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Hydro-geochemical evaluation of groundwater with studies on water quality index and suitability for drinking in Sagardari, Jashore

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Abstract: Sagardari union is facing groundwater crisis because of contaminations from agriculture and urban sewage, which bring a considerable change in water quality. In view of this, hydro-chemical analyses were undertaken on 35 groundwater samples and the following hydro-geochemical parameters, pH, total dissolved solids (TDS), total hardness (TH), electrical conductivity (EC), cations and anions, were analyzed. From the analytical results, it is found that pH value was lower than WHO drinking water standard and the middle-downstream portions of the investigation region show higher EC. The piper plot indicates that the groundwater in Sagardari falls in the categories of NaClHCO₃ hydro-chemical facies. Higher TH in groundwater was detected, but still in an acceptable range. In addition, salinity and arsenic ratio are higher and moderately higher, respectively. The spatial distribution of Groundwater Quality Index (GWQI) was determined by geo-statistical modelling of Sagardari union. The study provides information and supports the administration which to make better groundwater utilization and quality control in the Sagardari union.

Keywords: Sagardari union; Groundwater; Hydro-geochemistry; Spatial distribution; Water quality index

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Introduction

Global water resources are vulnerable due to the increasing trend of population, pollution potential, and climate change (Ali *et al.* 2012). It is important to human health and economic development because of its utilization in sanitation, energy, irrigation and household purposes (Alexandratos SD *et al.* 2019). The presence of abundant water on the earth's surface is partly owing to the occurrence of plentiful groundwater on its exterior (Bhuiyan *et al.* 2015; ZHANG Yu-

qin *et al.* 2018). Groundwater is one of the most valuable resources because of its superiority which has turned into a foremost concern in all categories of human consumption *i.e.* irrigation as well as other domestic consumptions (Haque, 2018). To meet up the increasing water demand, the use of groundwater is increasing day by day globally. However, various heavy or non-heavy metal with their carbonate, salinity, arsenic, magnesium hazard has been mainly responsible for the contamination of groundwater and the concern has been raised from central to the south-east of Bangladesh (Joarder *et al.* 2008). The scarcity of water during dry as well as the semi-dry period

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has become a serious problem in the southern part of Bangladesh due to the rapid increase of population, industrialization and urbanization with their higher consumption of groundwater in farming (63% from groundwater), drinking (78% from groundwater) and manufacturing activities (Biswas *et al.* 2014; Monir *et al.* 2011; Monir *et al.* 2012). The total percentage of groundwater usage indicated that more than 80% people directly or indirectly depend on groundwater (Mukherjee and Singh, 2018). From the beginning, groundwater was considered as a highly safe resource on the earth but in the present situation, it has become indecorous because the contamination of waste pollution rises in groundwater (Edet and Offiong, 2002).

Mukherjee (2018) studied on the anthropogenic activities of irrigation (>80% from groundwater withdrawal) that lead to groundwater depletion in most of areas within South Asia. The chemical constitutes in groundwater are determined by many anthropogenic as well as natural features (Safeeq and Fares, 2016). The natural features which have influenced the groundwater chemical constitutes include rainfall types and quantity, lithology and geology, topography of watersheds, aquifer properties, atmospheric aspects, and numerous rock-water interface procedures in the groundwater aquifers (Acharya *et al.* 2018b; Al Tanjil *et al.* 2019). In this regard, groundwater quality is correlated with its circumstances, such as the geological past of that area, lithology, hydrogeology, rocks, recharge, movement and storage of groundwater system. Moreover, Islam *et al.* (2018) worked on irrigation water quality index (IWQI) using GIS and multivariate indices in Gopalganj district, south-central Bangladesh. It is reported that various controlling variables in the hydrogeochemical processes can be used to determine the quality of groundwater (Farnham *et al.* 2003; Peterson and Hoef, 2014). The groundwater quality is negatively impacted by anthropogenic behaviors such as urbanization as well as the agricultural activities, which are considered to be the foremost trouble in the southern part of Bangladesh, as reported by LI Yu *et al.* (2007). Furthermore, the multifaceted groundwater quality parameters used in water resource assessments are adopted in an easy mathematical calculation to obtain the

results, which are mainly developed by the water specialists (Singaraja, 2017).

Simply speaking, water quality index (WQI) is to convert hydro-geochemical parameters and quality data into a single number of values. It helps to solve the quantification of water quality by simplifying complex datasets as well as producing an integrated value that represents water quality grade (Rabeiy, 2018; Singh *et al.* 2017). RamyaPriya and Elango (2018) reported that lithological types, recharge water and sources of lithological activities are responsible for the undisturbed groundwater quality. The human activities such as farming, mining, and manufacturing also influence the chemistry of groundwater significantly by increasing the contents of solid waste and domestic waste in groundwater. Recently, Islam *et al.* (2019) studied on the evolution of the groundwater quality of the south-western part of Bengal Basin, Bangladesh in order to evaluate the geochemical evolution and processes which are controlling the hydro geochemical behavior of the groundwater system. They found that the concentrations of trace metals (Fe^{2+} and Mn^{2+}) are higher in the shallow aquifer than in the deeper groundwater. However, the quality of groundwater in Sagardari, Jashore is mostly dependent on natural or normal geochemical process.

Ahmed *et al.* (2019) studied on the IWQI of groundwater samples for the purpose of irrigation and it was suggested that the groundwater in the northwest and southern area was excellent. In this study, the Piper diagram, Gibbs diagram, SSP and SAR have been used to identify the factors which influence the groundwater chemistry and water quality in the union of the Sagardari area. These processes provide an extensive view of groundwater quality conditions for the purpose of drinking. Therefore, the aim of this study is to indicate the restricted and accepted zones of groundwater in Sagardari union Jashore by the calculation of WQI.

1 Study area

1.1 Location

The main exploration area is approximately 147.75 km from the Bay of Bengal. The area

relates to the river Kopotaksho which is about 2 km. It is also directly connected with another river Sibsha in Khulna which is 110 km (appr.) to the river Kopotaksho. Groundwater samples were collected from the rural areas of Sagardari near Kopotaksho River in Keshabpur, Jashore,

Bangladesh. Fig. 1 represents the sampling sites in the study area. The reliance of whole region on groundwater is the main motive on the selection of the investigation area. This groundwater in this area could be developed for domestic, farming and profitable purposes.

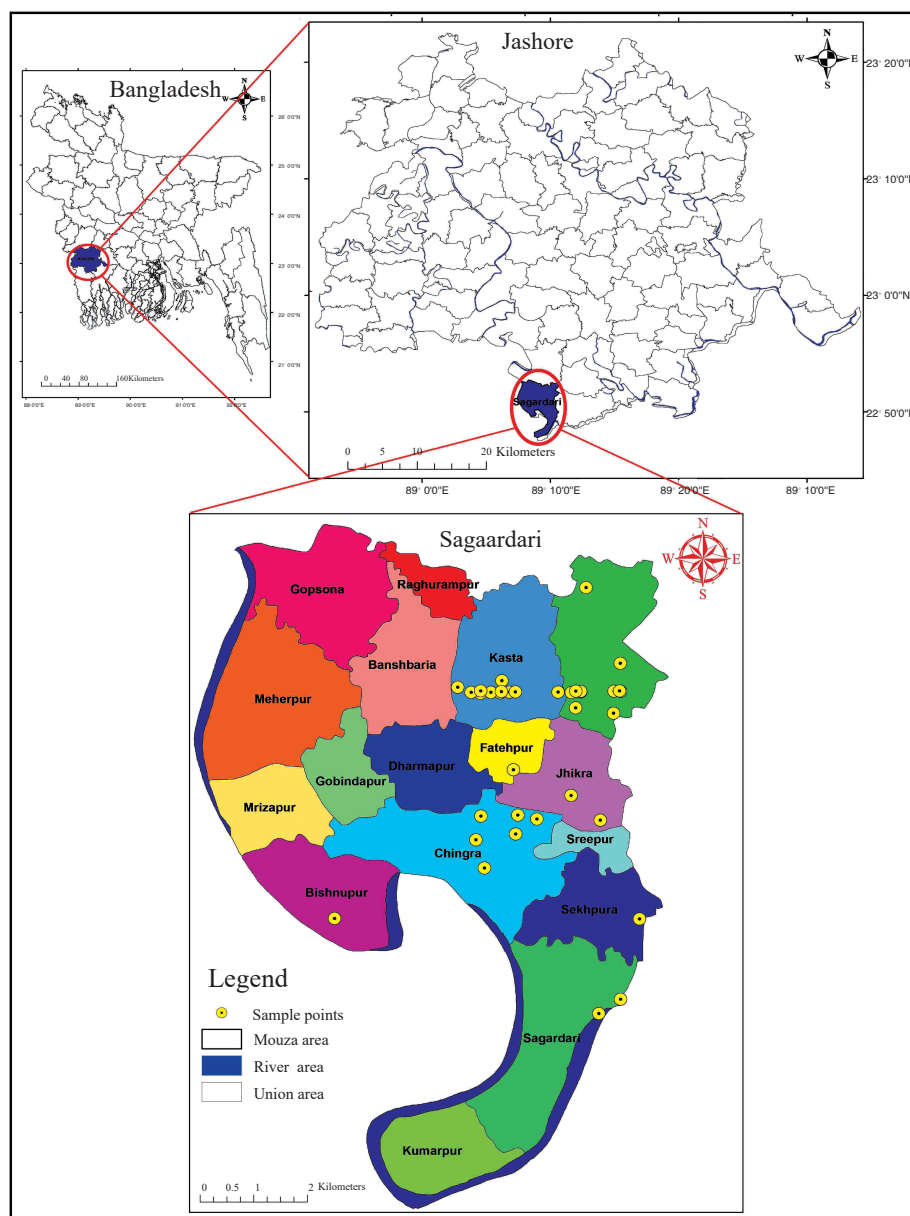


Fig. 1 Regional map of the investigation area with groundwater sampling points

1.2 Circumstance of climate

The southeast part of Bangladesh is covered by land and water bearing zone. The area has typical equatorial climate condition which is characterized by humid and high-temperature. The climate has two particular periods: June to October and November to May and can be furtherly

divided into four individual seasons: (1) Winter: December, January and February; (2) Pre-summer monsoon: March, April and May; (3) South-west Monsoon: June to September; (4) Autumn: October and November. The water originates from the intermediate or deep basin flow that flows from north to the southern part of Bangladesh. As the northern part is Upper Delta plain and southern

part is Lower Delta plain, groundwater largely follows the ground topography.

The yearly maximum temperature is around 39.0°C and yearly minimum temperature is 9°C. April to October is the period of high rainfall of this region which can reach up to 1 642 mm. It is mainly influenced by south west monsoon of the Indian Ocean. The typical humidity fluctuates monthly between a minimum of 68.6% to a maximum of 90% in a year. The main wet period (extended precipitation) is from April to October occurring from southwest with earlier summer thunderstorms to the northwest. November to March is the arid season in the west with anticyclones during winter. The most caustic rainstorm of cyclonic winds can be over 52 km/h which happens during the pre-monsoon stage in April to May and another one during the post-monsoon stage in November. November to February is considered as winter and typical precipitation is approximately 1.8% of the overall precipitation around the whole country.

2 Materials and methods

2.1 Sample collection

In this study, 35 deep well groundwater samples were taken from test bore holes (-243 m depth) in three various periods: Winter, monsoon and rainy season (Fig. 1). Each water sample was

collected by acidic-washed plastic bottle (500 mL and 100 mL). The sample bottles were fully filled with water so that there is no space or air bubble indented in the water sample (Sutadian *et al.* 2018). To prevent evaporation, bottles were preserved by using two plastic caps. The samples were carefully handled and precaution was taken during transportation from investigation area to the laboratory. Finally, water samples were analyzed by ion standard method, so that the actual value of the samples would not decrease continuously (Haritash *et al.* 2008).

2.2 Laboratory method

The groundwater samples were evaluated to determine their quality to meet the increasing demand on drinking water within the locality. High standard of protection was applied in this investigation to protect the samples, so that the organic contents of samples would not reduce with any chemical process. Also, the temperature and pH were measured on site by thermometric and electrometric equipment. They were evaluated in the laboratory to identify the absorption of different mechanisms samples. All parameters were considered including the main ion's absorption (Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^- , Fe^{2+} , As^{3+}), temperature, pH, electrical conductivity, hardness, salinity, manganese. The investigated water samples and their analyses are shown in Table 1.

Table 1 Hydro-geochemical analyses techniques for each parameter

Groundwater properties	Progression
Temperature	Technique of thermometric.
Foremost ions with trace constituent	Inductively attached with plasma-atomic of discharging spectrometry systematic process.
Chlorine	Ion selective electrode process.
Ions	Selective techniques of electrode.
pH	Technique of thermometric.
Conductivity	Technique of electrical conductivity.
Total dissolved solids	Filtration during 0.48 μm filmable filter, remains the filtrate desiccated on temperature 104 ~106°C.

2.3 Data analysis method

In this study, Grapher software (Version 15) was used for data analysis and WQI distribution graphs was illustrated using ArcGIS (Version 10.5) software.

2.3.1 Draw Piper diagram

The tri-linear piper diagram is mainly applied on categorical distribution of groundwater facies

which depend on the dominant ions (Piper, 1944). In Piper diagram, major ions of groundwater are divided into anions and cations, which are plotted in two 'triangles' showing major anions and major cations. Another part in the diagram is the 'diamond' part where the concentration of anions and cations are plotted together (Madhav *et al.* 2018). This tri-linear diagram was used to classify the groundwater facies which depend on the dominant anions and cations. Exploration of this trilinear diagram indicated the configuration of earth's groundwater chemical properties (Hubbard and Sheridan, 1994).

2.3.2 Gibbs plot

Marandi and Shand (2018) proposed two different diagrams to recognize the impact of hydro-geochemical processes such as atmospheric rainfall, water-rock interaction and evaporation on the geochemical properties of groundwater. The Gibbs plot indicates the proportion of cations $(Na^+ + K^+) / (Na^+ + K^+ + Ca^{2+} + Mg^{2+})$ and proportion of anions $(Cl^-) / (Cl^- + HCO_3^-)$. These two proportions are plotted against TDS. Mostly, Gibbs plot indicates that all the geochemical samples of the study area from the lithological dominance (Iqbal *et al.* 2009). The ratio of Gibbs cation and anion proportion's plots were pinched out of TDS v/s Cation and TDS v/s Anion proportion. The ratio of Gibbs are as following:

$$\text{Gibbs 1} = \left[\frac{(Na^+ + K^+)}{(Na^+ + K^+ + Ca^{2+} + Mg^{2+})} \right] \quad (1)$$

$$\text{Gibbs 1} = \left[\frac{(Cl^-)}{(Cl^- + HCO_3^-)} \right] \quad (2)$$

2.3.3 Magnesium hazard

Acharya *et al.* (2018a) established an index for measuring the magnesium hazard (magnesium ratio (MR)). Several auteurs recommended that the hazard value of magnesium in groundwater for drinking and agriculture purposes reported by Subramani *et al.* (2010). Magnesium hazard value is the ratio of the Mg^{2+} and the sum of Mg^{2+} , Ca^{2+} and mathematically it is defined by the following formula (Equation 3):

$$\text{Magnesium ratio} = \left[\frac{(Mg^{2+} \times 100)}{(Mg^{2+} + Ca^{2+})} \right] \quad (3)$$

2.3.4 Sodium adsorption ratio (SAR)

The sodium adsorption ratio indicates the hazard by the correlation of Ca and Mg concentration. The higher concentration of SAR leads to the worsening of groundwater and soil quality (DeSutter *et al.* 2015). The determination of SAR is recommended by Richards (1954) and expressed by the following formula (Equation 4) (All values in mg/L):

$$\text{SAR} = \left[\frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \right] \quad (4)$$

2.3.5 Soluble sodium percentage (SSP)

Soluble sodium percentage is about the content of sodium that is significant for the analysis of sodium percentage in the groundwater. Generally, the growth of plants is hindered by higher SSP in groundwater, and the soil permeability is reduced by its reaction (DeSutter *et al.* 2015). SSP was evaluated by applying the subsequent equation (Equation 5) (All values in mg/L) (Kadyampakeni *et al.* 2017).

$$\text{Gibbs 1} = \left[\left[\frac{(Na^+ + K^+)}{(Na^+ + K^+ + Ca^{2+} + Mg^{2+})} \right] \times 100 \right] \quad (5)$$

2.3.6 Water quality index (WQI)

The WQI is calculated from different water parameters to evaluate the water quality in the area and potential for drinking purposes (Chourasia, 2018; Kawo and Karuppannan, 2018; Rao and Nageswararao, 2013; Sharma *et al.* 2014). The following equation is used to measure the relative weight of the groundwater parameters (Equation 6):

$$W_i = \left[\frac{w_i}{\sum_i^n w_i} \right] \quad (6)$$

Here, the relative weight of the parameter is represented by W_i , weight of each parameter is represented by w_i and 'n' represents the number of the parameters. The calculation of the relative weight W_i value is shown in Table 2. Both parameters have a quality rating scale qi that was calculated by the following Equation (7):

$$qi = \left[\frac{(ci \times 100)}{si} \right] \quad (7)$$

Where: q_i is the quality rating, and C_i represents the concentration (mg/L) of each groundwater chemical parameter on each sample. Again, S_i represents the WHO drinking water standard for each of the parameter. The WQI and sub-index are calculated according to the correlation of Equation

3 and 4 individually

$$SI_i = (W_i \times q_i) \quad (8)$$

$$WQI = \sum SI_i \quad (9)$$

Where: (SI_i) is the sub-index of the i -th groundwater chemical parameters and q_i is the concentration of the rating based of i -th parameter.

Table 2 Parameters of groundwater chemistry with their weight (w_i) and relative weight (W_i) considering the range of standard values from World Health Organization

Parameters (mg/L)	Weight (W_i) (mg/L)	Relative weight (W_i)	WHO Permissible Limit (1997, 2002) (mg/L)
TDS	4	0.08	1 000
pH	3	0.06	8.5
Chloride	4	0.08	600
Alkalinity	3	0.06	400
Iron	4	0.08	0.3
Arsenic	4	0.08	0.01
Manganese	5	0.10	0.05
Hardness	4	0.08	500
Calcium	4	0.08	200
Magnesium	2	0.04	150
Sodium	3	0.06	200
Bicarbonate	3	0.06	600
Potassium	4	0.08	12

3 Results and discussion

3.1 Hydro-geochemical facies

3.1.1 Piper diagram

Bicarbonate, chloride, Na^+ , As^{3+} were considered the dominant ions (Fig. 2) and the major groundwater type in the study area was the $CaClHCO_3$ type. The triangle of cation is represented by plotting the comparative proportions of Mg and Ca on the axes of Y and X, individually (Fig. 2). To make it more clear, the parameter Ca has also been plotted on the reversed axis. In the same way, the relative percentages of parameters SO_4 and Cl are plotted on the axis of Y and X in the triangle of anions (Fig. 2). From the analytical Piper diagram (Fig. 2), the main dominant anions are Cl^- and HCO_3^- and most leading cations are Na^+ and Ca^{2+} . Though the Piper diagram shows several groundwater types in the investigation area, the

dominant groups are $Ca-Cl$, $Ca-HCO_3$, $Na-Mg-Cl$, $Ca-Mg-HCO_3$ and $Ca-Na-HCO_3$. The sample's identification of $Na-Ca-Cl$ has indicated the salinity of the groundwater. Exchange of cation is considered one of the most significant geochemical processes that mainly occur in aquifers (Kumar, 2013; Singh and Kumar, 2015) which significantly influence the salinization of groundwater. These are the main features of groundwater chemistry in this investigation area. $Ca-HCO_3$ indicates the main ion and is last associates of freshwater composition in the investigation area. $Na-Ca-Cl$ form indicated the major ion of the salinity composition. The concentration of dolomite and calcite ($Ca-Mg-HCO_3$ and $Ca-HCO_3$) are the main composition of fresh or excellent groundwater quality types. $Ca-Na-HCO_3$ and $Ca-Cl$ indicate the last associates of the salinity zone and the major ions which are identified as the unsuitable water quality area. These results are consistent with the value reported by Rajesh *et al.* (2012).

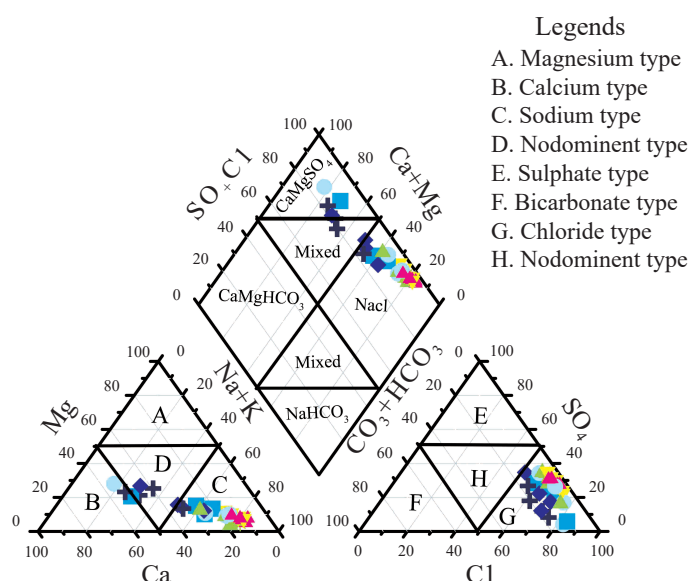


Fig. 2 Piper trilinear diagram presenting the comparative cations and anions properties of groundwater samples

3.1.2 Gibbs plot

In these two diagrams (Fig. 3), the correlation of EC (mg/L) with Gibbs 1 and 2 plots (Table 3) (cation and anion ratio) is divided by the proportions of $(Na+K)/(Na+K+Ca+Mg)$ and $Cl/(Cl+HCO_3)$ as a correlation of TDS. The vital sources of correlation of TDS with Gibbs 1 and 2 diagrams is distributed into three sections which are shown in Fig. 3, namely evaporation and crystallization dominance, rock dominance or weathering dominance and precipitation dominance. Similar results can be found in the literature (Vasanthavigar *et al.* 2012).

From Fig. 3, the correlation between TDS and Gibbs 1 $(Na+K)/(Na+K+Ca+Mg)$ has indicated that the majority (60%) of samples fall in precipitation dominance which is considered to be the main groundwater influencing factor in the investigation area. This result is also supported by Marandi and Shand (2018). The TDS of the total samples in this area fall in the range of 400 mg/L to 1 400 mg/L whereas Gibbs 1 ratio falls in the range of 0.25 to 0.8. The second factor is rock dominance where 22% of groundwater samples fall in, and TDS falls in the range of 1 400 mg/L to 2 600 mg/L and Gibbs 1 falls in 0.6 to 0.8. The evaporation-crystallization dominance zone has 18% of the groundwater samples, and TDS range is 2 600~3 600 mg/L and Gibbs 1 range is 0.7 to 0.8.

Moreover, from Fig. 3, the correlation of TDS with Gibbs 2 $[Cl/(Cl+HCO_3)]$ is also distributed in three zones namely evaporation and crystallization dominance, rock dominance or weathering dominance and precipitation dominance, supported by Balan *et al.* (2012). The leading zone of the groundwater samples is precipitation dominance where 58% of samples fall in. The range of TDS is 400 mg/L to 1 400 mg/L and Gibbs 2 range is 0.54 to 0.94. The second is the rock dominance zone where TDS range is 1 400 mg/L to 2 600 mg/L and Gibbs 2 range is 0.58 to 0.78. 25% of the samples fall in this zone. Therefore, the lowest zone is the evaporation and crystallization zone where 17% samples fall in and TDS range is 2 600~3 600 mg/L and Gibbs 2 range is 0.62 to 0.66.

3.2 Magnesium hazard

Ca^{2+} and Mg^{2+} can retain in any state of groundwater's chemical properties in equilibrium condition. When higher concentration of Mg^{2+} is found in groundwater chemistry, the soil and groundwater quality is harmfully affected (Organization, 2009). When the ratio of Mg^{2+} is over 50, it appears to be unsuitable for drinking purposes and has unfavorable effects on groundwater. The values in the investigation area are generally higher than the acceptable limit suggested by WHO standard (Fig. 4).

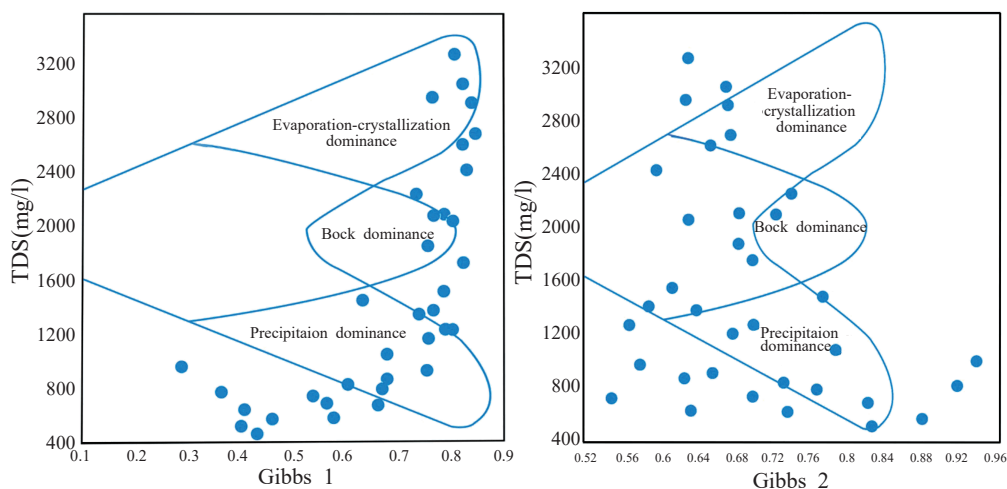


Fig. 3 Diagram of Gibbs where the ratio of cation and anion proportion of specific water samples with the correlation of TDS (mg/L) in Sagardari (Gibbs, 1970)

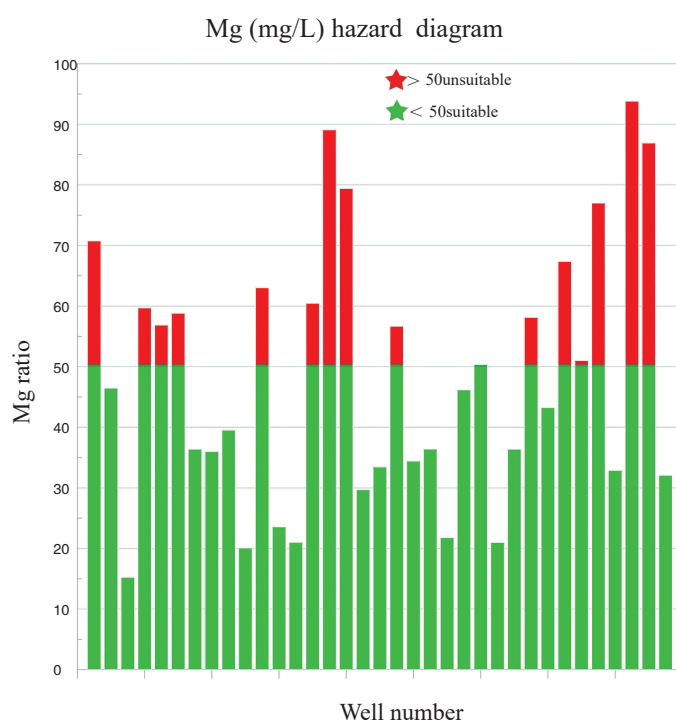


Fig. 4 Magnesium hazard ratio with the suitable and unsuitable limit in the investigation area

In this investigation, the magnesium hazard ratio was calculated using Equation 3. Fig. 4 indicated various magnesium ratios from 15.21 to 93.80. The average is 48.13 and the standard deviation is 21.27. From the total 35 groundwater samples, 42.85% fall in the red zone (unsuitable) and 57.14% of samples in the green zone (suitable), as shown in Fig. 4. The presence of magnesium normally increases the alkalinity of the soil and groundwater (Bousser *et al.* 2011; XU Pan-pan *et al.* 2019) and the alkalinity of this area is

moderately higher than the WHO limit (Table 3). The result of Mg ratio is supported by Shammi *et al.* (2016), who recommended the molar ratio of Ca: Mg should be lower than 1. If the molar ratio of Ca: Mg is higher than 1, it will affect the soil structure and increase the salinity.

3.3 Correlation diagram of salinity and salinity hazard by SSP and SAR

It is indicated by several authors (Sarker *et al.*

2000; Singh *et al.* (2009) that the correlation of sodium ratio (SSP and SAR) and EC is a sequence of the hazard of salinity. The ratio of SSP and SAR values are plotted against the EC in this investigation which is consistent with the study by ZHANG *et al.* (2013).

The SSP ranges from 3.51 to 85.41. According to the recommendation by Todd classification (Shahidullah *et al.* 2000), 14.66% (5 samples) of groundwater samples fall in excellent to good zone (Fig. 5), 11.44% (4 samples) in good to permissible zone, 20% (7 samples) in the permissible to doubtful zone, 17.44% (6 samples) in the doubtful to unsuitable zone and the last 37.54% (13 samples) in the unsuitable zone. This higher amount of SSP is the main reason which reduces the permeability of the soil and the soil is generally dry and hard (Annapoorna and Janardhana, 2015). The correlation between high groundwater alkalinity and high salinity, and the correlation

between high salinity and high amount of chloride and sodium are also supported by ZHANG *et al.* (2013).

According to Richards's classification (Richards, 1954), SAR values have been classified in the investigation area (Fig. 5). The SAR values are found in the range from 28.90 to 84.34. Moreover, 20.65% (7 samples) of groundwater samples fall in the 1st class where the SAR value is lower than 10 and classified as low sodium water or excellent class of groundwater. 15.44% (2 samples) of groundwater samples are found in the range from 10 to 18 which indicates in the medium sodium or good water class. 23% (8 samples) groundwater samples fall in the range from 18 to 26, which indicates the 3rd class or high sodium class or permissible class. Last class (4th) is the unsuitable class or high salinity class with values in the range of >26 .

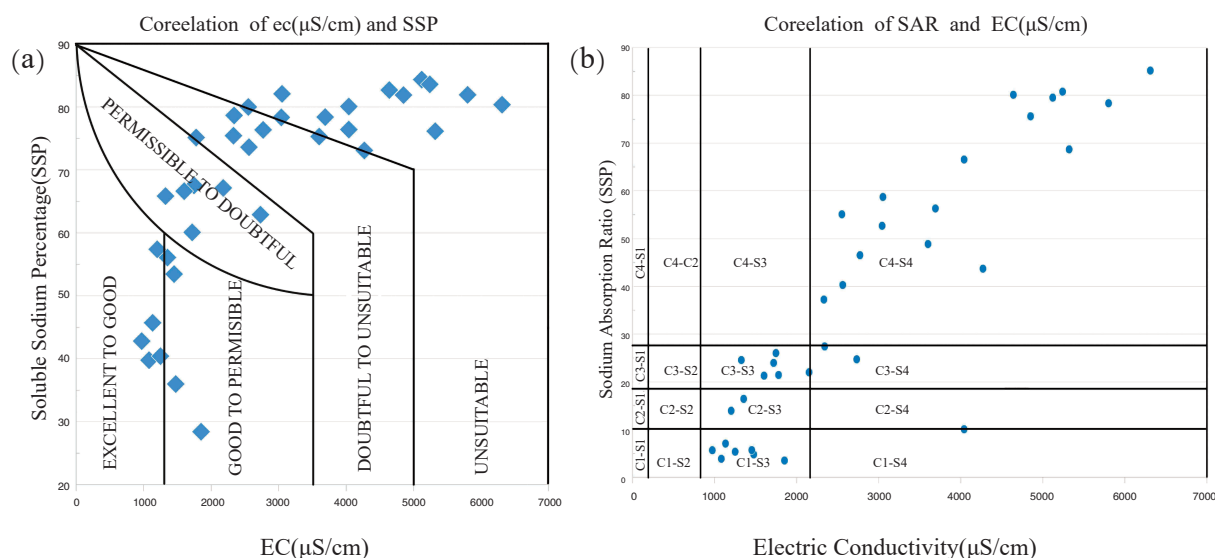


Fig. 5 (a) Correlation of EC and SSP; (b) the correlation of SAR and EC

According to the data plot on U.S. Salinity laboratory arrangement diagram (Richards, 1954), correlation of SAR as the hazard of alkalinity and EC as the hazard of salinity is shown in Fig. 5, where 25.76 % (9 samples) lie in the category of no salinity and permissible alkalinity zone (C1-S3) and these groundwater samples are suitable for drinking purposes. Moreover, 6.54% (2 samples) lie in the category of low salinity or low alkalinity (C2-S3) with permissible EC, which can also be consumed by drinking. 20.23% (7 samples) are found in the category of C3-S3 which indicates

permissible salinity and sodium and permissible EC zone. Lastly, 48% samples (17 samples) are found in the unsuitable zone in C4-S4, which indicates the category of high salinity and high EC.

3.4 Water quality index calculation

A maximum of five ranges have been allocated to each water quality parameters with the corresponding ranges of groundwater risk for drinking purpose (Table 4). These ranges are proposed by WHO. The foremost concern

of groundwater chemistry is that the presence of high concentration of specific parameters can significantly affect the groundwater for drinking purpose.

In this study, 13 groundwater chemical parameters were applied to estimate the WQI for drinking purposes in the study area. The relative weight and the actual weight which are used for measuring the actual concentration of the parameters are used as the main calculation factors of the groundwater quality assessment (Table 2). The parameters and weights used in the estimation of WQI in this study can be different from others

depending on the objectives and conditions of each investigation.

The result shows that 40% of the area is of excellent groundwater quality, 51.42% is of good groundwater quality and 8.57% is of poor groundwater quality (Table 5, Fig. 6). The physico-chemical distribution of groundwater chemical parameters have been measured and prepared for the calculation of WQI. It should also be mentioned that the selection and weighting of these groundwater parameters have been determined according to the relative significance of each parameter for drinking purposes.

Table 3 Descriptive statistics of hydro-geochemical parameters in groundwater and their comparison with World Health Organization (1997, 2002) standard for drinking water purposes

Parameter	Min	Max	Variance	Standard division	Average	Drinking limit (1997, 2002) (mg/L)
TDS (mg/L)	475	3 300	719 471.62	836.01	1 514.28	1 000
Con. of pH	7.74	8.24	0.01	0.12	8.00	8.5
Chloride (mg/L)	157.81	1 890.6	269 961.42	512.10	815.12	600
Alkalinity (mg/L)	340.09	599.9	5 973.39	76.10	454.14	400
Iron (mg/L)	0	0.44	0.44	0.124	0.137	0.3
Arsenic (mg/L)	0.002	0.089	0.0005	0.022	0.018	0.01
Manganese (mg/L)	0	0.111	0.001	0.033	0.041	0.05
Conductivity (uS/cm)	970	6310	2 405 173.67	1 528.54	2 867.6	500
Hardness (mg/L)	200	760	16 753.65	127.52	358	500
Calcium (mg/L)	49	149.66	555.92	23.23	75.42	200
Magnesium (mg/L)	15.21	93.80	315.11	17.49	41.16	150
Sodium (mg/L)	23.09	904.89	59 869.93	241.16	322.76	200
Bicarbonate (mg/L)	28.16	1 103.96	89 110.41	294.21	393.80	600
Potassium (mg/L)	10	25.98	20.09	4.41	18.86	12

Table 4 Ratings of groundwater irrigation quality on the basis of hydro-geochemical parameters such as EC, SAR, SSP, MH, WQI by Richards (Sadashivaiah *et al.* 2008), Wilcox (Balachandar *et al.* 2010)

Parameters	Range	Water class
EC	<250	Excellent
	250~750	Good
	750~2 250	Permissible
	>2 250	Doubtful
SAR	0~10	Excellent
	10~18	Good
	18~26	Doubtful
	>26	Unsuitable
MH	<50	Suitable
	>50	Harmful & Unsuitable

Table 4 (Continued)

Parameters	Range	Water class
SSP	<20	Excellent
	20~40	Good
	40~60	Permissible
	60~80	Doubtful
	>80	Unsuitable
IWQI	85~100	Excellent
	70~85	Good
	50~70	Permissible
	40~55	Doubtful
	0~40	Severe

Table 5 Classification of groundwater based on WQI in the investigation area

Samples ID	WQI	Water type
S-1	54.40	Good water
S-2	61.21	Good water
S-3	47.12	Excellent water
S-4	51.84	Good water
S-5	72.97	Good water
S-6	67.37	Good water
S-7	86.84	Good water
S-8	41.21	Excellent water
S-9	52.10	Good water
S-10	36.01	Excellent water
S-11	44.99	Excellent water
S-12	34.22	Excellent water
S-13	29.92	Excellent water
S-14	94.13	Good water
S-15	82.58	Good water
S-16	69.75	Good water
S-17	38.93	Excellent water
S-18	37.96	Excellent water
S-19	46.31	Excellent water
S-20	50.15	Good water
S-21	50.41	Good water
S-22	35.35	Excellent water
S-23	59.45	Good water
S-24	73.83	Good water
S-25	32.14	Excellent water
S-26	62.83	Good water
S-27	104.97	Poor Water
S-28	55.89	Good water
S-29	87.83	Good water
S-30	89.47	Good water
S-31	49.32	Excellent water
S-32	38.54	Excellent water
S-33	101.13	Poor Water
S-34	107.70	Poor Water
S-35	36.98	Excellent water

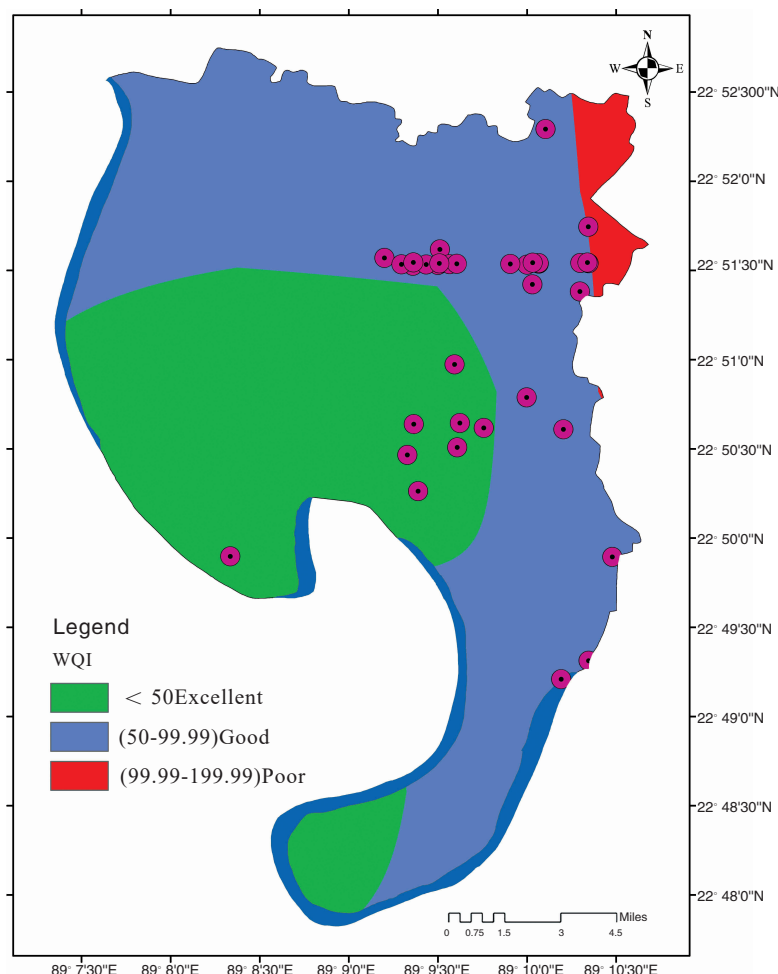


Fig. 6 Spatial distribution of Water quality index calculated from groundwater chemical parameters

4 Conclusions

(1) The hydro-geochemical parameters and water quality index methods are applied to identify the zoning of groundwater quality for drinking purposes. It is verified that the hydro-chemical properties of groundwater in the investigation area is dominated by both natural features and anthropogenic activities. The Piper trilinear diagram showed that 90% groundwater samples fall in the CaClHCO_3 category and others fall in the Ca-Cl , Ca-HCO_3 , Na-Mg-Cl , Ca-Mg-HCO_3 and Ca-Na-HCO_3 categories.

(2) Hydro-geochemistry reveals that the order of cation profusion in Sagardari is $\text{Na} > \text{Ca} > \text{Mg} > \text{K}$. It is also found that pH values in the groundwater samples are lower than the permissible limit (< 8.5) suggested by WHO (1997). From the spatial distribution, it is found that 40% of the total samples are of excellent quality groundwater, for

51.42% is of good groundwater quality and 8.57% is of poor quality, which reflects the allowable limit set by WHO (1997).

(3) Groundwater by the river side of the region presents the maximum salinity. It can be decided that 90% of the samples are safe for drinking purposes and around 10% samples are non-safe for drinking and household purposes. Numerous indices and proportions have been calculated and applied in this study to estimate the suitability of groundwater for drinking purposes. The results from the investigation area will be useful to identify the poor groundwater quality areas for effective groundwater management.

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