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Estimation of regional groundwater discharge and baseflow contribution in northern stretch of the Yamuna River system of Delhi

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Urban agglomerations in India of late have started facing drinking and domestic water scarcity. The city state of Delhi has witnessed accelerated urbanization and an exponential growth in population. In this context, it is desired to locate sustainable groundwater resources in Delhi. This communication examines the northern stretch of the Yamuna floodplain system in Delhi with respect to source sustainability. An aquifer can sustain extensive exploitation only if it is replenished regularly. Though the river floodplain system gets recharged by monsoon flooding, the recharged water may not sustain the source aquifer until the end of summer. Thus before exploitation all floodplains have to be examined vis-à-vis regional groundwater dynamics. In this context it was found that the floodplain system in the northern stretch of River Yamuna receives considerable regional groundwater flow. Some of this also contributes to river flow. The present study has estimated regional groundwater flow in this aquifer stretch of the Yamuna river system as 10,513,460 m^3/yr (~11 MCM/yr). Besides, the yearly baseflow contribution to the Yamuna in the study area has been estimated as 518,472 m^3/yr (~0.5 MCM/yr).

Keywords: Baseflow, flownets, floodplain, regional groundwater discharge, river system.

THE city state of Delhi has witnessed overexploitation of groundwater resources and fast depletion in groundwater reserves in majority of the aquifer systems[1–3]. The Yamuna, a perennial river, flows from north to south through Delhi (Figure 1).

The Yamuna floodplain in Delhi consists of a layer of younger (or newer) alluvium over an older alluvium[2–4]. The thickness of the younger alluvium layer varies from 70 m in North Delhi to 30 m in South Delhi[4]. The younger alluvium is an unconfined aquifer[5–8]. The specific yield of this aquifer had been estimated as 0.2 (refs 4, 6, 8, 9).

In the present study, groundwater flow to the Yamuna floodplain was estimated using a flownet construction. In such analysis of groundwater flow, water table contours represent equipotential lines and flow lines indicating the direction of groundwater flow are perpendicular to these

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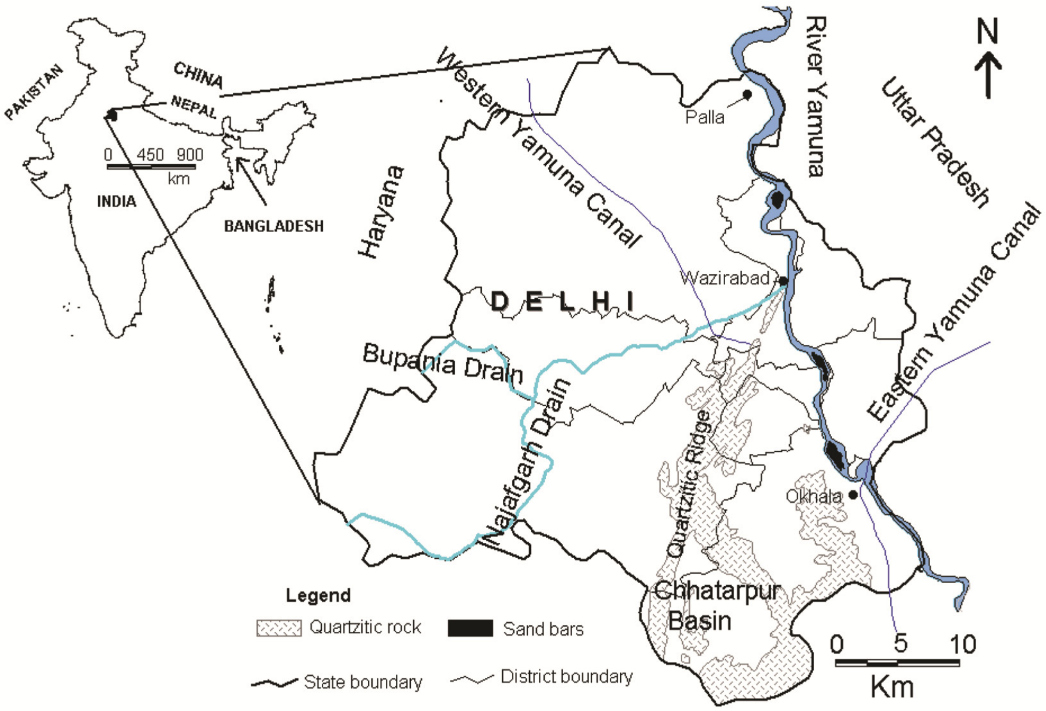

Figure 1. Map showing location of Palla area and River Yamuna in Delhi[4].

contours (Figure 2). The groundwater flow through the aquifer between two flow lines (Figure 2) is estimated using Darcy's law.

For the water table contours, we used the depth to water table data for January 2013 of the Central Groundwater Board (CGWB) from monitoring stations (Table 1). These data are available in the public domain in the yearbook reports for Delhi and Uttar Pradesh (cgwb.gov.in). Further, the land surface elevation data for these stations were taken from Google Earth imagery. The depth to water table data for a station was subtracted from the land surface elevation data to obtain the water table elevation value for that station (Table 1). With these water table elevation values (Table 1), using Kriging interpolation, water table contour map was prepared (Figure 2). On this map, the flow lines were made perpendicular to the water table contours to construct the flownet (Figure 2). We estimated the groundwater flow through unit saturated thickness of the aquifer along a channel between two flow lines using eq. (1) as follows

$$Q = k \times \left(\frac{h_1 - h_2}{l} \right) \times w, \tag{1}$$

where Q is the groundwater flow through unit saturated thickness of one channel between two flow lines; k the hydraulic conductivity of the medium, taken to be 20 m/day for newer alluvium[3,6]; h_1 and h_2 are the groundwater elevations along length l and w is the width of the flow channel.

In eq. (1), i the hydraulic gradient is represented as

$$\frac{h_1 - h_2}{l}.$$

Figure 2 reveals that there are many channels between flow lines through which groundwater flow takes place towards the Yamuna. So if we consider the jth channel, then the flow Q_j through unit saturated thickness of the such jth channel based on eq. (1) can be estimated using eq. (2)

$$Q_j = kiw. \tag{2}$$

The total flow through unit saturated thickness of all the channels which gives an estimate of the regional groundwater flow through unit saturated thickness is calculated using eq. (3)

$$Q_{\text{total}} = \sum_{j=1}^{n} Q_j, \tag{3}$$

where n is the total number of flow channels.

The estimated Q_{total} in eq. (3) can be multiplied by any aquifer thickness value to give the groundwater flow through that aquifer. So with data taken from Figure 2, we estimated regional groundwater flow per unit saturated thickness to the Yamuna floodplain system from both east and west banks of the river (Table 2). Using this

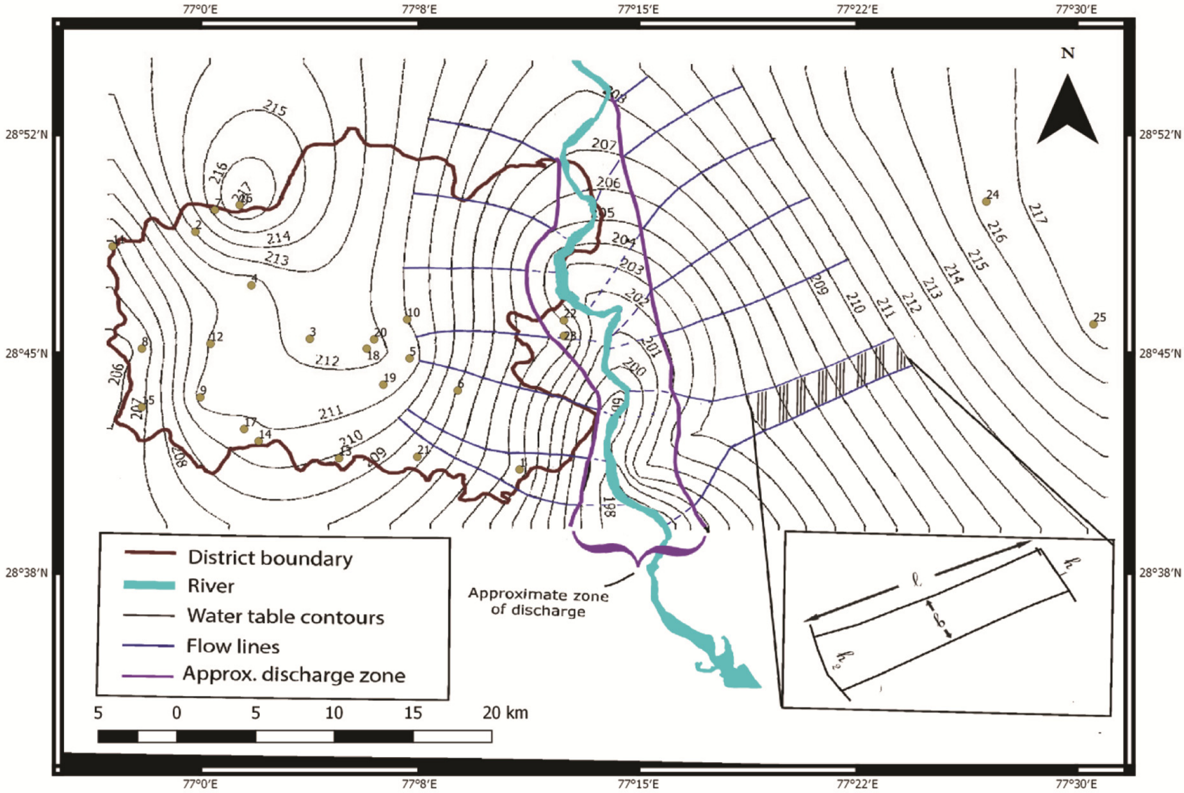

Figure 2. Flow net for estimation of groundwater flow. District shown is North West Delhi. The monitoring stations are shown as circular dots. The numbers besides these are the serial numbers of the respective locations shown in Table 1.

we estimated the baseflow contribution to the Yamuna, and regional groundwater flow into the flood plain system of the river from an aquifer of 40 m thickness.

In order to estimate the baseflow contribution to the Yamuna, the average saturated aquifer thickness exposed to the river is required. The channel cross-sections could be roughly estimated from Google Earth, but the problem was with the river stage. So we referred to data from Soni *et al.*[10] on river cross-section, stage and average water surface slope (0.00041) for the Yamuna near Palla (Figure 1). The stage for the other sites was extrapolated using water surface slope data. Further, with the help of Google Earth cross-section, the average saturated aquifer thickness exposed to the river in the study area was estimated as 3 m. So the baseflow contribution to the Yamuna is basically the regional groundwater flow through 3 m of saturated aquifer. Thus Q_{total} of eq. (3) was multiplied by 3 for both the east and west banks to estimate baseflow contribution to the river (Table 2). Similarly, for estimation of regional groundwater flow to the Yamuna floodplain system, aquifer of 40 m thickness was chosen; Q_{total} of eq. (3) was multiplied by 40 for both the east and west banks (Table 2).

There is a confluence of regional groundwater flow in this stretch of the Yamuna (Figure 2). On summing up the estimates for both banks of the river, our analysis shows that the non-monsoon baseflow to the river is 2160.3 m^3/day. While the total regional groundwater flow to the shallow aquifers of the Yamuna River system is 28,804 m^3/day or 10,513,460 m^3/yr (Table 2).

The natural discharge area of a groundwater system receives regional groundwater flow[11]. Thus floodplain areas close to the river receiving regional groundwater flow corresponding approximately to the area indicating end regime of a regional groundwater flow system were demarcated as discharge zone (Figure 2). The area was found to be roughly 120,263,736 m^2. With the estimated 10,513,460 m^3/yr of groundwater flow into 120,263,736 m^2 area, and specific yield[4] of the aquifer as 0.2, we estimated the expected rise in groundwater level (Δh) without any abstraction and enhancement in baseflow using eq. (4) as follows

$$\Delta h = \frac{V_{\text{t}}}{A \times S_{\text{y}}}, \tag{4}$$

where V_{t} is the total annual groundwater discharge, A the discharge area and S_{y} is the specific yield of the aquifer.

Thus from eq. (4), it is clear that if the total yearly regional groundwater flow volume is not extracted from the region, we should expect a rise in groundwater level of

Table 1. Groundwater-level data

Serial no.	Longitude	Latitude	Monitoring station	Land surface elevation (m amsl)	Depth to water table (m bgl)	Water table elevation (m amsl)
1	77.18222	28.68389	Ashok Vihar-IV	216	11.4	204.6
2	76.99722	28.81944	Auchandi	224	2.3	221.7
3	77.0625	28.75833	Barwala	215	5.9	209.1
4	77.02917	28.78889	Bawana	218	6.6	211.4
5	77.11944	28.74722	Delhi College of Engineering	217	5.2	211.8
6	77.14694	28.72889	Haiderpur	218	10.1	207.9
7	77.00833	28.83194	Hareoli	220	4.6	215.4
8	76.96667	28.75278	Jaunti	219	12.9	206.1
9	77	28.725	Kanjhawala	213	1.5	211.5
10	77.11806	28.76944	Khera Kalan	216	5.0	211
11	76.95	28.81111	Kutubgarh	215	7.2	207.8
12	77.00583	28.75556	Majara Dabas	215	3.9	211.1
13	77.07917	28.69028	Mangolpuri	219	3	216
14	77.03333	28.7	Mubarakpur	214	3.2	210.8
15	76.96667	28.71944	Nizampur	214	7.4	206.6
16	77.0225	28.83472	Qatlupur	219	1.7	217.3
17	77.025	28.70694	Rani Khera	214	3.5	210.5
18	77.095	28.75278	Rohini Sec-28	214	4.8	209.2
19	77.10444	28.73222	Rohini Sec-11	218	6.5	211.5
20	77.09917	28.75806	Rohini Sec-26	214.7	2.6	212.1
21	77.12389	28.69111	Sainik Vihar	218	1.8	216.2
22	77.2075	28.76889	Burari Auger	210.7	3.6	207.1
23	77.2075	28.76	Burari	208.7	3.8	204.9
24	77.44861	28.83667	Raoli	221	9*	212*
25	77.50972	28.76667	Muradnagar	215.7	2.8	212.9

*These data were not available and so were interpolated by us. The groundwater level was observed to be approximately 1 m below Muradnagar's for almost all other data points available, and the same trend was followed in this case also.

Table 2. Regional groundwater discharge and baseflow estimates

Location/ total estimates	Regional groundwater flow to the Yamuna floodplain system per unit saturated thickness	Baseflow contribution to the Yamuna assuming 3 m of saturated aquifer exposed to the river	Regional groundwater flow to shallow aquifer of 40 m thickness
West Bank	443.8 m^3/day	1331.4 m^3/day	17,752 m^3/day
East Bank	276.3 m^3/day	828.9 m^3/day	11,052 m^3/day
Total daily flow	720.1 m^3/day	2160.3 m^3/day	28,804 m^3/day
Total yearly flow	262,836.5 m^3/yr	518,472 m^3/yr*	10,513,460 m^3/yr

*This was calculated for eight non-monsoon months because it is the period when groundwater contributes to the river. During monsoon months, groundwater will not contribute to the river.

about 0.44 m/yr. With the average depth to water level being 5 m bgl, in five years the area would be waterlogged, and soil and groundwater would become saline. Rise in groundwater level will also enhance the baseflow contribution. So we examined the current statistics, where baseflow contribution is only about 8% of the regional groundwater, flowing into the floodplains; thus the baseflow contribution may increase and the expected rise in groundwater level may reduce to 0.4 m instead of 0.44 m. However, the possibility of waterlogging will exist if no groundwater is extracted from the floodplains; it may take seven instead of five years.

The estimate arrived at in this study is a ballpark figure. Despite this, the findings on groundwater availability may be significant for Delhi. A more detailed and extensive study would throw further light on how this water resource can be sustainably exploited. However, the regional groundwater dynamics clearly establishes the Yamuna floodplain system in the northern stretch of Delhi as a regional natural groundwater discharge zone, where the regional groundwater flow accumulates. Quantification of regional groundwater flow into the Yamuna floodplain system establishes: that (i) annual regional groundwater flow into the floodplain system works out to be 10,513,460 m^3/day, and (ii) annual baseflow contribution to the Yamuna works out to be 518,472 m^3/yr. With the given estimate of available water for exploitation, it is desirable to optimally exploit groundwater in the floodplain system of the study area. While this partially meets water requirement for a part of North Delhi, it will avoid waterlogging.

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Modulation in activity profiles in insecticide-resistant population of tobacco caterpillar, *Spodoptera litura* (Fabricius)

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Activity spectrum of detoxification enzymes was systematically assessed in tobacco caterpillar, *Spodoptera litura* collected from four locations in Kerala, India, to decipher the mechanism of insecticide resistance. Using the susceptible check ICAR-NBAIR strain, specific activity profiles of acetylcholine esterase (AChE) were found to be 16.16-, 10.71- and 4.88-fold higher in the Kovilnada, Palappur and Kanjikuzhi populations respectively. Specific activities of mixed function oxidase (MFO) were also found to be 19.24-, 17.11-, 6.08-fold higher in the same populations respectively, indicating the predominance of AChE and MFO towards imparting resistance. Carboxylesterase (CarE) and glutathion-*S*-transferase (GST) specific activity profiles were 3.62- and 3.37-fold higher in the Kovilnada population, followed by 2.89- and 2.98-fold higher in the Palappur population and as 2.10- and 1.15-fold higher in the Kanjikuzhi population, indicating their partial role in resistance development. Suppression of specific activities in synergism bioassays with AChE in chlorpyriphos + TPP treatment (9.32-fold), GST in chlorpyriphos + DEM (4.78-fold) and CarE in quinalphos + TPP (5.15-fold) highlighted the involvement of multiple detoxification enzymes conferring resistance to organophosphates. Reduced activity of MFO in case of lambda-cyhalothrin + PBO (5.35-fold), CarE in case of cypermethrin + TPP (7.36-fold) and 3.60-fold reduction in MFO in case of cypermethrin + PBO highlighted the role of esterases and MFOs towards resistance development against synthetic pyrethroids.

Keywords: Detoxification enzymes, insecticide resistance, *Spodoptera litura*, synergists.

INDISCRIMINATE use of insecticides targeting minor pests has resulted in their development as key pests by rapid gene alterations or physiological mechanisms which have provided these pests the capacity to tolerate toxic doses of insecticides. With the advancement in timeline, the number of insects known to be tolerant to various insecticides has also increased at an alarming rate. In 1986, 260 insect species were reported to have developed

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