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Geochemical evaluation of groundwater quality for drinking and irrigation purposes in Shamli district, Uttar Pradesh, India

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Abstract
Twenty three groundwater samples collected from various locations of Shamli district, Uttar Pradesh, India, were analyzed to review numerous quality parameters for their suitability for drinking and irrigation purposes. The suitability of the groundwater for drinking analyzed with reference to World Health Organization (WHO). The most of the chemical parameters (pH, TDS, hardness, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^-,Cl^-, SO_4^{2-}, NO_3^-, B^- and F^-) are within the permissible limit of WHO for drinking water. The interpretation of analytical data showed that $CaMgHCO_3$ is the dominant hydro-chemical facies in the area. Gibbs plot specifies that all the samples fall in rock dominance. The suitability of groundwater for irrigation purpose is assessed by various criteria like residual sodium carbonate (RSC), percent sodium (% Na), sodium adsorption ratio (SAR), magnesium ratio (MR), permeability index (PI), Kelly's index (KI), US salinity diagram and Wilcox classification. All these criteria showed that groundwater is excellent to good and suitable for irrigation purpose in the study area.

Keywords: Hydro-chemical facies, groundwater, drinking and irrigation water quality, Shamli, Uttar Pradesh

1. Introduction
Water is an important natural resource. Which is essential for life. Water on earth is present in various forms. In these forms of water, groundwater is an important form (Sushil Kumar *et al.*, 2020) [27]. Due to inadequate supply of surface water demand for groundwater has increased several times in present days for drinking, irrigation and other uses in the World. Groundwater is a very important water supply source worldwide. In India, it is the major source of water supply in urban and rural areas. Due to over exploitation of groundwater, its obnoxiously affected its amount and quality. Earlier groundwater was considered safe as compared to surface water but now-a- days because of inappropriate waste management practices leads to increased pollutants in groundwater (Iqbal and Gupta, 2009) [11]. The chemistry of groundwater is controlled by numerous natural as well as anthropogenic factors. The important natural factors which control the water chemistry are precipitation pattern and amount, geological features of watershed and aquifer, meteorological factors and various rock-water interaction processes in the aquifer (Raju et.al., 2016; Singh et. al., 2015)[19,21]. Anthropogenic activities which affect the water chemistry are dumping of solid waste, domestic and industrial waste, mining and agricultural activities (Hem, 1991; Raju, 2007; Singh *et al.*, 2016) [9, 17, 22]. In order to understand the pollution trends and their impacts on an aquifer, it is, therefore, important to have knowledge on the natural baseline quality for assessment of environmental changes (Edmunds *et al.*, 2003) [6] for taking appropriate management measures in time for sustainable development. Utilization of land without following the environmental norms, causing a lot of variation of quality of groundwater within a short distance, which constraints the developmental activities drastically everywhere. Therefore, monitoring of groundwater quality is essential in every area which affects the suitability of water for drinking, irrigation and industrial use. Several research has done on hydro-chemical features, groundwater pollution and its quality status for the consumption of groundwater for drinking and irrigation purposes in various regions

(Ahamed and Loganathan, 2017; Patel *et al*., 2016; Raju *et al*., 2016; Sughoush Madhav *et al*., 2018) [1, 14, 19, 26]. As the chemical quality of groundwater is controlled by many interrelated processes, the understanding of such processes is needed for water quality control and improvement. Therefore, the fundamental knowledge on the controlling process of chemistry of groundwater is a prerequisite for rational management of water resources. Keeping this in view, the present study is focused on hydro-geochemical facies of groundwater and their suitability for drinking and irrigation purposes.

2. Materials and Methods

2.1 The study area

The study was carried out in Shamli district, that was carved out from Muzaffarnagar district on September, 2011 as Prabudh Nagar and renamed Shamli in July, 2012. Shamli is the headquarter of the district. Shamli is located approximately 92 kilometres from Delhi along the Delhi-Saharanpur and Meerut Karnal highway. The district, covering an area of 1341 km^2 lies in the north-west of Uttar Pradesh. It is bounded on the north by the Saharanpur district, Bagpat district in south and west in Haryana state. It lies to the east of the Yamuna river, which marks the borders of two Indian states, Haryana and Uttar Pradesh. The district lies between 29^0 45′49.33″ - 29^0 42′ 33.33″ latitudes and 77^0 23′ 10.06″ -78^0 08′ 13.18″ longitude. The district has been subdivided into 03 tehsils and 5 development blocks. Entire district of Shamli falls between Yamuna and Krishna rivers.

The loamy soils of the area are very fertile. About 80 % of the total geographical area of the district is cultivated area. The main rabi crops are wheat and oil seed, while paddy and pulses are the main crops of kharif. The abundantly produced sugarcane is a perennial crop. The maximum irrigation needs are met by groundwater in Shamli district. The total groundwater contribution in the district is 94.43 %. The average annual rainfall in the district is 869 mm. About 80 % of rainfall takes place from June to September. During monsoon surplus water is available for deep percolation to groundwater. The climate is sub humid and it's characterised by general dryness except in the brief period during the monsoon season. Summer is hot and winter is a pleasant cold season. May is the hottest month. The mean daily maximum temperature is about 40 ^{0}C, mean daily minimum temperature is about 24 ^{0}C and maximum temperature some time rises to 44 ^{0}C. With the onset of the southern monsoon by the end of June, there is an appreciable drop in temperature. January is the coldest month with mean daily maximum temperature at about 20 ^{0}C and mean daily minimum temperature at about 7 ^{0}C. The air is dry during the major parts of the year. In southwest monsoon season, the air is very humid and April and May are usually driest months (CGWB, 2017) [3].

2.2 Geology and hydrogeology

The entire Shamli district is a flat terrain falling in middle Yamuna plain. Shamli district is underlain by quaternary alluvium deposited by Ganga and Yamuna river system. Lithologically the alluvial sediments comprise of sand, silt, Clay and kankars in varying proportions.

Groundwater occurs under phreatic to semi confined and confined conditions. The near surface aquifer is under unconfined/water table condition. The shallow phreatic aquifer is tapped by dug wells. In 2015 the depth to water level ranges from 11.46 to 23.27 mbgl during pre-monsoon, whereas it ranges from 11.00 to 23.35 mbgl in post monsoon (CGWB, 2017) [3].

2.3 Sampling of groundwater

Twenty three groundwater samples were collected from various locations of Kairana tehsil of Shamli district. The samples were collected in 500 ml polyethylene bottles from tube wells water. Before sampling, bottles soaked in 1:1 HCl for 24 hrs were rinsed with distilled water followed by deionised water. At the time of sampling, the sampling bottles were thoroughly rinsed two to three times using the groundwater to be sampled. Water samples from tube wells were collect directly from the outlet point after running the tube well for about half an hour to drain out the water retained in the pipe. The sample bottles were labelled, tightly packed, transported immediately to the laboratory and stored at 4 ^{0}C for chemical analysis.

2.4 Laboratory analysis

All groundwater samples were analysed for chemical properties viz., pH, electrical conductivity (EC), potassium, sodium, calcium, magnesium, bicarbonate, nitrate, chloride, sulphate, fluoride and boron with standard methods of water chemical analysis (APHA, 2005)[2]. Total dissolved solids (TDS) was calculated from electrical conductivity by using the formula TDS (mg/L) =EC (dsm^{-1}) x 640. The total hardness (TH) was calculated by using formula TH (mg/L) = 2.5 (Ca^{2+} in mg/L) + 4.1 (Mg^{2+} in mg/L) as the Ca^{2+} and Mg^{2+} were the principal ions responsible for total hardness.

Suitability of groundwater for irrigation was assessed with the assistance of various criteria like magnesium ratio (MR), sodium percentage (Na %), residual sodium carbonate (RSC), sodium adsorption ratio (SAR), soluble Doneen's permeability index (PI) and Kelly's index (KI).

3. Results and Discussion

3.1 Hydro geochemical

The groundwater quality data of the study area plotted on the Piper trilinear diagram to categorized the water facies on the basis of dominant ions (Piper, 1944)[15]. In Piper diagram, major ions are plotted in two base triangles as major cations and major anions. Piper diagram divides water into four basic types according to their placement near the four corners of the diamond. Water that plots at the top of the diamond is high in Ca^{2+} + Mg^{2+} and Cl^-+ SO_4^{2-}, which results in an area of permanent hardness. The water that plots near left corner is rich in Ca^{2+} + $Mg^{2+}$and HCO_3^- and is the region of water of temporary hardness. Water plotted at the lower corner of the diamond is primarily composed of alkali carbonates (Na^+ + K^+ and HCO_3^- + CO_3^{2-}), water lying near the right hand side of the diamond may be considered saline (Na^+ + K^+ and Cl^- + SO_4^{2-}).

Analysis of Piper diagram evident that alkaline earth and bicarbonate are the dominant ions in the groundwater (Figure 1). The major groundwater type of the study area is $CaMgHCO_3$ type and is the region of water of temporary hardness.

3.2 Gibbs plot

The Gibbs diagram is widely used to establish the relationship of water composition and aquifer lithological characteristics (Gibbs, 1970) [8]. Gibbs proposed two diagrams to understand the hydro-geochemical procedures with admiration to precipitation dominance, rock dominance and evaporation dominance over the administration of geochemistry of groundwater. Gibbs plots are the graph of ratio of cations [(Na + K)/(Na + K+ Ca)] and anions [(Cl/(Cl +HCO_3)] against total dissolved solids (TDS). The study area data plots on Gibbs diagram denote that rock dominance mechanisms is controlling groundwater chemistry (Figure 2a and 2b). In alluvial plains, the rock water interface is the main procedure that governs the chemistry of groundwater (Raju *et al.*, 2011; Sughosh Madhav *et al*., 2018) [18, 26].

3.3 Aptness of groundwater for drinking purpose

The aptness of groundwater for drinking purpose has been evaluated on the basis of pH, TDS, hardness, Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-,Cl^-, SO_4^{2-}, NO_3^-, B^- and F^-. The determined values of the groundwater samples were compared to standard for drinking water given by WHO (2017) [31].

The pH shows the acidic or basic condition of water quality. If the pH is not within the prescribed limit of 6.5 to 8.5, it damages mucous membrane present in eyes, nose, mouth, abdomen, anus etc. (Subba Rao *et al*., 2012) [25]. The pH (7.2 o 8.0) in all groundwater samples (100 %) observed from the study area is within the safe limit (Table 1).

The determined TDS from the study area is between 220 to 730 mg/L (Table 1). Based on the TDS content allowed for drinking water, all the groundwater samples in the study area are within the permissible limit of TDS (500 mg/L) except in one sample (sample no. 18). Normally, the higher TDS decreased palatability and causes gastrointestinal irritation in the consumers. But, the prolonged intake of water with the higher TDS can cause kidney stones, which are widely reported from different parts of the country (Garg *et al*., 2009) [7].

The hardness is also an important criteria for determining the suitability of water for drinking. The higher level of hardness causes unpleasant taste. In the present study area, the total hardness (TH) is vary from 160 to 520 mg/L (Table 1), which is within the permissible limit of TH (500 mg/L) in all samples except one sample (sample no. 18).

The concentration of Ca^+ recorded from the study area is varied from 24.06 to 94.24 mg/L, which is below the permissible limit of WHO (200 mg/L) in all groundwater samples (Table 1). The concentration of Mg^+ observed is ranging from 17.01 to 68.04 mg/L, which is also below the permissible limit of WHO (150 mg/L) in all groundwater samples (Table 1).

The content of Na^+ observed between 6.9 to 23.92 mg/L, which is within the recommended limit of Na^+(200 mg/L) for safe water in all the groundwater samples (Table 1). However, higher Na^+ makes the water unsuitable for drinking because it causes severe health problems like hypertension (Holden, 1970) [10].

The K^+ maintains fluids in balance stage in body. The contents of K^+ in all the groundwater samples is between 1.96 to 7.04 mg/L, which is below the prescribed level of K^+ (12 mg/L) suggested by WHO (Table 1).

Bicarbonate is a major element in human body, which is essential for digestion. The concentration of HCO_3^- is ranging from 149.85 to 518.5 0 mg/L, which is under the desirable limit of HCO_3^- (600 mg/L) for drinking water recommended by WHO in all the groundwater samples (Table1). The safe limits of Cl^- and SO_4^{2-} for drinking water are 250 and 150 mg/L, respectively. In the present study area the concentration of Cl^- and SO_4^{2-} are in the range of 17.40 to 48.28 mg/L and 14.42 to 38.92 mg/L, respectively (Table 1). The concentration of Cl^- and SO_4^{2-} in all the samples are beneath the recommended limit of WHO.

The recorded concentration of NO_3^- is from 4.96 to 93.62 mg/L, while the prescribed limit of NO_3^- in the drinking water is 50 mg/L (Table 1). The concentration of NO_3^- is 1.87 times higher than those of its desirable limit in approximately 4 % (Sample no. 18) of the total groundwater samples. The higher value of NO_3^- may be due to the poor drainage and use of high amount of nitrogenous fertilizers.

The permissible limits of B^- and F^- for drinking water are 2.4 and 1.5 mg/L, respectively. In this study, the concentration of B^- and F^- in groundwater samples are in the range of 0.59 to 2.84 mg/L and 0.35 to 1.89 mg/L, respectively (Table 1). The concentration of B^- and F^- are 1.18 and 1.26 times higher than those of their prescribed limits suggested by WHO, which is approximately 4 % (Sample no. 21) of the total groundwater samples in both the parameters.

3.4 Suitability of the groundwater for irrigation

The evaluation of groundwater quality for irrigation purpose was carried out with the help of different criteria like SAR, Na %, RSC, MR, PI, and KI (Table 2).

3.4.1 Residual sodium carbonate

Residual sodium carbonate is calculated to assessment of the harmful effect of carbonate and bicarbonate on the quality of water used for irrigation purpose (Raju, 2007) [17] and it is calculated by using the formula:

$$RSC = (CO_3^{2-} + HCO_3^-) – (Ca^{2+} + Mg^{2+})$$

Where values of all the ions are expressed in meq/L.

On the basis of RSC, Eaton (1950) [5] categorized the irrigation water into three categories such as safe (RSC <1.25 meq/L), marginally suitable (RSC 1.25 to 2.50 meq/L) and unsuitable (RSC > 2.5 meq/L). In the present study, it is found that all the groundwater samples fall into the safe category (Table 2). Similar findings also reported by Shushil Kumar et.al. (2020) [25] in groundwater samples of adjacent Muzaffarnagar district.

3.4.2 Electrical conductivity and percentage sodium

Electrical conductivity and percent sodium play a crucial role to evaluating the suitability of groundwater for irrigation purpose. The higher Na^+ in the irrigation water renders it unsuitable for soils, containing exchangeable Ca^+ and Mg^+ ions, as the soils take up Na^+ in exchange for Ca^+ and Mg^+ causing dispersion of clay particles and impairment of tilth and permeability of soils. Sodium forms alkaline soils, with a combination of carbonates, which do not support the plant growth. Percent sodium is widely used parameter for assessing the suitability of water for irrigation purposes (Wilcox, 1955) [30]. The % Na is obtained by the formula given below:

$$\% Na = (Na^+ + K^+)/ (Ca^{2+} + Mg^{2+} Na^+) x 100$$

Where all the ions are expressed in meq/L.

Wilcox (1955) [30] classified the irrigation water based on % Na and electrical conductivity into five distinct categories of suitability for irrigation such as excellent to good, good to permissible, permissible to doubtful, doubtful to unsuitable and unsuitable. On the basis of Wilcox classification, out of

23 groundwater samples, 22 samples are in excellent to good and one sample is in good to permissible categories (Figure 3).

3.4.3 Sodium adsorption ratio

The sodium hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed as the SAR. Sodium adsorption ratio is calculated based on the formula (Rhichards, 1954)[20] as given below:

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

Where all the concentrations of all ions are expressed in meq/L.

The measured value of EC is varied from 420 to 1140 µS/cm (Table 1) and the calculated value of SAR is between 0.24 to 1.27 (Table 2) from the groundwater samples of the study area. These data of the area are plotted in the salinity hazard versus sodium hazard diagram by the USSLS (1954; Figure 4), which explain the water quality for irrigation.

The USSLS's diagram categorize the water quality into 16 regions to assess the degree of suitability of water for irrigation (Figure 4), in which the salinity hazard (C) can be divided into four sub-regions, such as low salinity hazard (C1,< 250 µS/cm), medium salinity hazard (C2, 250 to 750 µS/cm), high salinity hazard (C3, 750 to 2250 µS/cm) and very high salinity hazard (C4, >2250 µS/cm) considering them as good, moderate, poor and very poor classes, respectively. Similarly, the sodium hazard (S) can also be classified into four sub-regions, such as low sodium hazard (S1, <10), medium sodium hazard (S2, 10 to 18), high sodium hazard (S3, 18 to 26) and very high sodium hazard (S4, >26), considering them as good, moderate, poor and very poor classes, respectively.

Approximately, 78.26 % of the total groundwater samples fall in the region of C2-S1 (Table 3), indicating a water of moderate salinity (C2) and low sodium hazard (S1) which can be used for irrigation on almost all soil types without little danger of the exchangeable sodium. In the region of high salinity hazard (C3) and low sodium hazard (S1), approximately 21.74 % of the total groundwater samples are observed. This water can be used for irrigation on almost all soil types with special management for salinity control.

3.4.4 Magnesium hazard

Generally Ca^{2+} and Mg^{2+} maintain a state of equilibrium in water and they do not behave equally in soil system. In equilibrium, more Mg^{2+} can effect soil quality by rendering it alkaline resulting in decrease of crop yield (Kumar et.al., 2007)[11]. Szabolcs and Darab (1964) [28] proposed a magnesium hazard value of water for irrigation purpose. Magnesium hazard (magnesium ratio, MR) value can be acquired by following formula:

$$MR = [Mg^{2+} / (Ca^{2+} + Mg^{2+})] \times 100$$

Where all ionic concentrations are expressed in meq /L.

If the irrigation water posses the MR above 50, it seems to be unsuitable for irrigation purpose because it adversely affects the crop yield (Raju *et al*., 2011) [18]. In the present study area, the MR is varied from 29.52 to 75.19 (Table 2). The MR exceeds the value of 50 in 60.86 % of the total groundwater samples, which are not suitable for irrigation on the basis of MR. In the remaining 39.14 % of the groundwater samples, the MR is less than the value of 50 and hence they are suitable for irrigation.

3.4.5 Permeability index

The permeability of soil is affected by long term use of irrigation water and is influenced by sodium, calcium, magnesium and bicarbonate contents in soil (Raghunath, 1987)[16]. On the basis of permeability index (PI), Doneen (1964)[4] has develop a criterion for evaluating the suitability of water for irrigation. Permeability can be calculated by the formula given below:

$$PI = [(Na^+ + \sqrt{HCO_3^-}) / (Ca^{2+} + Mg^{2+} + Na^+)] \times 100$$

Where all the ions are expressed in meq/L.

On the basis of PI the water quality can be classified into three classes. They are class I, class II and class III. The class I, which has 100 % maximum permeability is suitable for irrigation. The class II, which shows 75 % maximum permeability, is marginally suitable for irrigation. The class III, which is associated with the 25 % maximum permeability, is unsuitable for irrigation.

The PI is obtained to be varied from 35.53 to 62.81 from the present study area (Table 2). According to the classification of PI, all the groundwater samples (100 %) fall under the class I, which are suitable for irrigation.

3.4.6 Kelly's index

Kelly's index (Kelly, 1940) [12] is used for the classification of water for irrigation purpose. On the basis of KI, water is categorized into three groups. If the value of KI is < 1.0, water is suitable for irrigation. If the value of KI is between 1.0 and 2.0, water is marginally suitable and when KI is > 2.0, water is unsuitable for irrigation (Srinivasanmoorthy et.al., 2014) [23]. Sodium measured against calcium and magnesium is considered for calculate the KI. KI is calculated by using the formula:

$$KI = Na^+ / (Ca^{2+} + Mg^{2+})$$

Where all the ions are expressed in meq/L.

Kelly's index in the present study varied from 0.055 to 0.310 (Table 2). KI of all the groundwater samples are < 1.0, they are suitable for irrigation.

Table 1: Ranges of chemical parameters of groundwater and their comparison with World Health Organization (2017) standard for drinking water.

Parameter	Minimum	Maximum	Mean	WHO (2017) permissible limit	Sample number (% samples) exceeding permissible limit
pH	7.2	8.0	7.5	6.5-8.5	-
EC(µS /cm)	420	1140	590	-	-
TDS (mg/L)	220	730	382	600	18 (4)
Hardness (mg/L)	160	520	268	500	18 (4)
Ca^{2+} (mg/L)	24.06	94.24	50.3	200	-
Mg^{2+} (mg/L)	17.01	68.04	33.69	150	-
Na^{+} (mg/L)	6.9	23.92	18.86	200	-
K^{+} (mg/L)	1.96	7.04	4.80	12	-
HCO_3^- (mg/L)	149.45	518.50	279.78	600	-
SO_4^{2-} (mg/L)	14.42	38.92	26.83	150	-
Cl^- (mg/L)	17.40	48.28	27.55	250	-
NO_3^- (mg/L)	4.96	93.62	18.63	50	18 (4)
B^- (mg/L)	0.59	2.84	1.11	2.4	21 (4)
F^- (mg/L)	0.35	1.89	0.74	1.5	21 (4)

Table 2: Computed values of SAR, % Na, RSC, MR, PI and KI in the groundwater samples of Shamli district, Uttar Pradesh

Sample number	SAR	% Na	RSC (meq/L)	MR	PI	KI
1	037	10.03	-1.67	32.09	42.32	0.087
2	0.24	7.40	-0.56	39.56	46.00	0.055
3	0.56	11.96	-0.94	35.23	43.83	0.114
4	0.42	10.31	-1.23	40.00	46.61	0.103
5	1.03	19.46	-1.08	32.00	49.75	0.223
6	0.67	18.26	-0.67	44.69	57.82	0.189
7	1.14	19.29	-0.44	32.10	47.98	0.216
8	0.99	19.14	-0.03	29.52	51.31	0.206
9	0.78	18.51	-0.16	60.48	56.31	0.191
10	0.64	16.55	-1.08	65.94	52.40	0.170
11	1.10	19.35	-0.67	62.79	48.41	0.217
12	0.35	8.04	-0.55	68.84	45.81	0.078
13	0.30	8.94	-0.30	65.74	51.16	0.073
14	0.35	8.85	-1.60	75.18	40.87	0.076
15	0.43	12.03	-0.69	72.61	49.02	0.102
16	0.68	15.04	-1.27	62.35	45.23	0.144
17	0.97	20.43	-0.04	54.60	56.10	0.224
18	0.74	11.36	-1.88	54.61	35.53	0.116
19	0.79	17.38	-0.69	61.22	53.84	0.193
20	1.22	25.56	0.07	66.36	62.81	0.310
21	0.76	15.66	-0.43	75.19	48.61	0.159
22	0.45	9.49	-1.46	51.64	38.29	0.083
23	1.27	20.27	0.40	47.01	50.69	0.240

Table 3: Criteria for groundwater quality for irrigation following the USSLS diagram (USSLS, 1954) in the Shamli district, Uttar Pradesh

Region	Salinity hazard	Sodium hazard	Sample numbers	% of samples	Broad water quality
C1-S1	Low	Low	-	-	Good
C1-S2	Low	Medium	-	-	Moderate
C1-S3	Low	High	-	-	Poor
C1-S4	Low	Very high	-	-	Very poor
C2-S1	Moderate	Low	1,2,3,4,5,6,8,9,10,12,13,14,15,16,17,19,20,21	78.26	Good
C2-S2	Moderate	Medium	-	-	Moderate
C2-S3	Moderate	High	-	-	Poor
C2-S4	Moderate	Very high	-	-	Very poor
C3-S1	High	Low	7,11,18,22,23	21.74	Moderate
C3-S2	High	Medium	-	-	Moderate
C3-S3	High	High	-	-	Poor
C3-S4	High	Very high	-	-	Very poor
C4-S1	Very high	Low	-	-	Very poor
C4-S2	Very high	Medium	-	-	Very poor
C4-S3	Very high	High	-	-	Very poor
C4-S4	Very high	Very high	-	-	Very poor

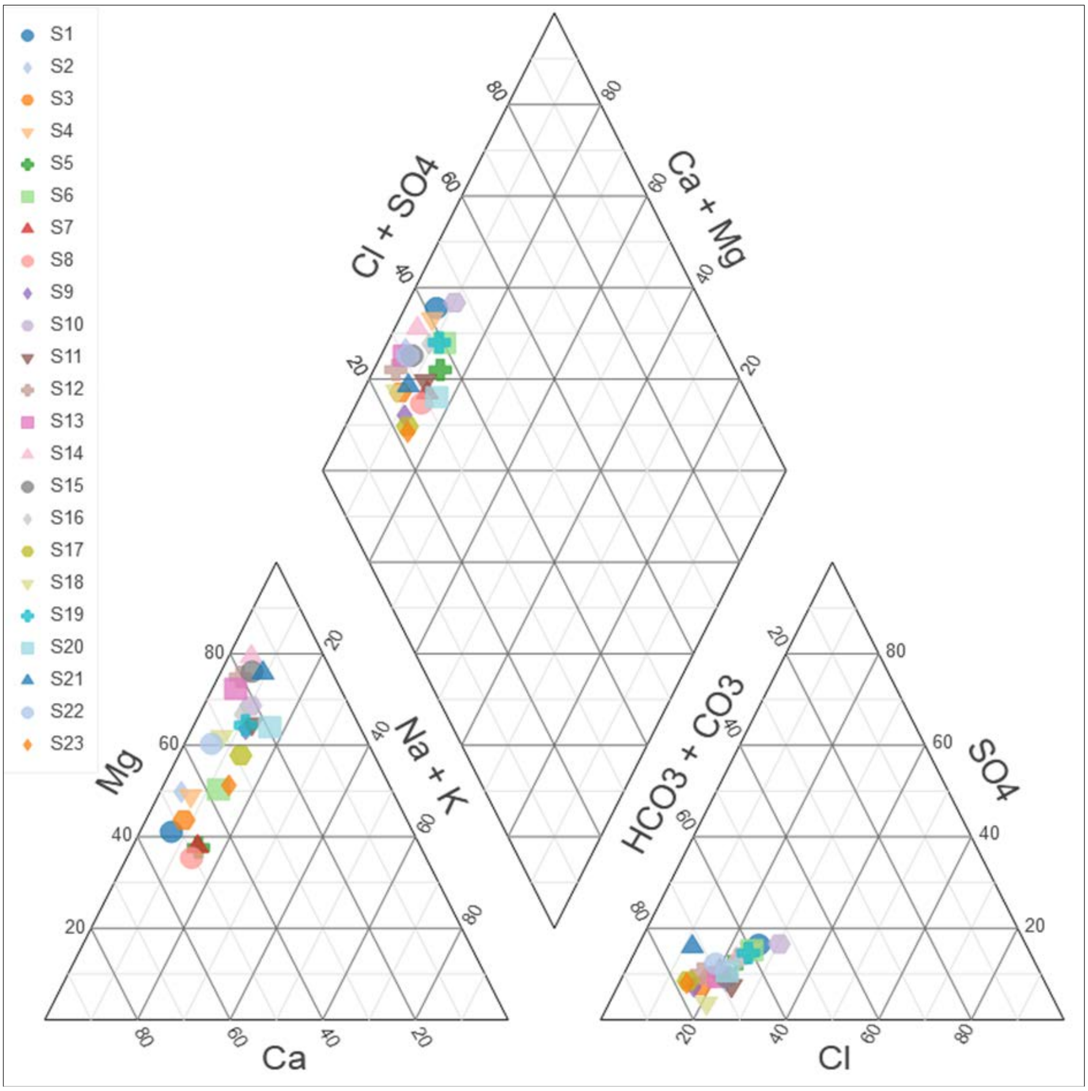

Fig 1: Piper tri-linear diagram representing the relative cation and anion composition of groundwater samples

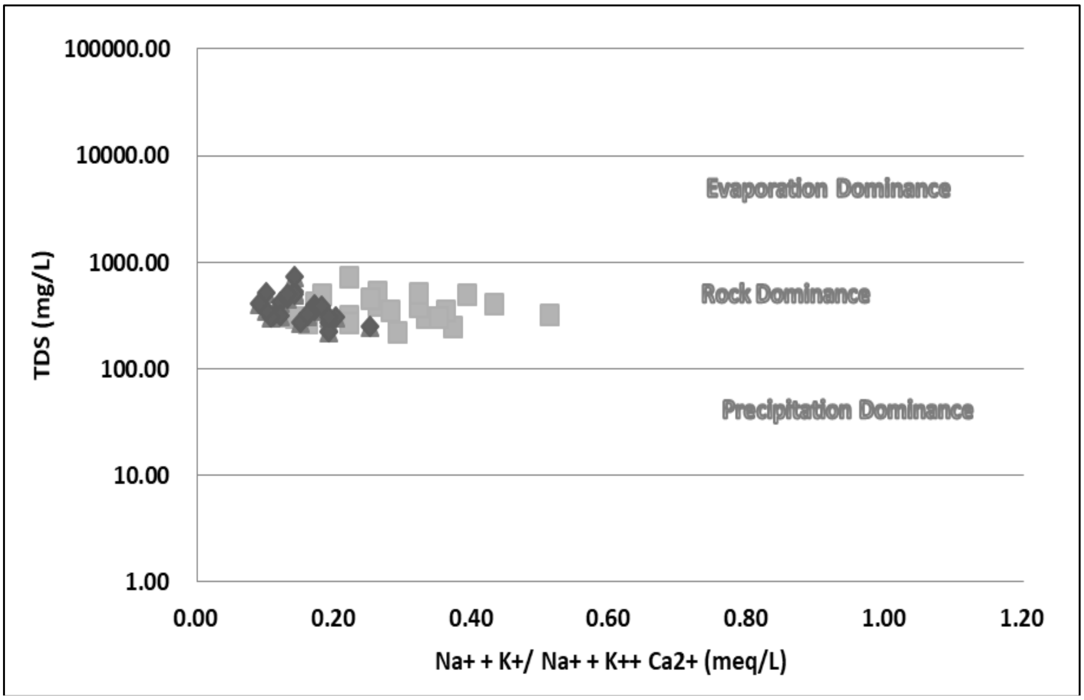

Fig 2a: Mechanism controlling groundwater chemistry (Gibbs I)

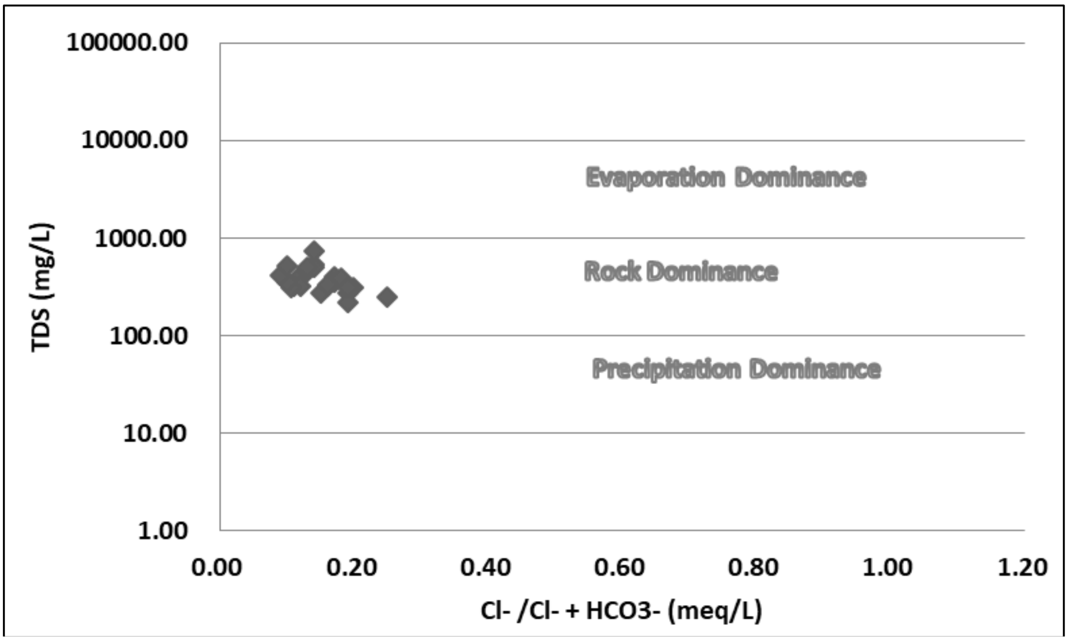

Fig 2b: Mechanism controlling groundwater chemistry (Gibbs II)

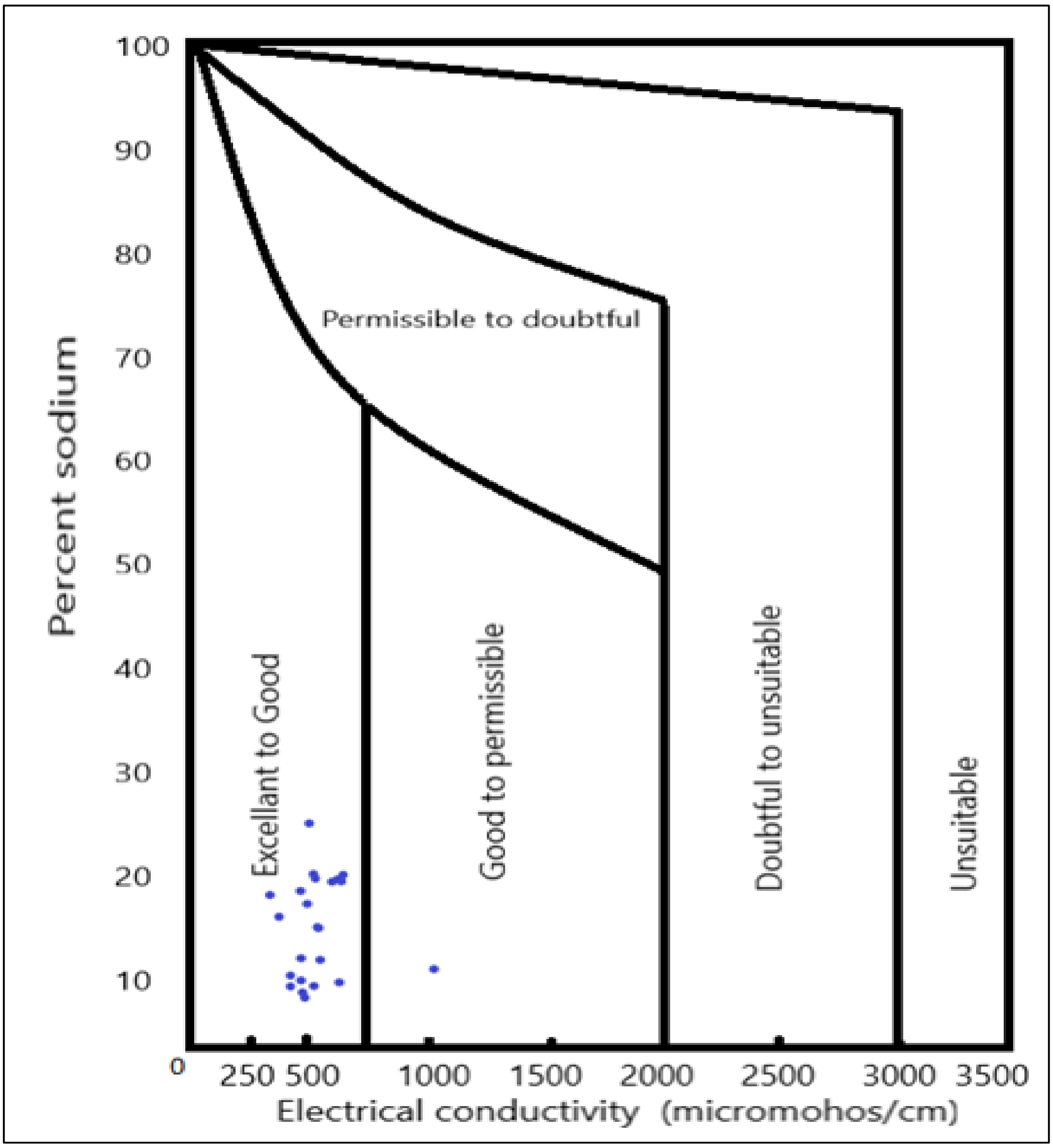

Fig 3: Classification of groundwater samples on the basis of electrical conductivity and percent sodium (Wilcox, 1955)

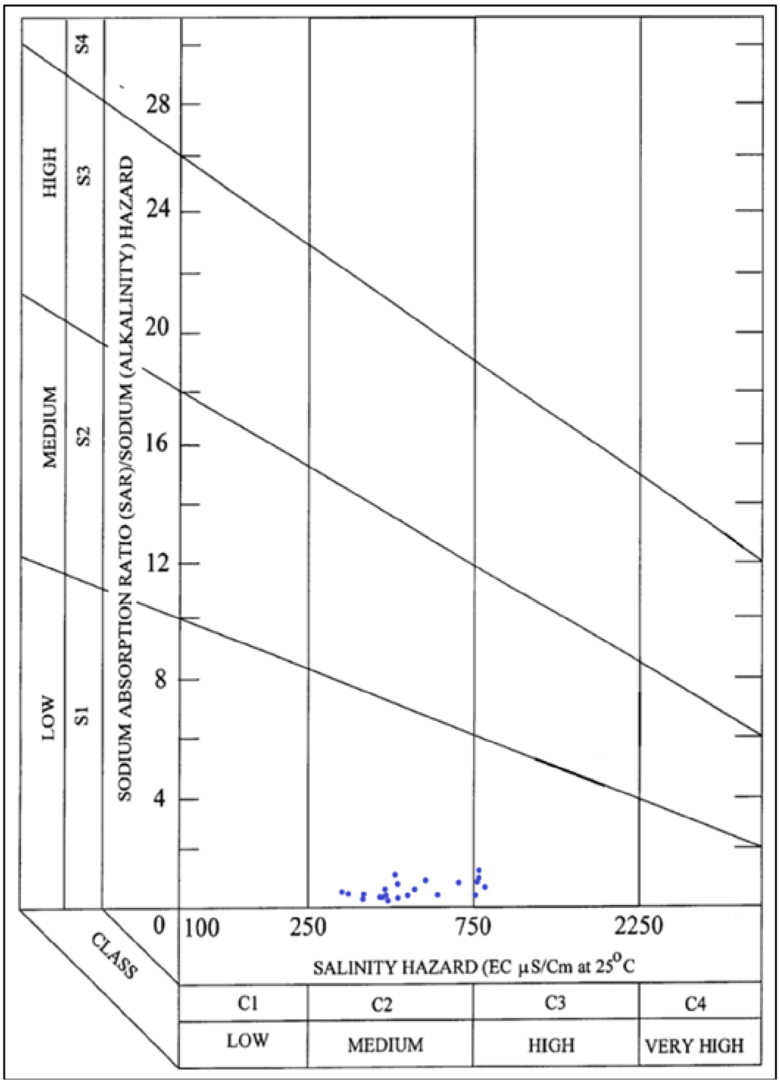

Fig 4: Classification of groundwater samples on the basis of salinity hazard and sodium hazard (USSLS, 1954)

4. Conclusion

It may be concluded that the major water type of the study area is $CaMgHCO_3$ type with temporary hardness. The groundwater of the study area is good and appropriate for drinking and irrigation purposes. However, because of population growth, intensive agriculture and increasing industrial activities within the area can cause to the declination of water quality in the future. Therefore, some management measures should be taken to maintain the water quality for sustainable use.

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