Chapter 17
Impact of Urbanization on Groundwater in Changing Climatic Scenario: A Case Study

Alifia Ibkar, Arunangshu Mukherjee, Nidhi Didwania, and Sneha Rai

Abstract The world is facing rapid urbanization in various aspects. It is predicted that India will have 50% of its population in urban centers by the end of 2030. Thus, understanding the urban characteristic to cope with reducing natural resources has produced a huge challenge. Groundwater, the primary drinking water source in many Indian cities, has faced a crisis of over-extraction and quality deterioration. Changing climatic condition has further added to the complexities of the urban hydrogeological condition. The present study is about two locations in the National Capital Region (NCR). In Haryana, Faridabad, one of the important urban centers of NCR, has witnessed a 32.5% decadal increase in population and rapid urbanization due to a considerable number of migrants. Manesar, one of the industrial townships of the NCR, has also witnessed intense urbanization due to industrial growth and migration. The average temperature of the area has increased by 2° with a corresponding increase in rainfall intensity along with a reduction in rainy days while maintaining the overall average rainfall of the area. The urbanization and associated industrialization resulted in groundwater level depletion at 0.7 m/year in parts of Faridabad and Manesar area and categorized as overexploited. The average groundwater electrical conductivity (EC) has increased. The impact also includes land subsidence in a few patches. The climate change-induced increased rainfall intensity and simultaneous urbanization have resulted in a reduction in infiltration. This has been further added by intensive extraction of groundwater to meet the essential requirements of the growing population. The chapter has discussed in depth the change in short-duration morpho-hydrogeological conditions due to overgrowth in the urban and industrial township.

Keywords Urbanization · Groundwater depletion · Climate change · Land subsidence · Rainfall intensity · Faridabad-Khoh Manesar

---

A. Ibkar · A. Mukherjee (✉) · N. Didwania · S. Rai
Manav Rachna Centre for Advance Water Technology & Management (MRCAWTM), Manav Rachna International Institute of Research and Studies (MRIIRS), Faridabad, India
e-mail: arunangshu.fet@mriu.edu.in

P. Thambidurai, A. K. Dikshit (eds.), *Impacts of Urbanization on Hydrological Systems in India*, https://doi.org/10.1007/978-3-031-21618-3_17

1 Introduction

Urbanization has been a global and significant socio-economic phenomenon that has occurred all over the world. Currently, about 55% of the world's population of 7.7 billion and about 35% of the Indian population of 1.4 billion live in urban areas, respectively (United Nations, 2018). The hydrogeological condition of the urban area widly differs from surrounding regional hydrogeological conditions due to urbanization and industrialization. Characterization of the urban hydrogeological condition of an area is significant for its resource management. The impact of urbanization on groundwater quantity and quality has been a growing concern for most urban areas. By 2030 half of the Indian population will be urban (United Nations, 2018). About 50% of the total requirement of urban water is drowned from aquifers (CGWB, 2021) where numerous small and medium towns completely depend on groundwater resources. Thus, the groundwater of urban areas is under great stress. As the second most populated country in the world, where groundwater is an essential resource for the sustainability of livelihoods, growth, and ecosystems, India is witnessing rapid groundwater depletion in many parts of the country (CGWB, 2021; Danger et al., 2021; Saha et al., 2018).

Further, changing climatic scenario has added to the complexities of the urban hydrogeological condition. Several institutions and individuals have studied the impact of changing climate in depth in the Delhi NCR area. Chauhan et al. (2022) worked on spatiotemporal distribution of rainfall and rainy day trends of the districts of Haryana State, India, during various seasons from the year 1901 to 2020. The study evaluated and analyzed the descriptive features of seasonal rainfall patterns to plan the well-organized usage of groundwater resources and sustainable groundwater management at the district level. Numerous investigations indicated an increase in the frequency of intense rainfall events in certain parts of the Indian subcontinent while it showed a reduction in the number of rainy days and total annual precipitation (Lal, 2003; Goswami et al., 2006; Dash et al., 2007, 2009; Sinha & Srivastava, 2000). Swain et al. (2022) assessed the groundwater quality of Gurgaon and Faridabad districts of Haryana with the help of geospatial and statistical methods. The study revealed the influence of human activities such as industrialization and rapid urbanization on the groundwater quality of these two areas. It is recommended that groundwater use for municipal water supply be managed to prevent the risk of health hazards. Dandge and Patil (2021) analyzed the spatial distribution of groundwater quality index with the help of remote sensing and GIS techniques. The research further addressed conducting frequent groundwater analysis to monitor the rate and type of contamination. Several eminent scholars, such as Chakraborty et al. (2014), Sati and Mohan (2017), and Mohan et al. (2011), carried out investigations over a span of 50 years on the impact of urbanization on urban climate, which identified urban settlement as a major cause of the rise in temperature in the past two decades. Garg et al. (2022) worked in Delhi NCR explaining a case study of the Faridabad city area on implications of unsustainable groundwater use correlating the groundwater depletion issue with land subsidence, revealing that overextraction of groundwater, particularly from its unconsolidated alluvial deposits, makes the region prone to subsidence.

1.1 Location of Study Area

In the present study, apart from general urbanization consequences on groundwater resources, two growing urban and industrial areas of the National Capital Region of Haryana are considered to investigate the impact of urbanization on groundwater conditions (Fig. 17.1). The locations are the urban area of Faridabad and Manesar of Gurgaon District, Haryana, India. Khoh (76°55′ 44″; 28° 21′ 15″) is situated in the foothill zone of residual Aravali hill near Manesar, having an area of 2 km^2 (200 ha), while Faridabad city lies between latitude 28°15′N to 28°30′N and

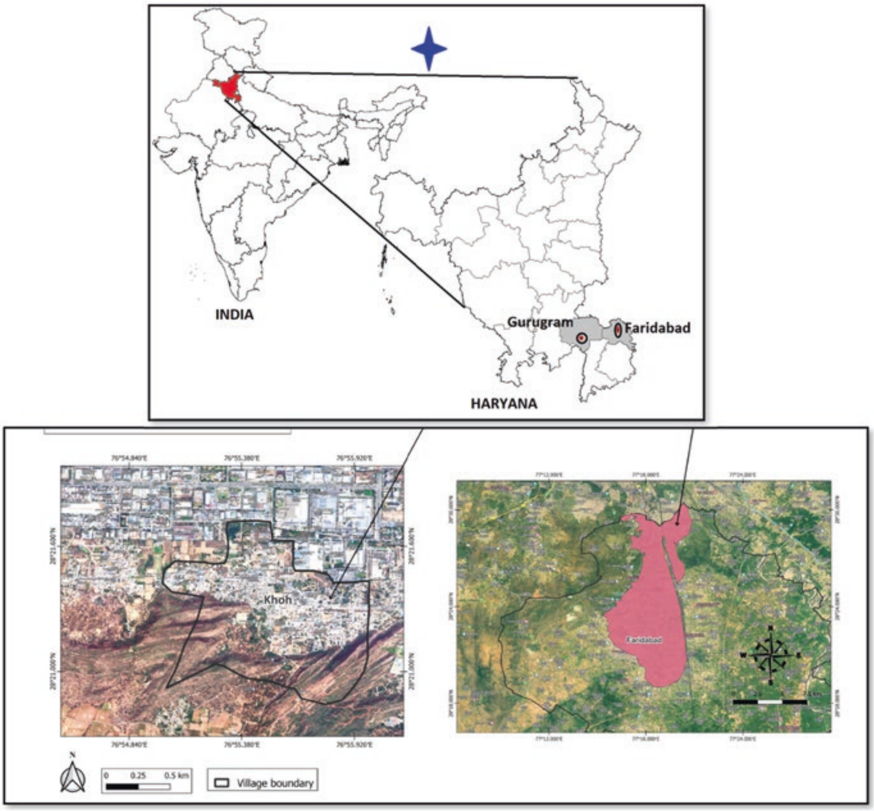

Fig. 17.1 Location map of two study areas, Khoh and Faridabad, Haryana

longitude 77°09′E to 77°30′E having 98.2% of the total urban population of the district concentrated in Faridabad Municipal Corporation area and covers 182 km^2.

2 Factors Influencing Urban Hydrogeological Conditions

Several factors influence the urban hydrogeological conditions more compared to the corresponding rural area. Though many of them are similar for both urban and rural areas, their intensity has been found to various degrees based on the density and extent of the urban area. In changing climatic scenarios, these factors became more relevant for urban areas due to their diverse land use and land cover pattern. The factors which influence the hydrogeological condition of an urban area can be divided into dynamic and static parameters. On the one hand, geology, macro-geomorphology, aquifer dimension, groundwater flow direction, transmissivity, and storativity remain static. On the other hand, population, micro-geomorphological features, land use land cover, rainfall pattern and intensity, runoff generation, rate of infiltration, groundwater abstraction, groundwater recharge, and its quality, surface water quantity, and quality are the main dynamic factors. These factors affect hydrogeological conditions differently in the urban area, particularly the recharge-discharge phenomena. The impact of these changes has been discussed in detail, considering the two study areas of Faridabad and Khoh, Manesar.

2.1 Geomorphology and Geology

Geomorphologically the area comes under the Yamuna sub-basin of the Ganga Basin. Bhuriya Nala is the main tributary that drains the Faridabad area. Other third to fourth-order streams that exist in the Faridabad area are Gochi Nala, Pakhal Nala, Jauhar Naala, Paliwaal Nala, Mehandwari Nadi, and Jair Nala which originate from Aravalli Hills and drain into either river Yamuna or disappear in the alluvial terrain. Faridabad city is bounded by Aravalli Hills in the west and the river Yamuna in the east. The altitude varies from 190 to 280 (Saini et al., 2017). The area has two distinct geomorphological units: the residual/denudational hills of Aravalli and the Yamuna Alluvial plains of lowland and upland. The Yamuna Alluvial plains can be further subdivided into active floodplain and older alluvial plains. A small portion of the area is also covered by Aeolian sand. The topography of the district is undulated plain, having linear ridges of quartzite running NS to NNE-SSW direction. The general slope of the area is NW to SE, west to east (CGWB, 2015; Saini et al., 2017). A large part of the Manesar area is occupied by scattered, isolated strike ridges of old rocks of Aravalli Mountain chain of Pre-Cambrian and alluvium sand of Recent to Subrecent origin. Geologically the Aravalli hills are folded meta-sedimentary rocks consisting of quartzite and argillite and belong to the Ajabgarh

Table 17.1 Stratigraphic succession of the study area with the corresponding geomorphology

Period	Age	Group/ formation	Geomorphic unit	Land use/ land cover	Description
Quaternary	Holocene	Newer Alluvium Disconformity and lacustrine deposits	Lowland (190–195 m RL)	Water use, sand quarrying, agriculture	Consists of unconsolidated interbedded, inter-fringing deposits of sand, clay, gravel, kankar, moderately sorted with alternation of fine fluvial sediments
	Late Pleistocene	Older Alluvium Unconformity and Aeolian deposits	Upland (190–200 m RL)	Agriculture, built-up land, brick kiln, forest, water bodies, wasteland	
Pre-Cambrian	Mid Proterozoic	Delhi Supergroup – Quartzites	Denudational Hills (220–280 m RL)	Wasteland, quarrying, forest, tourism	Massive gray colored with buff to brown leached surfaces at places, highly fractured and jointed. It is intruded locally by pegmatites and quartz veins and is interbedded with mica schist at places

After Saini et al. (2017) and Rahman et al. (2016)

Group of Delhi Supergroup of Mid Proterozoic age. The Ajabgarh Group of rock comprises mainly hard and massive bedded quartzite with local phyllitic intercalations (Table 17.1). These rocks are exposed as conspicuous ridges all along the western part of Faridabad and the southern part of Khoh, running roughly north-south in the direction. The ridge is locally known as Harchandpur-Badhkal Ridge and is formed of an anticlinal plunging fold. The fold axis trends along the N-S direction. The beds are steeply dipping between 50 and 80 degrees. The ridge is predominant in the south and subducted towards the north. Quartzites are light to dark gray to pinkish in color, hard, and highly jointed, having textural variations of fine-grained to gritty units. In Pali and Mohbatabad, the clipped ridge attains a height of more than 20 m. Marginal faults along the ridge produce 70–90-m-thick alluvial deposition along the foothill.

Quaternary alluvium unconformably overlies the Delhi Supergroup of rocks as 30–140 m thick over-burdened by loose unconsolidated sediments. On the basis of typical lithology, stratigraphic position, and continuity with the established sequence of the Ganga basin, the alluvium can be classified into Older and Newer Alluvium. The Newer alluvium disconformably overlies the Older alluvium. Older alluvium comprises horizontally bedded brown to yellowish clay-silt, brown, and gray sand. The sequence appears to gain thickness towards the east. It forms the main soil surface of the study. The Newer Alluvium is a 10–25-m-thick sequence of gray, very fine sand to silt, which disconformably overlies the Older Alluvium within the

Yamuna palaeo-banks in the lowland. It consists of Terrace Alluvium and Recent Alluvium. The Terrace Alluvium forms the bulk of Newer Alluvium and comprises loose, gray, very fine sand, slit, and clay. The Aeolian deposits comprise brownish, well-sorted, fine sand occurring as sand dunes on the sandy and slit-clay facies of Older Alluvium. Vertisol is a precious natural resource that is increasingly lost due to urbanization in Faridabad (Saini et al., 2017).

2.2 Hydrogeology

Hydrogeologically, Faridabad and Khoh areas can be divided into hard and soft rock terrains. The Khoh area is highly diversified in the mode of occurrence of groundwater, nature, and extent of the aquifer and its hydrogeological properties to groundwater flow characteristics under prevailing hydrodynamic and hydrochemical conditions. The hard and fractured quartzite up to a depth of 90 m produces a phreatic aquifer. At places, the lower part of hard and fractured rock forms a semi-confined aquifer, which remains in partial hydraulic connectivity with the phreatic aquifer. The groundwater level in the hard rock varies from 10 to 70 m in depth. The alluvial formation has a phreatic aquifer for the upper 60 m, and many a time produces semi-confined to the confined condition due to the presence of local clay horizon forming aquitard and aquiclude. Patchy occurrence of wind-blown Aeolian sand forms local phreatic aquifer. At places, perched aquifers of very local extent hanging on regional aquifers have been observed. In Faridabad, the urban area groundwater level in alluvial aquifer varies from water-logged conditions to deep as 60–70 m bgl. In alluvium, sand of various grades from the different potential aquifer zones. Shallow water levels have been observed towards Yamuna River. The water table has been found deeper along National Highway No 19, indicating that groundwater-stressed area has been formed traversing north-south due to heavy pumping along the highway caused by a dense network of tube wells due to the concentration of habitation and industries. The unconfined conditions prevail in alluvium and in weathered and jointed quartzites. In quartzites, it occurs in the weathered zones and interspaces within interconnected joints and fractures. The altitude of the water table ranges from 171.5 to 199.7 m amsl. It is observed that the groundwater flow is towards the central part of Faridabad from east and west. This phenomenon indicates heavy groundwater pumping along the National Highway for industrial and domestic purposes.

2.3 Long-Term Rainfall and Temperature

Environmental change-related investigations assume paramount significance these days because of its effect, which is observed to influence the rainfall pattern and temperature globally. According to the Intergovernmental Panel on Climate Change

(IPCC, 2007), future climate change is likely to affect agriculture, increase the potential hunger issues and the possibility of water scarcity, and lead to more rapid melting of glaciers (Jain & Kumar, 2012). It is very important to analyze the prevailing patterns in climatic conditions to interpret the impact of changing climate. On the basis of meteorological data, most of the distinguished patterns have been focused on rainfall and temperature indices (Chauhan et al., 2022). The study area, situated in the northern part of India, represents prevailing characteristics of humid subtropical to semiarid with generally dry winters extending from November to January (DES, 2014). The state of Haryana shows a normal rainfall of 558.02 mm (WRIS, 2022), whereas the normal rainfall for Faridabad and Gurgaon districts, in particular, was 521.4 mm and 583.2 mm, respectively, for the entire study period (Figs. 17.2 and 17.3). An analysis has been done to understand the Spatio-temporal change in the number of rainy days during different seasons for a duration of 120 years from 1901 to 2020 in several districts of Haryana. The study has revealed that the maximum number of rainy days was noticed during the monsoon season. The least number of rainy days were observed in post-monsoon, followed by winter and pre-monsoon season. Faridabad and Gurgaon are located in the southeastern parts of the Haryana state. A further recent analysis by IMD of the past 30 years of data (1989–2018) shows Faridabad district having 29–34 rainy days with an annual mean of 618.8 mm and Gurugram district having 25–29 rainy days with a mean annual rainfall of 529 mm (Guhathakurta et al., 2020). The rainfall data has been collected from WRIS (2022) and a decadal variation in rainfall has been analyzed for Faridabad and Gurgaon districts of Haryana.

Global climate projections, given inherent uncertainties, indicated several changes in India's future climate. One of the significant impacts of climate change will definitely include warming of 0.5 °C in overall India by the year 2030

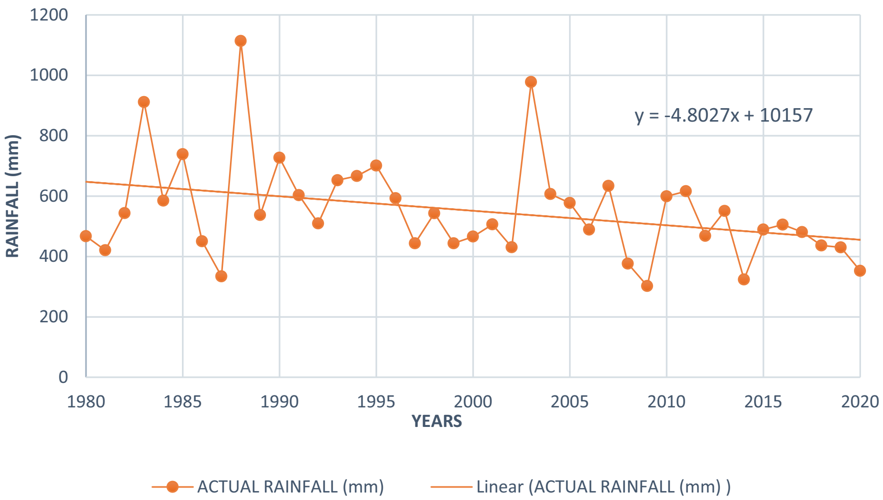

Fig. 17.2 Decadal variation in annual rainfall pattern of Faridabad during 1980–2020

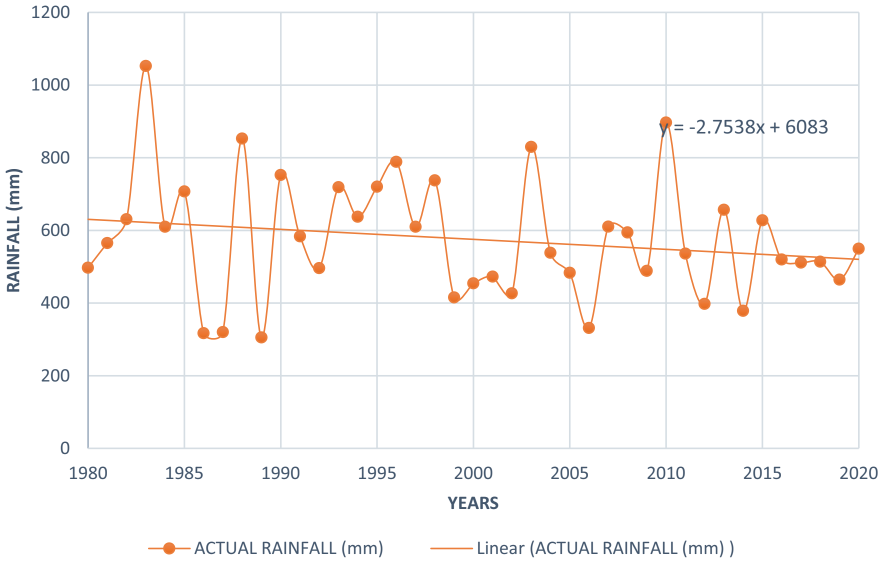

Fig. 17.3 Decadal variation in annual rainfall pattern of Gurgaon during 1980–2020

(approximately equal to the warming over the twentieth century) and warming of 2–4 °C by the end of this century, with the maximum increase over northern India (NIC, 2009). Eminent researchers have developed and analyzed the climatic indices based on long-term meteorological datasets of temperature and rainfall, which are further used to conduct a quantitative evaluation of the variations in weather patterns due to climate change (Duan et al., 2014; Talchabhadel & Karki, 2019; Ferreira et al., 2021; Teixeira et al., 2021; Chauhan et al., 2022). Chakraborty et al. (2014) addressed that urban settlement area, which mainly includes residential area and industrial area, shows much higher variation in temperature. In the year 2000, the industrial area shows a 22.3 °C temperature in winter and a rise of 10 °C in summer, which shows a 32.5 °C temperature. Observing the variation in 2010, it can be noticed that the industrial area is showing 24.2 °C in winter and 34.5 °C in summer. It can be concluded that the increase is around ±2 °C during the last 10 years in the urban areas. Sati and Mohan (2017) carried out investigations on Delhi NCR for a duration of 50 years to correlate the rapid change in land use land cover with the dramatic rise in surface temperature. The study found an almost 17-fold increase in the urban settlement areas from 1972 to 2014, including a 40% reduction in water bodies (from 221 km^2 in 1972 to 136 km^2 in 2014). The study based on model simulations has inferred that there is a change of 1.5 °C in the surface temperature due to land use land cover changes alone that have occurred because of urbanization over the same period. However, a study by Mohan et al. (2011) indicated a similar variation in temperature (2 °C) during 1906–2004. This study shows that the actual rise in temperatures that occurred in urban and its adjacent areas is more prominent in the city areas (1.5–2 °C) compared to the increase in temperature due to global warming of 0.6–0.9 °C according to IPCC (2007). Thus, from the studies conducted by various scholars, it can be concluded that rapid urbanization has remarkably affected the urban climate in the last few decades.

2.4 Demographic Changes

As globalization and urbanization are becoming integral in the present scenario, half of the country's population will be living in urban areas by 2030 (United Nations, 2018). In India, natural population increase, economic growth, and rural-urban migration result in rapid urbanization and a dynamic transformation of peri-urban areas (Dikshit, 2011; Follman et al., 2018). At the current rate of growth, the urban population in India is estimated to reach a staggering 60 crores by 2030 (United Nations, 2018). According to Census 2011, as many as 53 cities in India had a million plus population. It is projected that more than 50% of the country's population will be urban by 2050 (WUP, 2018). Faridabad, one of the fastest-growing north-western Indian cities and part of the Delhi-National Capital Region (NCR), has followed an increasing trend in the urban population from 7.16% in 1971 to 79.51% in 2011 (Teotia & Kumar, 2015; Ranjan et al., 2021). Similarly, Gurgaon, which is situated adjacent to Delhi NCR has followed an increasing trend in the urban population from 10.62% in 1951 to 68.82% in 2011 (Fig. 17.4).

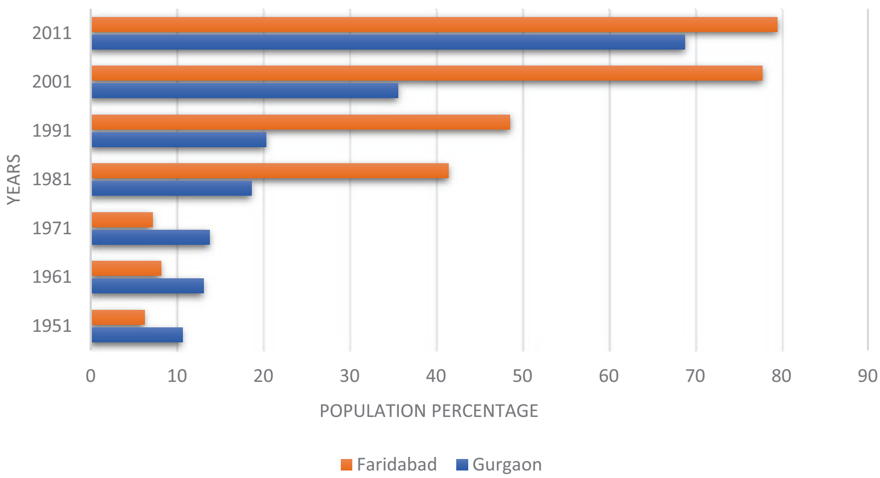

Fig. 17.4 Bar graph showing the decadal change in percentage of urban population to total population in Faridabad and Gurgaon

3 Discussions

The investigation has been carried out on the basis of both primary and secondary data. The study area has been demarcated using Google Earth to get the exact boundary and to identify the locations for sample collection. RS-GIS and Google earth has extensively used to compare and analyze land use, land cover change, and level of urbanization with time. The investigation of the quality of groundwater in the Faridabad and Khoh areas has been undertaken on the basis of samples collected from the locations and further multiple laboratory examinations. The locations of each sampling point were noted using GPS. The samples of groundwater have been collected, and laboratory experiments were done to measure EC (electrical conductivity), TDS (total dissolved solids), pH, nitrate, total hardness, alkalinity, fluoride, chloride, etc. using standard methods. A topographical survey was carried out to identify of elevation profile at the microlevel. Geophysical investigations of the Faridabad area were done to delineate the basement position, identify the freshwater saline water interface in the identified locations, and assess its hydrogeological suitability. Geophysical investigations at Manesar were done to locate community water well sites and artificial recharge sites by using Gradient Resistivity Profiling and Vertical Electrical Sounding. Borehole data were collected to understand the sub-surface lithology. Data so obtained were archived for use. The results were discussed as suitable in the following para.

3.1 Change in Land Use Landcover

3.1.1 Micro Morphometric Changes

The present-day Faridabad city covers an area of about 182 km^2, but during 1989 was restricted to only 67 km^2. In the last 33 years, the urban area has expanded about 275% by converting the peri-urban areas to urban areas (Fig. 17.5). This has not only changed the land use land cover (LULC) character of Faridabad but also significantly modified the micro morphometric features and altered the hydrogeological conditions in this area. Further detailed remote sensing and GIS study have revealed that within the core urban area of Faridabad city (67 km^2) itself, the LULC has changed a lot (Fig. 17.6). The built-up area has risen from 46% to 71% (including road) during last 33 years. At the same time area under waterbodies has reduced from 5 to <1%, and the area under vegetation and cultivation shrinked from about 31% to 20%. Further, the bare lands were also converted to built-up areas (Fig. 17.5).

Therefore, the density of built-up areas has increased by 154%. In general, runoff co-officiant for the paved area is considered 70%, but the increase of built-up area density will likely increase runoff and further reduce infiltration. This is considered one of the major causes of the generation of flash floods in old parts of the cities. Gradual reduction of open space produces larger runoff from the paved area (Table 17.2), and pre-existing drainage systems cannot carry the additional runoff

Fig. 17.5 Google map of the present (2022 in red 182 km^2) and past (1989 in blue 67 km^2) area under Faridabad city

load. Urban flash floods have become a major concern in many cities in India, including Faridabad. Streets get submerged for many hours or even days, and life becomes measurable in several parts of the city, particularly in the low-lying areas. The changing climate conditions aggravated such a phenomenon. This feature of urbanization needs detailed investigation and deliberation.

The estimated runoff generation from the core zone area of Faridabad city (67 km^2) considering the LULC character in 1989 and 2022 is given in Table 17.2. It reflects that runoff generation has increased from nearly 16 MCM to about 22 MCM when the quantum of rainfall remains nearly constant during this period. However, this estimation does not consider the increase in the intensity of rainfall due to the reduction of rainy days from nearly 32 days to about 25 days during the same period. It is predicted that the actual generation of runoff must be higher than what has been estimated. The nearly vertical bedding of folded Ajabgarh quartzite of study area has NNE-SSW strike. This produces typical micro fabric for runoff

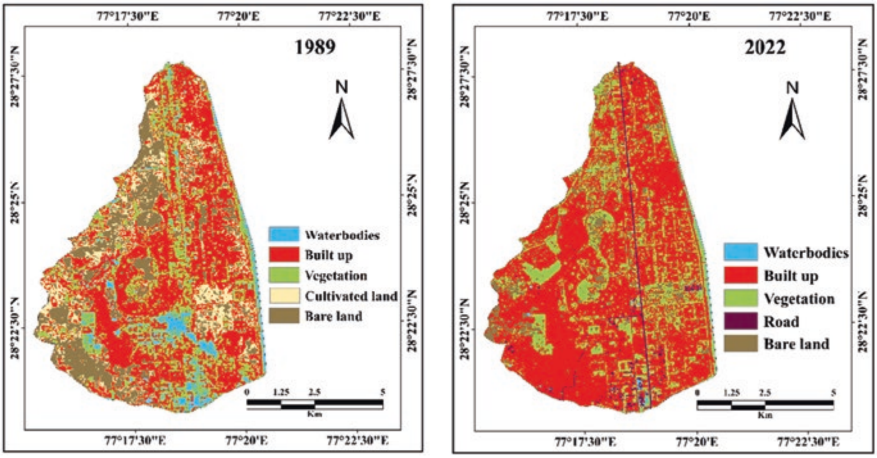

Fig. 17.6 Change in land use land cover from 1989 to 2022 in 67 km^2 Faridabad city area

Table 17.2 Estimation of runoff generation based on LULC between 1989 and 2022 in Faridabad

Class_Name	Coefficient of Runoff (%)	Area 1989 (m^2)	Area 2022 (m^2)	Runoff 1989 (m^3)	Runoff 2022 (m^3)
Waterbodies	0	3,483,000	508,000	0	0
Vegetation	15	11,993,000	13,621,000	1,079,370	1,225,890
Cultivated land	15	8,859,000	0	797,310	0
Buildup area	80	31,034,000	46,195,000	13,034,280	19,401,900
Road	80	0	1,880,000	0	902,400
Bare land	15	12,049,000	5,209,000	1,084,410	468,810
Total (m^3)				15,995,370	21,999,000
Rainfall is taken constant 0.6 m/annum from 1989 to 2022				15.99 MCM	21.99 MCM

generation in this area which gets altered due to the construction of residential colonies, commercial zones, amenities, and infrastructures such as storm water drains, gutters, laying of water supply pipes, cables of electric and telecommunication, construction of roads, etc. (Fig. 17.7).

3.2 *Inference from Study of Ponds*

One of the major impacts of urbanization can be seen in urban water bodies. Due to urbanization, it has been observed in both the study areas that pond/small water body has been affected. However, the impact of urbanization on the water bodies is dependent on the geographical location and morphological position of such water bodies within the urban area. Based on morphological position and geographical location, the pond may show reduction or enhancement in its water volume apart from total drying

Fig. 17.7 Change in land use between 2004 and 2022 of the Greenfield colony area of Faridabad. (Source: Google Earth)

out due to encroachment and alteration in land use pattern. The ponds in the low-lying area within a higher elevation or ponds of a lower gradient area within the low-lying area have shown an increase in the volume of water, whereas ponds of higher morphological position or on an elevated area have shown a reduction in water volume or even been dried up. In both our study areas, such ponds are available. For example, the IMT pond of Khoh, Manesar (Fig. 17.8), situated in the lower gradient, is showing an increase in water volume; the pond is receiving both drain water and rainwater, whereas the temple pond has gone dry due to urbanization. It has been observed that the increase in the volume of water in IMT ponds is due to the accumulation of grey

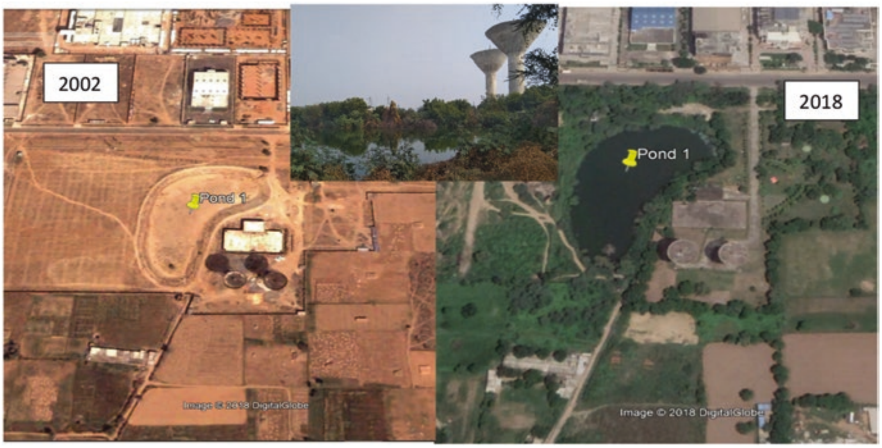

Fig. 17.8 Google image of 2002 and 2018 along with photo of IMT pond Khoh

water, and such cases are plenty in urban areas. The other three ponds have been converted to sewage tanks. On the other hand, change in the land use pattern of the pre-existing water body is very easy and frequent when ponds/water bodies get dry. A unique technique has been developed and named pond hydrograph to assess the pond water level. In this method, with the help of historical images, a particular pond's submergence area is calculated several times. Based on the water-filled area, a time series curve has been plotted to show the fluctuation in water level within a pond. An example of such a pond hydrograph is depicted in Fig. 17.9.

3.3 Disposal of Liquid Waste

Due to urbanization, the local urban bodies are under pressure to provide adequate water to a large part of their population. It has been estimated (CPHEEO, 1999) that 80% of the domestic water supply reappears in the form of household discharge. Therefore, a large quantity of gray water is generated due to urbanization and related population growth. Management of grey water is one of the biggest challenges due to urbanization and industrialization. Presently, no major river in India exists which can provide water of portable quality without treatment. The urban and industrial discharge are largely responsible for such a situation. So, urbanization directly impacts the surface water quality, and many a time, the water quality of canals is driven by such surface water bodies/rivers. At Faridabad, within a stretch of 9.5 km, 7 illegal discharge point has been observed discharging domestic grey water into the canal system. This includes structured channel discharge and non-structured casual discharge. The discharge is also bound to pollute groundwater due to canal seepage, particularly in the relatively shallow groundwater zone. Figure 17.10 depicts points of such discharge in the Gurgaon canal within the Faridabad city area.

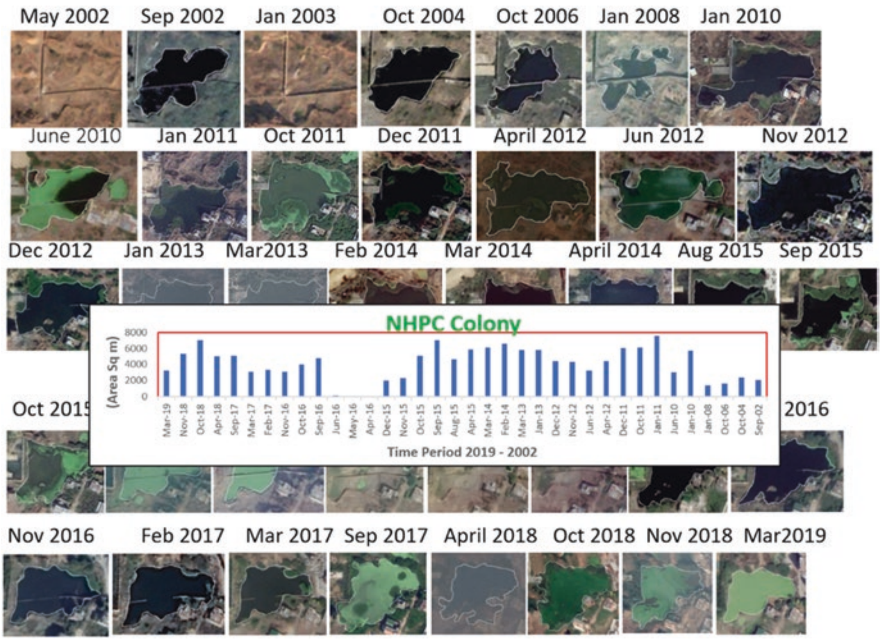

Fig. 17.9 Long-term changes in pond submergence area and pond hydrograph of NHPC pond Faridabad

Fig. 17.10 Gray water discharge points along Gurgaon canal in Faridabad city area

3.4 Disposal of Solid Waste

In spite of all efforts, a maximum of 75–80% of solid waste can be collected, segregated, and disposed of properly. Still, 20–25% of solid waste generated every day remains untreated and disposed of in unauthorized way/unscientific ways. Large part of this untreated solid waste obstructs surface run-off/flow from drains carrying grey water and hinders infiltration. Thus, situations often arise when drains overflow or a shallow impervious layer is created due to polyethylene in low-lying urban areas. No scientific data is available on how much impact is created due to the untreated disposal of solid waste material, including plastic materials.

3.5 Groundwater Depletion

Groundwater at present is the only source of water for Khoh Manesar. The population has increased tremendously since 2006. All 5 dug wells, and almost all tube wells (TW) of Khoh in the depth range from 75 to 80 m have gone dry (Fig. 17.11). The numbers of dry TWs in Khoh are a few hundred. The concentration of dry wells is more along the foothill zone where the hard rock aquifer is being tapped. Discharge and sustainability of wells tapping water from 85 to 100 m depth range

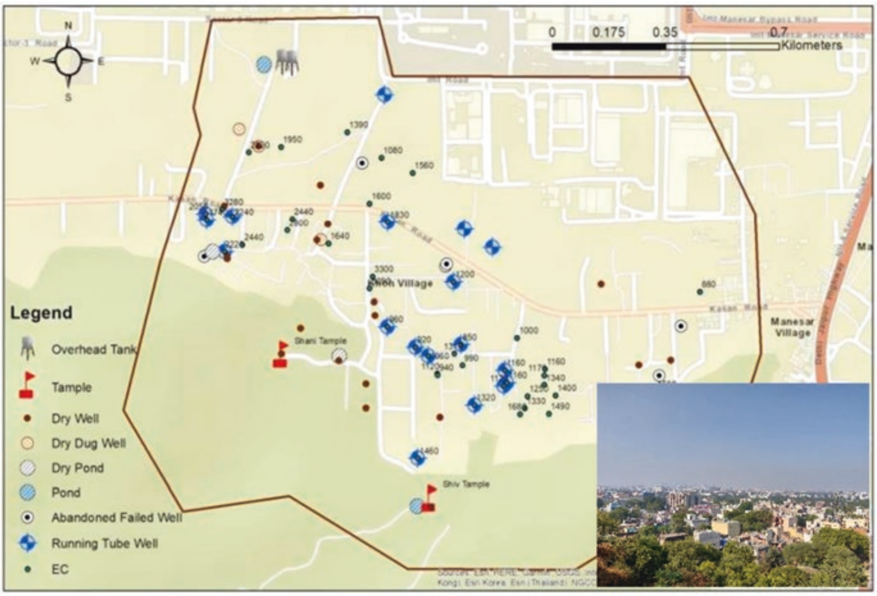

Fig. 17.11 Map of monitored wells and pond in Khoh Manesar along with a photograph showing the intensity of urbanization

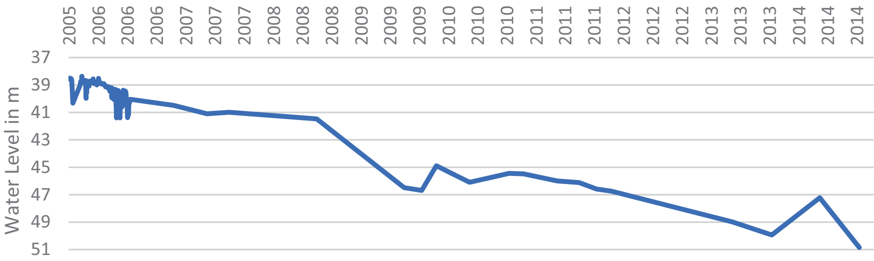

Fig. 17.12 Long-term trend of depleting groundwater of Faridabad

are reducing fast. Earlier, each house had its own TW, but due to well failures and increasing requirements, dependency on supply water is rising daily. The groundwater level in the area varies between 70 and 140 m bgl. Tube well depth ranges from 90 to 225 m bgl. Well discharge is generally low and varies largely from 0.1 to 2.0 lps. The alluvial aquifer has a better discharge than hard rock aquifers. Groundwater quality is found to be fresh to slightly brackish, and EC ranges from 850 to 3300 μs/cm. Due to the sudden and abnormal increase in the population of Khoh, the land use pattern has totally altered. This has reduced natural recharge substantially and increased flash food generated water logging of streets during monsoon. The area has a moderately steep slope, high susceptibility to erosion, moderate overflow, slow permeability, shallow depth, sandy or gravelly soil with low moisture capacity, and low inherent fertility. Though there are few attempts of artificial recharge of groundwater using roof water, no sincere community effort has been taken up in this direction; thus, Khoh area is under water stress condition. The groundwater of the Faridabad urban area has depleted a lot in the last few decades. The depletion rate has been estimated at 0.7 m/year (Fig. 17.12). Faridabad urban area is dependent on groundwater. There exist over 1600 TW and 22 Ranney wells to cater to the needs of the Faridabad area. The area is categorized as over-exploited and hardly able to feed the current requirement of a two million population.

3.6 Groundwater Quality

Long-term assessment of groundwater quality is very important due to its significance in determining suitability for drinking purposes and agricultural, domestic, and industrial uses as well. The groundwater gets contaminated due to a huge amount of hazardous waste from industries, landfills, unabsorbed fertilizers, pesticides, and other statements. Due to extensive urbanization and industrialization, groundwater quality is deteriorating, leading to potential health risks to the citizens. Conductance calculates the flow capability of water that is specifically associated with ion concentration in the water (EPA, 2012). In the present investigation, the data of EC in Faridabad for the last two decades collected from the

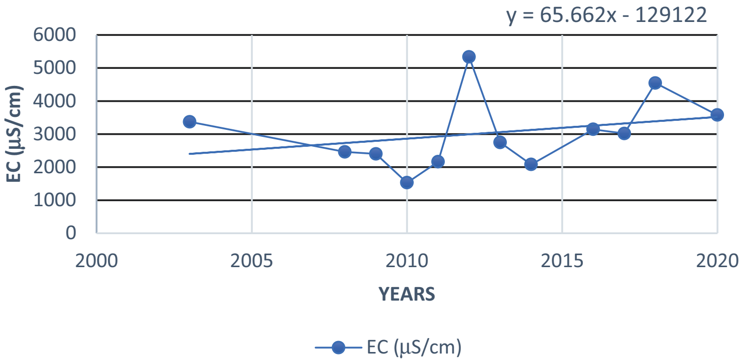

Fig. 17.13 Variation in electrical conductivity during 2002–2022

CGWB groundwater yearbooks has been plotted. The observed values show a range of 1527–4542.5 µs/cm. The groundwater for the entire study area shows an average of 3029 µS/cm of electrical conductivity. The data reveals that there is an increasing trend in EC from 2000 to 2020 from moderate to highly saline (Fig. 17.13). Sewage discharge or agricultural runoff can cause an increase in conductivity due to the presence of anions like nitrate, chloride, and phosphate. Thus, the abrupt rise in conductivity is indicating towards contamination of groundwater. In Khoh village, Gurgaon, the groundwater quality is found to be fresh to slightly brackish, and EC ranges from 850 to 3300 µS/cm.

3.7 Land Subsidence

Land subsidence is considered to be one of the severe geological hazards. According to US Geological Survey (USGS), excessive groundwater extraction is responsible for more than 80% of land subsidence (Garg et al., 2022). The extensive study of land subsidence of Delhi NCR indicates that the extent of subsidence increased continuously with time. Analyzing the land subsidence condition during 2014–2016, the maximum subsidence rate was relatively low, around 2.15 cm/year, and the spatial extent was negligible. However, during subsequent years, the deformation rates increased at a very high rate of 5.3 cm/year by the end of 2018 and 7.83 cm/year for the year 2018–2019 (Garg et al., 2022). This accelerating rate of land subsidence can be correlated with the high rate of groundwater depletion in Faridabad, which acts as reliable evidence of this condition. However, at certain locations, land subsidence and groundwater depletion do not follow a similar trend due to some discrepancies, including aquifer response to groundwater change, seasonal variation of groundwater, and differences in temporal sampling.

4 Conclusions

The impact of urbanization on groundwater conditions has been established in several parts of the country and the world. Further climate change scenario has intensified the adverse impact of urbanization on groundwater conditions. The present study considers two locations of urbanization within the area of the National Capital Region. The study has been able to characterize the key factors that govern the static and dynamic properties of urban areas, which significantly impact the groundwater scenario during changing climatic conditions. The expansion of the city area at the same time enhances the density of paved areas with a growing population has a many-fold impact on recharge discharge phenomena. The current study area largely belongs to alluvial terrain and has shown quality deterioration due to over-extraction of groundwater. Land subsidence has a hazardous impact on a densely populated area. The shrinking area under water bodies and pollution of low-lying surface water bodies are some important findings of this study. The study, however not able to find exact quantification of impact due to expansion and intensive paving and recommend further study on these aspects. The micro-level changes of morpho hydrogeological conditions were found to be significant factors for the flash flood generation.

Acknowledgments The authors thankfully acknowledge the Department of Science and Technology, Government of India, for the grant of Project "Co-solving water logging and groundwater depletion issue in parts of Faridabad Smart City using Underground Taming of Flood Water for Aquifer Storage and Recovery" (DST/TMD/EWO/WTI/2 K19/EWFH/2019/237(G)) to the corresponding author. The authors also thankfully acknowledge the Management of MRIIRS for providing logistic support and allowing authors to publish the paper. Special thanks to Mr. Ritwik Ganguly, Geovale Kolkata, for helping in the preparation of LULC maps. The authors are grateful to the editors of this book for their generous invitation to contribute a chapter in this publication.

References

Census of India. (2011). *Primary census abstract, Haryana, Series 7, Tables – A5-A8*. Directorate of Census Operations.

CGWB. (2015). *Aquifer mapping and formulation of aquifer management plan for the National Capital Region (NCR), Haryana (Volume II)*. Central Ground Water Board Ministry of Water Resources, River Development & Ganga Rejuvenation Government of India North Western Region.

CGWB. (2021). *Ground water year book of Haryana state 2020–2021*. Department of Water Resources, River Development and Ganga Rejuvenation, Ministry of Jal Shakti, Government of India.

Chakraborty, S. D., Kant, Y., Bd, B. (2014, January–February). Study of land surface temperature in Delhi City to manage the thermal effect on urban developments. *International journal of advanced scientific and technical research, 4*(1). ISSN 2249-9954.

Chauhan, A. S., Singh, S., Maurya, R. K. S., Rani, A., & Danodia, A. (2022). Spatio-temporal and trend analysis of rain days having different intensity from, 1901–2020 at regional scale in Haryana, India. https://doi.org/10.1016/j.ringps.2022.100041

CPHEEO. (1999). *Manual on water supply and treatment*. Central Public Health and Environmental Engineering Ministry of Urban Development.

Dandge, K. P., & Patil, S. S. (2021). Spatial distribution of ground water quality index using remote sensing and GIS techniques. *Applied Water Science, 12*(2022), 7. https://doi.org/10.1007/s13201-021-01546-7

Danger, S., Asoka, A., & Mishra, V. (2021). Causes and implications of groundwater depletion in India: A review. *Journal of Hydrology, 596*(2021), 126103.

Dash, S. K., Jenamani, R. K., Kalsi, S. R., & Panda, S. K. (2007). Some evidence of climate change in twentieth-century India. *Climatic Change, 85*(3), 299–321.

Dash, S. K., Kulkarni, M. A., Mohanty, U. C., & Prasad, K. (2009). Changes in the characteristics of rain events in India. *Journal of Geophysical Research – Atmospheres, 114*, D10.

DES. (2014). *Statistical abstract of Delhi*. Directorate of Economics and Statistics.

Dikshit, K. R. (2011). The city and the urban fringe: An introductory note. In J. K. Dikshit (Ed.), *The urban fringe of Indian cities* (p. 1). Rawat Publications.

Duan, H. B., Zhu, L., & Fan, Y. (2014). Review on the integrated assessment model of energy-environment-economy for the global change. *Journal of Systems Engineering, 29*, 852–868. http://cnki.com.cn/Article/CJFDTotal-XTGC201406014.htm

EPA. (2012). *Conductivity in water: Monitoring and assessment*. US Environmental Protection Agency.

Ferreira, F. L. V., Rodrigues, L. N., & da Silva, D. D. (2021). Influence of changes in land use and land cover and rainfall on the streamflow regime of a watershed located in the transitioning region of the Brazilian Biomes Atlantic Forest and Cerrado. *Environmental Monitoring and Assessment, 193*, 16. https://doi.org/10.1007/s10661-020-08782-5

Follman, A., Tups, G., & Dannenberg, P. (2018). Multi-temporal transect analysis of peri-urban developments in Faridabad, India. https://doi.org/10.1080/17445647.2018.1424656

Garg, S., Motagh, M., Indu, J., & Karanam, V. (2022). Tracking hidden crisis in India's capital from space: Implications of unsustainable groundwater use. *Nature Scientific Reports, 12*, 651. https://doi.org/10.1038/s41598-021-04193-9

Goswami, B. N., Venugopal, V., Sengupta, D., Madhusoodanan, M. S., & Xavier, P. K. (2006). Increasing trend of extreme rain events over India in a warming environment. *Science, 314*(5804), 1442–1445. https://doi.org/10.1126/science.1132027

Guhathakurta, P., Narkhede, N., Menon, P., Prasad, A. K., & Sangwan, N. (2020). *Observed rainfall variability and changes over Haryana state* (Met Monograph No.: ESSO/IMD/HS/Rainfall Variability/09(2020)/33). IMD.

IPCC. (2007). Summary for policymakers. In S. D. Solomon et al. (Eds.), *Climate change-the physical science*. Cambridge University Press.

Jain, S. K., & Kumar, V. (2012). Trend analysis of rainfall and temperature data for India. *Current Science (Bangalore), 102*(1), 37–49.

Lal, M. (2003). Global climate change: India's monsoon and its variability. *Journal of Environmental Studies Policy, 6*(1), 1–34.

Mohan, M., Kandya, A., & Battiprolu, A. (2011). Urban heat island effect over National Capital Region of India: A study using the temperature trends. *Journal of Environmental Protection, 2*, 465–472.

National Intelligence Council. (2009). India: The impact of climate change to 2030 a commissioned research report. NIC spacial report no 2009-03D, 54p.

Rahman, T. A., Arpan, S., & Jafri, M. D. A. (2016). Ground water modeling of Faridabad District, Haryana, India. *International Journal of Agriculture Sciences, 8*(47), 1957–1965.

Ranjan, K., Sharma, V., & Ghosh, S. (2021). Assessment of urban growth and variation of aerosol optical depth in Faridabad District, Haryana, India. *Pollution, 8*(2), 447–461. https://doi.org/10.22059/POLL.2021.329185.1163

Saha, D., Marwaha, S., & Mukherjee, A. (2018). Groundwater resources and sustainable management issues in India. In *Clean and sustainable groundwater in India*. Springer. https://doi.org/10.1007/978-981-10-4552-3_1

Saini, H. S., Kaura, L. P. S., Mujtaba, S. A. I., Verma, K., & Pant, N. C. (2017). Assessment of the soils around Faridabad, NCR in the context of changing Landuse, Indian. *Journal of Geosciences, 71*(1), 219–226.

Sati, A. P., & Mohan, M. (2017). The impact of urbanization during half a century on surface meteorology based on WRF model simulations over National Capital Region, India. *Theoretical and Applied Climatology, 134*. https://doi.org/10.1007/s00704-017-2275-6

Sinha, R. K., & Srivastava, A. K. (2000). Is there any change in extreme events like heavy rainfall? *Current Science, 79*(2), 155–158.

Swain, S., Sahoo, S., & Taloor, A. K. (2022). Groundwater quality assessment using geospatial and statistical approaches over Faridabad and Gurgaon districts of National Capital Region, India. *Applied Water Science, 12*, 75. https://doi.org/10.1007/s13201-022-01604-8

Talchabhadel, R., & Karki, R. (2019). Correction to: Assessing climate boundary shifting under climate change scenarios across Nepal. *Environmental Monitoring and Assessment, 191*, 707. https://doi.org/10.1007/s10661-019-7907-0

Teixeira, D. B. D., Veloso, M. F., & Ferreira, F. L. V. (2021). Spectro-temporal analysis of the Paraopeba River water after the tailings dam burst of the C'orrego do Feij˜ao mine, in Brumadinho, Brazil. *Environmental Monitoring and Assessment, 193*, 435. https://doi.org/10.1007/s10661-021-09218-4

Teotia, M. K., & Kumar, R. (2015). *The state of cities in North-Western India: A case of selected JNNURM cities* (Study focus city: Faridabad). CRRID.

United Nations. (2018). *Revision of world urbanization prospects | Multimedia library*. United Nations Department of Economic and Social Affairs. https://www.un.org/development/desa/publications/2018-revision-of-world-urbanizationprospects.html

World Urbanization Prospects. (2018). Published by the Population Division of the United Nations Department of Economic and Social Affairs (UN DESA). https://www.un.org/development/desa/publications/2018-revision-of-world-urbanization-prospects.html

WRIS. (2022). *Water resources information system*. https://indiawris.gov.in/wris/#. Accessed in May 2022.