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Editors

Groundwater and Society

Applications of Geospatial Technology

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Dedicated to
The Millions of Farmers of India

Foreword

I am happy to learn that Springer is bringing out a book entitled *Groundwater and Society: Applications of Geospatial Technology*. The book is edited by Pravat Kumar Shit, Gouri Sankar Bhunia, Partha Pratim Adhikary, and Ch. Jyotiprava Dash, who are eminent scholars and researchers in the field of groundwater resources and application of geospatial technology.

Demand for fresh water has become crucial in the last few decades and the problem will intensify in the future. Therefore, the issues and concerns regarding fresh water are experiencing growing recognition among academicians throughout the world. Groundwater in this context is one of the formidable solutions, but its availability, reckless use, and also misuse are yet to be investigated with deeper introspection. Considering the need of the hour, research on judicious use and management of groundwater is gaining importance in India.

In the twenty-first century, groundwater is an essential key for societal growth and development. Due to population growth, rapid urbanization, industrialization, and associated groundwater contaminants, serious health risks are evident and they pose a challenge to our society. The contribution of groundwater is immense in improving agriculture development, food security and many other aspects. So, our human society needs to establish an action plan that will considerably reduce contaminants and pollution of groundwater resources and allow development of the potential of groundwater resources and management of these resources using geospatial modeling and indigenous low-cost technologies through eco-friendly approaches.

This book presents an overview of recent advances in geospatial knowledge for the assessment and management of groundwater resources, giving special attention to how to use the local level of groundwater resources for societal development. The present volume also deals with various aspects of hydrogeological characteristics, groundwater quality, groundwater vulnerability, groundwater resources management, as well as social and economic considerations.

It is hoped that the contents of this book will contribute to an improved understanding of the impacts of human activity on groundwater resources and will provide useful guidance for policy makers and planners to include groundwater in crop adaptation schemes and strategies. I do believe that this book will be very beneficial for undergraduate and postgraduate students, researchers, social workers, and scientists working in the field of environmental sciences, hydrogeology, soil sciences, and agricultural sciences.

I extend my warm greetings to all those associated with the publication and congratulate Springer for launching this book.

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Sanat Kumar Guchhait

Acknowledgments

The preparation of this book has been guided by several hydrologic pioneers. We are obliged to these experts for providing their time to evaluate the chapters published in this book. We thank the anonymous reviewers for their constructive comments that led to substantial improvement of the quality of this book. Because this book was a long time in the making, we want to thank our family and friends for their continued support. Dr. Pravat Kumar Shit thanks Dr. Jayasree Laha, principal, Raja N.L. Khan Women's College (Autonomous), Midnapore, for her administrative support to carry on this project. Dr. Partha Pratim Adhikary thanks ICAR-Indian Institute of Soil and Water Conservation, Research Centre, Koraput, Odisha, for its support to edit this book. This work would not have been possible without constant inspiration from our students, knowledge from our teachers, enthusiasm from our colleagues and collaborators, and support from our family. Finally, we also thank our publisher and its publishing editor, Springer, for their continuous support in the publication of this book.

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Part I
Groundwater Resources and Societal Development

Chapter 1
Introduction to Groundwater and Society: Applications of Geospatial Technology

Pravat Kumar Shit, Gouri Sankar Bhunia, Partha Pratim Adhikary, and Ch. Jyotiprava Dash

Abstract Water is the basic requirement for the development of civilization. The primitive civilizations were developed along the surface water bodies to meet the demand of water for the society. With the progress of time, the population-led demand for water was increased in those civilizations and which ultimately led to conflicts. The Indus valley civilization was destroyed mainly because of issues related to water management. In the recent times with the advent of modern tools and gadgets, the issues related to water have increased manifold. The demand from drinking, domestic, agriculture and industry has also increased alarmingly. To meet these demands, use of groundwater has increased tremendously all over the world. With the higher demand, the problems also became higher. In this context, modern tools and techniques like remote sensing, geographical information system, geostatistics and modelling have the potentiality to manage the groundwater-related problems and play a vital role for societal development. In this book we intended to offer novel advances and applications of remote sensing, geographical information system and geostatistical techniques in a precise and clear manner to the research community to achieve in-depth knowledge in the field. The scientific understanding, development and application of geospatial technologies related to water resource management have been advanced. Geostatistics and geospatial techniques for groundwater science assemble the most up-to-date techniques in GIS and geostatistics as they relate to groundwater. Therefore, this book will help the readers

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to find the recent advancement of the geospatial techniques and its application in the groundwater resources in a single volume.

Keywords Societal development · Remote sensing · GIS · Groundwater Quality and Pollution Assessment · Precision agriculture · Resource management

1.1 Introduction

Groundwater is the water found below the earth surface and accounts for 30% of available freshwater of the earth. It is a very important natural resource and has a significant role in the economy of any nation. People from all over the world are using sub-surface water to meet their various needs like drinking, washing, etc. for a long period of time (WWAP-UNESCO 2009). The increase in population increases the demand, and thus the exploitation of groundwater is gradually increasing. The contribution of groundwater to irrigation and food industry is highly significant and slowly leads to its over-exploitation (Smith et al. 2016). Globally, we use nearly 70% surface and sub-surface water as irrigation. India is the largest user of groundwater in the world followed by China and the USA, using an estimated 250 km^3 of groundwater per annum. The developing countries are using groundwater at a faster rate. For example, in India, the contribution of groundwater is 62% in agriculture sector, 85% in rural water supply and 45% in urban water consumption. All over the world, groundwater is being used for industrial development, and it triggered unprecedented changes in the state of groundwater level. The groundwater is pumped out faster than it can replenish itself through underground recharge. This imbalance of input and output in groundwater extract creates a lot of problem (Chenini and Mammou 2010).

The groundwater crisis is an issue which can be solved at local level but has a global concern. The issue of groundwater management needs to be addressed in a global scale to ensure sustainable use of groundwater resources and to reverse the depletion of reserved groundwater. If this valuable resource cannot be managed properly, it will be a threat to the existence of living beings in the near future. Despite the increasing pressure placed on water resources by population growth and economic development, the laws governing groundwater rights have not changed accordingly, even in developed nations. Nor is groundwater depletion limited to dry climates: pollution and mismanagement of surface waters can cause overreliance on groundwater in regions where annual rainfall is abundant.

Availability of good quality water in abundant quantity is the prime concern for the establishment of human settlement. The early settlers were totally dependent on surface water (Maisels 2001), and with the advent of civilization this demand enhanced considerably. This leads to the competition for faster development among the people (Taylor et al. 2013) which leads to the gradual increasing of water demand as well as scarcity. The earlier settlers were also exposed to climate change and other monsoonal aberrations (Pereira et al. 2009), although water pollution was not so much important. To get rid of this crisis, people started the groundwater extraction to overcome the water scarcity problem. The regulating water demands are also dramatically increased, promoting the deficit of groundwater storage, depletion of the water table (Qureshi et al. 2010) and reduction of recharge rate. The humans are in dire need to find out the adaptive strategies and restrain water demands alongside the increase of rainwater recharging capacity, groundwater storage and efficiency in water utilization.

Therefore, for the optimal utilization and preservation of this treasure, systematic planning and management using modern tools and techniques are essential. For the greater interest, a measurement of groundwater resource is really significant for the sustainable management, and with the advent of powerful and high-speed personal computers, efficient techniques for water management have evolved, of which RS (remote sensing), GIS (geographic information system) and GPS (Global Positioning System) and geostatistical techniques are of great significance (Magesh et al. 2012; Kumar et al. 2014; Adhikary et al. 2011, 2015; Thapa et al. 2017; Nasir et al. 2018).

1.2 Key Aims of the Book

Groundwater is inarguably the world's single most important natural resource. It is the foundation of the livelihood security of millions of farmers and the main source of drinking water for a vast majority of people residing in rural as well as urban areas. The prospects of continued high rates of growth of the world's economy will depend critically on how judiciously we are able to manage groundwater in the years to come.

Over the years the world is consuming huge amount of groundwater for its growth and development. The contribution of groundwater is immense to make our world better in food security and many other aspects. Even as groundwater has made us self-sufficient in food, we are now facing the crisis of depleting water tables and water quality. The deep drilling by tube wells that was once part of the solution to the problem of water shortage now threatens to become a part of the problem itself. We, therefore, need to pay urgent attention to the sustainable and equitable management of groundwater.

Our intention in editing this book is to offer novel advances and applications of RS-GIS and geostatistical techniques in a precise and clear manner to the research community to achieve in-depth knowledge in the field. It will help those researchers who have interest in this field to keep insight into different concepts and their importance for applications in real life. This has been done to make the edited book more flexible and to stimulate further interest in topics. All these motivated us towards novel advances and applications of geospatial technologies and geostatistics.

This book advances the scientific understanding, development and application of geospatial technologies related to water resource management. Geostatistics and geospatial techniques for groundwater science assemble the most up-to-date techniques in GIS and geostatistics as they relate to groundwater, one of the most important natural resources. Therefore, this book will help the readers to find the recent advancement of the geospatial techniques and its application in the groundwater resources in a single volume.

1.3 Sections of the Book

The book is organized into three parts: (I) Groundwater Resources and Societal Development; (II) Groundwater Availability, Quality and Pollution; and (III) Sustainable Groundwater Resources Management.

1.3.1 Section I: Groundwater Resources and Societal Development

This section concerns itself with the specific uses and management of groundwater as a component of integrated water management for societal development. Modern geospatial and geostatistical technologies have been described and used to address the issue of groundwater-related conflicts generally arising in the society. Overall, these fundamentals are tried to capture in five chapters of the section. These chapters are essential either to understand the spatial process of groundwater variation or to quantify these variations through the lens of society. The second chapter talks about how societal development has been started with the availability of freshwater in the world and how the conflicts have arisen because of water scarcity and pollution. In this context how the integrated approach of remote sensing and geographic information system has the potentiality to address the issue of groundwater scarcity and quality on a spatial scale through the involvement of the society has been described in Chap. 3. Chapter 4 deals with geospatial and geophysical approaches for assessment of groundwater resources in alluvial aquifers. This has been described through a case study from India. There are many issues related to groundwater management using space technology. Chapter 5 deals with those issues and suggested comprehensive solution to deal with those issues. The village level assessment of groundwater quality has the most importance to solve the problem comprehensively. Thus Chap. 6 documented the village level assessment of groundwater quality through multi-criteria-based GIS analysis. Overall, this section talks about how geospatial techniques will be useful to address the groundwater-related societal conflicts and how modern tools can play a greater role for societal development.

1.3.2 Section II: Groundwater Availability, Quality and Pollution

The second section deals with the regularity and monitoring of groundwater resources. This section discusses about the groundwater potential zone identification, the amount of water available in the aquifer, recharge and discharge characteristics of groundwater resources. Here remote sensing and GIS techniques have been extensively used. In this section, the threats of over-extraction and subsequent groundwater pollution emerging out because of high dependency led to high exploitation of groundwater resources by societal, economic and environmental development. The evolution of effective management systems to address these threats has been discussed. Ten chapters have been dedicated in this section. Delineation of groundwater potential zones is a very important issue which serves as the first point for groundwater management. Chapters 6, 7, 8, 9, 10 and 11 discuss about the delineation and mapping of groundwater potential zones using modern tools, techniques and modelling. The applicability of GIS-based Fuzzy Analytical Hierarchy Process approach has been highlighted in these chapters. The performance of Frequency Ratio Approach and Artificial Neural Network has also been discussed with case studies in this section. The appraisal of groundwater quality is the topic of present-day research. Chapters 12, 13 and 14 deal with this aspect. Multi-criteria-based GIS approach, use of groundwater quality indices and HPI were used to understand managing groundwater pollution through case studies. Chapter 15 deals with fluoride dynamics in Precambrian hard rock terrain of North Singhbhum Craton and effect of fluorosis on human health and society. Thereby the problem of fluoride has been dealt with in this section. Salt water intrusion in the coastal aquifer is a problem. Therefore Chap. 16 assesses the coastal aquifer vulnerability for saltwater intrusion using GALDIT model and geo-informatics. This thing has been explained through a case study of Chennai coast.

1.3.3 Section III: Sustainable Groundwater Resources Management

The third section deals with the application of geospatial techniques to tackle man-induced changes in groundwater conditions. The environmental and socio-economic impacts on groundwater resources have been dealt with in detail. How different approaches like watershed management and agro-forestry can remediate the twin problem of groundwater quantity and quality deterioration and the role of RS and GIS to support in this aspect has been addressed. The role of stakeholder's participation to tackle the groundwater-related problems for long-term basis through which viable national, regional and local systems can be evolved has also been addressed. Altogether there are seven chapters to cover these aspects. Chapter 17 discussed about the impact of watershed development models on water resources especially on groundwater utilization. This has been illustrated with a live case study from a tribal watershed of India. Chapter 18 deals with the impact of long-term groundwater behaviour on agricultural development. This has been discussed with a case study from an agriculturally developed state of north-west India. Chapter 19 deals with the spatial appraisals of groundwater recharge potential zone identification using remote sensing and GIS. Water stress is an important aspect which controls the agricultural activity through the world. In this aspect Chap. 20 deals with spatial mapping of groundwater depth to prioritize the areas under water stress in the Rayalaseema region of Andhra Pradesh, India. Groundwater vulnerability was explored using AHP and GIS techniques in Chap. 21 with the help of a case study from India. A geoscientific study on Birbhum District, West Bengal, India, was presented in Chap. 22 where the applicability of geospatial technology, weight of evidence and multilayer perceptron was used for groundwater management. This study critically examined the modern tools and techniques for efficient management of groundwater resources. The last chapter deals with water resources management in the context of sustainable development goals of the United Nations. This is addressed with the help of a good case study from India. Overall, this section has given comprehensive idea about the importance of RS, GIS, modelling and other modern tools and techniques for sustainable water resources management.

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Chapter 2
Groundwater and Society in India: Challenging Issues and Adaptive Strategies

Subrata Jana

Abstract The scarcity of freshwater is escalating higher than the predicted level in India alongside the other countries in the world. The surface, subsurface and groundwater resources are gradually reducing in quantity and quality concern. The states and union territories of the western, southern and central India are already severely suffering from the scarcity of freshwater. Rate of groundwater extraction accelerated after the implementation of the green revolution and urban-industrial development. The river's natural flow has been diverted and protected for socio-economic development. Therefore, the lower riparian states are deadly affected by ecological and hydro-geomorphological perspectives. The fisheries have been widely adopted in those areas as an alternative to traditional crop cultivation, which extract more groundwater for freshwater supply and enhance the rate of groundwater depletion. Moreover, the rainwater recharge into the soil layer as well as in the groundwater table has been gradually reducing due to concretized urban infrastructural development. The surface runoff becomes accelerated, enhancing the soil erosion rate. In India, about 75% of total water bodies have been polluted from domestic wastes. Besides, about 80% of rural people are compelled to use unsafe water, which resulted in the death of more than 700 children per year from diarrhoea. In this situation, India achieves the third place in the world in terms of water export. In such juxtaposition condition, about 60% and 85% of irrigation water and drinking water supply came from the groundwater, respectively. Recently, over 60% of tube wells are malfunctioning due to excessive rate of groundwater depletion. The su ffering of the people is tremendously increasing concerning the availability of drinking water and irrigation water. People are extracting groundwater from the far depth to overcome the crop failure and drinking water problem. But, the severity of water scarcity becomes enhancing year after year in conjunction with global warming and climate change. In this concern, the government has taken different water scarcity preventive measures in individual household level to the regional level. Now, the main motto is to execute the 3-R concept (recycle, reuse and recharge) in association with the other various techniques of water storage (like

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rainwater harvesting) and groundwater recharge (like percolation tank, recharge tube well). In addition, awareness programmes are being campaigned from the grass-root level to increase the efficiency in water utilization among the people.

Keywords 3-R concept · Climate change · Crop failure · Groundwater depletion · Rainwater harvesting · Urban-industrial development · Water scarcity

2.1 Introduction

Availability and supply of freshwater is the primitive aspect to the establishment of human settlement, not only for their drinking water but also for their livelihood practices. The early civilizations were entirely dependent on the surface water supply (Enzel et al. 1999; Maisels 2001). Afterwards, increasing population density immensely enhanced the demand for freshwater. People were running across the earth's surface to find out the suitable place for constructing settlement on the basin of surface water sources. Therefore, almost the entire freshwater source areas in the earth were occupied by human beings. The fresh surface water storage becomes reducing with the promotion of competition for faster development among the people (Shah 2009; Taylor et al. 2013). People planned to bifurcate the rivers and natural water sources with their innovative ideas, which emphasizes the gradual increasing of water demand as well as scarcity. People started groundwater extraction to overcome the water scarcity problem. Water demands also dramatically increased, promoting the deficit of groundwater storage and depletion of the water table (Kulkarni et al. 2004; Qureshi et al. 2010). Moreover, the societal development leads to the concretization of the earth's surface, which promotes the deficiency in the ability of water recharge into the soil layer as well as in the groundwater table.

India is the largest user and third largest exporter of groundwater; it extracts about 230 km^3 groundwater per year that is about 25% (more than the combined use of China and the Unites States) of the global total (Maheshwari et al. 2014; Murtugudde 2017; India Today 2019). In India, over 60% of irrigated water and 85% of drinking water supply depend on groundwater (World Bank 2011, 2012; Grönwall and Danert 2020). The freshwater demand is gradually increasing with the prolonged socio-economic development and associated livelihood practices. The primitive nature of agricultural practices has converted into modern trends with the implementation of technological innovations. The green revolution has emphasized enhancing crop production using more fertilizers and irrigational water supply (Singh 2000; Pingali 2012). Recently, the traditional agricultural land has been converted into fisheries concerning more profit, particularly in the coastal and floodplain areas (Gowing et al. 2006). The effect of industrialization is also enhancing the scarcity of water (Lal 2000). In every case, groundwater has been extensively extracted in support of the available supply and scarcity of surface water. Besides, the water quality has deteriorated with the encroachment of harmful pollutants. The inconsistent nature of monsoonal rainfall also enhanced the episodic scarcity of groundwater (Sinha et al. 2015). Therefore, the gross availability of freshwater storage and supply shrinks dramatically with the ever-increasing demands. In India, about 60% of aquifers will be in a critical situation in 20 years if the recent trends continue (Gandhi and Namboodir 2009; World Bank 2012).

The earlier human civilizations had tremendously suffered from global warming and associated climate change and inconsistency of monsoon rainfall pattern in India among the other regions of the world (Pereira et al. 2009), although water pollution was not an issue at all for abolished or shifting of civilization in that period, which is the most threatening issue in the recent perspective. The excessive rate of glacial retreats also becomes a threat to the future society regarding the availability of freshwater supply in most of the rivers in northern India (Richardson and Reynolds 2000). The people are at the terminating stage to survive, and there have been urgent needs to find out the adaptive strategies and restrain water demands alongside the increase of rainwater recharging capacity, groundwater storage and efficiency in water utilization. So, the present study emphasizes the efficient utilization of freshwater concerning the sustainability of human civilization incompetent from earlier societies.

2.2 Water Source and Civilization: A Changing Spectrum

2.2.1 Water Source and Establishment of Settlements

There has been a reciprocal relationship between the water source and establishment of the settlement, as water is the backbone of a society. The people can only survive within this earth because of water. People use water for drinking as well as for irrigation. The ancient people established their settlements in the wider floodplain areas of the major river valleys depending on the river courses as a water source (Postel and Richter 2012; Singh et al. 2017). The Indus civilization is the best example of ancient civilization, which was formed based on the Indus River in northwestern India (Possehl 2002; Dixit et al. 2018). However, the well-established civilization was entirely ruined due to the reducing water supply and prolonging drought phase (Sangomla 2019). Remaining people moved mainly towards the east and north ensuring water availability. In the later phase, people have distributed over the major river valley regions of India. Moreover, the monotonic and inconsistent nature of Indian summer monsoon (ISM) emphasized the water scarcity on a regional basis (Basu et al. 2020). People are fighting against such water scarcity through the utilization of groundwater. Therefore, the modern civilizations not only preferred and formed their settlement just in the riverside location, nearer to the floodplains and in the coastal areas but also selected places for their settlement based on the availability of groundwater. The population density and water demand have reciprocally increased in the well-established settlement areas. The water quality also deteriorates with the increasing demand for societal development (Adhikary et al. 2015). The physicochemical compounds have been released from the industrial effluents and also from the extensive agricultural sectors. People have been compelled to extract water from the subsurface and groundwater storage. In the modern perspective of the settlement construction, the availability and source of surface water is not the mandatory aspect. People can construct far away from surface water source points based on the availability of groundwater.

2.2.2 Water Source and Livelihood Practices

People have adopted agricultural practices to survive their livelihood. The fertile floodplain areas have been utilized depending on the river water source and direct rainwater in this purpose. Initially, life-supporting food grain cultivation was the prime aspect of earlier people. However, the other cash crops were also cultivated in the following periods due to more profit issue, which required more water for irrigation (Singh and Jyoti 2019). People were distributed in the different landscape areas of the hills, plateaus and plains in finding their way of livelihood. Despite the harsh terrain condition, the unfavourable undulated lands of hilly and plateau regions have been modified for their agricultural land. The crop failure was the familiar issue in the dry regions and the fringe areas of the plateau and hills (Glantz 2019; Singh et al. 2019). Therefore, people constructed the check dams in the different parts of the tributaries to provide irrigation water in their agricultural land. The large dams and barriers have been also constructed to solve multiple problems. In this consequence, the lower courses of the river valley become water fed during the dry seasons, creating the ecological imbalances with the extinction of local aquatic species (Choudhury et al. 2019; Sarkar and Islam 2020). The dam and reservoir water did not fulfil the excessive demand for irrigation water in the ever-increasing areas of agricultural land. In this concern, the groundwater is to be the only alternative option to the farmers. Recently, about 90% (228.3 billion m^3) of the total available groundwater (253 billion m^3) was used for irrigation purpose (DownToEarth 2019a). Moreover, fisheries become intensively emerging in the areas of floodplain, delta plain and coastal zone for better profit in the fishery sector. Voluminous groundwater has been extracted every year to fulfil the demand for freshwater in the fisheries (Colvin et al. 2019).

2.2.3 Modern Civilization and Deterioration of Groundwater Quality

The industrial revolution brings new thinking and better aspects of development. Uneven competition creates an unbalanced development among different societies. Water is the most important aspect for industrial setup in any area. The natural river flow has been diverted to fulfil the demands of water for urban-industrial development (Arfanuzzaman and Syed 2018; Kumar and Verma 2020). The groundwater is also extracted for the other activities in the industry-based towns. Industrial effluents are mostly discharged into the natural water flows of rivers without any significant level of treatment (Gurjar and Tare 2019; Mohanakavitha et al. 2019; Mishra et al. 2020). The pollutant materials have penetrated the soil layer and mixed with the subsurface water table. After the green revolution in India, chemical fertilizers and pesticides have been massively utilized in the agricultural fields. The excessive level of pesticides and chemicals has been washed out from the agricultural fields and ultimately mixed up with the subsurface and surface water. The groundwater tables are also contaminated with the pollutants of subsurface water due to the seasonal fluctuation of water table caused by the monsoonal rainfall. The untreated urban waste and pathogens are also accelerating the degradation level of water quality. Therefore, the water quality of the surface, subsurface and groundwater has continually deteriorated every year.

2.2.4 *Water Quality and Human Health*

Even in the twenty-first century, most of the people both in the rural and urban areas have compelled to take the untreated drinking water. Especially, the miseries of the rural people are exceptionally in worst conditions regarding the supply and availability of safe drinking water. The shallow depth tube wells and dug wells, even the surface water, are the most important source of drinking water. The poor people never think about the quality of water; they only think about the availability of it. Mainly, water from the riverbed and underground has been supplied in the urban areas. In India, the drinking water from the surface, subsurface and groundwater has been contaminated with harmful pollutants and metals in most of the areas. About 75% of total water bodies remain polluted in the country (Saha 2019); among those about 75–80% of water bodies are polluted from the domestic sewage (Mallapur 2016). Therefore, people of the rural as well as urban areas are continuously suffering from drinking water problems.

In India, 816 municipalities adopted the sewage treatment plants among which only 64% is in the operational stage and the rest are in non-operational and under construction stage (Table 2.1). The operational plants are only treated 81% waste out of the total treatment capacity of 23277.36 million litres per day (Table 2.1). Moreover, water pollution is enhancing with the poor sanitation facilities in rural areas and even in the urban areas and slum areas (Table 2.2). In India, about 12.6% and 18.9% of households, respectively, in the urban and slum areas don't have any sanitation facilities (Table 2.2). Therefore, the miseries of the common people are accelerated during the rainy seasons due to contamination of water bodies with the harmful physicochemical components coming from wastes. Moreover, the peoples of the coastal areas have been suffering from the saline water encroachment into the groundwater table (Behera et al. 2019). Concerning the water quality index, India remains in the 120th place among 122 countries, and about one billion people are

Table 2.1 Status of sewage treatment plants in India (based on CPCB 2015; Mallapur 2016)

States	Punjab	Maharashtra	Tamil Nadu	Uttar Pradesh	Himachal Pradesh	All India
Capacity of municipal STPs (MLD)	1245.45	5160.36	1799.72	2646.84	114.72	23277.36
Total number of municipal STPs	86	76	73	73	66	816
Operational capacity (MLD)	921.45	4683.9	1140.83	2372.25	79.51	18883.20
Number of operational STPs	38	60	33	62	36	522
Number of non-operational STPs	4	10	1	7	30	79
Number of under construction STPs	31	6	28	3	–	145
Number of proposed STPs	13	–	11	1	–	70

Note: STPs stand for sewage treatment plants, and MLD is the million litres per day

Table 2.2 Status of sanitation facilities in India (after Mallapur 2016)

Type of latrine	Urban households (%)	Slum households (%)
Latrine within the premises	81.4	66.0
Water closet	72.6	57.7
Pit latrine	7.1	6.2
Other latrine	1.7	2.2
No latrine within the premises	18.6	34.0
Public latrine	6.0	15.1
Open field	12.6	18.9

suffering from unsafe drinking water (The Economic Times 2018; India Today 2019). Also, in India, about 80% of rural people are compelled to use water from unsafe sources, and every day more than 700 children (under 5 years of age) die in diarrhoea connected with the unsafe water and poor sanitization (India Today 2019).

2.3 Groundwater Depletion and Society

2.3.1 Climate Change and Groundwater Depletion

Climate change or climatic oscillations have also remained in the different periods of human civilizations, and people made their adjustment and adapt to the harsh condition in those periods. But, human civilization is now in trouble and tremendously affected in the recent context of global warming and climate change. The water scarcity has been prolonging with the gradual depletion of the groundwater

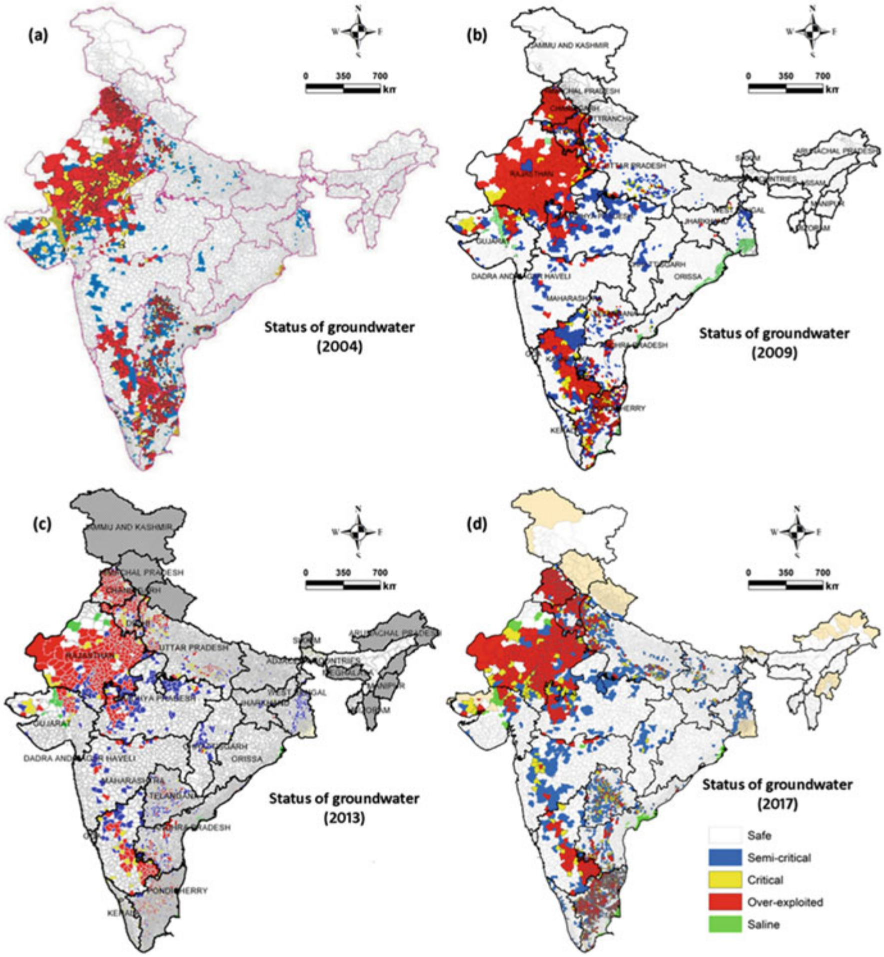

Fig. 2.1 Categorical safety status of Indian groundwater in the year of (**a**) 2004, (**b**) 2009, (**c**) 2013 and (**d**) 2017. (Based on CGWB 2020)

table and scarcity of surface water in association with seasonal drought events. As per the Intergovernmental Panel on Climate Change (IPCC) special report (2018), the ratio of population rendering to water stress owing to climate change would be reduced by 50% if the global warming can be limited to 1.5 °C instead of 2 °C as approved in the Paris Agreement (Hoegh-Guldberg et al. 2018; DownToEarth 2020b). The regional inconsistent nature of monsoonal rainfall creates a harsh impact over the Indian society, mainly in central, western and southern India (Fig. 2.1). The people suffering in those regions have been panic-stricken day by day, particularly during the summer months (Fig. 2.2). Indeed, groundwater plays a crucial defensive role against the water scarcity on a regional basis. For instance, crop productivity declined by 20% due to deficit rainfall during 1963–1964. But it

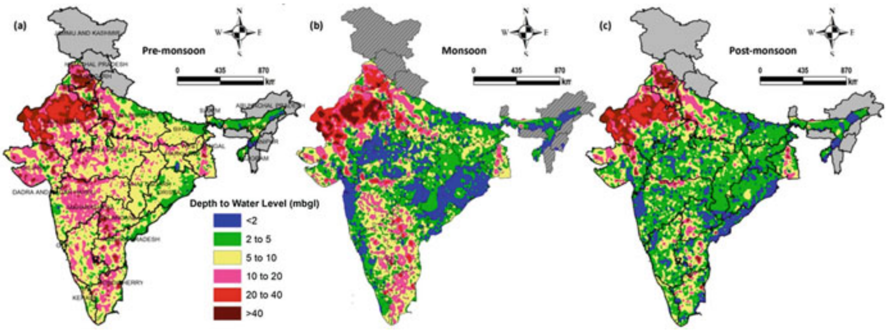

Fig. 2.2 Spatio-temporal fluctuation of groundwater level in India during (**a**) pre-monsoon, (**b**) monsoon and (**c**) post-monsoon seasons of 2019. (Based on CGWB 2020)

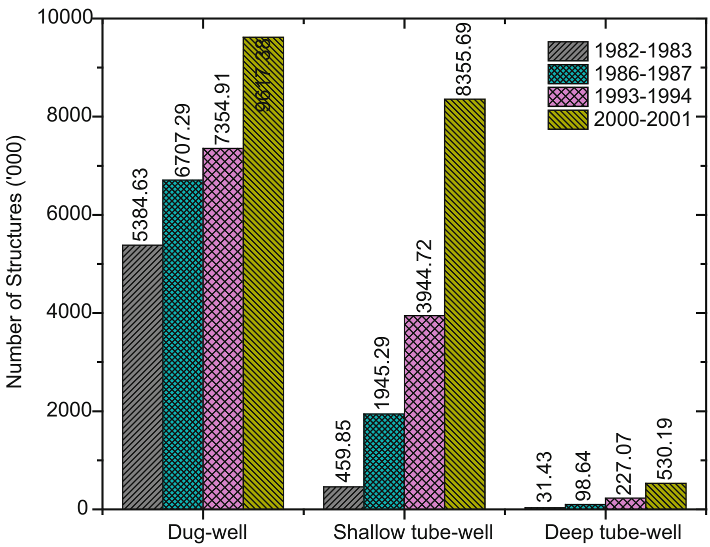

Fig. 2.3 Escalating number of groundwater extraction structures in India during 1982–2001. (Based on CGWB 2007)

had a very negligible impact on crop productivity at similar drought effects during 1987–1988 (Gornall et al. 2010; World Bank 2012), which was only possible due to use of groundwater in extensive areas. However, the groundwater table is constantly declining, and sometimes the tube wells are not able to supply the required water and failed to pull out waters, which invite crop failure in drought-prone areas (Kala 2017; Singh et al. 2019, 2020).

The number of dug wells and tube wells (shallow and deep) has constantly increased (Fig. 2.3), which might dig out up to the deeper part depending on the local and regional level variation of the water table to extract groundwater and minimize the sufferings of the people. The naturally recharged water during the rainy season also moved up to the deeper part due to the degradation of subsurface impermeable layer by boreholes of tube wells. Therefore, the local dug wells also shrank during the dry season. This condition has been intensified after the construction of the deep tube wells, while the dug wells are naturally able to supply the required drinking water to the villagers in the rain-fed drought-prone areas. Therefore, the number of tube wells (both the shallow and deep) is dramatically increased compared to the dug wells (Fig. 2.3). Over 60% of wells are unable to extract water due to depletion of groundwater table in Indian states (like Delhi, Punjab, Haryana, Himachal Pradesh, Uttar Pradesh, Tamil Nadu, Andhra Pradesh, Karnataka, Kerala and Meghalaya) and union territories (like Chandigarh, Dadra and Nagar Haveli and Puducherry) (World Bank 2012; CGWB 2018). Consequently, people are suffering to survive their livelihood and compelled to leave those areas. As per the CGWB (2018), among India's total administrative blocks, 253 have been categorized as 'critical', 681 as 'semi-critical' and 1034 as 'over-exploited', meanwhile 4520 administrative blocks till remained under 'safe' category in terms of rate of groundwater depletion (World Bank 2012; CGWB 2018). This situation is more awfully visible in the highly populated and economically developed areas. The severity level of the groundwater status has continuously increased year after year in the numerous administrative blocks (Fig. 2.1). The affected coastal areas from the saline water encroachment into the groundwater aquifers have been tremendously increasing alongside the increasing salinity level in the western parts of the Indian territories (Fig. 2.1), whereas the areas having over-exploited, critical and semi-critical level are also increasing, particularly in the western and southern India (Fig. 2.1). According to the CGWB (2018), during the pre-monsoon period, the water level declined in about 61% of wells out of 14,465 monitored wells in India within a decade (2007–2016). Among those wells having groundwater at more than 40 m below ground level, the number increased by 49 wells in terms of groundwater depletion in 2017–2018 compared to 2016–2017 (World Bank 2012; CGWB 2018). Moreover, the seasonal water fluctuation level (Fig. 2.2) associated with the depth to water level is increasing in terms of spatial extents in the western and southern Indian territories. Although central India has been buffering its groundwater deficit with a sufficient volume of groundwater recharge during monsoon season, it becomes eradicated during crop cultivation in the post-monsoon and pre-monsoon seasons (Fig. 2.2).

2.3.2 Urbanization and Groundwater Depletion

Urbanization initiates the concretization of the earth's surface, which minimizes the penetration level of rainwater into the subsurface layers. Therefore, the surface runoff and soil erosion rate have maximized in most of the areas. The volume of groundwater is gradually decreasing in conjunction with the minimum level of recharge facilities. Moreover, urban society needs more facilities, and most of these are related to water utilization. In most of the urban centres, groundwater is