S. P. Sinha Ray *Editor*

Ground Water Development - Issues and Sustainable Solutions

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The Members of Centre for Ground Water Studies, Kolkata

Foreword

India is facing a perfect storm in terms of managing water, both surface and underground. Decades of continued mismanagement by central, state and municipal authorities, private sector and general public as well as political apathy and interference, institutional incompetence, rapid industrialization and urbanization, a steadily increasing population aspiring and demanding a better quality of life, poor implementation of existing environmental laws, pervasive corruption, poor adoption of currently available cost-effective technologies and absence of good policies at all levels of government are only some factors which have contributed to the development of this perfect storm. All the indications are that unless the current water management practices all over the country are significantly improved, the situations will get progressively worse.

In spite of this sad current state of affairs, there are no real signs that politicians are waking up to address effectively the rapidly deteriorating water situations all over the country and are willing to take hard decisions to improve the existing conditions. Policies have been mostly ad hoc, incoherent, short term, often incorrect and at best incremental. Even these policies are rarely implemented properly. It really has not mattered which political parties have been in power at central and state levels; net results have been steadily deteriorating water conditions all over the country both in terms of quantity and quality.

At the central level, the last competent water minister who stayed in the position for a reasonable period of time was Dr. K. L. Rao. It was more than half a century ago. During the past 20 years, India has had ten water ministers. One even lasted all of one day! During the same period, the Ministry has had 14 secretaries. Not surprisingly, this revolving door has ensured that not one minister nor one secretary has had any lasting impact on water management of the country.

Surface water conditions in the country are bad, but groundwater situation is even worse.

Groundwater abstractions in the country are increasing steadily and significantly. It has become progressively more and more unsustainable over the past six decades. Consequently, in many parts of the country, groundwater levels have been declining by more than 1 metre per year. Lack of proper wastewater management from domestic, industrial, agricultural and mining sources has ensured progressive deterioration of groundwater quality by known and unknown contaminants. This is already endangering the health of both humans and ecosystems.

Monitoring of surface water quality is poor. However, monitoring of groundwater quality is truly dismal!

During the past three decades, there has been an explosive growth of private tubewells in agricultural farms because of the absence of reliable surface water supply for irrigation. This is compounded by Indian laws which guarantee exclusive rights to landowners over groundwater. These factors, plus free electricity to farmers for pumping, have ensured groundwater use in the country has been unsustainable for decades.

Consider monitoring of groundwater quantity and quality uses. Despite having four separate central bodies regulating groundwater, there is no single groundwater database for the country. In 2016, the Standing Committee of Water Resources of the Indian Parliament finally recommended the need for having a central groundwater database. However, when this will happen is anybody's guess.

Data on groundwater availability, use and quality are patchy and often unreliable. The best estimate now is India is using 230–250 km^3 of groundwater each year. More than 60% of irrigated agriculture and 85% of domestic water use now depend on groundwater. Because of prolonged and poor groundwater governance, India alone now accounts for one-quarter of the global groundwater use. The country currently uses more groundwater than China and the USA combined.

In 2009, NASA reported that the Indus Basin is the second most overstressed aquifer in the world. The Basin includes Punjab and Haryana, the two main granaries of the country. NASA also noted that groundwater depletion rate in North India is about 1 metre every 3 years. This is 20% higher than an earlier assessment of the Indian Water Ministry.

The extent and gravity of the Indian groundwater situation is not in doubt. With increasing population, urbanization and industrialization, the situation will get progressively worse. Nearly half of India's employments are now in the agricultural sector. This means groundwater management in India needs urgent attention from all the levels of government, private sector, academia, research institutions and general public.

I am thus heartened to see Dr. Syama Prasad Sinha Ray, one of the India's leading groundwater experts, writing an authoritative and objective book on the groundwater problems of the country and their sustainable solutions. There is absolutely no question that this book was long needed. I not only wish the book much success but earnestly hope that India's policymakers and academics will make a determined attempt to implement many of the solutions recommended in this book. The country has simply no other choice.

Asit K. Biswas

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Co-founder, International Water Resources Association,
World Water Council, and Third World Centre for Water Management
Mexico City, Mexico
Stockholm Water Prize Laureate

of his highly illustrious work in the field of Water Development and Management, has kindly written the "Foreword" of the book. I have no words to acknowledge such kindness.

I am deeply obliged by the active cooperation of my colleagues in CGWS, especially Shri. Abhijit Ray, president, and Dr. Sandhya Bhadhury, assistant secretary, whose encouragement at every stage made it possible to go ahead with the publication in spite of my ailing conditions. Shri. Saheb Das, technical assistant, CGWS, offered most useful secretarial assistances in making correspondences with the authors and Springer IN which is deeply acknowledged.

My special thanks are due to the editorial groups of Springer IN, specially Dr. Mamta Kapila, Mr. Daniel Ignatius Jagadisan and Ms. Raman Shukla who have continuously provided guidance in making out the publication.

Kolkata, India S. P. Sinha Ray

Thoughts from Abroad: Communication Received from Prof. Asit Kumar Biswas

Regrettably groundwater management has not received adequate attention in India for decades. How much groundwater the country has, how much of it is being withdrawn every day and how much is being replenished annually are not reliably known. In the absence of reliable estimates and public apathy and lack of sustained political and bureaucratic will to manage groundwater efficiency and equitably on long-term basis, serious mismanagement is continuing to take place.

The problem was compounded by poor advice the country received from the development banks in the 1970s and 1980s, which equally, unfortunately, the Indian Government accepted without any serious scrutiny. Thus, for the World Bank/IFAD Project on UP Groundwater Irrigation of the 1980s had to have dedicated electrical transmission lines so that the farmers would have 24-h free electricity for pumping. This was in spite of the fact that the inhabitants of major cities like Lucknow did not even have continuous electricity supply. This was a necessary condition for the World Bank/IFAD loan for the project.

Not surprisingly, food production did increase for several years, but no one, neither the World Bank nor the Indian Government, anticipated the long-term economic and social costs to the country of such ill-conceived policies. It created many vicious circles. As farmers pumped water indiscriminately, groundwater levels started to decline. Consequently, the farmers had to install higher horsepower pumps for pumping water from greater depths. Thus, groundwater levels have continued to decline precipitously in many parts of the country for decades. Free, or highly subsidized, electricity for pumping has ensured that nearly all Indian utilities are nearly bankrupt. It has thus been a lose-lose situation for the country as a whole, both in terms of water and electricity.

In drought years, pumping by the farmers intensifies further because of surface water shortages. A major problem is likely to be that continuation of such unsustainable practices may soon reach tipping points during future drought years. This could deplete groundwater to such levels in the coming years that pumping becomes impossible or seriously uneconomic. In addition, this would contribute to serious environmental problems, including land subsidence.

This is *only* one of the numerous groundwater management problems the country is facing at present.

I sincerely hope that the seminar will discuss these types of complex and real issues and come out with a roadmap for sustainable development and management of groundwater in India for the coming years.

Dated: June 16, 2017

India's Wells Are Running Dry, Fast

Ratanpura Lake, on the outskirts of Ahmedabad, Gujarat, has almost completely dried up. Amit Dave/Reuters

Over the past 3 years, the monsoon – the rainy season that runs from June through September, depending on the region – has been weak or delayed across much of India, causing widespread water shortages.

With the onset of summer this year, southern India, particularly Karnataka, Kerala and Tamil Nadu states, are already wilting under a blistering sun and repeated heatwaves. Drought is expected to affect at least 8 states in 2017, which is a devastating possibility in a country where agriculture accounted for 17.5% of GDP in 2015 and provides the livelihood for nearly half the population.

Across rural India, water bodies, including man-made lakes and reservoirs, are fast disappearing after decades of neglect and pollution.

"They have drained out the water and converted the land into a plot for schools, dispensaries, and other construction activities", Manoj Misra of NGO Yamuna Jiye Abhiyan warned in *The Hindu* newspaper as far back as 2012.

Residents wait for the government-run water tanker in Masurdi village, Maharashtra. Danish Siddiqui/Reuters

Not a Drop to Drink

It was not always this way. For the past 2500 years, India has managed its water needs by increasing supply.

Prior to industrialization and the accompanying global "Green Revolution" in the 1960s, which saw the development of high-yield variety crops using new technologies, India's water availability was plentiful. Households, industries and farmers freely extracted groundwater and dumped untreated waste into waterways without a second thought.

But such practices are now increasingly untenable in this rapidly growing country. Per capita availability of water has been steadily falling for over a decade, dropping from 1816 cubic metres per person in 2001 to 1545 cubic metres in 2011.

The decline is projected to deepen in the coming years as the population grows. India, which currently has 1.3 billion people, is set to overtake China by 2022 and reach 1.7 billion in 2050.

Water scarcity is also exacerbated by a growth in water-intensive industries, such as thermal power production, extraction and mining, as India seeks to feed and power its growing population. In addition to affecting biodiversity, these activities also alter natural water systems.

Still, successive governments have pursued the same old supply-centric policies, paying little heed to the country's waning clean water supplies.

For nearly 50 years, a misguided groundwater policy has sucked India dry; water tables have declined by an average of 1 metre every 3 years in some parts of the Indus basin, turning it into the second most overstressed aquifer in the world, according to NASA.

Across nearly the whole country, basic sewage management is also lacking. According to the Third World Centre for Water Management, only about 10% of wastewater in the country is collected and properly treated. As a result, all water bodies in and around urban centres are seriously polluted.

Today, the country is struggling to provide safe drinking water to every citizen.

Sugarcane production is highly water-consuming and should be managed more efficiently. Kolkata, 2015. Rupak De Chowdhuri/Reuters

What Conservation?

Even so, residents of New Delhi or Kolkata today use more than twice as much water, on average, than people in Singapore, Leipzig, Barcelona or Zaragoza, according to data compiled by the Third World Research Centre.

The water use in Delhi is 220 litres per capita per day (lpcd), while some European cities boast figures of 95 to 120 lpcd.

Excess consumption is attributable in part to citizen indifference about conserving water after so many years of plentiful supply. Since large swaths of many Indian megacities lack piped supply of clean water, leaks and theft are common. Cities in India lose 40% to 50% due to leakages and non-authorized connections.

At this point, the only viable option for India would seem to be managing demand and using water more efficiently.

The country is making tentative steps in that direction. The 2016 new National Water Framework, passed, emphasizes the need for conservation and more efficient water use.

But under India's Constitution, states are responsible for managing water, so central policies have little resonance. Neither the 1987 nor 2012 National Water Policy documents, which contained similar recommendations to the 2016 policy, had any real impact on water use.

And after millennia of exclusive focus on expanding the water supply, the idea of curbing water consumption and increase reuse remains a mostly alien concept in India.

Water Wars

Consistent supply-centric thinking has also resulted in competition for water as states negotiate the allocation of river water based on local needs.

The century-long conflict over the Cauvery River, for example, involves Andhra Pradesh, Tamil Nadu and Karnataka – three major south Indian states. With each state demanding ever more water, the river simply cannot keep up.

In Karnataka, where agricultural policies are heavily skewed towards water-guzzling commercial crops, such as sugarcane, mismanaged ground and surface water are dying a slow death. Still the state continues to petition the Cauvery Water Dispute Tribunal for an increase in its share.

Water scarcity in Karnataka is aggravated by non-existent water quality management. Its rivers are choked with toxic pollutants, and oil-suffused lakes in Bengaluru, the capital, are reportedly catching fire.

Meanwhile, in the northern part of the country, the Ravi-Beas River is causing conflict between Punjab and Haryana states.

In India's water wars, rivers are a resource to be harnessed and extracted for each riparian party's maximum benefit. Very little emphasis has been placed on conserving and protecting existing water sources. And not one interstate negotiation has prioritized pollution abatement or demand management.

Even policies from the national government, which claims to target water conservation and demand management, remain reliant on supply-side solutions. Big infrastructure programmes, such as the Indian river-linking plan, envision large-scale water transfer from one river basin to another, again seeking to augment supply rather than conserve water and reduce consumption.

Sand mining on the Cauvery river in 2017. Prashanth NS/Flickr, CC BY-SA

For inspiration on managing demand, India could look to Berlin in Germany, Singapore and California, all of which have designed and implemented such policies in recent years. Successful measures include raising public awareness, recycling water, fixing leaks, preventing theft and implementing conservation measures such as water harvesting and storm water management.

Between rapidly disappearing freshwater, unchecked pollution and so many thirsty citizens, India is facing an impending water crisis unlike anything prior generations have seen. If the nation does not begin aggressively conserving water, the faucets will run soon dry. There is simply no more supply to misuse.

Asit K. Biswas, distinguished visiting professor, Lee Kuan Yew School of Public Policy, National University of Singapore; Cecilia Tortajada, senior research fellow, Lee Kuan Yew School of Public Policy, National University of Singapore; and Udisha Saklani, independent policy researcher

Distinguish Visiting Professor
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October 6, 2015

Asit K. Biswas

Communication Received from John M. Mc Arthur

A good understanding of groundwater resources – their amount and quality – is essential for the planning and development of any nation that wishes to avoid the mistakes of the past. Those mistakes have left a global legacy of both polluted water on the surface and underground and over-abstraction that impedes sustainable development and reduces the quality of life for many peoples.

Through 30 years of working in India and with Indian colleagues, I know that Indian scientists and engineers currently have much of the knowledge necessary to formulate an excellent management plan for groundwater in India and could rapidly complete their understanding were they given the right conditions in which to do so. Principal amongst those conditions is an increased willingness to share data and understanding between the numerous institutions that are involved in groundwater management and to do so especially at the level of junior staff. In a federated country, that means that states and the centre should work together better. Let me list the organizations involved at present:

1. Central Ground Water Board, Ministry of Water Resources, River Development and Ganga Rejuvenation
2. Ministry of Drinking Water and Sanitation
3. State Ground Water Boards (in West Bengal the State Water Investigation Department)
4. Public Health Engineering Departments
5. The Departments of Science and Technology
6. IITs, IISWBM and universities and research organizations such as NGRI, CWRDM, BARC
7. Municipal corporations in urban areas and Panchayats in rural areas

An enduring management plan for groundwater in India, and I emphasize the word *enduring*, can only be achieved if all relevant organizations buy in to the plan, and that means working together and sharing data and information. Junior staff, in particular, should be freed to exchange and discuss information with less restraint than now from bureaucratic impediment. I hope the seminar succeeds in bringing together relevant people to help achieve those aims.

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20th October, 2015

Communication Received from Prof. K. M. Ahmed

Challenges of Groundwater Management in Bangladesh in 2050: Mission Impossible Vis-a-Vis Visions for Sustainable Development

Groundwater in the Context of Bangladesh

Groundwater has been the backbone of Bangladesh's remarkable achievements in the fields of access to safe water and food security. Despite being a delta country crisscrossed by numerous rivers including the Ganges-Brahmaputra-Meghna, dependence of groundwater is increasing every day to meet the demands of various sectors.

Current Challenges of Groundwater Management: Mission Impossible?

The ever-increasing demands along with natural stressors result into major challenges for management of the vital natural resource in the country. Increasing population is the major challenge where groundwater is the main source of safe water for drinking and domestic purposes in rural and urban areas. Meeting the demand for increasing food production is another major challenge for the world's most densely populated country. Significant increase in dry season rice production through groundwater irrigation has made the country self-sufficient in rice, and production of all major crops has also increased. Demand for water is also increasing due to faster rate of urbanization and industrializations; groundwater is the major source of supply of municipal and industrial waters. The scenario of too much and too little surface water compels to use more and more groundwater all over the country, and large groundwater is fresh and free from pathogenic contaminants over most of the country, and switching to this source for drinking saved millions of lives over the year. Occurrences of natural arsenic and salinity are the two most severe water quality issues of the current time. Millions of people are still drinking arsenic above national and international standards, whereas people living in the coastal areas are exposed to high salinity. Also, pollution of groundwater due to municipal, agricultural and industrial sources is becoming widespread. People living in the slums in the big cities and adjacent to industrial towns suffer from safe water scarcity.

Groundwater abstraction is increasing every day without a proper management and monitoring plan. Conventional water pumps are becoming inoperative in many areas due to declining water levels and need to be replaced by alternative expensive pumping technologies. Groundwater governance is almost nonexistence in the country due to mainly lack of proper institutional arrangements. There are rules, regulations and policies to ensure proper management, but enforcement is lacking.

Bangladesh in 2050: Water Challenges for the Emerging Tiger

Bangladesh economy is growing fast and will become the 23rd largest economy in 2050. Water for agricultural and industrial sectors will be much needed to sustain this growth. Bangladesh population will reach 202 million in 2050, and about half of the people would live in urban areas. Dhaka is the fastest growing megacity and will be joined by other megacities in 2050, resulting in a very high demand of municipal water supply. Intensification of agriculture would continue, and production has to be increased by 97.4% to ensure food security. Groundwater irrigation would play the major role here, but at the same time, agricultural pollution will become a major issue. Industrial development would surpass many western economies which would lead to more abstraction and more contamination. Emerging contaminants like pharmaceutical by-products and personal care products can be a major source of groundwater pollution. Intra-sectoral conflict would increase particularly between domestic water supply and irrigation sectors. Transboundary groundwater issues will emerge, and sharing both surface and groundwater resources with neighbouring countries will pose a major challenge. Climate change may have significant impacts on the hydrologic cycle, and hydro-disasters may become more frequent, resulting in quality- and quantity-related issues for the groundwater resources.

Visions for Sustainable Groundwater Management

Better governance has to be the main agenda for meeting the challenges of groundwater management in 2050. A national institute empowered with necessary technical, financial and legal resources is crucial for ensuring sustainable use of the vital natural resource. Full commitment towards adaptation to integrated water resource management has to be ensured at all levels. Decentralized water management at planning area or basin scales has to be introduced. Managed aquifer recharge has to be adopted at all levels to augment the declining water levels. Water-sensitive urban designs have to be adopted and implemented for major urban areas and urban conglomerates for reducing impacts of urbanization on groundwater. Recycle and reuse of wastewater has to be promoted by combining technical options and awareness of stakeholders. Regional cooperation on water has to be increased for basin-wide management by conjunctive management. Bangladesh will have to adapt various water purifying technologies including reverse osmosis for salinity removal. Paradigm shift in people's perception about groundwater, which is now undervalued by users, is necessary for proper evaluation of the resource. Groundwater management has to be placed high in the political agenda in order to make it everybody's business. Courses on groundwater sciences have to be introduced at tertiary levels to produce more water experts. The research institutes have to be equipped with state-of-the-art laboratory facilities. Predictive groundwater modelling can aid better in decision-making. National monitoring system has to be updated along with open access to data for all users and interested parties. Groundwater has to be protected from overexploitation and degradation by introducing abstraction controls and licensing.

Groundwater: Vital Resource for a Better Bangladesh in 2050

Like today, groundwater shall remain one of the main sources of water for various uses in 2050 as well. However, ensuring sustainability of groundwater development shall become a mammoth challenge. Various natural and anthropogenic stressors will make the sustainable management extremely difficult.

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About the Editor

S. P. Sinha Ray has been a member of Central Ground Water Board and Central Ground Water Authority, Ministry of Water Resources, Government of India. He has more than 40 years of experience in groundwater exploration, development and management. By virtue of his long association with the country's apex organization dealing with groundwater resources, he has acquired substantial expertise in the field. Besides having a vast knowledge of the subject within the country, he has also gained insights and know-how in other countries like Algeria, Bangladesh, the USA, Korea, Zimbabwe and Japan. He is a Fellow of West Bengal Academy of Science, a Member, International Association of Hydrogeologists and Emeritus President, Centre for Ground Water Studies, Kolkata.

Part I
Major Ground Water Development Issues in South Asia

Major Ground Water Development Issues in South Asia: An Overview

S. P. Sinha Ray and Abhijit Ray

Abstract The complex nature of ground water problems in South Asia, i.e., India, Pakistan, Nepal, Bangladesh, Sri Lanka, and Myanmar, requires an in-depth analysis of the ground water regimes in different hydrogeological framework including ground water quality. Major ground water problems which require effective management include overexploitation, chemical contamination, seawater intrusion, and uneven distribution in time and space. Suitable policy framework for ground water utilization by individual countries and implementation of measures underlined in the policy need to be taken up.

Keywords Ground water · Overexploitation · Chemical contamination · Policy framework · South Asia

1 Introduction

Ground water resources play a major role in ensuring livelihood security across the world. The ground water crisis is acquiring alarming proportion in many parts of South Asia. Ground water contribution to poverty alleviation is very high in South Asia. The complex nature of ground water problems in South Asia implies that a precise understanding of the ground water regimes in different hydrogeological settings and socioeconomic conditions is a primary necessity for sustainable and equitable management. Major countries in South Asia, considered for this paper, are India, Pakistan, Nepal, Sri Lanka, Bangladesh, and Myanmar. The present deterioration of ground water sources on which people rely for their livelihoods, drinking and sanitation, and daily domestic needs means that water and sanitation pressures will simply grow from bad to worse. South Asian countries are characterized by wide variation of ground water levels in shallow aquifers, associated with monsoon rainfall. Rapid urbanization has resulted in important changes to ground water both by modifying preexisting recharge and discharge patterns.

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Ground water is vulnerable due to its relatively limited circulation, ability to transport pollutants originating from geogenic and anthropogenic stresses. Strategies to respond to ground water overexploitation and deteriorating water quality must be based on a new approach, considering ground water as a common property and redefining the institutional structure governing ground water. Development of practical policy and management options needs to be formulated and implemented at the earliest.

2 Ground Water Resources in South Asian Countries

Country-wise description is given below.

2.1 India

Ground water in India occurs in diversified geological formations with significant variation in lithological composition, in complex tectonic framework, and within different climatological conditions. Although country-wise aquifer mapping has been taken up by the Central Ground Water Board recently, from the existing knowledge, aquifers are available from the two principal geological formations, i.e., fissured formations and porous formations. The fissured formations are available in almost two-thirds of the country and include igneous and metamorphic rocks, volcanic rocks, consolidated sedimentary rocks, and carbonate rocks where ground water is available in near-surface weathered zone and deeper fracture zones in which secondary porosities have been developed due to weathering action and fracturing by tectonic activities. Volcanic rocks represented by Deccan Traps, Rajmahal Traps, etc. having low permeability have limited ground water potentialities. Carbonate rocks characterized by karstification in Vindhyans are promising aquifers due to the presence of saturated solution cavities and channels. However, vesicular lava has primary porosity. Igneous and metamorphic rocks like granite gneiss, charnockites, khondalites, schists, etc. have limited ground water potentialities.

The unconsolidated sediments deposited by riverine alluvium in major and minor river systems together with coastal and deltaic sediments constitute the major potential aquifers in the country. The hydrogeological setup of Ganga-Brahmaputra river valleys contains by far the most prolific aquifer system in the country.

The semi-consolidated Gondwana System of rocks also contains ground water in fissures, joints, and bedding planes under favorable hydrogeological environment. Older alluvium sediments of Plio-Pleistocene age also have moderately potential aquifers in porous zones.

The annual ground water recharge from rainfall in India is 342.43 km^3 and that of canal recharge is about 89.46 km^3. Thus the total replenishable ground water resources of the country is 431.89 km^3. CGWB has estimated state-wise fresh ground water resources also (Gandhi and Bhamoriya 2011). When considered basin-wise, Ganga basin is by far, the most ground water worthy (170.99 km^3/year). Although ground water utilization in domestic and industrial sector is within 15% of the total ground water resource, major share of the resource is allotted for irrigation sector.

The chemical quality of ground water in the country shows wide variation. While arsenic contamination in ground water is the most devastating menace in Ganga-Brahmaputra Plains having major impacts in the states of West Bengal, Bihar, Jharkhand, Assam, and Uttar Pradesh, high fluoride in ground water has been detected in 22 states of the country. Again, high concentration of uranium occurs in Andhra Pradesh, Jharkhand, Odisha, Rajasthan, Telangana, and Punjab. Besides these, industrial discharges, urban activities, disposal of sewage waters, and application of fertilizers and pesticides cause various pollution like excess nitrate in ground water. In some localized pockets, ground water is polluted by chromium, manganese, and selenium. Both inland and coastal salinity in ground water within 100 m depth are also very common.

The Central Ground Water Authority has been formed in 1996 to address various issues related to ground water protection. Overexploitation of ground water due to excessive ground water withdrawal has been identified through ground water monitoring system designed to address ground water level variation and the chemical quality change in ground water regime.

Ground water legislation based on the reformed Model Bill advocated by the Central Ground Water Authority has been adopted in some of the states of the country. To determine precisely the quantity and quality of India's ground water, Central Ground Water Board has launched the Aquifer Mapping Programme. Managed Aquifer Recharge Programme is also being taken up in the areas of high ground water stress.

2.2 Bangladesh

Unconsolidated sedimentary aquifers, belonging to Pleistocene and Holocene age, formed by alluvial sediments of Ganga-Brahmaputra-Meghna (GBM) delta system occur in major parts of the country. The country can be broadly divided into six major hydrogeological units (Ahmed et al. 1994) such as Zone I (Holocene piedmont plains), Zone II (Holocene Deltaic and Floodplains), Zone III (Pleistocene Terraces), Zone IV (Holocene depressions), Zone V (Tertiary Hills), and Zone VI (Holocene Coastal plains). Hydrogeological conditions vary significantly from unit to unit.

Ground water levels of the shallow aquifers fluctuate with annual recharge from monsoon rains. However, information regarding behavior of the water level in deeper aquifers are vary little and scanty. Jones (1987) considered that fresh ground water may be available from older Tertiary rocks from the depth of 1800 m. The regional flow of ground water is, by and large, from north to south.

The ground water recharge, under the studies of National Water Plan Phase-2, 1991, can be described as 9786 million m^3, 6594 million m^3, 1498 million m^3, 1249 million m^3, and 1961 million m^3 for NW, NE, SE, SC, and SW regions, respectively. The total ground water resource available in the country has been estimated as 21,088 million m^3, of which only 946 million m^3 is balance left for further development. The deep aquifer from Barisal and Patuakhali districts occurs within the depth range of 238–328 m, separated from the upper aquifer system by a 65–165 m thick clay layer.

Although 90% of rural drinking water is supplied from ground water, the principal use of ground water in Bangladesh like India is for irrigation.

Arsenic contamination of ground water in shallow aquifers was detected in the southwest part in 1993, but subsequently it has been found in central and northeastern regions also. Forty-four out of sixty-four districts in Bangladesh are affected by high arsenic in ground water.

The problems associated with the development of ground water in Bangladesh include unplanned process of expanding irrigation coverage, overexploitation of ground water, excessive use of ground water for summer paddy (Boro) cultivation, creation of ground water for markets, etc. However, ground water pollution due to excess arsenic content in ground water has posed considerable concern.

2.3 Pakistan

The Indus Basin, formed by alluvial deposits, is having unconfined aquifer system at shallow depth. About 79% of the Punjab province is having fresh ground water with less than 1000 mg/l TDS, whereas in Sindh province fresh ground water is available within 28% of area from 20 to 25 m depth. Indiscriminate use of ground water has caused enhanced level of salinity. In Tharparkar and Umarkot, the situation is further complicated by the occurrence of high fluoride in ground water. In North-West Frontier Province, abstraction in excess of recharge especially in Karak, Bannu, Kohat, and D.I. Khan has lowered water table and caused contamination from underlying saline water. In Balochistan, the Makran coastal zone and Kharan contain highly brackish (as high as 3000 mg/l) ground water which is being used for drinking water sources. In Mastung Valley as also in Makran coast and Kharan, ground water also contains high fluoride.

A ground water recharge of 56 billion cubic meters for the country has been estimated. The potential storage is the aquifer system of the Indus Plain and mountainous valley of NWFP and Balochistan. It has been established that ground water withdrawal exceeds annual average recharge in areas outside the Indus Basin. In Balochistan water table is receding 0.6–0.9 m annually on average. In one estimate, it has been observed that out of the total 68 billion cubic meters ground water, 60 billion cubic meters is already being extracted, leaving a balance of 8 billion cubic meters for exploitation.

Salinity of ground water shows wide variation from 1000 to 3000 mg/l and above. In many areas mining of ground water has set in causing intrusion of saline water and seepage of polluted water from agricultural field. The net addition of salts to the Indus Basin irrigation system is around 33 million tons, contributed by the canal water annually. Ground water in Pakistan which occurs under varying conditions is affected largely by changes in the prevailing climatic conditions. Above 50 ppb As has been detected in cities like Multan, Sheikhupura, Lahore, Kasur, Gujranwala, and Bhawalpur. It was found that in some districts of Sindh (Ahmed et al. 2004), As level exceeds 200 ppb in shallow depths. Under the arid condition, high fluoride and high salinity are quite widespread water-related problems.

In order to streamline the ground water exploitation, extraction, and management practices, each province in Pakistan has formulated its own laws to manage ground water resources. The key issues of ground water development are resource degradation, resource depletion, and equity deficiency and industrial policies (Qureshi 2004 and Qureshi et al. 2009).

2.4 Sri Lanka

The geology of Colombo represents the geology of Western Coast having sediments of Quaternary age comprising of high-level gravel formation embedded in a matrix of laterite and pebble-free layers of laterite. The floodplain deposit of Kelani River consists mainly of alluvium deposits. The geology of Kandy and surrounding areas is characterized by a thick band of marble and coarse crystalline rock with intruded calcsilicate gneiss. Other crystalline rocks prevalent in the area are hornblende-biotite gneiss, garnet-biotite gneiss, granulite gneiss, etc.

Six types of aquifers have been identified (Srimanne 1952, 1968; Arumugam 1966, 1974): These are the following: Shallow Karstic Aquifer of Jaffna Peninsula, Deep Confined Aquifers, Coastal Sand Aquifers, Alluvial Aquifers, Shallow Regolith Aquifer of the Hard Rock Region, and Southwestern Laterite (Cabook) Aquifer. Hydrogeological setting of all these aquifers has been adequately studied. In the Jaffna Peninsula, 100–150 m thick Miocene limestone, Karstic in nature, occurs in a form of solution channels and cavities. Annual rainwater recharge has been estimated between 10 and 20×10^7 cum., 50% of which drains out to sea (Balendran 1968). About 80% of this ground water is being used for agriculture and 20% for domestic purposes. Enhanced level of nitrate around the municipal area of the Peninsula has been reported. A number of deep confined aquifers occur within the sedimentary limestone and sandstone formations of the northwestern and northern coastal plains. The average depth of the wells reaching the artesian aquifers in the well-defined basins is from 30 to 50 m having yield potentialities 3–10 l/s (Wijesinghe 1973). High ground water use for agriculture in Vanathavilluwa basin has caused leaching of salts which increased the conductivity of the water.

The coastal sand aquifers are represented by shallow aquifers on coastal spits and bars in the Kalpitiya Peninsula and Mannar Island in the Northwest region and shallow aquifers on raised beaches in Nilaveli-Kuchchaweli, Pulmoddai, and Kalkuda in the northeastern region. Ground water is very limited but has precious resources in this aquifer. The Alluvial Aquifers occur in coastal and inland floodplains, dissected and depositional river deposits, and inland valleys of different shapes, forms, and sizes. Old buried riverbeds with high ground water yields are present in the lower Kelani River Basin.

The alluvial thickness varies between 10 and 15 m, and moderate quantity of ground water is extracted throughout the year. Because of low storage capacity, weathered zone or regolith of the Hard Rock Region contains limited ground water. The regolith layer is only 2–10 m in thickness. However, ground water also occurs at depth in the Hard Rock Region in the fracture zones restricted to 30–40 m depth which has been tapped by bore wells to support domestic water needs of the Dry Zone. Southwestern laterite, generally called "Cabook," has good water-holding capacity within the vesicular laterites which are developed by dug wells as well as shallow tube wells. In the outer Colombo and surrounding area due to rapid urbanization and setting up of industrial estates, these vesicular laterites face overexploitation situation and enhanced nitrate levels in ground water.

Shallow Karstic Aquifer in Jaffna Peninsula is the most intensively utilized. The aquifer gets recharged by November–December rains of the northeast monsoon. Monitoring of ground water has confirmed a significant imbalance between ground water recharge and discharge situation. In the Deep Confined Aquifer safe abstraction rates have been estimated as 3 MCM/year for the Vanathavillu aquifer basin to 8 MCM/year for the Paranthan aquifer basin. Yield of the artesian wells within 50 m depth ranges from 0.5 to 25 l/s. The study conducted in Shallow Coastal Sand Aquifer indicated that Nilaveli-type Aquifer has more recharge than Kalpitiya Aquifer. The Alluvial Aquifer of the larger river systems in the southwestern part of the country does not show reduction in quantity even in drought months. Shallow Regolith Aquifer, restricted mainly in the North Central and northwestern provinces, has an estimated recharge of 100 mm during the Maha season. During severe drought conditions, this aquifer having limited ground water resources causes depletion. Southwestern Laterite (Cabook) Aquifer gets recharge during first rains after the dry period in February to March and gets recharge several times during the year.

It has been established that tank irrigation is having an important impact to sustainable ground water use in Sri Lanka. Water Resources Board set up in 1966 with a vision to adequate access to clean and safe water for all is subsequently from 1999 looking after the management of ground water resources with adequate emphasis.

2.5 Nepal

The high mountains of the Himalayas and central hill regions are dominated by ancient crystalline rocks comprising mainly granites, metamorphic rocks, and old indurated sediments. The southern lower-lying parts of Nepal and isolated intermountain basins (e.g., Kathmandu Valley, Mugu Karnali Valley) are occupied by Mesozoic to Quaternary sediments. Recent Alluvial Sediments constitute the low-lying Terai plains along the Indian border.

Ground water availability is very limited in hilly regions. However, in Kathmandu Valley, ground water occurs in thick alluvium sequence. Both shallow (within 10 m depth) and deep (310–370 m) aquifers occur in the valley in which the shallow one is under unconfined and deep one is under confined state. A large quantity of ground water is being withdrawn in Kathmandu Valley through shallow and deep tube wells (Pandey and Kazma 2011). However, development of deep aquifer has caused a recession of piezometric surface to the tune of 15–20 m (Khadka 1993). Kastric limestone aquifer occurs beneath the alluvial sequence of Kathmandu Valley, which, however, has not been exploited. Throughout the Terai region, shallow and deep aquifer of varying thicknesses occupy except in Kapilavastu and Nawalparasi (Upadhyay 1993). However, the deeper aquifer shows artesian condition.

Although ground water quality data is not available adequately, it has been seen that shallow ground waters are at risk from contamination of pathogenic bacteria, pesticides, nitrates, and industrial effluents. In some parts of the Terai region, anaerobic conditions are observed with high concentrations of arsenic and iron. The deep aquifer in Kathmandu Valley and Terai region shows higher values of iron, manganese, etc. However no high arsenic deep ground water has been reported so far. Springs from the Karstic limestone aquifer is reportedly calcium-bicarbonate type with good chemical quality. In deep aquifer high concentration of ammonium (<3–35 mg/l N), possibly of natural origin, has been observed. From the available data, it has been found that higher concentrations of arsenic occur within shallow aquifers (restricted to 50 m) in the Terai region. Areas of crystalline basement with sulfide mineral veins may also contain contaminated ground water with trace elements like zinc, copper, cobalt, lead, and cadmium.

2.6 Myanmar

Myanmar can be divided into four geological regions: Central Lowland, a vast alluvial plain with intermittent outcrops of hills and mountains containing Dry Zone, Sham Highland in the East, Western Fold Belt, and Rakhine Coastal Belt. The Irrawaddy group comprising mostly loosely cemented sand and sandstone beds occupies about 38% of the Dry Zone. In the Central Basin, Irrawaddy sands comprise a large proportion of quartz pebbles, gravels, conglomerate, and red earth beds. Irrawaddy group aquifers consisting mainly of sands occur within maximum depth of 350 m in which ground water occurs in semi-confined to confined state. Shallow tube wells occurring within 40–70 m depth in Magwe and Monywa districts can yield 270–4700 m^3/day. Ground water is available throughout the Dry Zone. While alluvial and Irrawaddy groups are usually freshwater bearing, Pegu (marine sandstone) units are mostly brackish or saline (Tun 2003).

Available ground water varies considerably both in quantity and quality in four major aquifer groups in the Dry Zone due to their depositional environments, lithology, and mineralogy. Quality deterioration is associated with the occurrence of various trace elements like iron, manganese, and arsenic. In Irrawaddy delta region within an area of 3000 km^2, higher level of arsenic has been detected, and the World Bank (2005) has estimated that about 3.4 million people are at risk of arsenic hazards.

District level figures estimated on the ground water recharge are around 4777 MCM/year. Ground water is mainly used for domestic purposes, while in agriculture sector also, its contribution is significant in the Dry Zone area. However, in some areas ground water shows underdevelopment.

The major ground water development issues include unrestricted ground water withdrawal which may cause overexploitation syndrome, water quality deterioration, decline of ground water level due to excessive withdrawal from confined artesian aquifers, etc. A well-knit ground water data monitoring system and precise ground water assessment are to be made.

3 Key Issues of Ground Water Problems in South Asia

- Overexploitation of ground water
- Contamination of ground water contained in shallow aquifers due to geogenic stresses
- Seawater intrusions in coastal area
- Anthropogenic activities polluting the ground water
- Participation of stakeholders in water management
- Proper policy framework regulating the water utilization
- Implementation of measures underlined in the policy
- Coordination among the agencies entrusted with supplying water and maintaining hygiene considering health impacts

4 Conclusions

A review of hydrogeological situation in the megacities of South Asia reveals several alarming trends of overexploitation of ground water causing long-term decline of ground water level, ingress of saline water, and deterioration of ground water quality. This calls for a new approach to ground water governance and sound management plan. There is a dire need to evolve workable methods and approaches to synchronize the demand and supply gap. In order to improve the water supply in urban areas, the installation of water meters needs to be encouraged. Building a near social framework including community participation at all levels of water system is necessary. The community participation in water pumping policies, incentives of efficient use, affordability by low-income users and other vulnerable grumps, and water awareness, especially among women and children, are prime factors for success of any domestic water project. The shift policy for the permission of safe, adequate, equitable, suitable, and affordable water is critical for the health and the project of the region.

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