ASSESSMENT OF GROUNDWATER QULITY USING WATER QUALITY INDEX IN AFZALPUR TALUK KARNATAKA, INDIA

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Abstract

The assessment of groundwater quality is essential for human consumption and also helpful for emerging water quality index in the study area of Afzalpur taluk. For this purpose many geo-chemical parameters were studied, Apart from fluoride and nitrate, most of the geochemical parameters are within the permissible limit, due to more usage of chemical fertilizers in the study area and also geogenic and man-made activities. Piper plot represents that, the maximum number of samples belongs to Ca^{2+}*-* Mg^{2+}*-* HCO_3^{-} *group. The main hydro geochemical factor influencing the chemistry of groundwater is rock dominance. As per WQI results showed that 100 % of samples are comes under Good categories. Hence, this study showed that, both use of GIS and WQI is very innovative techniques for evaluating groundwater quality.*

Key words: *Geology. Groundwater. WQI. Gibb's plot.*

1. Introduction

In the monsoon period during precipitation, surface water can percolate through cracks, slits, and splits to the underground, where water comprises an essential concentration of heavy metals and total dissolved solids. This could have resulted in a high temperature and pH based on the type of rock structure, and the impartial geochemical surroundings belong to alkaline water. It might also have a substantial effect on environmental and human health, and contain pollutants that are greater than water quality limits. According to Muralidhara et al., Adimalla et al., (2019), and the USEPA (1993), pollution from man-made and natural activities that introduce pollutants into the groundwater system may also be the cause of groundwater quality issues. Seepage, depth, and the makeup of dissolved rock all affect the quality of groundwater. Negative changes brought forth by industry, agriculture, and urbanization around the world have contaminated freshwater and created health hazards.

(Elango et al., 2012, Qian and Li, 2011, Qian et al., 2012, Li and Qian, 2018, Li et al., 2018a, 2018b, Wu et al., 2014, 2017, Zhang et al., 2018, Elango et al., 2003). India's agriculture is an important commercial area, supporting the majority of the population. (Datta and Tyagi, 1996). With over 20 million tube wells, 45 % of groundwater is used for agriculture and 80 % for residential use. (Kumar et al., 2005; Sunitha and Sudharshan Reddy, 2019, Singh, 1983). Groundwater quality information provides insights into rocks' geological history, levels, movement, and aquifer loading capacity. Water quality indexes (WQI) coordinate community and plan makers' understanding of water quality, enabling effective regulation. (Satyajit et al., 2020; Chimankpam et al., 2019, Prasad et al., 2019; Suvarna et al., 2018). Researchers use parameters to determine drinking water appropriateness, but few focus on groundwater quality and quality indices in the study area. (Adimalla and Venkatayogi 2018). Channamma et al., (2022) reported that weathering of rock-forming minerals strongly reflects the water chemistry in study area of Afzalpur taluk. The research highlights the importance of assessing groundwater quality and quantity for effective water management strategies. It emphasizes the need for a database to establish drinking water quality indicators in the Afzalpur taluk area, using GIS techniques.

2. Study area

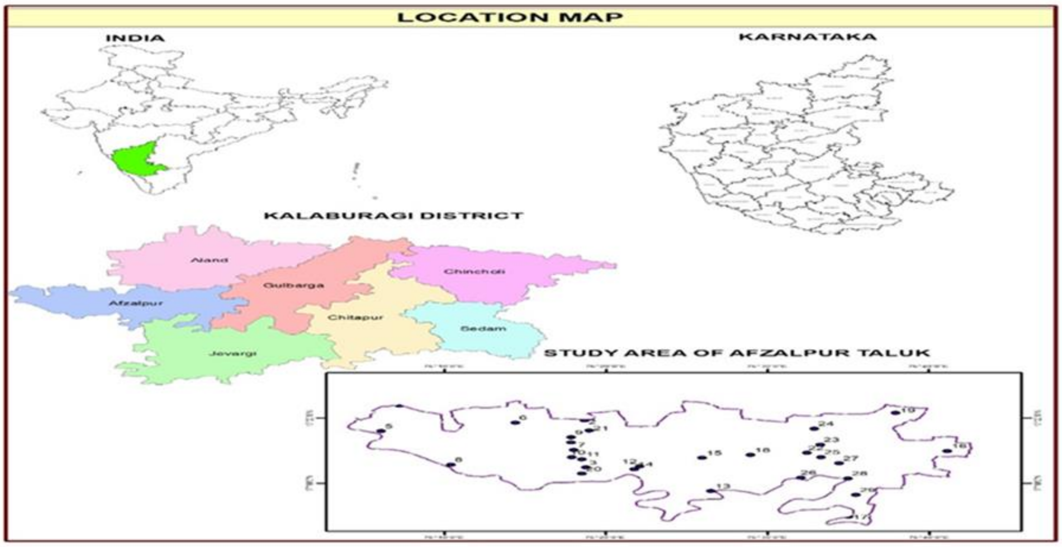


Fig 1: Shows Location map of the study area

Table 1: Shows geo-chemical parameters of groundwater samples

Sl.No.	Temp.(°C)	pH	EC	TDS	TH	Ca^{+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	F^-	SO_4^-	NO_3^-
GW 1	35	6.1	1011	493.5	354.4	134.2	42.3	47.4	2.1	121.3	41.2	0.9	78.3	7.5
GW 2	35	7.2	1023	503.2	402.3	127.6	44.5	52.5	1.1	124.2	43.2	0.4	65.4	73.1
GW 3	34	6.5	928.9	460.4	346.2	142.4	36.2	61.3	1.4	132.1	44.3	0.8	45.6	63.5

GW 4	33.5	6.4	850.4	425.2	402.2	130.8	41.8	48.2	1.9	130.2	37.7	1.2	48.5	50.7
GW 5	34.5	6.1	968.9	476.7	382.3	126.8	54.3	55.4	2.1	137.2	34.1	1	58.5	7.8
GW 6	33.5	6.6	839.3	418.7	342.6	142.7	39.5	58.4	2.4	129.3	30.9	1.2	70.5	48.1
GW 7	33.7	6.2	870.4	435.2	314.5	135.8	48.5	54.6	7.2	143.2	40.8	1.2	64.3	52.6
GW 8	34.5	6.3	948.3	471.4	372.4	123.9	43.2	60.2	2.4	127.7	37.9	1.1	60.2	10.3
GW 9	34.8	6.1	973.2	486.6	329.5	133.2	55.6	48.3	3.1	110.7	36.1	0.9	45.6	12.4
GW 10	33	6.2	790.4	395.2	377.5	141.3	44.3	45.4	1.9	132.5	35.5	0.7	42.3	70.4
GW 11	33.7	6.3	884.3	438.9	363.4	131.8	48.3	61.4	1.3	128.3	42.7	0.8	48.9	6.8
GW 12	35	6.1	1002	521.3	402.5	125.9	36.9	52.9	2.5	117.3	46.2	1.2	67.1	49.9
GW 13	35.2	6.2	1018	479.3	389.4	140.8	37.2	50.3	1.4	121.9	36.8	1.1	70.8	59.4
GW 14	33.5	6.1	845.7	436.5	365.7	138.1	38.2	46.1	1.3	136.3	35.5	1.3	78.4	8.4
GW 15	34	6.2	894.8	447.4	337.8	126.2	31.5	39.8	2.2	128.8	41.5	0.8	38.2	68.8
GW 16	35	6.1	992.4	496.2	369.5	133.7	27.8	45.4	1.5	106.3	44.1	0.6	36.7	7.6
GW 17	35.2	6.2	1020	489.8	379.4	123.1	48.4	47.8	2.3	131.8	38.8	1.2	32.1	56.5
GW 18	35	6.1	1008	487.6	402.4	137.2	39.6	52.8	2.2	123.1	37.9	1.3	40.5	75.9
GW 19	33	6.3	790.9	390.4	406.3	124	44.1	37.8	2.1	132.5	40.2	0.7	42.8	49.3
GW 20	33.6	6.2	885.6	442.8	354.3	139.7	37.8	40.4	1.4	136.2	48.2	0.9	66.4	10.2
GW 21	34.5	6.1	967.8	483.9	411.2	144.1	43.2	62.2	2.1	130.8	33.6	0.5	60.3	11.4
GW 22	34.7	5.9	981.4	490.7	359.3	139.4	48.1	63.2	1.2	125	35.8	1.1	58.9	53.6
GW 23	34	6.2	928.5	464.2	388.5	134.8	44.3	58.1	1.4	109.2	40.9	1.2	45.6	72.5
GW 24	33.6	6.3	870.6	438.3	374.2	127.9	38.9	53.7	1.2	112.8	36.6	1	56.4	59.3

GW 25	33.8	7.1	884.9	440.5	334.1	126.2	28.9	39.9	2.3	125.5	39.9	0.5	60.4	67.8
GW 26	34.4	6.3	938.5	465.7	343.5	134.9	31.4	44.4	1.3	128.1	36.8	0.8	63.2	10.9
GW 27	33	7.2	794.3	395.6	331.5	135.8	46.9	50.4	3.1	133.2	31.6	1.3	73.4	10.6
GW 28	33.8	6.6	887.8	436.7	337.7	120.7	52.1	53.5	1.2	125.5	44.3	1.1	59.4	62.6
GW 29	33.5	6.4	843.4	421.2	338.4	136.7	55.3	47.7	1.8	132.3	37.5	1.0	48.9	12.3

Table 2: Shows geo-chemical parameters and compare with WHO and BIS for drinking water quality.

Parameter	Conc. ions		Standards range	Sample exceeded permissible limit
	Range	Mean	BIS	BIS
Temp. (°C)	---	--	---	---
pH	5.9-7.2	6.3	6.5-8.5	NIL
EC	790.4-1023	918.71	--	NIL
TDS	390.4-521.3	456.32	500-2000	NIL
TH	314.5-411.2	365.97	300-600	NIL
Ca^{2+}	120.7-144.1	133.09	75-200	NIL
Mg^{2+}	27.8-55.6	42.38	30-100	NIL
Na^{+}	37.8-63.2	51.02	---	---
K^{+}	1.1-7.2	2.05	----	---
HCO_3^-	106.3-156.2	128.50	150	2
Cl^-	30.9-48.2	38.99	250-1000	NIL
F^-	0.4-1.3	0.96	1.0-1.5	NIL
SO_4^-	32.1-78.4	56.12	200-400	NIL
NO_3^-	6.8-75.9	39.66	45-100	17

2.1 WQI Results

Table 3: Shows classification of drinking WQI (Muralidhara Reddy *et al.*, 2019)

Class	WQI value	WQI status	% of samples
1	<50	Excellent	Nil
2	51-100	Good	100
3	101-200	Poor	Nil
4	201-300	Very poor	Nil
5	>300	Unsuitable	Nil

WQI is a widely used equation to assess groundwater quality for drinking purposes (Subba Rao, 1997), (Mouna et al., 2012, Pradhan et al., 2001). It is determined using the relative weight method, consisting of three steps: weight assigning, where each criteria is assigned a weight based on its significance, and calculation of relative weight using an equation (Brown et al., 1970).

Wi= $\frac{Wi}{\sum_{i=0}^{n} Wi}$

"Rating of quality (qi)" contains the third step, as determined by the next equation:

Qi = $(\frac{Ci}{Si}) \times 100$

Where, the concentration of each parameter is denoted as Ci in individual water sample, and Si is the specified value of an individual parameter prescribed by WHO. Lastly, the Wi and qi were used to determine the SIi for each parameters and therefore WQI can be determined by the equation as shown below:

SIi = Wi × qi

WQI = $\sum_{i=1}^{n} SIi$

Where, SIi is the sub-index of each parameter.

3. Result and Discussion

Assessment for groundwater quality for drinking purpose

Based on the WHO (2011) standards, groundwater quality was assessed for drinking purposes.

pH: The groundwater samples had an average pH of 6.3 mg/L, with a range of 5.9 mg/L to 7.2 mg/L (Table 2). The majority of groundwater samples in the study area are alkaline. Although it doesn't directly affect human health, changes in pH will have an effect on the wellbeing of different ecological creatures (Umer et al., 2019).

Electrical conductivity (EC): In the groundwater samples the range of EC was found that 790.5 µS/ cm to 1023 µS/ cm with an average value of 918.7 µS/ cm (Table 2). The desirable limit of EC in drinking water is 1500 µS/ cm (WHO, 2011). Usually, variation of EC depends on temperature and concentration of ions present in the groundwater. If the EC concentration high, the consistent TDS concentration also high. At 27 °C.

Total dissolved solids (TDS): The amount of TDS in groundwater samples differs in different type of geographical structures and their mineral solubility (WHO, 1984). In the groundwater samples, the TDS value varies between the minimum value of 390.4 mg/L and the maximum value of 521.3 mg/L, with an average value of 456.3 mg/L (Table 2).

WHO (2011) recommended that the maximum allowable TDS is 500 mg/L and the maximum is 456.3 mg/L, so most samples fall within the allowable limit. According to the recommendations of the United States Geological Survey (2000) (Table 3).

Total hardness (TH): According to the World Health Organization, the maximum permissible limit of TH is 600 mg/L, and the desirable limit is 100 mg/L. The total hardness ranges between 314.5 mg/L to 411.2 mg/L with the mean value of 365.9 mg/L (Table 2). According to Sawyer et al., (2003) if the groundwater samples is comes under <75 category, that is considered as safe, 75-150 is considered as moderate to hard, 150-300 is considered as hard and >300 is considered as very hard category (Table.3) in the study area all sampling sites containing is comes under very hard category due to leaching of calcium and magnesium bicarbonates through during groundwater recharge.

Major cations and anions

Bicarbonate (HCO_3^-): in groundwater ranges from 106.3 mg/L to 156.2 mg/L, with a mean value of 128.5 mg/L. (Table 1). The HCO_3^- concentration in groundwater is comparatively higher, it doesn't harm human health. In the study area maximum number of groundwater samples is fall down within the permissible limit (WHO, 2011).

Chloride: concentration in the study region ranges from 30.9 mg/L to 48.2 mg/L, with a mean value of 38.9 mg/L (Table 1). The acceptable limit for chloride in drinking water is 250 mg/L, and the permissible limit is 1000 mg/L (WHO 2011). In the study area, all groundwater samples were fall under the recommended limit.

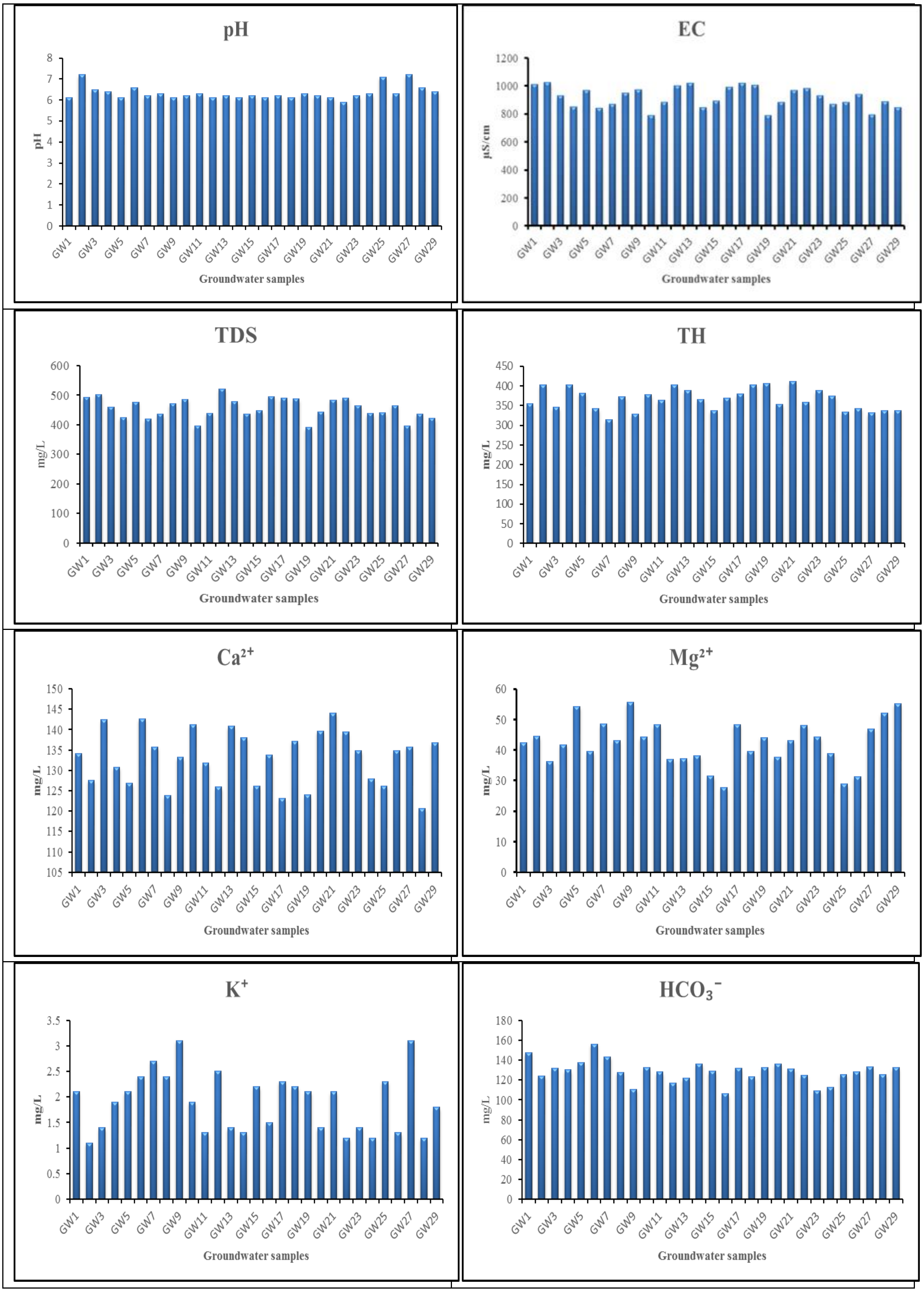
Calcium (Ca^{2+}) and magnesium (Mg^{2+}): The concentration of calcium ranges between 120.7 mg/L to 144.1 mg/L, with a mean value of 133.0 mg/L, and the value of magnesium ranges between 27.8 mg/L to 55.6 mg/L, with a mean value of 42.3 mg/L. (Table 1). According to WHO 1984, the permissible limit of calcium is 200 mg/L.

Sodium (Na^+) and potassium (K^+): ions, are available in rock and soil, and easily dissolved in groundwater: generally, these ions are not dangerous. Nevertheless, if it crosses the permissible limit, it may be harmful to human health, like hypertension, heart illness, or kidney problems. Sodium ranges between 37.8 mg/L and 63.2 mg/L, with a mean value of 51.0 mg/L, and potassium varies between 1.1 mg/L and 7.2 mg/L, with a mean value of 2.0 mg/L (Table 1).

Sulphate: concentration in the study region ranges between 32.1 mg/L to 78.4 mg/L and the mean value of 56.1 mg/L. if the sulphate concentration is high in drinking water it causes cathartic effect on human health and gives unpleasant smell in drinking water. All groundwater samples were comes under the permissible limit of sulphate in the study region.

Nitrate: The amount of nitrate in this study area differs from 6.8 mg/L to 75.9 mg/L with an average of 39.6 mg/L (Table 1). More usage of chemical fertilizers, animal dung and agricultural runoff is main causes to increase nitrate concentration in groundwater in this study area.

Fluoride (F^-): the amount of fluoride in this area differs between 0.4 mg/L to 1.3 mg/L with an average of 0.9 mg/L (Table 1). All groundwater samples comes under within the permissible limit according to WHO and BIS standards.


pH
pH
Groundwater samples
EC
µS/cm
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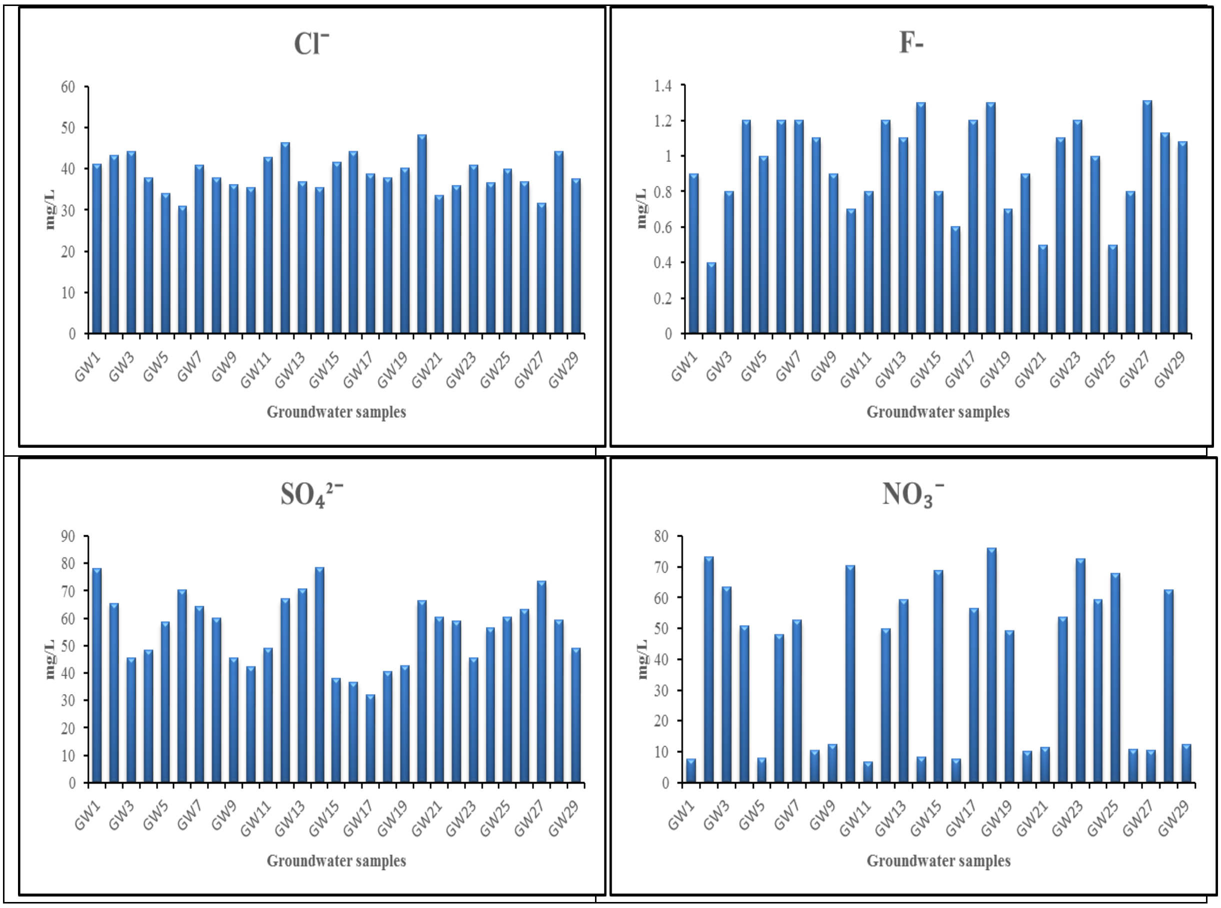

Fig 3: Shows Graphical representation of geo-chemical parameters

Table 4: Groundwater classification based on the TH, TDS

Parameter	Classification	Range	No. of samples	% of samples	Reference
TDS	Fresh water	<1000	18	62	US geological Survey (2000)
	Slightly saline	1000-3000	02	06	
	Moderately saline	3000-10,000	Nil	Nil	
	High saline	10,000-35,000	Nil	Nil	
TH	Safe	<75	Nil	Nil	Sawyer *et.al.*, (2003)
	Moderate	75-150	Nil	Nil	
	Hard	150-300	Nil	Nil	
	Very hard	>300	20	68	

Table 5: Correlation of groundwater quality parameters

	pH	EC	TDS	TH	F-	Cl^-	SO_4^{2-}	NO_3^-	HCO_3^-	Na^+	K^+	Ca^{2+}	Mg^{2+}
pH	1												
EC	-0.00	1											
TDS	-0.03	0.96	1										
TH	0.17	0.19	0.15	1									
F^-	-0.44	0.01	0.03	-0.03	1								
Cl^-	0.07	0.23	0.31	0.02	-0.40	1							
SO_4^{2-}	0.13	0.05	0.10	-0.10	0.27	-0.07	1						
NO_3^-	0.39	-0.03	-0.11	0.26	-0.02	-0.03	-0.30	1					
HCO_3^-	0.14	-0.44	-0.49	-0.31	0.28	-0.32	0.45	0.01	1				
Na^+	0.28	0.22	0.23	-0.12	0.23	-0.16	0.19	-0.04	0.13	1			
K^+	-0.21	-0.12	-0.10	-0.51	0.34	-0.09	0.05	0.10	0.23	0.12	1		
Ca^{2+}	-0.02	-0.24	-0.27	-0.36	0.10	-0.16	0.28	0.08	0.26	0.13	-0.04	1	
Mg^{2+}	0.02	-0.01	-0.06	-0.08	0.08	-0.38	-0.01	-0.18	0.17	0.25	0.34	-0.26	1

3.1 Correlation of the geo - chemical parameters of the groundwater

According to correlation coefficient (Table-5) was adopted for find out the association between arithmetical variables. A strong correlation among magnesium and total hardness used to found the mechanisms of carbonate dissolution in semi-arid area (Subramani et al., 2005)

In this research, it was observed that the variables such as Ca^{2+},CO_3^-, HCO_3^-, F^-, SO_4^{2-} and NO_3^- has been positively correlated with pH and EC, TDS, TH, Mg^{2+}, Na^+, K^+, and Cl^- negatively correlated with pH. TDS, TH, Ca^{2+}, Mg^{2+}, Na^+, CO_3^-, HCO_3^-, Cl^-, and SO_4^{2-} showing positive correlation with EC and K^+ and F^-, NO_3^- negatively correlated with EC. TDS has positively correlated with TH, Ca^{2+}, Mg^{2+}, Na^+, CO_3^{2-}, HCO_3^-, Cl^-, and SO_4^{2-} while negatively correlated with K^+, F^-, and NO_3^-. The variable TH has positively correlated with Ca^{2+}, Mg^{2+}, Na^+, CO_3^-, F^- and NO_3^-. While negatively correlated with K^+, HCO_3^-, Cl^-, and SO_4^{2-}. The Ca^{2+} has positive correlation with Na^+, CO_3^{2-}, and $SO_4^{2-}$and NO_3^-, while negatively correlated with Mg^{2+}, K^+, HCO_3^-, Cl^- and F^-. The variables such as Na^+, K^+, CO_3^-, HCO_3^-, F^-, SO_4^{2-} showing positive correlation with Mg^{2+}whereas negatively correlated with and Cl^- and NO_3. Na^+ positively correlated with K^+, CO_3^{2-}, F^-, SO_4^{2-} and NO_3^- and negatively correlated with HCO_3^- and Cl^-. The variable K^+ is positively correlated with CO_3^{2-}, HCO_3^-, Cl^-, and SO_4^{2-} while negatively correlated with NO_3^-. The CO_3^{2-} has positive correlation among Cl^-, F^- and NO_3^- and negatively correlation with $HCO_3^-$and SO_4^{2-}. HCO_3^- variable is positively correlated to F^- and SO_4^{2-} while negatively correlated with Cl^- and NO_3^-. Cl^- variable is negatively correlated with F^- and SO_4^{2-} and NO_3^-. F^-variable is positively correlated with SO_4^{2-} and negatively correlated with NO_3^-. Lastly, SO_4^{2-} is negatively correlated with NO_3^- (Table-5).

3.2 Mechanism controlling groundwater chemistry

According to Gibbs 1970 classification, by this observation, among twenty-nine sampling sites the more number of sampling sites were fall down in the occurrence of cations and anions dominance from groundwater (Figure 4). It indicates the presence of more cations and anions presence in the water samples shows the rock dominance in the study area. Remaining sampling sites shows less number of cations and anions for groundwater distribution in the form of evaporation and rainfall dominance.

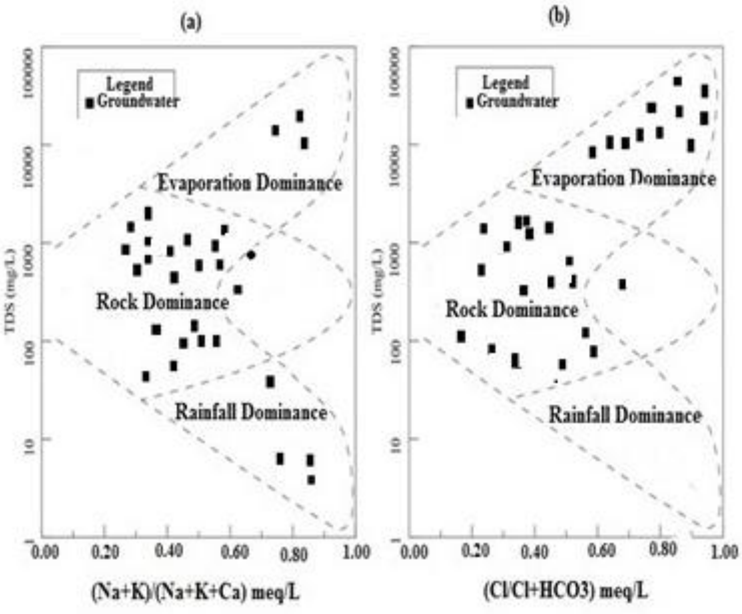

Figure 4: Mechanism controlling chemistry of groundwater for cations (a) and anions (b) by Gibbs (1970)

3.3 Evolution of groundwater chemistry mechanism

Gibbs diagram is plotted in order to evaluate the sources of dissolved chemical components in the area, such as evaporation dominance, rock dominance, and precipitation dominance in this region. In order to know the chemical reaction between the composition of water and controlling mechanism of the natural water chemistry, Gibbs diagram is plotted using graphical plots of anions (Cl^-) / (Cl^- + HCO_3^-) and cations (Na^+ + K^+) / (Na^++ K^+ + Ca^{2+}) against TDS (Fig. 4). It reveals that most of the groundwater samples fall in rock dominance and some samples were partially inclined towards precipitation dominant; it suggested that groundwater chemistry is determined by rock water interactions and influenced by rock weathering and evaporation dominance which is further influenced by anthropogenic activities, leading to increase in chloride, sodium, and TDS in groundwater. According to this study, the rock–water interaction is one of the predominant factors determining groundwater chemistry in this region.

Table 6: Shows relative weight per geo-chemical parametrs

Chemical parameter	Weight (wi)	Relative weight (Wi)	Si	Ci	qi	SIi
pH	3	0.071429	8	6.3	74.1	8.7
EC µS/cm	3	0.071429	1500	918.7	263.6	0.9
TDS mg/L	4	0.095238	600	456.3	78.0	0.2
TH mg/L	4	0.095238	500	365.9	67.7	0.1
Ca^{2+} mg/L	4	0.095238	75	42.3	46.6	31.0
Mg^{2+} mg/L	3	0.071429	50	133.0	16.0	0.1
Na^+ mg/L	3	0.071429	200	51.0	21.4	0.1
K^+ mg/L	3	0.071429	12	2.0	109.5	2.4
HCO_3^-	3	0.071429	400	128.5	33.1	0.1
Cl^- mg/L	2	0.047619	200	38.9	189.0	9.4
F^- mg/L	4	0.095238	1.5	0.9	17.5	1.5
SO_4^{2-} mg/L	4	0.095238	250	56.1	165.3	2.2
NO_3^- mg/L	5	0.119048	10	39.6	147.0	4.9
	42	**1**				**61.3**

3.4 Water quality index (WQI) of the study area

The water quality index is the essential calculated method to evaluate the water quality trend information. It provides data on water quality in a single value. Mostly it is done from suitability for human consumption. WQI calculation is followed by three steps (Horton, 1965; Pradhan et al., 2001). The first step is based on its significant effect, for 12 parameters (such as pH, TDS, TH, Ca^{2+}, Mg^{2+}, K^+, Na^+, Cl^-, SO_4^{2-}, NO_3^-, F^-) each parameter is assigned a weight (wi) about primary health. According to the maximum weight, 5 is allocated to parameters such as nitrate, sulphate and fluoride, and the minimum weight 1 is allocated to total dissolved solids, total hardness. The second and third steps are the calculation of relative weight and grade quality respectively (Table 6). Computed WQI values are represented in (Table 4). WQI values vary from54.5 to 815.4 with a mean of 165 (Table 5). Based on water quality index results this region has been classified as five classes as excellent, good, poor, very poor, unsuitable to drinking purpose.

According to this classification, 42 % of samples are good, 42 % belong to poor, and 4% fall in very poor category. 12 % of samples are unsuitable for drinking purposes in this region (Table 7). As per WQI classification, eastern and southern parts of this region were not suitable for drinking purposes (Fig. 8).

Table 7: WQI at individual sampling sites

Locations	WQI result	Classification
GW1	85.39	Good
GW2	70.62	Good
GW3	53.94	Good
GW4	71.75	Good
GW5	86.09	Good
GW6	78.13	Good
GW7	89.1	Good
GW8	92.04	Good
GW9	83.05	Good
GW10	73.06	Good
GW11	64.33	Good
GW12	69.75	Good
GW13	86.85	Good
GW14	81.91	Good
GW15	86.87	Good
GW16	65.93	Good
GW17	54.69	Good
GW18	87.03	Good
GW19	61.37	Good
GW20	68.08	Good
GW21	66.12	Good
GW22	70.02	Good
GW23	69.23	Good
GW24	73.22	Good
GW25	63.21	Good
GW26	76.26	Good
GW27	68.31	Good
GW28	73.24	Good
GW29	80.21	Good

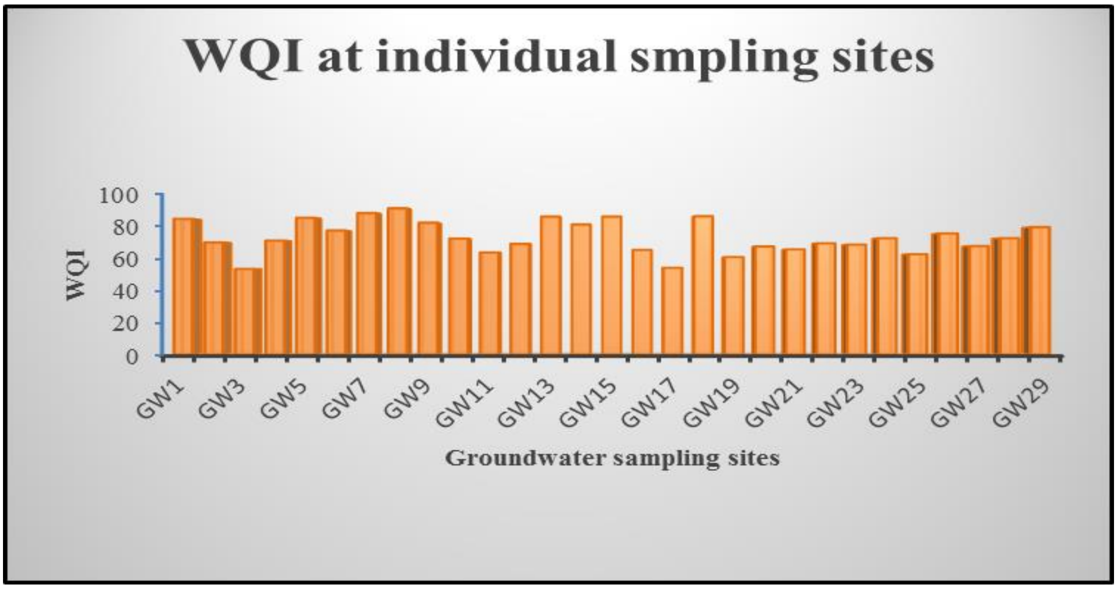

Fig 8: shows WQI in groundwater sampling sites

4. Conclusion

The results of this study reveal that groundwater water is alkaline in nature, all of the geochemical parameters were within the permissible limit except nitrate. 32 % of the groundwater samples are above the allowable limit for nitrate. More use of chemical fertilizer, cow dung, and agricultural runoff and improper waste dumping. Dominant ions in this study area is $K^+ > Mg^{2+} > Ca^{2+} > Na^+$ and $HCO_3^- > Cl^- > NO_3^- > SO_4^{2-} > F^-$ for cations and anions. Entire study area comprises rock dominant proven by Gibb's plot, predominant hydro geochemical factor controlling the water chemistry. As per in this observation, the rock–water interaction is one of the greatest significant elements controlling groundwater chemistry in this study region. As per WQI results, 100 % of samples are potable. The outcomes of this study showed that the broad use WQI is very useful to assessing groundwater quality and with perfect observation of geographical area of groundwater quality can plan well for optimal uses and groundwater resources management.

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