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# Assessment of Groundwater for Drinking and Irrigation in Kalanaur Block (Rohtak) Haryana, India

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**ABSTRACT**

Groundwater is an essential source of drinking and irrigation in rural areas across the globe. Water pollution is among the leading problem in causes of health-related disorders all over the world. Physico-chemical analysis of water gives an insight into the quality of water. Various physical and chemical parameters were examined to calculate the water quality index (W.Q.I.) in villages of the Kalanaur block of Rohtak district (Haryana), India. The suitability of groundwater for irrigation purposes was determined by calculation of Sodium Adsorption Ratio (S.A.R.), Sodium Percent (Na %), Residual Sodium Carbonate (R.S.C.), Permeability Index (P.I.), U.S. salinity plot and Wilcox diagram, etc. Most water samples were of high W.Q.I., indicating poor water quality. A minimum value of W.Q.I. was 58.38 for $S_{17}$ and the maximum was 454.41 for $S_{12}$. Most of the parameters analyzed suggested that water was polluted due to very high concentrations of T.D.S., chloride, magnesium and bicarbonate ions. S.A.R., Na %, R.S.C. and P.I. values were in the excellent to good range. Piper trilinear plot indicated that most of the water samples belonged to mixed Ca-Mg-Cl and Ca-$HCO^{-}_3$ type of water facies. Gibbs plot suggested a significant interaction between water and rocks in the area. Almost 50% of the water samples were suitable for irrigation.

**Keywords:** Groundwater, physico-chemical analysis, water pollution and water quality index.

## I. INTRODUCTION

Water is an essential prerequisite for the survival of living organisms. Availability and accessibility to safe drinking water in adequate volume is the essential and foremost requirement for developing a healthy society. Apart from using freshwater as a source of drinking, cooking and other human uses, it is also used by farmers to irrigate the fields. However, freshwater availability is only 3% compared to marine water, which is 97% of the total water on the planet [1]. Due to high salinity, marine water is unsuitable for human consumption, agricultural and industrial purposes. A large amount of freshwater is trapped in glaciers, and the rest available to humans is present in rivers, lakes, ponds, and groundwater. Among all the above sources, groundwater is critical because nearly one-third of the population relies on it [2]. The overall use of groundwater in daily routine activities varies *viz.* 65% for drinking, 20% for irrigation and livestock and 15% for industry and mining [3]. Rural people are more dependent on groundwater to meet their essential requirements.

Nevertheless, nowadays, groundwater is depleting rapidly, primarily due to overexploitation. Excessive use of fertilizers and pesticides for high crop yield in agricultural regions further exaggerates the situation and puts pressure on groundwater [4]. Moreover, in recent years, water pollution has increased drastically due to increased urbanization, the release of commercial and household waste in rivers, agricultural runoff and transportation [5], [6]. Sources of water pollution can be classified into point sources and non-point sources. Point sources are located at specific places and are easy to identify, monitor and regulate and include discharge from the sewage treatment plant, factories and underground lines [7]. Non-Point sources are located in broad, diffused areas such as croplands, urban streets, parking lots, etc. Consumption of contaminated water may cause an outbreak of severe chronic disease. People in rural areas are more prone to waterborne diseases due to a lack of awareness and proper healthcare facilities. Over 2 lakh people in Haryana are affected due to contaminated groundwater and rural areas of Rohtak district were found to be moderately polluted.

It is pertinent to mention that if groundwater gets contaminated, it cannot be restored to its pure form [8]. Thus, regular monitoring of groundwater quality becomes vital to check water pollution. The pollution level and suitability of groundwater for drinking are analyzed by its physicochemical parameters. Sodium Absorption Ratio (S.A.R.), Sodium Percent (Na %), Residual Sodium Carbonate (R.S.C.) and Permeability Index (P.I.) are some of the parameters considered important for determining the suitability of water for irrigation [9], [10]. Based on the physicochemical parameters, the water quality index (W.Q.I.) is calculated, indicating the water quality for drinking. Hence, the present study was conducted to analyze physicochemical characteristics and to suggest measures to improve water quality in some selected villages of Rohtak district (Haryana) India.

## II. MATERIAL AND METHODS

### 1 Study area

Rohtak is one of the 22 districts of Haryana state in Northern India. The district is divided into five community blocks viz. Rohtak, Meham, Sampla, Lakhanmajra and Kalanaur. The geo-coordinates of the Kalanaur block are 28° 49′ 52″ N and 76° 23′ 44″ E. The average temperature ranges from 2°C to 46°C. In summers, the temperature reaches up to 46°C and winters are too cold with temperature dropping down to 2°C. The average annual rainfall in the block is 44.3 cm. Soil is generally sandy loam, suitable for cultivating wheat and rice. Five villages *viz.* Bhali Anandpur, Ballab, Baniyani, Marodhi Jattan and Marodhi Rangran were selected to check the hydro-chemistry and Water Quality Index (W.Q.I.) of groundwater from Kalanaur block in Rohtak district, Haryana (India). All these villages are adopted by Maharshi Dayanand University, Rohtak (Haryana) India, under the university outreach programs. Bore wells, hand pumps and wells are the important groundwater sources in these villages. A study site map was created with the software QGIS 3.16.

## III. Sample collection and analysis

### 1 Sample collection

Water samples (N = 22) from different drinking water sources like hand pumps, wells and bore wells were from March to May 2018 during morning hours. Each sampling site was divided randomly into four or five sampling points depending upon the source, which is used by the majority of villagers for drinking purposes (Fig. 1). Samples were collected in plastic bottles cleaned with detergent and dilute nitric acid were rinsed with de-ionized water and allowed to dry in the sunlight. The plastic bottles with samples were marked with sampling numbers, i.e., $S_1$, $S_2$, $S_3$,................, $S_{22}$. The collected samples were preserved for further physicochemical analysis in an icebox and were brought to the Ecology Laboratory of Botany Department, Maharshi Dayanand University (Rohtak) Haryana for further analysis.

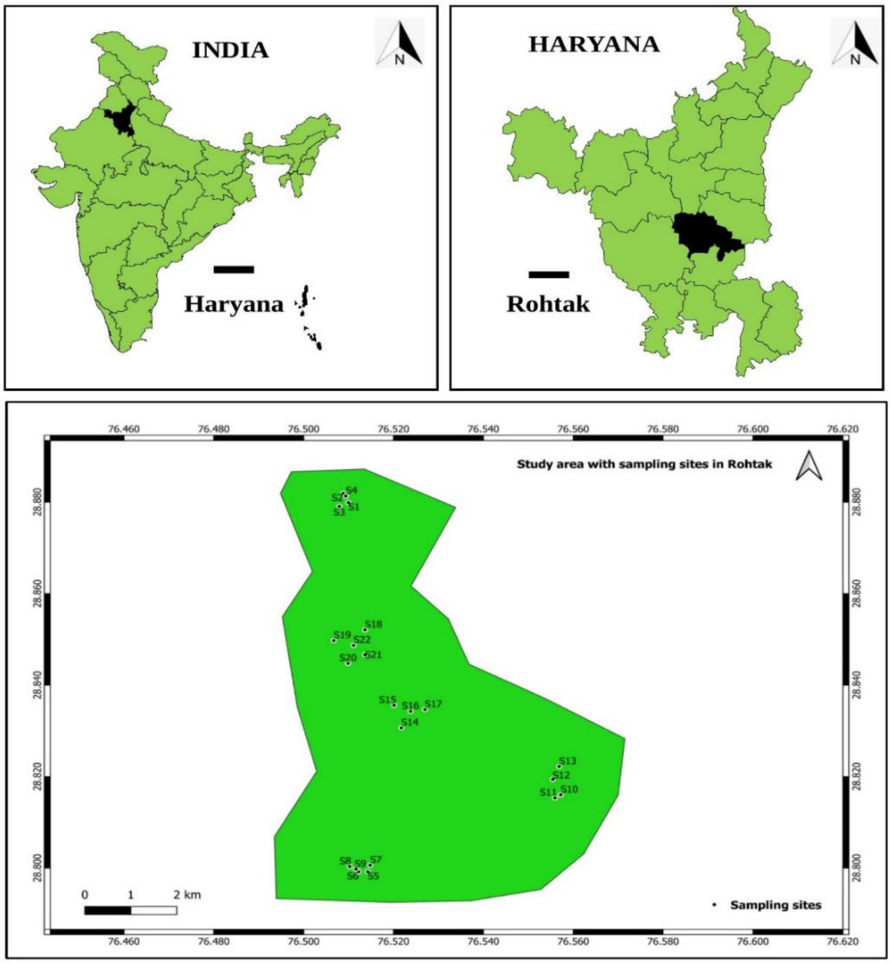


**Fig. 1 :** Map of the study site

### 2 Sample analysis

A total of 14 parameters were studied, which included physical parameters *viz.* colour, odour, temperature, pH, conductivity, total dissolved solids (T.D.S.) and chemical parameters (cations and anions) *viz.* chloride, calcium, magnesium, sulphate, sodium, potassium, carbonate and bicarbonate. The samples were analyzed in triplicates. The physical parameters, including pH, T.D.S. and conductivity, were measured on-site using a digital pH meter (ESICO–1615), T.D.S. (ESICO–1615) and conductivity meter (E.I.–7200), respectively. Sense organs measured color and odour. Chloride, carbonate and bicarbonate concentrations were measured using titration procedures employing standard EDTA, H.C.L. and $AgNO_3$ as titrants [11]. Sulphate was measured using a spectrophotometer, taking the absorbance of the sample at 420 nm. The titration method was also exploited to determine calcium and magnesium concentration using EDTA, NaOH, $NH_4Cl$, $NH_4OH$ and mureoxide as an indicator [11]. Sodium and potassium ions were determined by Flame Photometer (ESICO, Model No- 381). The light intensity at 589 nm and 766.5 nm are proportional to the concentration of Sodium and potassium ions, respectively, which can be determined by a light dispersion device.

## 3 Water Quality Index

It is a number that reflects the combined effect of various parameters on water quality. It rates the water samples according to the concentration of different parameters considered for study purposes. Generally, the lower the water quality index value, the better the water quality. The water quality index is calculated in three steps.

**Step 1:** Parameters to be considered for calculating the water quality index (W.Q.I.) were assigned weight. In the present study, ten parameters were taken into consideration. Each of these parameters was assigned a weight (A.W.) from 1 to 5 according to their relative importance in the determination of water quality [12]–[14]. Each parameter's relative weight (R.W.) was obtained from the assigned weight (Table 1). Relative weight was calculated from the assigned weight using the following equation:

$$RW = \frac{AW}{\sum_{i=1}^{n} AW} \quad (1)$$

Where,

$R.W.$ = relative weight

$A.W.$ = assigned weight

**Step 2:** A quality rating was assigned to each parameter apart from pH by dividing the concentration of specific parameters in a water sample by its respective standard value from BIS (2012) [15].

**Table 1. Permissible limits, assigned and relative weights**

| Parameters | Indian Standard (BIS 2012) | Assigned Weight (A.W.) | Relative Weight (R.W.) |
|---|---|---|---|
| pH | 6.5-8.5 | 4 | 0.11428 |
| EC | - | 3 | 0.08571 |
| TDS | 500 | 5 | 0.14285 |
| $Cl^-$ | 250 | 5 | 0.14285 |
| $Ca^{2+}$ | 75 | 3 | 0.08571 |
| $Mg^{2+}$ | 30 | 3 | 0.08571 |
| $SO_4^{2-}$ | 200 | 5 | 0.14285 |
| $Na^+$ | - | 4 | 0.11428 |
| $K^+$ | - | 2 | 0.05714 |
| $HCO_3^-$ | 200 | 1 | 0.02857 |
| | | ∑ AW = 35 | ∑ RW = 1 |

The following equation was used to assign a quality rating to each parameter:

$$Q = [C_i/S_i] \times 100 \quad (2)$$

For pH the following equation was used:

$$Q = \left[\frac{C_i - V_i}{S_i - V_i}\right] \times 100 \quad (3)$$

Where,

$Q$ = quality rating

$C_i$ = concentration of specific parameters in the water sample

$S_i$ = recommended value for specific parameter

$V_i$ = ideal value (7 for pH)

**Step 3:** Sub-index (S.I.) for each parameter was obtained in the following way:

$$SI = RW \times Q \quad (4)$$

The value of $SI$ was further used to calculate the water quality index (W.Q.I.) as follows:

$$WQI = \sum_{i=n-1}^{n} SI \quad (5)$$

**4 Classification of W.Q.I.**

Usually, the value of W.Q.I. ranges from 0 to 301. Quality of water, depending on the value of W.Q.I. is classified as follows: <50=Excellent water, 51-100=Good water, 101-200=Poor water, 201-300=Very poor water and >300=Unsuitable for drinking [12]–[14].

**5 Irrigation Quality**

For irrigation, the parameters like sodium absorption ratio (S.A.R.), sodium percent (Na %), residual sodium carbonate (R.S.C.), permeability index (P.I.), Kelly's ratio (K.R.) and magnesium hazard (M.H.) were calculated using the following formulae:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \qquad (6)$$

Sodium ($Na^{+}$), calcium ($Ca^{2+}$) and magnesium ($Mg^{2+}$) are in mg/L.

$$Na\,\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100 \qquad (7)$$

The concentrations of all the ions are in meq/L.

$$RSC = [(CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})] \qquad (8)$$

The concentrations of all the ions are in meq/L.

$$PI = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Na^{+} + Ca^{2+} + Mg^{2+}} \times 100 \qquad (9)$$

The concentrations of all the ions are in meq/L.

$$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \qquad (10)$$

The concentrations of all the ions are in meq/L.

$$MH = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \qquad (11)$$

The concentrations of all the ions are in meq/L.

**6 Correlation analysis**

The data were suitably tabulated and analyzed. The coefficient of correlation (r) among different parameters was calculated using the following equation:

$$r = \frac{N(\Sigma XY) - (\Sigma X)(\Sigma Y)}{\sqrt{[N\Sigma X^{2} - (\Sigma X)^{2}]}\,\sqrt{[N\Sigma Y^{2} - (\Sigma Y)^{2}]}} \qquad (12)$$

Where

$r$ = Coefficient of correlation

$N$ = total number of samples

$X$ and $Y$ = two different parameters

## IV. RESULTS AND DISCUSSION

**1 Physical parameters**

The results for the six physical parameters analyzed with mean and standard deviation are depicted in Table 2.

**1.1 Colour and Odour**

It was observed that the colour and odour for all the samples were within a preferable range and thus suitable for drinking. Similar observations were made [16] in the Gurugram district of Haryana state.

**1.2 Temperature and pH**

The temperature recorded from all the samples was in the normal range. Sample $S_2$ had the lowest temperature of 23.2±0.4 °C and sample $S_{21}$ had a temperature of 28.2±0.3 °C. All the samples' pH values were within the standard range [15]. Minimum and maximum pH values were observed in samples $S_{12}$ (6.6±0.3) and $S_{16}$ (8.2±0.1), respectively. The results obtained concord with the study carried out in different state districts [17]–[19].

**1.3 Electrical conductivity (E.C.) and Total dissolved solids (T.D.S.)**

Minimum E.C. was recorded for $S_{17}$ (402±2.4 μ-mho/cm) and maximum for $S_{12}$ (5370±5.1 μ-mho/cm). More than half of the samples had E.C. more than the permissible limit. More than 85% of the samples were out of the permissible limit for the T.D.S. value. Sample $S_{17}$ (268±2.5 mg/L) had a minimum value of T.D.S. while $S_{12}$ (3580±4.8 mg/L) had the maximum value. The values of E.C. and T.D.S. are directly proportional to each other. A higher value of T.D.S. indicates higher inorganic water pollution. High values of E.C. may be due to the continuous process of mineralization at sampling sites [18]. Further, the physiographic depression can cause a water logging problem in the region and this may result in a higher amount of dissolved solids in water [20], [21].

**2 Chemical parameters**

The results, along with mean and standard deviation values for eight parameters, are presented in Table 3.

**2.1 Chloride ions**

The values for chloride ions ranged from 55.38±2.2 mg/L in $S_{17}$ to 1589.14±5.3 mg/L in $S_{12}$. More than 70% of the analyzed samples were out of the acceptable range [15]. Chloride ions, along with sulphate ions are major inorganic ions capable of degrading water quality. Moreover, mineralization, agricultural runoff and domestic waste released in sewerage may have contributed to the high chloride content in water [22], [23].

**Table 2.** Physical parameters along with mean and standard deviation values

| S. No. | Colour | Odour | Temperature (°C) | pH | Conductivity (µ-mho/cm) | T.D.S. (mg/L) |
|---|---|---|---|---|---|---|
| $S_1$ | Colourless | Agreeable | 24.2±0.2 | 7.4±0.3 | 1652±2.1 | 1093±4.2 |
| $S_2$ | Colourless | Agreeable | 23.2±0.4* | 7.4±0.2 | 884±1.2 | 835±3.2 |
| $S_3$ | Colourless | Agreeable | 24.1±0.3 | 7.0±0.3 | 740±2.5 | 494±2.5 |
| $S_4$ | Colourless | Agreeable | 24.2±0.3 | 7.2±0.2 | 2050±2.7 | 1370±5.8 |
| $S_5$ | Colourless | Agreeable | 27.2±0.4 | 6.9±0.4 | 2030±1.6 | 1340±3.5 |
| $S_6$ | Colourless | Agreeable | 28.0±0.2 | 7.2±0.3 | 1196±2.6 | 1640±6.2 |
| $S_7$ | Colourless | Agreeable | 27.6±0.3 | 7.0±0.1 | 2060±2.1 | 1350±2.8 |
| $S_8$ | Colourless | Agreeable | 27.4±0.4 | 6.8±0.4 | 1432±2.6 | 946±4.5 |
| $S_9$ | Colourless | Agreeable | 27.3±0.3 | 7.0±0.3 | 2080±2.8 | 1750±4.1 |
| $S_{10}$ | Colourless | Agreeable | 27.2±1.0 | 8.2±0.3 | 879±4.0 | 562±2.5 |
| $S_{11}$ | Colourless | Agreeable | 27.4±0.6 | 8.1±0.2 | 754±4.2 | 497±2.8 |
| $S_{12}$ | Colourless | Agreeable | 27.6±0.2 | 6.6±0.3* | 5370±5.1** | 3580±4.8** |
| $S_{13}$ | Colourless | Agreeable | 27.5±0.5 | 8.2±0.2 | 901±4.7 | 596±2.5 |
| $S_{14}$ | Colourless | Agreeable | 27.9±1.0 | 7.4±0.3 | 1577±1.8 | 1050±1.8 |
| $S_{15}$ | Colourless | Agreeable | 27.8±0.4 | 7.1±0.2 | 2530±2.9 | 1680±2.6 |
| $S_{16}$ | Colourless | Agreeable | 27.6±0.5 | 8.2±0.1** | 772±2.2 | 513±3.6 |
| $S_{17}$ | Colourless | Agreeable | 27.5±1.0 | 8.1±0.2 | 402±2.4* | 268±2.5* |
| $S_{18}$ | Colourless | Agreeable | 26.8±0.6 | 7.2±0.3 | 3640±1.8 | 2410±2.5 |
| $S_{19}$ | Colourless | Agreeable | 27.4±0.2 | 7.7±0.2 | 2460±2.8 | 1650±4.1 |
| $S_{20}$ | Colourless | Agreeable | 27.8±0.4 | 7.4±0.4 | 1670±1.5 | 1130±2.2 |
| $S_{21}$ | Colourless | Agreeable | 28.2±0.3** | 7.3±0.3 | 5140±2.8 | 3470±3.5 |
| $S_{22}$ | Colourless | Agreeable | 27.1±0.2 | 7.5±0.2 | 4630±4.2 | 3090±4.2 |

*Minimum value & **Maximum value

**2.2 Calcium ions**

Sample $S_{17}$ had a minimum value of 20.04±0.9 mg/L and $S_{21}$ had a maximum value of 481.7±2.8 mg/L. Half of the water samples were out of the permissible limit. Usually, the calcium content in water is determined by the presence of carbonates and minerals. As most of the water samples had no carbonate content, the presence of minerals along with the dissolution of concrete in water carried by wind might be the potential factors for the presence of calcium in groundwater. Similar results were obtained in the Faridabad and Rohtak districts of Haryana [24].

**2.3 Magnesium ions**

The lowest value for calcium was recorded in $S_{17}$ (60.65±1.5 mg/L) and the highest in $S_{12}$ 568.33±2.2 mg/L. All the samples were out of the permissible limit [15]. Such a high level of magnesium ions in water samples may be attributed to the washing away of minerals by rainfall and agricultural runoff. The results were in concordance with other studies [25].

**2.4 Sulphate ions**

Minimum sulphate content was observed in $S_{17}$ (17.21±1.2 mg/L) and the maximum was reported in $S_{22}$ (439.8±1.5 mg/L). Approximately 60% of the samples were out of the acceptable limit and a high level of sulphate with chloride ions can significantly reduce the water quality. Runoff from the nearby catchment area may contribute to water sulfate ions. The results obtained were in agreement with studies conducted in other regions [26], [27].

**2.5 Sodium ions**

Sample $S_{17}$ (29±2.5 mg/L) had a minimum value of sodium, while sample $S_{21}$ had a maximum value of 156±2.5 mg/L for sodium. All the samples were within the acceptable limit and considered safe for drinking. Sodium ions are mainly released from waste generated by industries drained into rivers. As no prominent industries were in the region, the lower values of sodium ions may be attributed to this factor. Similar results were obtained by others [28], [29].

**2.6 Potassium ions**

The value of potassium ions ranged from 4±1.0 mg/L in $S_{14}$ to 132±2.5 mg/L in $S_6$. Only three samples were out of the permissible limit, and the rest were safe for drinking. The high evaporation rate may have contributed to a high value of potassium in some samples. The findings concord with a study in the Jhajjar district of the Haryana state in India [30].

**2.7 Carbonate and Bicarbonate ions**

Other samples had nil carbonate content except for sample S13, which has 0.5±0.2 mg/L carbonate ion concentration. Bicarbonate ions concentration was minimum in the case of $S_{17}$ (170.8±2.8 mg/L) and maximum in $S_{18}$ (1102.8±1.7 mg/L). As in most of the samples analyzed, the pH value was within the standard range, so the dissociation of carbonic acid into carbonate ions would be less; thus, most samples were carbonate-free. Bicarbonate ions are mainly added to groundwater by the erosion of limestone present in the upper layers of soil. The results are supported by other findings [31].

**3 Water Quality Index (W.Q.I.)**

The W.Q.I. for most of the water samples was above 100 thus most of the water samples were categorized as poor to very poor (Fig. 2). Samples $S_{11}$, $S_{14}$, $S_{16}$ and $S_{17}$ were classified as good water for drinking, as W.Q.I. for these samples was below 100. Sample $S_{12}$, $S_{18}$, $S_{21}$ and $S_{22}$ were unsuitable for drinking as the value of W.Q.I. exceeded 300. Sample $S_{17}$ was the best for drinking with a W.Q.I. of 58.38 and sample $S_{12}$ was highly polluted and unsuitable for drinking. Various studies have obtained similar results [32]–[35].

**4 Suitability of groundwater for irrigation**

The suitability of groundwater for the purpose of irrigation was examined by calculation of Sodium Adsorption Ratio (S.A.R.), Sodium Percent (Na %), Residual Sodium Carbonate (R.S.C.), Permeability Index (P.I.), Kelly's ratio, Magnesium hazard, U.S. salinity plot and Wilcox diagram.

**4.1 Sodium adsorption ratio (S.A.R.)**

A high value of S.A.R. can reduce the permeability of the soil and, therefore, alter soil structure. The S.A.R. value for the samples ranged from 3.22 in $S_2$ to 16.40 in $S_{14}$. A SAR value of <10 is considered suitable for irrigation [36]. Sample $S_4$, $S_6$, $S_{14}$ and $S_{20}$ had a value of S.A.R. that cannot be used for susceptible crops but can be used for irrigation in case of moderately sensitive crops. A total of 18 samples (81.81 %) were safe for irrigation and the rest were unsuitable (Table 4)

**Table 3.** Chemical parameters along with mean and standard deviation values

| S. No. | Chloride (mg/L) | Calcium (mg/L) | Magnesium (mg/L) | Sulphate (mg/L) | Sodium (mg/L) | Potassium (mg/L) | Carbonate (mg/L) | Bicarbonate (mg/L) |
|---|---|---|---|---|---|---|---|---|
| $S_1$ | 778.78±2.5 | 76.15±0.5 | 390.31±1.6 | 331.6±1.5 | 85±1.2 | 15±1.5 | 0 | 527.04±2.1 |
| $S_2$ | 629.50±1.9 | 80.16±1.4 | 309.48±2.5 | 226.9±0.9 | 45±1.3 | 80±2.2 | 0 | 495.32±2.8 |
| $S_3$ | 447.14±2.3 | 86.17±0.8 | 214.93±1.3 | 162.7±1.6 | 37±2.2 | 11±2.5 | 0 | 366±4.0 |
| $S_4$ | 330.29±2.8 | 46.09±2.1 | 164.82±2.4 | 215.7±2.5 | 144±1.5 | 6±3.3 | 0 | 527.04±3.5 |
| $S_5$ | 758.66±2.5 | 56.11±1.3 | 358.66±1.9 | 249.2±1.5 | 82±1.0 | 52±1.8 | 0 | 414.8±2.2 |
| $S_6$ | 1290.68±1.5 | 225.2±2.8 | 111.1±1.5 | 369.1±0.7 | 156±1.5 | 132±2.5** | 0 | 707.6±1.8 |
| $S_7$ | 793.92±1.3 | 81.76±1.5 | 346±0.9 | 216.7±1.2 | 68±0.8 | 43±1.5 | 0 | 292.8±1.5 |
| $S_8$ | 406.72±2.5 | 64.12±1.2 | 224.69±1.5 | 213.4±1.5 | 66±2.5 | 29±0.9 | 0 | 341.6±2.5 |
| $S_9$ | 926.20±3.5 | 90.58±2.2 | 440.02±2.2 | 294.8±2.2 | 105±1.2 | 57±2.4 | 0 | 512.4±3.8 |
| $S_{10}$ | 249.84±3.2 | 24.05±1.2 | 84.39±2.5 | 26.51±2.6 | 70±1.8 | 33±3.2 | 0 | 292.8±3.5 |
| $S_{11}$ | 124.96±2.1 | 20.04±2.2 | 64.61±3.2 | 22.32±1.1 | 63±2.2 | 32±1.0 | 0 | 268.4±4.0 |
| $S_{12}$ | 1589.14±5.3** | 120.2±2.5 | 568.33±2.2** | 401.7±1.5 | 146±2.5 | 132±2.8 | 0 | 707.6±2.6 |
| $S_{13}$ | 159.04±3.5 | 26.45±1.2 | 97.02±2.5 | 29.76±1.0 | 69±1.8 | 38±0.9 | 0.5±0.2** | 341.6±3.3 |
| $S_{14}$ | 173.24±1.2 | 25.65±0.8 | 69.88±0.9 | 55.33±2.2 | 114±1.3 | 4±1.0* | 0 | 285.6±1.5 |
| $S_{15}$ | 743.86±2.5 | 74.55±0.9 | 303.28±1.2 | 99.98±0.9 | 129±0.9 | 7±0.8 | 0 | 561.2±1.9 |
| $S_{16}$ | 122.12±1.5 | 21.64±1.5 | 77.79±2.5 | 24.18±2.2 | 63±2.2 | 30±1.5 | 0 | 468.4±3.5 |
| $S_{17}$ | 55.38±2.2* | 20.04±0.9* | 60.65±1.5* | 17.21±1.2* | 29±2.5* | 12±1.2 | 0 | 170.8±2.8* |
| $S_{18}$ | 833.54±1.9 | 62.52±1.9 | 508.99±2.2 | 209.72±2.6 | 137±1.9 | 85±1.5 | 0* | 1102.8±1.7** |
| $S_{19}$ | 479.96±2.5 | 103.4±2.5 | 410.09±2.6 | 324.5±1.5 | 72±2.5 | 68±2.5 | 0 | 1020±3.2 |
| $S_{20}$ | 316.60±1.5 | 84.97±2.2 | 159.55±1.8 | 162.7±1.8 | 156±2.5 | 16±1.5 | 0 | 666±3.3 |
| $S_{21}$ | 1517.98±4.5 | 481.7±2.8** | 290.09±2.2 | 432.4±2.2 | 156±2.5** | 24±2.2 | 0 | 341.6±2.5 |
| $S_{22}$ | 1356.10±3.8 | 226.0±1.5 | 513.82±1.5 | 439.8±1.5** | 66±1.3 | 32±2.1 | 0 | 341.5±2.5 |

*Minimum value & **Maximum value

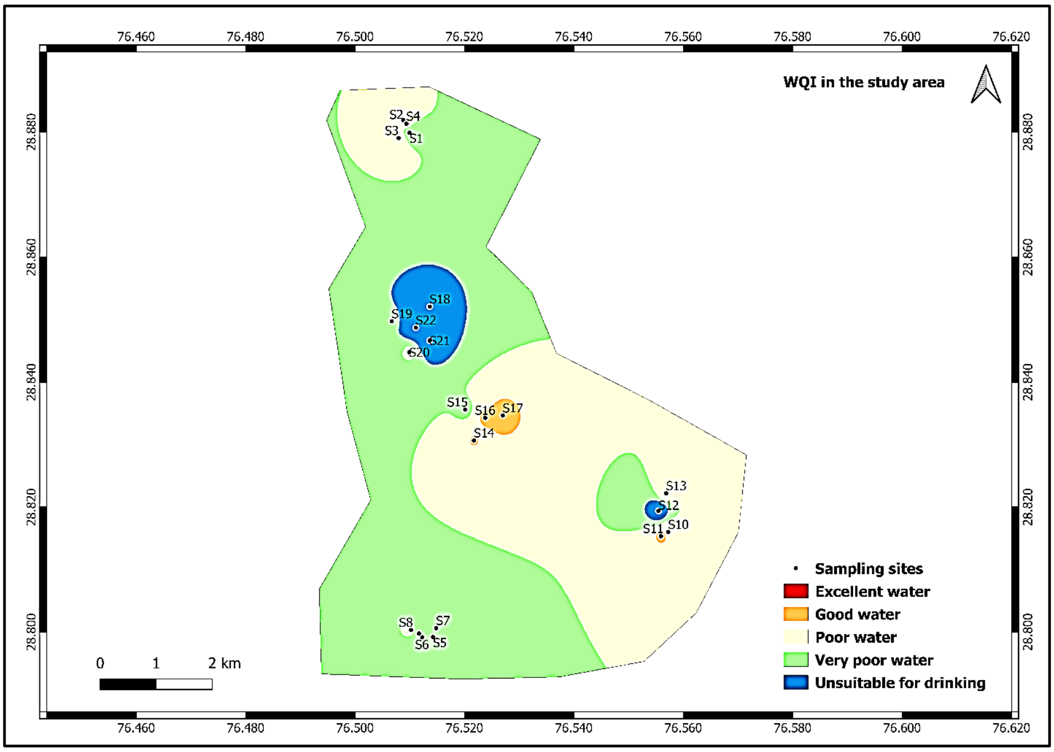


**Fig. 2 :** Spatial distribution of W.Q.I. values in the study area

### 4.2 Sodium percent (Na %)

It denotes the percentage of sodium in water. All the samples analyzed were safe for irrigation (Table 4).

### 4.3 Residual Sodium Carbonate (R.S.C.)

The calculation of R.S.C. concentration units of ions was converted to meq/L. Based on residual sodium carbonate, water can be categorized into three classes. If the R.S.C.>2.5, then water is not suitable for irrigation, i.e., hazardous; if 1.25< R.S.C. <2.5, then water is moderately hazardous; if R.S.C. <1.25, then water is suitable for irrigation [37]. All the studied samples were excellent for irrigation (Table 4).

### 4.4 Permeability index (P.I.)

The permeability index was calculated by the equation developed by Doneen in 1964 [9]. Ionic concentrations are expressed in meq/L. Based on the Permeability Index Doneen 1964 [9] classified water into three categories: classes I with maximum permeability, class II with 75% of maximum permeability and class III with 25% of maximum permeability. Class I and II are classified as suitable for irrigation while, class III is not suitable for irrigation. All the samples were in class I and thus were suitable for irrigation (Fig. 3). The values of the Permeability Index (P.I.) are indicated in Table 4.

### 4.5 Kelly's ratio (K.R.)

Kelly's ratio measures sodium against calcium and magnesium [38]. A Kelly's ratio greater than one indicates that the water sample is unsuitable for use and has high sodium content and Kelly's ratio less than one is suitable for use. Kelly's ratio ranged from 0.053 to 0.705. In the present study, all the analyzed samples had Kelly's ratio of less than one and were suitable for irrigation (Table 4)

### 4.6 Magnesium hazard (M.H.)

An excess amount of magnesium in water can cause magnesium hazards. Water with higher magnesium content makes the soil more alkaline and, thus reduces crop yield. The value of M.H. ranged from 44.86 to 93.06. Out of all the samples, 20 (90.90 %) samples were unsuitable for irrigation and only 2 (9.09 %) samples were suitable for irrigation (Table 4).

**Table 4. Classification of water samples for irrigation based on various parameters**

| Parameter | Range | Water Quality | No. of Samples |
|---|---|---|---|
| **S.A.R.** | <10 | Excellent | 18 |
| | 10 – 18 | Good | 4 |
| | 18 –26 | Fair | 0 |
| | >26 | Poor | 0 |
| **Na %** | <20 | Excellent | 13 |
| | 20 – 40 | Good | 8 |
| | 40 – 60 | Permissible | 1 |
| | 60 – 80 | Doubtful | 0 |
| | >80 | Unsuitable | 0 |
| **R.S.C.** | <1.25 | Safe | 22 |
| | 1.25 – 2.50 | Marginal | 0 |
| | >2.50 | Unsuitable | 0 |
| **P.I.** | >75 | Highly Permeable | 22 |
| | 75 – 25 | Permeable | 0 |
| | <25 | Impermeable | 0 |
| **K.R.** | <1 | Suitable | 22 |
| | >1 | Unsuitable | 0 |
| **MH** | <50 | Suitable | 2 |
| | >50 | Unsuitable | 20 |

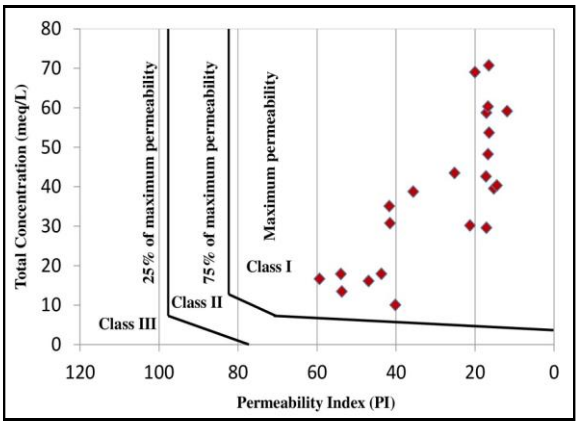


**Fig. 3: Classification of water for irrigation on basis of the Permeability Index [9]**

### 4.7 U.S. salinity plot

U.S. salinity plot is widely used to check the suitability of the water for irrigation purposes; in this plot, S.A.R. is plotted against E.C. Here, sodium hazard is represented by S.A.R., i.e., alkalinity and salinity hazard is represented by E.C. [39]. Most samples belong to S2 and C3 categories, i.e., medium alkalinity and high salinity. This water is unsuitable for irrigation and can only be used for crops with a very high salinity and alkalinity tolerance. There was only one sample ($S_{17}$) with categories S1 and C2, i.e., low alkalinity and medium salinity, which was suitable for irrigation (Fig. 4).

### 4.8 Wilcox's diagram

Wilcox's diagram can be used to check the suitability of water for irrigation. This diagram plots sodium percent (Na %) against electrical Conductivity (E.C.). Based on sodium and salinity hazards, this diagram classifies water into five categories (Fig. 5). Approximately 50% of the samples were within the permissible range and the rest were categorized as doubtful and unsuitable for irrigation.

## 5 Hydrogeochemical facies and control factors

Hydrogeochemical facies and other control factors were determined using Piper trilinear and Gibbs plots.

### 5.1 Piper trilinear plot

Based on dominant ions, the water can be categorized using a Piper trilinear plot [40]. Piper trilinear plot represents major cations and anions in two triangles and one diamond. The type of water is determined by the placement of cations and anions in the figure. Most water samples were under mixed Ca-Mg-Cl and Ca-$HCO^{-}_{3}$ types of water facies (Fig. 6).

### 5.2 Gibbs plot

The processes such as atmospheric precipitation, evaporation and rock weathering that control groundwater chemistry can be determined by using Gibbs plot [41]. It is the ratio of cations [$Na^+$/ ($Na^+$+$Ca^{2+}$)] and anions [$Cl^-$/ ($Cl^-$+$HCO^-_3$)] against total dissolved solids (T.D.S.). Most of the study samples fall in the evaporation dominance, and some are under rock dominance [Fig. 7(a) and 7(b]. The samples under evaporation dominance show an increase in salinity due to the higher concentration of $Na^+$ and $Cl^-$ ions with increasing concentration of T.D.S. Samples under rock dominance indicate that there is a significant interaction between rocks and water [42]–[45]. Interaction between rocks and water leads to rock weathering, thus adding solutes to water in the form of ions.

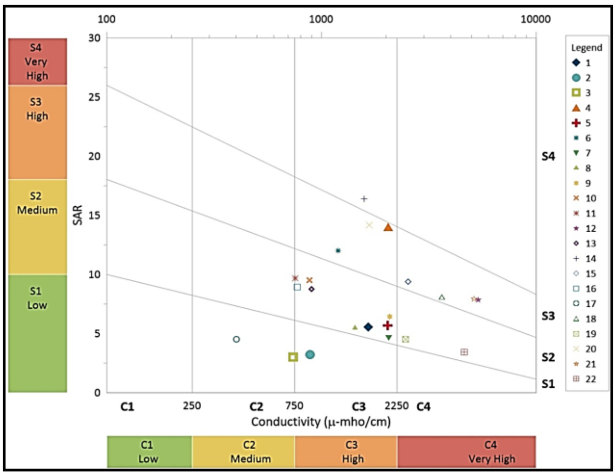


Fig. 4: U.S. salinity plot for samples analyzed [39]

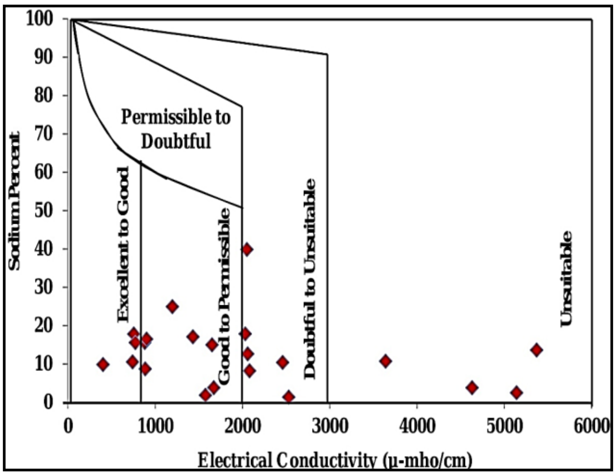


Fig. 5: Wilcox's diagram for the samples analyzed [10]

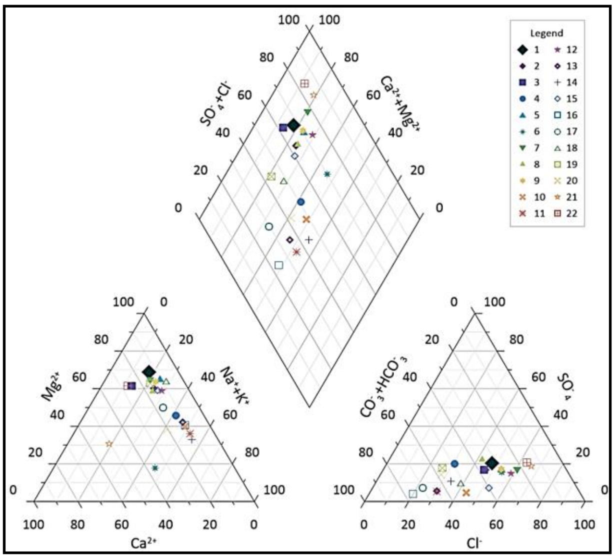


Fig. 6: Piper trilinear plot for the samples analyzed [40]

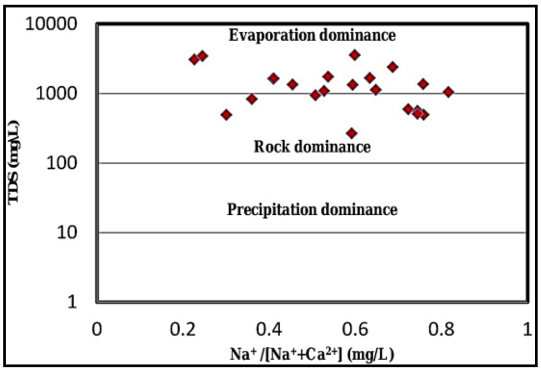


Fig. 7(a): Gibbs plot for samples analyzed [$Na^+$/($Na^+$+$Ca^{2+}$)] [41]

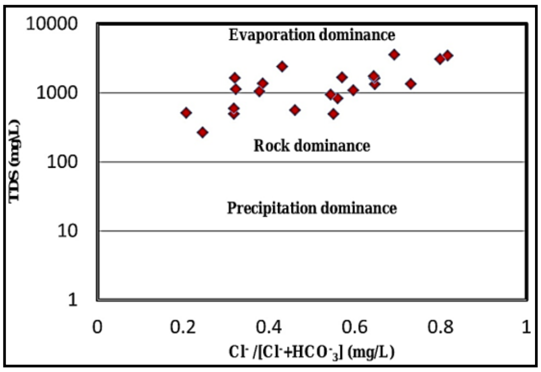


Fig. 7(b): Gibbs plot for samples analyzed [$Cl^-$/($Cl^-$+$HCO_3^-$)] [41]

## 6 Correlation coefficient

A strong positive correlation was observed between E.C. and other parameters, except for carbonate ions. The correlation between E.C. and T.D.S. was robust and highly significant at $p<0.05$. The pH of the samples was negatively correlated with all the other variables and similar observations were made for carbonate ions (Table 5).

Table 5. Co-efficient of correlation among different parameters

| Parameters | pH | E.C. | T.D.S. | $Cl^-$ | $Ca^{2+}$ | $Mg^{2+}$ | $SO_4^{2-}$ | $Na^+$ | $K^+$ | $CO_3^{2-}$ | $HCO_3^-$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 1 | | | | | | | | | | |
| EC | -0.351 | 1 | | | | | | | | | |
| TDS | -0.370 | 0.998* | 1 | | | | | | | | |
| $Cl^-$ | -0.600 | 0.738* | 0.762* | 1 | | | | | | | |
| $Ca^{2+}$ | -0.230 | 0.889* | 0.892* | 0.689* | 1 | | | | | | |
| $Mg^{2+}$ | -0.599 | 0.235 | 0.266 | 0.715* | 0.082 | 1 | | | | | |
| $SO_4^{2-}$ | -0.602 | 0.644* | 0.668* | 0.884* | 0.638* | 0.734* | 1 | | | | |
| $Na^+$ | -0.420 | 0.608* | 0.614* | 0.491 | 0.484 | 0.189 | 0.399 | 1 | | | |
| $K^+$ | -0.296 | 0.658* | 0.671* | 0.561 | 0.431 | 0.424 | 0.475 | 0.272 | 1 | | |
| $CO_3^{2-}$ | -0.366 | -0.142 | -0.150 | -0.229 | -0.128 | -0.224 | -0.279 | -0.131 | -0.028 | 1 | |
| $HCO_3^-$ | -0.264 | 0.378 | 0.386 | 0.289 | 0.153 | 0.505 | 0.377 | 0.481 | 0.554 | -0.139 | 1 |

*Significant at $p<0.05$

## V. CONCLUSION

Twenty-two water samples from different sites were analyzed for 14 physical and chemical parameters. Colour, odour, temperature, pH, sodium, potassium and carbonate were reported within standard limits. More than half of the samples ' electrical conductivity, calcium and sulphate were out of acceptable limits. T.D.S., chloride, magnesium and bicarbonate in all the samples were out of permissible limits and thus contributed significantly to water contamination compared to other parameters. W.Q.I. for 31.81% of samples were in the poor category and 31.18% were in the very poor water range. W.Q.I. for 18.18% of analyzed samples was good and 18.18% were unsuitable for drinking. S.A.R., Na %, R.S.C. and P.I. indicated that water in the region is suitable for irrigation. U.S. salinity plot shows that very few samples are suitable for irrigation. Wilcox's diagram indicated that more than 50 % of samples were unsuitable for irrigation. The results from this study highlight that the water in this region is polluted in the moderate to severe range. Long-term exposure to this water quality can devastate people's health, either through drinking or irrigation through food contamination. Hence, regular monitoring of groundwater resources and community participation through mass awareness could prove beneficial to keep a check on water pollution. Results obtained from this study can further be helpful in exploring the region's water quality.

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