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A Hydro-Geochemical Evaluation of Groundwater Suitability for Irrigation and Domestic Purposes: A Case Study from Narmada Mahi Inter-Stream Region of Gujarat, India

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ABSTRACT: In order to ascertain pre-monsoon and post-monsoon compositional variations in the groundwater under different aquifer conditions, water samples were collected from Narmada-Mahi inter-stream area, covering coastal plains, alluvial plains, piedmont zone and highlands. Samples were collected from shallow aquifer (hand pumps/dug well) and deeper aquifers (tube/bore wells) and analysed for major and minor ionic concentration. Study indicates that the groundwater quality in the study area is highly diverse and complex due to influence of sea water intrusion (coastal salinity), inherent sediment salinity, quality deterioration due to overexploitation and pollution.

Geochemical analysis has established that the ground water in the study area has high concentration of major and minor ions. These ionic concentrations tend to decrease from western coastal plain to the eastern highlands parts. Some of the inland aquifers do show high concentration of ions but they are localized. The analysed samples were compared with the WHO (1993), ISI (1983) and ICMR (1975) drinking water standards and observed that samples have either one or two constituents in higher concentration making it unfit for drinking. Further, various indices viz. Kelley's Ratio, Residual Sodium Carbonate, Schoellar Index, Sodium Hazards (SAR) and Wilcox Irrigation Water Classification were also used to characterized water based on its ionic chemistry for its irrigation suitability. Few samples were also analysed for δ^{18} O isotopic variation and distribution in groundwater samples of study area.

Keywords: Geology, Groundwater, Geochemical, Total Dissolved Solids, Suitability

1 THE STUDY AREA

The study area constitutes a part of Mahi - Narmada inter-stream region of Gujarat state, India. It has distinct hydro-physiographic boundaries; which is bordered by the Gulf of Cambay in the West, the rocky uplands in the East, Mahi River in the North and Narmada River in the South and sprawl in about 11,000 sq. km. The area lies between 72º 30' E and 73º 43' E longitudes and 21º 40' N and 22º 53' N latitudes (Figure 1). The western and central part of the region comprises huge thickness of marine, fluvial and aeolian sediments of Quaternary period. These sediments consist of intercalations of sand, silt, clay and gravel bands strongly calcretised. These Quaternary deposits are good repository for groundwater in unconfined, semi-confined and confined conditions. The Eastern part of the study area is covered by hard rocks consisting of Cretaceo-Eocene; Deccan trap- basalts, intrusive granite, basement gneisses followed by meta-sediments; quartzite, phyllites, slate, schists and marble, etc.

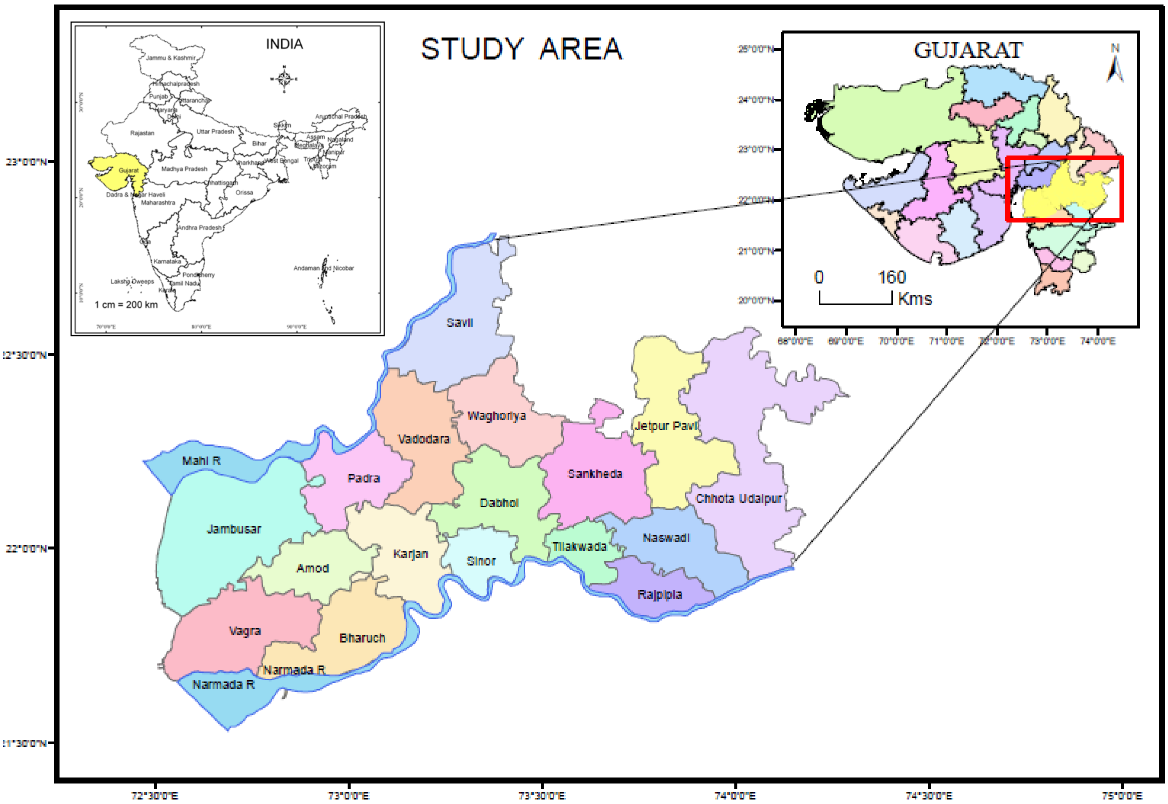

Figure 1. Location Map of the Study Area.

2 MATERIALS AND METHOD

Groundwater samples were collected from study area in a well-spaced grid pattern for geochemical analysis (Figure 2). Samples were collected from borewell (BW), handpump (HP) and few open wells (OW) representing deeper, intermediate and shallow subsurface samples. The American Public Health Association (APHA) has prescribed standard analytical techniques for determining the dissolved chemical content in groundwater. The water analysis was carried out using standard methods given in *"Standard methods for the examination of water and waste water"*.

$\delta\ ^{18}O$ measurements were carried out on 55 samples well spread over the study area, and measurements were done at PRL, Ahmedabad using a Stable Isotope Ratio Mass Spectrometer (GEO 2020, PDZ Europa U.K.) with automatic water equilibration system. The $\delta\ ^{18}O$‰ values are with respect to the V-SMOW and NRM (Narmada water, $\delta^{18}O$ = -4.5 ‰) was used as a laboratory water standard. The trace element analysis was done at IIT Powai, using ICP-AES instrument.

3 RESULT AND DISCUSSIONS

Hydrogeochemical investigation has been carried out with a view to characterize groundwater for its domestic and irrigation suitability. Various institute/organization has recommended the quality standard for drinking water among them some of the important ones are World Health Organisation (WHO), the Indian Council of Medical Research (ICMR) and the Bharat (Indian) Standard Institution (ISI). These standards include maximum desirable value and maximum permissible limit. The suggested drinking water standards by various institutions are given in Table-1 along with obtained range of parameters for the groundwater samples from the study area for four different seasons, to observe changes in groundwater condition with time and the effect of rainfall i.e. pre and post monsoon scenario. The study indicates that the drinking water quality deterioration is from east to west and also with depth. In few samples high fluoride concentration has also been observed which is mainly attributed to the geogenic processes and also due to rapid depletion of ground water (Dabral & Sharma, 2013).

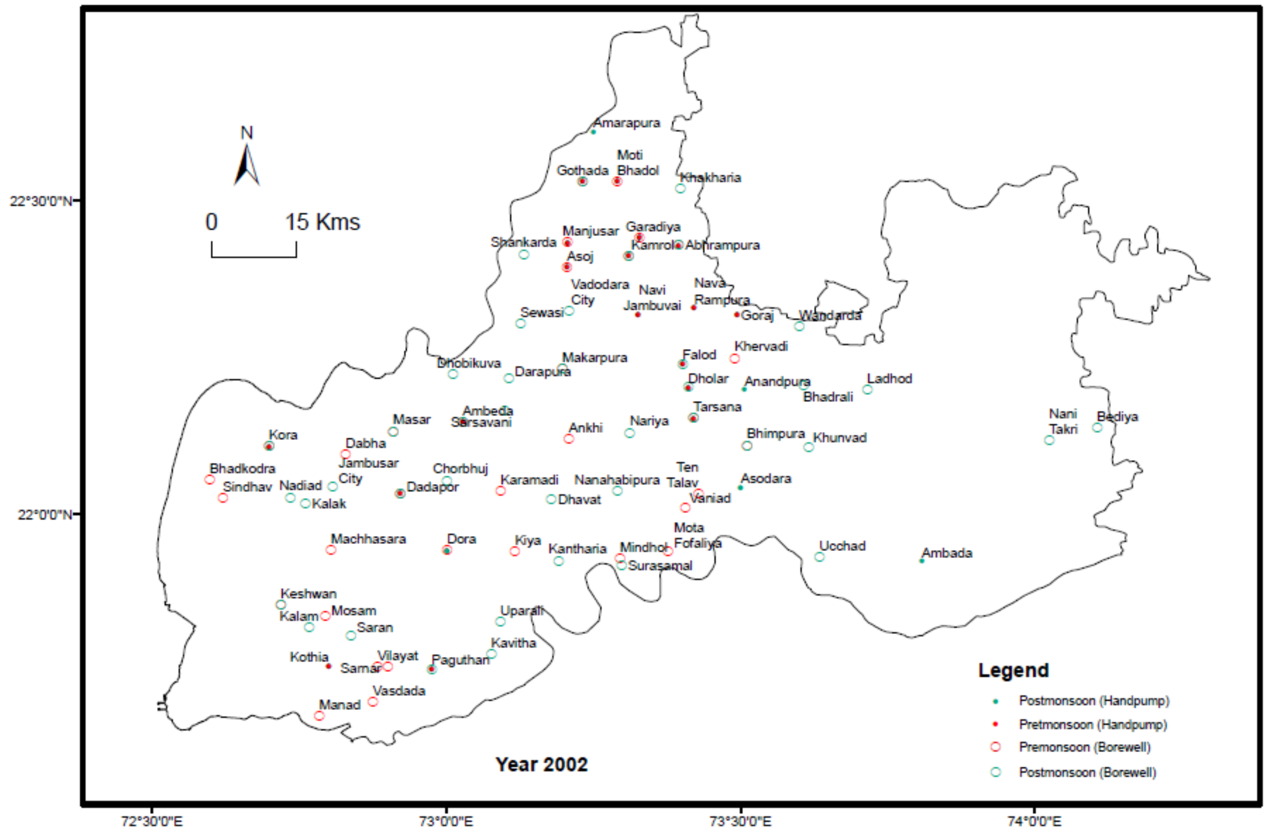

Figure 2. Locations of Water Samples in the Study Area (Pre and Post-monsoon 2002)

There are various indices available to characterized water based on its ionic chemistry for its irrigation suitability. Some of the important indices frequently used in irrigation classification are:-

1. Kelley's Ratio
2. Residual Sodium Carbonate
3. Schoellar Index
4. Sodium Hazards (SAR)
5. Wilcox Irrigation Water Classification

As a part of irrigation suitability the review of Ec values have established that only 6% (Pre-monsoon, 2002), 57% (Post-monsoon, 2002), 18% (Pre-monsoon, 2003) and 17% (Post-monsoon, 2003) was found to be in fresh water category. The alkali hazards as Kelley's Ratio, indicates 75% (Pre-monsoon, 2002), 43% (post-monsoon, 2002), 69% (Pre-monsoon 2003) and 69% (Post-monsoon, 2003) of the samples fall above the one ratio, indicating prone to alkali hazards.

Table 1. Comparison of Groundwater Samples from Study Area with Drinking Water Quality Standards.

Sr. No.	Parameters	ICMR (1975)	ISI (1983)	WHO (1993)	Study Area Samples			
					Pre Mon. 2002	Post Mon. 2002	Pre Mon. 2003	Post Mon. 2003
1	PHYSICAL PROPERTIES							
2	Colour (Hazen)	5 (25)	10	5 (50)	Colourless			
3	Odour	Not Desirable	Unobjec-tionable	Not Desirable	Odourless			
4	Taste (JTU)	"	Agreeable	"	NA	NA	NA	NA
5	Turbidity	5 (25)	10	5 (25)	NA	NA	NA	NA
6	CHEMICAL PROPERTIES							
7	pH	7.0-8.5 (6.5-9.2)	6.5-8.5	7-8 (6.5-9.2)	7.61-8.87	7.06-8.6	7.06-8.71	6.65-8.48
8	TDS (mg/l)	500 (1500)	2000	500 (1500)	420-9542	200-15094	205-9450	168-81000
9	TH (mg/l)	300 (600)	300	300 (600)	92.4-2667	58-3500	58-3850	70-16100
10	Calcium (mg/l)	75 (200)	75	75 (200)	18.5-370.6	5-589.5	12.8-384.2	10.1-6115
11	Magnesium (mg/l)	50 (150)	30	50 (150)	0.55-459.6	0.0-492.8	0-863.4	0-260.9
12	Chloride (mg/l)	200 (1000)	250	200 (600)	49.9-3798.8	20-6240	27-4099	60-50000
13	Sulfate (mg/l)	200 (400)	150	200 (400)	50-7800	30-10770	40-7300	19-59189
14	Fluoride (mg/l)	1.0 (1.5)	0.6 (1.2)	--(1.5)	NA	NA	0.11-6.65	0.1-13
15	Nitrate (mg/l)	20 (50)	45	--(50)	NA	NA	0.2-265	0.2-325
16	Copper (mg/l)	0.05 (1.5)	0.05	1.0 (1.5)	NA	NA	0.001-0.018	NA
17	Iron (mg/l)	0.3 (1.0)	0.3	0.3 (1.0)	NA	NA	0.3-1.7	NA
18	Manganese (mg/l)	0.1 (0.5)	0.1	0.1 (0.5)	NA	NA	0.004-0.04	0-2.9
19	Zinc (mg/l)	5.0	5.0	5.0	NA	NA	0.002-0.06	NA
20	No. of Sample Analysed				52	145	101	101

NA - Not Analysed

Evaluation of groundwater Permeability Index has established that bad category water is almost absent except one location at Rarod village (Karjan Taluka). About 57% (Pre-monsoon, 2002), 45% (Post-monsoon, 2002), 54% (Pre-monsoon, 2003) and 53% (Post-monsoon, 2003) of groundwater fall in excellent category. The abundance of carbonate and bicarbonate ions is denoted by residual Sodium Carbonate. Most of the samples are within the safe permissible limit with more numbers of samples having negative value, indicating that the concentration of Ca^{2+} and Mg^{2+} ions exceeds far more than Carbonate and Bicarbonate values. The Schoellar Index (SI) point to the possibilities of ion exchange reaction in groundwater. The SI index for about 70% (Pre-monsoon, 2002), 79% (Post- monsoon, 2002), 77% (Pre- monsoon, 2003) and 71% (Post-monsoon, 2003) samples are in chloro-alkaline disequilibrium whereas few samples are indicative of base exchange reactions. The adsorption of sodium by soil is measured as SAR (Sodium Adsorption Ratio). The SAR values indicate that only one sample in pre-monsoon 2002 and six samples in post 2002 fall in good water category while in pre and post monsoon year of 2003 none of the samples fall in good water category. Majority of the samples fall in bad water category i.e. C4-S4 to C3-S3. Owing to high ion concentration ground water is not fit for irrigation, especially in coastal and alluvial plain regions (Table 2).

δ^{18} O isotopic concentration of groundwater sample shows considerable variation in stable isotopic values ranging between -3.16 to 1.06‰ (Dabral et. al., 2013). The depleted values are indicating that the area is being recharged from surface water, while enriched values are from coastal plain area, which indicate salinity ingress. Pieper's Trilinear plot has been used to determine the genetic classification of water. The mean dominant cation in pre and post-monsoon 2002 and pre-monsoon 2003 in groundwater samples are in the order of $Na^+ > Mg^{++} > Ca^{++} > K^+$, while anion shows $SO_4^{2-} > Cl^- > HCO_3^-$ dominance. Similarly in post-monsoon 2003 samples are in the order of $Na^+ > Ca^{++} > Mg^{++} > K^+$, while anions shows $SO_4^{2-} > Cl^- > HCO_3^-$ dominance respectively.

Overall ground water facies in the study area is Na-Mg-Ca-K: SO_4-Cl-4CO_3 type. On the whole, groundwater quality tends to deteriorate from eastern hilly zone to western coastal plains which also follow the ground water gradient direction. The groundwater movement direction as evident from reduced water level map indicates that highlands act as a recharge zone to the shallow and deeper aquifers

(Dabral, 2009). Some of these aquifers through lower aquitard layer are in hydraulic connectivity with the lower aquifers thereby gets recharged.

Table 2. Categorization of Groundwater for Irrigation Purpose Based on Various Indices.

Indices	Parameter	Category	Pre-monsoon 2002	Post-monsoon 2002	Pre-monsoon 2003	Post-monsoon 2003
			% of Sample			
Kelley's Ratio	<1	No Alkali Hazard	23	43	30	32
	>1	Alkali Hazard	77	57	70	68
Residual Sodium Carbonate (RSC)	>5	Harmful	2	12	15	16
	>2.5	Hazardous	4	12	16	17
	1.25-2.5	Marginal	4	8	6	8
	<1.25	Safe	90	67	63	59
Schoellar Index	+ve	Base exchange reaction	29	18	24	32
	-ve	Cation-anion exchange	71	82	76	68
Sodium Hazards (SAR)	Based on plot of Salinity vs sodium	Good	12	73	36	33
		Moderate	7	40	41	39
		Bad	33	32	24	29
Wilcox Irrigation Water Classification	Based on plot of total concentration vs percent sodium	Class-I	Nil	Nil	Nil	Nil
		Class-II	Nil	26	1	3
		Class-III	4	6	8	7
		Class-IV	15	26	21	28
		Class-V	81	42	71	63

4 CONCLUSION

The average range of constituent ions in groundwater samples of pre and post monsoon periods indicate minute but noticeable change in their ionic content. The average difference indicate an overall decrease in pH, TDS, Ca, Mg and Sulphate whereas increase in total hardness, chloride and nitrate concentration from pre to post monsoon season.

In general the water quality in the study area deteriorates from eastern highland to western coastal plain which follows the ground water gradient direction and also with depth. The eastern portion being highland and act as zone of recharge, water quality is good for both drinking and irrigation purpose. The western part being close to Gulf of Cambay has inherent salinity which unfits water for both drinking and irrigation purpose. In central part groundwater by and large is of moderate quality but with depth quality deteriorates. Moreover, at places there are pockets of inherent salinity.

Categorising water in accordance with the drinking water standards has established that majority of samples have either one or two constituents in higher concentration making it unfit for drinking. Similarly owing to high ion concentration groundwater is not fit for irrigation, especially in coastal and alluvial plain regions.

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