Resource availability for water supply to Bangalore City, Karnataka

Bangalore city with an extent of 800 sq. km, located at more than 920 m amsl, forming part of the catchments of Arkavati river to the west and Ponnaiyar river (South Pinakini) to the east, lies between 12°49′34″N and 13°9′9″N lat., and 77°27′41″E and 77°47′5″E long. Nearly 560 sq. km being the built-up area has been a mosaic of concrete structures and asphalt roads. The rest is open area which includes new layouts and parks, gardens, race course, golf-club, etc. The population of the city, which is at present 85 lakhs, is expected to cross 95 lakhs by the year 2020.

Bangalore city forming a part of the semi-arid tract is in the agro-climatic environs of Eastern Dry Zone of Karnataka. The area is drained by first to fourth-order streams, among which the first and second-order streams predominate. While the rivulets and streams of the Arkavati river flowing amidst mounds, hills and rock-cut valleys are mainly trained by NNE–SSW and ENE–WSW lineaments, the drainages of Ponnaiyar river flow more along the NW–SE and WSW–ENE fractures in an otherwise moderately undulated terrain (Figure 1).

The city forms a part of the Gneissic Complex with migmatites, granodiorites and intrusive granites weathered to an average depth of 15 m and covered by red loamy to gravelly soils of varying thickness. The eastern precinct of Bangalore has a spread of about 60 m thick saprolite formation covered by 2–5 m lateritic soil. The saprolite and lateritic soil both being clayey, form an impermeable mantle. The rock formations below about 280 m depth are devoid of potential fractures. Though the area is congenial for rapid surface run-off, the mosaic cover of concrete buildings and asphalt roads prevents infiltration of rainwater into city aquifers and promotes ‘heavy over-land flow’; often inundating low-lying areas. The flow paths of first and second-order streams have mostly been distorted. The Vrishabhavati and Ponnaiyar rivers have shrunk both in width and depth due to encroachments and silting. Though the geohydrological set up depicts effluent drainage characteristics, no base flow is visualized as the water table in general is depleted below the channel base.

The normal annual rainfall (NAR) of the area is 830 mm and 50.37% of it is from the southwest monsoon (June to September). September is the month with a characteristic peak[1]. Of the NAR accounting for 66,400 ha m over 800 sq. km, 46,480 hectare metre (ha m), is over built-up area and 19,920 ha m over open area. The average rainfall in the city for the period from 1999 to 2010 was 937 mm.

In the absence of measured data, the surface run-off was estimated at 17,040 ha m/yr (25.66% of NAR) by applying Ingli’s formula for non-ghat catchment:

$$R = \frac{(P - 178.8)P}{2540},$$

where R is the run-off and P the precipitation (NAR), both in millimetres.

The groundwater table levels monitored from 12 observation dug wells by the Department of Mines and Geology (DMG), Bangalore, from 1973 were discontinued between 1985 and 2000 as these wells became dry over a long period and also a few became nonexistent due to urbanization. A few shallow bore wells drilled in lieu of these wells a decade ago also became non-functional. During 2010, the DMG constructed 12 piezometers and 10 of them were installed with digital water level recorders (DWLR) having telemetry facility. The DWLR data recorded are given in Table 1.

Though depth of piezometers ranged from 108 to 158 m, water-bearing fractures in them were struck between 55 and 150 m and the water-level data represent the fluctuation of the piezometric surface of water struck under semi-confined aquifer conditions. Also, quarterly recording of water levels in the city over a period of time by the Central Ground Water Board (CGWB) from

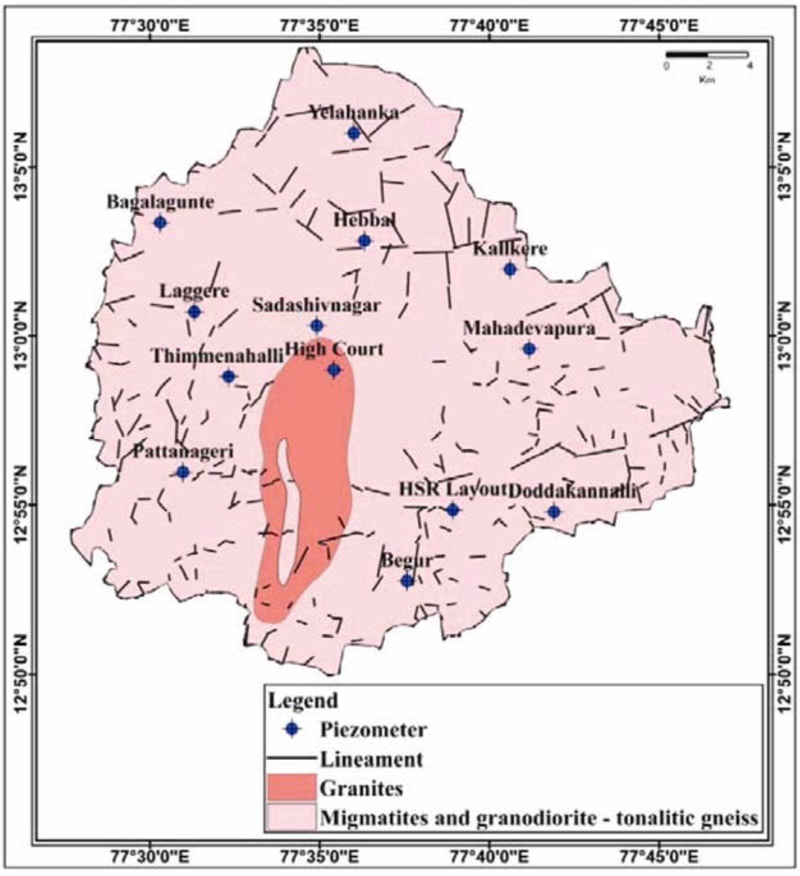

Figure 1. Lithologic and lineament map of Bangalore city.

Table 1. Piezometric water level, 2011

Location	Coordinates		Depth drilled/water struck (m)	Depth to water (m)								
	Latitude	Longitude		April	May	June	July	August	September	October	November	December
Doddakannalli	77.70	12.91	120/55	26.61	26.43	26.75	27.21	27.48	27.54	26.26	26.81	26.95
Hebbal	77.61	13.05	135/95	38.42	36.97	47.55	35.42	30.23	22.21	25.03	24.04	28.07
HSR Layout	77.65	12.92	125/55	78.52	77.53	88.01	58.83	60.12	65.09	59.23	66.76	70.11
Kallkere	77.68	13.04	141/136	75.88	74.54	81.23	76.37	74.34	86.25	82.16	77.16	74.12
Laggere	77.52	13.02	113/56	34.67	33.29	33.54	32.46	21.62	19.18	19.52	19.83	22.94
Mahadevapura	77.69	12.99	158/150	32.95	25.93	23.98	19.27	16.43	14.06	13.54	10.44	10.25
Pattanageri	77.52	12.93	152/142	16.79	16.86	16.65	16.65	13.73	14.47	16.29	14.98	15.55
Sadashivnagar	77.58	13.01	147/108	6.62	6.39	6.22	5.82	4.07	4.07	4.18	4.12	4.23
Yelahanka	77.60	13.10	155/106	48.86	49.09	53.1	43.49	48.27	36.12	34.52	35.24	35.07
Bagalagunte	77.50	13.05	108/33	28.31	27.71	27.60	25.49	21.70	21.20	20.90	20.84	24.42

13 monitoring stations[2] indicated building up of the water table at places where the Cauvery river water supply is adequate (with no secondary dependence on groundwater). Further, decline in groundwater table from the core area to the peripheral parts was also observed because of greater dependence on groundwater as the river water supply is insufficient or yet to be initiated.

The water table-level data are discontinuous from 1985 and hence inadequate. Therefore, recharge estimations were arrived at based on the Groundwater Estimation Methodology (GEM)-1997 (ref. 3) recommendations to consider the rainfall infiltration between 3% and 9% depending upon the prevailing hydrogeological conditions of the hard rock area. In the present case, infiltration of rainwater in the built-up area is prevented because of the mosaic cover of concrete structures and asphalt roads. However, there could be some open spaces left, and hence rainfall infiltration to aquifer at 2% in the built-up area and 6% in the open area has been considered, which amounts to 930 and 1195 ha m/yr respectively. Also, from 96 perennial tanks[4] recharge to groundwater is estimated at 905 ha m according to the guidelines of GEM-1997 (ref. 3). The Vrishabhavati and Ponnaiyar river systems together carry an estimated[5] sewage load of 721 million litres/day (MLD)[5], i.e. 26,316 ha m/yr. Groundwater recharge from sewage discharge is estimated at 263 ha m/yr, which accounts for 1% of the total sewage discharge. Thus, the total groundwater recharge into the city aquifer from various sources is estimated at 3290 ha m/yr.

Of the 66,400 ha m of water from NAR, with estimated surface run-off at 17,040 ha m and groundwater recharge at 2,125 ha m, the balance of 47,235 ha m, i.e. 71.14% rainfall is accounted to as evapotranspiration.

Thus at 140 lpd/head (ref. 6), the water requirement for a population of 95 lakhs by the year 2020 shall be 133 ha m/day, i.e. nearly 48,600 ha m/yr.

Let us now consider the present status of water supply.

River sources: The overall potentiality created by BWSSB from the Arkavati (Hesarghatta and Tippagondanahalli reservoirs – 6040 ha m/yr) and Cauvery river (stages I–IV, phase I – 29,565 ha m/yr) sources is 35,605 ha m/yr. As against the annual requirement of 48,600 ha m, BWSSB though has created a potential of 35,605 ha m from the river sources (stage-IV, phase II to tap another 27 ha m/day is still on anvil), the effective supply after conveyance and other losses of nearly 30% is only 24,923 ha m.

Groundwater: No realistic data of bore wells in the city are available even from the Government institutions or agencies. However, a rough estimate shows nearly 3.12 lakh bore wells. To meet a part of the deficit, BWSSB is supplying about 1300 ha m/yr of groundwater from 7000 bore wells at around 5,000 lpd/bore well. In addition, from about 105,500 privately owned bore wells registered with the BWSSB[7], about 3,851 ha m/yr of groundwater at about 1,000 lpd/bore well is being drawn for domestic purposes. That apart, about 7,300 ha m/yr of groundwater is being extracted from about 2 lakh unregistered private bore wells to meet the domestic, commercial and industrial needs. Thus, as against the groundwater recharge of 3,290 ha m/yr, groundwater draft is conservatively estimated at 12,451 ha m/yr, i.e. 378% or nearly four times the annual recharge. While the geohydrological and drilling data have revealed absence of potential fractures beyond 280 m depth, now bore wells are being drilled around 300 m; more so in the peripheral parts, implying extraction of static groundwater resources, i.e. a scenario of mining of groundwater. In a study, 30% of bore wells at 100 m depth, 54% between 100 and 200 m, 15% between 200 and 300 m and 0.56% beyond 300 m depth, have been reported[7].

The present scenario is that against an annual demand of 48,600 ha m, only 37,374 ha m is now being supplied from both surface and groundwater resources. The shortage in supply of nearly 11,226 ha m of water means nearly 22 lakh people face water scarcity. This too in the prevailing situation of excessive exploitation of 9,161 ha m/yr of groundwater against the annual recharge. In case the city aquifers become barren because of overexploitation, an additional 24.38 lakh population in the city will be badly affected.

We propose the following recommendations. As a measure to counter the shortage in water supply, if the storm water discharge of 17,040 ha m/yr (which is being wasted by being drained along with the sewage water) is protected and conserved, this can meet the requirement of about 23 lakh people, i.e. nearly 24% of the city population. Further, if the total sewage load of 26,316 ha m/yr being generated in the city is treated up to tertiary level and brought to the safe standard of domestic and drinking water usage and even 70% of such treated water is made available, it can serve about 26 lakh people in the city. Thus, the surface run-off and the treated sewage water together can serve the water requirement of about 50 lakh people, i.e. 53% of the city population. Better management and judicious usage of the water resources available within the city will prevent the uneconomical and anti-environmental proposals like diversion of water from the west-flowing rivers like the Nethravati in the Western Ghats and/or from distant river systems like the Krishna.

Groundwater is now not a sustainable resource. It is susceptible to the vagaries of rainfall. It needs to be considered only as a stand-by resource to be used during scarcity or drought. The groundwater table should be allowed to revive up to the unconfined aquifer horizon. Also, there should not be exploitation of groundwater resources beyond 60% of the corresponding annual groundwater recharge.

1. Rao, M. K. M. and Jagannathan, V., *Geokarnataka*, MGD Centenary Volume, 1994, pp. 388–395.
2. Hunse, T. M., Farooqi, M. A. and Jayaprakash, H. P., *Geol. Soc. India Mem.*, 2011, **79**, 84–88.
3. Groundwater estimation methodology, Ministry of Water Resources, Government of India, 1997.
4. Reddy, S., In *Groundwater Hydrology and Groundwater Quality in and around Bangalore City*, Department of Mines and Geology, Bangalore, 2011, p. 90.
5. Tippeswamy, M. N., *J. Geol. Soc. India*, 2011, **77**, 491.
6. Bangalore Water Supply and Sewerage Board, *Hand Book of Statistics*, 1996, pp. 1–145.
7. Srikanta Murthy, D., In *Groundwater Hydrology and Groundwater Quality in and around Bangalore City*, Department of Mines and Geology, Bangalore, 2011, pp. 18–28.

ACKNOWLEDGEMENTS. We thank H. R. Srinivasa, Director and H. M. Khayum Ali, Additional Director, Department of Mines and Geology, Bangalore for their encouragement.

Received 10 August 2011; revised accepted 19 March 2012

G. V. HEGDE[1,*]
K. C. SUBHASH CHANDRA[2]

[1]*Department of Mines and Geology, No. 49, Khanija Bhavan, Race Course Road, Bangalore 560 001, India*
[2]*No. 17, 'Ganga Block', Goodwill Apartments, Chandra Layout, Bangalore 560 040, India*
**For correspondence.*
e-mail: hegdegv@gmail.com

Brick pieces soaked in liquid culture medium – a new matrix for seed germination and plantlet development for orchid *Flickingeria nodosa* (Dalz.) Seidenf.

In vitro seed germination, growth and development of plants are largely determined by the composition of the culture medium. The main components of most plant tissue culture media are mineral salts and sugar as carbon source. Other components may include organic supplements, growth regulators and a gelling agent[1,2]. The growth of cultures and production of shoots or roots are strongly influenced by the physical consistency of the culture medium. Gelling agents are usually added to the culture medium to increase its viscosity because of which plant tissues and organs remain above the surface of the nutrient medium[3]. The most commonly used gelling agent in plant tissue culture media is agar due to its stability, high clarity, non-toxic nature and resistance to plant metabolites[4–6]. Several attempts have been made to look for an alternative gelling agent as agar is expensive and also due to the threat of exhausting the sources of agar. Some of these alternatives include starches and plant gums[7,8], alginates[3,9], gelrite[10], agarose[11], isubgol[12], starch[13–15], cotton fibre[16], glass wool[17], polystyrene foam[6], glass beads[14,18], filter paper[17] and glass marbles[19]. Furthermore, several alternative supporting matrixes have been tried for *in vitro* germination of orchid seeds and nodal culture using glass beads for *Vanilla* nodal culture[3]; polyurethane foam disc, coconut coir, betel nut coir, leaf litter for asymbiotic seed germination and plant regeneration of *Cymbidium aloifolium*[20]. But, most of these materials are less explored in application than agar and have their own limitations. Hitherto, there is no report on the use of brick pieces as supporting matrix for the germination and development of orchids. However, brick pieces and charcoal are the materials that are being used for *in vivo* cultivation and hardening of orchid plants. Keeping this in view, an economical method with brick pieces soaked in liquid culture medium has been formulated for *in vitro* seed germination and development of a medicinally important orchid, *Flickingeria nodosa.* Furthermore, not much work has been documented on the *in vitro* studies of *F. nodosa.*

F. nodosa (Dalz.) Seidenf. is a medicinal epiphytic orchid found in the Eastern Himalayas, Sri Lanka and in parts of the Western Ghats in India, namely Kodagu, Hassan, Uttara Kannada and Udumbansholai[21,22]. It has a creeping rhizome sending erect pseudobulbous greenish-yellow or yellow shoots and occurring in large colonies on tree trunks. The white flowers with pink lips produced singly or in twos last only for a day. The sidelobes of the lips are deeply spotted with violet-pink, and midlobe is white with red markings[21,22].

Bricks were collected from the field for preparation of the supporting matrix. They were broken into small pieces of approximately 1 cm and sieved to remove the mud particulates. Brick pieces were surface-sterilized by thoroughly washing several times in running tap water to remove the mud particulates. The brick pieces were then soaked in 2% (w/v) potassium permanganate solution for 30 min to kill the fungal spores that might be present in them, and rinsed several times with running tap water and twice with 70% ethanol to remove the traces of potassium permanganate. They were immersed in sterile water and the pH was adjusted between 5.6 and 5.8 as the brick pieces may have some acidic or