Occurrence of groundwater in the Ponnaiyar river catchment covering eastern parts of Bangalore city, Karnataka, India

The mega city Bangalore, spread over an extent of 800 sq. km, located at more than 920 m amsl with N to NW stretch of high land extending from Kalsandra at the mid-southern boundary to almost Peenya in the north, and covering part of core area localities like Basavanagudi, High Grounds, Malleshwaram, Yeshwanthpura, etc. forms a divide between the Arkavathi river catchment of the Cauvery Basin in the west and Ponnaiyar river (also called 'South Pennar' or 'Dakshina Pinakini') catchment in the east. The catchment part of these river systems in the city area is drained by first to fourth-order streams (Figure 1).

The Arkavathi river catchment, with an extent of 365 sq. km in the Bangalore urban limit, mainly represented by the southerly flowing Vrishabhavathi drainage system, geo-morphologically dotted with hills and mounds is characteristically a highly undulated terrain with narrow, deep rock-cut valleys and intermittent rock exposures on the stream beds. The flow system of the Vrishabhavathi and its subsidiary drainages is fracture-controlled, often displaying evidences of faults and shears.

Contrary to the Arkavathi catchment, the Ponnaiyar catchment in the east with an extent of 435 sq. km in Bangalore urban, forms almost a vast plain terrain, displaying moderately undulated to rolling topography. The Ponnaiyar river catchment is controlled by easterly flowing drainage systems; Hebbal valley, a main drain for Yelemallappashetty Kere in the northeast and Koramangala–Challaghatta valleys in the southeast draining into the Bellandur tank and further into the Varthur Lake in the east. There has been a topographic fall of about 50 m over a flow length of 15 km from the origin point of these subsidiary streams up to the eastern periphery of the city. The flow path of these subsidiary drainage systems is broad and shallow, and over the chemically altered rock mantle. Interestingly, the stream paths of the Hebbal valley in the north and the main drain of HSR Layout up to the Varthur Lake in the south display parallel easterly linear flow. Similar characteristic parallel linear easterly flow features are also seen at Bagalur–Doddajala drainage systems beyond Yelahanka in the north.

The effects of urbanization have resulted in the distortion and diversion of the original flow path and thereby exhibit no integrated spatial pattern in the stream systems. The natural drainage systems in the Bangalore urban area have also shrunk both in width and depth because of encroachment and silting. The mosaic cover of concrete buildings and asphalt roads in the city has been a major causative factor for heavy over-land flow.

Bangalore city forms a part of gneissic complex with migmatites, grano-diorites, intrusive granites and dolerites dykes. The north to northwest trending narrow intrusive granite belt, earlier described as the conspicuous high land forms a divide between the Arkavathi and Ponnaiyar river catchments (Figure 1). However, in the Ponnaiyar catchment, from east of the Central high land up to the eastern periphery and from 12°55′N lat. up to the northern periphery of Bangalore and further beyond, the gneissic formation has undergone the process of chemical weathering since geological past, resulting in the formation of a vast, thick mantle of clayey saprolite. The upper part of the saprolite is matured and reworked impermeable clay and has attained

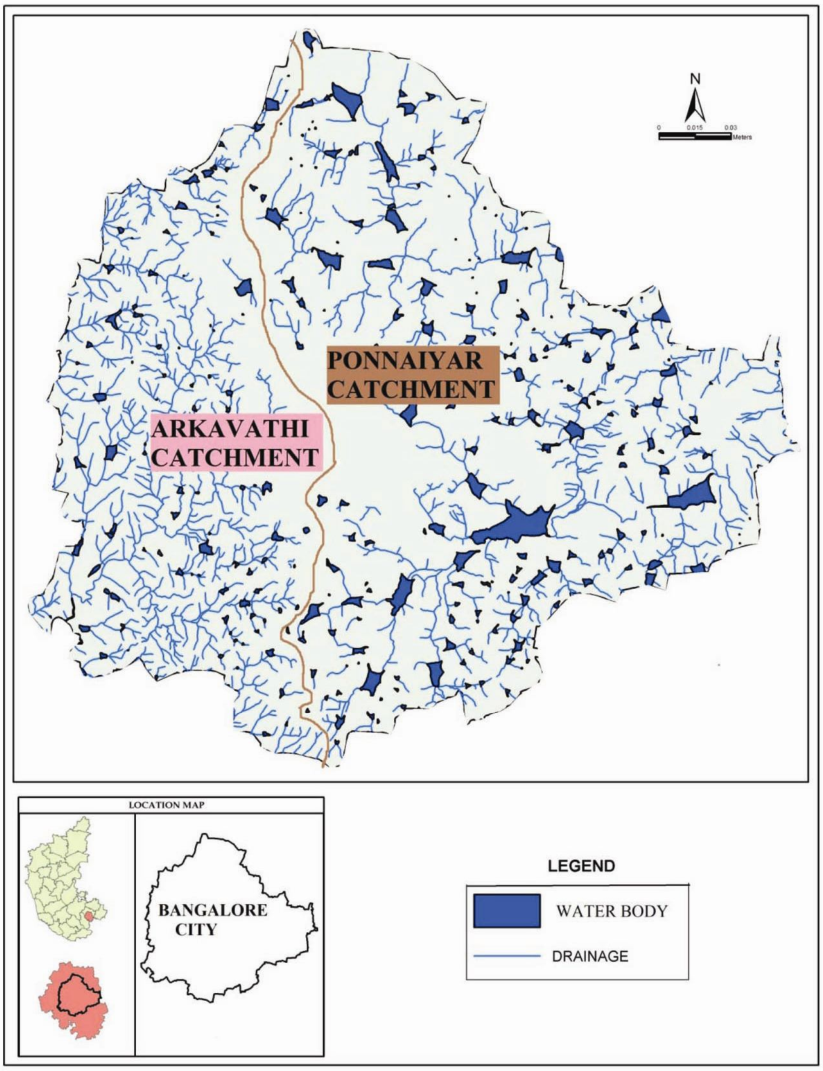

Figure 1. Bangalore city drainage.

considerable thickness. The youngest product of the chemical weathering is at the bottom since the weathering is a downward proceeding process[1]. Permeability may therefore progressively emerge at greater depths in the saprolite mantle. Topographically, the moderate flat relief has appreciably prevented erosion of the clay formation. The laterite cap rock, in general, has been eroded away and seen at places as remnants beyond the eastern limits as near Hoskote (77°47′45″E; 13°04′48″N). The soil covering the saprolite derived out of laterite is also highly clayey.

Normally, in a hard-rock terrain like those of gneissic or granite formations, some connectivity exists between unconfined and semi-confined aquifer zones. In the sense, part of the water recharged into the unconfined media percolates into the semi-confined aquifer horizon. But, between the unconfined and semi-confined aquifer zones, a transitional zone exists where the rock body exhibits a double porosity system with the rock matrix being partially weathered and the count of joints moderate. Such a type of transitional semi-unconfined aquifer system below the unconfined media is normally up to a depth of 20–25 m. Thus, in general, the unconfined and semi-unconfined aquifer zone together extends up to 40–45 m below the surface. There on, the semi-confined aquifer zone forms almost a fresh rock with no interstitial space left between the mineral grains, but has joints and/or fractures that act as the only water conduits. These joints also become compact and sparse at further depths. The semi-confined aquifer zone ends up to a depth when the parent rock becomes a fresh massive rock horizon without any joints or fractures and no more functions in any form as an aquifer unless it is structurally deformed[2]. Depending upon the capacity of the aquifer to accept, store and transmit water, the quantum of water that infiltrates reaches the upper surface of the massive rock horizon which is impermeable. Later it gets into the process of gradually saturating all the fractures, joints and any voids in an ascending manner from the bottom line of the semi-confined aquifer. Davis *et al.*[3] have referred to the 'fissured aquifers' (of Bangalore) within the first 100 m below the ground surface as 'discontinuous aquifers' because of the discreet hydraulic conductivity.

However, major part of the Ponnaiyar catchment in the city is a saprolite terrain. The thickness of the saprolite mantle increases as we moved from west to east and attains a varying thickness of 50–60 m at the eastern precincts of Bangalore (Figure 2). They are generally covered by red lateritic soil of 2–3 m thickness. The saprolite formation and lateritic soil, both being clayey, together form an impermeable layer at the surface[2]. The saprolite being clayey and impermeable, functions as 'aquiclude'. Mehta *et al.*[4] applying a 'GIS-based distributed groundwater model' indicated that in the central part of the city, groundwater levels are shallower than in the natural state by 4.7 m and they consider it 'as consistent with the trend documented by CGWB for core areas of the city supplied by piped water supply'. But, we note that the shallow groundwater so reported is in parts of the central N to NW-oriented high land forming mainly the intrusive granite belt that forms the divide between the Arkavathi and Ponnaiyar catchments. The granite forming the central high land is weathered to variable depths between 10 and 20 m and further below it is fresh and sparsely jointed. Many of the bore-wells drilled in the granite belt as in certain parts of Basavanagudi, Gandhi Bazaar, Prakashnagar (Hanumanthapur–Rajajinagar), Malleswaram, etc. remained dry without tapping any potential fracture almost up to a depth of 230–240 m. This implies that shallow groundwater condition in the area is probably due to the presence of hard massive rock at shallow depth and/or perched water-table conditions. Such perched water-table conditions are also common in the saprolite terrain.

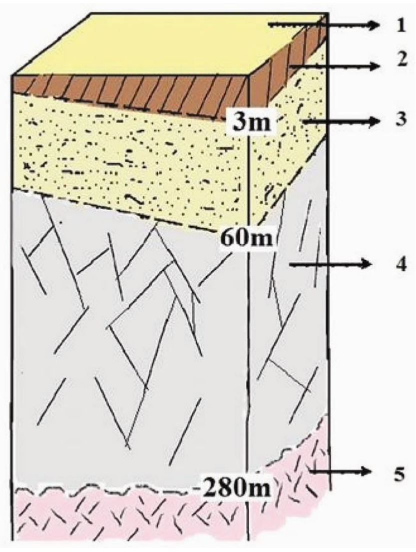

Figure 2. Schematic diagram depicting confined aquifer. 1, Mosaic of concrete building; 2, Lateritic (clayey) soil; 3, Saprolite (impermeable); 4, Confined aquifer; 5, Hard massive rock (impermeable).

It is interesting to note that while the normal annual rainfall (NAR) of Bangalore city is 830 mm, NAR of the Ponnaiyar catchment is 794.8 mm and that of the Arkavathi catchment is 863 mm, indicating a decline in NAR as we moved from west to east of Bangalore. Out of 794.8 mm of NAR in the Ponnaiyar catchment, nearly 51% is contributed from the southwest monsoon (June to September), 31% from the northeast monsoon (October to December) and rest 18% during pre-monsoon season[5]. In the absence of measured data, the run-off has been estimated at 24.27% for the urban part of the Ponnaiyar catchment[2]. Major part of the Ponnaiyar catchment, apart from being an impervious saprolite horizon, has been the built-up area that has become a mosaic of concrete structures and asphalt roads. This has further prevented infiltration of rainwater into the ground and promoted heavy over-land flow. However, there are some pockets of undisturbed natural landscape in the adverse geo-hydrological saprolite terrain demonstrating perched aquifer conditions. The lineament zones are in general the only zones that act as water conduits and promote groundwater recharge in the terrain. An earlier study has indicated the rainfall infiltration into the aquifer under such conditions as limited to 2% (ref. 2). Nearly 73% of the rainfall can thereby be accounted towards 'evapotranspiration'.

The unaltered part of gneissic rocks below the impermeable saprolite mantle has in its original form remained hard and fresh with joints being compact and sparse at great depths and almost beyond 280 m from the surface forms an impermeable massive rock horizon[2]. The lakes and tanks in the Ponnaiyar catchment of the city are more in number and big in size (Figure 1). Though these water bodies are larger in water storage capacity, the accumulation of clayey silt on the tank/lake beds has also retarded the effective infiltration of water from its storage to the groundwater body.

Looking into the prevailing geo-hydrological aspects of the Ponnaiyar catchment in the Bangalore city limit, we strongly propose that the sparsely jointed/fractured, unaltered-fresh and compact part of the rock body located between the impermeable 'clay loaded saprolite mantle' above and the massive rock horizon below, as 'the confined aquifer' and not 'the semi-confined aquifer' as generally considered. There can hardly be any percolation of water into this zone through the vast thick stretch of impervious clayey saprolite formation above. If there can be any groundwater recharge into this zone, it can be through the composite aquifer zone of the neighbourhood locality that may have some extended connectivity through joints and fractures. Also, the prominent regional E–W, ENE–WSW and NW–SE lineaments extending into the urban limits of the Ponnaiyar catchment may be the other source of some groundwater contribution into this zone.

A rapid field visit and local enquiries made in the southeastern and eastern parts of the Bangalore urban area revealed that most of the bore wells drilled beyond 250 m depth did not strike water or when tapped, the yield was poor and even that did not sustain for a few months period. In areas like east of HSR Layout, Ibbalur, WIPRO surroundings, Doddakannalli, Krishnarajapuram, C.V. Raman Nagar, etc. which have witnessed the growth of apartments and housing colonies, many bore wells drilled even beyond 280 m depth have yielded no returns. Field enquiry also revealed that some of the bore wells drilled about 5–6 years back which had tapped water at depths between 200 and 250 m, sustained only for 1 or 2 years and later most of them became dry.

The study by Hegde and Shashirekha[6] on the chemical quality of groundwater of Bangalore city, has revealed that out of 2137 groundwater samples that were analysed, nearly 33% in the SE zone and 27.5% in the NE zone of Ponnaiyar catchment contained more than 1000 ppm of total dissolved solids. The pH in general ranged between 6.5 and 8.5 with a transitional change from being acidic in the west to alkaline in the east. Similarly, more than 1.5 ppm of fluoride was noticed in the samples in the SE and NE peripheral parts of the Ponnaiyar catchment. Highest fluoride content of 5.54 ppm was noted in the SE parts at and around Belandur. The high fluoride content in groundwater can be attributed to long residence time of groundwater in the aquifer.

Based on tritium measurement, Davis *et al.*[3] have reported that the groundwater in Challaghatta and Koramangala valleys is modern in age (40–50 years). Based on ^{14}C values, they have estimated the age of groundwater in Hebbal valley at 4407 years. Thus, we conclude that consequent to the rapid growth of the city, the groundwater stored since ages in most parts of the confined aquifer zone of the saprolite terrain has been exploited and almost exhausted. Further, the groundwater age of 40–50 years in Challaghatta and Koramangala valleys indicates that the annual replenishment into the confined aquifer may have been negligible.

This entire scenario explicates the condition that the saprolite terrain, more so in the eastern peripheral parts of Bangalore, with poor annual replenishment and over exploitation of the long-stored groundwater reserves has resulted into a stage where the 'confined aquifer zone' has almost become barren, supporting our earlier view that groundwater has not been a sustainable resource[2]. Further, with the prevailing adverse geo-hydrological set-up and poor groundwater quality[6] in the Ponnaiyar catchment part of Bangalore city, the groundwater recharge measures to revive the near-barren confined aquifer is not a viable approach and will not yield the desired results.

Karnataka is pondering over the issue of diverting water from the west-flowing rivers in the Western Ghats to the east on the plea that most of the monsoon flow drains into the Arabian Sea. The Yettinahole diversion project which is under serious consideration to tap and divert to the east about 24 TMC of monsoon flow from a catchment area of 90 sq. km at 50% dependability[7] to quench the thirst of Hassan, Chickmagalur, Kolar, Chickaballapur, Bangalore, Tumkur and Ramanagara districts, involves construction of eight dams in two phases at the head waters of Gundia river, a tributary of Kumardhara, which in turn is a major tributary of the main Netravati river. The project report insists calling these dams as 'weirs', but the height of these is said to have been designed at 15 m, making them large dams according to the definition of the International Commission on Large Dams[7].

The Netravati river which originates at a height of 1000 m amsl, flows over a length of 103 km with a catchment of 1353 sq. km amidst the dense evergreen forests of the Western Ghats. Many mini hydroelectric projects have been set up causing damage to the environment of the ecologically sensitive region[8]. The area is said to be home to significant rare species of flora and fauna and survival of amphibians are dependent on the river water flow. Such dams/weirs will affect the aquatic ecosystem. There will be increase in salt proportion in the lower regions of the river and estuary part also due to saline water (sea water) encroachment when the inland flow is reduced near the coast. The steep slope in the head reaches is said to be over a flow length of 8 km and later it becomes steep to moderate. The mean annual rainfall is 4160 mm. The average annual run-off of Netravati river at Bantwal gauging station is 11,057 million cubic metres[9]. The Netravati river supplies the main source of drinking water, to Mangalore City Corporation, Bantwal town and also many other sub-regions of its catchment. The pH of water is mildly acidic. The dissolved oxygen is lesser during non-monsoonal months and the concentration of dissolved organic carbon increases during non-monsoonal months and contains concentration of dissolved trace elements (V, Ba, Cr, Co, Ni, Mn, Zn, Fe, Mo, Cu, As)[10]. The chemical quality of the river is reportedly in general below the permissible limits for drinking and deserves a detailed study.

Due to global warming, already weather variability is being experienced. The complex changes in water availability due to climate change are yet to be understood. An increase in mean temperature could increase potential for evapotranspiration in the forests and trigger changes in the environment. Temperature differences influence the timing of the southwest and northeast monsoons. Changes in rainfall can lead to varying discharges in the river and sedimentation at the estuary part. For fisherman, it could lead to changes in catch composition[11]. It is also reported that due to global warming there has been a rise in sea level at 1.75 mm/yr along the west coast[12] and this may cause further impact on the west-flowing river system if the natural flow is disturbed and diverted.

Giving a balanced view into all these aspects and looking into the prevailing adverse geo-hydrologic conditions, we strongly suggest that before considering aspects like diversion of westerly flowing rivers, the most important measure first to be exercised by every citizen and all the private/public agencies is to 'catch the water where it falls' and that could mainly be through adoption of rooftop rainwater harvesting measures which we consider as more appropriate and effective in the area.

Rainwater is a fresh water source and can be harvested where it is required. Harvesting of rainwater mitigates urban flooding. Ramasesha[13] defines rooftop rainwater harvesting as a technique of capturing and storing rainwater to be used later for domestic use, washing, watering plants, flushing toilet, etc.

Rainwater falling on the terrace can be collected through pipelines and stored in a storage tank for direct use. The total volume of rainwater available from any rooftop is a product of total rainfall and surface area of collection. Depending upon the quantity of water collected and stored during the monsoon, it comes to use in the later months of the year. The rainwater collection also depends upon the intensity of rainfall. The roof water harvesting potential can be arrived at by the formula: roof area × run-off coefficient × annual rainfall[13]. Given the water crisis that comes up every year, Shivakumar, after having tabulated the rainfall data for over last 100 years found that there is more than enough rainfall in the city. He also noted that the gap between two good rains is seldom more than 90–100 days. He has built tank of 45,000 l in his residence and has achieved total water self-sufficiency through rooftop rainwater harvesting[14].

Out of 38,595 ha m of NAR over 465 sq. km extent of the Ponnaiyar catchment in the city, the estimated surface run-off of 9900 ha m/yr needs be on priority properly conserved, stored and effectively protected from pollution in the existing chain of cascading water bodies/lakes in each of the valley systems in areas like that of Ulsoor, Challaghatta, Belandur, Varthur, etc. in the south and Yelahanka–Jakkur–Hebbal–Nagavara–Hennur-Kalkere-Yelemallappashetty Kere in the northern part. The water so available, if brought to the drinking water standards, nearly about 15 lakh people in the area who in the absence of effective public water supply are dependent upon groundwater and are facing acute scarcity of water because of the dwindling groundwater resources, will largely benefit.

In addition, the effective adoption of public–private–participation model as is successfully adopted in countries like Singapore, is to be implemented to recycle and reuse the wastewater generated in the area after due treatment.

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