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Groundwater quality assessment of north of Iran (Golestan Province) using multivariate factor analysis and GIS techniques

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ABSTRACT

Groundwater is one of the most important sources of drinking water. Since the quality of water directly influences consumers' health, it is essential to assess the quality of water and related factors. This descriptive-analytical study was performed on physical and chemical variables of water samples collected in the dry and wet seasons during 2006–2020 period. Changes in groundwater quality were investigated by factor analysis (FA) model and geographic information system (GIS) software. Based on factor analysis model, EC, TDS, TH and Mg^{+2} levels were the most important factors affecting the quality of water. Due to the high level of hardness (dry seasons; 389.4 mg/l and wet seasons; 418.4 mg/l) and sodium in water (dry seasons; 138 mg/l and wet seasons; 158 mg/l), necessary measures should be taken before drinking and agriculture uses. Changes in the water quality were more related to natural factors and human activities. The invasion of saline water into the groundwater aquifers in the study area should be considered.

Key words: factor analysis, GIS, groundwater quality, north of Iran

HIGHLIGHTS

- The high water hardness.
- Increasing the concentration of elements during these years in two region.
- The ranks of abundance of the ions are as follows: anions including $HCO_3^- > SO_4^{2-} > Cl^-$ and cations including $Ca^{2+} > Mg^{2+} > Na^+ > K^+$.
- The higher risk of water invasion in Aghghala region in comparison with Gorgan region.
- Consistency of application of these two methods to analyze water quality data.

1. BACKGROUND

Groundwater is considered as the main portion of the water supply in arid and semi-arid regions. Proper assessment of groundwater for different purposes requires a thorough understanding of its chemical composition (Khodapanah *et al.* 2009). In recent decades, the increase in usage of groundwater resources for human and agricultural purposes has led to a significant drop in the groundwater level in most countries, so that the regional decline of groundwater resources has become a global issue. Soil structure and surface water quality in a region can determine the quality and composition of groundwater (Jahanshahi *et al.* 2014). Groundwater quality depends on the quality of recharged water, atmospheric precipitation, inland surface water and subsurface geochemical processes. Temporal changes in the origin and constitution of the recharged water, hydrologic and human factors may cause periodic changes in groundwater quality (Amiri *et al.* 2014). Once groundwater is polluted, it is hard to stop the pollution and human health is closely related with the groundwater quality.

The level of water resources in Iran is relatively unfavourable since the country is located in an arid and semiarid region. Amount of rainfall in Golestan province (north of Iran) is more than the average annual precipitation in the country. The potential of groundwater aquifers in the province is estimated at about 1,250 million cubic meters per year that about 4% belong to the drinking water sector, 3% for industrial sector and residual sector is about 93% which related to agricultural sector. There are almost 25,009 wells in this province, of which about 35% of the total wells in the province include deep wells with a depth of more than 50 meters and 65% of the wells in the province are semi-deep wells with a depth of less than 50 meters. Due to the aforementioned facts, the increase in withdrawal of groundwater for domestic and agricultural purposes has caused a significant drop in level of groundwater in this region. This phenomenon caused that the concentration of cations and anions in groundwater is increased that could have harmful effects if not controlled. In some studies, different models were used for assessment of groundwater quality (Rahmati *et al.* 2015; El-Rawy *et al.* 2019). At present, there have been lots of methods for water quality evaluation such as fuzzy mathematics method, membership degree method, factor analysis (FA) method (Amiri *et al.* 2014). Among various methods, FA and geographic information system (GIS) are effective tools for providing a framework of groundwater quality changes. FA attempts to explain the correlations between the observations in terms of the underlying factors, which are not directly observable (Boyacioglu 2006). In addition GIS is an excellent and useful tool to handle a huge amount of spatial data and can be used in the decision making process in a number of fields such as hydrology and environmental management.

In this research, water quality assessment was conducted at deep wells and semideep wells in during dry and wet seasons and the selected parameters for assessment were : electrical conductivity (EC), total dissolved solids (TDS), sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), total hardness (TH), sulfate (SO_4^{2-}), chloride (Cl^-), potassium(K^+), hydrogen carbonate (HCO_3^-), and pH. Therefore, the main aim of this study is examine the capability of GIS and FA techniques for groundwater quality assessment in the Gorgan and Aghghalah plain of Golestan Province in Iran.

2. MATERIALS AND METHOD

2.1. Description of the study area

The Gorgan and Aghghala plain is located in the east of Golestan province of Iran with a total land area of about 3,379 km^2 (15% of the total area of Golestan province) (Figure 1). Gorgan County is located in zone 36 °50′19″N and 54 °26′05″E and Aghghala County is located in zone 37° 01′ 0.12″ N and 54° 27′ 0.00″ E. The average of annual temperature is 17.7 °C (63.9 °F) and the amount of annual rainfall is 601 millimetres (23.7 inch). The climate of the study area varies from arid to semiarid (Mollalo *et al.* 2015). General direction of groundwater flow is from south to north, following the overall basin slope. The study area contains a dense population practicing a wide variety of agricultural, industrial, and tourist activities as various attractions including forest parks, monuments, historic sites, and natural waterfalls are accessible. However, soil loss and sedimentation phenomena have been accelerated because of intensified agricultural and industrial activities as well as the destruction of forests (Ahmadi Mirghaed *et al.* 2018). The maximum depth of the water table in the study area is 50–200 m (east of the area) and its minimum is about 1 m in Aghghala County. In this area, there are sources of pollution that degrade the quality of surface waters including transport of eroded land and leachates from mining activities and solid waste disposal sites. In addition to, one of the highlight properties of Aghghalah area is the high level of groundwater and EC (Zafarzadeh *et al.* 2015). The geographical map and the sampling stations of the study area have shown in Figure 1.

2.2. Method of investigation

In this descriptive-analytical study, groundwater quality data of 58 regional monitoring deep and semideep wells were obtained and analyzed seasonally (dry and wet seasons) during 2006–2020. In the first step, qualitative properties of groundwater of different wells were collected and the results were combined finally. In order to reduce the amount of data and determine the most effective variables by principal component analysis, 11 parameters including pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), bicarbonate (HCO_3^-), calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^+), potassium (K^+), sulfate (SO_4^{2-}), chloride (Cl^-) are used to evaluate the groundwater quality for drinking. In this study, only prominent water-quality parameters were considered based on their importance in affecting groundwater quality as reported in the earlier studies conducted in some parts of Gorgan and Aqhghala district (Honardoust *et al.* 2011; Khaledian *et al.* 2018).

Samples were collected in 1-L polyethylene containers, and the location of sampling was recorded by a GPS device. The plastic containers used for the collection of the water samples were rinsed with the samples to be collected according to the Barcelona method (Barcelona 1985). Some water quality indices such as pH and EC were determined at the sampling site with a digital portable device. Other parameters were measured in laboratory by using a HACH spectrophotometer (Model DR/2400, USA) and titrimetric method using digital titrator (HACH) (Model 16900) (APHA 2005). The data related to the stations examined were recorded, and geographic coordinates were given codes. The geologic map of the study area scanned and imported into ArcGIS version 9.2.

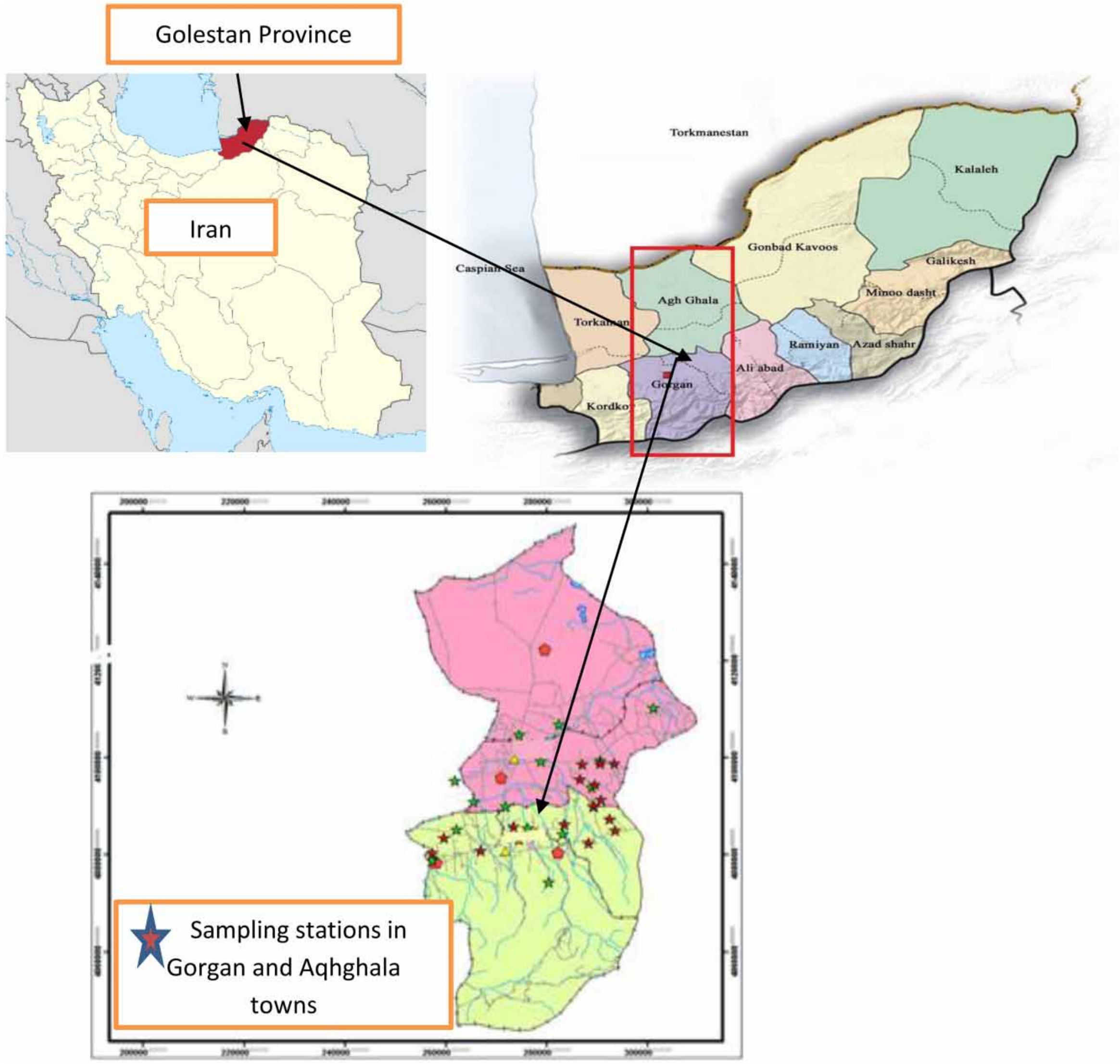

Figure 1 | Map of the study area and sampling stations in Gorgan and Aqhghala towns, Golestan Province, Iran.

After determining the water quality, the values obtained were compared with the water quality standards including Institute of Standards and Industrial Research of Iran (ISIRI) and World Health Organization (WHO) guideline (ISIRI 2009; WHO 2011) (Table 1). In addition, to identify the main factors affecting the groundwater quality FA was used. This statistical method provides the important uncorrelated factors to account for as much of the variability in the data as possible. The factors actually reflect the mechanisms affecting groundwater composition. The correlation coefficients of each variable with each factor are referred by factor loadings. A number of variables that are most closely correlated are the main factor. In fact, summarizes the information of a matrix of data with a few variables. For this purpose, the method identifies a number of new factors. These factors represent the main variables that have lost little information. This method maximizes the sum of the variance of the loadings in the factor matrix (El-Rawy *et al.* 2019).

In addition to, GIS interpolation technique is widely used to produce groundwater quality map and groundwater potential zone demarcation in sampling stations. GIS, a tool that is used for storing, analyzing and displaying spatial data is also used for investigating ground water quality information.

3. RESULTS AND DISCUSSION

3.1. Chemical properties of groundwater in the study area

Results of descriptive analysis of the qualitative data of water samples in terms of the variables tested are shown in Table 2. According to Table 2, the mean of EC and TDS is more than the maximum permissible limit for drinking

Table 1 | The standard values of different elements of drinking water quality and their maximum permissible limits according to ISIRI and WHO

Variable	Maximum permissible limit (ISIRI)	Allowable limit (WHO)	Unit
pH	6.5–9	6.5–8.5	–
EC	–	750	μScm^{-1}
TDS	1,500	1,000	mg L^{-1}
TH	500	600	mg L^{-1}
HCO_3^-	–	100	mg L^{-1}
SO_4^{2-}	400	200	mg L^{-1}
NO_3^-	50	10	mg L^{-1}
Cl^-	400	200	mg L^{-1}
Na^+	200	200	mg L^{-1}
K^+	–	10	mg L^{-1}
Ca^{2+}	300	75	mg L^{-1}
Mg^{2+}	30	30	mg L^{-1}

Table 2 | Statistics summary of hydrochemical parameters in study area from 2006 to 2020

	2006–2007				2011–2012				2019–2020			
Parameter	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
pH	6.9	7.9	7.38	0.22	6.57	8.5	7.2	0.39	6.82	7.99	7.4	0.34
EC (μS/cm)	644	11,385	2,050	2,775	539	10,610	1,897.4	2,558.3	528	9,980	1,680.7	2,024
TDS (mg/l)	419	7,711	1,259	1,703	338	6,466	1,175	1,554.5	335	6,088	1,053	1,249
Ca^{2+} (mg/l)	44	120	87	6.3	36	130	98	5.33	38	119	85	3.6
Mg^{2+} (mg/l)	19.4	516.3	**96**	11.3	19.4	486	**87.5**	9.44	24.3	410.6	**74.1**	6.5
Na^+ (mg/l)	10	131.6	49.5	12.8	10.1	136	62.5	15.55	14.9	182	78	13.5
K^+ (mg/l)	3.1	7.2	5.2	2.4	2.7	10.5	7.4	0.2	3.3	11.7	8.4	0.2
HCO_3^- (mg/l)	152.5	610	238.2	1.51	140.3	573.4	378.2	1.31	183	732	372.1	1.5
SO_4^{2-} (mg/l)	21.6	226	72	8.2	7.2	184	89	7.6	36.9	217	95	11
Cl^- (mg/l)	17.7	112	84	7.38	10.5	122	91	6.44	14	135	101	5.3

water based on Iranian drinking water standard and WHO. The EC value is the most important variable for assessing salinity hazards and irrigation purposes. The EC values were obtained between 528 and 11,385 μS/cm with an average of 2,049.9, 1,897.4 and 1,680.7 μS/cm in 2007, 2012 and 2020 years, respectively. The higher EC values in groundwater wells are related to dissolution of limestone and salts leaching from soil and the high evaporation. These factors could be affected on the quality of groundwater especially in the hot and dry climate such as Aghghala area. According to WHO (2011) guidelines, the permissible limit of EC is 750 μS/cm. The mean values of EC were more than the required drinking water standards based on WHO guidelines (WHO 2011). TDS is a measure of the inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and small amounts of organic matter that are dissolved in water. TDS in drinking-water originate from natural sources, sewage, urban runoff, and industrial wastewater. The amount of TDS varied from a minimum value of 335 to a maximum value of 7,711 mg/l. The mean value of this parameter was 1,259.2, 1,174.9, and 1,052.7 mg/l during the study years, respectively. The mean values of TDS were more than the required drinking water standards based on WHO guidelines (WHO 2011) and less than the required drinking water standards based on Iranian drinking water standard according to Table 2 (ISIRI 2009). The presence of high levels of TDS may be objectionable to consumers, owing to excessive scaling in water pipes, heaters, boilers and household appliances. The surface water is most affected by the contaminants that could be responsible for the elevated concentrations of EC and TDS over the groundwater values (Atikul Islam *et al.* 2017). The aerial distribution of the major cations and anions based on wet and dry seasons is shown in Table 3. During wet and dry seasons, the pH was 7.3 and this value was in agreement with WHO guideline and Iranian drinking water standard (ISIRI).

Table 3 | Chemical composition of groundwater samples during wet and dry seasons

	Wet Seasons		Dry Seasons			
Parameter	**Mean**	**SD**	**Mean**	**SD**	**WHO guideline**	**ISIRI***
pH (standard unit)	7.3	0.3	7.3	0.3	6.5–8.5	6.5–9
EC (μS/cm)	1,882	2,468.9	1,728.8	2,194	750	–
TDS (mg/l)	1,166	1,512.6	1,068	1,327.9	500	1,500
Ca^{2+} (mg/l)	116	5.1	108	4.6	75	300
Mg^{2+}(mg/l)	85	9.1	67	8.5	30	30
Na^{+}(mg/l)	158	14.1	138	12.3	200	200
K^{+}(mg/l)	4.9	0.2	3.9	0.2	30	–
HCO_3^- (mg/l)	378.2	1.5	378	1.4	200	–
SO_4^{2-} (mg/l)	73	12.8	93	15.8	200	400
Cl^- (mg/l)	59.5	6.4	53	6.1	250	400
Hardness(mg/l_{CaCO3})	418.4	143.4	389.4	156.8	500	500

However, the average pH revealed that the water is overall in the neutral range in both periods. The value average of EC was 1,882–1,728 (μS/cm) during wet and dry seasons, respectively. According to WHO (2011) guidelines and ISIRI, the permissible limit of EC is 750 (μS/cm). All samples exceeded the standard EC value during wet and dry seasons. On the other hand, the EC values in the wet season were higher than in the dry season. This result was showed that the dissolution of mineral materials by atmospheric precipitation frequently increases EC in the study area as there was a dry and hot area in the north section of the study area. The TDS values follow from the above algorithm. According to Table 3, TDS value in the wet season was higher than in the dry season. In case of TDS, the optimum level is 500 mg/l and the maximum permissible limit is 1,500 mg/l. The obtained TDS value showed that the TDS values were out of the WHO guideline and ISIRI. In addition, it can be said that the water quality in the study area is in the category of brackish water (TDS > 1,000 mg/l) (Selvam *et al.* 2014). Chloride ions (Cl^-) in the water of the region have increased slightly during these 15 years, and due to its low amount, it can still not be said that there is a risk of salinity in the study area. The presence of chloride ions is effective in increasing the hardness and Qureshi *et al.* (2021) studies confirm this phenomenon (Qureshi *et al.* 2021). Our results showed that the hardness is high and the presence of chloride ions can be one of the causes of this phenomenon.

According with Table 2, the values of cationic ions including Ca^{2+}, Mg^{2+}, Na^+, and K^+ were in standard limit and only the values of Mg^{2+} ions were more than the standard limit, which related to type of soil and limestone in region. About anionic ions, the higher values of HCO_3^- and SO_4^{2-} in comparison with other elements have indicated that the soil type in this area, in addition to limestone, is also carbonate and sulfate, and this phenomenon can effect on the strength of pH, and water hardness. The high hardness of water in this area confirms these results that have shown in Table 3. According with Table 3, the total hardness values were 418.4 $\pm$143.4 and 389.4 $\pm$ 156.8 mg/l_{CaCO3} in wet and dry seasons, respectively. These values of water hardness showed that the water hardness is in agreement with WHO guidelines and Iran water quality standard (ISIRI 2009; WHO 2011). As Table 3 shows, water quality has not changed much in both wet and dry seasons in this region. The results of Memon *et al.* (2021) showed that no apparent changes were visualised in the quality of water during the onset of pre- and post-monsoon seasons over the year (Memon *et al.* 2021).

But there is a risk of increasing the concentration of elements during these years according to Table 2. Table 2 shows that anions and cations have an increasing trend and this increase is due to improper utilization of groundwater resources in the region and inadequate wastewater disposal (no Mg^{2+}).

3.2. Spatial distribution maps for groundwater quality parameters

The aerial distribution of the major cations and anions is shown in Figure 2. The results is shown that the EC values in the north (Aqhghala region) were higher than the other areas. Furthermore, the EC values has increased from 2006 to 2020. This may be related to dissolution of mineral matters and the motivation of surface runoff from upstream to downstream because in this area, there is a steep slope from the south to the

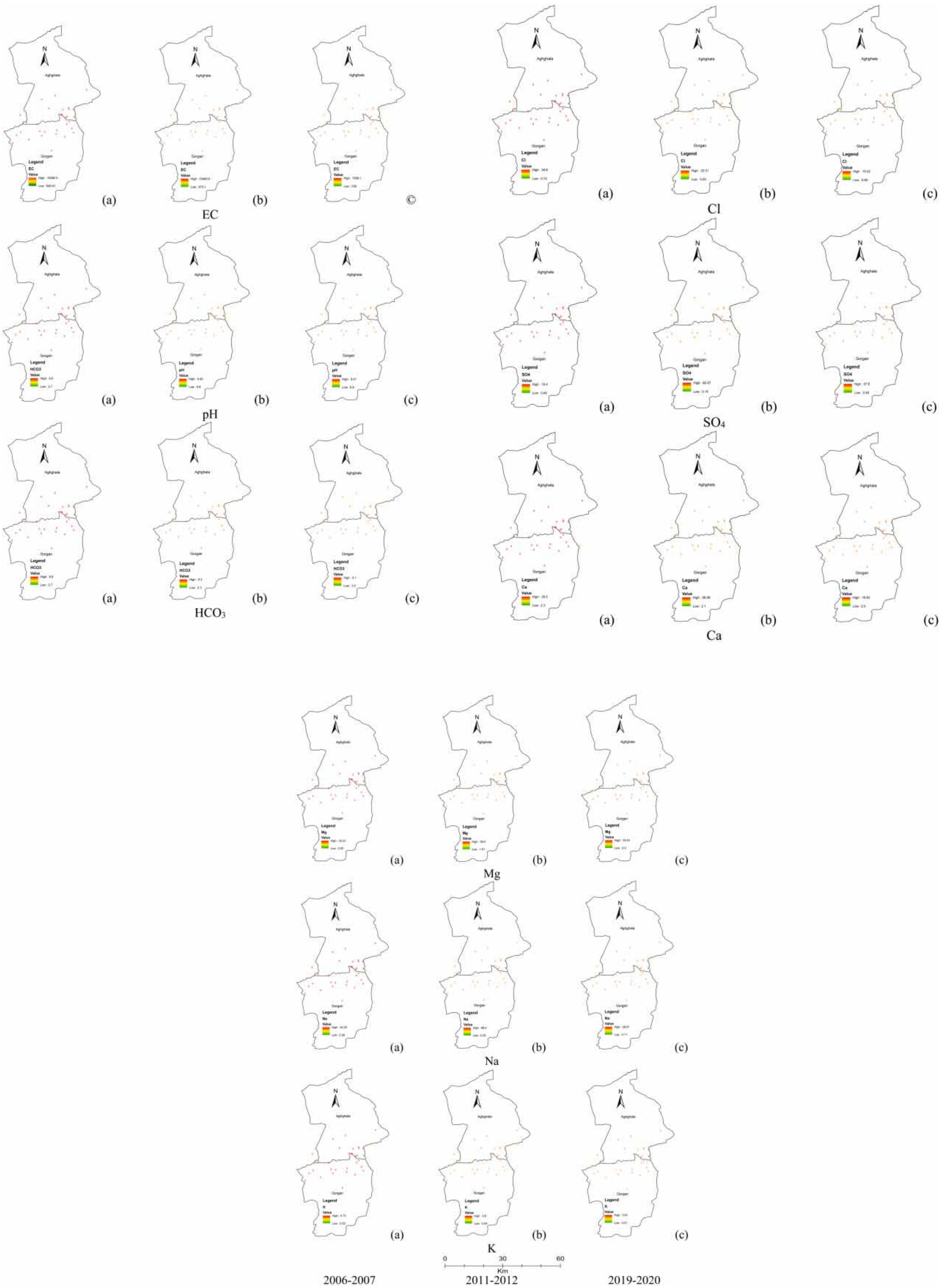

Figure 2 | Comparison of water quality parameters in different time intervals during 2006–2020 in Gorgan and Aqhghala cities in Golestan province.

north and the much surface runoff reaches in north part of study area in rainy seasons. In the case of pH, there is a similar pattern to EC. Figure 2 shows that on the north side of the area the water quality is slightly alkaline. Due to the high groundwater level in this area, it can be said that the quality of groundwater is strongly dependent on surface phenomena such as the entry of sewage and surface runoff. Generally, the shallow aquifer more than deep aquifer are affected by surface runoff and anthropogenic activities might also have influenced in this regard. The obtained results have shown two different pattern about the major anions such as HCO_3^{2-} ion and Cl^- ion (Figure2). Among the anions, HCO_3^{2-} ion in Gorgan area was more than Aqhghala area. The high amount of bicarbonate is related to the soil type of the region. The hydrochemical quality of water in this area is mainly calcium and magnesium bicarbonate and calcium and magnesium chloride. Their cations are calcium and magnesium and their anions are chloride and bicarbonate, which is dominated by bicarbonate.

This increase has spread throughout the total region. In contrast, in the case of Cl^- and SO_4^{2-}, this increase is seen in the northern part because of direct connection with invasion of saline water. In recent years, drought and excessive groundwater abstraction have caused saline water to flow from upstream saline areas to this area. Reduction of agricultural products and deterioration of water quality are the most important complications of this phenomenon. But the results on cation values such as Ca^{+2}, Mg^{+2}, Na^+ and K^+ have shown similar patterns. The concentration of all cations increase in the east of the northern part of the study area due to the movement of surface and groundwater from the upstream to this area and the dissolution of limestone. Also, the use of chemical fertilizers can be effective in increasing Mg^{+2} and SO_4^{2-} ions. As well, only in case of K^+, the increase of concentration not only in the northern part but also in the central part of the study area have seen. The total concentration of strong acids (Cl^- and SO_4^{2-}) exceeds that of the weak acids (HCO_3^{2-}). The Na^+ and Cl^- ions in north part driven from intensive evaporation due to high temperature and leaching of salts soil. Overall, the spatial distribution of the study area showed that the north of study area (Aghghala area) is affected by high saline water from saline soils upstream and Caspian Sea.

3.3. Correlation analysis

To find out interrelations among various parameters, spearman's correlation was done. The positive significant correlations were found between EC and TDS ($r = 0.99$). In other hand, the results showed that strong significant correlation were been between TDS and EC with the parameters specially Mg^{2+}, SO_4^{2-}, Cl^- with p value o.o1 and $r > 0.8$. In fact, the above results showed that the groundwater in these area have the salinity nature Due to the influx of saline water into the groundwater of the study region. In addition, between EC and TDS with the other parameters have a positive correlation with $p_{\text{value}} < 0.01$ and a significant negative correlation with pH ($r = -0.75$). In fact, due to the minimum pH less than 7 in water samples (Table 2) in different years, the dissolution of the elements from the soil and rocks of the area and the increase of EC and TDS have been caused.

3.4. FA

To determine the effective components on the groundwater quality, FA was used. FA is a multivariate statistical method to rearrange original variables into fewer underlying factors to retain as much information contained in the original variables as possible (Amiri *et al.* 2014; Ahmadi Mirghaed *et al.* 2018). FA shows a correlation among dependent and independent variables. According to Table 4, FA generated three significant factors that are involved in water quality changes.

Based on the obtained results for the dry seasons, the first factor (F1) accounted for 35% of the total variance of the data includes EC, TDS, Na^+, K^+, HCO_3^{2-}, Cl^- with loading values of 0.76, 0.76, 0.81, 0.83, 0.82, and 0.81, respectively. The variables K^+, HCO_3^{2-}, Cl^- have a high positive loading of F1 that due to dissolution of halite deposits leads to increase in salinity in groundwater and total amount of water-soluble salts in the sampling wells and followed EC and TDS. The high level of TDS and EC are influenced by the presence of ions in water. So, in the dry season, as the rainfall decreases, the concentration of ions in the water increases. According to Table 3, the presence of Ca^{2+} and Mg^{2+} shows the geological impact and dominance of carbonate formations on groundwater quality. As mentioned, the high values of HCO_3^{2-} rather than the other variables and the positive correlation with Ca^{2+} and Mg^{2+} ($p < 0.01$) confirmed our results. Al Rawy *et al.* showed that low Na^+/Cl^- ratio reflect continuation of exchange reaction and the high ratio reflect reduction in clay capacity for exchange reactions. The Na^+/Cl^- ratio is an indicator for the efficiency of the base exchange reaction (El-Rawy *et al.* 2019).

Factor 2 accounts for about 29% of the total variance and includes Mg^{2+} and SO_4^{2-} with loading value 0.83 and 0.9 respectively in dry seasons. This factor can be assumed as weathering of carbonate and evaporate minerals.

Table 4 | The load matrix obtained by the varimax method for the mean of qualitative parameters of water samples collected in the dry and rainy seasons

Variable	Factor loadings (varimax normalized), extraction method PCA					
	Dry season			Rainy season		
	PC 1	PC 2	PC 3	PC 1	PC 2	PC 3
pH	0.16	0.02	**−0.71**	0.38	−0.62	−0.08
EC	**0.76**	0.62	0.02	**0.92**	0.03	0.18
TDS	**0.76**	0.62	0.00	**0.96**	0.02	0.14
TH	0.06	0.69	0.67	0.04	**0.9**	0.36
Na^{+}	**0.81**	0.29	−0.45	**0.91**	−0.36	0.01
K^{+}	**0.83**	0.00	0.03	0.13	−0.11	−0.03
Ca^{2+}	0.09	0.35	**0.84**	−0.14	**0.77**	−0.16
Mg^{2+}	0.00	**0.83**	0.18	0.21	0.37	0.68
HCO_3^{-}	**0.82**	−0.19	0.12	0.54	0.25	−0.67
Cl^{-}	**0.81**	0.4	−0.25	**0.93**	−0.18	0.08
SO_4^{2-}	0.19	**0.9**	0.09	0.39	0.13	**0.8**
Explained variance	3.94	3.20	2.02	4.2	2.21	1.79
Proportional of total (%)	35	29	18	38	20	16

Bold values indicate high correlation between variables.

Due to the high values of these two ions in comparison with the other ions, it can be expected that the groundwater of the study area is affected by saline water especially in the north of the area. In wet seasons, factor 2 accounts for about 20% of the total variance and includes TH and Ca^{2+} with loading value 0.9 and 0.77 respectively. Hardness has always been considered as an important index for water quality. The level of water hardness is mostly higher in the wet season in compare to the dry season. Water hardness is of great importance since it can cause corrosion in water distribution systems, boilers and industrial pipes, leading to blockage and rupture (Golpayegani *et al.* 2012). Our results agreement with the obtained results of factor analysis and in fact, the water hardness is one of the most important problems for consumers in this area.

Factor 3 consists of two variables including pH and Ca^{2+} with loading value of −0.71 and 0.84 accounts for 18% in dry seasons respectively and SO_4^{2-} accounts for 16% of total variance with loading value of 0.8 in wet seasons. Sulfate is a strong base that could to form with most bivalent cations. Concentration of SO_4^{2-} in wet seasons is higher than dry seasons and maybe it is related to the climatic change. Generally, SO_4^{2-} ions are investigated in the study of abnormal contaminations. Therefore, the impact of human factors on this factor should be taken into account. An agricultural activity such as application of chemical fertilizer and animal manure raises the level of potassium and sulfate. The increased level of sulfate can also be attributed to the disposal of domestic sewage. In dry seasons, it is observed that the association of pH and Ca^{2+} reflects the influence of Ca^{2+} in the area. As well, a negative correlation between pH and bivalent cations was found according with Table 4 the optimum pH value should be between 7 and 8.5, while its maximum allowed level is set as 6.5 and 9 based on WHO standard and Iranian standard (ISIRI 2009). The results of our study showed that pH did not exceed the standard value in the samples taken during the two seasons and these results confirmed by statistically analysis.

Comparison of our results with results of previous studies show that the main factors involved in the water quality changes are related to natural sources, and parameters such as TDS, EC, TH, and pH, undergo drastic changes (Amiri *et al.* 2014; Jahanshahi *et al.* 2014; Selvam *et al.* 2014; Mollalo *et al.* 2015; Ahmadi Mirghaed *et al.* 2018; Khaledian *et al.* 2018).

Generally, the real applications of FA and GIS for determining water quality are suitable for managers of water and sewage companies and the other decision makers. They can study such findings to identify water quality problems in the region and take action to solve the problem. Also, data analysis of parameter values can identify the causes of the risks of undesirable water consumption.

4. CONCLUSIONS

The following conclusions have been drawn from the results of the present study:

- The results of geochemical assessment of the study area were performed using different techniques.
- The results showed that seasons would have serious effects on water quality.
- The ranks of the abundance of the ions are as follows: anions including $HCO_3^- > SO_4^{2-} > Cl^-$ and cations including $Ca^{2+} > Mg^{2+} > Na^+ > K^+$.
- The high salinity of the plain and may be due to the invasion of saline water into the groundwater aquifers in the north of the study area (Aghghalah zone) and leaching and dissolution of mineral elements of rocks and soils.
- Generally, the water hardness is high and the level of water hardness is mostly higher in the wet season in compare to the dry season.
- pH values were higher in the dry season compared to the wet season and pH values was lower than standard limit.
- The EC and TDS values for all samples over the study period were higher than the standard values set by the WHO and Iranian standard.
- The results of multivariate FA and GIS techniques indicated that these techniques can help in better interpretation of the results and are complementary.
- Comparison of our results with results of previous studies show that the main factors involved in the water quality changes are related to natural sources, and parameters such as TDS, EC, TH, and pH undergo drastic changes.
- Such findings could help solve the region's water quality problems

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST STATEMENT

The authors declare there is no conflict.

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