World Academy of Science, Engineering and Technology
International Journal of Biological, Biomolecular, Agricultural, Food and Biotechnological Engineering Vol:7, No:7, 2013

International Science Index, Agricultural and Biosystems Engineering Vol:7, No:7, 2013 waset.org/Publication/16547

Groundwater Quality Assessment for Irrigation Use in Vadodara District, Gujarat, India

S. M. Shah and N. J. Mistry

***Abstract*—**This study was conducted to evaluate factors regulating groundwater quality in an area with agriculture as main use. Under this study twelve groundwater samples have been collected from Padra taluka, Dabhoi taluka and Savli taluka of Vadodara district. Groundwater samples were chemically analyzed for major physicochemical parameter in order to understand the different geochemical processes affecting the groundwater quality. The analytical results shows higher concentration of total dissolved solids (16.67%), electrical conductivity (25%) and magnesium (8.33%) for pre monsoon and total dissolved solids (16.67%), electrical conductivity (33.3%) and magnesium (8.33%) for post monsoon which indicates signs of deterioration as per WHO and BIS standards. On the other hand, 50% groundwater sample is unsuitable for irrigation purposes based on irrigation quality parameters. The study revealed that application of fertilizer for agricultural contributing the higher concentration of ions in aquifer of Vadodara district.

***Keywords*—**Groundwater pollution, agricultural activity, irrigation water quality, sodium adsorption ratio (SAR).

I. Introduction

GROUNDWATER which occurs beneath the earth surface is considered free from contamination, hence usable but anthropogenic as well as natural factors are affecting the quality as well as quantity of this valuable resource due to unplanned urbanization and industrialization for the past few decades in few parts of the country.

Understanding the potential influences of human activity on ground water quality is important for protection and sustainable use of ground water resources, as well as groundwater extraction has been increasing continuously to keep pace with agricultural development in rural areas hence the hydro geochemistry study is important. Ground water in the study area is utilized for both agricultural and drinking purposes [1]-[3].

Irrigation water quality is generally judged by some determining factors such as Sodium absorption ratio (SAR), soluble Sodium percentage (SSP), residual sodium carbonate (RSC), and electrical conductance (EC). Along with the above indicators, some additional indices to categorize the groundwater for irrigation like Kelly's ratio (KR) and total hardness (TH) were studied [12]. The location of this study areas were the Padra taluka, Dabhoi taluka and Savli taluka of Vadodara district. People of this district are the pioneer users of shallow and deep tube wells for drinking and irrigation Purpose.

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II. Study Area

Vadodara is located at 22°18'N 73°11'E / 22.30°N 73.19°E in western India at an elevation of 39 meters (123 feet). It has the area of 148.95 km² and a population of 4.1 million according to the 2010-11 censuses. The city sites on the banks of the River Vishwamitri, in central Gujarat. Vadodara is the third most populated city in the Indian, State of Gujarat after Ahmadabad and Surat. The city has Nandesari Industrial Estate which is comprised of around 1,200 small and large-scale industries i.e. dye industries, engineering, textile, and Pharmaceutical and petroleum industries.

Study Area: Taluka: Padra, Dabhoi and Savli.

III. Geology and Hydrogeology

The study of geo hydrological condition is very important as far as the exploration and recharge of the ground water is concerned. The study needs special attention to the city like Vadodara which is highly complicated. Some of the areas are having good aquifers which are good for exploration and recharge, but some of the areas are having nonproductive saline aquifers which are not good for exploration as well as recharge. Geohydrology it is recent to sub recent alluvium formation (comprises of alluvium Sand, clay, silt, gravel etc.) with alternate clay, sand, silt gravel etc.

IV. Material and Methods

The current study was designed to investigate the conditions of groundwater contamination in the study area. The hydro geochemistry study was undertaken by randomly collected twelve groundwater samples from dug wells.

Samples from open well for confined aquifer of the study area during May (Pre Monsoon) and October (Post Monsoon) for year 2011 were drawn and analyzed as per the Indian standards. The hydrological study was undertaken by groundwater samples for different parameters shown in the Table I and Table II.

Water quantity parameters such as pH, electrical conductivity (EC), Total dissolved solids (TDS), Total hardness (TH), CO_3^-, HCO_3^-, Calcium (Ca^{+2}), Magnesium (Mg^{+2}), Chloride (Cl^-), Sodium (Na^+) and Potassium (K^+) were estimated by standard method [4].

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V. Results and Discussion

Twelve groundwater samples were drawn from the wells which included open wells and analyzed for physicochemical parameters. The results of the physicochemical analysis are presented in Table I for pre monsoon and Table II for post monsoon for the year 2011.The critical parameters exceeding the BIS permissible limits along with the permissible limits for these parameters are presented in Table IV.

A. pH

pH is one of the important factors of ground water. Almost all samples were within maximum permissible limit prescribed by BIS for Padra Taluka, Dabhoi Taluka and Savli Taluka (Table I and II) [5].

B. Electrical Conductivity (EC)

Conductivity is the measure of capacity of a substance to conduct the electric current. Most of the salts in water are present in their ionic forms and capable of conducting current and conductivity is a good indicator to assess groundwater quality. Electrical conductivity is an indication of the concentration of total dissolved solids and major ions in a given water body.

Electrical Conductivity in groundwater varies from 270 to 3200 µmohs/cm (Table I and II) whereas permissible limit is<1500 micromohs/cm for domestic use (Table III). Conductivity values are divided into the three groups from general experience. The division based on conductivity values suggest that 75% of the wells are below the safe limit of 1500 micromohs/cm while 25% of the wells are in the range of 1500-3000 micromohs/cm and 0% of the wells are above 3000 micromohs/cm range for pre monsoon and 66.67% of the wells are below the safe limit of 1500 micromohs/cm while 25% of the wells are in the range of 1500-3000 micromohs/cm and 8.33% of the wells are above 3000 micromohs/cm range for post monsoon of Vadodara District.

C. Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) are the concentrations of all dissolved minerals in water indicate the nature of salinity of water. The total dissolved solids in all the study area varies from 10 to 2120 mg/ l (Table I and II). The higher the value of total dissolved solids is attributed to application of agricultural fertilizer contributing the higher concentration of ions into the groundwater. 16.67% samples for pre monsoon and post monsoon were exceeding maximum permissible limit for the study areas of the of Vadodara district by BIS (Table VI) [5], [12].

D. Calcium (Ca)

Calcium is naturally present in water. Calcium is a determinant of water hardness, because it can be found in water as Ca ions. Calcium content in the groundwater varies from 10 to 90 mg/l. Almost all samples were within maximum permissible limit for Padra taluka , Dabhoi Taluka and Savli taluka prescribed by the BIS (Table VI) [5].

E. Magnesium (Mg)

A large number of minerals contain Magnesium. Magnesium is washed from rocks and subsequently ends up in water. Magnesium has many different purposes and consequently may end up in water in many different ways. Chemical industries add magnesium to plastics and other materials as a fire protection measure or as filter. It also ends up in the environment from fertilizer application and from cattle feed. The value from Magnesium ranges from 09 to 322 mg/l (Table I and II). 8.33% samples of pre monsoon and post monsoon samples of Padra taluka , Dabhoi Taluka and Savli taluka were exciding the maximum permissible limit prescribed by BIS (Table VI) [5].

F. Sodium (Na)

Sodium is the sixth most abundant element in the Earth's crust and Sodium stems from rocks and soils. Not only seas, but rivers and lakes contain significant amounts of Sodium. Concentrations however are much lower depending on geological conditions and wastewater contamination. The Sodium content in the study areas has shown variations from 14 to 525 mg/l (Table I and II). 33.3% samples for pre monsoon and 37.5% samples for post monsoon of Padra taluka , Dabhoi Taluka and Savli taluka were exciding the maximum permissible limit prescribed by BIS (Table VI) [5].

G. Irrigation Water Quality

Irrigation water quality varies greatly upon the types and quantity of dissolved salts. Thus, water for irrigation suitability is determined not only by the total amount of salt present but also by the kind of salt. The irrigation water quality is judged by the four most applied criteria. These are: (I) total dissolved solids (TDS) i.e. the total salt concentration measured by EC (II) relative proportion of Sodium to other cations, expresses by Sodium Adsorption Ratio (SAR) (III) concentration of certain specific elements and (IV) residual Sodium Carbonate (RSC) [6]-[8], [13].

H. Sodium Adsorption Ratio (SAR)

The sodium adsorption ratio (SAR) is commonly used as an index for evaluating the sodium hazard associated with an irrigation water supply. It is generally recognized as the most applicable technique for determining the adjusted SAR hazard index [9]-[11].

The SAR is defined as the square root of the ratio of the Sodium (Na) to Calcium + Magnesium (Ca + Mg), i.e.:

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{\mathrm{Ca+Mg}/2}} \qquad (1)$$

where, all cation measurements are expressed in millimoles per liter (mmol/l). Alternatively, if the cation measurements are expressed in milliequivalents per liter (meq/l), then the SAR is defined to be:

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$$SAR = \frac{Na^{+}}{\frac{\sqrt{Ca^{+2}+Mg^{+2}}}{2}} \quad (2)$$

Irrigation waters having high SAR levels can lead to the build-up of high soil Na levels over time, which in turn can adversely affect soil infiltration and percolation rates due to soil dispersion.

Additionally, excessive SAR levels can lead to soil crusting, poor seedling emergence, and poor aeration.

Measurements of the electrical conductivity (EC, dS/m) and/or total dissolved solids (TDS, mg/L) also represent commonly used indexes for evaluating the salinity hazard of the irrigation water. Generally, the potential for water infiltration and/or soil dispersion problems can only be adequately addressed when the salinity and SAR indexes are considered together. Increasing EC levels tend to mitigate negative sodium effects, but can simultaneously induce crop stress (by degrading the quality of the available water for the crop via salinization). Hence, to properly assess the suitability of a particular irrigation water supply, the apparent salt tolerance of the specific crop must also be taken into consideration

For typical irrigation waters,

The quality of irrigation water depends primarily on the presence of dissolved salts and their concentrations. Sodium Absorption Ratio (SAR) and Residual Sodium Carbonate (RSC), Soluble Sodium percentage (SSP) are the most important quality criteria, which influence the water quality and its suitability for irrigation.

When waters having appreciable concentrations of calcium (Ca^{+2}) and/or bicarbonates (HCO_3^-) are employed for irrigation, a variable fraction of this constituent will precipitate in the soil as $CaCO_3^-$ according to the equation:

$$Ca^{+2} + 2HCO^{-}_{3} = CaCO_3 + H_2O + CO_3 \quad (3)$$

TABLE V
CLASSIFICATION OF GROUNDWATER ON THE BASIS OF SAR

PARAMETER	RANGE	WATER CLASS
SAR	<10	EXCELLENT
	10-18	GOOD
	18-26	DOUBTFUL
	>26	UNSUITABLE

I. Kelley's Ratio (KR)

Sodium measured against Ca^{2+} and Mg^{2+} is used to calculate Kelley's ratio [11]. The formula used in the estimation of Kelley's ratio is expressed as,

$$KR = \frac{Na^2}{Ca^2 + Mg^2} \quad (4)$$

A Kelley's Ratio (KR) of more than one indicates an excess level of sodium in waters. Hence, waters with a Kelley's Ratio less than one are suitable for irrigation, while those with a ratio more than one are unsuitable for irrigation. For pre monsoon 33.3% Kelley's ratio (KR) values for the groundwater of study area are less than 1 and indicate good quality water for irrigation purpose while remaining 66.67% is more than 1 indicates the unsuitable water quality for irrigation (Table VII). While for post monsoon 50% Kelley's ratio (KR) values for the groundwater of study area are less than 1 and indicate good quality water for irrigation purpose while remaining 50% is more than 1 indicates the unsuitable water quality for irrigation (Table VII).

J. Soluble Sodium Percent (SSP)

The Soluble Sodium Percent (SSP) for groundwater was calculated by the formula,

$$SSP = \frac{Na^{+}x100}{Ca^{+2} + Mg^{+2} + Na^{+}} \quad (5)$$

where, the concentrations of $Ca^{+2,}$ $Mg^{+2}$and Na^{+} are expressed in milliequivalents per liter (epm). The Soluble Sodium Percent (SSP) values less than 50 or equal to 50 indicates good quality water and if it is more than 50 indicates the unsuitable water quality for irrigation. The values of Soluble Sodium Percent (SSP) ranges from 30.48 to 92.84 (Table I). 25% Soluble Sodium Percent (SSP) values for the groundwater of study area are less than 50 and indicate good quality water for irrigation purpose while remaining 75% is more than 50 indicate the unsuitable water quality for irrigation (Table VII). For post monsoon 50% Soluble Sodium Percent (SSP) values for the groundwater of study area are less than 50 and indicate good quality water for irrigation purpose while remaining 50% is more than 50 indicate the unsuitable water quality for irrigation (Table VII).

VI. CONCLUSION

The analytical results shows higher concentration of total dissolved solids (16.67%), electrical conductivity (25%), Chloride (0%), total hardness (0%) and magnesium (8.33%) for pre monsoon and total dissolved solids (16.67%), electrical conductivity (33.3%), Chloride (0%), total hardness (0%) and magnesium (8.33%) for post monsoon which indicates signs of deterioration as per WHO and BIS standards. The groundwater of the rural Vadodara is aquifer exhibit conductivities from 270 to 3200 micromohs/cm. A few wells of the study area record extraordinary values of conductivity due to the application of fertilizer for agricultural exhibiting the higher concentration of ions contributes to groundwater degradation in varying degrees. Groundwater sample is unsuitable for irrigation purpose according to Sodium adsorption ratio (SAR), Soluble Sodium Percent (SSP) and Kelley's Ratio (KR). The data structures show that application of fertilizer for agricultural contributing the higher concentration of ions in aquifer of Vadodara District.

ACKNOWLEDGMENT

Authors are thankful to the Gujarat water resource development centre for their support for acquiring data of the study area.

APPENDIX

TABLE I
PHYSICO-CHEMICAL PARAMETERS OF DUG WELL OF VADODARA DISTRICT (PRE MONSOON)

	pH	EC	TH	TDS	HCO_3	Cl	Ca	Mg	Na	K	SAR	KR	SSP
WELL NO		µS/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	ppm	ppm			
W-1	8.4	740	210.80	530	305	56	30	33	71	2.0	12.65	1.13	52.98
W-2	8.5	1440	565.81	840	268	288	20	126	64	1.5	7.49	0.44	30.48
W-3	8.8	1290	396.77	860	329	192	55	63	56	92.7	7.29	0.47	32.18
W-4	8.5	1370	124.06	1070	610	80	20	18	215	71.60	49.32	5.66	84.98
W-5	7.0	2430	259.83	1790	622	312	15	54	260	298	44.27	3.77	79.03
W-6	8.7	3200	593.78	2120	634	592	10	90	392	112.4	55.44	3.92	79.67
W-7	8.4	540	99.23	440	268	32	15	15	20	95.30	5.16	0.67	40
W-8	8.4	1590	185.57	1080	427	232	10	39	278	0.50	56.16	5.67	85.01
W-9	8.4	1230	347.35	880	439	120	55	51	80	69.0	10.99	0.75	43.01
W-10	8.4	2640	173.35	1850	781	392	15	33	525	1.40	107.16	10.94	91.62
W-11	8.4	870	235.38	620	256	96	25	42	57	57.7	9.85	0.85	45.96
W-12	8.4	790	260.48	530	256	72	40	39	59	1.10	9.39	0.74	42.75
MIN	7.0	540	99.23	440	256	32	10	15	20	0.50	7.29	0.44	30.48
MAX	8.8	3200	593.78	2120	781	592	55	126	525	298	107.16	10.94	91.62

TABLE II
PHYSICO-CHEMICAL PARAMETERS OF DUG WELL OF VADODARA DISTRICT (POST MONSOON)

	pH	EC	TH	TDS	HCO_3	Cl	Ca	Mg	Na	K	SAR	KR	SSP
WELL NO		µS/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	ppm	ppm			
W-1	8.7	990	124.06	710	390	80	20	18	168	1.3	38.54	4.42	81.55
W-2	8.4	1250	232.82	780	207	216	10	75	131	1.5	20.09	1.541	60.65
W-3	8.4	680	186.10	490	220	48	30	27	43	42.6	8.05	0.75	43
W-4	8.4	1380	62.16	1080	610	64	15	6	253	59.7	78.07	12.04	92.34
W-5	8.8	2000	197.93	1530	622	224	10	42	184	307.5	36.08	3.54	77.97
W-6	8.6	2410	395.59	10	464	416	90	322	322	80.6	22.43	0.78	43.87
W-7	7.7	270	87.00	87	122	24	20	9	14	13.3	3.67	0.48	32.56
W-8	8.2	1490	62.03	1180	695	64	10	9	278	61.0	90.19	14.63	93.60
W-9	8.6	1170	185.97	880	464	96	25	30	136	75.50	25.93	2.47	71.20
W-10	8.7	1980	111.45	1410	634	264	10	21	402	1.30	102.10	12.96	92.84
W-11	8.3	930	235.25	660	268	104	20	45	62	69.20	10.87	0.95	48.82
W-12	8.0	620	173.22	460	305	32	10	36	50	18.20	10.43	1.08	50.08
MIN	7.7	270	62.03	10	122	24	10	9	14	1.3	3.67	0.48	32.56
MAX	8.8	2410	395.59	1530	695	416	90	322	402	307.5	102.10	14.63	92.84

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TABLE III
CLASSIFICATION OF GROUNDWATER FROM CONDUCTIVITY VALUE

Conductivity Range Micromohs/cm	Classification	Percentage Of Sample (Pre Monsoon)	Percentage Of Sample (Post Monsoon)
<1500	Permissible	75.00	66.67
1500-3000	Not Permissible	25.00	25.00
>3000	Hazardous	-	8.33

TABLE IV
IRRIGATION WATER QUALITY BIS STANDARDS

Sr. No	Parameter	BIS-Limit(1998)
1	pH	6.5-8.5
2	Chloride	1000
3	Electrical Conductivity	1500
4	Total Dissolved Solids	2000
5	Total Hardness	600
6	Calcium	200
7	Magnesium	100
8	Sodium	200

TABLE VI
CRITICAL PARAMETERS EXCIDING THE PERMISSIBLE BIS STANDARD

Parameters	BIS Standards (1998)	No. Of Sample Exceed Permissible Limit	Percentage Of Sample Exceeding Permissible Limit	No. Of Sample Exceed Permissible Limit	Percentage Of Sample Exceeding Permissible Limit
		Pre Monsoon		Post Monsoon	
pH	6.5-8.5	2	16.67	2	16.67
EC	1500	3	25	4	33.3
Total Dissolved Solids	2000	2	16.67	2	16.67
Ca	200	4	33.3	-	-
Mg	100	1	8.33	1	8.33
Na	200	4	33.3	5	41.67

TABLE VII
CLASSIFICATION OF GROUNDWATER ON THE BASIS OF SAR, KR, AND SSP

Parameter	Range	Water Class	% Of Sample Exceed Permissible Limit Of Pre Monsoon	% Of Sample Exceed Permissible Limit Of Post Monsoon
SAR	<10 10-18 18-26 >26	Excellent Good Doubtful Unsuitable	16.67 16.67 25.0 41.67	41.67 16.67 0.0 41.67
KR	<1 >1	Good Unsuitable	33.3 66.67	50 50
SSP	<50 >50	Good Bad	25.0 75.0	50 50

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