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Determination of Hydro-Chemical Characteristics of Ground Water for Assessment of Quality for Drinking and other Domestic Purposes in North East Bhilwara, Rajasthan, India

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ABSTRACT

Present study is aimed to assess the hydrochemical characteristics of ground water in north east Bhilwara, Rajasthan for drinking and other domestic purposes. In order to evaluate hydrochemical characteristics of ground water 120 samples were collected and analyzed for various parameters such as Colour, Odour, Taste, Temperature, Turbidity, pH, TA, F^-, NO_3^-, SO_4^{-2}, TDS, Cl^-, TH, EC, Ca-H, Mg-H, CO_3^{-2}, HCO_3^-, Ca^{+2}, Mg^{+2}, Na^+, K^+, DO, COD, BOD and Trace metal ions and these parameters were used to evaluate hydrochemical characteristics. The Piper's trilinear diagram showed that in groundwater alkaline earth's (Ca+Mg) exceeded alkali (Na+K) in 100 %, strong acid anion ($Cl+SO_4$) exceeded in 55 % and weak acid anion exceeded (HCO_3+CO_3) in 45 % sampling stations. The composition of ground water is found Ca-Mg type, Ca-HCO_3 type, Ca-Cl and mixed cation and anion type, and alkaline (pH), fresh to brackish (TDS), good to doubtful (EC), hard to very hard (TH), fresh to brackish (Chloride), good to very poor (WQI), corrosive in 38.33 % samples (CR), dominance of cation-anion exchange reactions (CAI), and have anionic nature with good ionic balance (-10% to10%) in 37.5 % samples (IB). The abundance of major cations and anions is in order $Ca^{+2} > Na^+ > Mg^{+2} > K^+$ and $HCO_3^- > Cl^- > CO_3^{-2} > SO_4^{-2} > NO_3^-$.

Keywords: Alkaline earth, Alkali, Hydrochemical, Ionic Balance, Piper diagram

INTRODUCTION

The increasing population growth and change in life style has increased water consumption for domestic, industrial and irrigation purposes. Groundwater is an important water resource in Rajasthan (India). In several states of India, more than 90% of populations are dependent on groundwater for drinking and other purpose. The quality of ground water depends on different recharge of water, rainfall, geochemical processes, and human activities [1] and the quality is degraded by modern civilization, industrialization, urbanization and increase in population. In Rajasthan 60% parts is covered by great Thar Desert and have very poor precipitation, drought and improper management of water resources that increasing water scarcity and deteriorating ground water quality. Water quality assessment for drinking and domestic purpose is mostly based on hydrochemical characteristics of water and hydrochemical study reveals the quality of water that is suitable for drinking, agriculture and industrial purposes. Further, it is possible to understand the change in [2-4] quality due to rock-water interaction or any type of anthropogenic influence. Concentration of naturally occurring chemical ions is not health concern at particular levels but may affect suitability for drinking purpose. Chemical composition of ground water changes due to geogenic and anthropogenic activities. Use of water quality index to determine the water quality is considered one of the effective tools. It was developed by Oregon in 1970 [5].

The main objectives of this study are measuring the distribution of physico-chemical parameters in ground water of north east Bhilwara, Rajasthan (Jahazpur), to discuss the hydrochemistry and suitability for drinking and domestic purposes and provide reliable water quality data to design economically effective methods for treatment of ground water. In this case the methods proposed by Piper, USSL, (1954) (US Salinity Laboratory) [6], WQI classification and Correlation coefficient analysis method have been used to study critically the hydrochemical characteristics of groundwater.

METARIAL AND METHOD

Study Area

Jahazpur tehsil is part of north east Bhilwara, Rajasthan that situated between $25^0 01'$ & $25^0 58'$ North latitude and $74^0 01'$ & $75^0 28'$ East longitude covering geographical area of 10,455 sq km (Fig.1). It is part of semiarid zone and hydrogeology is phyllite, schist and Granite and gneiss type, Potential zone yield is 30-50 m^3/day [7].

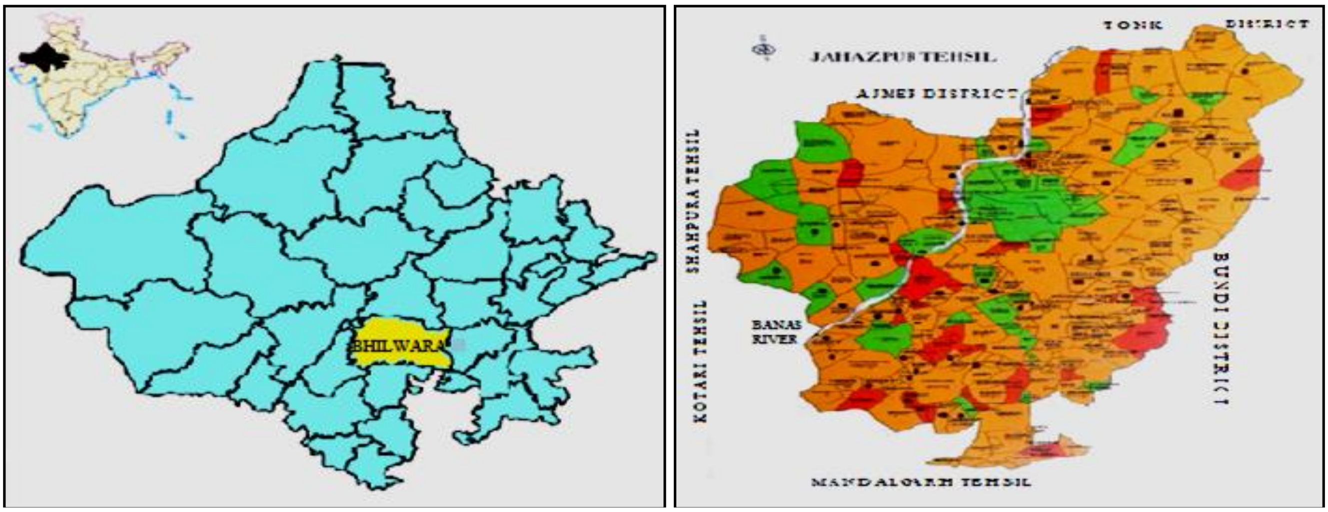

Fig. 1 Study area map

Methodology

Ground water samples from 120 sampling station in 37 gram panchayats in Jahazpur tehsil were collected during June 2014 in pre cleaned, dry and sterilized plastic bottles from hand pumps, dug wells bore wells and PHED supply. For all samples, temperature, pH and electrical conductivity (EC) were determined in the field with standard field equipment's and then carefully sealed with proper labelling and transfer to lab. Samples were analysed for major ions chemistry employing standard methods [8]. The range of analysed parameters along with their mean and standard deviation values are presented in Table 2.

Water Quality Index

Water quality index (WQI) is method of rating water that provides the composite influence of individual water quality parameter on the overall quality of water. The standards for drinking purpose [9] have been considered for calculation of WQI. In this method the weightage for various parameters is assumed to be inversely proportional to the recommended standards for the corresponding parameters [10]. BIS (2012)/WHO (2008) [11-12] drinking water standards considered for the calculation of WQI. For the calculation of WQI of ground water in the study area, 15 physico-chemical parameters were taken into account which are pH, TDS, NO_3^-, DO, TA, TH, EC, Ca^{+2}, Mg^{+2}, Na^+, K^+, Cl^-, SO_4^{-2}, HCO_3^- and F^-.

CALCULATION OF WATER QUALITY INDEX

First Step: Assignment of weight to Parameters-Weight (w_i) between 1 and 5 was assigned to each of 15 parameters depending to their relative importance in the overall quality of water for drinking purposes (Table 1).

Second Step: Determination of relative weight (W_i)

$$W_i = w_i / \sum_{i=1}^{n} w_i \qquad (1)$$

Third Step: Determination of quality rating scale (Q_i)

$$Q_i = (C_i / S_i) \times 100 \qquad (2)$$

Fourth Step: Calculation of sub index SI_i

$$SI_i = W_i \times Q_i \qquad (3)$$

Overall water quality index (WQI) was calculated by addition of each sub index values for each groundwater samples as follows

$$WQI = \sum SI_i \qquad (4)$$

Where, W_i= relative weight, w_i= weightate of each parameter, n= number of parameter, Q_i= quality rating, C_i= measured concentration parameter, S_i= BIS or WHO drinking water standards and SI_i= sub index of i^{th} parameter.

Chloro alkaline indices (CAI) = $[Cl^- - (Na^+ + K^+)]/Cl^-$ (5)

Corrosively Ratio (CR) = $\frac{\frac{Cl}{35.5}+2\left(\frac{SO_4^{-2}}{96}\right)}{2\left(\frac{HCO_3^- + CO_3^{-2}}{100}\right)}$ (6)

Ion Balance (IB) = [100 * (∑Cation - ∑Anion)] / [∑Cation + ∑Anio (7)

All concentrations are given in Meq/L

Correlation Coefficient $(r) = \frac{n\sum(xy)-\sum x\sum y}{\sqrt{n\sum x^2-(\sum x)^2}-\sqrt{n\sum y^2-(\sum y)^2}}$ (8)

Where, X and Y represents two different parameters, n = Number of total observations.

Table -1 WHO/BIS Standard, Weight (w_i) and Relative Weight (W_i) for each Parameter

S. No.	Parameter	S_i	w_i	W_i
1	pH	8.5	4	0.0870
2	TH	200	3	0.0652
3	Ca^{+2}	75	2	0.0435
4	Mg^{+2}	30	2	0.0435
5	HCO_3^-	500	3	0.0652
6	Cl^-	250	4	0.0870
7	F^-	1	4	0.0870
8	NO_3^-	45	5	0.1087
9	SO_4^{-2}	200	4	0.0870
10	Na^+	200	1	0.0217
11	K^+	10	1	0.0217
12	TDS	500	3	0.0652
13	EC	1500	3	0.0652
14	DO	5	4	0.0870
15	TA	200	3	0.0652
			$\sum w_i$ =46	1.0000

RESULT AND DISCUSSION

The use of water for any purpose is guided by standard set up by the World Health Organization, BIS, ICMR and other related agencies. The results of the analysed parameters in this study area were correlated with those of the World Health Organization (WHO, 2008) and BIS (2012) standards. The range of each physico-Chemical parameter in ground water with maximum, Minimum, Average and Standard deviation calculated is represented in Table -2. Colour and taste in ground water samples in study area are found agreeable and odour is unobjectionable in all samples. Temperature ranged from 24.9 to 33^{0}C, and comparatively higher temperature recorded in samples collected from bore wells and hand pumps. Turbidity in all samples was recorded within limit. Ground water in study area is found slightly alkaline in nature and in river basin part water is found comparatively more alkaline than hilly terrain part, in all the samples pH was determined above 7. DO, BOD, and COD in all samples were within desired limits.

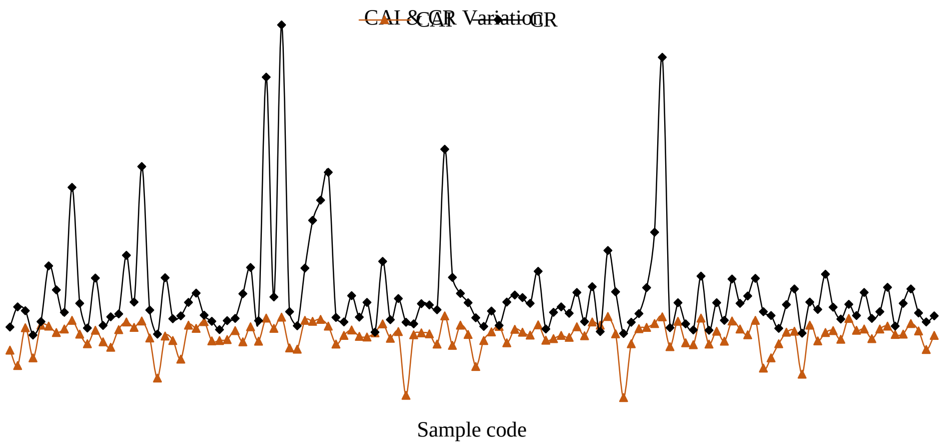

Fig. 2 Variation in CAI and CR in ground water samples

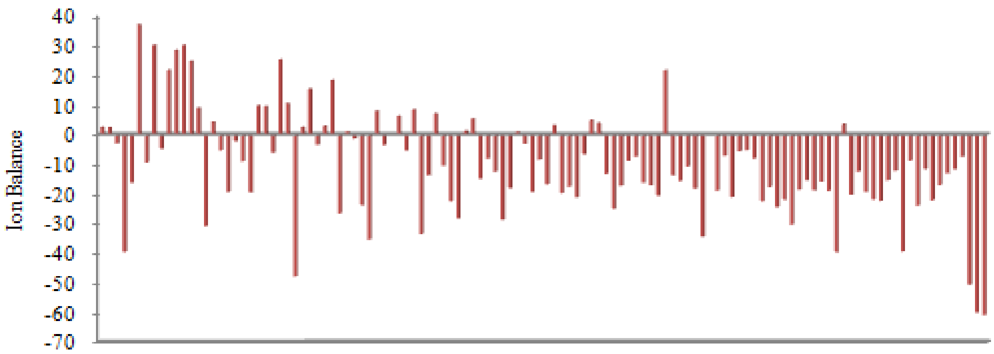

Fig. 3 Histogram showing variation in IB

Table- 2 Maximum, Minimum, Mean and Std. Deviation Values

S. No.	Parameter	Minimum	Maximum	Mean	STEDEV
1	Temp	24.9	33	28.39	1.94
2	Turbidity	0	3NTU	0.95	0.918
3	EC	390	5143	1345	979.6
4	pH	7.6	8.71	8.07	0.25
5	TDS	273	3600	955	694
6	TH	155	1455	375.9	193
7	TA	170	1011	396.3	180.6
8	DO	2.3	7.9	1.32	5.19
9	COD	0	86	19.88	20.91
10	Ca-H	75	1076	231.1	143
11	Mg-H	67	379	144.9	55.33
12	BOD	0	21	3.917	5.21
13	F^-	0.023	5.20	0.679	0.91
14	Cl^-	49.63	1155.67	194.31	191.4
15	NO_3^-	0.28	334.4	67.91	60.17
16	SO_4^{-2}	68	152	88.19	11.15
17	HCO_3^-	10	842	227.5	139.4
18	CO_3^{-2}	0	370	89.98	71
19	Na^+	23.4	95	49.84	16.31
20	K^+	0.06	1.3	0.404	0.292
21	Ca^{+2}	28.6	411	88.18	54.52
22	Mg^{+2}	16.3	92.1	35.19	13.45

Table -3 Classifications of Ground Water upon the Basis of Different Parameters

Classification Pattern	Categories	Ranges	Samples	% age
Electrical Conductivity (EC) [17]	Excellent	<250	0	0
	Good	250-750	33	27.5
	Permissible	750-2250	72	60
	Doubtful	2250-5000	14	11.66
	Unsuitable	>5000	1	0.833
Total Dissolved Solids TDS [18]	Fresh Water	<1000	81	67.50
	Brackish Water	1000-10000	39	32.50
	Saline Water	10000-100000	0	0
	Brine Water	>100000	0	0
Chloride (Cl^-) [15]	Extremely-Fresh	< 0.14	0	0
	Very-Fresh	0.14-0.85	0	0
	Fresh	0.85-4.23	74	61.67
	Fresh- Brackish	4.23-8.46	28	23.33
	Brackish	8.46-28.21	17	14.17
	Brackish-Salt	28.21-282.06	1	0.83
	Salt	282.06-564.13	0	0
	Hyper Saline	>564.13	0	0
Total Hardness (TH) [16]	Soft	0-75	0	0
	Moderately	75-150	0	0
	Hard	150-300	49	40.83
	Very hard	>300	71	59.17

Fluoride plays an important role in drinking water parameters excess concentration from prescribed level produce harmful effects such as dental and skeletal fluorosis, in 14.17 % water sample of study area fluoride exceeded to the maximum limit (1.5 mg/L) which is creating dental and skeletal fluorosis in local community. The concentration of fluoride in Banas river basin part of study area is comparatively found higher than Hilly terrain par [22-23]. Excess consumption of nitrate mainly produces methaemoglobinaemia (Blue baby disease) in below six month age children due to oxidation of Iron from (II) to (III) of haemoglobin, in 55 % ground water samples study are nitrate content exceeded the WHO (2008) standards (45 mg/L). The main sources of nitrate in ground water were identified in study area are excess uses of chemical fertilizers in farming, animal waste, septic tanks and on site sanitation etc. Chloride concentration ranged from 49.63 to 1155.69 mg/L and exceeded in 18.33% ground water samples and nature of ground water based on chloride content is determined fresh to brackish salt [15].Total hardness, Electrical conductance and TDS exceeded in 59.17 %, 28.33 % and 75.33% samples respectively and ground water of study area found Hard to very hard based on TH [16], good to unsuitable based on EC [17] and fresh to brackish based on TDS [18]. Concentrations of trace metal ions Fe, Cd, Cu, Zn, As and Pb are found within limits set by BIS (2012). Sodium and Potassium determined within limits in all samples and Calcium and Magnesium exceeded in more 50 % ground water samples and major sources of these alkaline earth and alkali metal ions is geogenic. The corrosivity ratio (CR) in study area ranged from 0.4 to 9.23 and in ground water of 61.67 % samples is found noncorrosive and safe for transport in any type of pipes whereas in 38.335 samples found corrosive that cannot be transported in metallic pipes . Higher concentrations of Cl^- and SO_4^{-2} increase the corrosion rate of metallic pipes [19]. CAI value in the study area ranged from -1.387 to 0.948 (Fig. 3) and in 89.11% ground water samples it is determined positive and in 10.83 % water samples negative that indicates that cation-anion exchange reactions are dominated over the base Exchange reaction in the ground water of study area. The negative value of CAI indicates that there is exchange between Sodium and Potassium (Na^++K^+) in water with Calcium and Magnesium (Ca^{+2}+Mg^{+2}) in rocks by a type of base exchange reactions and the positive value of CAI represents the absence of base-exchange reactions and existence of cation-anion exchange type of reactions [20]. Ion balance (Fig. 3) in 37.5% ground water samples it is determined within -10% to 10% range and negative in 74.17% ground water samples which indicate ground water is anionic in nature. According to standard rules, the ion balance of a fresh water sample with low TDS is considered to be good if the value is between -10% to +10%.

Correlation between Parameters

Correlation coefficient is a commonly used to establish the relationship between two variables. It is simply a measure to exhibit how well one variable predicts the other [21]. For this purposes, Spearman's rank correlation coefficient has been calculated between groundwater quality parameters in study area as shown in Table 4. A high correlation coefficient (near 1 or -1) means a good relationship between two variables and its value around zero means no relationship between them [22]. The correlation matrix shows up the negative correlation of pH with TH, NO_3^-, Cl^-, Na^+, Ca^{+2}, Mg^{+2}, SO_4^{-2}, Turbidity and Temperature but it showed a moderate positive correlation with F^-. Very strong positive correlation was observed between EC and TDS, EC and Cl^-, TH and Mg^{+2}, TH and Ca^{+2}, TDS and Cl^-. Strong positive correlation was found between TH and TDS, TH and EC, TH and Cl^-, Mg and TDS, Mg^{+2} and Ca^{+2}, SO_4^{-2} and Turbidity, Ca^{+2} and Cl^-, Ca^{+2} and TDS and TA and F^-. A moderate positive correlation between EC and NO_3^-, EC and Ca^{+2}, EC and Mg^{+2}, Cl^- and Mg^{+2}, NO_3^- and TDS, NO_3^- and Cl^-, NO_3^- and Mg^{+2}, TA and pH, COD and BOD, CO_3^{-2} and TA, and F^- and pH (Table 4). The positive correlations between TDC and EC, TA and pH and fluoride and pH are shown in Fig. 4 to Fig. 5.

Correlation between TDS and EC

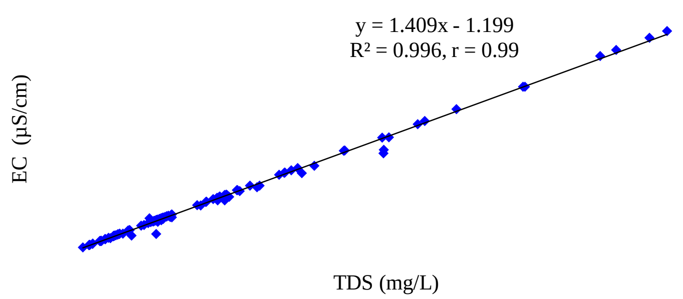

Fig. 4 Graph showing correlation between TDS and EC

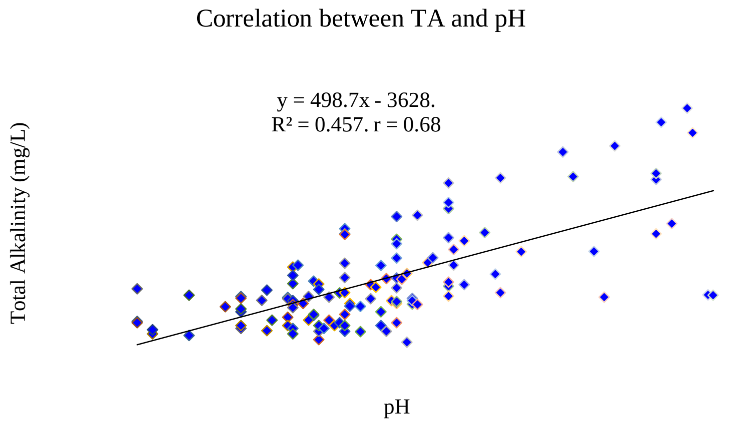

Fig. 5 Correlation between TA and pH

Table -4 Correlation Coefficient

Para meters	**pH**	**TDS**	**F^-**	**DO**	**BOD**	**COD**	**TH**	**EC**	**NO_3^-**	**Cl^-**	**CO_3^{-2}**	**HCO_3^-**	**TA**	**Na**	**K**	**Ca**	**Mg**	**SO_4^{-2}**	**Turb.**	**Temp**
pH	1																			
TDS	0.09	1.00																		
F^-	**0.62**	0.36	1.00																	
DO	0.13	-0.05	0.18	1.00																
BOD	0.21	0.09	0.45	0.06	1.00															
COD	0.11	0.16	0.34	0.14	**0.70**	1.00														
TH	**-0.31**	**0.75**	-0.07	-0.14	-0.08	-0.01	1.00													
EC	0.09	**0.99**	0.37	-0.04	0.09	0.15	**0.71**	1.00												
NO_3^-	-0.09	**0.61**	0.15	-0.09	0.01	0.08	0.47	**0.61**	1.00											
Cl^-	-0.03	**0.93**	0.19	-0.09	0.04	0.12	**0.73**	**0.94**	**0.53**	1.00										
CO_3^{-2}	0.31	0.31	0.33	-0.05	0.05	0.09	0.08	0.32	0.26	0.19	1.00									
HCO_3^-	0.36	0.07	0.54	0.18	0.31	0.12	-0.21	0.06	-0.09	-0.04	-0.39	1.00								
TA	**0.68**	0.40	**0.79**	0.09	0.28	0.17	-0.10	0.37	0.18	0.16	**0.60**	0.41	1.00							
Na	-0.04	0.17	-0.03	0.01	-0.05	-0.13	0.15	0.17	0.16	0.13	0.07	0.04	0.09	1.00						
K	0.30	0.23	0.44	0.14	0.06	0.08	-0.03	0.25	0.11	0.11	0.20	0.31	0.45	0.10	1.00					
Ca	**-0.31**	**0.71**	-0.07	-0.14	-0.07	-0.01	**0.99**	**0.70**	0.42	**0.72**	0.05	-0.20	-0.12	0.11	-0.02	1.00				
Mg	**-0.27**	**0.73**	-0.08	-0.13	-0.10	0.00	**0.93**	**0.67**	**0.54**	**0.69**	0.16	-0.22	-0.04	0.22	-0.05	**0.87**	1.00			
SO_4^{-2}	-0.05	0.06	-0.15	-0.12	-0.17	-0.13	0.18	0.06	0.08	0.11	-0.15	-0.07	-0.19	0.04	-0.07	0.19	0.13	1.00		
Turb.	-0.08	0.12	-0.14	-0.12	-0.17	-0.07	0.20	0.13	0.11	0.17	-0.05	-0.15	-0.18	0.00	-0.03	0.23	0.12	**0.79**	1.00	
Temp	-0.09	-0.12	-0.17	-0.37	-0.23	-0.06	-0.02	-0.13	-0.05	-0.10	-0.14	-0.11	-0.21	-0.17	-0.20	0.00	-0.06	0.07	0.04	1.00

Piper Diagram

The Piper-Hill diagram (Piper) is used to infer hydro-geochemical facies of water that include two triangles, one for plotting cations and the other for plotting anions. The cations and anion fields are combined to show a single point in a diamond-shaped field, all three fields have scale reading in 100 parts, from which inference is drawn on the basis of hydro-geochemical facies concept. In the present study, the classification of groundwater based on its geochemical facies has been done with the help of Piper (1953) diagrams [23] that gives different hydrochemical facies of ground water of study area. In the Piper diagram the alkaline earth's (Ca+Mg) and alkali (Na+K) cations and weak acid (HCO_3+CO_3) and strong acid (Cl+SO_4) anions are taken into consideration for defining the primary characteristics of water and two groups of water facies have been defined which are as follow:

1. Ca + Mg > Na + K – HCO_3 + CO_3 > Cl + SO_4
2. Ca + Mg > Na + K - Cl + SO_4 > HCO_3 + CO_3

Water with major cations (Ca+Mg) show permanent hardness and do not have bicarbonate hazard for irrigation [24]. While as the samples having (Na+K) type of water has temporary hardness and residual sodium carbonate. In study area Ca-Mg-type of water is predominated in all samples (100%), weak acid ions (HCO_3+CO_3)-type of water predominated in 55.83% samples and strong acid ions (Cl+SO_4)-type of water predominated in 44.67% samples. Calcium bicarbonate and Calcium chloride type water predominated in 15.83% samples and mixed type water in 84.17% samples. (Fig. 6)

Water Quality Index

In the study area value of WQI of ground water samples ranged from 55.71 to 249.61 with average of 107.5. 65 % of ground water samples fall in good, 27% in poor and 8% are in very poor categories (Fig. 7). These results are in agreement with previous hydrochemical results as reflected in the high EC and TDS of the samples. Quality deteriorated groundwater of the area was mostly from improper sanitation and waste dumping acts by the inhabitants of the study area.

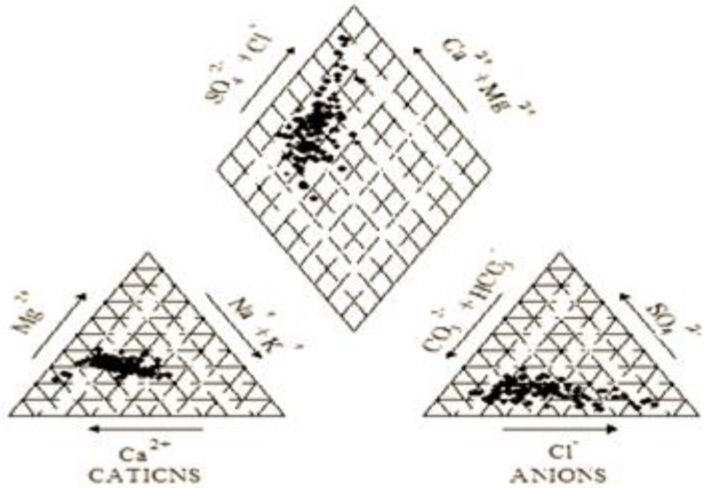

Fig. 6 Piper Diagram

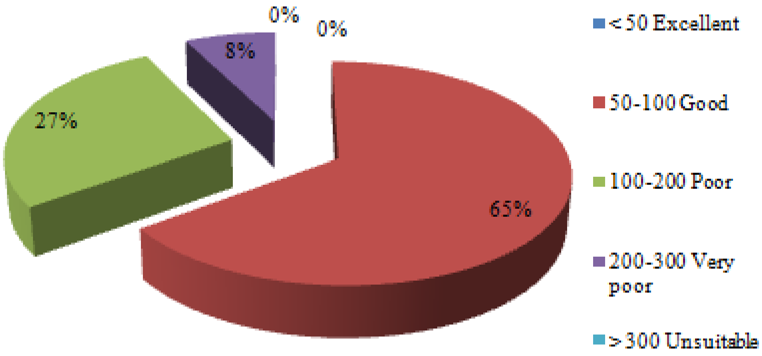

Fig. 7 Classification of water based on WQI

CONCLUSION

The groundwater quality of study area was assessed for its drinking and domestic suitability purposes. The quantitative chemical analysis results reflect that the dominant cations in the study area are Calcium and Magnesium (Ca + Mg) and the dominant anions are waek acid anions (HCO_3 + CO_3). Hydrochemical facies analysis as well the pH of water, both indicates that groundwater in the area is of alkaline nature. Most of the water samples were found to be moderately hard in nature with exceptions of a few hard to very hard types as well. EC have positive correlation with TDS, TH and Chloride. Fluoride concentration exceeded only in 14.17 % samples with highest value of 5.2 mg/L, Some cases of dental fluorosis and skeletal fluorosis were reported. Fluoride have positive correlation with pH and TA this indicating that alkaline nature of ground water increasing dissolution of fluoride bearing rocks which results higher fluoride content in water. Nature of ground water was assessed by using different physico-chemical parameters it is alkaline (pH), fresh to brackish (TDS), good to doubtful (EC), hard to very hard (TH), fresh to brackish (Chloride) and corrosive in 38.33 % samples (CR). The major type of reactions may be occurring in ground water according to CAI are cation-anion exchange reactions, and 37.5 % samples have good ionic balance (-10% to10%) and have anionic nature (IB). The WQI classification indicated that water is belong from good to poor categories. According to Piper trilinear classification ground water is divided in three groups alkaline earth cation excess with strong acid anion excess type, alkaline earth cation excess with weak acid anion excess type and mixed cation and anion type. The abundance of major cations and anions is in order $Ca^{+2} > Na^{+} > Mg^{+2} > K^{+}$ and $HCO_3^{-} > Cl^{-} > CO_3^{-2} > SO_4^{-2} > NO_3^{-}$.

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