Chapter 21
Artificial Recharge to Augment Groundwater Resources in Lucknow City

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Abstract The importance of water is obvious to everyone: we cannot imagine existence of life in the form of flora and fauna without water. At present, space scientists are vigorously engaged in searching for water on other planets. The existence of life on other planets is not conceivable for the human mind unless there is evidence of water. Groundwater is the major source of water in rural as well as in urban areas. About 85 % of the drinking water supply and 50 % of the irrigation supply in rural areas is met through extraction of groundwater. Similarly, 33 % of the domestic supply in cities is also met through tapping of groundwater by dug wells or tube wells (Athavale, Water harvesting and sustainable supply in India. Center for Environment Education, Ahmedabad, Rawat Publication, New Delhi, p 8, 23, 2003). There are certain areas in the country where the table depth has increased by several meters during the past three decades because of overextraction of groundwater resources. The signs of overexploitation are a continuous fall in the water table, drying of wells, or deterioration of groundwater quality. Just as other major urban centers in India, Lucknow is also facing an ironical situation of water crisis today. On the one hand there is acute water scarcity and on the other the streets are often flooded during the monsoon period. This situation has led to serious problems with the quality and quantity of the groundwater. Most of the existing traditional water-harvesting system in Lucknow City also has been neglected and fallen into disuse, worsening the urban water scenario. One of the solutions to improve the urban water crisis is rainwater to enhance groundwater resources through artificial recharge techniques. Keeping in mind all these facts, a plan has been prepared to generate data regarding projected population for 20 years (2009–2029), per capita per day requirement of water, requirement of artificial recharge, and availability of rainwater for recharge.

Keywords Water depletion • Rain water harvesting • Artificial recharge • Water development • Lucknow

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21.1 Introduction

The rapid growth of population and consequent urbanization has led to stress on available water resources as the consequence of overuse of surface water supplies and overexploitation of groundwater. Dependence on groundwater, to meet various requirements, is so heavy that water levels are declining rapidly and the dug wells and bore wells are even drying up. Because of the rapid rate of urbanization, cities are converted into concrete jungles. Thus, the natural recharge of the groundwater has diminished considerably because of the loss of open land. Therefore, in the present scenario there is an utmost need to augment groundwater storage.

Groundwater is the major source of water in cities. Almost 33 % of the domestic supply is met through tapping groundwater by dug wells or tube wells. There are certain areas in the country where the table depth has increased by several meters during the past three decades by overextraction of groundwater resources. Overextraction or overexploitation of groundwater resources means withdrawing more groundwater than is replenished annually through the process of natural recharge, during which a percentage of the water percolates through the soil and is added to the aquifers. The signs of overexploitation are a continuous drop in the water table, drying of wells, and deterioration of groundwater quality in terms of increased brackishness or the concentration of harmful substances such as fluoride (Athavale 2003).

Urban centers in India are facing an ironical water crisis situation today. On one hand there is acute water scarcity and on the other the streets are often flooded during the monsoon period. Thus, there are serious problems with groundwater quality and quantity although the city receives good rainfall. However, this rainfall occurs for short spells and with high intensity, so that most of the heavy rain falling on surfaces tends to flow away rapidly, with very little time to recharge the groundwater. Most of the existing traditional water-harvesting systems in cities have been neglected and fallen into disuse, which worsens the urban water scenario.

Therefore, one solution to improve the urban water crisis is rainwater harvesting. This technique involves capturing runoff to enhance groundwater resources through the process of artificial recharge. This solution is being practiced on a large scale in cities such as Chennai, Bangalore, and Delhi, where rainwater harvesting is a part of the local policy. Elsewhere, countries such as Germany, Japan, the United States, and Singapore are also adopting rainwater harvesting and artificial recharge techniques.

21.2 Basic Requirement for Artificial Recharge

The basic requirement for recharging groundwater is source water availability. The availability of source water is basically assessed in terms of noncommitted surplus monsoon runoff. This component can be assessed by analyzing the following:

1. Monsoon rainfall pattern
2. Frequency pattern

3. Number of rainy days
4. Variation in space and time

Broadly, to calculate a monsoon surplus, 50 % of the monsoon rainfall (i.e., during July, August, and September) can be considered as monsoon runoff.

21.2.1 Rainwater Harvesting

The rainwater in an urban area can be conserved through open land, parks, paved areas, roads, and pavements and rooftop rainwater-harvesting techniques (RTRWHT) for artificial recharge to groundwater. Among these, RTRWHT requires connecting an outlet/drop pipe from the roof of the building to divert the rainwater to either existing wells/tube wells/bore wells or specially designed structures.

Advantages of Rainwater Harvesting There are several benefits of this technique: rainwater is bacteriologically pure, free from organic matter, and soft in nature; it will help in reducing flood hazard; it will improve the quality of existing groundwater through dilution; rainwater may be harnessed at a place of need and may be utilized at time of need; and the structures required for harvesting the rainwater are simple, economical, and eco-friendly.

Practical Advantages of Rainwater Harvesting The several advantages of rainwater harvesting include availability not subject to outside utility control and not subject to pipeline interruption (seismic); quality is controlled by the consumer; available even when power is interrupted; reduces runoff and erosion; available even when storms and disaster strike; available immediately for fire suppression; reduces mosquito breeding grounds (dengue fever); thermal mass can naturally cool buildings; and ideal for people on low-sodium diets or with health concerns (weakened immunity systems).

21.3 Techniques of Artificial Recharge

Artificial recharge is the process by which the groundwater is augmented at a rate much higher than that occurring under natural conditions of replenishment through human intervention. Augmentation of groundwater resources through artificial recharge can be considered as an activity that supplements the natural process of recharge, which takes place through the percolation of a fraction of the rainfall through the soil to the water table. It is a form of water harvesting in which the surface water stored or flowing out of a watershed or basin during the rainy season is transferred to the aquifers and can be utilized in other months of the hydrological year. This water would be otherwise lost through evaporation or outflow from the watershed. The techniques of artificial recharge can be broadly categorized as follows (Fig. 21.1):

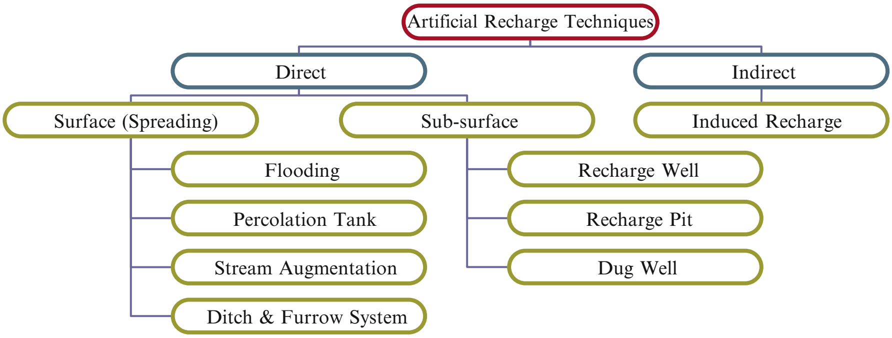

Fig. 21.1 Artificial recharge techniques

(a) Surface Spreading Methods: These methods are suitable where a large area of basin is available and aquifers are unconfined without an impervious layer above them. The rate of infiltration depends on the nature of the topsoil. If the soil is sandy, the infiltration will be higher than in silt-laden soil. The presence of solid suspensions in water used for recharge clogs the soil pores, leading to reduction in the infiltration rate, that is, the recharge rate. Water quality also affects the rate of infiltration.
(b) Subsurface Methods: In this method the structure lies below the surface and recharges the groundwater directly.
(c) Induced Recharge: This is an indirect method of artificial recharge involving pumping from an aquifer hydraulically connected with surface water such as perennial streams, unlined canals, or lakes. The heavy pumping lowers the groundwater level and a cone of depression is created. Lowering the water levels induces the surface water to replenish the groundwater. This method is effective where a stream bed is connected to the aquifer by a sandy formation.

21.4 Area of Study

Lucknow, the state capital of Uttar Pradesh is located in the Middle Ganga Plain and extends between 26°51′ north latitude and 80°36′ east longitude. It lies on the banks of the River Gomti and occupies an area of 340 km^2 in parts of three blocks: Sarojini Nagar, Chinhat, and Bakshi Ka Talab. It stretches more than 10 km along the Gomti River on both banks. The total length of River Gomti is 23.98 km, which covers an area of about 216.33 km. The Kukrail *nala* (drain) is 17.07 km long. There are 37 water bodies in Lucknow City, which covers an area of about 135.21 ha. Depletion of forest cover has left the city with only 2,086.61 ha under forest. According to Census 2001, the total population of Lucknow City was 2,245,509 (Statistical Abstract Uttar Pradesh 2008). The population density of 6,600 persons/km^2 with a high decennial growth of 39.98 % has put tremendous pressure on groundwater resources for drinking and other purposes (Kumar Arun et al. 2011) (Fig. 21.2).

Lucknow City depends heavily on groundwater resources and approximately 70 % of its water requirements are being met through this resource. Heavy withdrawal from

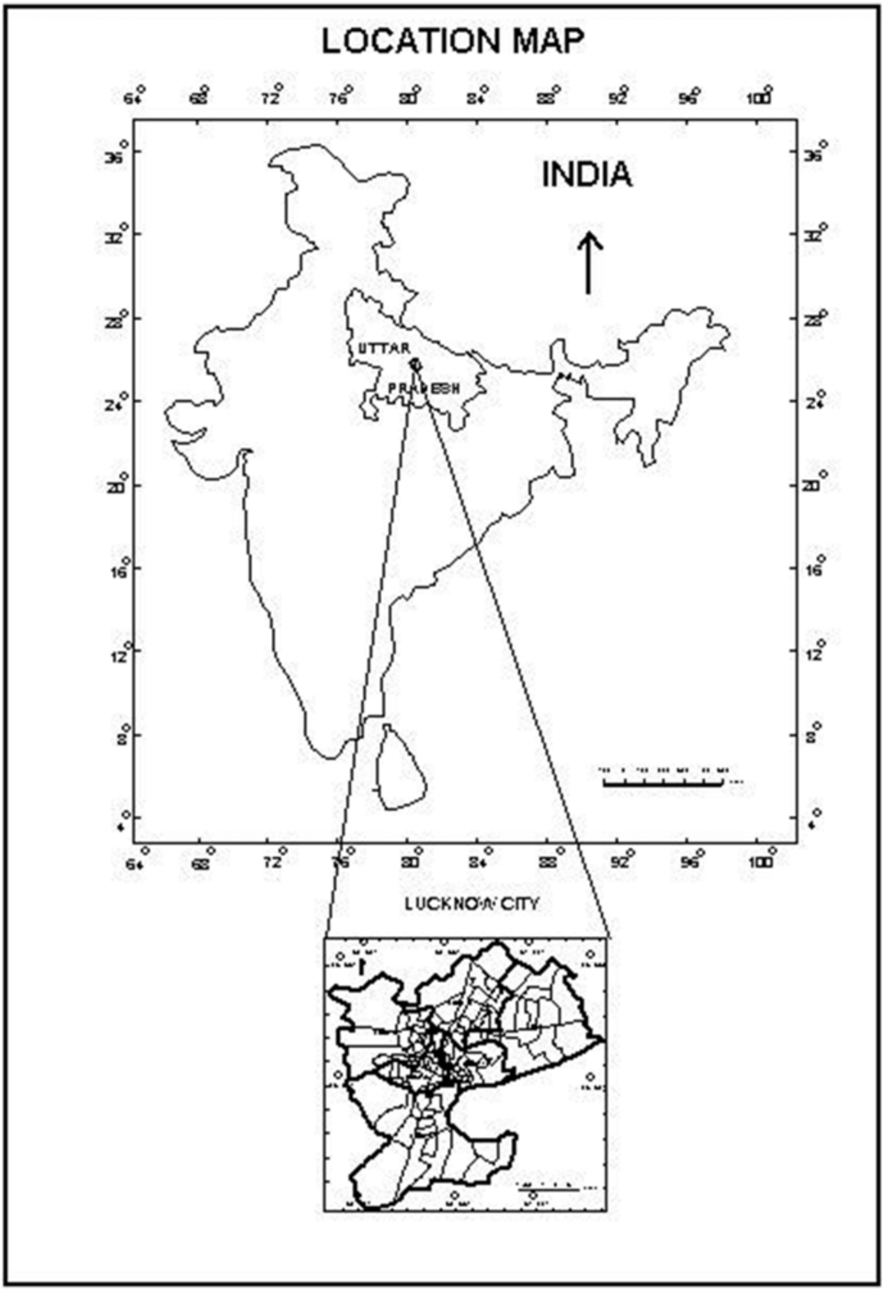

Fig. 21.2 Area of study

the first aquifer has led to a fall of the water table to 30 m or more in the heart of the city, and also the water table is declining at the weighted average rate of 0.73 m/year, which means it loses 6 lakh liters of groundwater daily from mining of groundwater.

Therefore, there is urgent need to evolve a mechanism for judicious use of groundwater and surface water resources to adopt a technique to surmount the present-day situation by augmenting groundwater resources through artificial recharge and conservation.

21.4.1 Climate and Rainfall

The climate of the city is subtropical, with three distinct seasons: monsoon, summer, and winter. The normal maximum mean temperature is 40.5 °C during May and the minimum is 6.9 °C during January. The long-term normal annual rainfall (1901–1970) recorded at Lucknow and Amausi observatories was 1,019 mm and 1,004 mm, respectively. The monsoon normal and annual rainfall recorded by the same observatories is 902 mm and 803 mm, and non-monsoon normal annual rainfall is 117 mm and 116 mm, respectively. The area has a subhumid climate; the hottest month is June and the coldest is January. The average annual rainfall recorded in Lucknow is shown in Table 21.1 and represented graphically in Fig. 21.3.

21.4.2 Physiography and Drainage

Lucknow City occupies the interfluvial region of the Gomti and Sai Rivers of the Middle Ganga Plain in the Ganga basin. It is an almost flat region with a conspicuous natural depression in the northeastern part around Jankipuram. The general

Table 21.1 25 years average (1981–2005) in Lucknow

Months	Avg. annual rainfall (mm)	No. of rainy days
Jan	20.5	1.6
Feb	15.5	1.3
Mar	8.4	0.9
Apr	4.1	0.4
May	20.6	1.9
Jun	106.5	5.2
Jul	236.9	11.2
Aug	213.6	10.5
Sep	218.4	9.0
Oct	43.5	1.6
Nov	6.0	0.5
Dec	14.3	0.9
Total	*908.4*	*45.0*

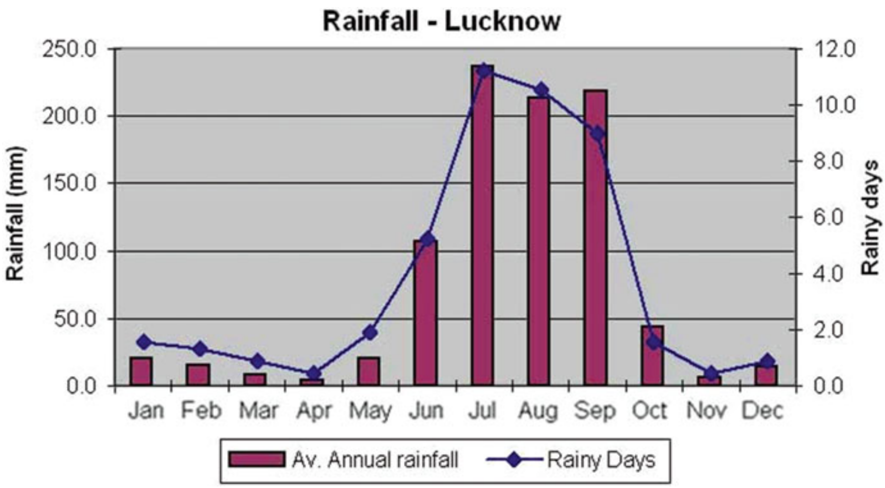

Fig. 21.3 Average annual rainfall and no. of rainy days in Lucknow, 1981–2005

slope of the city area is toward south and southeast. The elevation of the city area varies from 110 to 124 m above mean sea level in general.

The drainage system of the area is controlled mainly by River Gomti, which flows to southeast and Kukrail *Nala*, the only prominent tributary, which joins on the northern bank of the Gomti River. There are 23 *nalas* that drain into Gomti between Gaughat and Gomti Barrage. The drainage exhibits a dendritic to subdendritic pattern that is highly sinuous in nature. River Gomti originates from the spring line in the Terai belt of Pilibhit District. It flows southeasterly over a distance of 490 km before joining the River Ganga in Ghazipur District. The catchment area of the river is 30,500 km^2. Geomorphologically, the city area can be divided into three broad units: Younger Flood Plain, Older Flood Plain, and Interfluve Plain or Upland.

21.4.3 Hydrogeology

Lucknow urban and adjoining areas are underlain by quaternary alluvial sediments containing clay, silt, various grades of sand, and kankar (pebbles). Alluvium forms the most potential repositories of groundwater. There are four aquifer systems within the explored depth of 600 m. The first aquifer is spread within the depth of 150 m under unconfined to semi-confined conditions. Water transmission and flow from the aquifer varies from 1,000 to 1,500 m^2/day.

The Central Ground Water Board has carried out 27 exploratory drillings (down to a maximum depth of 600 m) in the district under its normal and accelerated exploration programs. The results of these exploratory drillings reveal the existence of four tier aquifer systems in the city area within the depth of 600 m, as detailed in Table 21.2.

Table 21.2 Lucknow aquifer system

Sl. no.	Aquifer	Depth range (m bgl)	Aquifer material
1.	I group	Ground level (GL)–150	Fine to medium sand
2.	II group	160–200	Silty to fine sand
3.	III group	250–350	Fine to medium sand
4.	IV group	380–600	Fine sand

The yield of the first aquifer is around 1,200 liters per minute (lpm) with 5–8 m of drawdown, and the second aquifer has a higher piezometric head but poor yield (around 500 lpm) with a large drawdown of about 30 m. The third and fourth aquifers have, by and large, the same yield (i.e., up to 1,200 lpm) as that of the first aquifer but the drawdown is large (about 30 m).

21.4.4 Groundwater Level Depth

The behavior of the groundwater level in the Lucknow urban area is being monitored by the Central Ground Water Board through 22 piezometers. The piezometer data revealed that the depth of the water level varied between 15 and 30 m below ground level (bgl) during May 2008. The deeper water levels have been observed in the central part of the city and around the Cantonment area and southeastern parts of trans-Gomti areas. The water level gradually becomes shallow toward the western and northwestern parts in the outskirts of the city area (Singh et al. 2011) (Fig. 21.4).

21.4.5 Water Level Trend (Long Term)

Long-term analysis of data from a hydrograph station located at Aminabad in Cis-Gomti area indicates that the water table has receded from 17.00 to 30.00 m during the decade of 1998–2008 and that the rate of decline of water level varies from 0.20 m/year in the peripheral area to 1.20 m/year in the central part of the city. Urban areas have an estimated 0.73 m/year decline on average (weighted average) in the water table (Singh et al. 2011) (Fig. 21.5).

21.5 Development and Quality of Groundwater

Although the blocks comprising parts of Lucknow City are categorized as safe, the city area is excessively exploited. The groundwater draft in the city area exceeds the net utilizable resources. The groundwater is generally potable in all aquifers. The water is the $CaMgHCO_3$ type and is suitable for both drinking and irrigation purposes.

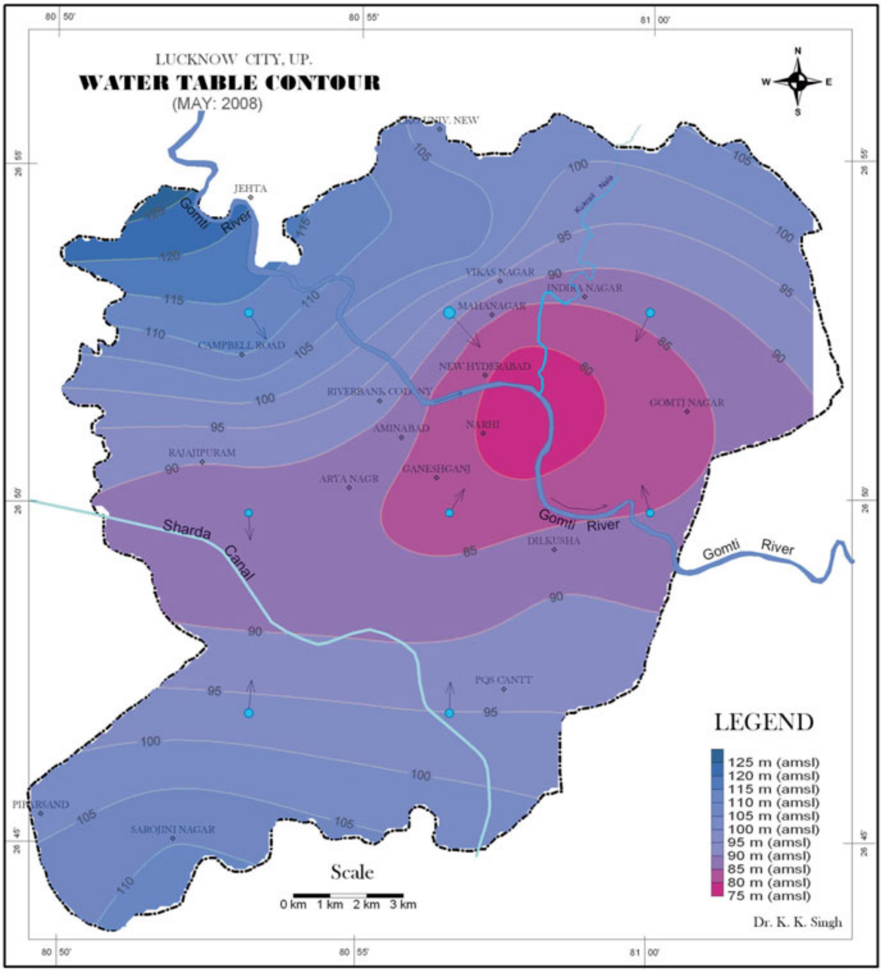

Fig. 21.4 Water table contour of Lucknow city, premonsoon: May, 2008

21.6 Effect of Urbanization on Groundwater Resources

An urban area evolves in the course of time, and population growth depends upon the rate of development. During the past ten decades (1901–2001), the area and population of Lucknow City have increased approximately eight times, that is, from 44.03 to 340 km^2 and from 256,239 to 2,245,509, respectively, causing severe stress on the groundwater (Dutta et al. 2011; Rai et al. 2004). The groundwater resource is an economical and readily available resource with ample supply in the aquifers. Urbanization puts extensive pressure on land and water resources. With increasing

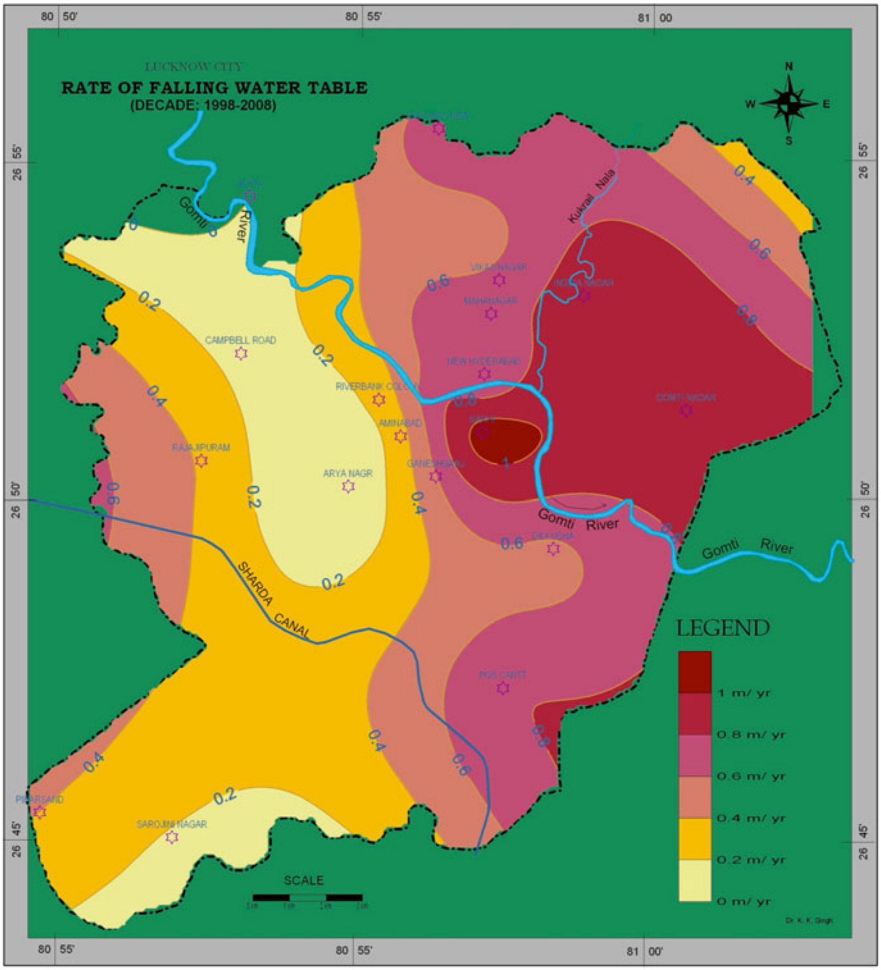

Fig. 21.5 Rate of falling water table in Lucknow city, 1998–2008

pace of urbanization, population density has increased considerably and is now 6,600 persons/km^2 with a decennial growth of 39.88 % in the Lucknow City area. Evolution of the urban area in Lucknow City has led to a decline of 20–30 m in water level in the areas of Gomti Nagar and the old city in particular and to general decline in other areas. The rate of the water table decline is alarming and is exceeding 1 meter per year (m/year), thus causing reduced efficiency or failure of tube wells. At present the water table is declining at a rate of 0.73 m/year (weighted average) in a city area of about 240 km^2 because of overexploitation of about 19.50 million cubic meters (MCM) of groundwater. To stabilize the present water level there is urgent need to artificially recharge the same volume of water through various recharge structures constructed in parks and open fields by utilizing techniques such as rooftop rainwater harvesting (RTRWH) and recharge from *Nala* through check dams and filtration wells (Rai et al. 2011).

21.7 Justification for Artificial Recharge

The all-round development of groundwater has put tremendous pressure on shallow as well as deep aquifers within the city. In general, the depth of the water level during a pre-monsoon period ranges between 10.00 and 32.00 m bgl (below ground level) and in the post-monsoon period between 6.00 and 32.00 m bgl (below ground level).

The water levels have receded during the past decade, and as a result all the dug wells having a maximum depth of 10–12 m have become dry. The trend of water level decline is almost as great as 1.20 m per year in some areas from overexploitation of groundwater, and the deepest water level observed is more than 32.00 m bgl (below ground level) in parts of the city area. The estimated available surplus surface water is of the order of 81.31 MCM (million cubic meters), which needs to be recharged artificially to groundwater through recharge structures.

21.7.1 Proposed Plan

As per the norm of the National Drinking Water Mission, the present per capita need of water in urban area varies between 130 and 150 LPCD (liters per capita per day). With the increasing population it is very difficult to maintain a balance between per capita need and availability of water.

Thus, artificial recharge to augment groundwater is a suggested measure in Lucknow City. Keeping in mind all these facts, a plan has been prepared to generate data regarding projected population for 20 years (2009–2029), per capita per day requirement of water, requirement of artificial recharge, and availability of rainwater for recharge. Based on Census 2001 population data, the projected population for 2009–2029 was calculated. Assuming 150 Lt/H/D (liters per head per day) or LPCD (liters per capita per day) of water need, the requirement of water is calculated. In the same way requirement of artificial recharge is calculated by subtracting 'supply of water from various sources' and 'proposed plan for surface water supply' from water requirements. Further, the availability of rainwater is calculated using the following formula:

$$\text{Availability of rain water} = \text{Area} * \text{Average Monsoon Rainfall} * .6$$

For calculating availability of surface water for artificial recharge, 50 % of noncommitted runoff is taken into consideration. In Lucknow City Jal Sansthan is now proposing a plan to increase surface water supply to minimize the supply of water from groundwater (Table 21.3).

Table 21.3 Annual requirement of groundwater after deduction of surface water supply and groundwater recharge from various sources

Year	Projected population (in thousands)	Requirement of water (in MCM)	Natural recharge from various sources (in MCM)	Supply of water from surface water (in MCM)	Supply of water from groundwater (in ham)	Proposed plan for surface water supply (in MCM)	Requirement of artificial recharge (in MCM)	Area of Lucknow city (in km^2)	Average monsoon rainfall (in mm)	Availability of rainwater (60 % of 9*10/1,000 in MCM)	Availability of rainwater for recharge (50 % of 11 in MCM)
		Assuming 150 Lt/H/D	(CGWD)	(Jal Sansthan)	(Jal Sansthan)	(Jal Sansthan)	(3-4-5-7)				
1	2	3	4	5	6	7	8	9	10	11	12
2009	2,962	162.16	21.53	91.25	87.6		49.38	337.50	802.00	162.41	81.3
2010	3,080	168.63	21.53	91.25	87.6		55.85	337.50	802.00	162.41	81.3
2011	3,203	175.10	21.53	91.25	87.6		62.31	337.50	802.00	162.41	81.3
2012	3,331	182.35	21.53	91.25	87.6	73	−3.43	337.50	802.00	162.41	81.3
2013	3,463	189.62	21.53	91.25	87.6	73	3.84	337.50	802.00	162.41	81.3
2014	3,602	197.18	21.53	91.25	87.6	73	11.40	337.50	802.00	162.41	81.3
2015	3,745	205.05	21.53	91.25	87.6	73	19.27	337.50	802.00	162.41	81.3
2016	3,895	213.25	21.53	91.25	87.6	73	27.47	337.50	802.00	162.41	81.3
2017	4,050	221.73	21.53	91.25	87.6	73	35.95	337.50	802.00	162.41	81.3
2018	4,211	230.57	21.53	91.25	87.6	73	44.79	337.50	802.00	162.41	81.3
2019	4,379	239.77	21.53	91.25	87.6	73	53.99	337.50	802.00	162.41	81.3
2020	4,554	249.33	21.53	91.25	87.6	73	63.55	337.50	802.00	162.41	81.3
2021	4,736	259.27	21.53	91.25	87.6	73	73.49	337.50	802.00	162.41	81.3
2022	4,924	269.61	21.53	91.25	87.6	73	83.83	337.50	802.00	162.41	81.3
2023	5,121	280.36	21.53	91.25	87.6	73	94.58	337.50	802.00	162.41	81.3
2024	5,325	291.55	21.53	91.25	87.6	73	105.77	337.50	802.00	162.41	81.3

2025	5,537	303.17	21.53	91.25	87.6	73	117.39	337.50	802.00	162.41	81.3
2026	5,758	315.26	21.53	91.25	87.6	73	129.48	337.50	802.00	162.41	81.3
2027	5,988	327.83	21.53	91.25	87.6	73	142.05	337.50	802.00	162.41	81.3
2028	6,227	340.91	21.53	91.25	87.6	73	155.13	337.50	802.00	162.41	81.3
2029	6,475	354.50	21.53	91.25	87.6	73	168.72	337.50	802.00	162.41	81.3
Total		5,177.21	452.23	1,916.25	1,839.6	1,314	1,494.72			3,410.51	1,707.3
Average		246.53	21.53	91.25	87.6	73	71.18			162.41	81.30

MCM (million cubic meters), *Lt/H/D* (litre per head per day), *CGWD* (central ground water department), *ham* (hectare meters), *mm* (millimeters)

21.8 Conclusion

Water resources are extremely vulnerable and once depleted take 100 years to replenish. The shortage of groundwater is more pronounced from urbanization and limited open areas. The groundwater level has reached a high level and has brought problems such as declining water table, failure of bore wells/tube wells, and deterioration in groundwater quality and quantity. Water has more than often been seen as a cause for social conflicts, protests, demonstration, and road blockage. In the current circumstances, rainwater harvesting could prove to be a viable solution for overcoming water scarcity.

The need for a policy framework for rainwater-harvesting systems arises mainly from a lack of a policy statement on the issue. There is a clear need to evolve a decentralized legal regime with regard to water that empowers people and makes them the real managers of the water resource. For promoting urban water harvesting, a policy should include a mix of carrot and stick approaches. Measures that need to be undertaken are these: rainwater harvesting to recharge the groundwater system should be essential, and town planning requirements and prerequisites for permission for development of new colonies should be required; provision of rainwater-harvesting structures in all planned buildings should be mandatory for issuing building permission; appropriate rebates on property/fiscal incentives should be granted for effective implementation of rainwater-harvesting systems; development of grazing fields, afforestation, and similar other work should be encouraged; priorities should be given to the scarcity areas in the planning of water resources development and a special water management system should be developed for economic use of water in these areas; and artificial recharge structures are to be constructed mostly with the objective of augmenting groundwater resources or to improve its quality. Assessment of impacts of the artificial recharge schemes is essential to assess the efficacy of structures constructed for artificial recharge and to evaluate the cost-effectiveness recharge mechanisms for optimal recharge into the groundwater system. This plan will also help to make necessary modifications in site selection, design, and construction of structures in future.

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