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Use of Environmental Isotopic Proxies for Evaluating Geo-Hydrologic and Pollution Aspects of Groundwater on Bangalore City, India

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Abstract

Water quality data from 81 samples sites (groundwater, surface water and sewage) before and after the monsoonal cycles, aquifer characteristics of Bangalore city were compared to assess the risk of urban development in hydrological environment. Isotopic and physicochemical investigations were carried out to characterize isotopic nature of sewerage and their influence on groundwater in the crystalline aquifer. The similarity of water quality data was assessed using PCA analysis and samples were differentiated as strong to moderate sewerage or geogenic influences. They were compared with the isotopic signature and discriminated as under the control of different sources. From the tritium measurement, it is inferred that groundwater is recharged within 50 years. ¹⁴C values is 56 pmC (~4407 years), indicative of a complex aquifer system in this urban area. Study evaluated the possibilities of isotopic signature for the study of geo-hydrologic and pollution aspects of groundwater in an urban set up.

Keywords: Water quality; Hydrology; Geo-hydrology; Groundwater; Environmental isotope

Introduction

Urbanization changes drastically the hydrologic cycle of natural areas. Buildings, roads, sidewalks, and parking lots make the land surface impermeable to the infiltration of precipitation, diminishing the natural recharge of the aquifer. Although natural infiltration decreases, artificial recharge from inadvertent leaks and discharges from water sources, such as water supply distribution and sewer systems, septic systems and cesspools, and irrigation of parks, augments aquifer recharge. This paper discusses the ongoing project aiming to develop a management strategy for groundwater development of urban area of Bangalore, a fast developing city of India. The crystalline aquifers get recharged from diversified sources like rain, river Cauvery water and lake water. In urban areas sources and their pathways are very complex and existence of secondary sources like storm water, potable water supplies, waste water or sewages are prominent with the other sources [1-3]. Among these sources sewage can affect people's immediate environments and leads to water related illnesses such as diarrhoea that kills 3-4 million children each year [4]. The impact of urbanisation on the hydrological cycle is complex and it affects almost all hydrological processes [5,6].

Materials and Methods

Study site description

Bangalore city has a contemporary population density of approximately 20000 people per km² with a population of more the eight million soles [7]. The capital city of Karnataka state, spans over a geographical area of 713 Km² situated at an altitude of about 894 m (MSL) Bangalore is located between 12°39' N and 13°18' N latitude and 77°22' E and 77°52'E longitude (Figure 1). Rapid increase in population, industrialization and migration of people from rural Karnataka and rest of the country in a relatively short span of time has put more pressure on the water balance of the city [8]. Bangalore city is blessed with uneven landscape with intermingling hills and valleys. The prominent ridges run parallel towards NNE-SSW direction. The particular physiographic setting of gentle slopes and valleys on either

side of this ridge hold better prospects of groundwater utilization and harvesting. The low lying area is marked by a series of tanks and small ponds.

The inner core area (290 Km²) is seweraged which covers four major valleys, (Vrishabhavathi, Koramangala Challaghatta and Hebbal) and five minor valleys (K&A Minor Valley, Kathriguppe Minor Valley, Tavarakere Valley, Hebbal Minor Valley I and Hebbal Minor Valley II). The primary objective being to drain off the sewage flowing into open drains, storm water drains etc., in order to convey the same to

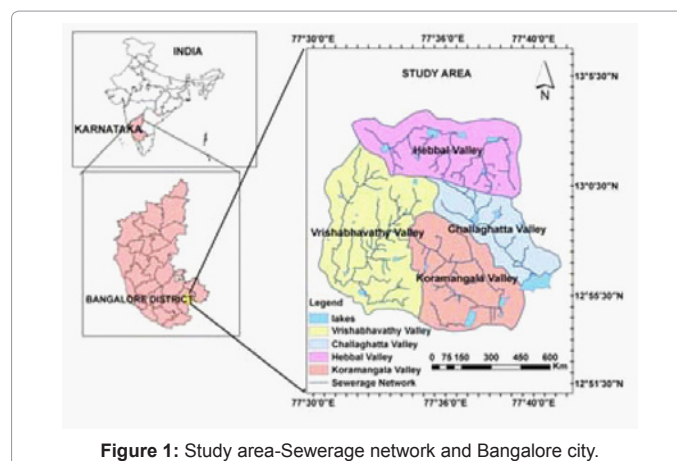


Figure 1: Study area-Sewerage network and Bangalore city.

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the sewage treatment plants for treatment before disposal. Survey conducted on this study and detailed analysis revealed that some treatment plants at certain stretches are not capable of handling the existing as well as the expected future flows.

At present Bangalore is using around 1200 MLD of water and approximately 960 MLD sewage generated. Presently BWSSB has facilities to treat 500 to 550 MLD with their eleven STP's. Consequently huge quantity of sewage is likely to interact with the groundwater resources. The present study attempts to explain this relationship through geochemical and isotopic approaches.

The study envisages assessing geohydrological controls and the urban pollution impacts on groundwater regime using hydrochemistry and environmental isotope techniques. Also, the information about the human impact on water regime is dispersed from different sources. An integral planning of water resources use and protection is based not only on information on hydrological, chemical, and ecological characteristics of water, but also impacts the water environment, water use, future needs and potential conflicts.

Hydro geological setup

Hydrogeology draws together the information on the aquifer setup (lithology and geology), topography and spatio-temporal behaviour of groundwater level and abstraction status. The surrounding areas of Bangalore are entirely underlined by Precambrian granite and gneiss of the Indian Precambrian Shield which are part of the peninsular granitic complex. Migmatite and gneiss are dominant, but there is a zone of granite and granodiorite some 20 km wide trending in a north-north-west direction across the far western part of the district. Minor areas of Charnokite occur in the far south western part of the district, and there are some small elongated bodies of amphibolites and schist aligned along a north-south trend through the central part. The dominant strike direction is northwest, with a subsidiary concentration of apparently smaller structures having an east north easterly strike [9]. They also refer to lineaments, presumably associated with fracturing (and/or the dolerite dykes), with a concentration of strike in a north-northeast alignment, and with a length ranging from 5 to 30 km. There are major lineaments with a north westerly strike too, although they might be associated with the dolerite dykes. The weathered zone is of considerable importance to the groundwater occurrence, because the fresh granitic and gneissic rocks have no primary porosity. They can only store and transmit water via open fractures, and a universal characteristic of such aquifers is that they mostly have very low hydraulic conductivity and a high degree of lateral in-homogeneity. In some rock types, the weathering process may increase the hydraulic conductivity by widening the fracture openings, and/or by creating a small amount of inter-granular space as some of the weathered products are removed by solution. The depth of weathering may be greater along the linear features, and there is some possibility that the degree of fracturing and the resultant hydraulic conductivity will be greater near the intersection of linear features (Figure 2).

The aquifer system in the Bangalore urban district is a combination of the shallow weathered zone, which extends to a maximum depth of about 60 m but is commonly less, and there is underlying fresh rock. The hydraulic conductivity of the weathered zone has been enhanced to a small degree, but is still relatively low. The deeper, fractured fresh rock parts of the aquifer have a very low hydraulic conductivity. Because of this difference in character, they may appear to be independent aquifers, but in the longer term and on a broad scale they will be interconnected. Recharge to the system will be through the shallow weathered zone and

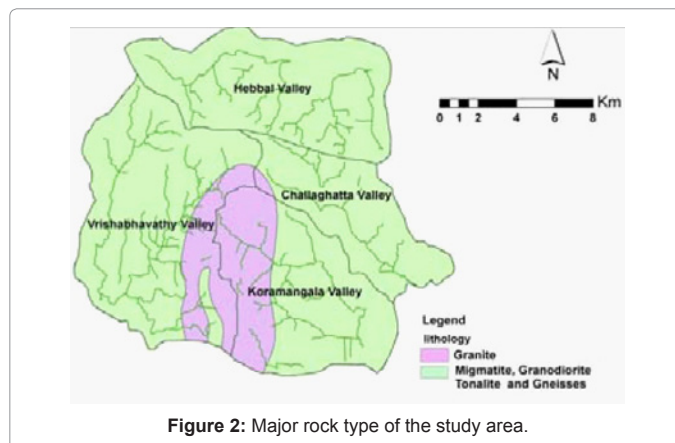


Figure 2: Major rock type of the study area.

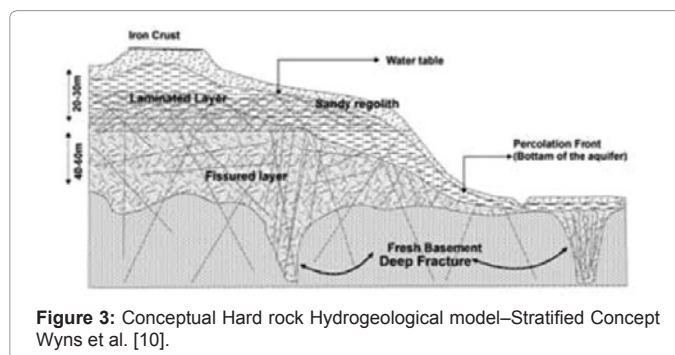


Figure 3: Conceptual Hard rock Hydrogeological model–Stratified Concept Wynn et al. [10].

from there some water drain into the deeper fractured rock aquifer. Studies indicate that the depth range 30–40 m is clearly the most common to locate water bearing fracture zone. From 40–90 m, there is very little difference in frequency of occurrence, but beyond 90 m the likelihood of intersecting a water-bearing zone decreases rapidly [10]. The “hard rock” aquifers, or “fissured aquifers”, present near the surface (within the first 100 m below ground surface) are considered as “discontinuous aquifers”, as a consequence of their discrete hydraulic conductivity. In fact, during a drilling, the first significant water bearing zones appeared within the fresh (hard) rock. The well intersects an impermeable rock that only vary locally (along a few centimetres or decimetres) showing significant permeable zones. Most of the wells exhibit a few of these water strikes (from 0 to 4 or 5 water bearing zones). The Schematic conception of the hard rock aquifer after [10] is shown in the figure 3. The weathered portion and the saprolite or regolith, is a clay-rich material derived from prolonged *in-situ* decomposition of bedrock and is few tens of meters thick (where this layer has not been eroded). Because of its clayey-sandy composition, the saprolite layer can reach a quite high porosity, which depends on the lithology of the parent rock (bulk porosity is mainly between 5 and 30% and displays generally a quite low permeability, about 10^{-6} m/s. Where this layer is saturated, it mainly constitutes the capacitive function of the global composite aquifer. The fissured layer is generally characterized by fresh (hard) rock cut by a dense horizontal fissuring in the first few meters and a depth-decreasing density of sub horizontal and sub vertical fissures [11,12]. The fissured layer mainly assumes the transmissivity role of global composite aquifer and provides the yield to the wells drilled in hard-rock areas. The hydrodynamic properties of the fissured layer are thus controlled by the distribution, the hydraulic conductivity, and the anisotropy of hydraulic conductivity and the connectivity of the fissures [13]. The fresh unfissured basement is

permeable only locally, where tectonic fractures are present. More complex weathering profiles can result from multiphase weathering and erosion processes. In Southern India for instance at least two main phases of weathering have been identified [14].

The Department of Mines and Geology (DMG) has monitored a network of just under 100 observation wells and bore wells in Bangalore District since 1973/1974. Many of the observation points were initially dug wells, which became dry when the water table fell below the bottom of the wells. In these cases the original well has been replaced by a bore well. The CGWB is also monitoring water levels at approximately quarterly intervals in a network of just over 100 wells in the Bangalore District since 1986 with a few wells from an earlier period of 1973. The overall change in the water table for the period April 1974 to April 1999 is shown in figure 4. Note the small area in the central part of Bangalore city where the water level rose during those periods which are a combined effect of precipitation along with the contributions of leakage from the BWSSB mains (and is presumed to represent a proportion of the unaccounted water) and leakage from storm water drains and the sewerage system.

The estimated recharge for Bangalore urban district in Monsoonal (46.96 mm) plus Non monsoonal (19.59 mm) equal to a total recharge of 66.55 mm with water level fluctuation method. The fluctuation data along with specific yield, average annual rainfall, average monsoon and average non-monsoon rainfall were used to determine the groundwater recharge for both monsoon and non-monsoon seasons. Since the monitoring network in the project area is limited, as part of this study the groundwater level mapping was undertaken. In the study period the depth of water table varied observed between 3.65 m and 7 m in the shallow wells. In the bore wells water table was between 7 m and 24.5 m from the ground level.

Collection of samples

A total of 81 samples sites were collected for a temporal period after and before Monsoonal cycle. Sampling sites were selected primarily on the basis of location in an attempt to attain the best possible spatial coverage of the basin, besides vicinity of sewerage network along four valleys. Efforts were also made to locate wells with discrete sampling intervals (in other words, short screened intervals) and groups of wells

that allowed samples to be obtained from a variety of depths within the aquifer system.

Analytical Methods

Some water quality parameters were measured in the field viz., temperature, dissolved oxygen, pH, and specific conductance, the major-element chemical composition (Ca, Mg, Na, K, Cl, B, SO₄, HCO₃) and minor constituents (NO₃ and F) in the laboratory. The water samples, filtered through 0.45 µm membrane filter were analysed for chemistry using the Standard Methods of Analysis. The stable isotope measurements were made using isotope ratio mass spectrometer. Tritium was measured using electrolytic enrichment followed by quantulus liquid scintillation counting. Sampling for radiocarbon was carried out in the field by CO₂ gas evolution method and measurements were made using liquid scintillation counting technique.

Results and Discussion

Multiple sources like Rain, Surface water infiltration from sewage, surface water bodies such as lakes, leaking surface water supply mains etc., are the general source of recharge in the fractured crystalline aquifers of Bangalore city [14]. As they move along ground-water-flow paths physical and chemical processes can affect these waters and consequently change the chemical and isotopic characteristics. Local variations in isotope composition can be recognized in a qualitative sense; it is not possible to a priori predict the isotopic composition of recharged waters.

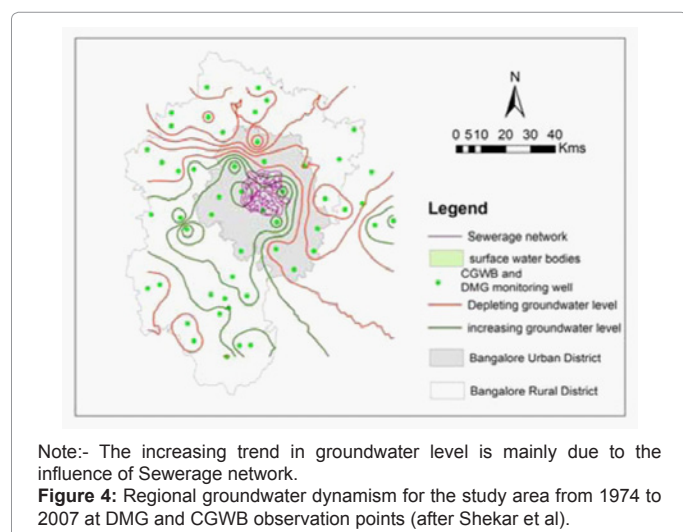
Inorganic chemical composition

The chemical composition of sewage differed substantially between the sites because of domestic and industrial inputs and surface water addition from the water supply leakages, besides, groundwater infiltration. The survey conducted on the sides of drainage channels brought to light numerous openings that facilitate the entry of different types of effluents and household wastes directly to the manholes. As a consequence in companion with precipitation data, inorganic chemical composition in the drainage channels magnified several times. The sewage of the study area is showing the characteristic of low acidic to highly alkaline nature. The results are showed in figure as spatial distribution of elements (Figure 5).

pH in groundwater is below the permissible values and the general trend in all the valleys implies slightly acidic to alkaline nature. A slight change at times could be due to the difference in the amount of draw down. Thus the impact of sewer line over pH is insignificant. Higher EC and TDS were observed in areas not receiving Cauvery water such as parts of Vrishabhavathy and Hebbal valleys. The low values of EC and TDS also imply the influence of supply water and heavy dilution occurring in the groundwater in the study area. It also indicates a large scale mixing of groundwater with another source having a lower specific conductance, when compared to other parts of Karnataka [15,16].

The cations like Calcium, Magnesium, Sodium and Potassium showed useful patterns depicting varied nature of geochemical characteristics among the valleys.

Calcium values of eleven sample exceeded the permissible limits viz. VB10, VB12 (Vrishabhavathy valley), KB2, KB10, KB11, KB12, KB17, KB19 (Koramangala valley), HB7, HB22 from (Hebbal valley), CB11 (Challaghatta Valley). The geological characteristics as well as the monsoonal soaking effects are responsible for these variations. It also



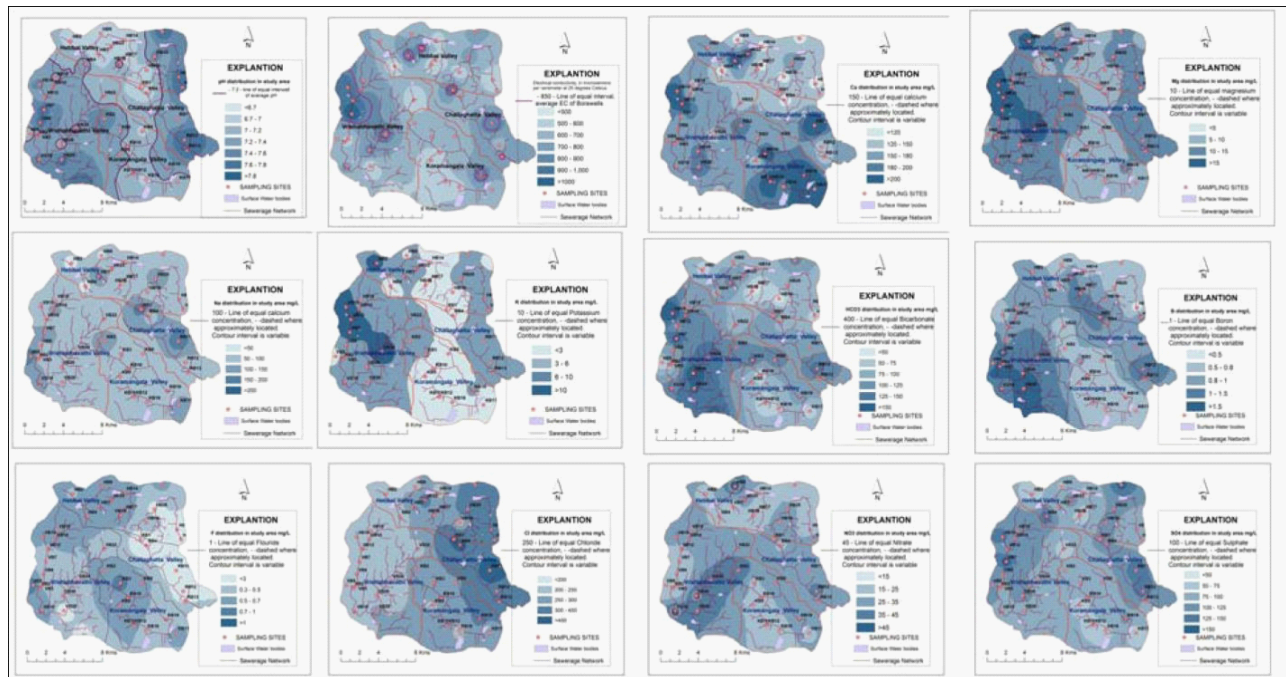


Figure 5: Spatial distribution of result of water quality analysis.

confirms the dilution effects and seasonal changes happening in the aquifer besides confirming the calcium clay rich aquifer.

The Magnesium is less than the permissible limits in all the valleys. Relatively low Magnesium concentration in ground-water samples confirms a general low saturation with dolomite. Also, points out the anthropogenic origin of magnesium in the groundwater. Sodium values exceeded the permissible levels (VB28, KB16, CB11, HB7 etc) manifesting the sewerage influence. The amount of recharge and the corresponding draw down processes appear to control sodium in the groundwater of these valleys. The spatial patterns explain the sewage interaction with aquifer (Figure 5).

Potassium observations in ten samples exceeded the permissible limit of 12 mg/L viz., VB3, VB14, VB18, VB22, VB28 (Vrishabhavathy valley), KB8, KB17 (Koramangala Valley), RB1 (Challaghatta Valley) HB7, HB25 (Hebbal Valley). Concentrated points were found near the open sewer lines with, high Potassium values again pointing out the sewer influence as well combined effect of weathering in granitic rocks.

Similar to cations, the anions also showed constructive patterns in terms of distribution of Sulphate, Bicarbonate, Chloride, Boron, Fluoride, Nitrate and Phosphate. Especially the conservative elements like Chloride, Sulphate and Nitrate supported sewage influence on groundwater.

The elevated sulphate and bicarbonate level again confirm the passage of sewage among the valleys. The spatial patterns also supported the sewerage influence on groundwater. A contradictorily elevated level of bicarbonates (100 mg/L to 1200 mg/L) was found in the groundwater among the valleys.

The sulphate reduction may be the possible cause of the elevated Bicarbonate in groundwater. The spatial patterns also supported these observations. A good correlation between Boron and Chloride suggests implying anthropogenic control over the solubility of boron. Boron

enrichment at lower conductivity is attributed to the solubility controls on the boron occurrence. The elevated levels of Boron and Chloride in groundwater confirm the contribution of sewage in the present study.

The Fluoride value failed to give any significant evidence on the effect of drainage. The optimum level of 1 mg/L is found in some parts across the valleys. The associated high bicarbonate levels in the groundwater are highly vulnerable to the Fluoride related health risks. The elevated occurrence of nitrates confirms the recharge of ground water by sewage and their interrelationship with respect to the seasons. The spatial patterns produced by the groundwater confirm the impact of sewage over groundwater in the study. The polluted water course also affected the phosphate concentration of wells among valleys.

The seasonal effects are prominent in the groundwater of Vrishabhavathy valley. Slightly acidic to alkaline pH, change in EC and TDS and major cations and anions promise a fast circulating groundwater net work accounted by the significant manifestation from the surrounding recharge areas. The change in the concentration of the physico-chemical parameters is visible in spatial projections for the different seasons. The pH changes, higher concentration of EC, TDS, total alkalinity, calcium, magnesium etc. support the influence of drainage on the ground water regime. The high Sodium and Potassium in the downstream of Vrishabhavathy valley also establish the presence of the polluted stream. Higher Sulphates, Bicarbonates and Phosphates among the stream side sources signify the controlling factor as open sewer. Nitrate observation confirms that the water flow has some control over the ground water regime. Koramangala valley experienced enriched concentration of Boron and Chloride indicating the source of recharge originating from a common source with considerable anthropogenic inputs. Again, elevated levels of sulphate, bicarbonate and phosphate confirm the influence of sewage on the ground waters in Challaghatta valley. Also it is supported by spatial projections. The elevated bicarbonate and sulphate and a good correlation of

Boron and Chloride is indicative of a common source of Recharge. Thus the recharge from the sewerage water differentially affected the groundwater characteristics.

The seasonal changes in pH, EC and TDS and the other chemical parameters confirm a prominent seasonal change in the groundwater regime. Some of these parameters are in close association with sewage network spread over the valley. The highest values coincided with the highest probable recharge sources. Evidently the groundwater of the Hebbal valley is more or less in tune with sewage characteristics in terms several parameters. Even in this case the concentration of boron, chloride, sulphate and bicarbonate confirms a large scale influence of exotic water.

The geochemical composition of groundwater in the present study indicated a direct relationship between the external influences and the relative abundance of cations. The differences in the water type determined confirmed a large proportion of mix up taking place in the study area. In general the natural order of abundance of major cations and anions in groundwater is; $Ca^{2+} < Na^{+} < K^{+} < Mg^{2+} = HCO_3^{-} < Cl^{-} < SO_4^{2-} < NO_3^{-} < CO_3^{2-}$. This order is not evidenced in the groundwater of the present case and it confirms the pollution from extraneous source.

The extent and magnitude of Rock-Water Interaction is the other question pertaining to the study area. To answer this, Gibbs diagram, widely employed to understand the rock dominance or evaporation dominance or precipitation dominance of the groundwater samples was used (Figure 6). The Gibbs plots of data from the study area

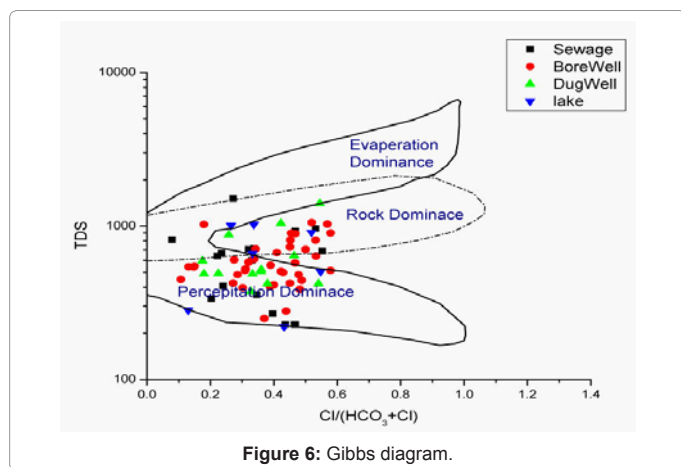


Figure 6: Gibbs diagram.

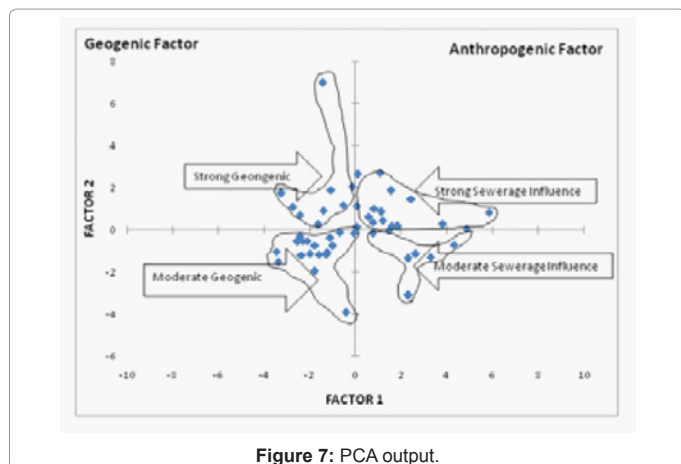


Figure 7: PCA output.

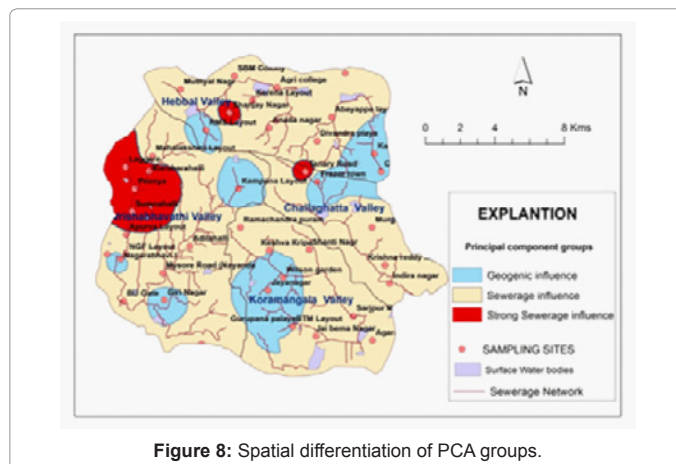


Figure 8: Spatial differentiation of PCA groups.

indicate that precipitation is the dominant process controlling the major ionic composition of groundwater in Bangalore city. The major ionic compositions of the aquifer medium explain a large amount of geochemical processes. Nevertheless, the rock interaction is also contributing to a good number of sample variations. Interestingly these samples correlated with the “geogenic samples” derived from the PCA analysis of the study (Figure 7). The spatial distributions of the sewage and geogenic influences are showed in figure 8.

Potability of groundwater

The potable quality of groundwater in terms of physico-chemical parameters with the WHO standards confirmed higher concentrations of the elements like Calcium, Potassium, Sodium, Chloride and Nitrates exceeding the limits. Therefore some immediate measures should be taken to treat the groundwater before letting into public supply.

Deuterium and Oxygen (δ^2H and $\delta^{18}O$)

The sewage influenced bore well water is giving a unique signature that is visible in the study. An identical trend was observed in the distribution of 2H in both the seasons whereas the trend of ^{18}O is concentrating around the post monsoon cycle. The great variation found in sewage indicates the presence of mixture of ground water and rain water and the process that water undergoes. Similar enriched values were found in the groundwater composition. Under the sewage influence the groundwater samples showed a highly depleted signature. The graphical analysis clearly indicate that the sewage is falling along with groundwater and enriched values point out the sources, dissolution and geochemical processes of groundwater as influenced by sewage in a greater way. The sewage influenced bore well water is giving it a unique signature that is visible. The local meteoric water line (LMWL) observed with the liner equation of $\delta D = 7.9 \delta^{18}O + 12.6$ (Figure 9). These observations correlated with those of [17,18], with a LMWL $\delta D = 7.89 \delta^{18}O + 10.39$ for Tamilnadu. In Kerala [19], a linear equation of $\delta D = (7.6 \delta^{18}O \pm 0.13) + (10.4 \pm 0.81)$ was observed. The south west monsoon, south east monsoon and the storm rain impacts are visible from the isotopic data of the present case. Dual monsoonal activities as well as the depression in weather affected the precipitation of Bangalore city (Table 1).

Sulphur 34 ($\delta^{34}S$)

The groundwater is greatly influenced by the exotic sulphate derived from various sources. Atmospheric sulphate from the vehicular pollution and industrial air pollution precipitates along with rainwater

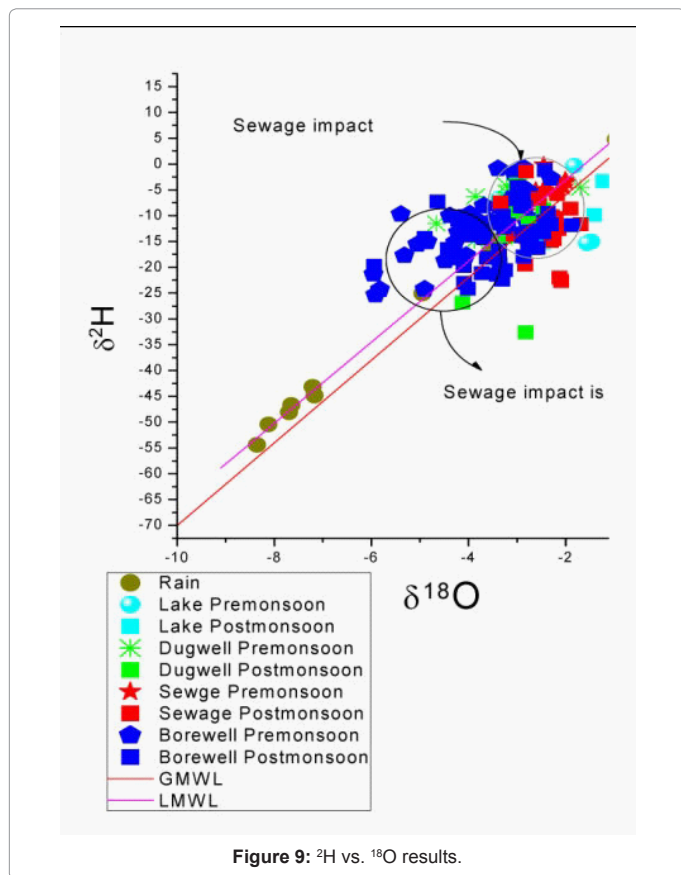


Figure 9: ^2H vs. ^{18}O results.

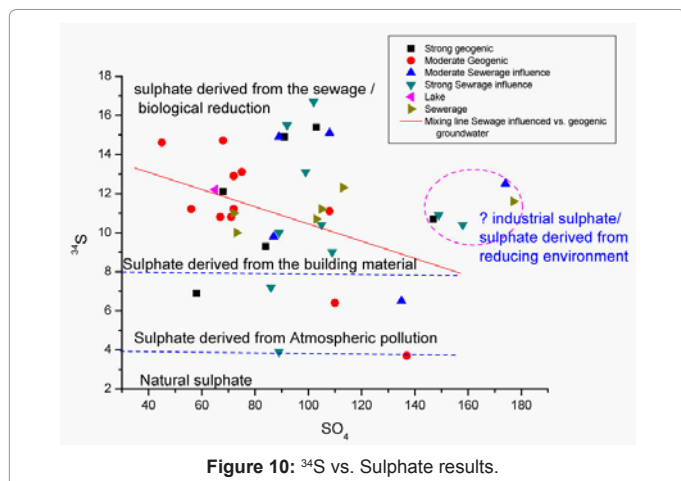


Figure 10: ^{34}S vs. Sulphate results.

or the surface water may get mixed, percolates and is expected to impart a signature up to 4‰CDT to 8‰CDT and further up to 12‰CDT [20] beyond 12‰, ^{34}S is the outcome of sulphate reduction from the biological processes. The sewage flowing through the sewerage line also undergoes biological and chemical reduction is responsible for the low values in the sewage samples. Thus groundwater also carries the signature emanating from the biological reduction. Sulphate- ^{34}S vs. Sulphate shows the high Sulphate and high ^{34}S composition can be expected from a mixed source of both sewage and biological reduction, occurring in the aquifer (Figure 10).

Tritium (^3H)

The Rain water collected was measured for tritium concentration. The precipitational variation varied widely between 3.8 ± 0.8 TU and 8.9 ± 0.2 TU (Figure 11), in 2008 and no previous data are available for tritium in precipitation in the study area. Studies observed a higher precipitation range in the Bay of Bengal, greater than 10TU and lower precipitation tritium in the vapour sources of Arabian Sea with less than 10 TU. In a recent study from Kozhikode (Kerala), the tritium in precipitation is recorded as below 5 TU [21]. In the present case, precipitation tritium evidently confirms the dual monsoonal influence in the study area (Table 2).

Summary and Conclusion

Lakes and Sewage network are interconnected in most of the areas owing to unplanned development of the city. In general most of the lakes except Kalkere and Hebbal lakes are strongly influenced by the precipitation and rest actively receive discharged groundwater. The sewerage is mainly derived from mixed use of groundwater, surface water rainwater and direct groundwater discharge. The untreated sewage entering into the lake get diluted with consequent decrease in pollution load, a common feature in the city, as evidenced from studies on Kalkere and Belandur lakes. The other lakes receive treated sewage.

The nature of sewerage is almost the same in all the valleys, with the raw sewage flowing through underground network, is getting leaked in some portions along the storm water drainage and get mixed with each other before entering the STP's. Treated sewage discharged into this storm water drainage flow with the untreated sewage in the city limits. The sampling survey along the sewage course observed several open channels from the industrial outlets that allow effluents directly into sewage channel. Also, direct house hold disposal is common in the some areas.

Tritium in sewage showed a greater variability between 4 ± 0.8 TU to 28.8 ± 0.4 TU which indicates that the water is influenced by different factors such as chemical effluents, including electronic wastes (do contain tritium) that is directly dumping into open manholes

Groups	well depth (m)	^3H TU	^{34}S	$\delta^{18}\text{O}$ ‰ (Pre monsoon 2008)	$\delta^{18}\text{O}$ ‰ (post monsoon 2008)	$\delta^2\text{H}$ ‰ (pre monsoon 2008)	$\delta^2\text{H}$ ‰ (post monsoon 2008)
Strongly Geogenic	Min.	4.3	2.7	6.9	-6.0	-4.9	-21.3
	Max.	243.8	10.5	15.4	-3.0	-1.9	-1.8
Moderately geogenic	Min.	9.1	3.2	3.7	-5.8	-4.6	-24.3
	Max.	140.2	9.3	14.7	-1.7	-2.3	-0.8
Strongly Sewerage influence	Min.	10.7	5.5	6.5	-4.7	-4.1	-18.2
	Max.	137.2	10.6	15.1	-2.9	-2.5	-11.5
Moderately Sewerage influence	Min.	7.6	1.9	3.9	-5.9	-5.9	-25.4
	Max.	189.0	9.3	16.7	-2.3	-0.2	-2.8

Table 1: Isotopic values in the major PCA generated groups.

Id	^3H TU	Age	pmC(%)
VB5	4.91	modern	115
VB30	2.99	modern	103
KB11	3.17	modern	114
HB4	2.69	4407 years)	58
RB4	3.87	modern	101
RB12	1.88	modern	117

Table 2: Tritium and age comparison with help of 14C as pmC results.

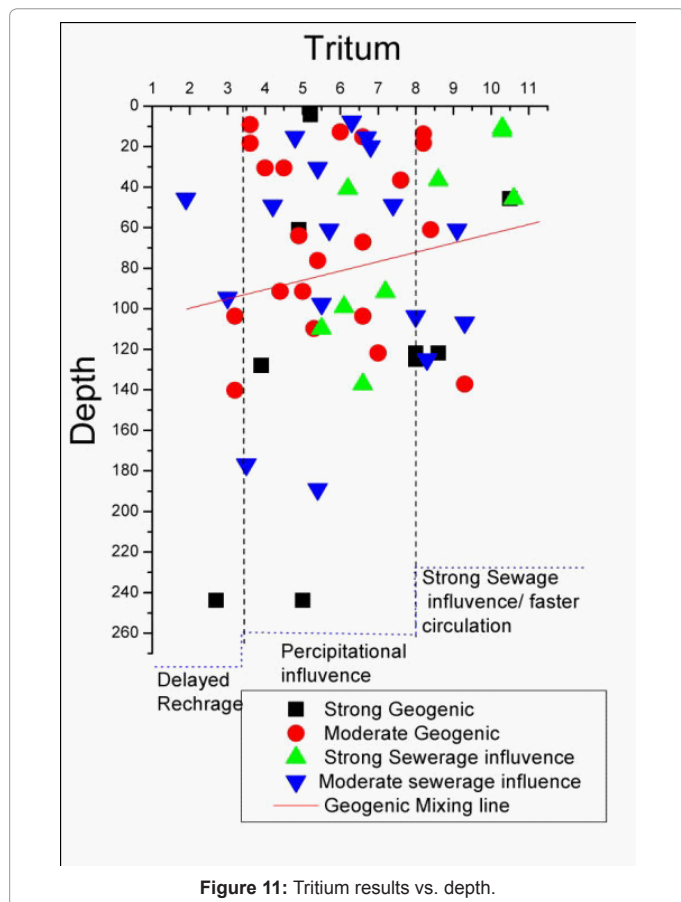


Figure 11: Tritium results vs. depth.

etc. Generally, a value less than 9 TU is the outcome of influence by precipitation water. The mixed water of pre-nuclear era has elevated tritium values of more than 10TU. The elevated tritium comes from the radioactive waste or the usage of tritium in the industrial products such as illuminating paints, parts of watch and other appliances [22]. Nonetheless, the exact source of tritium can't be told because the system is highly complex. The highest concentration points coincided with the highest known collection points of sewage. Tritium distribution independent of the depth and ground flow occurs through interconnected fracture. In general after 100 m depth tritium appears to be highly geogenic in nature. In the fast circulating groundwater it is highly influenced by the sewage that contributes anthropogenic tritium, as reflected by higher Tritium values in some samples of the preset study. The interconnected aquifer system with low permeability is affecting the concentration of the tritium in slow circulating waters.

From the tritium data emerging observations are i) the process of replenishment of groundwater is mainly by the infiltration of local rainfall and percolation of sewage water. Heterogeneous medium and incomplete mixing of water masses is responsible for the observed variations in tritium content of groundwater. The transit time is about 40-60 years. ii) Most of the sewage water in the area has tritium content in the range of 15-30 TU. The elevated tritium comes from the radioactive waste or the usage of tritium in the industrial products such as illuminating paints, parts of watch and other appliances. Six samples having low tritium content were analysed for ^{14}C . The values were 115 pmC (VB5) and 103 pmC (VB30) in Vrishabhavathy valley. In Koramangala valley it is 114pmC (KB11) and In Hebbal Valley HB4 56 pmC (4407) years is the calculated age) in 101 pmC (CB4) 117pmC

(CB12) (Chalghata valley). Evidence for bore well water mixing with sewage in Bangalore city is also clear by a comparison of ^{14}C activities with ^3H data. Some samples with low ^{14}C activities indicated an unadjusted radiocarbon ages of more than 3,000 years, yet contained detectable concentrations of ^3H (>3 TU) which confirms the presence of at least a fraction of post-1950's water. The ground-water samples with ^{14}C activities of more than 100 pmC represent this category and it is the outcome of anthropogenic input through the piston flow of recharged water [23].

- Calcium, Potassium, Sodium, Chloride and Nitrates are high. Generally the samples with high physico-chemical observations are experiencing external influence (sewage impact).

- The linear equation derived for precipitation $dD=7.9^{18}\text{O}+12.6$ and depleted delta values indicate the sewage influence on groundwater.

- The ^{34}S range from 3.9‰ to 16.7‰. 12‰ ^{34}S confirms sulphate reduction from the biological processes influenced by the sewage contamination.

- The plot on tritium confirmed three circulation phases like slow, medium and fast.

The "sewage influence signature" correlated with the sewage influence group extracted from the physico-chemical parameters. Ground-water temperatures did not exceed 30°C and the stable isotope composition can therefore be regarded as unaffected by water-rock interaction. Obviously the precipitation and the surface water sources are the main controlling factors. Under the sewage influence the groundwater sample showed a highly depleted signature. An identical trend was observed in the values of ^2H distribution in both seasons whereas the trend of ^{18}O is concentrating in the post monsoon cycle.

The saprolitic layers of the crystalline rock filled with calcium rich clay are controlling the major portion of the aquifer system of this area. The major wells are situated in the 40-60 m and 80-100 m range. The saprotic layer is recharged by the piston flow of groundwater movements under fast circulation. The study of the isotopic and chemical elements indicates that there are two zones wherein most of the wells are situated between 30 m and 100 m. The chemical behaviour of the water in this depth of aquifer is almost similar indicating that most of the groundwater source is connected with the surface water bodies. Overall, the most common and consistent (but not ubiquitous) change in water chemistry with increasing depth in the aquifer system appear. The periodic changes in the spatial distribution of the isotopic values are in tune with sewerage lines. The individual chemical and isotopic "signatures" within the study area are useful for the delineation and confirmation for the Geo-hydrologic and pollution aspects of the groundwater in urban areas.

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