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Research article

EVEN THOUGH BANGALORE MOTHER TAKES BATH BY HOLY WATER, SEWAGE IS FLOWING IN HER VEIN AS BLOOD-A CASE STUDY WITH ENVIRONMENTAL ISOTOPES!!

M. Jiban Singh[*] and R.K. Somashekar

Department of Environmental Science, Jnanabharathi, Bangalore University, Bangalore-56.
E-mail: mjscholar@gmail.com

Abstract

This case study with Environmental Isotopes Technique presents an amazing result of $\delta^{18}O$, $\delta^{2}H$, ^{3}H and ^{14}C concentration in the groundwater and surface water. Radioactive and stable isotopes analysis was done at the Tritium and Radiocarbon laboratory of Bhaba Atomic Research Centre (BARC), Mumbai, using Liquid Sanitization and Mass Spectrometric Methods respectively. Samples of groundwater from the urban nucleus (Hebbal and Challaghatta) of the of Bangalore city were studied. The average trend in $\delta^{18}O$ heavier and ^{3}H values (surface water>groundwater>rain water) during the pre-monsoon 2011 and post-monsoon 2012 suggest the possible percolation during the runoff in the monsoon seasons besides infiltration from sewage and lakes and possible contamination of ^{3}H in groundwater during both the seasons of the two years following recharge from sewage respectively. The old water representing Hebbal valley is computed age of HB2 located at #427, 9th cross, 5th main, RMS 2nd stage, Hebbal, Bangalore-94 is 4407 years.

Keywords: Contamination, Environmental Isotopes, Modern and Old Groundwater and Sewage.

INTRODUCTION

Bangalore, the capital of Karnataka state, spans over a geographical area of 2,174 Km^2 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 areas are marked by a series of tanks and small ponds. Bangalore city supports a contemporary population density of approximately 20000 people per km^2. A significant shift in the land use from agricultural to residential occurred over the 1920's. Coincident with this trend there has been a rise in industrial and commercial/institutional land uses. City experienced rapid industrial growth during the latter half of the 70's. Use of

urban groundwater from the open and bore wells declined at the beginning of 80's because of the implementation of river Cauvery drinking water scheme in part of the city. Nevertheless, intensive abstraction of groundwater for both domestic as well as industrial use continued and reached a peak in the early 1990s.

Evaluation of available groundwater resources, identification of source and origin of groundwater recharge, recharge chronology and groundwater quality are of great importance for systematic planning, development and management of groundwater to meet the current and future needs. Many a times, hydrological investigations based on conventional methods are too geologically based and non-quantitative, or too engineering based and although quantitative, lack insufficient geological understanding. Environmental Isotope techniques are recommended to fill this gap.

STUDY AREA

The Drainage System

The granitic ridge running from NNE to SSE governs the drainage pattern of Bangalore North. Towards east, the drainage is made up of a network of canals generally flowing from west to east with storage tanks along the canals, ultimately feeding the South Pinakini River.

In the west also the drainage pattern includes a network of canals generally flowing westwards with storage tanks, ultimately feeding the Arakavathy River. Also the Bangalore south drain towards east, into the Pinakini basin and to the west into the Arakavathy basin (Jiban Singh *et al.,* 2012). The Vrishabhavathiy is a minor river within the city marked with a series of tanks (Fig. 1a).

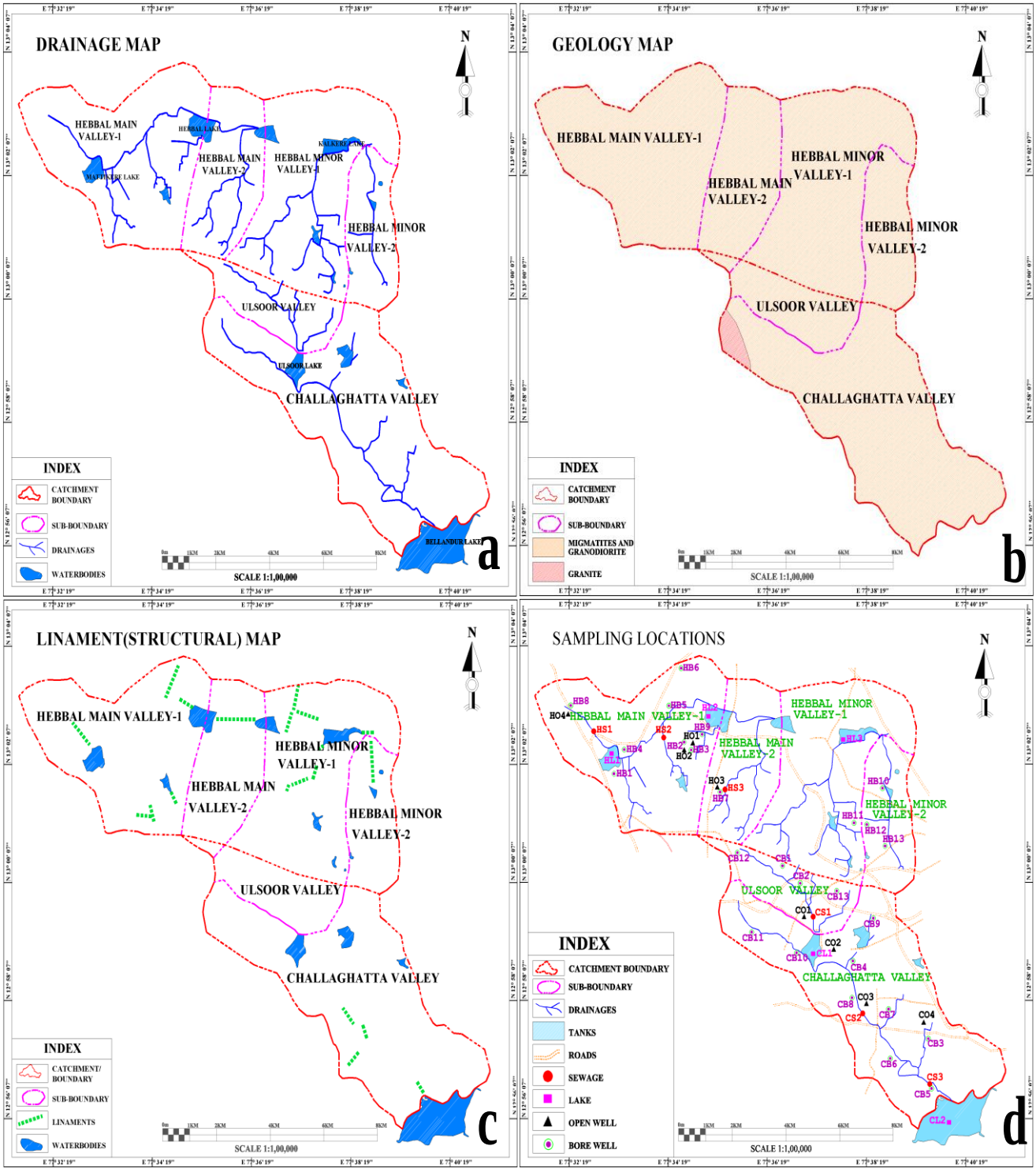
Geo-Hydrological Nature

Geologically the western portion of Bangalore is composed of gneissic granites belonging to Precambrian age. They are exposed as a continuous chain of mounds raising 90-150m above the ground on the western portion constituting the Bannerghatta groups of hills. Inclusions of quartz and pegmatite also occur here and there (Fig. 1b). Hydro-geologically western portion shows groundwater occurrence under water table in the weathered mantle of the granite gneisses and joints, cracks and crevices of basement rocks (Fig. 1c). Generally, the water table fluctuation in open and bore wells of Challaghatta valley are high around Domlur and Ulsoor Lake respectively, which are the major recharge areas of groundwater. The depth of water table is dependent upon the rate of weathering and topographic factors. Chief source of groundwater is infiltration and recharge by rainwater. Considering the climatic water balance, soil characteristics account for nearly 70% allowing only 20% rainfall being added to groundwater pool. Percolation and recharges in the groundwater account for 10% discharge through wells (Jiban Singh *et al.,* 2012).

MATERIALS AND METHODS

In a kernel case one can say that sampling is the process of selection, collection and transportation of the sample. Filtration and pre-treatment to keep the sample stable are the pre requisites before transporting the samples to laboratory for analysis. The BIS: 3025 (part-01) 1987 protocol is generally followed in groundwater sampling. Wherever necessary, separate sampling protocol has been used.
The sampling across Hebbal and Challaghatta valleys included 6 sewage samples, 5 surface water samples (lakes), 8 open wells and 26 bore wells samples selected after assessing the city's topography, drainage pattern, approach roads, well distribution etc. comprising hand pumps, government water supply lines and private bore wells (Fig. 1d).

The groundwater sources were within 70 to 500 m radius, proximity of open sewage system. The sample location was chosen in such a way that it represents either side of the represented both nearer and away from the sewage cannel (Fig. 1d).



Figures 1: a. Sewerage Network; b. Geology; c. Lineament variations and d. Sampling location of Hebbal and Challaghatta, Bangalore.

Also 12 rain water samples were collected during the first and second monsoon of 2011 for ^{18}O and ^{3}H measurement. After recording the ^{3}H levels (< 4 TU), to determine the carbon isotopic composition, $CaCO_3$ of groundwater was precipitated, which holds the total carbon contained as dissolved component.
After sampling, TDS, EC were measured in the field using PE -138 fields Kit (APHA, 2005) and salinity of water was classified according to Handa (1969). Tritium, ^{14}C and ^{18}O analysis was done at the Tritium and Radiocarbon laboratory of Bhaba Atomic Research Centre (BARC), Mumbai, using Liquid Sanitization and Mass Spectrometric Methods.

RESULTS AND DISCUSSION

DUTERIUM (δ^2H) AND OXYGEN-18 ($\delta^{18}O$)

Bangalore harbors no perennial river which resulted in the establishment of many lakes besides serial streams like Arakavathy, Pinakini and Vrishabhavathiy which were once the source of surface water and groundwater recharge. Currently, following rapid urbanization and industrialization, these lakes have vanished and have been converted into residential and commercial localities. Arakavathy, Pinakini, and Vrishabhavathiy streams are today part of open sewage network of the city. An accurate conceptualization is therefore a prerequisite for realistic understanding of the habitat. To understand the flow system better and translate this understanding to develop a groundwater model, data on radiogenic isotope viz. ^{3}H and ^{14}C with stable isotopes $\delta^{18}O$ and $\delta^{2}H$ can be used.
Variations in the stable isotopic signature of water in the catchment area are caused mainly by natural variations in the isotopic composition of rainfall, through mixing with pre-existing water and the influence of evaporation (Dansgaard, 1964 and IAEA, 1981). Twelve rain water samples collected from the Hebbal and Challaghatta valleys between June to December (South-East and North-East monsoons) of 2011 and 2012, had a mean $\delta^{18}O$ value of -4.40‰ and -5.14‰ SMOW and range between -12.63 to -1.82‰ and -8.12 to -0.97SMOW respectively (Fig. 2).
A comparison between $\delta^{18}O$ concentrations during the pre- and post-monsoon seasons of 2011 and 2012 of the open wells (-4.40 to -1.12 and -4.66 to -2.62‰), bore wells (-5.9 to -2.4‰), lakes (-1.75 to 1.54 and -3.03 to 3.37‰), and sewage (-2.70 to 0.60 and -2.98 to -2.04‰) with $\delta^{18}O$ concentrations during the monsoon rain water, in both the years confirm that the South-West monsoon (June to August) account to ~76 and 93% of total rainfall on the input signal respectively (Fig. 2). Also the groundwater from shallow quaternary aquifer has most probably originated from South-West monsoon precipitation. The average trend in $\delta^{18}O$ heavier values [Lake (0.04 and 0.20‰)> Sewage (-1.04 and -2.567‰)> Open well (-2.41 and -3.41‰)> Bore well (-2.52 and -4.08‰)> Rain (-4.40 and -5.14‰ SMOW)] suggest the possible percolation during the runoff in the monsoon seasons besides infiltration from sewage and lakes. It also supports the view that the sewage act as a hydraulic move to ground flow at some locations. The elevated areas like RMS 2nd stage in Hebbal valley showed depleted $\delta^{18}O$ indicating strong South-West monsoon influence and high runoff. Nonetheless the remaining showed an increasing trend in $\delta^{18}O$ suggesting low runoff (Fig. 3). Therefore, it is obvious that, groundwater $\delta^{18}O$ values indicate a preferential trend in their spatial distribution. Lighter $\delta^{18}O$ bearing water more commonly occurred at higher elevations and heavier at lower elevations in the entire valley presenting a clear enrichment in $\delta^{18}O$, due to evaporation from sewage and sewage mixed groundwater (Fig. 3).

In the surface water (open sewerage network system and lake), during the pre- and post-monsoon seasons of 2011 and 2012 the $\delta^{18}O$ and $\delta^{2}H$ fall in the range -2.70 to 1.54; -3.30 to 3.37‰ for $\delta^{18}O$ and -14.26 to 2.08; -15.54 to -3.30‰ for $\delta^{2}H$ respectively as well as for groundwater, the ranges for $\delta^{18}O$ are -7.30 to 2.75; -7.22 to -2.31‰ and -29.88 to 1.78; -35.00 to 1.14‰ for $\delta^{2}H$ respectively. This is contrary to the observations of Gupta *et al.*, (2005) and Majumdar *et al.*, (2005), but all ranges are in accordance with values given by Stüber *et al.*, (2003); Gupta *et al.*, (2005) and Majumdar *et al.*, (2005). Regarding groundwater samples plotted along the GMWL during the pre- and post-monsoon seasons of 2011 and 2012 (Figs. 4 & 5), the ranges of $\delta^{18}O$ and $\delta^{2}H$ isotopes are broad. This suggests that groundwater recharge occurred during an unrestricted period. Moreover, there is no evidence of stable isotopic variation with regard to the location of the samples or altitude, reflecting a similar input during the recharge period. In accordance with the monsoon system,

Deshpande *et al.*, (2003) showed evidence of a geographic distribution of the δ^2H and $\delta^{18}O$ isotopic signature in precipitation.

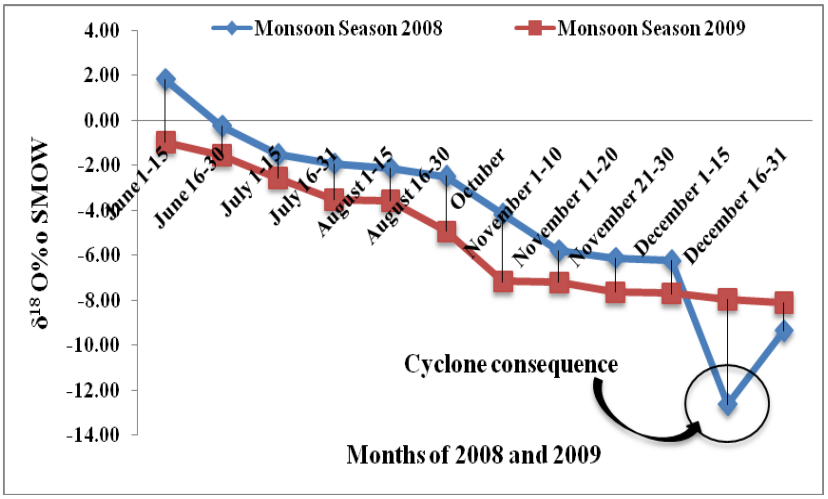


Figure 2: Fractionation of $\delta^{18}O$ ‰o SMOW concentrations in rain water in different months.

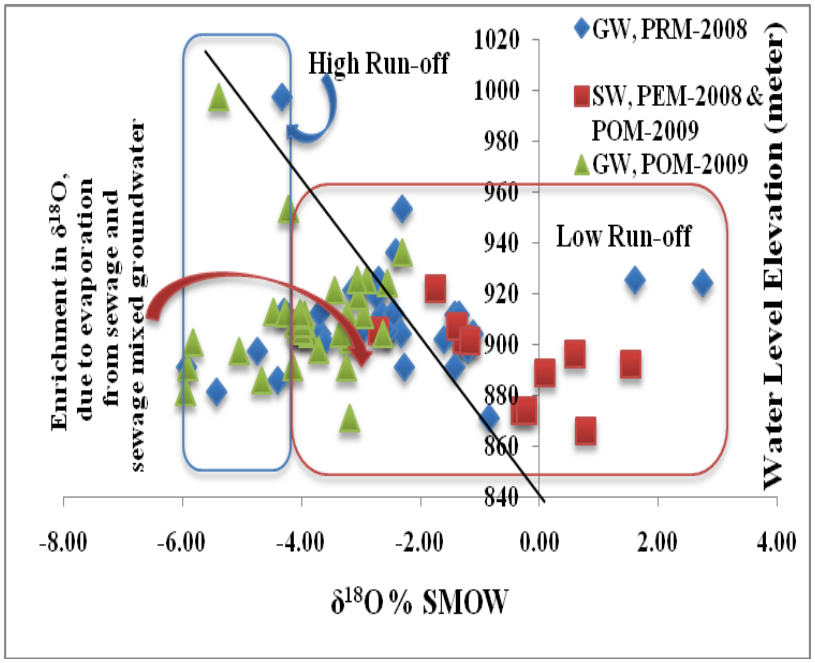


Figure 2: Plot of $\delta^{18}O$ vs. water level elevation of Surface and Groundwater samples ($\delta^{18}O$ values become heavier at lower elevations).

Gupta *et al.*, (2005) showed an average $\delta^{18}O$ in groundwater around 1±1‰, but a decrease in $\delta^{18}O$ more than -7‰ is due to North-East zone. They related the depleted values to atmospheric inputs marked by depressions and cyclonic storms originating from the Bay of Bengal. Similarly, in the present case, a few of the surface and groundwater samples showed a significant shift of more than 1‰ to the right of the GMWL (Figs. 4 & 5). The comparison of the $\delta^{18}O$ in the surface water, precipitation and groundwater in the Hebbal and Challaghatta valleys between the pre- and post-monsoon of 2011 and 2012 shows that nearly all surface waters and precipitation and more than 58% of groundwater display $\delta^{18}O$ enriched, marking more recharge during the pre-monsoon 2011 and lie right to the LMWL and GMWL (Fig. 4). These $\delta^{18}O$ and δ^2H enrichments in water sources may be linked to sewage and lakes contribution (Negrel and Lachassagne, 2000 and

Negrel *et al.*, 2007). However, most of the groundwater and precipitation display almost identical $\delta^{18}O$ and lie left to GMWL during the post-monsoon of 2012 reflecting small variations during the infiltration of recharge water (Fig. 5).

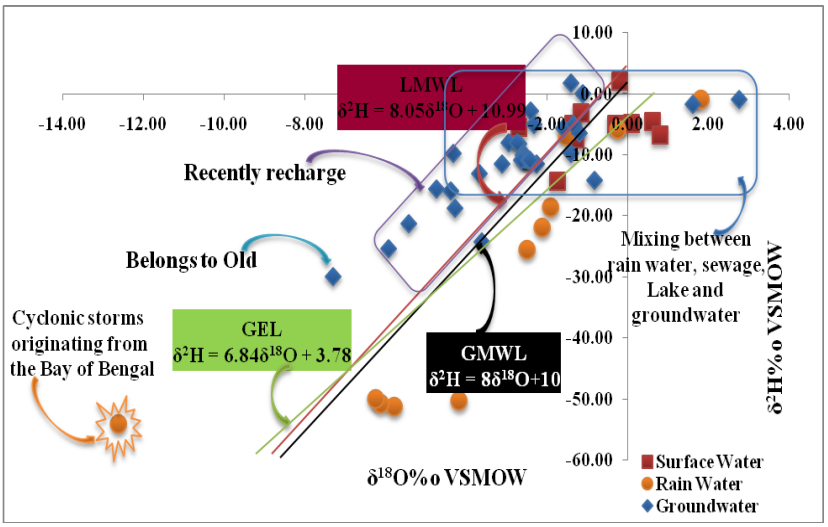


Figure 3: $\delta^{18}O$ vs. $\delta^{2}H$ of pre-monsoon of 2011.

On the other hand, the isotopic composition of groundwater is defined as the groundwater evaporation line (GEL, $\delta^{2}H = 6.84\ \delta^{18}O + 3.78$). The deviation from the LMWL along a lower slope is the result of no equilibrium isotope enrichment in evaporating groundwater and the slope depends highly on the relative humidity (Gonfiantini, 1986). In addition, if the GEL passes through an isotopic composition close to standard seawater ($\delta^{2}H = 0$ and $\delta^{18}O = 0‰$), isotopic evidence supports the GEL being caused by evaporation and seawater mixing. Moreover, during the pre-monsoon of 2011 the intersection points of LMWL, GMWL and GEL represent the mean isotopic composition of the original water, which is a mixture of recharged surface water during a long infiltration period (Fig. 4). This is long enough to reduce the seasonal variation of isotopic composition within the valleys (Clark and Fritz, 1997). The $\delta^{18}O$ values of groundwater which are right to GEL (heavier from GEL) and left to GEL (lighter from GEL) during the pre- and post- monsoon of 2011 and 2012 are similar to that of precipitation measured during the monsoon seasons of the corresponding years (Figs. 4 & 5). The wide range of stable isotopic composition of groundwater in the Hebbal and Challaghatta valleys is therefore a subject of more changeable evaporation and isotopic fractionation during different seasons. When the water table is shallow/low elevation, stronger evaporation may lead to stable isotopes enrichment (Fig. 3).

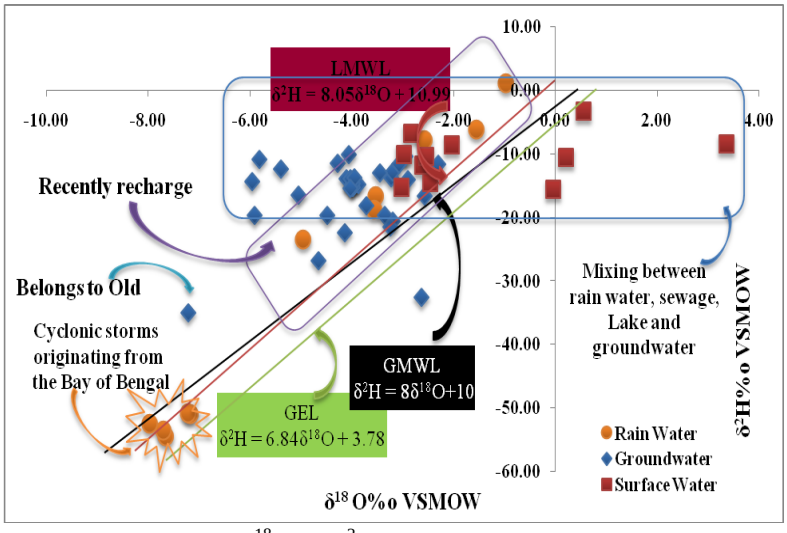


Figure 4: $\delta^{18}O$ vs. $\delta^{2}H$ of post-monsoon of 2012.

Particularly a bore well sample (HB2) located at RMS 2nd stage, Hebbal valley is characterized by low $\delta^{18}O$ and $\delta^{2}H$ values, ^{3}H content was 1.88 and 1.53 TU during both the seasons of two years, and ^{14}C activity is 58 pmC. This groundwater has been unlikely to be affected by the sewage recharge consistently and indicates an "old water'' type, and age has been calculated to be 4470 years (Figs. 4 & 5).

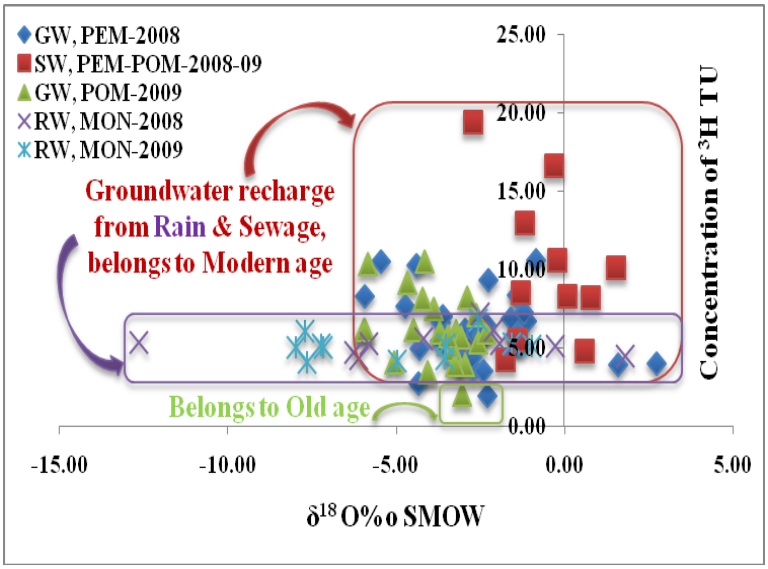


Figure 5: Scatter diagram of ^{3}H TU vs. $\delta^{18}O‰$ SMOW.

TRITIUM (^{3}H) AND CARBON-14 (^{14}C)

The apparent qualitative age of groundwater is the time determined from an age-dating tracer that has elapsed from the time water lost contact with the atmosphere (Fontes *et al.*, 1983 and Yurstsever, 1983). Tritium is a short-lived radioactive isotope of hydrogen with a half-life of 12.43 years. After the early 1960s, when the Nuclear Test Ban Treaty (NTBT) was signed, atmospheric testing of nuclear weapons ceased, ^{3}H concentrations in the atmosphere decreased and are approaching natural levels. Tritium has been widely used for the estimation of groundwater residence time (Fontes *et al.*, 1983 and Yurstsever, 1983). Eventhough, ^{3}H concentration alone generally cannot be used to quantitatively date groundwater, it can be used to qualitatively determine whether groundwater is **modern** (*less than about 50 years in age*) or **pre-modern** (*older than about 50 years in age*) (Alison and Hughes, 1978, Fontes, 1883, Yurstsever, 1983, Clark *et al.*, 1997 and Zouari *et al.*, 2003).

Modern age is further classified depending on the basis of ^{3}H values where values ranging from 1 to 4 TU could be attributed as mixture of recent water with old, the recent water with activities range between >4 and 18 TU and thermonuclear water activities range between >18 and >28 TU. During the pre-monsoon season 2011 and post-monsoon season 2012, with the same groundwater level in Hebbal and Challaghatta valleys, exactly 12 and 88% of the samples are symbolized as a mixture with recent activities, whereas the surface water represents post-thermonuclear water. Further modern groundwater, generally, is more susceptible to contamination than old because of many anthropogenic contaminants introduced during the 20th century (Plummer *et al.*, 1999). Therefore the valleys with depleted ^{3}H values belong to old groundwater, and those with higher ^{3}H values represent recharge from rain and sewage (Fig. 6). The spatial distribution of ^{3}H in the present case indicates that it follows the same trend as ^{14}C, with lower ^{3}H at higher elevations and depth and vice-versa in the entire valley (Fig. 7_A). The trend in ^{3}H values during the pre-monsoon 2011 and post-monsoon 2012 [Sewage (11.47 and 11.33)> Lake (10.59 and 10.46)> Open well (6.55 and 6.41)> Bore well (6.10 and 5.97)> Rain (5.38 and 5.15 TU)], suggest the possible contamination of ^{3}H in groundwater during both the seasons of the two years following recharge from sewage with little contribution from precipitation. The higher ^{3}H in groundwater samples along the sewage network again support the view that the sewage act as a hydraulic move to groundwater flow (Morteza *et al.*, 2006).

Supporting investigations of Wu *et al.*, (2002), in Hebbal and Challaghatta valleys, the ^{3}H values of groundwater also can be divided into three groups. The first group belongs to the nearest to the sewage network system within 1 km radius from the sewage influence zone. Here the groundwater ^{3}H average values are 6.33 to 6.18 TU during the pre and post-monsoon of 2011 and 2012, close to the values of surface water 9.74 to 9.61 TU respectively, suggesting that they contain some residual bomb ^{3}H. This indicates groundwater recharge by recent sewerage network system and that the hydrologic cycle is active. The second group belong to sewage network system lying within >1 to <2 km radius from the sewage influence zone. The groundwater ^{3}H values here ranged from <2.7 to 4.7 TU. This shows that the groundwater is a mix of sub modern (1950s) and recent recharges. The third group far from sewerage network system within <2.5 km radius where the ^{3}H values are <2.7 or <1 TU. This indicates that the groundwater is old (Fig. 7_B).

Environmental ^{3}H content in most of the groundwater samples in Hebbal and Challaghatta valleys, during the pre-monsoon 2011 and post-monsoon 2012 ranged from 2.69 to 10.59 TU and 2 to 10.46 TU except one location (HB2) where the value is <1.9 TU. The plot of F^- vs. ^{3}H, (Fig. 7_C), distinguishes three categories of samples. The first category, contains low ^{3}H and low F^- situated in RMS 2nd stage, Hebbal valley, belong to old and highly mineralized waters. Second category samples contain high ^{3}H with F^- levels < 2 mg/l, which are mostly from wells near the recharge areas of sewage/lake, belongs to modern and F^- might have been derived from geogenic sources without much contribution from contaminated surface waters. Third category samples contain high ^{3}H with high F^- concentrations (>2 mg/l), which are mostly from wells near mine pit and discharge areas and, belong to modern. The contaminated surface waters could be the source for high F^-, besides weathering of rocks.

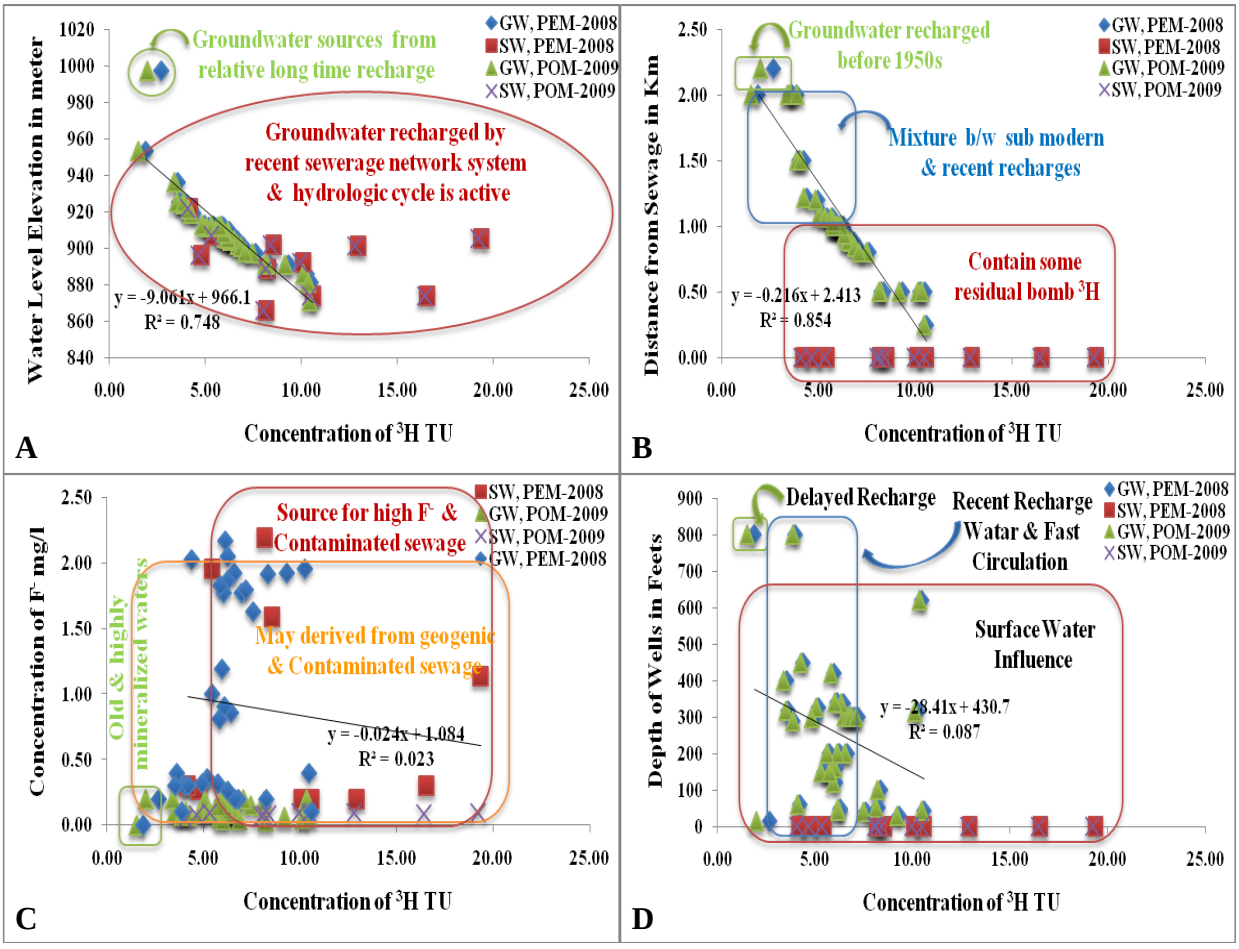


Figure 6: A: Lower ^{3}H at higher elevations; B: Higher ^{3}H at nearest from sewerage network system; C: Low ^{3}H and low F^{-} content, belong to old and highly mineralized waters and D: Lower ^{3}H at deeper depth vice-versa in the valleys.

In the study area, during the pre-monsoon, the ground and surface water from the Hebbal and Challaghatta valleys have a mean ^{3}H of 6.18 and 10.19 TU, ranging from 1.88 to 10.59 and 4.20 to 19.35 TU respectively. During the post-monsoon 2012, the ground and surface water exhibited a mean of 6.03 and 10.05 TU respectively. Further, the results of ^{3}H values of precipitation samples collected during the monsoon of 2011 and 2012 in the two valleys, ranged from 4.29 to 7.18 and 4.09 to 6.79 TU with an average value of 5.38 and 5.15 TU respectively (Fig. 6). This seasonal variation of ^{3}H content could also be due to the influence of different air masses on precipitation. The lower and higher ^{3}H content in precipitation are from the air masses coming from the northeast and southeast monsoon respectively. Maximum ^{3}H content was observed in the last week of the July, 2011, reaching a value close to 7.2 TU, which is due to the troposphere injection besides cyclone (Araguas-Araguas and Diaz Teijeiro, 2005). A secondary peak (> 6.15 TU) was observed in the first week of July, 2011 and 2012 can be related to stormy rains relatively enriched with ^{3}H (Araguas-Araguas and Diaz Teijeiro, 2005; Ouda *et al.*, 2005 and Saighi, 2005).

As a result of testing thermonuclear devices in 1952, another isotope was added to the atmosphere i. e., ^{14}C. Corresponding to 31.56 dpm/g of Carbon, before 1952, ^{14}C was about 100 pmC. During 1952, ^{14}C was at peak and subsequently came down due to moratorium on tests. The quantitative age of the water can be calculated by knowing the percent modern Carbon (pmC) but before arriving at conclusion several corrections are to be attended. Factors such as chemical dilution and isotopic exchange dissolved carbon of pure biologic origin and dissolved carbon of mixed origin need to be considered. After estimating the values of ^{3}H, samples viz., HO3, HB2, HB8, HB13, CB2 and CB4 with <4 TU, were selected for Carbon dating. The analysis showed that some of the groundwater in Hebbal and Challaghatta valleys belongs to old water with the pmC values ranging from 28 to 101 and with an average value of 73 pmC.

The maximum ^{3}H of 34 groundwater samples collected during the pre- and post-monsoon of 2011 and 2012 is >10.46 TU, indicating that a significant portion of urban groundwater in Hebbal and Challaghatta valleys has recharged modern water and therefore has a relatively short residence time in the aquifers (Hendry, 1988 and Koh *et al.*, 1999). Supporting the above, the ^{14}C data are required to confirm the hydrogeological model implied by isotopic data.

In the study area, the minimum ^{3}H contents are 1.88 and 1.53 TU during the pre- and post-monsoon of 2011 and 2012 respectively and ^{14}C activities range from 28 to 101 pmC, means that the groundwater corresponds to a late Pleistocene recharge except the samples at M.S. Ramaiyanagar, Gokul, Kerena Layout, Campus of Madras Engineering battalion of Indian Army, Domlur 2nd stage, Krishna Reddy Layout, Bellandur Lake, Devinagar 2nd cross, Ganganagar, HMT Layout, Anandanagar, Sindy Colony, K.S. Gardens, Ulsoor, Domlur, 11th stage, Muthyalnagar, RMS 2nd stage, Devinagar 1st cross, SBM Colony, Mathikere, Divandra palya, GKBK-agriculture College, Kalyannagar, Chalkere 1st cross, Pillanna garden 3rd stage, Batanary Road, Frazer town, Murgesh palya, Indiranagar, Tenment 2nd stage, Kempapur, Marathahalli, Karnataka Course, 100ft. Road, Krishnamurthynagara, Dickinson Road, Shivajinagara, Near Jayamahal Road and Jeevanahalli, they appear to have recharged by modern sewage/lake/ runoff as reported in earlier studies (UNESCO, 1972; Guendouz, 1985; Guendouz *et al.*, 2003 and Edmunds *et al.*, 2003).

On the other hand, unlike $\delta^{18}O‰$ variation which is primarily controlled by environmental conditions during recharge process, the variation in ^{14}C is due to residence time of groundwater in the aquifer. The measured ^{14}C ages does not show any increase with depth, which is contrary to the observation of Aeschbach-Hertig *et al.*, (1999). The old water representing Hebbal valley is the highest (^{14}C content, 58 pmC) among all the measured samples and the computed age of HB2 located at #427, 9th cross, 5th main, RMS 2nd stage, Hebbal, Bangalore-94 is 4407 years, which indicates a recharge period extending from the Late Pleistocene to recent Holocene age.

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