is noted at tank belts. Infiltration rate is an extremely important component for estimating the recharge. **Dr. B. Ghosh** and co-authors presented interesting case studies of participatory groundwater management and self-regulation in varied hydrogeological typologies in India. They argued that decentralized groundwater management can offer better solution for its long-term sustainability and social equity. **Dr. Bidyut Kumar Bhadra** and co-authors have presented interesting case study of groundwater recharge in arid region of Rajasthan. The study was carried out at three places of Rajasthan underlain by different aquifer systems. All the areas exhibits decline in groundwater level at various rates. They have opined for adopting preventive measures for increasing the recharge and efficient use of groundwater. **Prof. P.K. Singh** and others presented a case study of groundwater regime in coal mining area. The mining activity is impacting the water level and flow regime in the surrounding areas. In case studies around Jharia, East Bocaro and West Bocaro cold field of Jharkhank State detailed behavior of water level are discussed.

3.4 Groundwater Mapping and Application of Recent Techniques

Groundwater mapping involves multidisciplinary techniques to understand, map and assess various issues like, delineating the aquifers, hydraulic parameters of aquifers, well sustainability, assessing the resource availability, quality variation—both specially and vertically, groundwater pollution etc. As the groundwater resources are becoming scarce and its social and economic importance is increasing rapidly, there is a spurt in application of new technique. In the domain of groundwater lot of researches are going on to understand science and developing new technologies on accurately delineating the aquifers and characterizing them through various geophysical techniques and applications of isotope and tracers. Challenges are particularly to delineate deeper fractures which are water bearing and have good yield potential in hard rock terrain. Significant innovations are taking place for automatic water level measurement and quality monitoring through telemetry. Though groundwater modeling is being applied to understand the flow regime, wider applications are needed for predicting the future scenario under various stress conditions and pollution studies through solute transport modeling. Researches are also required for comprehensive understanding on impact of various climate change scenario and extreme rainfall event on groundwater regime. Besides, lot of technological development is taking place for analysis of harmful consequent in water even in nanogram level. Application of remotely sensed data for groundwater mapping is well established, but the new domains are emerging with an advent of gravity satellite which is being applied in assessing groundwater resource and its depletion.

Prof. P.K. Sikader and P. Sahu highlighted the stress on urban aquifer system of Kolkata and its impacts on natural recharge pattern using groundwater modeling. They provoked for using groundwater modeling as decision-making tool for better management of the confined aquifer surrounding Kolkata urban area. The recommendation can be replicated in other urban areas with similar hydrogeology setting. **Prof. Abhijit Mukherjee** discussed the hydrodynamics of groundwater flow using arsenic as tool for modeling. A regional hydrostratigraphic model has been developed in the Gangetic Plain of West Bengal to indicate that groundwater flow is dependent on the amount and timing of precipitation and is controlled by the topography and alignments of major streams, which can be heavily distorted in case the region experiences over pumping. **Dr. Subhash Singh** and co-authors have used gama logging in a very effective manner to detect the radio activity in fluoride-contaminated aquifer of Shivepuri district of Madhya Pradesh state to understand the extent of contamination.

4 Conclusion

Groundwater is rendering a yeomen service in India by providing significant contribution to water supply for drinking, irrigation, and industrial sector. The dependence on this resource is increasing day by day because of its three unique characteristics: (i) special distribution and use as a common pool resource, (ii) its availability in all agroclimatic region and terrain condition, and (iii) drought—proofing character of groundwater and its relative immunity to extreme events under climate change scenario.

In view of its overexploitation in large parts of the country, quality deterioration even in areas where they are available in plenty and rapidly increasing dependence on this resource for food and drinking security has thrown open serious challenges to all its stakeholders—the management of this resource in a sustainable manner. Sustainable management of this hidden resource is only possible when we have a comprehensive understanding of the system, both on a sound scientific understanding and social-economic prospective. The selected 21 papers from the Bhujal Manthan-2015, the largest groundwater discussion platform in India, organized by CGWB, embodies the groundwater issues of India. The papers extend valuable thoughts which would be useful for laying the road map for sustainable management of this resource. This volume will immensely benefit the researcher, policy makers, academia, and the stakeholders in understanding the various facts of this resource.

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