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

S. Jana (✉)
Department of Geography, Belda College, Belda, Paschim Medinipur, India

P. K. Shit et al. (eds.), *Groundwater and Society*,
https://doi.org/10.1007/978-3-030-64136-8_2

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

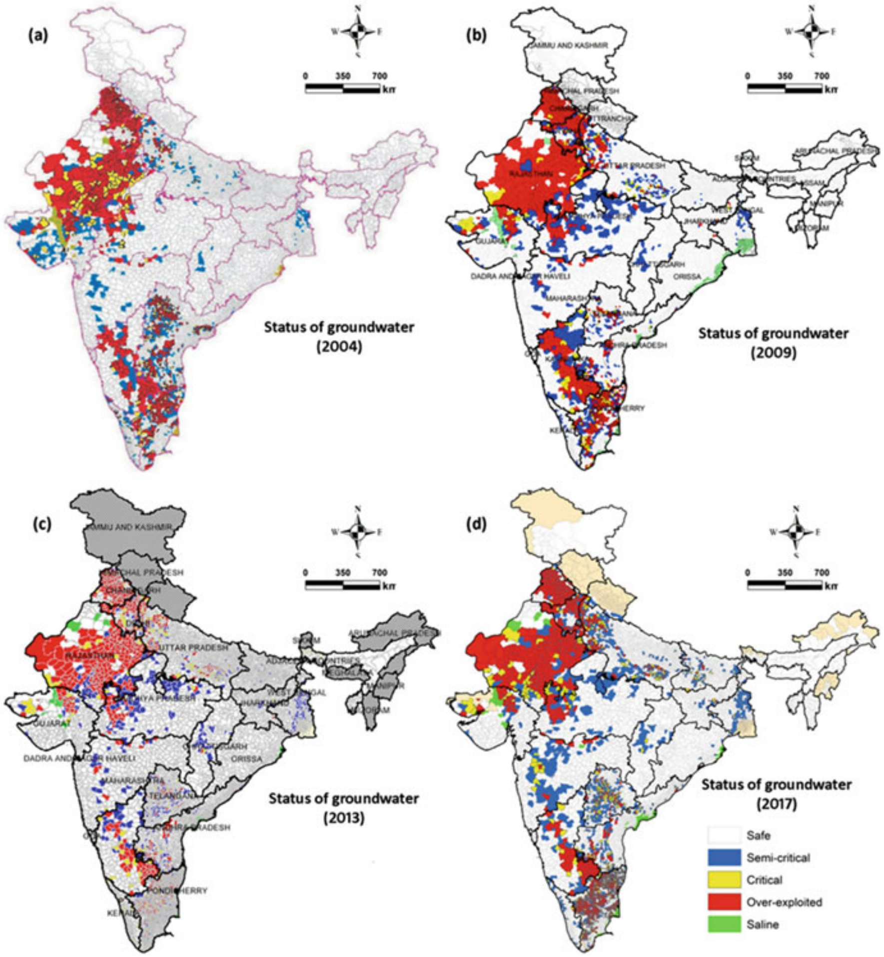

Fig. 2.1 Categorical safety status of Indian groundwater in the year of (**a**) 2004, (**b**) 2009, (**c**) 2013 and (**d**) 2017. (Based on CGWB 2020)

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

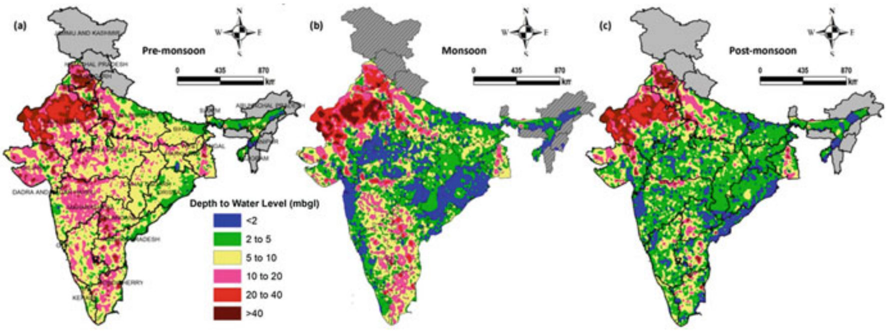

Fig. 2.2 Spatio-temporal fluctuation of groundwater level in India during (**a**) pre-monsoon, (**b**) monsoon and (**c**) post-monsoon seasons of 2019. (Based on CGWB 2020)

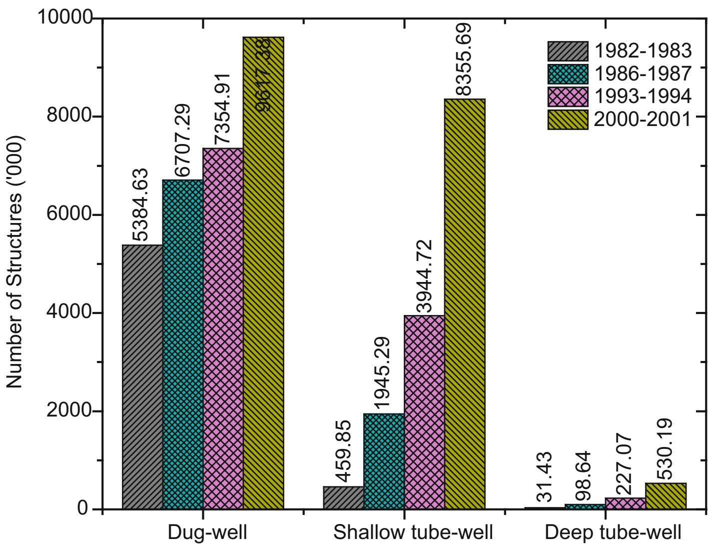

Fig. 2.3 Escalating number of groundwater extraction structures in India during 1982–2001. (Based on CGWB 2007)

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 the only option for completing people's livelihood. The number of people is also increasing with the expansion of urban areas. Therefore, more water is required for the individual urban sites, which is entirely collected from the groundwater. The juxtaposition effects of climatic inconsistency and associated reducing rainfall, concretization and associated reducing groundwater recharge, and extrapolated groundwater extraction due to urbanization and societal development intensify the gradual depletion of groundwater table mostly in the urban areas among the other parts of the country. During 2000–2010, the increasing rate of groundwater depletion is higher (23%) in India than the global rate of 22% (India Today 2019). The drinking water supposed to be supplied in the major cities which will come far away from their existing locations. In this regard, the proposed planning is to supply water in Delhi from the Tehri dam (more than 300 km away), Hyderabad from Nagarjuna Sagar Dam (105 km away) and Bengaluru from the Cauvery River (100 km away) to fight against water scarcity (Narain 2006; DownToEarth 2019b). But, long-term sustainability and cost-effectiveness are the main issues of these mega-projects. A similar type of project is adopted for Udaipur, Rajasthan, which draws water from Jaisamand Lake (60 km away), but the lake is drying up, and the city is dreadfully looking for a new way to overcome the upcoming thirst.

2.4 Groundwater and Future Society

The availability of surface water is reducing dramatically, and in most areas, it becomes polluted. In the context of global climate change, the inconsistency of monsoon rainfall and rapid rate of glacial melting will create suffering for the future generation in water availability concern (Pritchard 2019). The per-capita water demand is also swiftly increasing, in contrast with the reducing per-capita water availability (Fig. 2.4). The sustainability of the present and future human society is under a threatening condition concerning water stress and scarcity (Fig. 2.4). Therefore, groundwater is the key option for the future society to survive the human civilization and the only way of adaptation in the scenario of climate change. But, the unscientific human activities and rigorous development bring a threat to maintaining the quality and quantity of groundwater in addition to surface water. The population density, landholding size, water intensity of planted crops, the behaviour of water user, power subsidies for pumping irrigation water, government policies towards groundwater and overall economic policies of the country are playing a critical interacting influence on groundwater extraction and sustainability (Kumar 2018). Every year, people are obliterating law and order and encroaching into wetland and other water bodies after landfilling process, which leads to reducing water availability as well as degrading the water quality (Banerjee 2012; Bindra 2017). Therefore, there is an urgent need to take best suitable adaptive strategies through the 3-R concept (*Recycle*, *Reuse* and *Recharge*) to survive on earth. Concerning the sustainability, about 0.25 million stations have been set up to monitor the groundwater

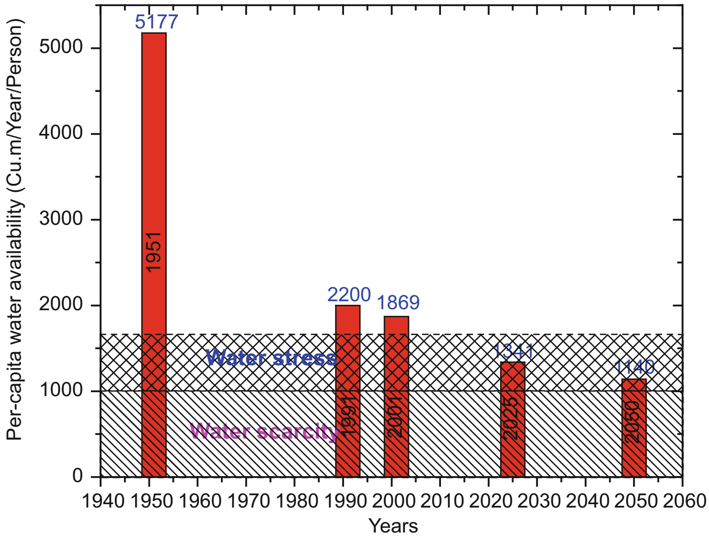

Fig. 2.4 Past and future of water availability status in India under water stress and scarcity condition. (Modified after CGWB 2007)

status for the restoration of groundwater in the impending 50 years through the application of scientific and artificial intelligence (DownToEarth 2019c).

2.4.1 Efficiency in Water Utilization

The convenient and limited utilization of water is the prior aspect to adaptation with the future threats of water scarcity. A maximum percentage of freshwater is utilized as irrigation water. Wheat and rice are the two extensively cultivated and highest water-guzzling crops in India. An average of 1654 litres and 2800 litres of water is required to produce 1 kg of wheat and rice, respectively (India Today 2019). In this regard, a four-member family consumes about 84,600 litres of water per month. Moreover, in the economic year 2014–2015, India virtually exported 10 trillion litres of water through exporting 3.72 million tonnes of basmati rice (India Today 2019). Therefore, the actual water export from our country is not only the highest in terms of drinking water supply, but also it becomes the highest position in terms of virtual water export through exporting food grains. In the socio-economic perspective, the irrigational water supply can't stop, but water utilization can be minimized through the selection of suitable crop in the region and seasonal perspectives. The dry-crop farming (like maize, millets and sorghum), crop diversification and crop rotation methods are the best options to minimize the water use, and it can also minimize the loss of water through evapotranspiration (Rana and Rana 2011). After the elapsed period (over 50 years) of commencement of the green revolution, the government authorities also encourage the farmers to plant other crops instead of rice cultivation. Bamboo trees plantation in the drought-prone areas will be most effective as it helps in recharging groundwater, minimizing soil erosion and even syncing carbons (DownToEarth 2020a). A large volume of water can be restored through the adaptation of zero-tillage cultivation method (Honsdorf et al. 2020; Singh et al. 2018). The areas' specific cropping pattern and crop selection can be useful to minimize the water uses. The bio-fertilizers should be introduced, instead of the chemical fertilizer, through which the moisture-holding capacity will increase (Mahdi et al. 2010). The irrigation water needs to be supplied through the pipelines instead of the open canal, and the evaporation loss should be minimized. In this connection, the farm-specific sprinkler irrigation method can be easily applied. The use of groundwater should not be permissible in the fisheries sector from where the maximum volume of water is evaporated. In our every day's life, we waste plenty of water without realization. For example, a single person can exploit up to 37 litres in 5 minutes showering, 570 litres per week for washing, 15 litres every day for mouth washing, 18 litres for every toilet visit and 25 litres for cleaning kitchen utensils and vegetables (India Today 2019). All these activities are necessary in our daily life, but we waste water without stopping the irrelevant water flow from a tap in most of the cases. The waste of safe drinking water is commonly observed in the restaurants by using only half of a bottle or glass during food intake. Besides, the water can be reused in different ways like irrigation, fisheries, horticulture, gardening, car washing, toilet use and washing of kitchen utensils at the first stage; also it can be injected directly into the subsurface layer. The government should take necessary steps like any kind of treated or untreated water should not be permitted to mix with a river and random and unlimited withdrawal of water from any sources without any prior concern.

2.4.2 Water Storage

The rainwater storage in the individual household level as well as in regional level is required to solve the water scarcity up to a certain level. The rainwater can naturally be stored into the soil layer, which also provides the water supply in the following fields depending on the elevation, terrain condition and soil characteristics. The tanks and ponds in the different terrain and landscape units can be constructed to store the excessive rainwater during the rainy season, which can be utilized in the rest of the season. In this concern, the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) plays a vital role in association with creating the employment opportunities among the rural dwellers (Esteves et al. 2013; Chakraborty and Das 2014). The stored water can also maintain the soil moisture level in the surrounding areas (Tiwari et al. 2011). The construction of micro-level check dams at the upper catchment areas is a fruitful method to supply irrigation water in the surrounding agricultural lands. Although the large dams and reservoirs store voluminous water, in ecological and hydro-geomorphological aspect it creates a harsh impact in the downstream section (Bhattacharyya 2011; Singh 2016). The ecological flow must be reduced, which can't able to maintain the ecological balance in the lower riparian stretches (Choudhury et al. 2019; Sarkar and Islam 2020). Rainwater harvesting plan is the most appropriate method of rainwater storage, and it can be stored in various ways like roof-top harvesting and underground harvesting (Sivanappan 2006). Most of the urban areas can utilize the rainwater at least for 3 months during the rainy season with the acceptance of this method. For instance, according to the Centre for Science and Environment (Delhi), the daily water demand in Delhi is about 2765 million litres for 18.8 million populations (as per the 2011 census). As per the IMD, during 13–19 August 2020, about 118.4 mm rainfall was received in Delhi (1483 km^2 area), which can produce 87 million litres of water (Sengupta 2020). But, the rainwater runoff co-efficient was about 13% of the total rainfall (during 13–19 August 2020), estimated by the Centre for Science and Environment.

2.4.3 Groundwater Recharge

The natural groundwater recharge capacity is reducing gradually due to the unscientific land management, forest degradation and dramatic rate of urban infrastructural development on different parts of the earth's surface (Chennamaneni and Rao 2007). As a result, the surface runoff as well as the soil erosion rate is increasing tremendously, which reciprocally triggers both events. The groundwater and subsurface water recharge capacity is reducing with due effects from increasing the surface runoff (Harbor 1994; Misra 2011). The thickness of the soil layer is also decreasing continuously, which promotes a minimum level of water holding capacity into the soil layer. The exposed permeable layers are also degrading due to the infrastructural development, and it leads to minimum rainwater recharge into the groundwater table. In this regard, artificial water recharge techniques (like check dam, percolation tank, spreading channel, recharge tube well, underground dam, subsurface dykes) are more effective and need to be implemented for the survival of the human civilization (CGWB 2007; Bhattacharya 2010). In the rural areas, the damaged tube wells mostly remain unused, and the upper part of the hollow is filled up with earthen material. However, the rainwater can easily be injected through such degraded tube wells. The paddy has been cultivated thrice per year in many places of the intensive subsistence cultivation systems. As a result, the agricultural fields remained saturated throughout the year. The permeability capacity has gradually reduced, and no such water can recharge into the soil layer and even into the subsurface layer. If the agricultural fields remain vacant or can be utilized for dry crops instead of rice paddy, the topsoil and the upper layer can be cracked during the dry season. Therefore, a certain volume of rainwater can easily enter into the subsurface and even into the groundwater table. In the urban areas, some part of the surface areas should remain vacant and require the water recharge facilities, through which the rainwater can also easily recharge into the groundwater.

2.5 Conclusion

In the history of human evolution, there is enough evidence of ruined human civilizations in the different historical periods. But, in the recent context of global warming, climate change and associated hydro-meteorological hazards, the existing human beings are facing a harsh experience regarding their persistence in the future earth. The volume of required freshwater resource is reducing with the gradual increase in demand. In this contradictory situation, sustainability is being the prime issue in the era of globalization and overturning socio-economic perspective. People are now a little bit concerned and might be scared about their existence and sustainability in this earth. People are now thinking and finding out the way to survive, and fighting not only to minimize the use of freshwater but also to preserve it. The urban-industrial and socio-economic development is also promoting water quality degradation. In overall perspectives, the quantity and quality of freshwater resources are diminishing from the earth. In India, the water scarcity is severely persisting mainly in the western, southern and central parts, along with the entire Indian territories. About 90% of total groundwater is used for irrigation purpose, while 75% of the total surface water bodies have been polluted in India. Most of these water bodies are being polluted from the domestic wastes. To tackle this situation, the government has taken many plans to prevent misuses of water and promote the awareness about the recycle, reuse and recharge of water. The adaptive strategies have been taken in the agricultural sector by implementing the dry crops and advanced cultivation techniques, which can prevent excessive use of irrigation water. However, all these adaptive strategies are not sufficient to overcome the existing severity of water scarcity. People should be more responsible about the existing deadly condition and hopefully, change their daily lifestyle concerning wastage of freshwater.

Acknowledgement The author would like to express his gratitude to Dr. Pravat Kumar Shit, Department of Geography, Raja N. L. Khan Women's College, for his suggestions in the completion of this book.

References

Adhikary, P.P.,Chandrasekharan, H., Trivedi, S.M., Dash, C.J. (2015). GIS applicability to assess spatio-temporal variation of groundwater quality and sustainable use for irrigation, Arabian Journal of Geosciences 8 (5), 2699-2711.

Arfanuzzaman, M., & Syed, M. A. (2018). Water demand and ecosystem nexus in the transboundary river basin: a zero-sum game. Environment, Development and Sustainability, 20(2), 963-974.

Banerjee, S. (2012). The march of the mega-city: Governance in West Bengal and the wetlands to the east of Kolkata. South Asia Chronicle, 2, 93-118.

Basu, S., Mohanty, S., & Sanyal, P. (2020). Possible role of warming on Indian summer monsoon precipitation over the north-central Indian subcontinent. Hydrological Sciences Journal, 65(4), 660-670.

Behera, A. K., Chakrapani, G. J., Kumar, S., & Rai, N. (2019). Identification of seawater intrusion signatures through geochemical evolution of groundwater: a case study based on coastal region of the Mahanadi delta, Bay of Bengal, India. Natural Hazards, 97(3), 1209-1230.

Bhattacharya, A. K. (2010). Artificial ground water recharge with a special reference to India. International Journal of Recent Research and Applied Studies, 4(2), 214-221.

Bhattacharyya, K. (2011). The Lower Damodar River, India: understanding the human role in changing fluvial environment. Springer Science & Business Media.

Bindra, P. S. (2017). The Vanishing: India's Wildlife Crisis. Penguin Random House India.

CGWB (2007). Manual on artificial recharge of groundwater. Central Ground Water Board, Ministry of Water Resources, Government of India, p. 198.

CGWB (2018). Ground Water Year Book - India 2017-2018. Central Ground Water Board Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India, Faridabad, p. 104.

CGWB (2020). 'Dynamic Ground Water Resources of India'. Central Ground Water Board Ministry of Jal Shakti, Department of Water Resources, River Development and Ganga Rejuvenation, Government of India. http://cgwb.gov.in/Dynamic-GW-Resources.html [Accessed on 15 September 2020].

Chakraborty, B., & Das, S. (2014). MGNREGA and water management: sustainability issues of built forms in Rural India. Journal of Construction in Developing Countries, 19(2), 33.

Chennamaneni, R., & Rao, S. (2007). Assessment of Urban Carrying Capacity. A Case Study of Environmental and Institutional Implications for Water Resource Management in Hyderabad. Dept. of Resource Economics Faculty of Agriculture and Horticulture, Humboldt- University of Berlin, Germany. Research Report 8, p. 45.

Choudhury, N. B., Mazumder, M. K., Chakravarty, H., Choudhury, A. S., Boro, F., & Choudhury, I. B. (2019). The endangered Ganges river dolphin heads towards local extinction in the Barak river system of Assam, India: A plea for conservation. Mammalian Biology, 95(1), 102-111.

Colvin, S. A., Sullivan, S. M. P., Shirey, P. D., Colvin, R. W., Winemiller, K. O., Hughes, R. M., ... & Danehy, R. J. (2019). Headwater streams and wetlands are critical for sustaining fish, fisheries, and ecosystem services. Fisheries, 44(2), 73-91.

CPCB (2015).Inventorization of sewage treatment plants. Central Pollution Control Board, Ministry of Environment and Forests, Govt. of India) Parivesh Bhawan, East Arjun Nagar, Delhi.

Dixit, Y., Hodell, D. A., Giesche, A., Tandon, S. K., Gázquez, F., Saini, H. S., ... & Petrie, C. A. (2018). Intensified summer monsoon and the urbanization of Indus Civilization in northwest India. Scientific reports, 8(1), 1-8.

DownToEarth (2019a). 'Environment ministry's 50-year plan to tackle water crisis'. DownToEarth, 08 August 2019. https://www.downtoearth.org.in/video/water/environment-ministry-s-50-year-plan-to-tackle-water-crisis-66095 [Accessed on 16 September 2020].

DownToEarth (2019b). 'Rainwater harvesting: Catch water where it fall'. DownToEarth, 01 July 2019. https://www.downtoearth.org.in/video/water/catch-where-it-falls-to-fight-drought-and-to-create-employment-65368 [Accessed on 10 September 2020].

DownToEarth (2019c). 'Environment ministry's 50-year plan to tackle water crisis'. DownToEarth, 08 August 2019. https://www.downtoearth.org.in/video/water/environment-ministry-s-50-year-plan-to-tackle-water-crisis-66095 [Accessed on 10 September 2020].

DownToEarth (2020a). 'Growing a cooperative forest can lead to water conservation and generate livelihood'. DownToEarth, 10 February 2020. https://www.downtoearth.org.in/video/water/every-drop-counts-how-a-cooperative-turned-250-acres-of-dharmapuri-green-69222 [Accessed on 10 September 2020].

DownToEarth (2020b). 'Water & climate emergency: A fluid future'. DownToEarth, 28 May 2020. https://www.downtoearth.org.in/news/water/water-climate-emergency-a-fluid-future-69827 [Accessed on 15 September 2020].

Enzel, Y., Ely, L. L., Mishra, S., Ramesh, R., Amit, R., Lazar, B., ... & Sandler, A. (1999). High-resolution Holocene environmental changes in the Thar Desert, northwestern India. Science, 284(5411), 125-128.

Esteves, T., Rao, K. V., Sinha, B., Roy, S. S., Rao, B., Jha, S., ... & IK, M. (2013). Agricultural and livelihood vulnerability reduction through the MGNREGA. Economic and Political Weekly, 48 (52), 94-103.

Gandhi, V.P. & Namboodir, N.V. (2009). Groundwater irrigation in India: gains, costs and risks. Indian Institute of Management, Ahmedabad, No. 2009-03-08, p. 38.

Glantz, M. H. (2019). Desertification: environmental degradation in and around arid lands. CRC Press.

Gornall, J., Betts, R., Burke, E., Clark, R., Camp, J., Willett, K., & Wiltshire, A. (2010). Implications of climate change for agricultural productivity in the early twenty-first century. Philosophical Transactions of the Royal Society B: Biological Sciences, 365(1554), 2973-2989.

Gowing, J. W., Tuong, T. P., & Hoanh, C. T. (2006). Land and water management in coastal zones: dealing with agriculture–aquaculture–fishery conflicts. In C. T. Hoanh, T. P. Tuong, J. W. Gowing, & B. Hardy (Eds.), Environment and livelihoods in tropical coastal zones: Managing agriculture–fishery–aquaculture conflicts (pp. 1–65). Wallingford: CAB International.

Grönwall, J., & Danert, K. (2020). Regarding Groundwater and Drinking Water Access through A Human Rights Lens: Self-Supply as A Norm. Water, 12(2), 419.

Gurjar, S. K., & Tare, V. (2019). Spatial-temporal assessment of water quality and assimilative capacity of river Ramganga, a tributary of Ganga using multivariate analysis and QUEL2K. Journal of Cleaner Production, 222, 550-564.

Harbor, J. M. (1994). A practical method for estimating the impact of land-use change on surface runoff, groundwater recharge and wetland hydrology. Journal of the American Planning Association, 60(1), 95-108.

Hoegh-Guldberg, O., Jacob, D., Bindi, M., Brown, S., Camilloni, I., Diedhiou, A., ... & Hijioka, Y. (2018). Impacts of 1.5 C global warming on natural and human systems. Global warming of 1.5° C. In: Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, ...& T. Waterfield (eds.) Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty, pp. 175–311.

Honsdorf, N., Verhulst, N., Crossa, J., Vargas, M., Govaerts, B., & Ammar, K. (2020). Durum wheat selection under zero tillage increases early vigor and is neutral to yield. Field Crops Research, 248, https://doi.org/10.1016/j.fcr.2019.107675

India Today (2019). 'World Water Day: 21 Indian cities, including Delhi, will run out of groundwater by 2020, affecting 100 million people'. India Today (Web Desk), New Delhi, 22 March 2019. https://www.indiatoday.in/science/story/world-water-day-2019-water-crisis-india-1483777-2019-03-22 [Accessed on 15 September 2020].

Kala, C. P. (2017). Environmental and socioeconomic impacts of drought in India: lessons for drought management. Applied Ecology and Environmental Sciences, 5(2), 43-48.

Kulkarni, H., Shankar, P. V., Deolankar, S. B., & Shah, M. (2004). Groundwater demand management at local scale in rural areas of India: a strategy to ensure water well sustainability based on aquifer diffusivity and community participation. Hydrogeology Journal, 12(2), 184-196.

Kumar, M. D. (2018). Water Policy Science and Politics: An Indian Perspective. Elsevier.

Kumar, N., & Verma, A. (2020). Inter-basin Water Transfer and Policies of Water Resource Management. In Environmental Concerns and Sustainable Development (pp. 257-274). Springer, Singapore.

Lal, M. (2000). Climatic change-implications for India's water resources. Journal of Social and Economic Development, 3, 57-87.

Mahdi, S. S., Hassan, G. I., Samoon, S. A., Rather, H. A., Dar, S. A., & Zehra, B. (2010). Bio-fertilizers in organic agriculture. Journal of phytology. 2(10): 42-54.

Maheshwari, B., Varua, M., Ward, J., Packham, R., Chinnasamy, P., Dashora, Y., ... & Shah, T. (2014). The role of transdisciplinary approach and community participation in village scale groundwater management: insights from Gujarat and Rajasthan, India. Water, 6(11), 3386-3408.

Maisels, C. K. (2001). Early civilizations of the old world: the formative histories of Egypt, the Levant, Mesopotamia, India and China. Psychology Press.

Mallapur, C. (2016). '70% Of Urban India's Sewage Is Untreated'. The Wire, 27 January 2016. https://archive.indiaspend.com/cover-story/70-of-urban-indias-sewage-is-untreated-54844 [Accessed on 16 September 2020].

Mishra, S., Kumar, A., Mishra, S., & Kumar, A. (2020). Estimation of physicochemical characteristics and associated metal contamination risk in the Narmada River, India. Environmental Engineering Research, 26(1).

Misra, A. K. (2011). Impact of urbanization on the hydrology of Ganga Basin (India). Water resources management, 25(2), 705-719.

Mohanakavitha, T., Shankar, K., Divahar, R., Meenambal, T., & Saravanan, R. (2019). Impact of industrial wastewater disposal on surface water bodies in Kalingarayan canal, Erode district, Tamil Nadu, India. Archives of Agriculture and Environmental Science, 4(4), 379-387.

Murtugudde, R. (2017). 'Pakistan World's Top Groundwater Exporter, India Ranks Third'. The Wire, 3 May 2017. https://thewire.in/agriculture/pakistan-worlds-top-groundwater-exporter-india-third [Accessed on 15 September 2020].

Narain, S. (2006). Community-led alternatives to water management: India case study (No. HDOCPA-2006-10). Human Development Report Office (HDRO), United Nations Development Programme (UNDP), p. 33.

Pereira, L. S., Cordery, I., & Iacovides, I. (2009). Coping with water scarcity: Addressing the challenges. Springer Science & Business Media.

Pingali, P. L. (2012). Green revolution: impacts, limits, and the path ahead. Proceedings of the National Academy of Sciences, 109(31), 12302-12308.

Possehl, G. L. (2002). The Indus civilization: a contemporary perspective. Rowman Altamira.

Postel, S., & Richter, B. (2012). Rivers for life: managing water for people and nature. Island Press, Lndon.

Pritchard, H. D. (2019). Asia's shrinking glaciers protect large populations from drought stress. Nature, 569(7758), 649-654.

Qureshi, A. S., McCornick, P. G., Sarwar, A., & Sharma, B. R. (2010). Challenges and prospects of sustainable groundwater management in the Indus Basin, Pakistan. Water resources management, 24(8), 1551-1569.

Rana, S. S., & Rana, M. C. (2011). Cropping system. Department of Agronomy, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, p. 80.

Richardson, S. D., & Reynolds, J. M. (2000). An overview of glacial hazards in the Himalayas. Quaternary International, 65, 31-47.

Saha, D. (2019). 'Government must prioritise on conserving water'. DownToEarth, 24 May 2019. https://www.downtoearth.org.in/blog/water/government-must-prioritise-on-conserving-water-64737 [Accessed on 16 September 2020].

Sangomla, A. (2019). 'Climate change pushed Indus Valley migrants west to east: Study'. DownToEarth, 21 November 2019. https://www.downtoearth.org.in/news/climate-change/climate-change-pushed-indus-valley-migrants-west-to-east-study-67862 [Accessed on 15 September 2020].

Sarkar, B., & Islam, A. (2020). Drivers of water pollution and evaluating its ecological stress with special reference to macrovertebrates (fish community structure): a case of Churni River, India. Environmental Monitoring and Assessment, 192(1), 45.

Sengupta, S. (2020). 'It rained hard in Delhi; what if all that water did not go waste'. DownToEarth, 21 August 2020. https://www.downtoearth.org.in/news/water/it-rained-hard-in-delhi-what-if-all-that-water-did-not-go-waste-72959 [Accessed on 10 September 2020].

Shah, T. (2009). Climate change and groundwater: India's opportunities for mitigation and adaptation. Environmental Research Letters, 4(3), 035005.

Singh, A. (2016). Managing the water resources problems of irrigated agriculture through geospatial techniques: An overview. Agricultural Water Management, 174, 2-10.

Singh, A. K., & Jyoti, B. (2019). Measuring the Climate Variability Impact on Cash Crops Farming in India: An Empirical Investigation. Agriculture and Food Sciences Research, 6(2), 155-165.

Singh, A. K., Das, B., Mali, S. S., Bhavana, P., Shinde, R., & Bhatt, B. P. (2019). Intensification of rice-fallow cropping systems in the Eastern Plateau region of India: diversifying cropping systems and climate risk mitigation. Climate and Development, 1-10.

Singh, A., Thomsen, K. J., Sinha, R., Buylaert, J. P., Carter, A., Mark, D. F., ... & Paul, D. (2017). Counter-intuitive influence of Himalayan river morphodynamics on Indus Civilisation urban settlements. Nature Communications, 8(1), 1-14.

Singh, G., Bhattacharyya, R., Das, T. K., Sharma, A. R., Ghosh, A., Das, S., & Jha, P. (2018). Crop rotation and residue management effects on soil enzyme activities, glomalin and aggregate stability under zero tillage in the Indo-Gangetic Plains. Soil and Tillage Research, 184, 291-300.

Singh, R. B. (2000). Environmental consequences of agricultural development: a case study from the Green Revolution state of Haryana, India. Agriculture, ecosystems & environment, 82(1-3), 97-103.

Singh, R. K., Singh, A., Kumar, S., Sheoran, P., Sharma, D. K., Stringer, L. C., ... & Singh, D. (2020). Perceived Climate Variability and Compounding Stressors: Implications for Risks to Livelihoods of Smallholder Indian Farmers. Environmental Management, 1-19.

Sinha, A., Kathayat, G., Cheng, H., Breitenbach, S. F., Berkelhammer, M., Mudelsee, M., ... & Edwards, R. L. (2015). Trends and oscillations in the Indian summer monsoon rainfall over the last two millennia. Nature communications, 6(1), 1-8.

Sivanappan, R. K. (2006). Rain Water Harvesting, Conservation and Management Strategies for Urban and Rural Sectors. In National Seminar on Rainwater Harvesting and Water Management 11-12 Nov. 2006, Nagpur, pp. 1–9.

Taylor, R. G., Scanlon, B., Döll, P., Rodell, M., Van Beek, R., Wada, Y., ... & Konikow, L. (2013). Ground water and climate change. Nature climate change, 3(4), 322-329.

The Economic Times (2018). 'India suffering worst water crisis in history, says Niti report'. The Economic Times, 14 June 2018. https://economictimes.indiatimes.com/news/politics-and-nation/india-suffering-worst-water-crisis-in-history-says-niti-report/articleshow/64591891.cms?from=mdr [Accessed on 15 September 2020].

Tiwari, R., Somashekhar, H. I., Parama, V. R., Murthy, I. K., Kumar, M. M., Kumar, B. M., ... & Sengupta, A. (2011). MGNREGA for environmental service enhancement and vulnerability reduction: rapid appraisal in Chitradurga district, Karnataka. Economic and political weekly, 46 (20), 39-47.

World Bank (2011). 'Water Sector in India'. The World Bank, 29 September 2011. https://www.worldbank.org/en/news/feature/2011/09/29/india-water [Accessed on 14 September 2020].

World Bank (2012). 'India Groundwater: a Valuable but Diminishing Resource'. The World Bank, 06 March 2012. https://www.worldbank.org/en/news/feature/2012/03/06/india-groundwater-critical-diminishing [Accessed on 14 September 2020].