Report

on

Reconnaissance Survey of Rainwater Harvesting (RWH) Structures Constructed in Arvari and Maheshwara River Catchments by Tarun Bharat Sangh, Rajasthan

A Preliminary Report

By

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PREFACE

The rainwater harvesting and water conservation measures in water scarce regions are useful techniques for augmentation of groundwater recharge and base flow in rivers, particularly during the lean flow season. However, no guiding document exists on the revival of rivers through rainwater harvesting and water conservation measures in the catchment. In this context, a suggestion was given by a Member of the NIH Society to document hydrological impact of such water conservation techniques. Therefore, a field visit was undertaken by NIH scientists to Arvari and Maheshwara river catchments in Rajasthan for preliminary investigations on the impact of rainwater harvesting structures and revival of these rivers. The field visit was aimed to visit various water conservation sites in both the catchments and to collect available information, and to suggest a future course of action. During the field visit, some measurements of groundwater levels were taken and water samples of surface water bodies and groundwater were collected for isotopic and chemical measurements for preliminary analysis.

The report entitled *"Reconnaissance Survey of Rainwater Harvesting (RWH) Structures Constructed in Arvari and Maheshwara River Catchments by Tarun Bharat Sangh, Rajasthan"*. Report has been prepared by Dr. S. P. Rai, Dr. Surjeet Singh, Er. C. P. Kumar and Dr. V. C. Goyal. It provides preliminary information on the impact of water conservation and rainwater harvesting structures surveyed and recommendation for a future study.

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Summary

In arid and semi-arid region, water scarcity is one of the main limiting factors for economic growth. This study highlights the noticeable prima facie visual field observations of RWH and impacts on groundwater recharge. A preliminary study of the major hydrochemical processes that control the variations of ions in the groundwater was also carried out. Groundwater and river, reservoir/ponds water were sampled from fifteen (15) locations in the Arvari and Maheshwara catchments for isotopic and chemical analysis. The measured ions (F^-, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl, NO_3^-, SO_4^{2-}, HCO_3^-) were generally low with wide variations. Two principal hydrochemical water types have been delineated. These are Ca-Mg-HCO_3 which constitutes about 73.4% and is dominated by alkaline earths metals and weak acids. The second water type Na-Mg-Ca-HCO_3 is the mixed water type where no particular cation dominates and HCO_3 is the main anion. The stable isotope reveals that the groundwater, river, reservoir/pond receive recharge from a common source of stable isotopic values of around -6.0‰ for $\delta^{18}O$ and -39.0‰ for δ^2H and the dam water undergoing significant evaporative enrichment of the isotopes. Tritium values in the study area are generally low and range from 1.24 to 5.31 TU; which indicates qualitative identification of modern recharge. Despite the small sample size of this work, isotope mass-balance calculations using $\delta^{18}O$ suggest a significant recharge through the anicuts to nearby groundwater for example at one site recharge ratio comes to about 50% in groundwater, hence the constructions of these dams and RWH should be encouraged to augment groundwater in the water scares regions of Rajasthan and other States of India. But before this, the foremost requirement is to properly document and disseminate such RWH practices and their positive impact on groundwater in a scientific manner to help the needy.

CONTENT

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

Groundwater, one of the most important natural resources, supports human health, economic development, and ecological diversity. The use of groundwater has increased because of factors such as high easy availabilty, excellent quality, recharging with rainfall consistently and low development cost (Todd and Mays 2005). Surface water accounts for 0.3 % of the fresh water that exists on earth. In comparison, groundwater amounts to 30 % of the fresh water (Gleick 1993). Globally groundwater provides 50% of current potable water supplies, 40% of the demand for self-supplied industry and 20% of irrigation water (Villholth 2006). Therefore, systematic development and management planning is crucial for establishing stabilised and secure sources of water.

In India, where about 15% of the world's population lives, groundwater accounts for over 80% of domestic water use in rural areas, and 55 – 60% of the Indian population (about 620 million people) is directly or indirectly dependent on groundwater for agricultural purposes for their livelihood. Due to increased use of groundwater, millions of people have been lifted out of poverty (Kemper 2007). An attempt to improve rural water supply has led to the establishment of Rajiv Gandhi National Drinking Water Mission in 1986. Although there has been tremendous progress, the goal to provide safe drinking water to all is still to be achieved (Sharma 2003).

The ownership of groundwater and lack of the regulation policy poses a big threat and difficulty in groundwater management. These management difficulties are exacerbated by the millions of wells that exist in the country and the structure of groundwater property rights. The groundwater property rights are attached to land, allowing land owners to extract groundwater as economically as possible (Saleth 2005). Groundwater use has increased exponentially in the last five decades in India (Kemper 2007) and the current top-down approach has not been successful to manage the groundwater. As a consequence, water levels declining almost in all the states (Rodell, Velicogna et al. 2009), while the fastest rate has been found in the northwestern India, covering state of Punjab, Haryana and Rajasthan. The groundwater fed rivers are drying up or discharges are declining due to decreasing base flow contributions as a result of declining groundwater levels.

Rajasthan is one of the states of India whose economic growth is largely dependent on water, more specifically on groundwater. 71% of the irrigation and 90% of the drinking water supply source in Rajasthan is groundwater (Rathore, 2003). Presently, there is tremendous pressure to exploit groundwater by the State and private users, i.e. by those who have access and control over this limited resource. The resulting consequences are also well known - in 2009, out of 207 blocks, 8% has been categorised under semi-critical (8.9%), 12% under critical and 80% under over-exploited by Central Ground Water Board (CGWB) (http://cgwb.gov.in/gw_profiles/st_rajasthan.html).

In response to this grave groundwater situation, numerous efforts have been initiated by State Government, NGO's and Civil Society. Among the NGO's, Tarun Bharat Sangh (TBS), which is a local Non-Government Organisation (NGO) headed by Magsaysay awardees Shri Rajendra Singh, came into the existence since 1987. TBS started building Rainwater Harvesting Structures (RWH) with the support of local community. For each structure that is built, the village community covers a proportion of the construction costs; either monetarily or through voluntary labour. The general results of RWH for communities in this area have been very positive. Dixit et al (2003) found that 85% of RWH structures have benefited small and marginal farmers by increased groundwater supplies. This has allowed farmers to increase the area under irrigation and decrease their dependency on the rain-fed *Kharif* crops.

Giving resource property rights to communities, so that it is managed as a commonly owned or common property resource (CPR), has been encouraged as an alternative to effectively manage the groundwater, particularly in developing countries (Berkes 1989; Bromley 1992; Ostrom, Walker et al. 1992; Bruns 2007; Moench 2007). But there are very few documented evidences of successful commonly owned groundwater institutions, and relatively little is known about such institutions that do exist and their governance to groundwater use (Mukherji and Shah 2005). One such CPR institution exists in the Arvari River catchment, namely the Aravari River Parliament (ARP), initiated in 1998 with the help of Tarun Bharat Sangh..

To assess the impact of rainwater harvesting structures on revival of river and groundwater recharge of surrounding area, a team of Scientist from National Institute of Hydrology (NIH), Roorkee including Dr. S.P. Rai, Scientist-D, and Dr. Surjeet Singh, Scientist-D alongwith Mr. Kanahiya Lal from Tarun Bharat Sangh (TBS) visited the Maheshwara and Aravari River catchment from 18th to 20th December, 2012.

About 300 tanks of different sizes ranging from small in size to big ones have been constructed in the Maheshwara catchment. The team visited a big size tank in the Muryewala Khajura village. The size of this tank was around 300 m long and 150 m wide. The total depth was around 30 m and around 5 m water depth was available in the tank at the time of visit. The catchment of this tank is around 5-6 sq.km. This tank also holds water in summer months during May and June. The tank is used to meet the demands for the irrigation and livestock. The main source of drinking water in this village is through hand pump. The depth of these hand pumps vary from 150 to 190 m. The "Dhok" tree is a typical and most commonly found in this region which is also known to be very beneficial from the soil conservation point of view. The main crops grown in this village are wheat and paddy. Nearly 58 beegha land is being irrigated using this tank. There is also one channel from this tank which serves the regulated water supply for the irrigation purpose. Generally, the cultivation was found in valley portions which have sufficient depth of soil. The economic condition of the farmers has also improved a lot in this village because of the development of both surface water and ground water resources with the support of Tarun Bharat Sangh (TBS).

The team also inspected agricultural fields and number of dug wells in the downstream area of this tank. The farmers were found cultivating their fields and huge moisture was available in the fields. Some farmers were also seen irrigating their fields through the wells. In this area, groundwater table isvery shallow, just 0.5 to 1.0 meter below the ground surface. The average depth of these dug wells vary from 6 to 8 feet and are used for the irrigation purpose.

The team also visited the *Aurakhar Nalla* in a valley portion which was another water conservation site in extremely undulated and dense forests of Chambal region having series of anicuts. These anicuts were constructed by the local people with financial support from the TBS. These anicuts were constructed during 2011-12. By construction of these anicuts, sufficient soil depth has been developed behind the anicuts for the agricultural purpose. Tilling in these agricultural fields was being done by bullocks. The wheat and mustard are the main crops grown in this valley. The team also visited a number of anicuts in the area, Khuri ka Pagora anicut was one among these, where water was available in the channel course. It remains till the month of June, as per information provided by local farmers.

The team also visited the Arvari catchment on 9th December, 2012. There are number of anicuts on the Arvari river with varying sizes ranging from small one to big size. The team visited various anicuts in the catchment. The first one was Kunj Sagar anicut. The depth of water stored behind the anicut was found to be around 8 to 10 feet and over flow from the Anicut was observed.. The water normally remains available in this anicut up to summer months May/June. The main purpose of anicut is for recharge to groundwater. After construction of this anicut, remarkable rise in groundwater levels has been observed, as discussed with the local people.

The team visited second anicut Pipoda in the Basi village which was constructed 6-7 years ago. The depth of the stored water was around 5-7 feet behind the anicut. The water of this anicut is used for the domestic purpose and to recharge the groundwater. In surrounding agricultural fields, irrigation is practiced through wells. The water in this anict remains up to the summer season. Some more structures Babri, tanks were also visited.

It was observed that Rain Water Harvesting Structures (RWH) constructed in the Aravari and Maheshwara catchment located in the districts of Alwar and Karauli of Rajasthan has increased the soil moisture and water availibity period in the near by area of these structure. However, there is no scientific data to assess the impact of rainwater harvesting structures on groundwater recharge. Therefore, during the visit to various RWH structures, surface water and groundwater samples were collected from various locations for the isotopic and chemical analysis to identify the sources of recharge to the groundwater. Total dissolved solids were also measured in field at various locations. In this report, an attempt has been made to present a ‘snapshot’ impact of the rain water harvesting structures on the groundwater and the future course of action.

1.1 STUDY AREA

The Arvari River catchment is located in the eastern part of Rajasthan (Fig 1) in the district of Alwar. The Arvari River catchment makes up about 7% of the larger Banganga River Basin as a tributary. The Arvari River catchment falls between latitude 27.1’30 and 27.22’15N and longitude 76.16’30 and 76.4’55E. The catchment drains into Sainthal Sagar dam, a medium size irrigation project built in 1898. The inflows into the dam come from the semi-arid ephemeral rivers of the Bidila and the Arvari. The Arvari River catchment is mainly in the Thanagazi block of the Alwar district (administrative divisions), and covers an area of about 476 km^2.

1.1.1 Climate

The climate of the Banganga River Basin is semi-arid with hot summers between March and June. May and June are the hottest months of the year with a mean daily maximum and minimum temperature in May of 42.1^0C and 25.7 ^{0}C. The winter extends from November to March, with temperatures dropping to a minimum of 7.7 ^{0}C and a maximum of 21^0C in January.

The average rainfall of the Banganga River Basin is 637.6 mm, with an average of 31 rainy days a year (1901-1998). Eighty percent of this rainfall falls during the south westerly monsoon between June and September (Ground Water Department Jodhpur 1999). The closest rainfall station to the Arvari River catchment is in the town of Thanagazi (15 km to the North of the catchment). Total annual potential evapo-transpiration is 1523.7 mm, highest in May (271.5 mm) and lowest in December (155.6 mm).

1.1.2 Geology and Hydrogeology

Geologically the catchment is a part of the Aravalli Hill range, which is one of the oldest mountain ranges in the world (Bhuiyan et al. 2006). The geological sequence generally consists of limestone, quartzite, phyllites, alluvial sediments and windblown sand, silt and clay.

In the Banganga River Basin, groundwater occurs in shallow alluvium layers and deeper hard rock areas. The alluvial system overlies the fractured hard rock aquifers, where the coarse nature of alluvium usually results in phreatic conditions, and the hard-rock aquifer is connected hydraulically. The alluvial deposits are sandy to coarse and form aquifers a few tens of metres thick. The underlying aquifer is fractured igneous and metamorphic rocks

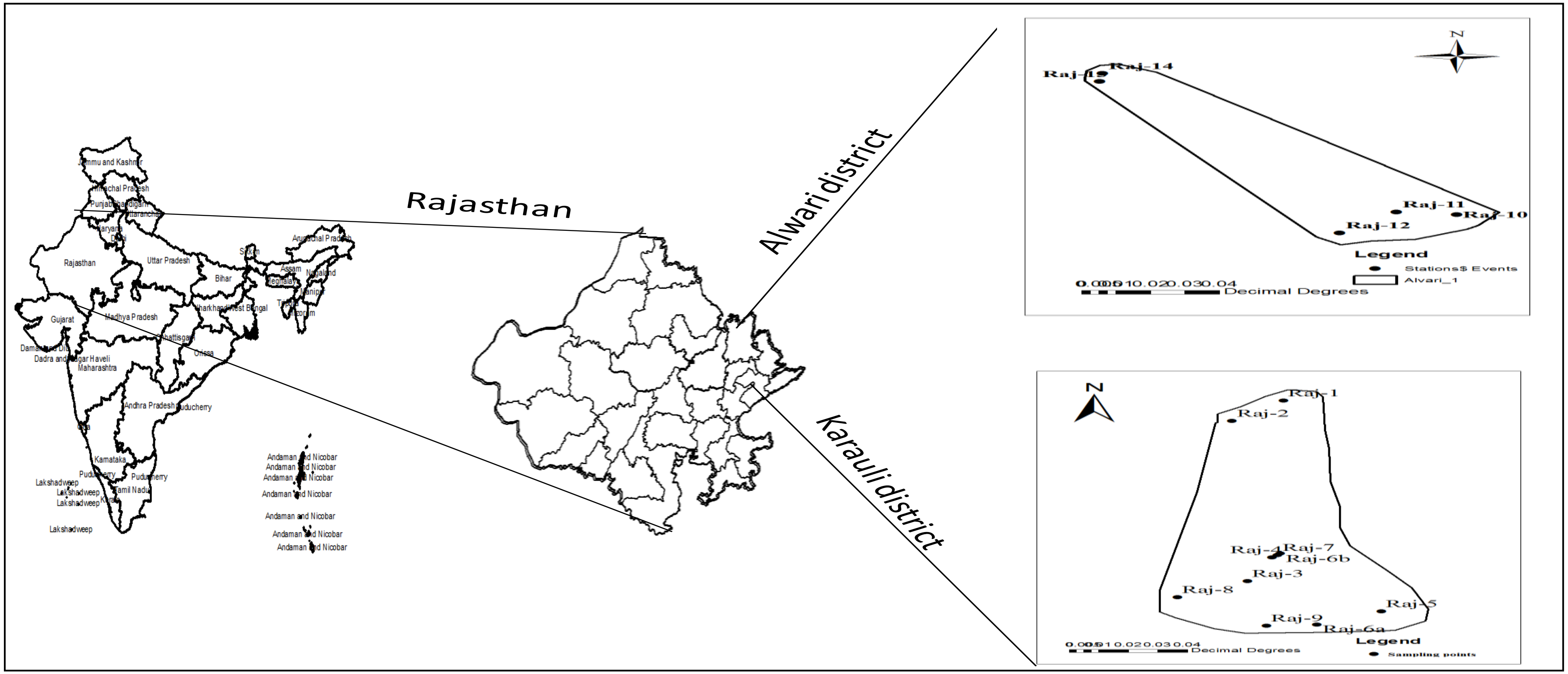

Figure 1. Sampling area

1.1.3 Soils

According to the National Bureau of Soil Survey and Land use Planning (NBSS and LUP), three broad soil types can be described in the Arvari River catchment (Shyampura and Sehgal 1995):

- Soils of the hills that are gravelly and light textured. They are generally found on rocky-outcrops, are shallow, well-drained and are loamy skeletal soils, which are severely eroded and strongly stony.
- Soils found on gently sloping terrain, with loamy-sand, sandy loam texture and these are well-drained. They are moderately shallow, calcareous, and are very severely eroded and strongly stony.
- Soils in the valleys, which are deeper and well drained. They are generally fine loamy soils on very gently sloping plains with dotted hillocks having loamy surface and slightly eroded.

1.1.4 Population, Economics and Social Aspects of the Area

In the Alwar district, 85% of the population lives in rural areas. The average population density is 273 persons/ km^2. In the Thanagazi block the current population is 144 119, with a rate of growth of 2.67% each year (Rathore 2003).

Agriculture is the main source of livelihood, which increased from 67% in 1981 to 76.5% in 1991 (Rathore 2003). The lack of surface water bodies in this area has made people entirely dependent on groundwater resources for water needs (Bhuiyan et al. 2006). There has been a shift in the use of energy for pumping wells; bullock operated wells have declined to 11%. There is a shortage of electricity in this area, so predominantly diesel pumps are used. The number of wells in the Alwar district and Thanagazi block is increasing every year. The number of diesel pumps increased from 1605 in 1991 to 3 741 in 2001. In the Thanagazi block, 96.3% of wells are privately owned. To increase groundwater access, deepening of wells is a common practice, along with digging of new wells (Rathore 2003).

A large percentage of the population of the Arvari River catchment is Scheduled Castes (SC), Scheduled Tribes (ST) or Other Backward Classes (OBC). These population groupings, recognised by the Constitution of India, are known as the ‘depressed classes’ under the earlier British colonial government. These classifications are based on the social and economic conditions of the communities. In the Alwar district the male to female ratio is 1000:887, and literacy in rural areas is 58% (77% for males, 39% for females) (NIC Alwar 08/07/2009).

CHAPTER 2

METHODOLOGY

In last two decades, isotopes along with geochemical data have been used to study the hydrological processes on local to regional scales. For examples, isotopes are used to study identify source of water, recharge source, recharge zone, residence time, flow velocity, to study the groundwater surface water interaction and to identify source of salinity etc.

Water from a total of fifteen boreholes, hand-dug wells and surface water (reservoir) were sampled at various locations (**Fig 1)** from the Arvari and Maheshwara river catchment. All the water samples were collected in 60 ml high density polyethylene bottles for major ions and 20 ml high density polyethylene bottles for stable isotopes. At the sampling points, the handpumps were pumped for 5-10 minutes before sampling to purge the aquifer stagnant water in order to acquire fresh aquifer water samples for analysis. Measurement of electrical conductivity (EC) and the geographical co-ordinates were conducted in the field.

The samples earmarked for major ion analysis were filtered through 0.45 µm cellulose filters prior to analysis. HCO_3^- titration was done in the laboratory using Sulphuric acid and methyl orange indicator. Sodium Na^+ and potassium K^+, magnesium (Mg^{2+}), calcium (Ca^{2+}), chloride (Cl^-), sulphate (SO_4^{2-}) nitrate(NO_3^-) were analyzed using ICS-90 ion chromatography at Nuclear Hydrology Laboratory, NIH, Roorkee. The ion-balance-error was computed, taking the relationship between the total cation (Ca^{2+}, Mg^{2+}, Na^+ and K^+) and the total anions (HCO_3^-, Cl^-, SO_4^{2-}) for each set of complete analysis of water samples.

The collected samples for stable isotope (oxygen and hydrogen) analysis were analysed by Stable Isotope Ratio Mass Spectrometer (SIRMS) at the Nuclear Hydrology Laboratory, NIH, Roorkee. The CO_2 equilibration method was used to determine $\delta\ ^{18}O$, while the H_2 equilibration method with Hokko beads was used to determine δ D following standard procedure (Epsein and Mayada 1983, Coleman et al. 1982). The measurement precision for $\delta\ ^{18}O$ was ±0.1‰ and for δ D it was ±1‰. All the $\delta\ ^{18}O$ isotope data reported in this study correspond to VSMOW.

Few samples were also collected for Tritium analysis in order to know the groundwater age. The tritium samples were analysed at Nuclear Hydrology Laboratory of NIH, Rookee, India. The tritium samples were enriched by electrolytic enrichment and analysed by the liquid scintillation counting method (Thatcher et al. 1977). Tritium concentrations are expressed in tritium units (I TU=3.24 pCi/ml; 1 tritium atom per 10^{18} hydrogen atoms).

After the chemical and isotopic analysis of water samples, interpretation was made to study the impact of water harvesting structures on groundwater recharge and other related aspects, as discussed in the next section.

CHAPTER 3

Results and discussions

Hydrochemistry

The results of the physico-chemical parameters for the 15 samples are presented in Table 1 while Fig 2 shows the Box and Whisker plots of the measured parameters.

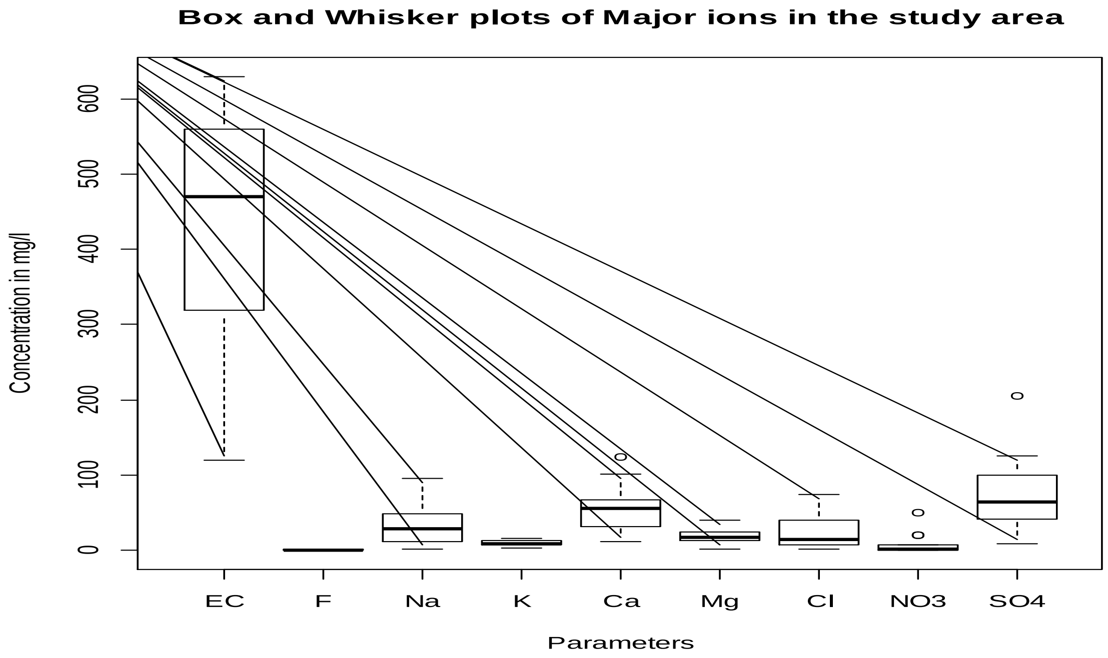

Fig 2. Box and Whisker plots of major ions in the study area plotted with R

The parameters measured exhibit a wide variation in terms of their concentrations in the entire study area. The Electrical Conductivity (EC) ranges from 120 to 630 µS/cm which represent fresh water type. The variability in the EC value is indicated by the rather high standard deviation (Table 2). The variation in the EC could be due to the samples types (groundwater and surface water).

Fluoride is an essential element for the health of bones and teeth, and is necessary element for primary health care. The World Health Organization (WHO, 2006) recommends that the highest permissible fluoride content in drinking water should be 1.50 mg/l. higher concentrations of this element in drinking water can lead to serious health problems. The average fluoride content in the study area is 0.50 mg/l with minimum and maximum values of 0.20 – 0.84 mg/l respectively.

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Table 2. Results of the physico-chemical parameters in the study area

Sample ID	Latitude	Longitude	EC (µs/cm)	Well Type	Depth (m)	Altitude (m)	F (mg/l)	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	NO_3 (mg/l)	SO_4 (mg/l)	HCO_3 (mg/l)
Raj-1	N26022'11.0"	E76055'29"	480	Open well	10.05	289	0.84	95.84	11.84	100.545	39.82	74.66	50.12	205.12	370
Raj-2	N26021'11.5"	E76054'26.6"	500	H pump	91.4	268	0.37	27.77	6.97	124.205	28.93	36.3	0	105.7	320
Raj-3	N260 13'22.2"	E76054'45.3"	140	Pond	9.1	355	0.28	2.28	3.39	11.525	2.795	1.42	0.12	51.24	60
Raj-4	N26014'31.7"	E76055'14.9"		H pump	225	346	0.58	21.64	5.27	55.065	15.62	13.36	20.19	39.3	250
Raj-5	N26011'53.9"	E76057'28.3"	300	River	-	294	0.2	7.14	6.22	29.79	8.24	9.46	0	41.18	120
Raj-6a	N26011'15.0"	E76056'10.2"		Dam	-	328	0.58	8.87	13.59	32.635	9.915	5.68	2.02	41.2	140
Raj-6b	N26014'43.3"	E76055'25.6"		H pump	213.4	352	0.5	37.05	9.48	61.59	17.11	20	0	53.94	340
Raj-7	N26014'38.8"	E76055'22.3"	339	Open well	5.18	339	0.51	18.59	6.8	68	16.77	13.42	20.16	64.28	240
Raj-8	-	-	430	Open well	7.62	-	0.45	13.59	3.56	65.53	17.22	3.84	5.44	78.78	290
Raj-9	N26011'11.9"	E76055'08.6"	460	Open well	8	341	0.76	28.05	6.38	51.43	18.73	8.58	5.82	92.28	260
Raj-10	N27009'11.2"	E76018'26.8"	630	Dam	-	372	0.52	64.42	15.72	22.33	30.73	43.02	0	110.34	170
Raj-11	N27009'11.2"	E76018'26.8"	630	Borehole		373	0.36	51.46	13.94	70.22	19.96	41.9	0	89.02	280
Raj-12	N27008'24.0"		600	Pond	-	-	0.43	66.91	15.65	32.68	31.99	44.24	0	124.94	230
Raj-13	N27014'56.6"	E76012'12.8"	520	Open well		454	0.77	43.93	8.67	58.015	17.23	18.48	7.65	21.46	320
Raj-14	N27015'17.5"	E76012'15.2"	120	Pond		446	0.4	0.7	7.98	11.905	1.53	0.68	1.72	8.62	80
Min			**120.00**			**268.00**	**0.2**	**0.7**	**3.39**	**11.525**	**1.53**	**0.68**	**0**	**8.62**	**60**
Max			**630.00**			**454.00**	**0.84**	**95.84**	**15.72**	**124.21**	**39.82**	**74.66**	**50.12**	**205.12**	**370**
Mean			**429.08**			**350.50**	**0.50**	**32.55**	**9.03**	**53.03**	**18.44**	**22.34**	**7.55**	**75.16**	**231.33**
SD			**173.38**			**54.28**	**0.18**	**27.47**	**4.165**	**31.43**	**10.78**	**21.19**	**13.63**	**49.34**	**96.58**
IS:10500*			**-**				**0.6-1.2**			**75**	**30**	**250**	**45**	**200**	**200**

*Indian Drinking water specifications, 1992 and reaffirmed 1993.

The relationship between fluoride concentrations and the EC is not apparent in the study area (Fig 3), but generally higher fluoride concentrations are associated with high EC values despite the weak relationship between these two parameters. This means that high fluoride levels in some of the wells sampled may be due to chemical weathering of the source material. In addition, the relationship between fluoride and calcium concentrations in groundwater in the study area is also poor (Fig 4), however, the positive correlation between the F and Ca suggest a common source for both parameters.

A poor relationship between these two parameters does not preclude fluoride enrichment due to the dissolution of fluorite in the aquifers. This is because of the other complex processes such as cation exchange, silicate mineral weathering, oxidation among others, which have a bearing on the concentration of calcium in the medium. For this reason, an examination of these processes is made to examine their extent of influence on the hydrochemistry of the water in the study area.

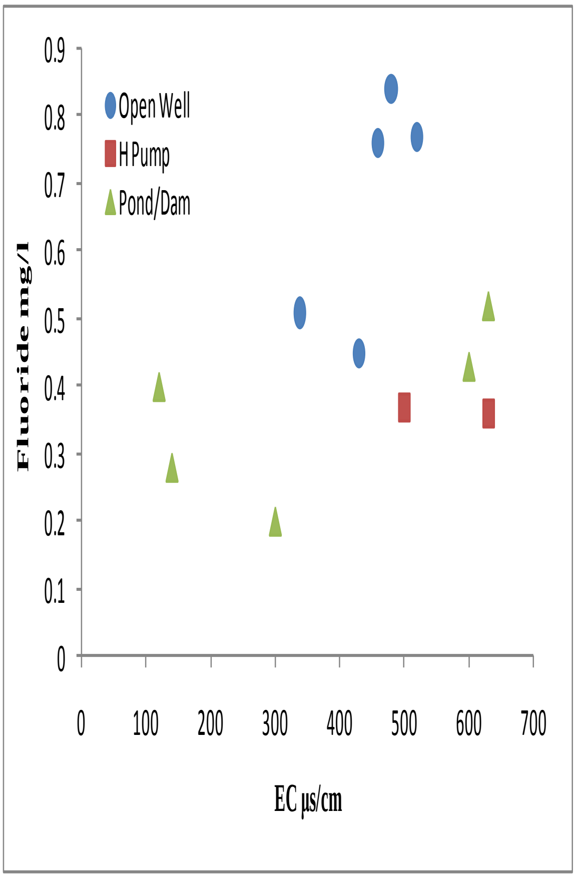


Fig 3.A scatter plot showing the relationship between fluoride concentrations and EC in the study area.

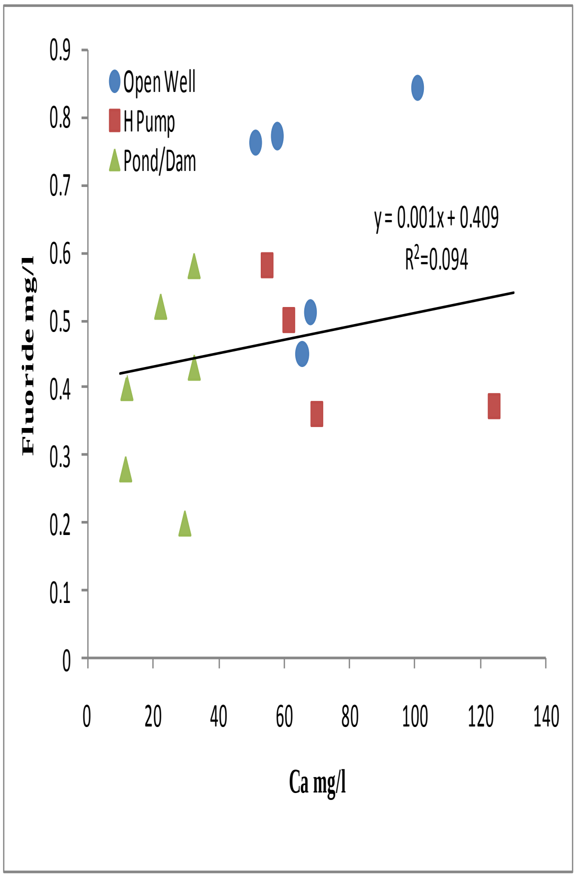


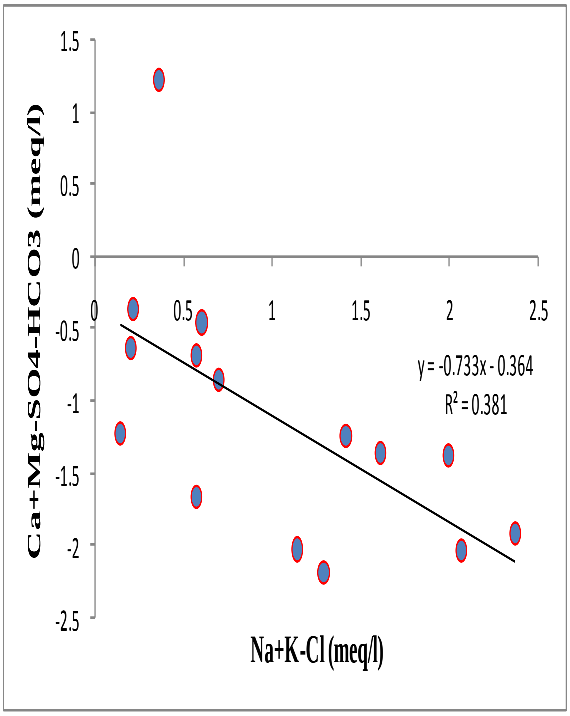
Fig 4. A scatter plot showing the relationship between fluoride and calcium concentrations in the study area.

3.1.1 Cation-exchange

Cation exchange has been noted as a major hydrochemical process. The Ca+Mg-SO_4-HCO_3 (meq/L) and Na+K-Cl (meq/L) indices, respectively represent the concentrations of the alkaline earth elements and alkali elements after subtracting the contributions of their sulfates and carbonate minerals (for the alkaline earth elements), and chlorides (for the alkali elements). These indices provide a good way of determining how the concentrations of the alkaline earth elements vary with those of the alkali elements. If the two indices vary inversely with a slope close to -1 and plotting away from the origin, cation exchange activity is most probably significant in the hydrochemistry (Jalali, 2007). In the current study, a plot of Ca+Mg-SO_4-HCO_3 (meq/L) against Na+K-Cl (meq/L) in shown in (Fig 5). The slope of the line is -0.73. Even though, the data is plotted away from the origin, cation exchange seems to play a minor role in the hydrochemistry.

3.1.2 Weathering

Mineral weathering can also contribute greatly to the groundwater chemistry, Kim *et al*. 2004 suggested that the 1:1 ratio would be maintained between total cation and alkalinity when mineral weathering is the major process affecting the groundwater chemistry. Feldspar and carbonates are the most important minerals regulating the chemistry of natural waters from the standpoint of reactivity and abundance in the earth's crust (Bowser and Jones, 1993; Kenoyer and Bowser, 1992) Feldspars such as plagioclase and K-feldspar occupy about 58% of the earth's crust and are reactive relative to other silicate minerals (Kim *et al*. 2004). In addition, carbonate minerals such as calcite and dolomite largely influence the water chemistry if they are present in the geological material because their dissolution rates are up to six orders of magnitude faster than those of alumino-silicate minerals (Lasaga 1984). As a result, the 1:1 relationship between total cation and alkalinity can be used as an indicator for the influence of mineral weathering on water chemistry. Fig 6 shows the relationship between total cation and alkalinity. Few samples are close to the 1:1 mineral dissolution lines with R^2 = 0.711, indicating that dissolution of minerals in the groundwater is a minor geochemical process governing the chemistry of the groundwater.



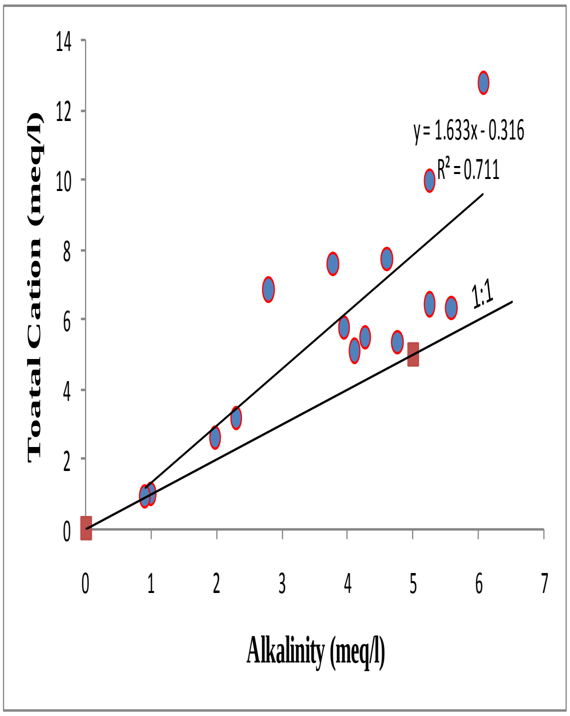


Fig 5. A biplot suggesting the possibility of cation exchange in the study area
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Fig 6. Relationship between Alkalinity and total cation in the study area.

3.1.3 Oxidation Process

The chemistry of groundwater is also likely to be significantly influenced by other chemical processes, such as oxidation of ammonium and/or organic matters. This oxidation process is one of the suggested reasons for the deviation from the mineral dissolution lines. To determine how much of the total water chemistry can be explained by the oxidation process, a mass balance analysis was performed, using the method suggested by Kim *et al. 2004.*

The oxidation of ammonium and organic matter increases the NO_3^- concentration by decreasing alkalinity and therefore, the total cation concentrations become unbalanced by alkalinity. The influence of Cl^- salts also causes the upward deviation from the mineral dissolution line by supplying additional cations without changing alkalinity. Therefore, the total cation concentrations were corrected for the effects of ammonium oxidation and Cl^- salt.

As the equivalent ratio between total cation and Cl^- is nearly 1:1 for Cl salt related processes, Cl^- concentration was subtracted from total cation concentration to correct for the Cl^- salt influence (Kim *et al*. 2004).

For the ammonium oxidation correction, it was assumed that NO_3^- is derived from ammonium oxidation (nitrification) only. Ammonium oxidation requires two equivalents of alkalinity to generate an equivalent of NO_3^-, so twice the amount of NO_3^- concentration was subtracted from the total cation to correct for the anthropogenic effect (Kim *et al*. 2004). Fig 7 shows the chloride correction graph, the results show that the total cation corrections make the relationships slightly linear with respect to alkalinity and the samples showed a closer relationship to the mineral dissolution lines with $R^2 = 0.779$ when the Cl^- correction was made.

Fig 8 shows the nitrate correction graph. The result shows that, there was a significant improvement in linearity when NO_3^- correction was made, $R^2 = 0.830$ indicating that most of the samples are influenced by this factor. It also emphasized the point that nitrification is a dominant NO_3^- supplying process in groundwater of the studied area.

The three processes showed little geochemical processes affecting the water in the study area. This leads to infer that, there is a worrying trend of increasing anthropogenic activities to the water chemistry in the study area.

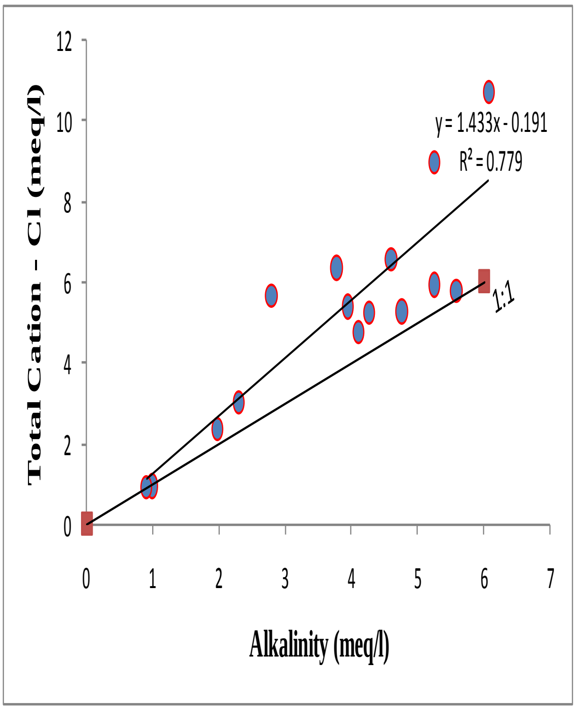

Fig 7. Relationship between Alkalinity and total cation-Cl

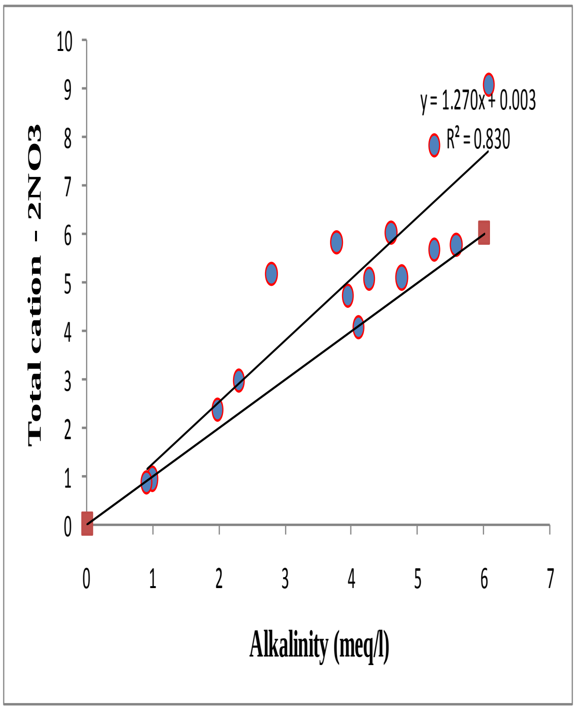

Fig 8. Relationship between Alkalinity and total cation-$2NO_3$.

3.1.4 Hydrochemical facies

Groundwater is grouped into facies depending on the dominant ions present (Piper 1944). Fig 9 shows the piper trilinear plot of groundwater in the study area. Two principal hydrochemical water types have been delineated. These are Ca-Mg-HCO_3 which constitutes about 73.4% and is dominated by alkaline earths metals and weak acids. The second water type Na-Mg-Ca-HCO_3 is the mixed water type where no particular cation dominates and HCO_3 is the main anion.

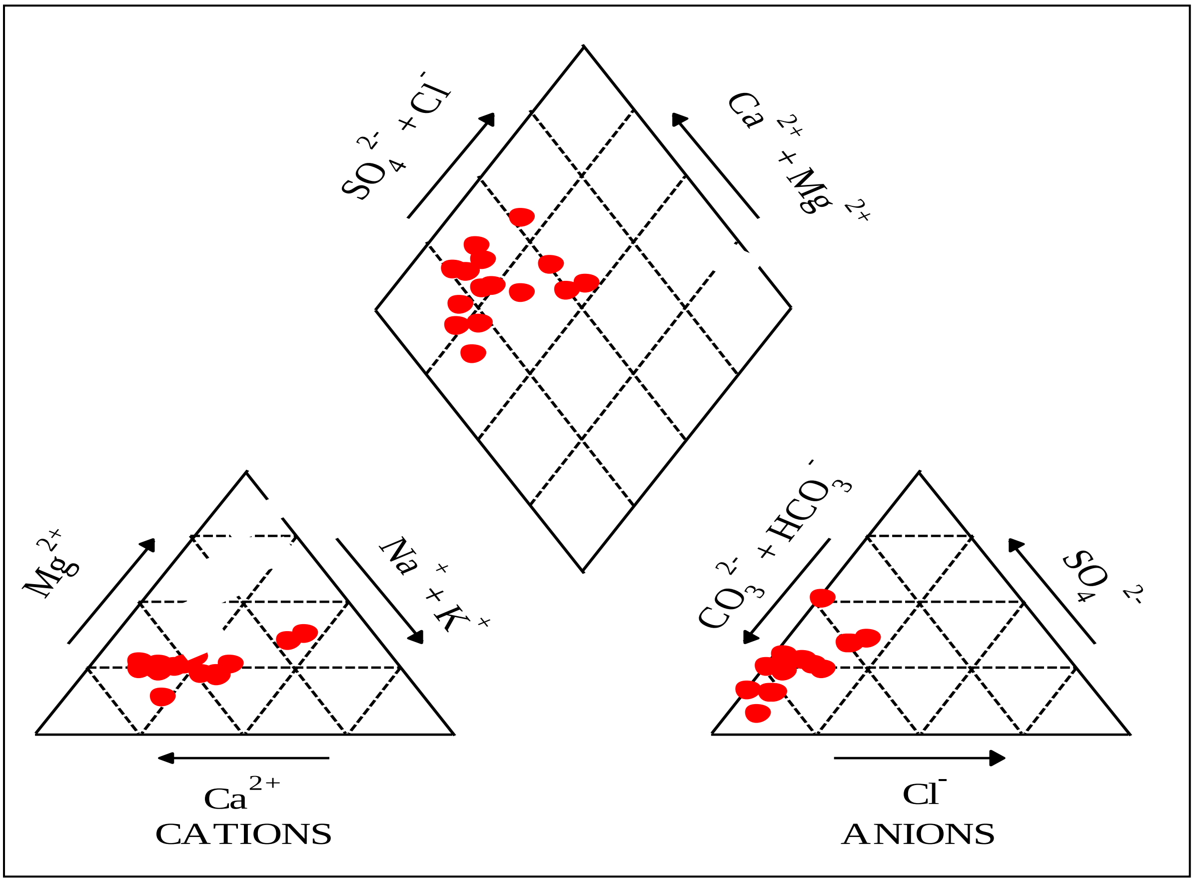

Fig 9. Piper diagram for the samples in the study area.

3.2 Results of stable isotope

The use of ^{18}O and ^{2}H isotopes in hydrogeology offers information on the origin and movement of groundwater. It can offer an evaluation of physical processes that affect water masses, such as evaporation and mixing (Geyh and Gu 1992). One of the major constraint in the use of these isotopes is the availability of long-term stable isotope records of local rainfall that is fundamental for understanding the relationship between isotopic compositions of groundwater and precipitation. Since it provides a baseline data for isotopic investigations in any area, which differs from the global line owing to the variations in climatic and geographic parameters. For this reason, the Indian Meteoric Water Line (IMWL) developed by Kumar et al. (2010) ($\delta^2H = 7.93\delta^{18}O + 9.94$) is used for interpretation of source groundwater. The $\delta^{18}O$ and δ^2H contents in the study area range from -5.14 to 1.55‰ and -35.63 to -7.73‰ respectively, with respective mean values of -2.31 and -22.80 (Table 3).

Table 3. Results of the $\delta^{18}O$, δ^2H and d-excess in the study area

Sample ID	**Well Type**	**$\delta^{18}O$ ‰**	**δ^2H ‰**	**d-excess ‰**	**^3H TU**
Raj-1	Open well	-4.72	-32.38	5.36	
Raj-2	H pump	-5.14	-35.63	5.48	
Raj-3	Pond	-2.58	-28.34	-7.74	
Raj-4	H pump	-3.20	-25.81	-0.23	4.29
Raj-5	River	-0.41	-16.24	-12.93	5.31
Raj-6a	Dam	1.55	-7.73	-20.14	
Raj-6b	H pump	-3.63	-27.93	1.15	1.24
Raj-7	Open well	-2.84	-24.41	-1.70	
Raj-8	Open well	-2.90	-22.79	0.38	
Raj-9	Open well	-1.86	-18.33	-3.42	
Raj-10	Dam	-1.63	-18.36	-5.31	
Raj-11	Borehole	-1.86	-19.46	-4.57	
Raj-12	Pond	-1.83	-18.77	-4.10	
Raj-13	Open well	-4.52	-34.08	2.09	
Raj-14	Pond	0.97	-11.77	-19.54	
Min		**-5.14**	**-35.63**	**-20.14**	**1.25**
Max		**1.55**	**-7.73**	**5.48**	**5.31**
Mean		**-2.31**	**-22.80**	**-4.35**	**3.61**
SD		**1.93**	**8.07**	**7.91**	**2.12**

Isotopic Composition of Groundwater River and Pond

The $\delta^{18}O$ versus δ^2H plot shows (Fig. 10a) the stable isotopes variations of the open well, handpump and the dam and trend of linear regression line, which is $\delta^2H = 4.041\delta^{18}O - 13.47$. The study area all the samples fall below the IMWL in the plot. The lower slope and intercept compared to the IMWL shows that groundwater, dam and the open wells have undergone evaporative enrichment process (Fig 10b and Fig 10c).

In this plot, it can be observed that, (i) all the samples falls (i.e. groundwater, handpum and pond/reservoir) on same line where as reservoir and handpump samples fall at the extreme ends

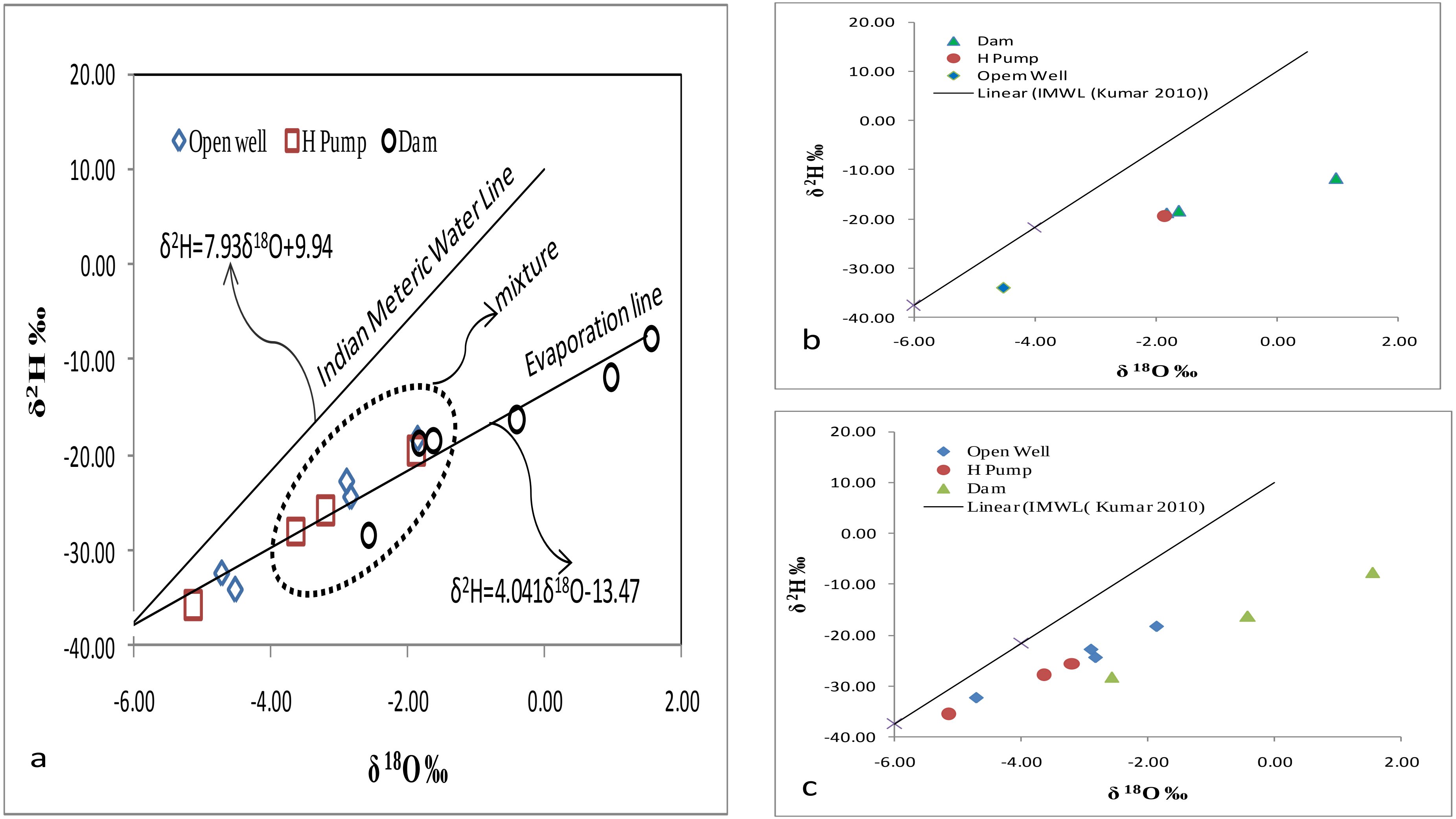

Fig 12. (a) Relationship between δ ^{2}H and and δ^{18}O in the study area (b) and (c) Relationship between δ ^{2}H and δ^{18}O at Arvari and Kiruali districts, respectively(H Pump = Handpump).

(ii) the evaporation line and IMWL, if extrapolated in backward direction it meets at -6 ‰ and -39‰, which indicates that source water isotopic composition, which has been altered (enriched from -6‰ to up to -2‰) due evaporation and mixing of surface water. (iii) the plot shows that isotopic composition (δ^2H and δ^{18}O) of all the samples falls between the two end members i.e. handpump of isotopic value -5.14‰ & -35.63‰ and reservoir water 1.55‰&-7.73‰. These observations suggest that, all the samples receive recharge from a common source of stable isotopic values of around -6.0 for δ^{18}O and -39.0 for δ^2H. The reservoir water undergoing evaporative enrichment and isotopic vales get enriched. The location where handpump isotopic composition is very close to the source or origin is showing insignificant evaporative enrichment while pond water is extreme evaporative enrichment. Groundwater samples fall in between these two end members indicating the mixing of reservoir water in groundwater through recharge. It suggests that there is interaction between groundwater-reservoir water.

One can use a two-component mixing model to estimate the fraction of surface water that mixes with groundwater/open wells. Although the number of the samples and data are very limited even though a attempt can be done to quantify the fraction of recharged water through the surface water body. For a two-component mixture, the fraction of surface water (f_{sw}) in the mixture is defined as:

$$f_{sw}= (Y_m- Y_{gw})/(Y_{sw}- Y_{gw})$$

where Y_m, Y_{gw}, and Y_{sw} denote the concentrations of δ^{18}O in the mixture, ground-water, and surface-water, respectively.

Differences in the isotopic composition of surface water, mixture water and ground water result in relatively high precision for detecting the mixing proportion of surface water in groundwater.

Isotope mass-balance calculations using δ^{18}O in above equation indicates that about 49% fraction of pond/reservoir water mixed up with the open wells/H pumps (sites Raj 9 and Raj 11). These sites are located in Maheshwara river catchment (Raj 9) and Arvari River catchment (Raj 11) in close vicinity to the ponds/reservoir (Fig. 1). Other groundwater samples show relatively smaller fraction. However in few samples does not show any recharge contribution from surface water. Probably, recharge is controlled by local hydrogeological and geomorphological conditions of the area.

Despite the small sample size of this work, the evidence suggest that Rainwater Harvesting Structures created along the Arvari River and their tributaries contributes to shallow groundwater through the recharge, hence the construction of these dams should be encouraged to augment groundwater in the study area.

The d-excess, defined as d-excess = $\delta^2H - 8\delta^{18}O$ (Dansgaard 1964), is a useful proxy for identifying secondary processes influencing the atmospheric vapour content in the evaporation-condensation cycle (Craig 1961; Machavaram and Krishnamurthy 1995). For atmospheric moisture not influenced by secondary evaporative processes, the d-excess approximates the y-intercept of the Global Meteoric Water Line (GMWL) of 10 (Marfia et al., 2004).

The d-excess values presented in Table 2 ranges from -20.14 to 5.48% with average of -4.35. The plot d-excess against $\delta^{18}O$ define a linear regression line of d-excess = -3.958 $\delta^{18}O$ -13.47 with R^2 = 0.934 (Fig 11). All the samples showed d-excess values lower than 10‰ with a negative correlation with $\delta^{18}O$. This observation has been observed to be the characteristic of isotopic composition in water samples from semi-arid climates (Geyh and Gu, 1992).

Conventionally, the sources of dissolve ions in water bodies could be deduced from the variation of the characteristic solute-concentration ratios such as Na^+/Cl^-, Ca^{2+}/Mg^{2+}, SO_4^{2-}/Cl^-, Br^-/Cl^- etc. However, in certain situations, water chemistry may undergo secondary changes such as ion exchange, oxidation and reduction, precipitation, evaporation etc. which make it very difficult to use ion-ratio approach to identify the sources of these ions.

Stable isotopes of water (^2H and ^{18}O) being relatively invariant over time, are therefore, well suited to study the complexities of groundwater hydrology in an area. Groundwater undergoing evaporation will have a positive correlation between $\delta^{18}O$ and conductivity whereas; groundwater salinization due to dissolution will have high EC without corresponding increase in $\delta^{18}O$. In the diagram of $\delta^{18}O$ versus conductivity in Fig 12, it was observed that, none of the above scenarios was apparent, but rather the groundwater shows a decrease in EC with increase in $\delta^{18}O$ (as the water samples become enriched). It also indicates that the groundwater is receiving significant recharge from an enriched source (pond/reservoir).

The pond/ reservoir water samples do not show any clear relations but are generally associated with low EC and high $\delta^{18}O$ values. The effect of evaporation also suggests that, the water samples have direct contact with the atmosphere, hence, increasing the risk of anthropogenic impact.

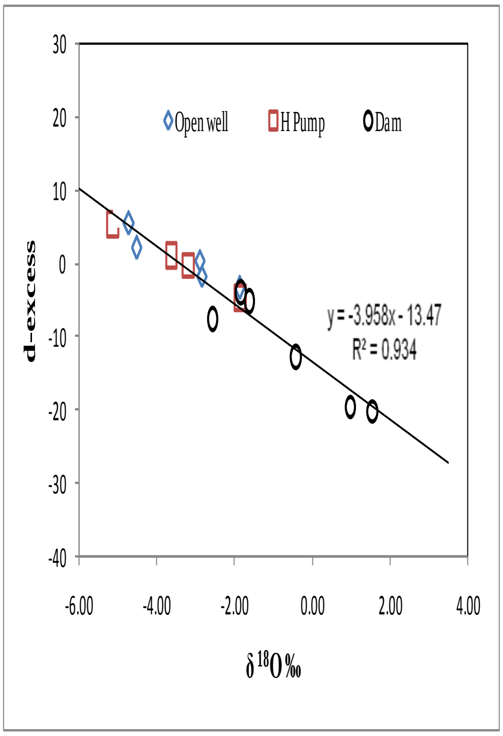

Fig 11. Relationship between d-excess and $\delta^{18}O$

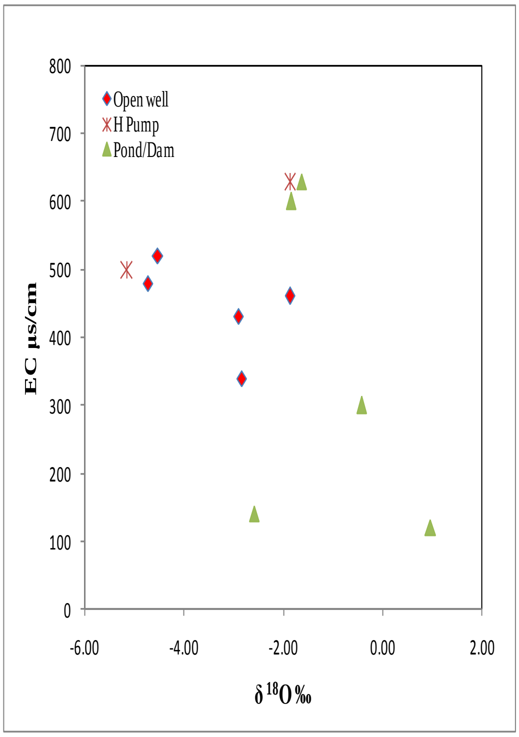

Fig 12. Relationship between EC and $\delta^{18}O$

Environmental Tritium and Groundwater Dating

Environmental Tritium is a powerful tool for quantitative groundwater research because it is a useful tracer for groundwater movement. Tritium, being a radioisotope, and as it loses half of its radioactivity every 12.34 years, hydrogeologists use tritium to estimate how long water has been underground. One may also trace the groundwater flow path and mean transport velocity. Hydrologists also use tritium to study the surface water and groundwater interaction in streams/lakes. It can also be used to identify the groundwater recharge zones for deeper aquifers along with many other associated information regarding aquifer dynamics. Tritium concentration in precipitation varied quite a lot during the last forty years due to atmospheric nuclear tests. Usually ground water will be a mixture of different water inputs at different times and so the tritium concentration will be a "mixture" of many years' input of tritium concentrations. If the tritium concentration is zero, then we can say that the water is old and has been cut off from the atmosphere for more than 50 years. Groundwater systems with recharge occurring prior to the 1950s will have a tritium level decreased by radioactive decay to below 1 TU. Detection of tritium takes advantage of the small amounts of radioactivity it emits.

The environmental tritium activity has been modelled to decipher the age of the groundwater at different aquifer as the age of recent water will be lower when compared with the older water. The residence time also helps us to identify the flow pattern of groundwater in the study area. Considering the modern water to have 9TU (Average Environmental tritium activity of precipitation in the study area) and half life period of environmental tritium is 12.5yrs the age of the groundwater has been projected using the formula:

$$A_t = A_0\, e^{-\lambda t} \qquad \text{eq (1)}$$

Where, A_t is tritium activity of sample; A_0 is tritium activity of Recent precipitation; λ is decay constant ($0.056 y^{-1}$) and t is the time or age.

To clearly understand the dynamics of groundwater the environmental tritium of three samples of reservoir and groundwater were analysed. Tritium values range from approximately 1.24 to 5.31 TU (Table 2), suggesting a range of ages, but these are difficult to interpret quantitatively, partly owing to the lack of detailed knowledge about inputs of ^3H in rainfall over time and also due to limited data. Tritium value of 4.29 TU was found for the site Raj 4 (handpump) located near the reservoir and 5.31 TU for the site Raj 5, which is a reservoir water. The higher value of tritium in Raj 4 and its closeness the tritium value of Raj 5 suggest a significant modern day recharge to the aquifer from the reservoir. However, 1.21 TU was found for the samples collected from Raj 6b site, which is a deep handpum with depth of about 700 ft. This implies that, this well is not receiving modern day recharge.

Conclusions

This study presents a preliminary result of the hydrochemical and isotopic characteristics of open wells, handpum and reservoir/ponds of Arvari and Maheshwara River catchment, fall under Alwar and Karauli districts of Rajasthan. The stable isotope analysis reveals that the all the sources i.e., open well, handpump, reservoir/pond receive water from a common source i.e. precipitation, the stable isotopic composition of source water fall around

-6.0‰ for $\delta^{18}O$ and -39.0‰ for $\delta^{2}H$. The reservoir/pond water undergo significant evaporative enrichment of the isotopes. Therefore, the enriched isotopic composition has been found for surface water body. Isotopic composition groundwater samples fall in between these two end members indicating the mixing of reservoir water to groundwater through recharge process. It suggests that groundwater is receiving contribution from the reservoir. Tritium values in the study area are generally low and range from 1.24 to 5.31 TU; however, which implies useful in qualitative identification of modern recharge. The chemical characteristics such as electrical conductivity, cations and anions show that their concentrations in the isotopically enriched samples are not higher than that of isotopically depleted samples. It also corroborates the finding of the isotope results.

Despite the small sample size of this work, the evidence (isotopic analysis) suggest that Rainwater Harvesting Structures created along the Arvari river and their tributarie contributes to shallow groundwater through the recharge. The preliminary analysis from this study indicates that efforts to construct more dams to augment the groundwater recharge be encouraged

Recommendations

During the of 19th and 20th December, 2012, discussions were held with Shri Rajendra Singh (JAL PURUSH), TBS on the progress of the two days field visit in Maheshwara and Arvari catchments. Discussions were also held on the strategy to propagate and translate such useful and effective soil-water conservation techniques in other water scares regions of Rajasthan and other States of India. Shri Rajendra Singh mentioned that there is still no documented scientific study to assess the impact of Rain Water Harvesting Structures on groundwater and its impact on maintaining the river base flow. Further, he emphasized that the document on impact of recharge structures may could be prepared in a manner such that it clearly highlights the following five main components: (i) The document should be such that it encourages the local people and water management authorities to initiate such types of soil and water conservation measures in water scares areas. (ii) The document should be simple and easily understandable to the common people, and the science behind it. (iii) The document should be such that it gets a wide publicity for the replication of these techniques in other regions of India. (iv) The document shoud highlight that using such RWH techniques, the problems of droughts and floods can be minimized to a large extent. (v)

These techniques can also be used as adaption measures to minimize the impacts of climate change.

Keeping in view the preliminary findings of the study and discussions with Shri Rajendra Singh, a detailed study needs to be planned to assess the impacts of such water conservation and recharge structures scientifically for an area which has a sufficiently long database of rainfall, groundwater levels, river flows and related data to analyse and establish effectiveness of Rainwater Harvesting Structures. On the basis of such detailed study, a document can be prepared covering all the points highligted by Sh. Rajendra Singh.

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