Hydro-Chemical Analysis of Groundwater Quality for Irrigation of Mehsana District, Gujarat State, India

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Abstract: ***Groundwater quality with reference to irrigation purpose in Mehsana district of Gujarat state is a baseline study for water scared region which covers around 1,81,698 hectare irrigation area. The present study is concerned to all nine tehsils (blocks) by assessing the groundwater quality extracting from the tube-well. In order to evaluate the quality of groundwater in study area, 26 groundwater samples were collected and analyzed for various parameters. Physical and chemical parameters of groundwater namely electrical conductivity, PH, total dissolved solids, Na, K, Ca, Mg, Cl, HCO3, CO3, SO4, NO3, NH3, PO4, Fe, F were determined. Chemical indices like percentage of sodium, EC, sodium adsorption ratio (SAR), residual sodium carbonate (RSC), permeability index (PI), kelly's ratio, Mg Hazards were calculated. Statistical analysis reveals that nearly 30 % water is suitable for irrigation purpose in the study area. As per the USSL Diagram showing the salinity hazard, most part of water samples falls under high salinity – medium to high alkalinity, which indicates seriousness of the groundwater quality.***

Keywords: Irrigation, Mehsana, sodium adsorption ratio (SAR), residual sodium carbonate (RSC), Kelly's Ratio, USSL Diagram.

1. Introduction

Groundwater plays a leading role in Indian agriculture development. The physical, chemical and bacterial characteristics of groundwater determine its usefulness for domestic, industrial, municipal and agricultural applications[1]. The major identifiable geochemical processes responsible for the evolution of the various ions are mineral weathering, chemical reactions and anthropogenic activities[2,5,6]. Suitability of irrigation water depends upon many factors including the quality of water, soil type, salt tolerance characteristics of the plants, climate and drainage characteristics of the soil. Groundwater always contains small amount of soluble salts dissolved in it[3,12]. Water chemistry differs depending on the source of water, the degree to which it has been evaporated, the type of rock and minerals it has encountered and the time it has been in contact with reactive minerals[4]. Hence, enough information of groundwater chemistry is very essential to properly evaluate groundwater quality for irrigation purpose. Paddy crops, vegetables and food crops are the common agricultural product of the people in the study area. The area falls under semi arid region with average rainfall around 600 mm, which is not sufficient for domestic and agriculture purpose. Canal network is strong, but having less output due to less water from the source. Treated & untreated water is supplied to most of the villages of the study area either from Dharoi dam or Narmada Canal for drinking and irrigation purposes respectively. Urbanization and industrialization has made immense pressure on groundwater resources and has resulted in quality deterioration of groundwater as well[13].

2. Study Area

Mehsana district is located in the heart of Gujarat state considered as semi-arid region. It is encompassed by the latitude of 23°15' to 23°53' north and longitude of 72°07' to 72°46' east covering a geographical area of approximately 430153 hectares. The total population of district is 18, 37,696 as per census 2011. North Gujarat is naturally endowed with one of the richest alluvial aquifers of India. The study area is having alluvial formation with alternate clay, sand, silt, gravel etc[21]

3. Climate

Climate of the district is characterized by a hot summer and a general dryness throughout the year except monsoon season, which is from June to September while October and November constitute the post-monsoon season. The average annual rainfall in Mehsana district is 668 mm and rainfall in different part of the district from 300 mm to 1300 mm with average number of 45 rainy days13. About 80% of annual rainfall is received during June to September. The variation in rainfall from year to year is large and study area falls in drought prone area hence is characterized by the erratic behavior of the rainfall.

4. Material and Methods

The current study was designed to investigate the conditions of groundwater contamination in the study area. The hydro-chemical analysis was undertaken by randomly collected 26 groundwater samples from bore wells covering all nine tehsils of mehsana district in May 2014. The samples were collected in sterilized polythene bottles and prior to sampling, all the samples were washed and rinsed with concerned groundwater. Then they were sealed and brought to the laboratory for analysis. The analysis was performed by referring the standard procedure recommended by the American Public Health Association (APHA), 2012.

5. Results and Discussion

The respective values of all water quality parameters are summarized in Table : A. Classification based on chemical indices - sodium adsorption ratio (SAR), EC, Kelly's Ratio, Residual sodium carbonate (RSC), Mg Ratio, Permeability index (PI) were calculated. The result was compared with standard parameter in each case.

(1) Sodium Absorption Ratio (SAR)

The sodium or alkali hazard in groundwater for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Absorption Ratio (SAR). There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If groundwater used for irrigation is high in sodium and low in calcium, the cation - exchange complex may become saturated with sodium.

$$\mathrm{SAR} = \frac{N_a{}^{+}}{\sqrt{\frac{C_a{}^{2+} + M_g{}^{2+}}{2}}} \text{ (All ions in epm)}$$

A simple method of evaluating the high sodium in water is the Sodium Absorption Ratio (SAR). Calculation of SAR value for a given groundwater provides a useful index of the sodium hazard of that water for soils and crops. Classification of water is made with reference to SAR by Herman Bouwer, 1978. The lower the ionic strength of solution, the greater sodium hazards for a given SAR. The value of SAR in the groundwater samples of the study area ranges from 1.42 to 135.32 as per the data available (Table : A). Only 15 % samples fall under the category of excellent, 11 % fall under the category of good, 3 % samples fall under the category of doubtful and 69 % samples fall under the category of unsuitable for Irrigation purpose. It shows that only 30 % water of the study area may consider suitable for irrigation purpose.

Table 1: Classification of Groundwater for irrigation based on SAR

Sr. No.	*Quality of water*	*Limiting Values of SAR*	*Total No. of Samples (Out of Total 26 Samples)*	*Percentage %*
1	Excellent (S1)	< 10	4	15 %
2	Good (S2)	10 – 18	3	11 %
3	Doubtful (S3)	18 – 26	1	3 %
4	Unsuitable (S4)	> 26	18	69 %

(2) Electrical Conductivity (EC)

The total concentration of soluble salts or salinity hazard in irrigation water can be expressed in terms of electrical conductivity. The primary effect of high EC water on crop productivity is the inability of the plant to compete with ions in the soil solution for water. Due to higher value of EC, less water is available to the root zone of plant due to osmotic pressure.

Table 2: Classification of Groundwater for irrigation based on EC

Sr. No.	*Quality of water*	*Limiting Values of EC (µs/cm)*	*Total No. of Samples (Out of Total 26 Samples)*	*Percentage %*
1	Excellent (S1)	< 250	0	0 %
2	Good (S2)	250 – 750	0	0 %
3	Doubtful (S3)	750 – 2250	8	30 %
4	Unsuitable (S4)	> 2250	18	70 %

(3) Kelley's Ratio

Kelley et al., (1940) have suggested that the sodium problem in irrigational water could very conveniently be worked out on the basis of the values of Kelley's ratio. The Kelley's ratio has been calculated for all the water samples of the study area.

$$\text{Kelly's Ratio} = \frac{N_a{}^{+}}{C_a{}^{2+} + M_g{}^{2+}} \text{ (All ions in epm)}$$

It varies from 0.09 to 4.38 epm for the study area. (Table : A).Table shows that only 8 samples (30 %) are safe for irrigation purpose. Groundwater having Kelley's ratio more than one is generally considered as unfit for irrigation.

Table 3: Classification of Groundwater for irrigation based on KAR

Sr. No.	*Quality of water*	*Limiting Values of KR*	*Total No. of Samples (Out of Total 26 Samples)*	*Percentage %*
1	Safe	< 1	08	30 %
2	Unsafe	> 1	18	70 %

(4) Residual Sodium Carbonate (RSC)

Residual Sodium Carbonate is defined as

$$\mathrm{RSC} = (CO_3 + HCO_3) - (C_a + M_g)$$

Where all concentrations are expressed in epm. The water having excess of carbonate and bicarbonate over the alkaline earth mainly calcium and magnesium, in excess of permissible limits affects irrigation unfavourably as stated by Eaton 1950 and Richards 1954. Table - 4 shows that 7 % of samples are safe for irrigation purpose in the study area. The rest are unfit for irrigation use in the post monsoon season. The range of residual sodium carbonate in groundwater in the investigated area varies from 380 to 809.

Table 4: Classification of Groundwater for irrigation based on RSC

Sr. No.	Quality of water	Limiting Values of RSC	Total No. of Samples (Out of Total 26 Samples)	Percentage %
1	Safe	< 1.25	2	7 %
2	Marginal	1.25 – 2.5	0	0 %
3	Unsuitable	> 2.50	24	93 %

(5) Magnesium Ratio

$$\text{Magnesium Ratio} = \frac{M_g * 100}{C_a + M_g}$$

Where all the ions are in epm.

Excess of magnesium affects the quality of soils which is the cause of poor yield of crops. The magnesium ratio of groundwater varies from 27.63 to 89.13 epm (Table - A). Only 12 samples (46 %) fall into suitable categories and 14 samples were found to be more than the permissible limit (50

%) in sample locations. High Mg ratio is due to surface water and subsurface water more reacted and passage through the limestone, kankar and granitic rock formation in the study area (Pandian et. al., 2007).

(6) Doneen's Permeability Index (PI)

The soil permeability is affected by long term use of irrigation water. It is influenced by sodium, calcium, magnesium and bicarbonate contents of soil. Doneen (1964) has evolved a criterion for assessing the suitability of water for irrigation based on Permeability Index (PI).

$$\text{Permeability Index (PI)} = \frac{N_a{}^{+} + \sqrt{HCO_3}}{C_a + M_g + N_a} * 100$$

(All ions in epm)

The result of study area is ranges from 21.46 to 88.09. The majority of the samples fall under class-I under sampling programs as per Doneen’s classification, which indicates that groundwater is good for irrigation.

Table 5: Classification of Groundwater for irrigation based on PI

Sr. No.	*Quality of water*	*Limiting Values of PI*	*Total No. of Samples (Out of Total 26 Samples)*	*Percentage %*
1	Class – I	> 75	20	77 %
2	Class - II	25 - 50	04	15 %
3	Class - III	< 25	02	08 %

(7) USSL Diagram : USSL Diagram for irrigation Water Quality Evaluation

One well-known diagram for classifying irrigation water was suggested by US salinity laboratory staff (1954) that called as USSL diagram. The USSL diagram best explains the combined effect of sodium hazard and salinity hazard.

Fig. 1 is a simple scatter chart of sodium hazard (SAR) on the Y-axis versus salinity hazard (EC) on the X-axis .The EC is plotted by default in a log scale. Water can be grouped into 16 classes. Waters are divided into four classes with respect to conductivity, the dividing points between classes being at 250, 750 and 2250 micromhos per centimeter. These classes limits were selected in accordance with the relationship between the electrical conductivity of irrigation waters and the electrical conductivity of saturation extracts of soil.

The curves of Fig . I can be constructed by the use of the following empirical equations (US Salinity Laboratory Staff, 1954):

Upper curve: S = 43.75-8.87 (log C) (1)

Middle curve: S = 31.31-6.66 (log C) (2)

Lower curve: S = 18.87-4.44 (log C) (3)

Where, S, C and Log are abbreviation of sodium Adsorption ratio (SAR), Electrical Conductivity (EC), in micromhos per centimeter and logarithm to base 10, respectively.

These equations point as straight lines on rectangular coordinate paper when log C is used.

Using the SAR and EC value as coordinates, locate the corresponding point on the diagram.

The position of the point determines the quality classification of the water. The significance and interpretation of the quality class ratings on the diagram are summarized as:

For purposes of determination and classification, the total concentration of soluble salts (salinity hazard) in irrigation water can be adequately expressed in terms of specific concentration. Based on the EC, irrigation water can be classified into four categories according to saline effect :

Low-salinity water (C1) can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs normal irrigation practices except in soils of extremely low permeability.

Medium - salinity water (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt-tolerance can be grown in most cases without special practices for salinity control.

High-salinity water (C3) cannot be used on solid with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

Vary high salinity water (C4) is not suitable for irrigation under ordinary condition, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching and vary salt-tolerant crops should be selected.

Based on the SAR, irrigation water can be classified into four categories according to alkaline effect :

Low-sodium water (S1) can be used for irrigation on almost all soils with little danger of developing harmful levels of sodium.

Medium - sodium water (S2) may cause an alkalinity problem in fine-textured soils under low leaching conditions. It can be used on coarse textured soil with good permeability.

High-sodium water (S3) may produce alkaline problem. This water requires special soil management such as good drainage, heavy leaching and use of chemical amendment like gypsum.

Very High-sodium water (S4) is usually unsatisfactory for irrigation purposes. It may produce alkaline problem.

Water Characteristics as per USSL:

Sr. No.	*Type*	*Quality of Water*
1	$C_1 - S_1$	Good
2	$C_1 - S_2$	Medium to Good
3	$C_1 - S_3$	Medium
4	$C_1 - S_4$	Medium to Bad
5	$C_2 - S_1$	Medium to Good
6	$C_2 - S_2$	Medium
7	$C_2 - S_3$	Medium to Bad
8	$C_2 - S_4$	Bad
9	$C_3 - S_1$	Medium
10	$C_3 - S_2$	Medium to Bad
11	$C_3 - S_3$	Bad
12	$C_3 - S_4$	Very Bad
13	$C_4 - S_1$	Medium to Bad
14	$C_4 - S_2$	Bad
15	$C_4 - S_3$	Very Bad
16	$C_4 - S_4$	Very Bad

Classification of irrigation water with respect to SAR is primarily based on the effect of exchangeable sodium on the physical condition of the soil. However, Sodium-sensitive plants may suffer injury as a result of sodium accumulation in plant tissues when exchangeable sodium values are lower than those effective in causing deterioration of the physical condition of the soil.

The sodium Adsorption ratio (SAR), which was calculated for the water samples based on the formula provided by the US salinity Laboratory Staff (1954) as follows :

$$SAR = \frac{N_a{}^{+}}{\sqrt{\frac{C_a{}^{2+} + M_g{}^{2+}}{2}}} \; (All\ ions\ in\ epm)$$

Where, ion concentration (in parentheses) is expressed in milli equivalents per liter. U.S. Salinity Laboratory diagram (1954) interpretation is given in the Fig.1. Two most significant parameters - sodium and salinity hazards indicates usability of water for agricultural purposes. USSL classification of groundwater in the study area is given in Table 3. According Fig – 1, total 26 groundwater samples have been taken across the study area, three samples (11.53 %) falls into C3–S1 category, which indicates high salinity with low sodium. One sample (3.84 %) falls into C3–S2, which indicates high salinity with medium sodium and irrigation is possible subject to land permeability and leaching. One sample (3.84 %) falls into C3–S3, C4-S3, two samples (7.69 %) falls into C3-S4 and three samples (11.53 %) falls into C4-S4, which indicates high salinity with high sodium where water is not suitable for irrigation purpose.

6. Overall Result Discussion

In this study, the assessment of groundwater for irrigation has been evaluated on the basis of standard guidelines. Different analysis can be used to get the real ground water condition whether it is suitable for agriculture or not. As per classification based on SAR, 70 % water is not fit for irrigation or can be used with some treatment. The same result was confirmed by the classification of EC and analysis by Kelley's Ratio. As per analysis made by RSC and Magnesium hazard, the value of suitable water is only 7 % and 46 % respectively. As per PI, it reveals that soil is more potential for permeability.

According to U.S. Salinity diagram, the 11.53 % of groundwater samples belong to C3–S1 (High Salinity – Low SAR) under the present investigations and this type of groundwater should be used for soils of medium to high permeability. 3.84 % falls into C3–S3 category where ground water may use subject to ground condition and amendment in the soil. Remaining part falling under C3-S4, C4-S3 and C4-S4 is absolutely not suitable for irrigation water. Hence, it is suggested that suitable measures in terms of enhancement of drainage has to be made in areas where high salinity is observed for satisfactory crop growth.

7. Conclusion

In this study, the assessment of groundwater for irrigation has been evaluated on the basis of standard guidelines by American Public Health Association (APHA) and other classifications. The analysis evidently says that groundwater extracting in Mehsana district is partially fit (only 30 %) for Irrigation purpose. Most of the water samples are affected by high Electrical conductivity, Sodium, Potassium, TDS, Magnesium hazards as concerned with irrigation water. In the present study, it is evident that high salinity of groundwater persists at majority of sites. Similarly analytical solution clearly indicates that ground water in most part of the study area is not suitable for irrigation purpose. Artificial recharge and control on extraction of groundwater is the only long term and feasible solution for the problem.

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Table : A

Sr. No	Place	Block/ Taluka	EC	HCO3	Ca	Mg	Na	SAR	RSC	KR	PI
1	Nadasa	Mehsana	5810	366	85	174	902	79.26	107	3.48	79.34
2	Karsanpura	Vadnagar	3240	830	30	48	115	18.41	764	1.47	74.51
3	Kukarwada	Vijapur	2550	537	110	165	146	12.45	262	0.53	40.18
4	Dangarwa	Kadi	7030	1318	320	189	886	55.54	809	1.74	66.12
5	Dabu	Vadnagar	1910	510	110	42	228	26.15	358	1.50	65.94
6	Gorisana	kheralu	7540	1196	165	261	1038	71.12	770	2.44	73.26
7	Bhandu	Visnagar	3460	293	100	132	422	39.18	61	1.82	67.14
8	Panchot	Mehsana	2780	647	105	69	384	41.17	473	2.21	73.38
9	Dasaj	Unjha	890	378	80	36	43	5.65	262	0.37	39.27
10	Vadnagar	Vadnagar	3700	732	115	126	478	43.54	491	1.98	70.24
11	Shihi	Unjha	1190	366	90	75	24	2.64	201	0.15	22.82
12	Chada	kheralu	4570	769	225	189	387	26.90	355	0.93	51.78
13	Valam	Visnagar	2430	146	30	96	330	41.58	32	2.62	75.02
14	Vadnagar	Vadnagar	13700	293	460	213	2211	120.53	-380	3.29	77.26
15	Hadol	Satlasana	1240	366	15	123	29	3.49	228	0.21	28.82
16	Khodamali	Satlasana	1520	464	70	90	95	10.62	304	0.59	45.70
17	Mumanvas	Satlasana	1560	634	40	24	262	46.32	582	4.09	88.09
18	Suraj	kadi	3770	756	135	147	427	35.96	474	1.51	64.10
19	Khavad	kadi	5850	561	165	225	718	51.42	171	1.84	66.94
20	Visnagar	Visnagar	12460	159	190	288	2092	135.32	-319	4.38	81.89
21	Kukarwada	Vijapur	2530	964	85	114	260	26.07	765	1.31	63.41
22	Pudgam	Visnagar	5100	695	160	153	690	55.16	382	2.20	71.42
23	Rantej	Becharaji	6780	427	160	144	946	76.73	135	3.11	77.33
24	Bavlu	Kadi	4900	598	145	213	552	41.26	252	1.54	63.35
25	Gambhu	Becharaji	1840	244	105	69	157	16.83	82	0.90	52.15
26	Dharoi	Satlasana	850	293	60	60	11	1.42	173	0.09	21.46

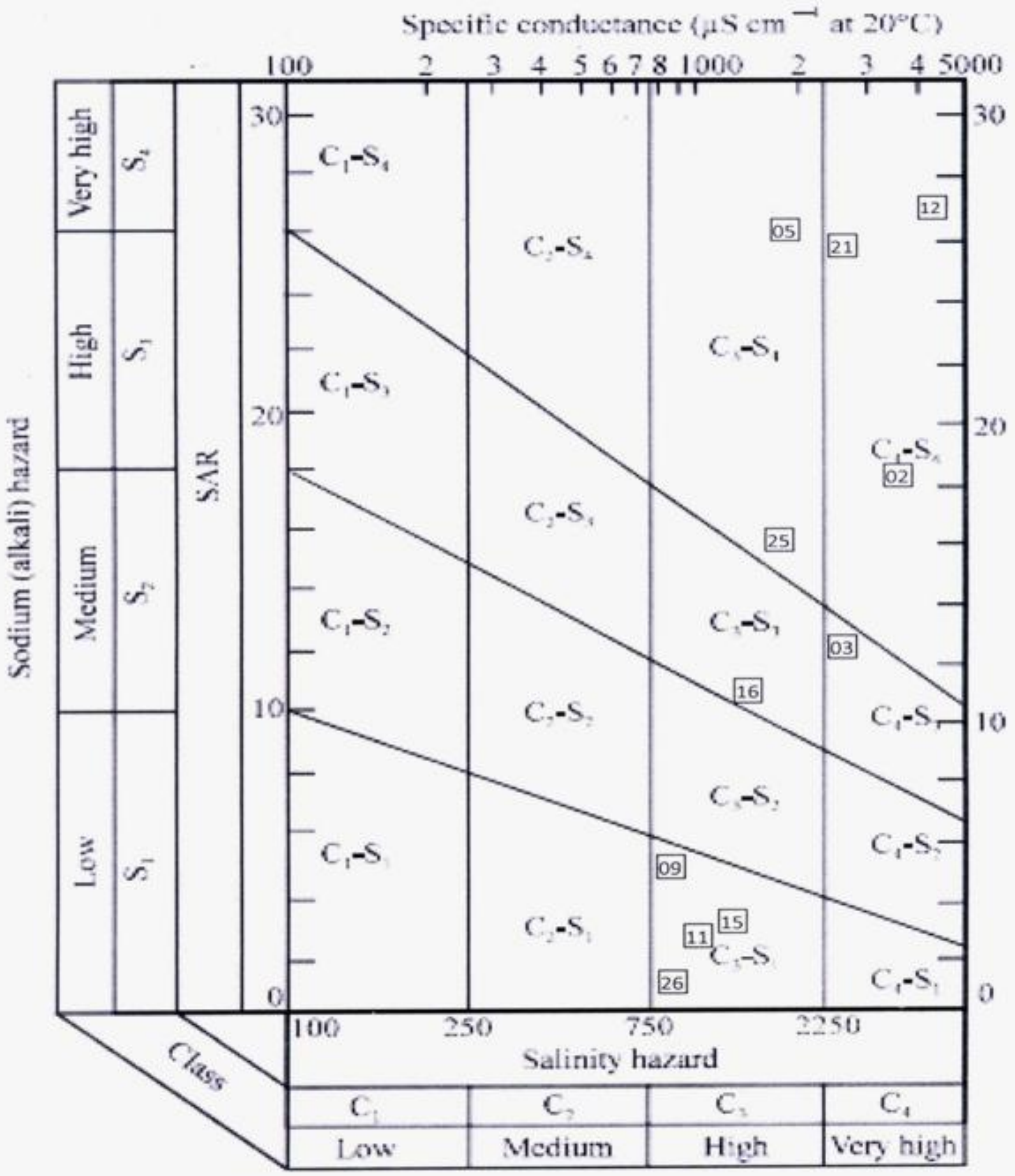

Fig – 1 USSL Diagram for Classification of Irrigation Water

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