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 scared region which covers around 1,81,698 hectare irrigation area. The characteristics of the soil. Groundwater always contains characteristics of the plants, climate and drainage small amount of soluble salts dissolved in it including the quality of water, soil type, salt tolerance Suitability of irrigation water depends upon many factors minerals it has encountered and the time it has been in degree to which it has been evaporated, the type of rock and chemistry differs depending on the source of water, the evolution of the various ions are mineral weathering, chemical reactions and anthropogenic activities. 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. 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. 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 resulted in quality deterioration of groundwater as well.

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. The major identifiable geochemical processes responsible for the evolution of the various ions are mineral weathering, chemical reactions and anthropogenic activities. 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. 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. 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 resulted in quality deterioration of groundwater as well.

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. Climate

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 days. 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 hydrochemical 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.

\[
\text{SAR} = \frac{N_a^+}{C_n^{2+} + M_g^{2+}} \quad \text{(All ions in epm)}
\]

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

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Quality of water</th>
<th>Limiting Values of SAR</th>
<th>Total No. of Samples (Out of Total 26 Samples)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Excellent (S1)</td>
<td>&lt; 10</td>
<td>4</td>
<td>15%</td>
</tr>
<tr>
<td>2</td>
<td>Good (S2)</td>
<td>10 – 18</td>
<td>3</td>
<td>11%</td>
</tr>
<tr>
<td>3</td>
<td>Doubtful (S3)</td>
<td>18 – 26</td>
<td>1</td>
<td>3%</td>
</tr>
<tr>
<td>4</td>
<td>Unsuitable (S4)</td>
<td>&gt; 26</td>
<td>18</td>
<td>69%</td>
</tr>
</tbody>
</table>

(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.

(3) Kelly’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.

\[
\text{Kelley’s Ratio} = 10 \frac{N_a^+}{C_a^{2+} + M_g^{2+}} \quad \text{(All ions in epm)}
\]

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 2:** Classification of Groundwater for irrigation based on EC

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Quality of water</th>
<th>Limiting Values of EC (µs/cm)</th>
<th>Total No. of Samples (Out of Total 26 Samples)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Excellent (S1)</td>
<td>&lt; 250</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>2</td>
<td>Good (S2)</td>
<td>250 – 750</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>3</td>
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<td>50 – 2250</td>
<td>8</td>
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</tr>
<tr>
<td>4</td>
<td>Unsuitable (S4)</td>
<td>&gt; 2250</td>
<td>18</td>
<td>70%</td>
</tr>
</tbody>
</table>

(4) Residual Sodium Carbonate (RSC)

Residual Sodium Carbonate is defined as

\[
\text{RSC} = (\text{CO}_3 + \text{HCO}_3) - (C_n + M_g)
\]

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 3:** Classification of Groundwater for irrigation based on RSC

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Quality of water</th>
<th>Limiting Values of RSC (epm)</th>
<th>Total No. of Samples (Out of Total 26 Samples)</th>
<th>Percentage</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Safe</td>
<td>&lt; 1.25</td>
<td>2</td>
<td>7%</td>
</tr>
<tr>
<td>2</td>
<td>Marginal</td>
<td>1.25 – 2.5</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>3</td>
<td>Unsuitable</td>
<td>&gt; 2.50</td>
<td>24</td>
<td>93%</td>
</tr>
</tbody>
</table>

(5) Magnesium Ratio

\[
\text{Magnesium Ratio} = \frac{M_g^+}{C_a^{2+} + M_g^{2+}} \times 100
\]

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 epm).
Middle curve: \[ S = 31.31 - 6.66 \log C \] (2)
Upper curve: \[ S = 43.75 - 8.87 \log C \] (1)

1954) suggested by US Salinity Laboratory Staff that called USSL diagram. The USSL diagram best explains the significance and interpretation of the quality classification of the water. The position of the point determines the quality classification of the water. The quality class ratings on the diagram are summarized as:

- 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.

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:

1. 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.

2. 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.

3. 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.

4. 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.

Table 5: Classification of Groundwater for irrigation based on PI

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Quality of Water</th>
<th>Limiting Values of PI</th>
<th>Total No. of Samples</th>
<th>Percentage</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Class - I</td>
<td>&gt; 75</td>
<td>20</td>
<td>77%</td>
</tr>
<tr>
<td>2</td>
<td>Class - II</td>
<td>25 - 50</td>
<td>04</td>
<td>15%</td>
</tr>
<tr>
<td>3</td>
<td>Class - III</td>
<td>&lt; 25</td>
<td>02</td>
<td>08%</td>
</tr>
</tbody>
</table>

(All ions in epm)

(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).

\[
\text{Permeability Index (PI)} = \frac{\text{Na}^+ + \sqrt{\text{HCO}_3^-}}{\text{Ca}^2 + \text{Mg}^2 + \text{Na}^+} \times 100
\]

(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.

(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. 1 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.
US salinity Laboratory Staff (1954) as follows:

The sodium Adsorption ratio (SAR), which was calculated indicates usability of water for agricultural purposes. USSL (1954) interpretation is given in the Fig. 1. Two most milli equivalents per liter. U.S. Salinity Laboratory diagram than those effective in causing deterioration of 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.

In this study, the assessment of groundwater for irrigation purpose 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 water. Artificial recharge and control on extraction of groundwater is the only long term and feasible solution for the problem.

### Classification of irrigation water with respect to SAR

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:

\[
SAR = \frac{N_a^+}{\sqrt{\frac{C_{2+}^2 + M_{2+}^2}{2}}}
\]  

(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. US salinity 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.

### References


Table : A

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Place</th>
<th>Block/ Taluka</th>
<th>EC</th>
<th>HCO3-</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>SAR</th>
<th>RSC</th>
<th>KR</th>
<th>PI</th>
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<td>5810</td>
<td>366</td>
<td>85</td>
<td>174</td>
<td>902</td>
<td>79.26</td>
<td>107</td>
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<td>3240</td>
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<td>146</td>
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<td>Kadi</td>
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<td>320</td>
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</table>
Yogesh Patel received the B.E. and M.E. degrees in Civil Engineering from L.D.College of Engineering, Ahmedabad in 1998 and 2000 respectively. After study, he is serving IN Civil Engineering Department of Sankalchand Patel College of Engineering, Visnagar. Presently, He is working as Head of Department in the Institute.

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