

---

# An approximate projection of availability of the fresh groundwater resources in the South West district of NCT Delhi, India: a case study

Shashank Shekhar

**Abstract** The future availability and sustainability of fresh groundwater resources in the South West district of the national capital territory (NCT) Delhi, India, have been projected. Due to a rapid decline in groundwater level and quality, the district has been required by the Government of India to regulate development of groundwater resources. Shallow groundwater is mostly saline and water resources in the area are limited. The methodology applied here involves microzonation of the district in terms of thickness of fresh groundwater and then quantification of present and future availability of freshwater in different freshwater zones, including tentative timescales. The calculation method has been aided by data on historic trends in water level at representative groundwater monitoring stations, located either in fresh groundwater zones or near to them. It is estimated that the presently available 481 million m<sup>3</sup> of resources will be reduced to 374 million m<sup>3</sup> by year 2007 and to 303 million m<sup>3</sup> by the year 2012, and by the year 2022 the district will have only 176 million m<sup>3</sup> of available fresh groundwater resources.

**Résumé** La disponibilité et durabilité future de ressources d'eau douce dans la partie sud du district du Territoire Capital National (NCT en anglais) de Delhi en Inde, a été étudiée. Le Gouvernement Indien a demandé au district de réguler le développement de ses ressources en eaux souterraines, en réponse à une diminution rapide du niveau et de la qualité de ces dernières. Les ressources phréatiques sont généralement salées, et la ressource limitée dans la zone concernée. La méthode ici appliquée consiste en la microzonation de l'épaisseur des eaux douces, et en l'évaluation présente et future de la disponibilité de ces eaux dans différentes zones, y compris leur évolution dans le temps. La méthode de calcul a été

facilitée par la mise à disposition de niveaux piézométriques enregistrés au droit de stations de références situées dans les zones d'eau douce ou à proximité. Il est estimé que le volume disponible de 481 millions m<sup>3</sup>, sera réduit à 374 millions m<sup>3</sup> en 2007, 303 millions m<sup>3</sup> en 2012, et seulement 176 millions m<sup>3</sup> en 2022.

**Resumen** Se ha proyectado la disponibilidad futura y sostenibilidad de los recursos de agua subterránea fresca en el distrito suroccidental del Territorio Capital Nacional (NCT) Delhi, India. El Gobierno de India ha requerido que el distrito regule el desarrollo de aguas subterráneas en respuesta a los descensos rápidos de los niveles y la calidad del agua. El agua subterránea somera es predominantemente salada y los recursos hídricos del área son limitados. La metodología utilizada involucra la microzonificación del distrito en términos de espesor del agua subterránea fresca y posteriormente la cuantificación de la disponibilidad presente y futura de agua fresca en diferentes zonas de agua fresca, incluyendo escalas de tiempo tentativas. El método de cálculo se ha apoyado en tendencias históricas de niveles de agua en estaciones representativas de monitoreo de agua subterránea que se localizan en zonas de agua subterránea fresca o cerca de ellas. Se estima que los recursos actualmente presentes, cerca de 481 millones m<sup>3</sup>, se reducirán a 374 millones m<sup>3</sup> para el año 2007 y a 303 millones m<sup>3</sup> para el año 2012, y que para el año 2022 el distrito tendrá solo 176 millones m<sup>3</sup> de recursos de agua subterránea fresca disponible.

**Keywords** Delhi · Groundwater management · Over-abstraction · Central ground water board · Microzonation

---

Received: 11 September 2004 / Accepted: 16 March 2006  
Published online: 28 June 2006

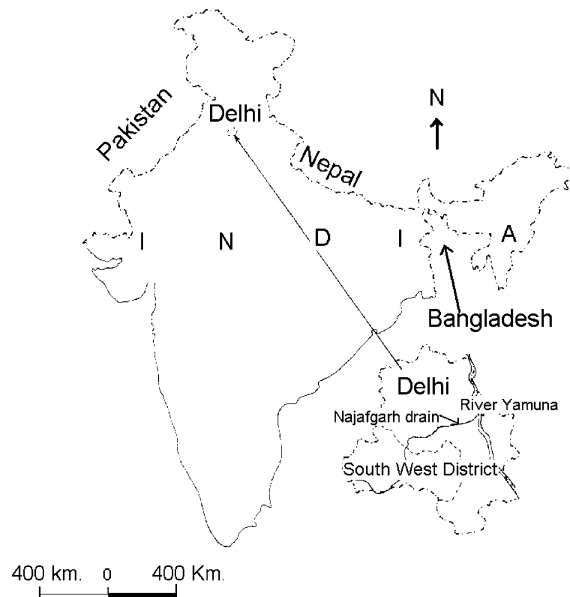
© Springer-Verlag 2006

---

S. Shekhar (✉)  
Central Ground Water Board, Ministry of Water Resources,  
Government of India,  
18/11 Jamnagar House, Mansingh Road, New Delhi, 110001, India  
e-mail: shashankshekhar\_01@indiatimes.com  
Tel.: +91-011-9212600385

## Introduction

The South West district of the national capital territory (NCT) of Delhi, India (Fig. 1), has been required by the Government of India to regulate development of groundwater resources. The step was taken due to a rapid decline in groundwater level and quality (the current electrical conductivity of fresh groundwater is <1,500 μS/cm at 25°C). The district falls within a difficult scenario with regards to replenishable fresh groundwater resources. The



**Fig. 1** Map showing location of the study area

study, reported here, tries to project future availability of fresh groundwater resources in the years 2007, 2012 and 2022. From a hydrogeologic perspective, the district has a simple geology comprised of Alwar quartzites in the east and fluvioaeolian deposits in the rest of the district (Fig. 2a). The borehole data of the Central Ground Water Board (CGWB) show alternate fluvial and aeolian bands distributed sporadically. The sediments are mostly silt with medium to fine sand and clay. The depth to bedrock (basement) is influenced by the steep escarpment at the margins of the hard rock area and mild undulation in the rest of the district (Fig. 2). On the fringes of the hard rock, the depth to bedrock is in the range of <math>30\text{--}300\text{ m}</math> below ground level (m b.g.l.); the depth to bedrock increases as one moves away from the hard-rock exposure to the west (Fig. 2b). The depth to bedrock in the rest of the area is found in the range of 300–400 m b.g.l. Shekhar et al. (2005) describe the escarpment mentioned above as a fault zone and consider it to be one of the basic controls on variation in the depth to the groundwater fresh/saline interface in this district.

Premonsoon depth to water in the district varies in range of 2–5 m b.g.l. (Fig. 3a). The southwestern part of the district, comprising the Jhuljhuli and Roata areas (Fig. 3a), has shallow groundwater in a range of 2–5 m b.g.l. The area to the north of the above-mentioned zone, encompassing Dhansa and similar localities along the N–S stretch of the Najafgarh drain—including Dwarka Sector-3 and localities such as Amber Hai, Pochanpur and Bamnoli—has a depth to water in the range of 5–10 m b.g.l. The zone comprising localities such as Kair, Mandela Khurd, Bagargarh, etc. (Fig. 3a), has a depth to water in the range of 10–15 m b.g.l., and another zone to the east of the Najafgarh drain comprising areas such as Palam and Manglapuri, has a depth to water in the range of 10–15 m b.g.l. The central portion of the area to west of the

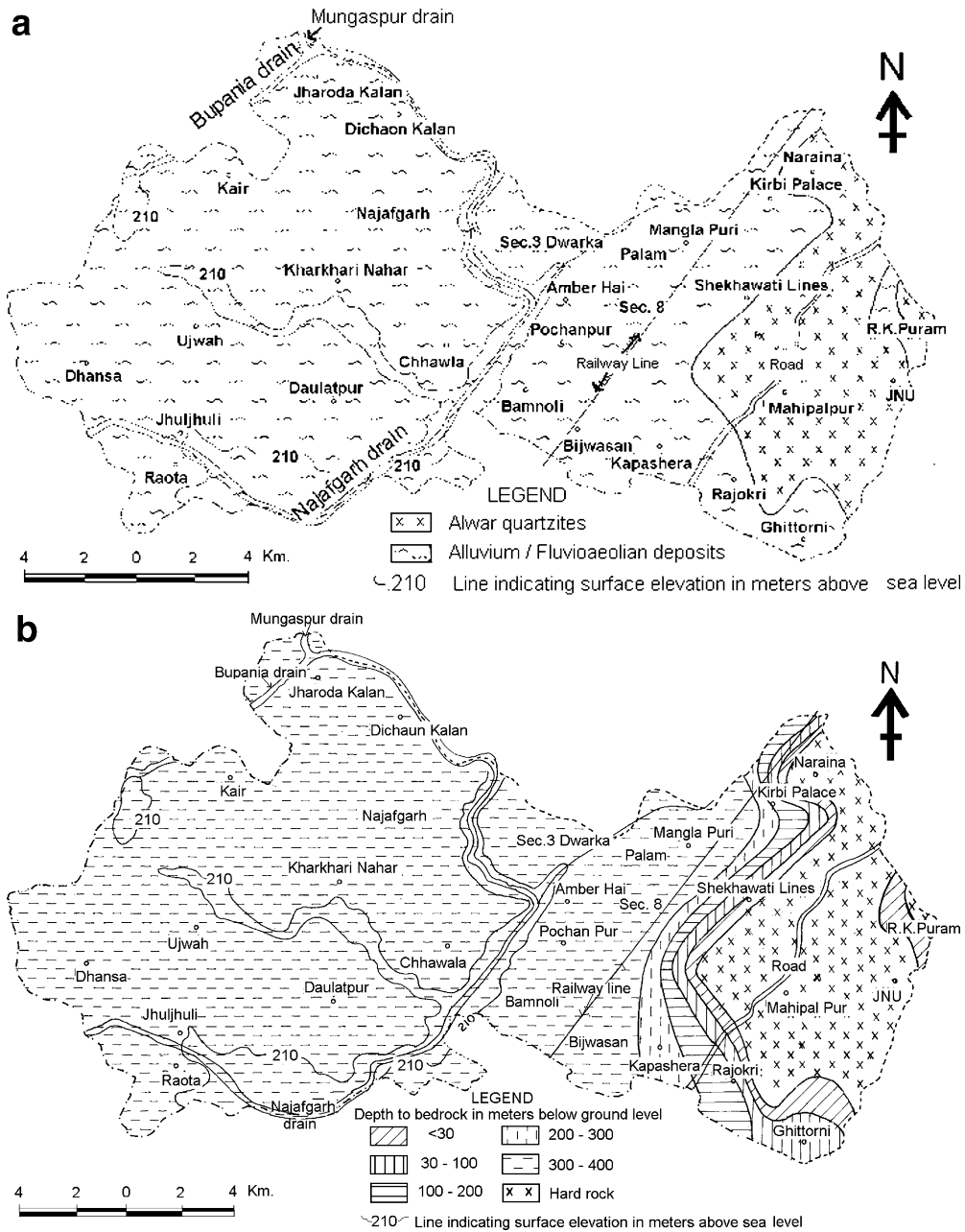
Najafgarh drain, including localities such as Ujwah, Daulatpur, Chhawala, Kharkhari Nahar, Najafgarh, Jharoda Kalan and Dichaon Kalan, has a depth to water in the range of 15–20 m b.g.l. To the east of the Najafgarh drain, a narrow strip of region passes through Naraina and Bijwasan which has a depth to water in the range of 15–20 m b.g.l. The region with depth to water in the range of 20–30 m b.g.l. occurs to the east of the Najafgarh drain and passes through Shekhawati lines. The southeastern part of the area shows deeper groundwater levels in the range of 30–50 m b.g.l. (Fig. 3a). The deepest groundwater levels are observed in hard rock areas at higher elevations and in those areas adjacent to them.

In a broader perspective, the deepest groundwater levels to the west of the Najafgarh drain are found towards the central part of the area and further north. The depth to groundwater in the region to the east of the Najafgarh drain shows an increasing trend moving from the west to the southeast (Fig. 3a).

## Methodology

Shekhar (2004) and Shekhar and Singh (2005) talk about the availability of fresh groundwater in the district. Total available fresh groundwater in the district has been calculated on the basis of a map showing the thickness of fresh groundwater zones in different parts of the district. The same map (Fig. 3b) has been further classified here by giving nomenclature to different freshwater thickness zones to facilitate zonewise quantification of fresh groundwater resources. Thus, the methodology involves the microzonation of the district in terms of the thickness of fresh groundwater zones, and then projecting available resources in freshwater zones with the help of data from representative groundwater monitoring stations of the Central Ground Water Board (CGWB) that are located either within a fresh groundwater zone or near to it. Similar work has been carried out by CGWB for the Delhi suburb of Dwarka, wherein this methodology was used to evaluate the sustainability of fresh groundwater resources (CGWB 2003). In order to calculate the volume of the total available fresh groundwater resources in the district, areas having a thickness of freshwater zones in the range of 0–10 m (Fig. 3b) were not considered, because the majority of these areas have a thickness of freshwater in the range of 0 to <math>5\text{ m}</math>.

Shallow groundwater is mostly saline in this area. Wherever a limited amount of freshwater (5 to 10 m thickness) is found, it cannot be utilized because the average drawdown in tubewells operating in this region is about 10 m, which is equal to or more than the available freshwater thicknesses. The zone with a thickness of fresh groundwater in a range of 30–40 m (zone E in Fig. 3b), contains a small patch with thickness of freshwater in the range of 20–30 m, which has been ignored for the purposes of calculation; the whole of zone E is considered to have a thickness of freshwater in the range of 30–40 m.



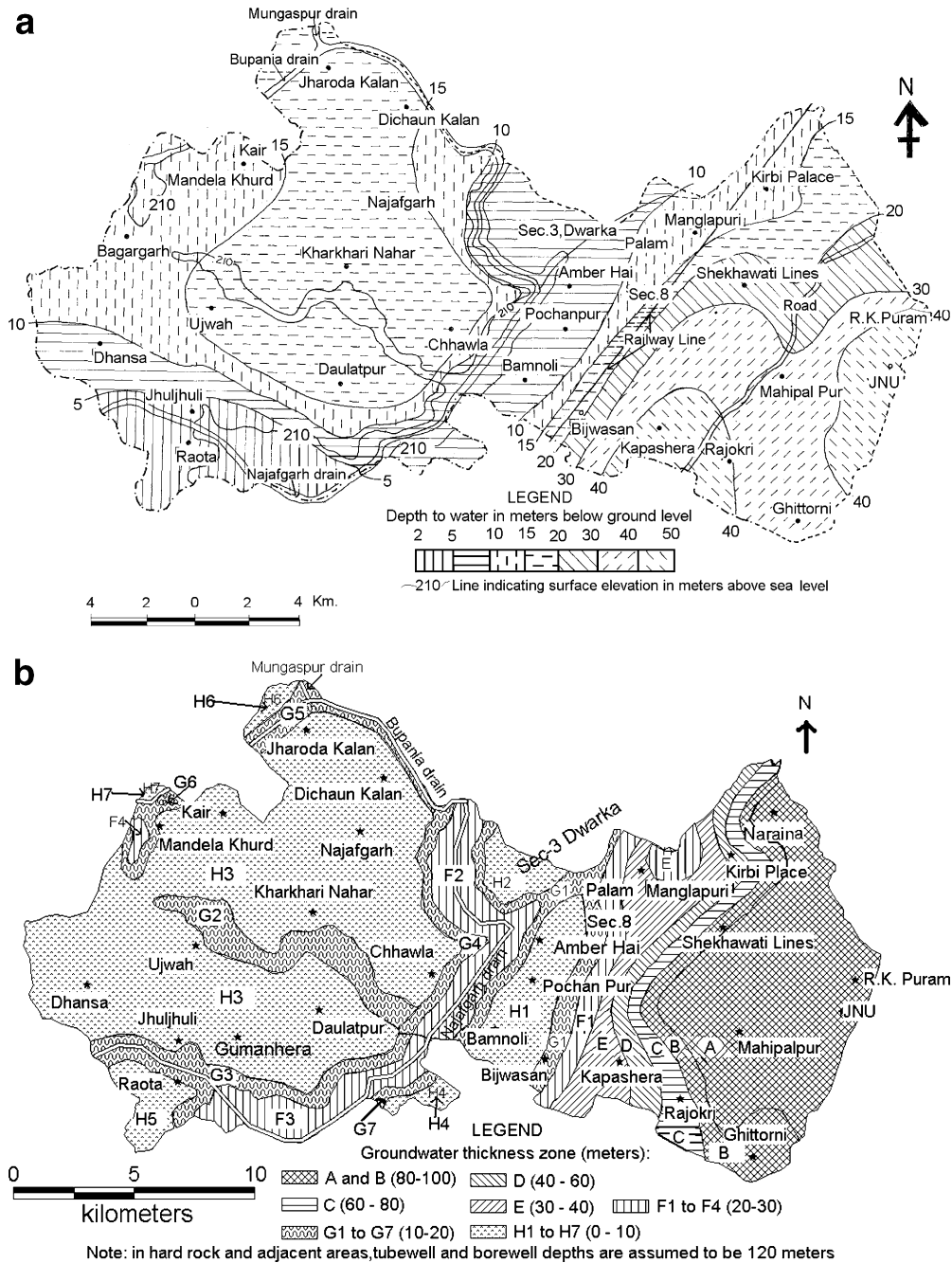
**Fig. 2** a Geological map of South West district, NCT Delhi. b Depth to bed rock (basement) map of the South West district, NCT Delhi

Utilizing the perspective of Shekhar and Singh (2005) on a local scale, an approach has been adopted to evaluate the total available fresh groundwater resources on a regional scale. The mean values of freshwater thickness ranges in respective freshwater zones, have been used to calculate the fresh groundwater resource for the district. The specific yield for the hard rock terrain has been determined as 0.015, and for alluvial/fluviaeoelian deposits the specific yield has been recorded as 0.1. The formulae used to assess the volume of available fresh groundwater are given below:

$$v = A.T.S_y \text{ and } T = M - D \tag{1}$$

Where

- v Volume of fresh groundwater available (m<sup>3</sup>)
- A Areal extent of the zone (m<sup>2</sup>)
- T Utilizable freshwater thickness (m)
- S<sub>y</sub> Specific yield of the formation
- M Mean of the freshwater thickness range (m)
- D Average value of the assumed drawdown in a fresh-water zone (m)



**Fig. 3** a Map showing premonsoon depth to groundwater in the South West district, NCT Delhi. b Map showing the thickness of fresh groundwater zones in the South West district, NCT Delhi

**Results**

With help of Eq. 1, the present availability of fresh groundwater resources of the district was calculated as 481 million m<sup>3</sup> (Shekhar and Singh 2005). The projection of future availability of fresh groundwater resources in the district have been attempted on the basis of the yearly decline in water levels of different fresh groundwater zones shown in Fig. 3b. The average value of the yearly decline in the water level of the district was used to calculate the utilizable freshwater thicknesses (*T*) that

would be available in the years 2007, 2012 and 2022. The likely volume of fresh groundwater available in the future was calculated from *T*, using Eq. 1.

Evaluating the future availability and sustainability of fresh groundwater resources was straightforward, due to the fact that there are a considerable number of groundwater monitoring stations (Fig. 4) more or less evenly distributed throughout the district. As mentioned earlier, the approach to this evaluation involved a zonal approach, where different freshwater zones (Fig. 3b) were studied separately to yield an average rate of decline in ground-

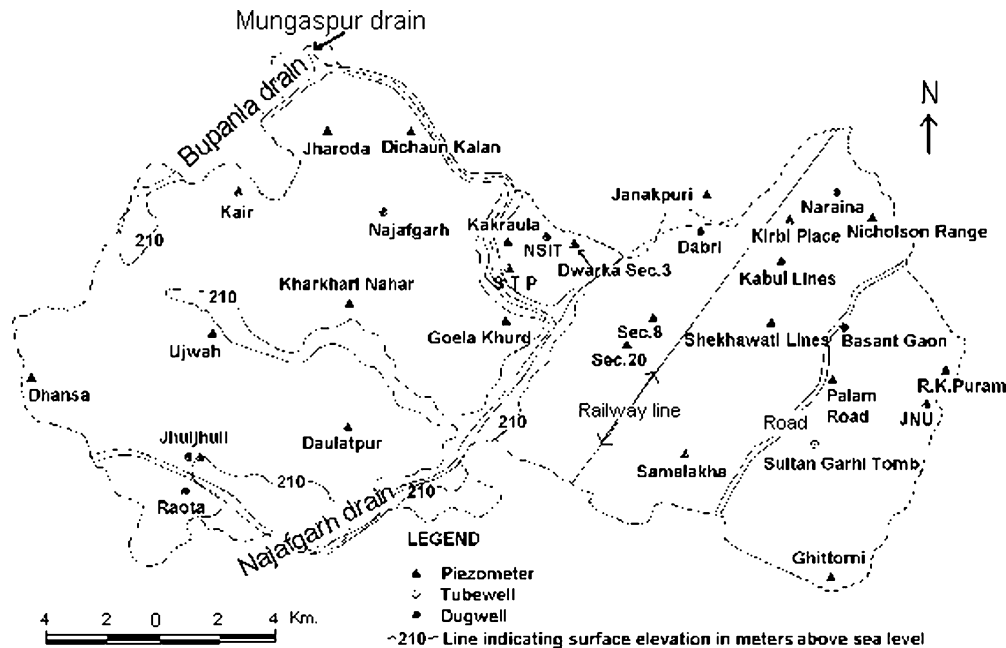


Fig. 4 Map showing location of key wells (groundwater monitoring stations) in the South West district, NCT Delhi

water levels within different freshwater zones, based on the average change in groundwater level over years 1997–2003 (Table 1).

Representative groundwater monitoring stations for each freshwater zone were selected based on their proximity to the respective freshwater zones (Table 1; Figs. 3b and 4). The two dugwells of Raota and Jhuljhuli (Fig. 4) that were used as groundwater monitoring stations

are just adjacent to the Najafgarh drain. The trend in groundwater level given by these two monitoring stations (see Table 1) is not in tune with the general trend of the water levels observed in all the other groundwater monitoring stations of the area. Thus, for projection and quantification of fresh groundwater resources in the freshwater zones F3 and G3 (Fig. 3b), on the basis of proximity to the zones, these dugwells could have been

Table 1 Premonsoon decline in water level (in meters) of representative groundwater monitoring stations

SN	Representative groundwater monitoring stations (Fig. 4)	Freshwater-zone thickness (m), see zones in Fig. 3b	1997–1998 (m)	1998–1999 (m)	1999–2000 (m)	2000–2001 (m)	2001–2002 (m)	2002–2003 (m)	Average annual rate of decline (m)
1	JNU	80–100 (A)	–	–	–	5.00	3.07	3.37	3.813
2	Palam Road	80–100 (A)	6.14	–2.20	8.80	1.90	3.25	–1.59	2.717
3	Basant Gaon	80–100 (A)	2.82	0.50	4.70	0.90	4.48	–	2.680
4	R.K. Puram	80–100 (A)	0.69	2.40	3.00	2.60	2.83	2.29	2.302
5	Naraina	80–100 (A)	1.60	–1.10	1.30	–	0.43	–	0.558
	Average hard-rock area (SN 1, 2, 3, 4 and 5)								2.414
6	Shekhawati lines	80–100 (B)	0.76	1.70	1.70	1.48	1.57	0.85	1.343
7	Kirbi place	60–80 (C)	–	–1.20	1.90	–0.12	2.40	0.57	0.710
8	Kabul line	40 – 60 (D)	1.48	0.30	1.60	1.12	0.56	2.32	1.230
9	Sec-8 (Dwarka)	10–20(G1), 20–30 (F1), 30–40(E)	0.68	0.40	2.50	1.35	2.07	2.62	1.603
	Average mid-eastern region (SN 6, 7, 8 and 9)								1.222
10	Dwarka Sec-3	0–10(H2)	–	–	–	0.60	–0.15	0.67	0.373
11	Goela khurd	10–20(G4), 20–30(F2)	0.57	0.33	0.50	0.52	3.93	–2.58	0.545
12	Jhuljhuli	10–20(G3), 20–30(F3)	0.32	–0.55	0.11	–0.06	–0.05	–0.04	–0.044
13	Raota	10–20(G3), 20–30(F3)	0.31	–0.40	–0.13	0.13	–0.20	–	–0.058
14	Kharkhari Nahar	10–20 (G2,G6), 20–30(F4)	1.32	0.20	2.44	1.54	0.78	0.99	1.212
15	Ujwah	10–20 (G2,G6), 20–30 (F4)	2.06	0.68	2.30	–0.30	0.80	1.71	1.208
	Average Ujwah and Mandela depression (SN 14 and 15 )								1.210
16	Dhansa	0–10 (H3)	0.05	–0.85	1.86	0.84	–0.32	0.50	0.347
17	Daulatpur	0–10 (H3), 10–20 (G3,G7), 20–30(F3)	0.53	0.32	1.00	1.40	3.49	–	1.348
18	Jharoda	10–20 (G5)	–	0.20	1.17	0.91	0.50	0.75	0.706

SN station number

selected, but because the general regional trends were contrary to the local trends given by these dugwells, for the purpose of regional quantification, the other groundwater monitoring station nearby (Daulatpur) was selected. The basic assumptions in the exercise presented are enumerated in the following:

1. The level of exploitation of groundwater resources in the coming years remains at the same level as it is today; this is likely to be so because the Government of India has notified this district regarding the regulated development of groundwater resources and thus, very few tubewells (nearly none) are permitted to be drilled in this district.
2. Recharge to groundwater by natural and artificial means will remain at the same level as of today for years to come
3. There has not been much change in geomorphic and land-use patterns in the district
4. Features like canal irrigation networks, huge surface water bodies, etc., will not be developed in the near future

The yearly decline in premonsoon water levels observed in representative groundwater monitoring stations for the period 1997–2003 was studied to arrive at an average value representing the rate of decline in respective freshwater zones (Table 1). Pre and postmonsoon water levels were studied on the assumption that if a decline in premonsoon water levels renders the aquifer unsuitable for groundwater exploitation, a rise in postmonsoon water level will not be of much use as regarding a sustainable exploitation of groundwater resources. Groundwater monitoring stations were grouped to represent regional areas in hard rock and other freshwater zones, and for each area, numeric values were derived that were supposed to

represent the annual rate of decline in different freshwater zones of the district.

The different numeric values and their averages are given in Table 1. Examining data in Table 1, it becomes evident that the average rate of decline in hard rock areas of the district, represented by freshwater zone A, corresponds to 2.4 m/year. While the average rate of decline in the mid-eastern part of the district (zones B, C and D and zones E, F1 and G1) corresponds to 1.2 m/year. The average rate of decline for the F2 and G4 freshwater region (represented by Goela Khurd groundwater monitoring station in Fig. 4) equals 0.5 m/year. Similarly, for the freshwater zone in the Ujwah and Mandela depression, the average rate of decline has been assumed to be 1.2 m/year. On the basis of the present rate of decline in different zones, the number of years it will take for fresh groundwater resources to become unsuitable for exploitation is given in Table 2.

The mean of the yearly premonsoon decline rate averaged over different freshwater zones provides a simple tool for projecting groundwater scenarios for years to come. Thus, fresh groundwater pockets/areas of the district were studied and analyzed and the projection results are tabulated in Table 3; freshwater thickness in different freshwater zones was calculated for the years 2002, 2007, 2012 and 2022. On basis of the freshwater thicknesses for different years, new freshwater zones in different years were made. These freshwater zones were used for further quantification of fresh groundwater resources in the district. Table 3 shows how, in successive years, the future freshwater thicknesses (and ultimately volume of fresh groundwater) will decline on the basis of the past six years' premonsoon behavior.

As mentioned earlier, the present availability of fresh groundwater in the district was worked out by Shekhar and Singh (2005) to be 481 million m<sup>3</sup> (see Table 3). It is estimated that 481 million m<sup>3</sup> of available fresh ground-

**Table 2** Sustainability of the fresh groundwater resources based on average rate of decline for the period 1997–2003

TL (Fig. 3b)	Area (km <sup>2</sup> )	AFT (m) (2002)	Average drawdown (m)	UFT (m) (2002)	FTZ (m) (Fig. 5) (2002)	ARD (Table 1) (m/year) (1997–2003)	Number of years needed to exhaust the resources
A	67.82	90	20	70	80–100	2.400	29
B	18.44	90	20	70	80–100	1.200	58
C	14.17	70	10	60	60–80	1.200	50
D	11.29	50	10	40	40–60	1.200	33
E	23.35	35	10	25	30–40	1.200	21
F1	9.520	25	10	15	20–30	1.200	13
F2	18.80	25	10	15	20–30	0.545	28
F3	12.89	25	10	15	20–30	1.348	11
F4	1.003	25	10	15	20–30	1.200	13
G1	14.69	15	10	5	10–20	1.200	4
G2	13.87	15	10	5	10–20	1.200	4
G3	12.71	15	10	5	10–20	1.348	4
G4	5.690	15	10	5	10–20	0.545	9
G5	6.007	15	10	5	10–20	0.710	7
G6	3.178	15	10	5	10–20	1.200	4
G7	1.336	15	10	5	10–20	1.348	4

AFT average freshwater thickness, FTZ freshwater thickness zones, UFT utilizable freshwater thickness, ARD average annual rate of decline, TL type locality marked on Fig. 3b as A, B–G6, G7 indicating fresh groundwater thickness zones in different regions of the district

**Table 3** A projection of the volume of fresh groundwater resources available in succeeding years

TL (Fig. 3b)	Area (km <sup>2</sup> )	AFT (m) (2002)	UFT (m) (2002)	FTZ (m) (2002)	SFRA (MCM) (2002)	ARD (m/year) (1997-2003)	AFT (m) (2007)	UFT (m) (2007)	FTZ (m) (2007)	SFRA (MCM) (2007)	AFT (m) (2012)	UFT (m) (2012)	FTZ (m) (2012)	SFRA (MCM) (2012)	AFT (m) (2022)	UFT (m) (2022)	FTZ (m) (2022)	SFRA (MCM) (2022)
A	67.82	90	70	80-100	71	2.400	78	58	60-80	59	66	46	50-70	47	42	22	20-40	22
B	18.44	90	70	80-100	129	1.200	84	64	60-80	118	78	58	50-70	107	66	46	40-60	85
C	14.17	70	60	60-80	85	1.200	64	54	40-60	77	58	48	30-50	68	46	36	20-40	51
D	11.29	50	40	40-60	45	1.200	44	34	30-40	38	38	28	20-30	32	26	16	10-20	18
E	23.35	35	25	30-40	58	1.200	29	19	20-30	44	23	13	10-20	30	11	1	0-10	
F1	9.520	25	15	20-30		1.200	19	9	10-20		13	3	0-10		1	0	0-10	
F2	18.80	25	15	20-30		0.545	22	12	10-20		20	10	5-15	19	14	4	0-10	
F3	12.89	25	15	20-30		1.348	18	8	10-20		12	2	0-10		0	0	0-10	
F4	1.003	25	15	20-30	63	1.200	19	9	10-20	38	13	3	0-10		1	0	0-10	
G1	14.69	15	5	10-20		1.200	9	0	0-10		3	0	0-10		0	0	0-10	
G2	13.87	15	5	10-20		1.200	9	0	0-10		3	0	0-10		0	0	0-10	
G3	12.71	15	5	10-20		1.348	8	0	0-10		2	0	0-10		0	0	0-10	
G4	5.690	15	5	10-20		0.545	12	2	0-10		10	0	0-10		4	0	0-10	
G5	6.007	15	5	10-20		0.710	11	1	0-10		8	0	0-10		0	0	0-10	
G6	3.178	15	5	10-20		1.200	9	0	0-10		3	0	0-10		0	0	0-10	
G7	1.336	15	5	10-20	29	1.348	8	0	0-10		2	0	0-10		0	0	0-10	
H1-H7	188.6	5	0	0-10														
Totals	423.34				481					374				303				176

AFT average freshwater thickness, FTZ freshwater thickness zones, UFT utilizable freshwater thickness, SFRA static freshwater resources available, ARD average annual rate of decline, TL type locality marked on Fig. 3b as A, B-G6, G7 indicating fresh groundwater thickness zones in different regions of the district, MCM million m<sup>3</sup>

water resources will have reduced to 374 million m<sup>3</sup> by year 2007 and to 303 million m<sup>3</sup> by year 2012, and by year 2022, the district will have only 176 million m<sup>3</sup> of available fresh groundwater resources. Figure 5 is a bar graph showing how, in successive years, the volume of fresh groundwater available in the district will decrease, while Fig. 6 is a composite bar diagram showing how the area underlain by saline and freshwater will behave in successive years. The projected figures provide a clue as to how the system will behave in the future with regards to availability of fresh groundwater. This will provide an important input for purpose of holistic and visionary planning in the district.

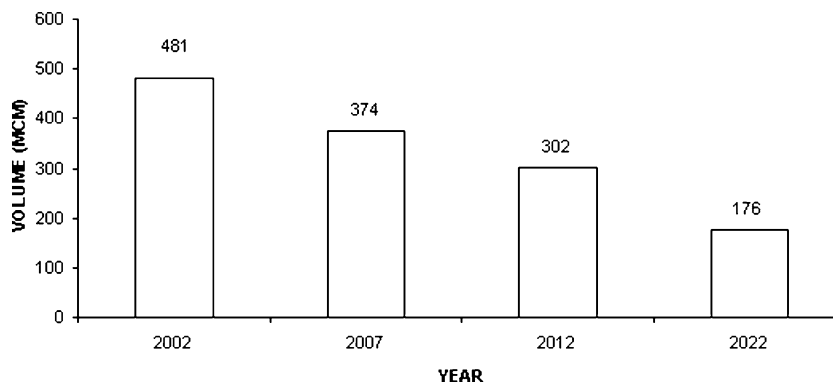
**Discussion**

With the approach used here, it becomes clear that the district has very poor utilizable fresh groundwater potential. Even so, the regions adjoining hard rock areas and traversed by the fault zone have better potentiality compared to other freshwater regions of the district. Similarly, freshwater zones along the Najafgarh drain, and one containing depressions, have somewhat better potentiality compared to other freshwater zones of the district, excluding the one mentioned earlier. These areas, having limited groundwater development potentiality, should be viewed with caution and treated as a buffer stock to meet emergency potable water requirements in the district.

At this stage, it would be appropriate to discuss the effectiveness of the methodology used here. There is an evenly distributed groundwater-monitoring network of stations in all formations of the district and in zones with different freshwater thicknesses. Once microzonation of the district with respect to freshwater thickness is complete, the groundwater monitoring stations act as effective control points for the quantitative assessment of fresh groundwater in different zones. Since the water level in these groundwater monitoring stations are regularly measured, and have been for a considerable period of time, the trend of the water level can be easily established. With the assumption that the system will behave in the future similarly to how it behaves now, and if other basic components of the system remain the same, prediction of groundwater scenarios have been possible.

The basic objective here has been to make individuals, communities, government bodies, planners, etc., aware of the approximate present and future availability of fresh groundwater resources in the district, so that individuals can become more responsible users of water, and the community and government can adopt developmental projects and water management practices with present and future fresh groundwater availability in mind. The objective has been accomplished in a very simple and effective manner. The objective could also have been achieved by simulation of the system on computer and then using numerical modeling techniques.

Simulating a complex system for the type of area mentioned here (where saline water occurs below fresh-

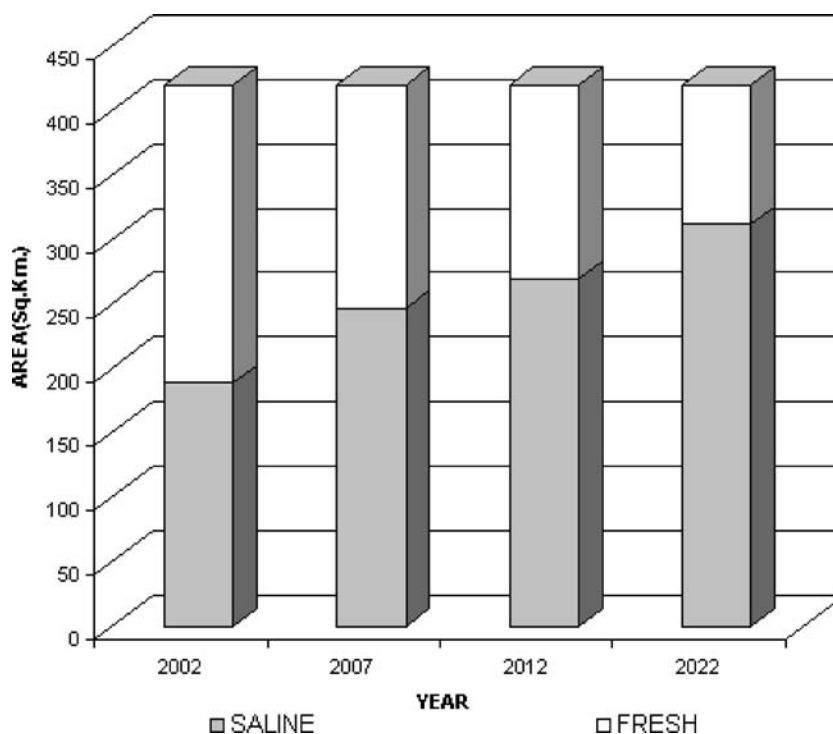


**Fig. 5** The bar graph shows the projected volume of fresh groundwater resources available in successive years in South West district, NCT Delhi

water at different depths, where there is a faulted zone on the fringes of the hard rock controlling the depth to the fresh/saline interface in groundwater, where there is a huge drain and where hard-rock exposures have considerable freshwater thickness underneath, etc.) would generally involve considerable simplification of the system. Verification of output of numerical modeling effort would again be provided by the same groundwater monitoring stations and historic data from those stations. Thus, to begin with, it was decided to adopt this methodology where field-based control points (groundwater monitoring stations) are key components. It is envisaged that the scope of future work in this area will be a computer-based functional numerical model that can act as a decision support system, incorporating all the minute details and complexities such as density dependent flow, fresh and saline water diffusion, heterogeneity and

anisotropy in aquifer, groundwater draft and recharge pattern in the district, etc.. This will take considerable time and effort. Thus, a beginning has been made with a very simple approach. Having established that the fresh groundwater resources available at present and projected for the future are dismal, some suggestions with regards to water management in the district are proposed.

The water available to residents in the district should be used judiciously and in an efficient manner and water conservation habits should be incorporated into people's habits in daily life. The practice of dual water supply for residents of the district should be taken up in terms of freshwater for drinking purposes and saline groundwater for other domestic and horticultural activity. Wastewater and sewage should be prevented from going directly into village ponds in the area; instead local onsite treatment of wastewater should be taken up by the government and



**Fig. 6** The composite bar graph shows the relative areal extent of fresh and saline water in successive years in the South West district, NCT Delhi



community on the scale of individual villages or group of villages. An attempt to recycle treated wastewater should be made. At the individual and community level, surface runoff from rural and urban parts of the district during monsoon times should be harvested and used for recharging the groundwater. Properly cleaned village ponds and parks in urban areas could be used at the community level for this purpose.

In hard-rock areas of the district there are numerous quarries, ponds and barren patches of land (observed during field survey) that can be utilized efficiently for recharging the groundwater by making suitable artificial recharge structures. The district does not have any canal irrigation facility and, in this respect, it will be desirable to have a canal network in rural areas of the district. This will reduce stress on groundwater in the district and, at the same time, the network of canals will locally recharge surface water to groundwater. Conjunctive use of surface and groundwater can then be taken up in command areas of the canal network. With regards to the Najafgarh drain carrying a large volume of water in the area, a pilot project study should be initiated to ascertain how this volume of water could be best utilized for recharging the groundwater in parts of the district in an eco-friendly manner and without contaminating the groundwater. Once this feasibility is established, then limited exploitation of groundwater utilizing only the additional recharged volume of groundwater can be planned on for meeting emergency water requirements of the district.

Lastly, there should be an emphasis on using salt tolerant varieties of crops. This will lead to utilization of shallow saline groundwater for agricultural purposes. Recharge to groundwater using excess surface runoff

during monsoon time may create limited freshwater lenses above subsurface saline waters. The efforts of the individual, the community, and government bodies, working in harmony, can bring some hope to the residents of this water-scarce district.

**Acknowledgements** The author is grateful to Dr. Saleem Roamani, Chairman, Central Ground Water Board (CGWB) and retired CGWB scientist Dr. S.B. Singh for useful discussions during the course of this work. The discussion, from time to time, with fellow colleagues (P.N. Singh, S.K. Mohiddin, B.K. Gupta and Purohit) is duly acknowledged. The author also acknowledges meticulous review comments by an anonymous reviewer and the editorial team of Hydrogeology Journal which helped to improve the manuscript.

## References

- CGWB (2003) Sustainable development of groundwater resources of Dwarka Sub-City, Report, Central Ground Water Board, Ministry of Water Resources, Government of India, Delhi
- Shekhar S (2004) Integrated groundwater management study of the South West district with special reference to fresh/saline water interface, Report, Central Ground Water Board, Ministry of Water Resources, Government of India, Delhi
- Shekhar S, Singh S B (2005) The occurrence and availability of fresh groundwater resources in the South West district of NCT Delhi, India, paper presented at the National Conference on "Earth Science: Its Relevance to Society", 14th Biennial Convention of the Indian Geological Congress, Jointly organized by the Indian Geological Congress, Roorkee and the Department of Geology, 2–4 December 2005, University of Delhi, Delhi
- Shekhar S, Singh S B, Romani S (2005) The controls to the variation in depth to fresh/saline interface in the groundwater of the South West District, NCT, Delhi: a case study. *J Geol Soc India*, 66:17–20