IEESE International Journal of Science and Technology (IJSTE), Vol. 3 No. 2, June 2014, 8-13
ISSN : 2252-5297

Stable Isotopic Characterization In Surface And Groundwater Interaction In A Hard Rock Terrain Of A Semi-Arid Region

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Abstract. The Deuterium (δD) and Oxygen-18 (δ^{18}O) isotopes can be used to understand the surface and groundwater interaction and identifying the recharge sources. Pelig.K.B [5] identified that origin, age, distribution of waters in a region including occurrence and recharge mechanism, interconnections between groundwater bodies and identification of recharge sources and areas can be easily identified by environmental isotopic techniques. The study area has 16 tanks and 72 wells. Variation in stable isotopic signature of groundwater in Sindapalli sub-basin was used to understand the process of surface and groundwater interaction and recharge process in hard rock aquifer. The present paper describes the groundwater condition in the sub-basin and gives a detailed account of the isotopic signature in precipitation, tank water and well water. The pre and post monsoon water samples of each tank and wells are taken for isotopic analyses for identifying the recharge sources of groundwater level within the sub-basin. The samples were analyzed fort isotopic data and it is presented in terms of the Global Meteoric Line (GML) and its variation with Local Meteoric Precipitation Line (LML) with respect to tank and groundwater line as δD vs δ^{18}O plots for 2009 and 2010. The results indicated that the δ^{18}O and δD values of groundwater are changing from pre and post monsoon with respect to aquifer depth and indicate the presence of recharge due to rainfall. It is noted that interaction of surface water with hard rock's might cause δ^{18}O to be high. The spatial variation of δ^{18}O values in the study area can be used in identifying suitable locations for undertaking artificial recharge measures in the aquifer to supplement the natural recharge of groundwater.

Key-Words: *Stable isotopes, Semi-arid, δD, δ^{18}O, GML, LML*

1. Introduction

Semi-arid zones are to be viewed as ones where favorable water balance is achieved only seasonally Abdulla (2004) [1]. The ratio of the surface to subsurface runoff is low in the semiarid zone. These regions are characterized by water scarcity, vulnerability to desertification, and climate variability. The investigation of hydrological processes in this region is of major interest not only for water planning strategies, but also to address the possible impact of future climate and land-use changes on water resources. Recharge in semi-arid areas is a challenging task, mainly because of limitation in *situ* measurements, and also due to the local nature of some processes. According to Peligh [5] direct recharge measurements are very difficult in semi-arid catchments and contain a high level of uncertainty. It is understood that all hydro-geologic, hydrodynamic and isotopic interpretations have to be space and time related. Singh.J.M. [7] In his experimental studies proved that Isotopes play a vital role in studying the soil moisture variation, its movement and recharge through the unsaturated zone. Clark and Fritz [2], stable isotopes such as δ^2H and δ^{18}O can be used as conservative groundwater tracers since their values remain constant as long as there is no fractionation along the flow path. The concept that the hydrological cycle system can be viewed as a global distillation column of waters fed by evaporation from the ocean as moisture, which condenses as a result of cooling of air masses as it rises to higher levels. Ding [3] indicate that the degree of depletion of heavy isotopic water species of hydrogen and oxygen is correlated in the residual waters, provided an equilibrium exists between the condensed phases and vapors at all times. For stable isotopes, their differences in isotopic species in water play an important role in the variation that is observed in the atmospheric water cycle by promoting fractionating effects during vapor.

2. Study Area

Sindapalli Uppodai is a sub- basin of Vaippar river basin, receives drainage from its own catchment. It originates from the plain terrain nearby Duraiswamypuram village of Sivakasi Taluk, runs for a distance of 26 km and it joins in Arjunanadhi at the downstream of Allampatti village.

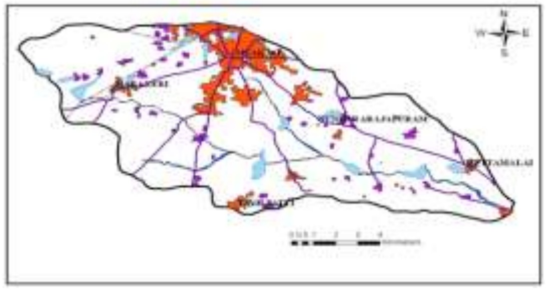

Figure1. Base Map of Sindapalli Uppodai Sub-Basin

The base map of Sindapalli Uppodai is delineated from the Survey of India toposheet consists of many tanks which form a cascade of tanks as shown in Figure 1. The maximum rainwater is collected and stored in these tanks and utilized for the needs of irrigation and drinking water demands through directly as well as recharging ground water aquifers. The entire Sindapalli Uppodai sub basin falls under semi arid region a sub basin. The location of the basin Latitude is of 9° 25’00”N to 9° 30’00” N and Longitude 77° 45’00”E to 77° 55’00”E. The soil types were found to be Loamy Sand and geologically the entire sub-basin is classified into hard rock terrain. The Major portion of the sub-basin is covered by Granitic gneisses. The area between Ammapatti and Melotampatti lie at elevations of 117 to 90 m above msl.

3. Methodology

The methodology of work is shown in figure 2. The study area is delineated from SOI (Survey General of India) topo sheet and the tanks and wells in study area is identified. A network of wells established for collection of water samples. The field investigations like geo-hydrological studies, water sampling for isotope analysis of pre and post monsoon groundwater tank water and precipitation samples, monitoring for depth to groundwater levels were undertaken during 2009 and 2010.

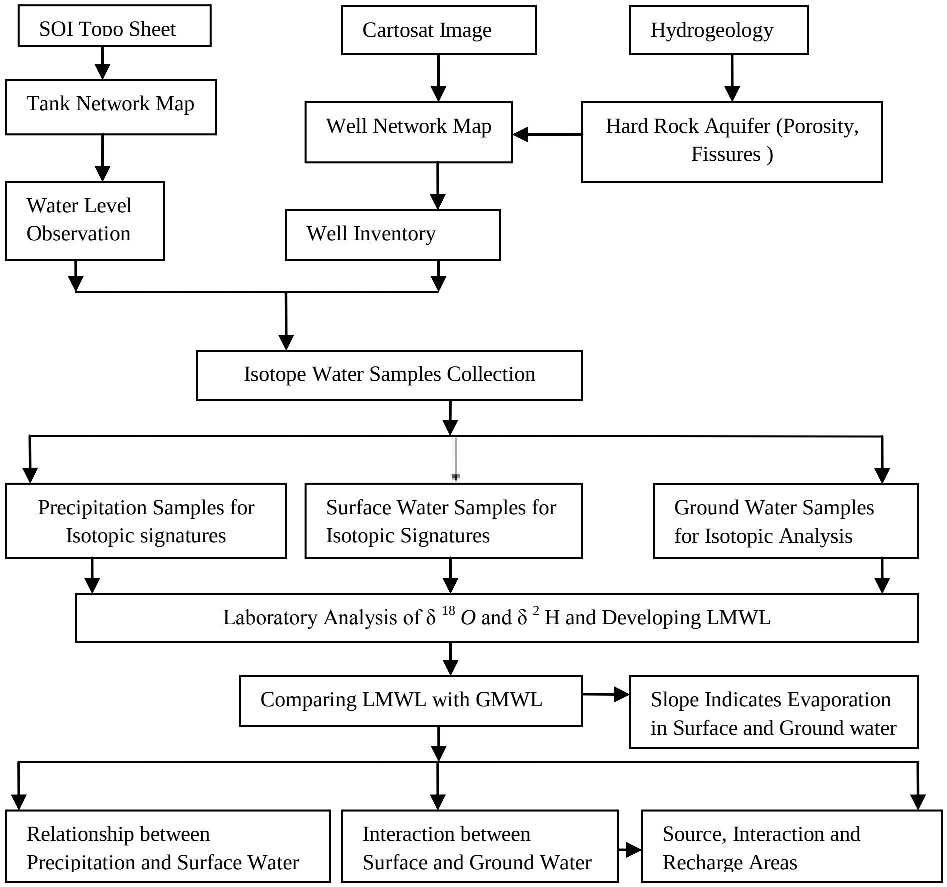

Figure 2. Identifying Isotopic Signature in Surface and Ground Water Interaction

Hydrological investigations were conducted to monitor water levels and collection of samples from 12 locations like, Duraiswamypuram, Sitturajapuram, Mutthalnayakanpatti, Melotampatti etc. The water samples of precipitation,tank water and groundwater were collected during December 2010, January 2010 and October 2010 for isotope analysis. Efforts were made to avoid any contamination, evaporation, and effect of exchange with atmosphere small amount of sample is enough for isotopic analysis to be on safer sides and for repeated measurements a minimum of 250 ml sample was collected in bottle. The samples were collected at sufficient depth for isotopic analysis. The sample bottles were tightly sealed and transported to NIH laboratory at Roorkee for isotopic analysis. The samples were analyzed for δD and δ18O stable isotope using Continuous flow stable isotope ratio mass spectrometer and Dual inlet stable isotope ratio mass spectrometer available at NIH, Roorkee.

4. Sampling & Analysis

The difference in isotopic character is designated by a Greek letter δ and it is defined in following equation 1 $\delta=(R_{sample}-R_{reference})/R_{reference}$ (1)

Where R's ratio of $^{18}O/^{16}O$ D/H isotopes in case of water. The difference between samples and references are quite small, δ values are therefore, expressed in per millie differences (%) i.e.per thousand, δ(%) = δx 1000 as in equation 2.

$$\delta(\%) = [((R_s-R_r)/R_r] \times 10^3 = [(R_s/R_r)-1] \times 103 \quad (2)$$

If the δ value is positive, it refers to the enrichment of the sample in the heavy isotope species with respect to the reference and the negative value corresponds to the sample depleted in the heavy-isotope species. The reference standards normally considered are SMOW (Standard Mean Oceanic Water) and VSMOW (Vienna Standard Mean Ocean Water). The relation between δD and $\delta^{18}O$ that has been observed in global precipitation is expressed mathematically by the equation known as Global Meteoric Water Line (GMWL). The relation between δD and δ18O can be written in a standard form as a linear equation 3

$\delta D\% = 8\delta\,^{18}O + 10$ (3)

One can develop regional and local meteoric water lines on the pattern of standard relationship between δD and $\delta^{18}O$ valid on regional or local levels. The slope of the line corresponding to $\delta^{18}O$ versus δD of water undergoing evaporation decreases as humidity decreases. That is the slope of the standard meteoric water line of can range between 8 and 3 in the case of evaporation depending on the relative humidity. The results of this are that residual liquid water has undergone evaporation plots to the right of the meteoric water line following a slope of 3 to 8. Water that has experienced the greatest evaporation factor are farthest from the meteoric water line. The slope of this divergent line indicates that relative humidity during the evaporation process. Waters of closed basins must have undergone evaporative fractionation. The measured error in the estimate is ± 0.1 % in $\delta^{18}O$ and is ± 0.1% in δD. The $\delta^{18}O$ value varies from -0.90 to -10.70 in precipitation and -2.8 to -4.61 during December 2009 for water samples from tank at Siturajapuram and Melotampatti shows the evaporation effect at tank clearly $\delta^{18}O$ has a value of -2.55 at Melotampatti; -5.02 at Thayilpatti; -1.79 at Ammapatti; -3.11 at Oorampatti; -3.43 at Aanaiyur; -4.3 at Aanaikuttam for groundwater during December 2009. The linear equation of local precipitation occurred in Sivakasi, LMWL i.e, a local meteoric water line during the study period is plotted for $\delta^{18}O$ and δD. The equation (4) as explained previously is found to be,

$$\delta D\% = 8.0262\delta^{18}O+12.528 \quad (4)$$

5. Results & Discussion

The $\delta^{18}O$ vs δD plots of LMWL, for the study area is shown in figure 3 for December 2010. The results indicate the slope of GWL for December 2010(4.6198) and January 2011(4.4057) is less than that of LMWL (8.0262). This shows that the residual liquid water has undergone evaporation and plots to the right of the meteoric water line. GWL shows the evaporation effect.

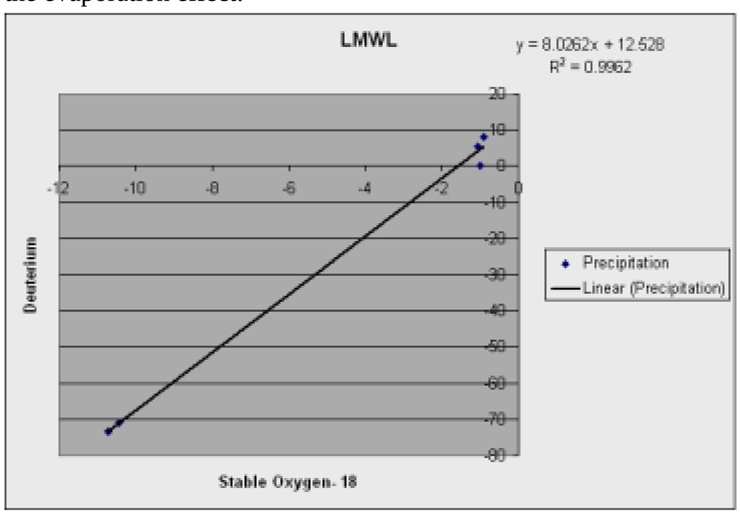

Figure 3. LMWL for Sindapalli Uppodai Sub-basin

The TWL of December 2010 (7.8982) has less slope compared to slope of LMWL and the isotopic composition changes shows that the groundwater has undergone evaporation. The isotopic composition of groundwater in some wells shows depletion due to recharge from precipitation. The slope of January 2011 (4.4057) is shown in Figure 5 slightly decreases indicating the recharge to groundwater with slightly more evaporation effect. Nagabhushanam P. (2005) [4] Interaction of recharging water with hard rock's will cause the $\delta^{18}O$ of the groundwater to be shifted to higher values, but it will not significantly affect the δD values.

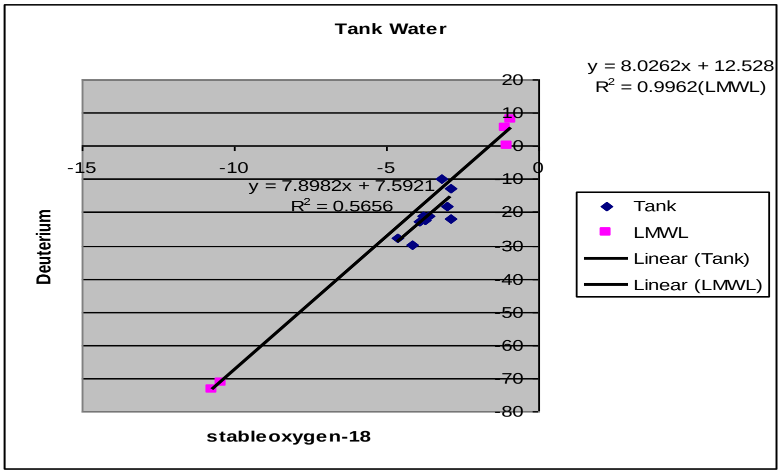

Figure 5 Comparing LMWL with Surface Water Line

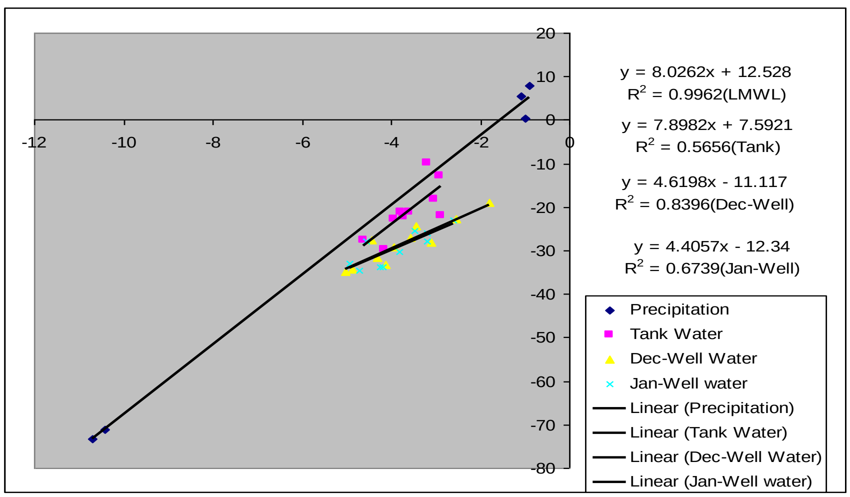

Figure 6 Comparing Surface Water Line with Jan Well Water Line

The intercept of GWL in the month of December (2010) (4.6196), January (2011) 4.4057 and TWL (7.8982) this indicates the repetitive evaporation effect ion groundwater during irrigation return flow. The enrichment shows that the ground water storage is very limited in the study area. The areas where the values have depleted due to recharge and enriched due to evaporation can be distinguished. The areas around Vilampatti showed significant variation in $\delta^{18}O$ values in both the plots and indicates the seasonal response of the aquifer due to recharge and evaporation. The areas around Aanaikuttam where isotopic values show more depletion during monsoon season are suitable for taking artificial recharge measures. Some of the areas show very less or no depletion or enrichment in the $\delta^{18}O$ values over the season both indicating the stabilization of $\delta^{18}O$ value in hard rock aquifer with the recharging rainwater as it reaches the water table which is quite deep here. The δD values are showing those of precipitation indicating presence of recharge from rainfall at deeper aquifers but these aspects have to be further investigated.

6. Conclusion

The analysis indicated that the stable isotope values of $\delta^{18}O$ and δD in the groundwater of the aquifer are varied not only over the seasons, but also in space, even at larger depth indicating the presence of rainfall recharge in the aquifer. The $\delta^{18}O$ vs δD plot of December 2010 clearly indicated the presence of rainfall recharge. The less slope of GWL in $\delta^{18}O$ vs δD plot of January 2011 indicates the evaporation effects are high. This may be due to meager storage in aquifer from available precipitation and subsequent reuse or repeated use of pumped groundwater recharge from irrigation return flows and recharge from the tank water. Hence there is necessary of undertaking artificial recharge from aquifer from the tanks. The interaction of recharging water with hard rock aquifer has caused the $\delta^{18}O$ values to be high where as δD values remain unchanged as that of recharging water as it moves downwards to reach deep groundwater table. The areas where isotopic value shows more depletion during monsoon season is suitable for undertaking artificial recharge measures.

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