Piezometric water-level conditions in Bangalore city, Karnataka, India

Earlier works[1] have revealed that Bangalore city predominated by migmatites, granodiorites and intrusive granites, in general does not carry potential fractures beyond 280 m depth. However, bore wells are being drilled in the peripheral parts beyond 300 m. The unconfined and part of the semi-confined aquifers having gone dry, bore wells are now being competitively drilled at greater depths. Mehta *et al.*[2] have presented 'a thought experiment to clarify what a socio-ecological water balance of Bangalore could look like, one that can be refined in the future as data and knowledge accumulate'. Echoing recent independent estimates of groundwater by Hegde and Subhash Chandra[1], Mehta *et al.*[2] have brought out a conceptual model which demonstrates what the water balance looks like in different parts of Bangalore city.

In order to monitor the variation and dwindling of groundwater levels, the Department of Mines and Geology (DMG) constructed a network of 12 piezometer wells at different parts of the city[3]. The water in these wells was struck under semi-confined conditions. Ten of these piezometer wells were installed during 2011 with digital water level recorders (DWLRs) and provided telemetric facility for obtaining high-frequency data. After a cursory examination of the telemetric piezometer water-level data of DWLR that were available to us for the period May 2011 to June/July 2012, we noted that the hydrographs of the monitoring stations located at Yelahanka, Hebbal and HSR Layout showed certain abnormal fluctuations and variations. Hence, the water-level data of these three stations were analysed to study the possible causative factors for such abnormal variations. This correspondence presents the findings of the analysis.

Though DWLR has been programmed by DMG to record water levels once every two hours (Figure 1) we noted, in general, the daily data recorded at 6 p.m. representing the maximum depletion due to groundwater withdrawal in the vicinity and at 6 a.m. the maximum recovery of groundwater levels. The piezometers at Yelahanka, Hebbal and HSR Layout monitoring stations were drilled up to 155, 135 and 125 metres below ground level (mbgl) and the water-bearing potential fractures in them were struck respectively, at depths of 106, 95 and 93 mbgl. The water levels in these wells represent the piezometric head of the potential fracture(s) tapped under semi-confined aquifer conditions. The water levels recorded by DWLR at these three stations reflect the variations in the piezometric head only. The average monthly piezometric levels for 6 p.m. and 6 a.m. were determined from the DWLR dataset and further the monthly net rise (ΔR) and the monthly decline (ΔD) were arrived at (Table 1). The piezometer water-level fluctuations (Figure 2) were correlated with the monthly rainfall data arrived at from the daily rainfall statistics of the rain gauge (RG) station (located in the vicinity of each of the monitoring well). The data analyses of the water-level fluctuations/variations in the piezometers of the referred three monitoring stations are now further discussed.

Yelahanka: There is a public water supply bore well with pump installed and maintained by Bangalore Water Supply and Sewerage Board (BWSSB) within a distance of 100 m from the piezometer. The potential fracture struck in the piezometer well was at 106 mbgl. The hydrograph of piezometric water level (Figure 1 *a*) for the period of observation demonstrates four distinct trends: (i) from May to August 2011, (ii) from September 2011 to January 2012, (iii)

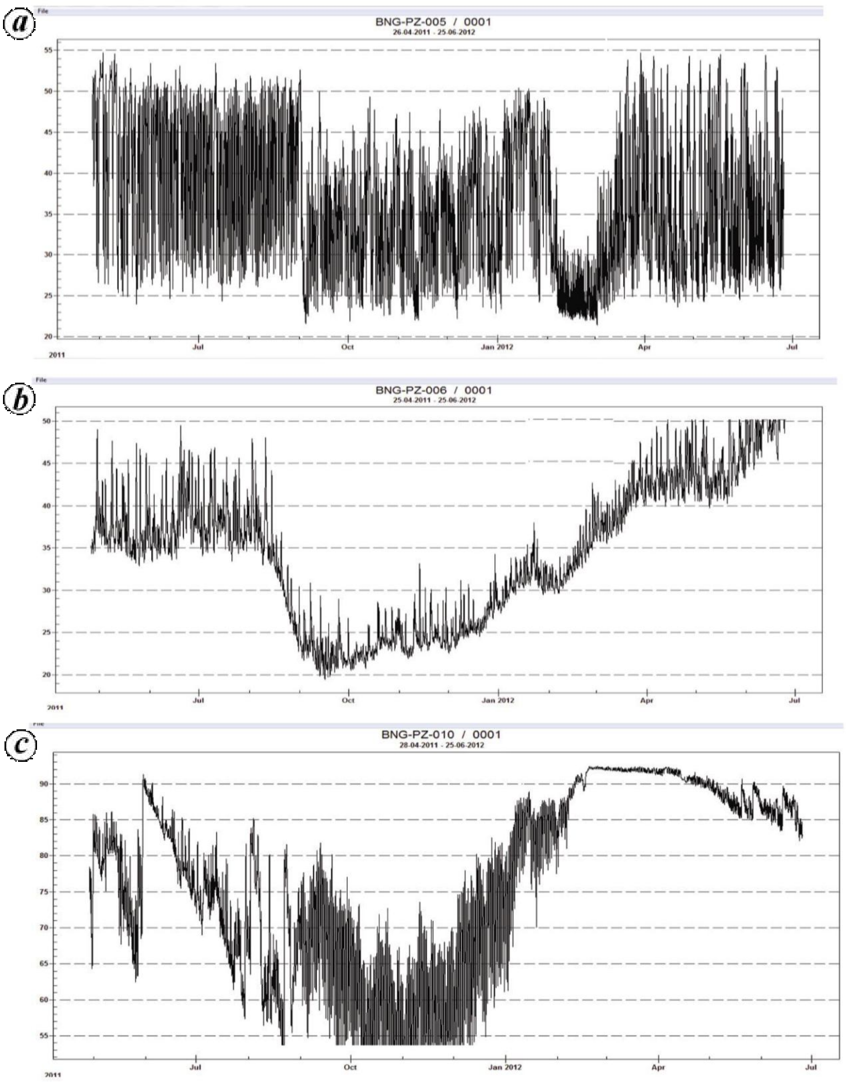

Figure 1. Hydrograph of (***a***) Yelahanka, (***b***) Hebbal and (***c***) HSR Layout showing two-hourly variations. (Note: Depth in metres below ground level.)

Table 1. Piezometric water level (mbgl) and monthly rainfall (mm) (6 p.m. and 6 a.m. water level–average for the month)

Station	Year	Time	January	February	March	April	May	June	July	August	September	October	November	December
Yelahanka (monitoring well)	2011	6 p.m.	–	–	–	–	44.8	46.2	45.1	45.7	35.24	35.8	34.8	36.8
		6 a.m.	–	–	–	–	34.6	31.8	29.6	32.6	36.03	28.4	27	28.3
		Monthly average	–	–	–	–	39.7	39	37.4	39.1	35.64	32.1	30.9	32.5
		Δ Rise (m)	–	–	–	–	265	153	162	159	153.9	196	159	148
		Δ Decline (m)	–	–	–	–	272	156	140	210	146.1	162	141	152
		Net rise (m)	–	–	–	–	–	–	22.4	–	7.87	33.7	17.9	–
		Net decline (m)	–	–	–	–	6.8	3.3	–	50.8	–	–	–	3.68
	2012	6 p.m.	42.2	24.3	36.6	37	36.1	37.2						
		6 a.m.	35	24.1	29.2	30	31.8	33.5						
		Monthly average	38.6	24.2	32.9	32.9	33.9	35.4						
		Δ*R* (m)	178	108	161	248	251	152						
		Δ*D* (m)	178	53.3	189	253	266	147						
		Net rise (m)	0.18	55.1	–	–	–	5.41						
		Net decline (m)	–	–	27.9	5.03	15.6	–						
Yelahanka rain gauge	2011	Rainfall	–	–	–	62	94	13	87	263	41	95	69	3
	2012		–	–	–	4	115	21	99	–	–	–	–	–
Hebbal (monitoring well)	2011	6 p.m.	–	–	–	–	37.3	39.6	38.4	33.7	23.22	24.3	24.5	26.5
		6 a.m.	–	–	–	–	33.3	36.5	36.6	31.8	21.43	23.2	23.7	25.8
		Monthly average	–	–	–	–	35.3	38	37.5	32.8	22.32	23.8	24.1	26.2
		Δ*R* (m)	–	–	–	–	89.8	78.8	85.4	64.9	39.4	24.3	39.1	43.8
		Δ*D* (m)	–	–	–	–	91.9	91.1	79.5	66.3	38.3	26.8	38.8	46.8
		Net rise (m)	–	–	–	–	–	–	5.96	–	1.1	–	0.26	–
		Net decline (m)	–	–	–	–	2.12	12.3	–	1.48	–	2.47	–	3.06
	2012	6 p.m.	31.5	33.7	40.4	44.7	45	49.3	–	–	–	–	–	–
		6 a.m.	30.3	32.4	38.8	42.3	42.65	41.9	–	–	–	–	–	–
		Monthly average	30.9	33.1	39.6	43.5	43.8	45.6	–	–	–	–	–	–
		Δ*R* (m)	33.4	34	42.6	67.4	65.1	78.8	–	–	–	–	–	–
		Δ*D* (m)	36.3	43.3	50.6	73.2	74.5	91.1	–	–	–	–	–	–
		Net rise (m)	–	–	–	–	–	–	–	–	–	–	–	–
		Net decline (m)	2.83	9.26	8.01	5.83	9.45	12.3	–	–	–	–	–	–
Hebbal rain gauge	2011	Rainfall	–	–	–	111	59	60	97	291	98	128	17	5
	2012		–	–	–	12	79	–	–	–	–	–	–	–
HSR layout (monitoring well)	2011	6 p.m.	–	–	–	–	75.7	82.3	71.4	68	75.20	65.7	66.1	76.50
		6 a.m.	–	–	–	–	73.9	81.50	69.5	64.7	57.94	53.9	53.7	52.5
		Monthly average	–	–	–	–	74.8	81.9	70.4	66.3	66.57	59.8	59.9	64.5
		Δ*R* (m)	–	–	–	–	7.07	25	95.5	165	79.12	47.1	45	51.7
		Δ*D* (m)	–	–	–	–	5.33	37.4	83.3	169	87.12	67.4	53.8	71.9
		Net rise (m)	–	–	–	–	1.74	–	10.2	–	–	–	–	–
		Net decline (m)	–	–	–	–	–	12.4	–	3.92	8	20.4	8.76	20.2
	2012	6 p.m.	85.9	90.4	92	92.3	87.7	86.2	–	–	–	–	–	–
		6 a.m.	75.9	88.8	91.7	89.5	87.4	85.4	–	–	–	–	–	–
		Monthly average	80.9	89.6	91.8	90.9	86.1	84.1	–	–	–	–	–	–
		Δ*R* (m)	46.5	16.6	8.5	10.9	31.7	31.4	–	–	–	–	–	–
		Δ*D* (m)	70.1	30.7	13.5	11.4	26.8	25.3	–	–	–	–	–	–
		Net rise (m)	–	–	–	–	4.94	6.13	–	–	–	–	–	–
		Net decline (m)	39.5	14.1	4.96	0.5	–	–	–	–	–	–	–	–
HAL (old air port) rain gauge	2011	Rainfall	–	–	–	196	130	90	124	204	169	124	61	9
	2012		–	–	–	12	147	16	95					

February 2012 and (iv) from March 2012 to July 2012.

Among these four distinct trends, it is noted that during the period when there was no rainfall since December 2011 (Table 1), there had been a distinct unusual increment of nearly 25 m in the piezometric water level during February 2012 (Figure 1 *a*). On field enquiry, it was learnt that the public water supply bore well of BWSSB under reference was not functioning during that period due to certain technical problems. This increment in the piezometric water level of the monitoring well at the time when the BWSSB public water supply bore well was not in operation can be evidently considered as due to interconnectivity of potential fracture between the public water supply BWSSB bore well and the monitoring well. Further, the steep decline of the piezometric water level in the monitoring well during the period of pumping from the BWSSB well and subsequent recovery during the period of non-pumping, evidently indicates its direct effect and impact over the piezometric water level of the monitoring well. This also implies the inter-connectivity of the potential fractures between them.

The maximum depth of water level recorded in the piezometer well was 46.23 mbgl at 6 p.m. during June 2011 and minimum depth to water level was 24.31 mbgl in February 2012. During the period from May 2011 to June 2012, the total net decline in the piezometric level was 113.11 m and the total net rise was 142.56 m, thereby indicating a rise of 29 m in the piezometric head (Table 1).

Hebbal: The piezometer has struck the potential fracture at 95 mbgl. The minimum and maximum monthly average depth to piezometric water level at 6 p.m. was respectively, 23.22 mbgl (September 2011) and 49.29 mbgl (June 2012). However, at 6 a.m., the average monthly minimum and maximum depth to water level in the piezometer was 21.43 mbgl (September 2011) and 42.65 mbgl (May 2012) respectively (Table 1). For the period from May 2011 to June 2012, there was a net decline of 12.29 m. Further, during the period from May to August 2011, the piezometric water level which fluctuated between 33 and 38 m, showed a sudden rise of 16 m during September 2011. This is from the intensive rainfall of 291 mm during August 2011 (Figure 2 *b*). From October to December 2011, there was a slow and gradual depletion of 2.39 m in the piezometric water level. But, from January to June 2012, depletion in the piezometric level was of the order of 14.72 m (Figure 1 *b* and Table 1).

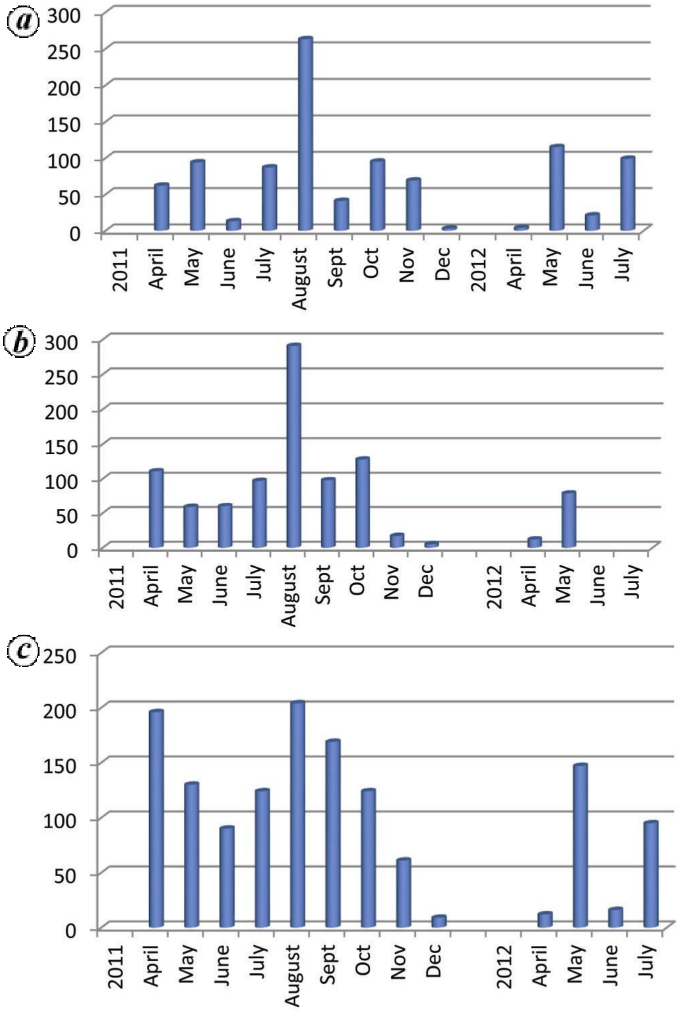

Figure 2. Monthly rainfall (mm) at (*a*) Yelahanka (*b*) Hebbal and (*c*) HSR Layout.

HSR Layout: The piezometer well has struck the potential fracture at 93 mbgl. The minimum and maximum monthly average of the piezometric water levels (arrived at from the daily data) at 6 p.m. was 65.73 mbgl (October 2011) and 92.29 mbgl (April 2012) respectively. Similarly, the average monthly minimum and maximum depth to piezometric level at 6 a.m. was 52.45 mbgl (December 2011) and 91.68 mbgl (March 2012) respectively. For the period from May 2011 to June 2012, the total net decline in the piezometric water level was of the order of 132.74 m as against the net rise of 23.01 m, thereby indicating an overall decline of 109.73 m for the said period (Table 1 and Figure 1 *c*). Thus the decline in the piezometric level as against the net rise remained consistent and significant. While the rainfall for the year 2011 was 1142 mm, it was only 270 mm for the period from January 2012 to July 2012 (Figure 2 *c*). Though the area received 416 mm of rainfall from April to June 2011, spread over 28 rainy days (highest rainfall of 110 mm on 23 April), there has not been any rise in the piezometric water level. But, there has been a rise of nearly 18 m from the monsoon rainfall for the period from July 2011 to November 2011 when the dependence on groundwater for domestic and other uses was relatively less.

The foregoing account of analysis of water-level data and the corresponding hydrographs has brought out the following significant points:

- The high-frequency hourly data from DWLRs has provided high precision/

accurate micro-level ground information about the variations in the piezometric surface of the water levels.

- The site-specific case study of Yelahanka has evidently brought out the impact of withdrawal of groundwater from the nearby BWSSB public water supply bore well over the piezometric water levels of the monitoring well, indicating mutual connectivity of potential fractures between the monitoring well and the public water supply well.
- Though there is not much variation in the quantum of rainfall during the period from April 2011 to July 2012 at the Yelahanka and Hebbal RG stations (966 mm and 957 mm respectively), there has been an appreciable decline in the piezometric level at Hebbal station from October 2011 to July 2012, whereas in the case of Yelahanka, the piezometric level remained almost consistent (except during February 2012), in spite of the impact of withdrawal of groundwater from the public well in the vicinity. This probably indicates the groundwater recharge almost being equivalent to the withdrawal.
- In spite of rainfall of 1098 mm from April 2011 to November 2011, there was a net decline of 41.54 m in the piezometric water level at HSR layout monitoring station, indicating groundwater withdrawal in excess of recharge. Further, from December 2011 (64.50 mbgl) to March 2012 (91.80 mbgl), the piezometric water level reached a maximum depth with a net decline of 79 m, resulting in the piezometer going dry.
- Considering the wide extent of 800 sq. km of Bangalore city and wide variation in the geomorphological, geological and geo-hydrological set-up and heterogeneity of aquifer condition, it is necessary to establish at least one high-frequency water-level monitoring station for each of the 10 sq. km grid area. The data generated from increasing the monitoring stations can be one of the important source materials for specific groundwater modelling to address various geo-hydrological issues.

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Anomalous silver concentration in volcano-plutonic rocks of Siwana Ring Complex, Barmer district, Western Rajasthan

Acid plutonic-volcanic caldera-related environments provide an ideal setting for uranium, thorium and rare metal concentrations. Siwana Ring Complex (SRC) is a well-preserved, ENE–WSW trending elliptical-shaped collapsed caldera structure measuring 30 km × 25 m, comprising basalt–rhyolite–pyroclastic sequence intruded by peralkaline–aegirine–reibeckite-rich granites along the sub-circular fractures. These rock units are traversed by agpaitic, rare earth elements (REE)-rich, felsite, microgranite and aplite dykes of varied dimension all along the periphery of SRC and also within the central caldera sequences. The rocks in SRC are exposed along Ramaniya–Mokalsar–Deora–Kitnod–Indrana–Siner–Kundal area in the Survey of India toposheet numbers 45 C/2, 6, and 10 (Figure 1). The volcano-plutonic complex has been extensively studied for its stratigraphy, geology, structure, petromineralogy, geochemistry and geochronological aspects[1–4].

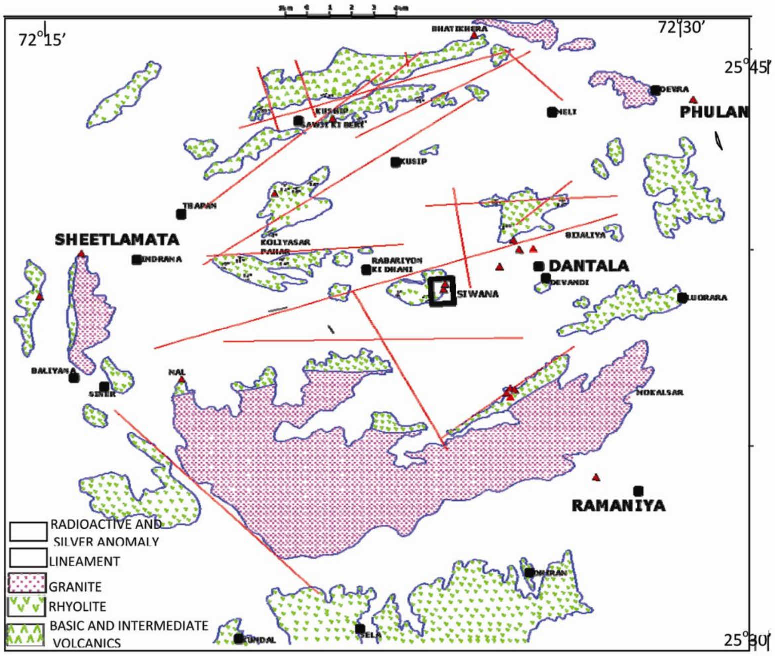

Figure 1. Geological map of Siwana Ring Complex showing radioactivity anomalies and silver occurrences (modified after Bhushan and Mohanty[9]).