Chapter 9
Groundwater System of National Capital Region Delhi, India

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Abstract Water scarcity in National Capital Region (NCR), Delhi, has gradually become one of the most crucial issues for its citizens in the last few decades. The rapid decline in groundwater level due to heavy abstraction, change in land use pattern, and climate can be seen throughout the NCR. Further; this decline coupled with deterioration of groundwater quality also raises serious concerns. The NCR Delhi is identified as a low-rainfall region, yet by its location in the Yamuna River Basin it has always sustained itself against water scarcity for years in the past. The understanding of groundwater system of NCR Delhi and recent changes are very important for evaluating groundwater environment of NCR. This is a necessary prerequisite for regulated groundwater development and management in this region. Thus, this article reports all the facets of groundwater of NCR. The information and findings in the article will be useful for planners, scientists, engineers, and administrators.

9.1 Introduction

The National Capital Region (NCR) of India (Fig. 9.1) constitutes whole National Capital Territory (NCT) Delhi (1,483 km^2) along with parts of Haryana (12,069 km^2), Rajasthan (8,380 km^2), and Uttar Pradesh (10,853 km^2) and covers a total area of approximately 32,785 km^2. Ganga and Yamuna are main rivers flowing north to south in NCR (Fig. 9.1). NCR Delhi is a water scarce region (Shekhar 2006; Chatterjee et al. 2009; Shekhar et al. 2009; Sarkar et al. 2016a; Macdonald et al. 2016). However, it has been established that if available resource is properly managed, it will cater to this scarcity (Rao et al. 2007; Shekhar et al. 2009, 2015; Shekhar and Rao 2010). Though Indo-Gangetic Plain has high potential of groundwater (Macdonald et al. 2016; Saha et al. 2016), still it requires proper understanding of the system for effective utilization of the resource.

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A. Mukherjee (ed.), *Groundwater of South Asia*, Springer Hydrogeology,
https://doi.org/10.1007/978-981-10-3889-1_9

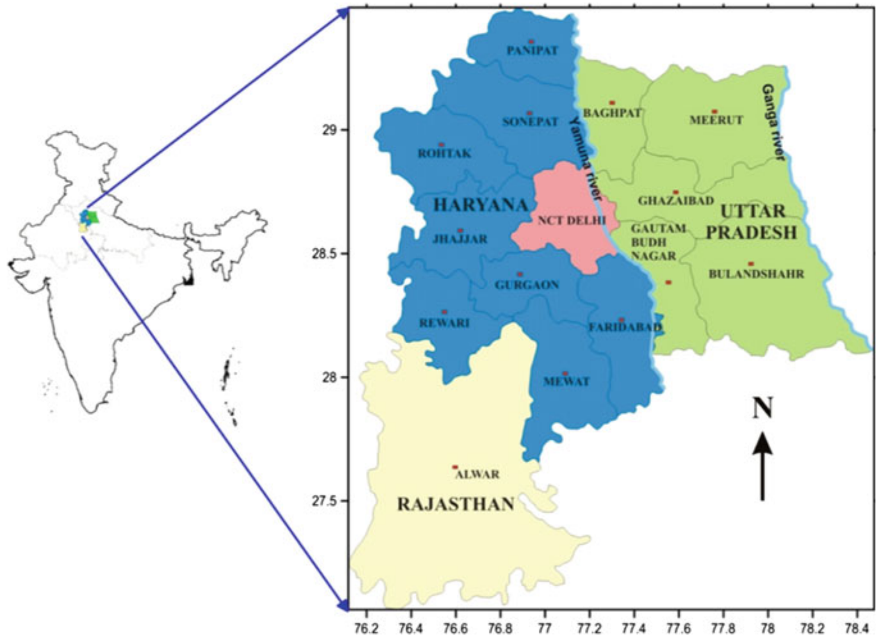

Fig. 9.1 Location map of Delhi, NCR. It covers subregions of three neighboring states (i.e., Haryana, Uttar Pradesh, and Rajasthan) and whole Delhi, NCT. Two major rivers, Yamuna and Ganga, flow from north to south direction. River Yamuna passes almost through the middle while River Ganga flows in the east (After Shekhar 2014; *source* http://ncrpb.nic.in/). More related information regarding groundwater of South Asia is available in Mukherjee (2018)

9.2 Population

The population in NCR has increased drastically in a decade due to employment and better lifestyles. The comparison of area of Delhi and other districts of NCR and the changes in population density over 2001–2011 is shown in Fig. 9.2.

The cumulative area of NCR is 32,785 km^2 in which about 36,268,118 people were living in the year 2001 and it increased to 45,026,595 people in 2011 (Indian Census 2011). Delhi has the highest population density followed by Ghaziabad and Faridabad. However, the population is increasing at a highest rate in Gurgaon (74%), followed by Ghaziabad (42.3%), Mewat (37.9%) over a decade (2001–2011; Fig. 9.2). Delhi stands at eighth position in ascending/descending order in terms of population growth rate for 2001 and 2011.

The average male percentage in the NCR was about 53.3% (2001), which increased to 53.88% (2011). Figure 9.3 clearly shows that the Delhi has the highest population (2011) and 97.5% of them resides in urban areas (Indian census 2011).

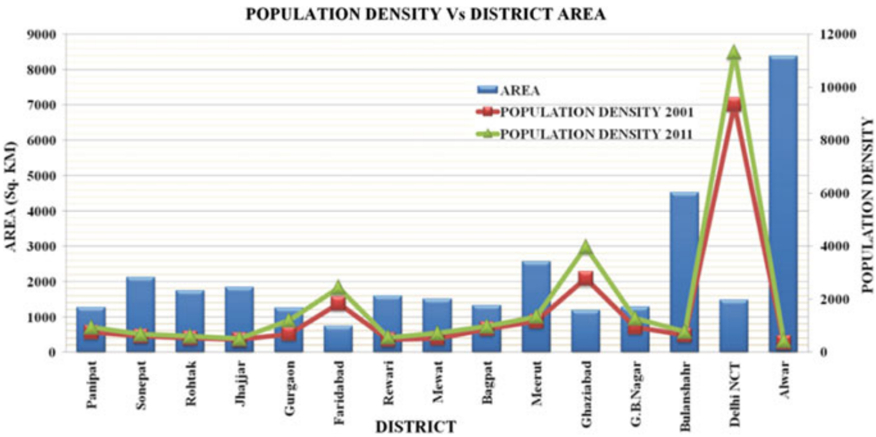

Fig. 9.2 Comparison of area and change in population density over a decade period (Indian census 2011)

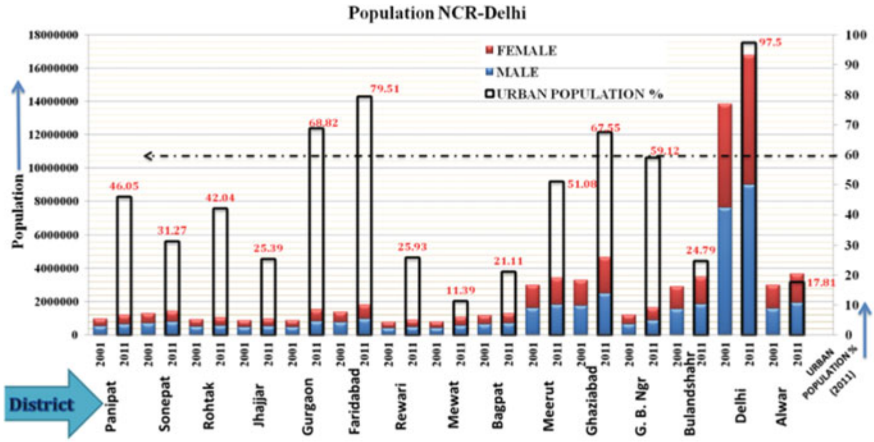

Fig. 9.3 Population distribution in terms of gender and dwelling. *Source* Indian census (2011)

Regions sharing the Delhi border, e.g., Faridabad, Gurgaon, Ghaziabad, and Gautam Buddha Nagar are those areas where more than 60% of their populations are residing in the urban regions which clearly indicate accelerated urbanization. Other districts such as Meerut and Panipat are also approaching the scenario where about 60% of population would be living in cities (Fig. 9.3).

9.3 Land Use/Land Cover

Migration of population toward NCR has influenced the land use pattern. Changes in land use/land cover for the years 1999 and 2012 are shown in Fig. 9.4. Migration to the NCR region has increased the buildup area by 34.6%, while green areas, wastelands, and water bodies have decreased by about 22.5, 40, and 6%, respectively, in the year 2012 with respect to 1999. But the agricultural practices have decreased by a very negligible percentage of 0.77% in NCR (Fig. 9.4). The minor decrease in the water bodies may affect the groundwater recharge.

9.4 Geology/Geomorphology of NCR Delhi

The NCR is mainly covered with Indo-Gangetic Alluvial Plains of Quaternary age (Chhabra et al. 2010; Table 9.1). The main sources of alluvium are the two major rivers namely Yamuna and Ganga which flow through the region (Fig. 9.5).

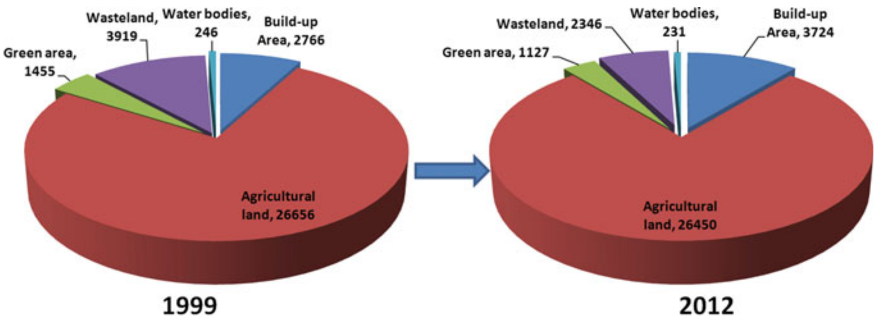

Fig. 9.4 Land use/land cover classification of NCR Delhi (NRSC 2016, available from www.bhuwan.nrsc.gov.in). *Note* Area in the figure is in km^2

Table 9.1 Stratigraphic successions of Delhi and adjoining areas (Sharma (Anon.); Thussu 2006)

Age	Group	Formation
Pleistocene and recent (Quaternary)	Quaternary alluvium	Recent alluvium comprising sands "kankar," gravel, silt, clay, etc.
		Older alluvium and piedmont gravels, pebbles, cobbles, sand, clay, and calcareous concretions
Unconformity		
Post-Delhi intrusive		Quartz veins, pegmatites, granites, amphibolites
Precambrian Delhi super group	Ajabgarh group, Alwar group	Quartzite, phyllites, mica schist, calc-schist, gneiss, marble, basic flows quartzite, conglomerate, and minor schist

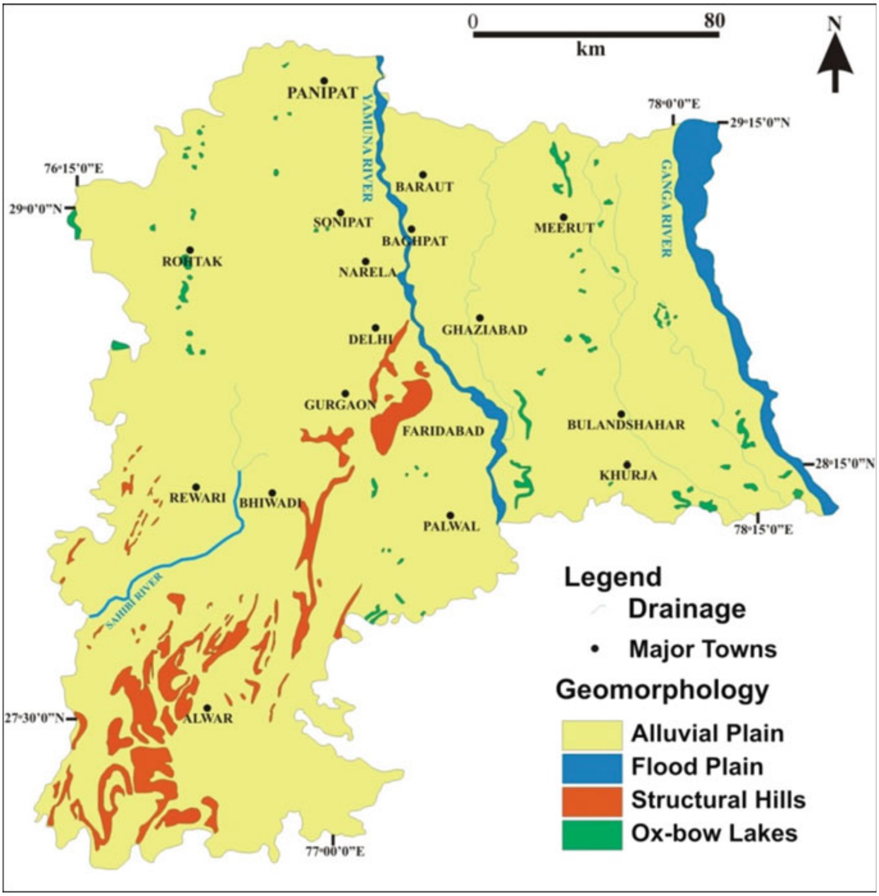

Fig. 9.5 Geological and geomorphologic map of NCR Delhi. Modified after NCRPB (Anon.)

Further, the region is broadly divided into four geomorphic units (Fig. 9.5). These include: alluvial plains, active floodplain areas, upland areas in the form of structural hills and depression covered by oxbow lakes and other isolated water bodies (Kaul and Pandit 2004; NCRPB (Anon.); Bawa et al. 2014). While the active floodplains are confined to areas in the vicinity of the rivers, the structural hills are mainly exposed in southern part of the region. These hills are the parts of Aravalli Ranges and are found exposed with a trend of NE–SW direction (Fig. 9.5).

The stratigraphic succession of the NCR is dated from Precambrian to recent age (Thussu 2006; Table 9.1).

The basement rock is found at variable depths as we move away from the Delhi Ridge (Shekhar and Sarkar 2013). For example, in Panipat, basement is not encountered even after drilling up to 460 m, whereas in Rohtak and Jhajjar, it has been encountered at 370 and 315 m, respectively (CGWB 2013a, b and c).

Similarly, in Ghaziabad, in the vicinity of ridge, basement was found at 116.4 m but as we move away, the rocks are at 330 m depth (CGWB 2009a). In the south of Delhi, basement is near surface to 300 m in central and eastern part of the Mewat (CGWB 2012a) and about 350 m deep in the vicinity of Yamuna in Faridabad (CGWB 2013d).

9.5 Hydrogeology

The hydrogeology of NCR Delhi has a strong link with geomorphology. Alluvial plains are best potential aquifer in the NCR. The varied grade of sand, along with gravels and kankars, forms good aquifers for the groundwater (CGWB 2013b, c, d and e). The groundwater of NCR aquifers is recharged from rainfall, rivers, canal seepage, irrigation, return flow, and water bodies. The alluvial aquifer in the western part of NCR (i.e., Haryana subregion) is medium- to fine-grained sand. Gravels and coarse-grained sand are also reported at a few places which forms potential aquifers. But these zones laterally and vertically are of small extent. In western part of NCR, clay zones dominate over the sandy aquifer (CGWB 2013b, c and e). In Faridabad and Mewat, alluvial aquifers are also reported to have calcareous concretions (CGWB 2012a, 2013d). The aquifer in eastern part of NCR encompassing Uttar Pradesh subregion is mainly composed of coarser sand except the trans-Hindon region (CGWB 2009a).

As the eastern part of the NCR is near to the River Ganga, they are likely to be dominated by the sediments of the Ganga (CGWB 2009a). The central portion of NCR is dominated by River Yamuna, and the small portion in the west is a part of Ghaggar Basin (CGWB 2013e). In between Ganga and Yamuna, tributaries like Hindon meet Yamuna downstream of Okhla barrage.

9.5.1 Aquifer Characteristics

Regionally, there are three major aquifer groups in the NCR. The first aquifer is in unconfined condition; second one is semi-confined to confined state; and third aquifer group is deeper, also confined in nature (CGWB 2009a, 2013a, d, and f). Sand and gravels are aquifer horizon and are underlain and overlain by impermeable clay layers. First aquifer group is up to 200 m thick as in northern part Ghaziabad (CGWB 2009a), and second aquifer group lies between 130 and 250 m in Panipat (CGWB 2013a), 90–200 m in Sonipat (CGWB 2013f), and 170–350 in Ghaziabad (CGWB 2009a). The third aquifer system can be found at depth range of 286–366 m in Panipat (CGWB 2013a), 250–400 m in Sonipat (CGWB 2013f), and 350–450 m in Ghaziabad (CGWB 2009a).

According to the yielding capacity of aquifer, NCR is broadly classified into three zones (Shekhar 2014; Fig. 9.6).

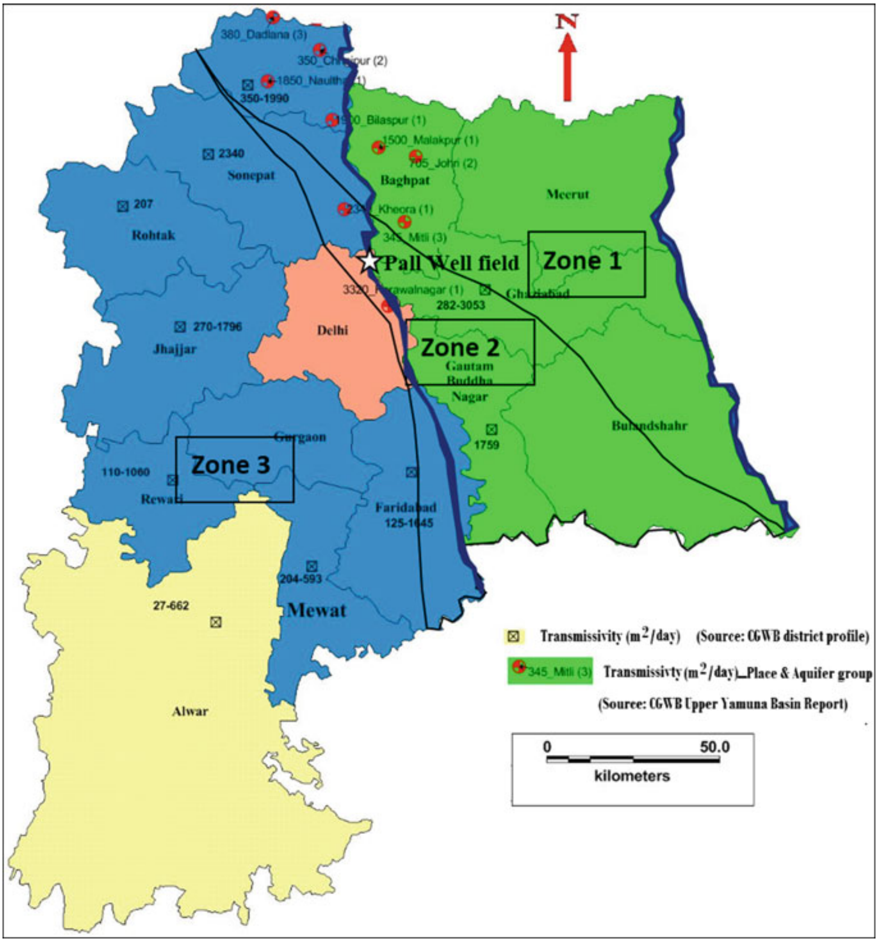

Fig. 9.6 Aquifer zoning and transmissivity variation in NCR. Modified after (Shekhar 2014; CGWB 1985, 2009a, b, 2012a, 2013a, b, c, d, e, f, and g; NCRPB (Anon.), WAPCOS). The figure shows the variation in transmissivity of aquifer across the NCR. Values against red symbol show transmissivity (m^2/day) followed by the site name and aquifer group

Zone 1 is the region which is in the vicinity of Ganga River and upper stretch of Yamuna in NCR. Regions such as Panipat, Meerut, eastern Ghaziabad, and eastern Bulandshahr fall under zone 1. This zone has freshwater in whole aquifer column and can yield significant amount of groundwater. Zone 2 can be broadly classified into two horizons. The upper horizon is younger and higher yielding aquifer than the lower one which has comparatively low yield capacity. The water in upper horizon is fresh, whereas the water in lower horizon is saline in nature (Shekhar et al. 2009, 2015; Shekhar and Prasad 2009; Sarkar et al. 2016a). The quality of groundwater deteriorates as we move from zone 1 to zone 2 in Ghaziabad

Table 9.2 Different hydrogeological properties of NCR and command area

District	Transmissivity	Discharge	Irrigation		
	(m^2/day)	(lpm)	Tube well (km^2)	No. of tube well	Canal (km^2)
Panipat	350–1990	605–3258	680	83,855	280
Sonipat	2340	4541	600	37,385	850
Rohtak	207	870		16,995	840
Jhajjar	270–1796	124	640	29,008	600
Gurgaon		400–1000			
Faridabad	125–1645	200–6629	870		230
Rewari	110–1060	358–2911	1010	28,102	
Mewat	204–593	410–910	720	31,669	160
Ghaziabad	282–3053	1003–2842	1066.36	30,509	207.71
G.B.Nagar	1759	480–960			
Delhi NCT		100–2400			
Alwar	27–662.4	10–1003		3246	7.89

Source (CGWB (Anon.), 2009a, b, 2012a, 2013a, b, c, d, e, f and g); CGWB Delhi state profile (lpm—liter per minute)

(CGWB 2009a). Zone 3 mainly covers the entire subregions of Haryana, Delhi, and Rajasthan state (Fig. 9.6).

The aquifer of third zone is of low yielding capacity. These zones have limited freshwater in upper aquifer horizons. The freshwater under zone 3 region is mainly tapped by tube wells/dug wells or hand pumps of shallow aquifer (CGWB 2013b, c and f). In hard rock aquifers of districts such as Gurgaon, Rewari, Faridabad, Mewat and Alwar and Delhi (Zone 3), freshwater is trapped in joints, fractures, and crevasses (CGWB 2012a, 2013d, e and g). Sahibi River Basin also has fair capacity to yield the groundwater at the rate of 100–300 m^3/day for more than 10–12 h (CGWB 2013g). The variation in the discharge capacity of the aquifer, number of tube wells, and area which is irrigated by tube wells and canals in different districts are shown in Table 9.2.

9.5.1.1 Experimentation for Aquifer Characterization

For determining the aquifer potential on Yamuna River Bank in Delhi stretch, a pumping test was conducted in Palla well field through a project financed by M/s WAPCOS Ltd.

Two observation wells were installed at radial distance of 36 and 48 m far from the pumping well to monitor the effect of pumping on the aquifer. Subsequently, the recovery of water level in both observation wells was also recorded. The effect of pumping in aquifer, along with the site plan, is shown in Fig. 9.7.

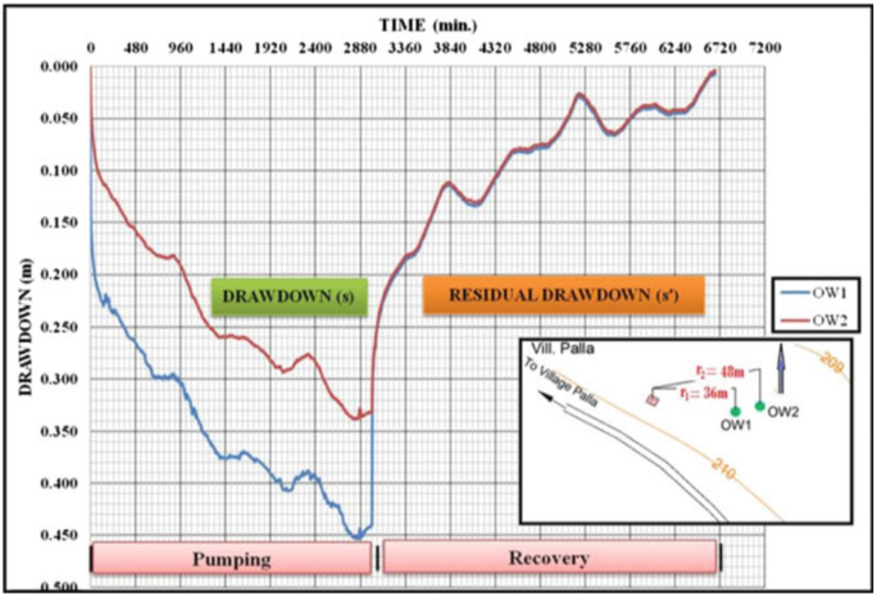

Fig. 9.7 Effect of long-duration pumping test in aquifer and its recovery. The figure shows drawdown in the aquifer during pumping and recovery after the cessation of pumping

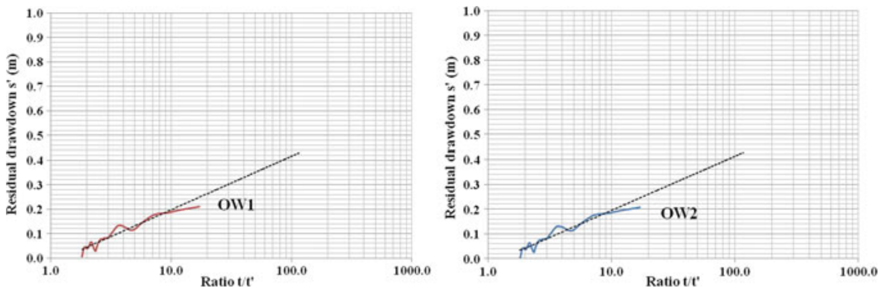

Fig. 9.8 Residual drawdown versus t/t′ ratio for determining the aquifer transmissivity

The pump was run for a long duration of about 50 h, at the discharge rate of 1980 liter per minute (lpm), and its post pumping-recovery was observed for about 61 h. At the end of pumping, drawdowns of 0.44 and 0.33 m were recorded from observation well 1 and 2, respectively. Both observation wells showed recovery of about 99% in 61 h.

The recovery data of this stress test were analyzed using this recovery straight-line fitting approach (Fig. 9.8; CGWB 1982).

For estimation of transmissivity, we used recovery data for the period 187–3660 min. The initial recovery data had fluctuations, and it was difficult to be used for interpretation. With the given data, a plot of residual drawdown (s') versus ratio of time after pumping started (t) and time after pumping closed (t') was drawn for both observation wells (Fig. 9.8). A straight line was fitted through the data, and change in water level during recovery ($\Delta s'$) for a complete log cycle was observed.

The formula used for calculating the transmissivity is given below:

$$\text{Transmissivity}(T) = (2.3 * Q)/(4\pi\Delta s') \quad \text{(CGWB 1982)} \tag{9.1}$$

where

T transmissivity (m^2/sec)
Q discharge rate (m^3/sec)
$\Delta s'$ change in residual drawdown for one log cycle

For OW1, $\Delta s'$ was observed as 0.22 m on log cycle of t/t' which resulted in transmissivity of 0.02745 m^2/sec, and for OW2, $\Delta s'$ is observed as 0.23 m for one log cycle of t/t' producing transmissivity of 0.0263 m^2/sec. The well was placed in the younger alluvium of 110 m thickness (WAPCOS 2012). The hydraulic conductivity estimated from recovery data of OW1 and that of OW2 were 21.5 and 20.6 m/day, respectively.

The high value of transmissivity indicates high potential of aquifer near the Yamuna floodplain in Delhi stretch. The full post-pumping recovery of water level reveals that aquifer can maintain its original condition even after a long high stress condition. However, resilience capability of the aquifer depends on the threshold of stress and it may take much more time to regain its original condition.

9.6 Groundwater Availability

The annual dynamic groundwater resources in NCR is approximately 8.48 BCM while the net abstraction is estimated to be around 7.58 BCM (Sharma (Anon)). This shows that there is recharge availability of around 0.90 BCM annually over and above abstraction. However, most of the blocks in the NCR are at critical stage of groundwater development (CGWB 2011; Fig. 9.9).

It is clear from the figure that fourteen out of twenty-three blocks are overexploited (limit marked as red line). The stage of groundwater development is ratio of gross groundwater draft for all the purposes to net annual groundwater availability and calculated as percentage. Data of subregions of Haryana, Uttar Pradesh, and Rajasthan are taken from CGWB (2011) while those of Delhi NCT are taken from Chatterjee et al. 2009).

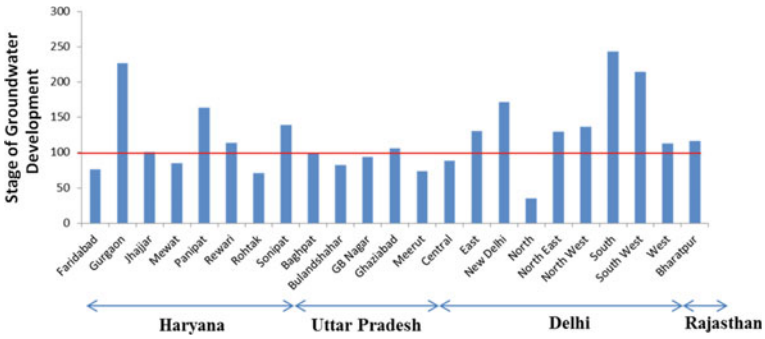

Fig. 9.9 Stage of groundwater development of all blocks in Delhi NCR

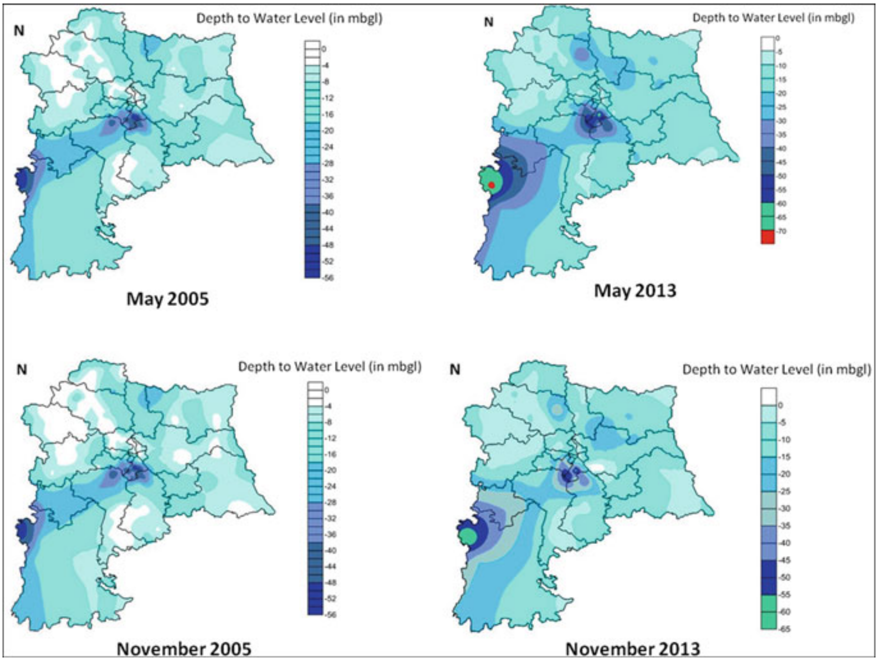

Fig. 9.10 Depth to water level of NCR Delhi for the years 2005 and 2013 (CGWB 2015, accessed from http://gis2.nic.in/cgwb/Gemsdata.aspx)

9.6.1 Decline in Water Level

The depth to water level maps for pre- and post-monsoon seasons (Fig. 9.10) for NCR indicate water level decline during 2013 with respect to 2005.

The water level maps for the year 2005 show the presence of a large shallow groundwater zone (with water level <5 mbgl) in parts of northwest Delhi, Sonipat, Rohtak, extending to Panipat and Jhajjar districts in Haryana. On the other hand, only small parts of South Delhi and western Alwar seem to have water level in range of 45–55 mbgl (Fig. 9.10).

In respect of 2005, the water level maps for the year 2013 show an overall decline in water level across the region. This trend of decline was observed for pre-monsoon as well as post-monsoon seasons. The rate of decline is so rapid that virtually no location in NCR seems to have shallow groundwater levels of <5 mbgl in pre-monsoon season of 2013. In deeper water level areas like western part of Alwar District, the decline has been quite substantial. In fact, the depth to water level has reached 70 mbgl from the depth of 56 mbgl reported in 2005 (Fig. 9.10).

9.6.2 Recharge Possibilities

There are many manmade bunds and natural ponds in the NCR and are much crucial from the groundwater recharge point of view (Fig. 9.11).

Further, Bajpai (2011) highlighted the relevance of understanding the hydrogeomorphic conditions in groundwater management strategies in NCT Delhi. Thus, development of water harvesting structures with the help of basic understanding of local environ is of utmost important. In addition, Shekhar et al. (2015) also suggested considering and studying quality of groundwater before strategizing any groundwater management plan.

Hence based on the suggestion and observations of previous workers (Chatterjee et al. 2009; Shekhar and Prasad 2009; Bajpai 2011; Shekhar 2014; Soni et al. 2014; Shekhar et al. 2015), following measures could be implemented to enhance recharging possibility and better management of existing freshwater resources in different parts of NCR:

- Preservation of the active floodplains as strategic potential water resource to meet drinking water requirement of NCR.
- Development of the active floodplain water resource in NCR as natural disaster mitigation strategy.
- Preservation of water bodies in Alwar quartzites of NCR for augmentation of groundwater resource.
- Stringent action against anthropogenic activities that violates the regulations on groundwater development, particularly in overexploited and critical areas.
- Rainwater harvesting in urban areas for augmenting groundwater resources.
- Rejuvenation of defunct or extinct groundwater recharge structures such as ponds or "*baolis.*"

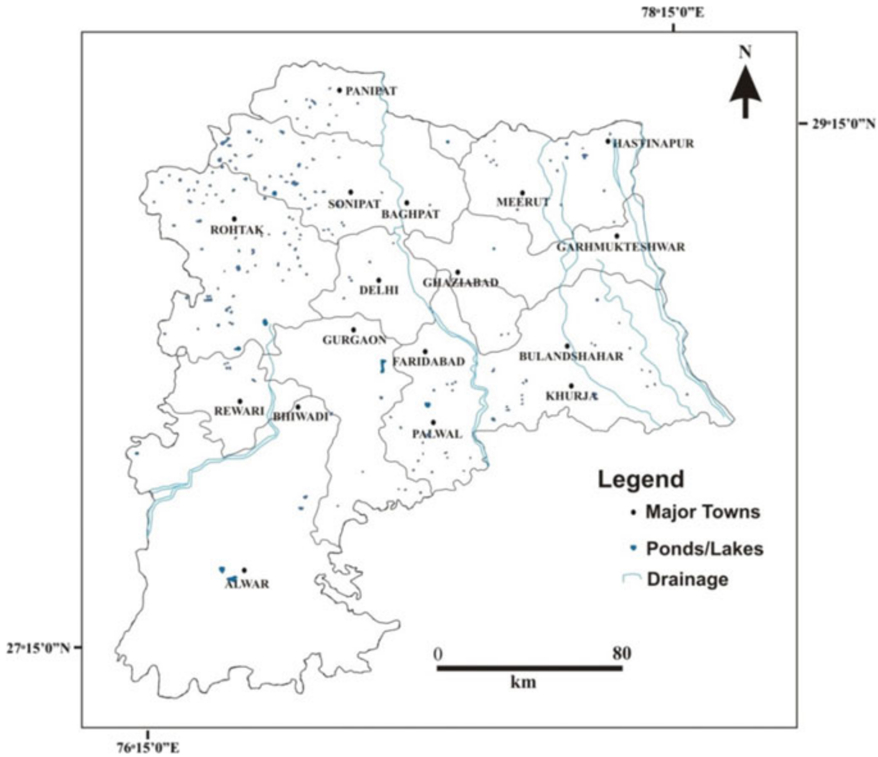

Fig. 9.11 Recharge structures in Delhi NCR. *Source* NCRPB (Anon.)

9.7 Groundwater Quality

The groundwater quality of the Nation Capital Region (NCR) has become a serious concern for policy makers and citizens in the last few years. Although traditionally, the groundwater quality in parts of this region is primarily controlled by geogenic factors (Sarkar et al. 2016a), in recent years, anthropogenic sources also led to drastic changes. These include large-scale urbanization linked to heavy abstraction of groundwater. This also leads to up-coning of saline water throughout the NCR (Shekhar et al. 2005; Shekhar 2006; Sarkar and Shekhar 2015). Groundwater contamination by infiltration of wastewater in shallow aquifers through localized point and nonpoint sources has also been reported (CGWB 2012b; Shekhar and Sarkar 2013; Sarkar and Shekhar 2015; Sarkar et al. 2016a, b). The extent of groundwater contamination, however, is uneven. This can be seen by looking into major ion chemistry represented by spatial hydrochemical facies variation as well as other contaminants.

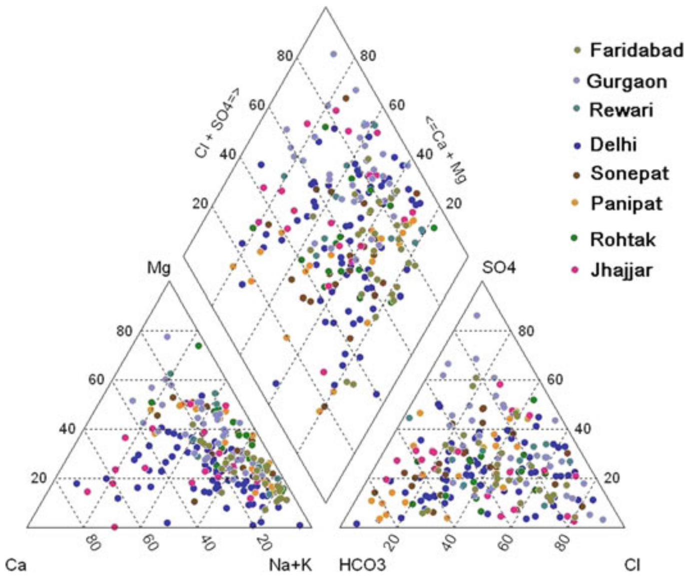

Fig. 9.12 Hydrochemical facies variation in parts of NCR for 2010. Based on CGWB (2012b, c)

9.7.1 Hydrochemical Facies Variation in Parts of the NCR

The extent of groundwater contamination is uneven as seen in spatial hydrochemical facies variation in parts of NCR (Fig. 9.12).

The hydrochemical facies variations observed in parts of NCR give a clear dominance of Na-K cations over Ca-Mg cations. However, there seems to be no distinct spatial trend for facies variation in general. The groundwater samples representing hydrochemical facies from different parts of NCT Delhi (dark blue points) vary from typical Ca-HCO_3-type to Na-Cl-type facies. Detailed evaluation of these facies by Sarkar et al. (2016a) reveals a geomorphic control on facies with presence of HCO_3-dominant facies in active floodplains and chloride-type facies in parts of older alluvial plains. Hydrochemical facies from Jhajjar District (dark pink points) also varies from typical Ca-HCO_3-type to Na-Cl-type facies (Fig. 9.12).

Facies variations in other parts of NCR such as Panipat, Sonipat, and Rohtak (represented by orange, brown, and dark green points, respectively) show Na-K-dominant mixed facies. On the other hand, groundwater samples from south Haryana (Rewari, Gurgaon, and Faridabad) show predominantly Na-K-Cl-SO_4-type facies (Fig. 9.12).

Studies conducted in other parts of NCR such as NOIDA in Gautam Buddha Nagar (Singh et al. 2011) and Baghpat (Alam and Umar 2013) highlight the presence of Ca-HCO_3-dominant to mixed-type facies. The spatial variation in hydrochemical facies indicates multiple sources for groundwater contamination in the entire region; a fact also reflected by studies related to other groundwater contaminants such as nitrate, fluoride, iron, boron.

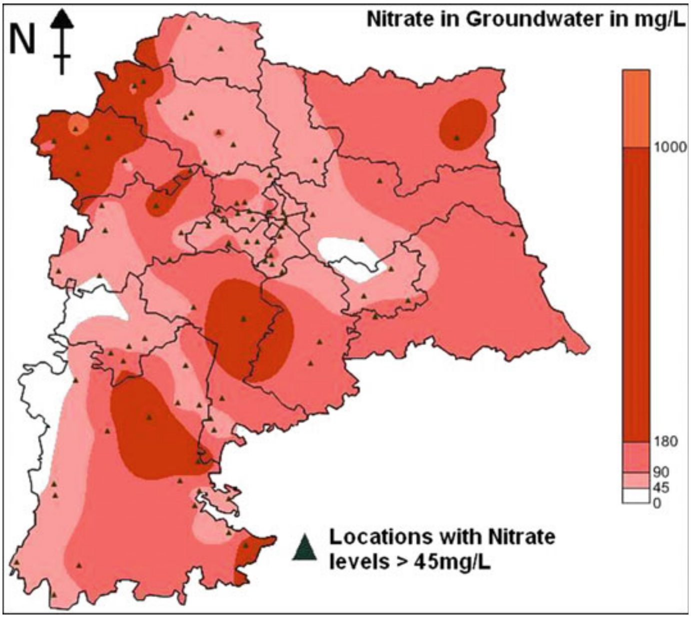

Fig. 9.13 Nitrate contamination in NCR. Based on CGWB (2010)

9.7.2 *Nitrate*

Nitrate is a groundwater contaminant which is usually linked to anthropogenic processes. These include infiltration of the wastewater in groundwater (Shekhar and Sarkar 2013) or pollution to groundwater due to either return irrigation water or contamination by sewage (CGWB 2012b). The permissible limit for nitrate in drinking water as set by BIS (1991, 2012) is 45 mg/l.

Based on this specification, CGWB (2010) reported more than 85 locations in NCR (Fig. 9.13) where groundwater had nitrate levels beyond the permissible limit.

Further, it was also observed that certain parts of Rohtak District (Haryana) had extremely high level of nitrate contamination with Nidana in Rohtak having nitrate levels of 1292 mg/l in groundwater followed by 765 and 760 mg/l in Samargopalpur and Kalanaur in the same district. A recent survey published by CGWB (2012b) and reported in Sarkar et al. (2016a) has reported even higher nitrate levels in some localities in NCT Delhi with 1500 mg/l in Tikri Kalan locality, thus highlighting widespread contamination of groundwater by nitrate in the region.

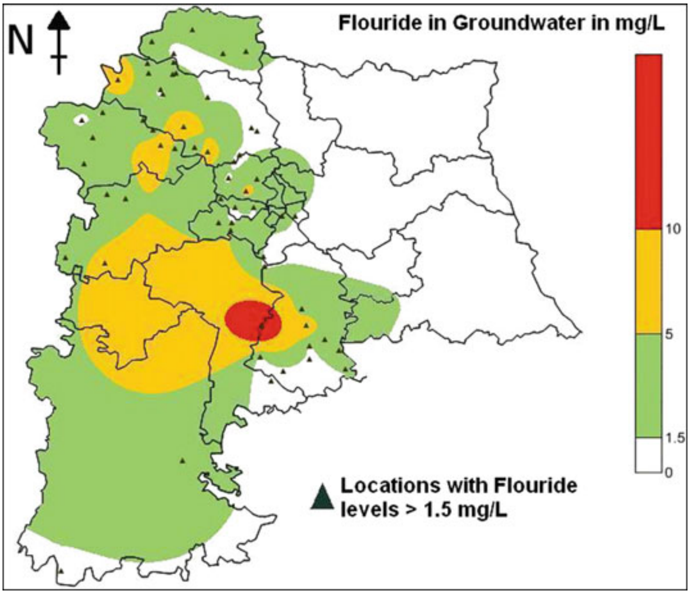

Fig. 9.14 Fluoride contamination in NCR. Based on CGWB (2010)

9.7.3 *Fluoride*

Fluorine is the lightest, electronegative element in the halogen group and also abundant (625 mg/kg) in the earth's crust, and it is mobile at a higher temperature (Edmunds and Smedley 2001). The sources of fluoride include fluorine-bearing minerals such as fluorite, cryolite, topaz, apatite, micas (Hem 1985; Pickering 1985; Datta et al. 1996; Ali et al. 2016).

In NCR, CGWB (2010) reported the presence of fluoride in different parts of NCR Delhi (Fig. 9.14), with around 60 locations showing fluoride level more than the permissible limit of 1.5 mg/l set by BIS (2012). It could be observed that almost all high contaminated locations are confined to the western parts of the Yamuna Basin with a zone of very high fluoride levels in Gurgaon and Faridabad districts of Haryana (Fig. 9.14), with highest level of fluoride in NCR (17 mg/l) reported from Nuh in Gurgaon District (CGWB 2010).

9.7.4 *Iron*

The presence of Iron in NCR could be linked to both geogenic and anthropogenic sources. It can occur as both ferrous (Fe^{2+}) and ferric (Fe^{3+}) ion linked to oxidation–reduction reactions in subsurface (Freeze and Cherry 1979; CGWB 2010). On the

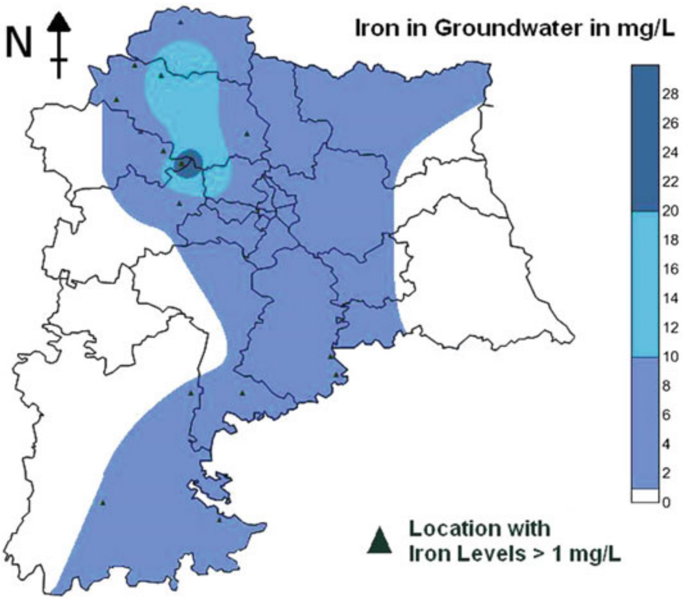

Fig. 9.15 Iron contamination in NCR. Based on CGWB (2010)

other hand, anthropogenic sources such as infiltration from waste effluents present in discharge (CPCB 2008) or the corrosion of steel and cast iron pipes during water distribution (WHO 2008) could also lead to iron enrichment in groundwater.

CGWB (2010) reported 15 locations in NCR having iron concentration more than 1 mg/l, which is the permissible limit set by Bureau of Indian Standards (BIS) at that point of time (Fig. 9.15; BIS 1991). The highest level of Iron in NCR (30 mg/l) was reported from Hassangarh in Rohtak District (CGWB 2010).

9.7.5 Arsenic and Other Heavy Metals

The reports about presence of arsenic and other heavy minerals such as lead, cadmium, copper, and nickel in groundwater of the NCR have become frequent in recent years. However, most of these reports indicate localized contamination of groundwater due to anthropogenic sources.

Alam and Umar (2013) reported 0.006 mg/l of arsenic from groundwater of Baghpat District. Similarly, Dubey et al. (2012) reported arsenic levels in groundwater as high as 107–180 ppb near Badarpur thermal power plant in Delhi.

There are reports of high chromium and cadmium levels in groundwater (7.85 and 0.017 mg/l, respectively) from old landfill site in Bhalaswa, northwest Delhi (CGWB 2012b; Sarkar et al. 2016a).

The presence of Boron in groundwater could be linked to both geogenic and anthropogenic sources. Sarkar et al. (2016b) reported presence of boron concentration in groundwater in parts of NCR Delhi. They observed that the contamination was highly localized which over the years have spread possibly by anthropogenic activities.

Based on the studies conducted by government agencies and researchers, it can be inferred that the groundwater quality of NCR has been primarily controlled by geogenic factors that had led to uneven contamination in parts of the region. However in last few years, groundwater quality degradation has enhanced and become more widespread due to influence of anthropogenic factors.

9.8 Surface Water Quality and Remedial Measures

The major source of surface water pollution in NCR includes untreated wastewater from the drains such as the Najafgarh Drain in NCT Delhi—that makes it highly unsuitable for various purposes.

In NCT Delhi, there were overall 22 drains discharging about 42.65 m^3/sec in the year 2005 (CPCB 2006). The 22 km stretch of River Yamuna in NCT is most polluted section of its whole river path. Since the rivers are in dynamics with the groundwater, pollutants discharged in rivers not only pollute them but also degrade the groundwater quality. So, it is very necessary to treat the generated wastewater before discharging it in the main river system so that quality of surface water, groundwater, and river ecology could be maintained.

Delhi has sewers of about 6000 km in length. There are three major drains namely Najafgarh, Shahdara, and supplementary drains which meet the River Yamuna in Delhi stretch. First and last drains meet river at downstream of Wazirabad barrage and another one at downstream to Okhla barrage. The pollution in River Yamuna is also a major factor for groundwater contamination in parts of NCR with significant contribution from cities such as Delhi, Baghpat, Sonipat, and Panipat to the pollution load in the river (Upadhya et al. 2011). CPCB (2006) reports pollution load contribution to River Yamuna as: 3% from Panipat, 2% from Sonipat, 2% from Baghpat, and 79% from Delhi.

The Delhi Jal Board (DJB) had initiated an interceptor project for decreasing the pollution level of the river. The approach behind this project was to trap the small drain and treat them before they meet the main drains so that the pollution level in Yamuna could be minimized (CSE 2009).

At present (as on September 20, 2015) Delhi Jal Board has achieved the capacity of treating 450 million gallon per day (2250 million liters per day) of sewage through 30 sewage treatment plants (STPs) installed at 17 locations across Delhi (Press release by DJB). Similarly, other STPs are also installed for the treatment of wastewater in different locations across NCR. In Haryana subregion of NCR, STPs are installed in Panipat, Sonipat, Gohana, Gurgaon, HUDA, and Faridabad. Similarly, in Uttar Pradesh subregion, Two STPs are installed in Ghaziabad and NOIDA (CPCB 2008).

9.9 Conclusions

The NCR Delhi has a good potential of groundwater development that could be integrated in holistic and sustainable management of its water resources. The subsurface lithology indicates the presence of localized high yielding aquifers that could be exploited judiciously for mitigation of drinking water crisis. The pressure of population along with urbanization is turning the NCR Delhi into a water scarce region. However, simple steps of rejuvenating preexisting water harvesting structures, preservation of active floodplains, ensuring environmental flows in rivers, prudent concretization together with constant vigilance on groundwater quality front may help in sustaining the water supply system of the region. It may also be advisable to adopt suitably planned conjunctive use of surface and groundwater for urban water supply in NCR. This may reduce stress on groundwater system. Further; cooperation among local authorizes and citizen could help in the improvement of overall groundwater management in the region.

Acknowledgements S.K. thanks the Department of Geology, University of Delhi, for a CAS fellowship. A.S. acknowledges the Council of Scientific and Industrial Research (CSIR) for a financial grant toward a senior research fellowship. S.A. acknowledges the Department of Geology, University of Delhi, for a non-NET scholarship. The financial support for experimentation in Palla area by M/S WAPCOS limited, Government of India, is also duly acknowledged.

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