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Evaluation of groundwater suitability for the domestic and irrigation purposes in Konaro Ophiolitic Area, Iranshahr, SE Iran

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Abstract

Hydrogeochemical characteristics of groundwater and its suitability for domestic and irrigation, purposes were evaluated in Konaro ophiolitic area. Heavy metals pollution is accounted for a major pollution in the natural environment are that can pose a serious threat to ecosystems because of their biodegradation potential, toxicity and sustainability (Moslempour and Shahdadi 2013) 8 representative groundwater samples were collected from wells and qanat and analyzed for major cations and anions. The order of dominance of cation and anions were Na> HCO_3> SO_4 > Mg> Cl> Ca> K, respectively. The rock weathering and dissolution of minerals processes, especially ophiolitic rocks minerals are dominant in controlling the groundwater quality in the study area. Electrical conductivity (EC) and total dissolved solid (TDS) show high positive correlation with total Hardness (TH), K, Na, and SO_4^-. As per the WHO standards for domestic water purposes, majority of samples show that the groundwater is suitable for drinking. The spatial distribution maps of physicochemical parameters were prepared in ArcGIS. The suitability of groundwater for agriculture purpose was evaluated from EC, TDS, sodium adsorption ratio (SAR) and Na% which ranges from excellent to not suitable, so majority of the groundwater samples are suitable for irrigation. The results revealed that the GQI quality index varied between 89% and 91% in the Konaro area, which in terms of quality rating, the water samples from these resources laid in appropriate to acceptable range. Moreover, based on examining the zoning map, the GQI quality index accounted for the lowest value in the east direction of the study area. Thus, most of the groundwater samples from this study (sample W2) confirm the beneficial use of aquifers in the area for domestic, agricultural, and irrigation purposes.

Keywords: *GQI, Domestic purpose, Irrigation purpose, Ophiolitic area, Konaro, Iranshahr*

1. Introduction

One-third of the world's population uses groundwater for drinking purposes. Therefore, it is necessary to assess the quality of groundwater in order to achieve sustainable development (Mosaferi et al. 2014). In arid and semi-arid regions, the importance of groundwater resources is greater (Shanmugam and Ambujam 2012). One of the important factors in the sustainability of the development of a region is the provision of sufficient and suitable water resources for various uses, which in addition to quantity, its quality is also of special importance. Today, water quality is one of the components that need to be considered in water resources management planning as well as watershed health assessment and management changes (Khadam and Kaluarachchi 2006). Natural and human factors in each region cause physical, chemical, microbial and biological changes in the quality of water resources. Many researchers in this field and in different regions have evaluated water quality, some by examining the physicochemical properties of water and the amount of anions and cations, some by examining the amount of heavy elements and some microbial properties of water (Mosaferi et al. 2014; Ewaid 2017; Beyene et al. 2019).

Groundwater demand has increased due to intensive agriculture, urban growth, industrialization, population growth, etc., which leads to a reduction and risk of groundwater pollution. Assessing the quality of groundwater requires the determination of ion concentration, which is decided in the appropriate context for domestic, agricultural and industrial use. Chemical reactions such as weathering, precipitation, dissolution, ion exchange, and various biological processes usually occur below the Earth's surface. The study of hydrogeochemistry is a useful tool for identifying these processes responsible for groundwater chemistry (Jeevanandam et al. 2007). Water quality depends on geological conditions, natural water movement, rock type, aquifers, climate change, water residence time, and soil inputs when water infiltrates (Todd 1980; Laurent et al. 2010, Dabiri et al. 2018).

Therefore, the present study was conducted to evaluate the appropriateness of groundwater for domestic, irrigation and industrial use with the approval of water quality standards. To identify the major types of water in the study area, it is necessary to identify hydrochemical facies. Multivariate statistical analysis tools have been used to derive the parameter affecting groundwater quality. ArcGIS software is used to show the spatial

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distribution map of groundwater quality using the inverse distance weighted algorithm (IDW).

The seasonal river of Konaro lacks surface water flow given the continuing successive droughts. Therefore, water for drinking and agricultural uses has been supplied by underground water through drilling wells and digging of qanats from the river bed. In case of the Konaro River basin, study on evaluation of groundwater quality has not been carried out so far. The outcomes of the study may be helpful to local habitants to avoid health risk related problems.

2. Materials and methods

2.1. Study area

The study area has been located in southeast of Iran, Sistan and Baluchistan Province and Iranshahr City. Iranshahr is located in the central area of Baluchistan, at an average altitude of 591 m above sea level, 345 km from Zahedan City. The study area is located between the eastern longitudes of 60^{o} 50' to 61^{o} 20' and northern latitudes of 27^{o} 05' to 27^{o} 20' (Fig. 1). Due to the lack of rainfall, this region is one of the driest regions in the country in terms of climate and is among the hot and dry regions. The maximum temperature in July-August is about (50-55) and the lowest in January-February is about (20-25). In general, Iranshahr region is one of the arid and low rainfall areas, rainfall in the plains, especially in summer is very low and the annual rainfall is about 60 mm. This amount of rainfall is present in 6 to 7 months of the year and the rest of the year is completely dry and without rainfall. The rains in the region are of the type of heavy and short-term showers and are usually followed by floods. Therefore, the climate of the study area is considered to be arid according to the De Martonne method.

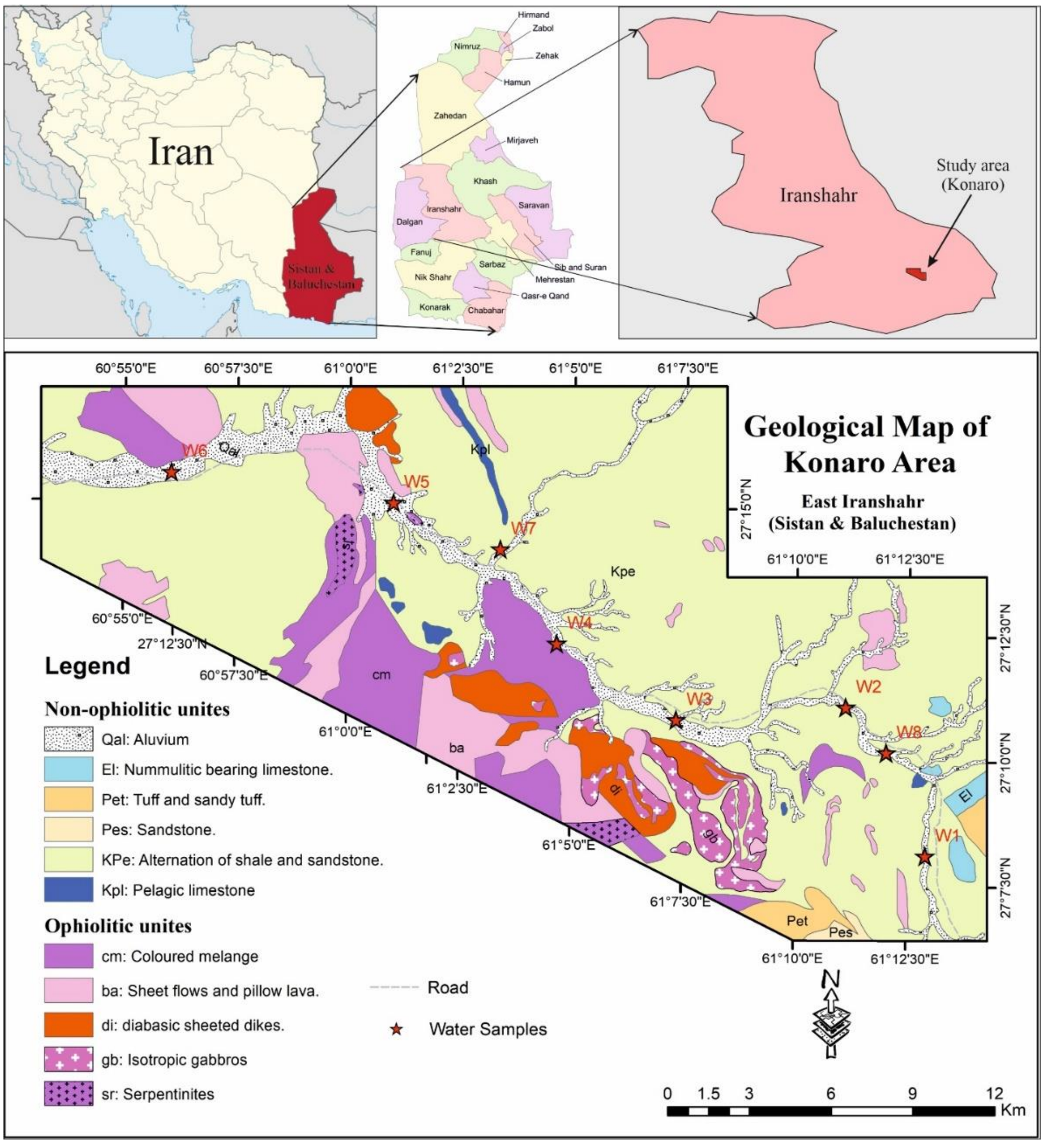

Fig 1. Geological map of the study area and water sampling points (modified from geology map of 1:100,000 of the Iranshahr sheet).

The hydrological system of the study area included rivers, floodwaters, and streams originating from the heights of the basin. This basin system has been expanded from east to west and includes several large and small floodwaters often without a specific name. These floodwaters flow to the Konaro River. This river supplies the Iranshahr Plain after flowing. In the case of rainfall and occurrence of seasonal flood, the river flows into the plain and during years with low rainfall, the main river flow is cut off. As shown in Fig. 1, the geological units of the study area include ophiolitic and non-ophiolitic units. The most outcrops of ophiolitic units are found in the southwestern part of the region. Ophiolitic unites in study area include of coloured mélange, sheet flow and pillow lava, diabasic sheeted dikes, isotropic gabbros and serpentinized peridotites. Non-ophiolitic unites in Konaro area are mainly flycshes (shale with sandstone) and limestones. The major minerals in the study area are quartz, feldspars, calcite, muscovite, talc, chlorite, hornblende, chrysotile and augite. Along with these ophiolitic units, there are some outcrops of chromites in the area where mining activities have taken place. In fact, ophiolitic units in the study area are the most important source of heavy metals to the environment.

2.2. Sample collection and analytical procedure

In order to evaluate the water quality in the study area, due to the limited water resources, 8 water samples were taken in December 2017 (Fig. 1). In this study, the water samples were taken from the drinking and farming wells and in order to determine the chemical properties of each source. The geographical location of each water samples was determined with a handheld global positioning system (GPS). Samples were stored in polyethylene bottles, then after filtering the samples, 0.15 cc nitric acid ($pH \leq 2$) was added into each bottle in order to stabilize the heavy metals and transferred quickly to laboratory and stored in a refrigerator. Electrical conductivity (E_c), pH and Temperature were measured in situ using a pre-calibrated portable digital pH-meter and E_c meter. In the laboratory, samples were filtered in order to remove suspended sediments. Major ions were analyzed employing standard methodologies (Apha 1995): sulfate (SO_4^{2-}) by spectrophotometric turbidimetry; bicarbonate (HCO_3^-) by titration with HCl, chloride (Cl^-) by standard $AgNO_3$ titration; calcium (Ca^{2+}) and magnesium (Mg^{2+}) by titration using standard EDTA; sodium (Na^+) and potassium (K^+) by flame photometry in the chemistry laboratory of Islamic Azad University of Zahedan Branch.

3. Results and discussion

3.1. Physicochemical Features

Understanding the water quality is important as it is the main factor determining its suitability for drinking, domestic, agricultural and industrial purposes (Subramani et al. 2005). The analytical results of physicochemical characteristics of Konaro water samples are given in Table 1. Hydrogen ion concentration (pH) is a significant factor in riverine ecosystems and is a measure of toxicity to vegetation and living organisms. The pH range of 7.43 to 8.40 recorded in Konaro water indicates (Table 1) that the water is mostly slightly alkaline. The pH value has increased from the southeast of the region to the northwest and the highest value is related to the sample W8 belong to well groundwater (Fig.2a). The pH values in all samples are slightly lower than the pH value specified in Standard 1053 (8.5) and are in a better condition (Table 1). pH of fresh waters is governed by the carbonate-bicarbonate-carbon dioxide equilibrium (Yang et al. 2007). Electrical conductivity (EC) is the most important parameter to demarcate salinity hazard and suitability of water for irrigation purposes. The conductivity of Konaro groundwater varied between 948 and 1842 µS/cm, with an average conductivity of 1188 µS/cm (Table 1). The EC value, as seen in Fig 2b, has the highest value in and around samples W2 and W8. The value of total dissolved solids (TDS) in the water samples varies from a minimum of 582 mg/l to a maximum of 1212 mg/l (Table 1), which shows that the level of solids in water was good. Like the EC parameter, the TDS value in samples W2 and W8 is higher than in other samples (Fig. 2c) and it is also higher than the value specified in Standard 1053 (1000) (Table 1). The concentration of sulfate anion in the samples of the Konaro region is 1.24 to 12 mg/L (Table 1) which shows that the level of sulfate in water was very good. WHO permissible limit of sulfate for drinking water is 250 mg/l. The most common source of toxicity in irrigation water is the chloride ion. Chloride is not adsorbed or held back by soils, therefore it moves readily with the soil-water and is adsorbed by crops, moves in the transpiration stream, and accumulates in leaves (Ayers and Westcot 1994). Chloride in the Konaro water samples ranges from 0.6 to 3 mg/l with an average of 1.8 mg/l (Table 1). The permissible limit of chloride content prescribed by WHO for drinking water is 200 mg/l. The amount of TH in the groundwater samples of the Konaro area varies from a minimum of 9.56 to a maximum of 13.61 (Table 1). The highest TH value of the samples is related to the W6 sample (Fig. 2d). Compared to the 1053 standard (TH value is 200), TH values are much lower and more acceptable in Konaro area samples (Table 1).

Table 1. Field measurements and analytical data (concentrations are expressed in mg/l and Ec in µmhos/cm).

Samples	depth	EC	pH	TDS	TH	SO4^{2-}	HCO$_3^-$	Cl$^-$	Ca^{2+}	Mg^{2+}	Na$^+$	K$^+$
W1	25	1128	7.47	738	10.48	4.6	4.9	1.4	1.4	1.7	7.6	0.1
W2	50	1842	7.43	1212	12.35	12	4.7	0.6	0.5	2.7	14	0.2
W3	55	1014	7.47	668	11.11	3	4.7	2	0.5	2.4	6.6	0.1
W4	60	997	7.43	651	9.56	2.2	5.1	2.3	0.7	1.9	6.8	0.1
W5	1	948	8.23	600	11.27	1.6	4.2	3	0.4	2.5	5.7	0.1
W6	20	970	7.75	582	13.61	1.24	4.5	1.8	1.5	2.4	7.1	0.1
W7	35	951	8.10	627	9.88	1.9	4.6	2.6	0.5	2.1	6.2	0.1
W8	35	1651	8.40	1010	11.45	1.7	4.7	0.9	0.8	2.3	9	0.1
Min	1	948	7.43	582	9.56	1.24	4.2	0.6	0.4	1.7	5.7	0.1
Max	60	1842	8.40	1212	13.61	12	5.1	3	1.5	2.7	14	0.2
Mean	35	1188	7.79	761	11.21	3.53	4.7	1.8	0.8	2.25	7.88	0.11
WHO						450	*	250	100	50	200	*
Iran1053			8.5	1000	200	250	*	250	300	30	200	*

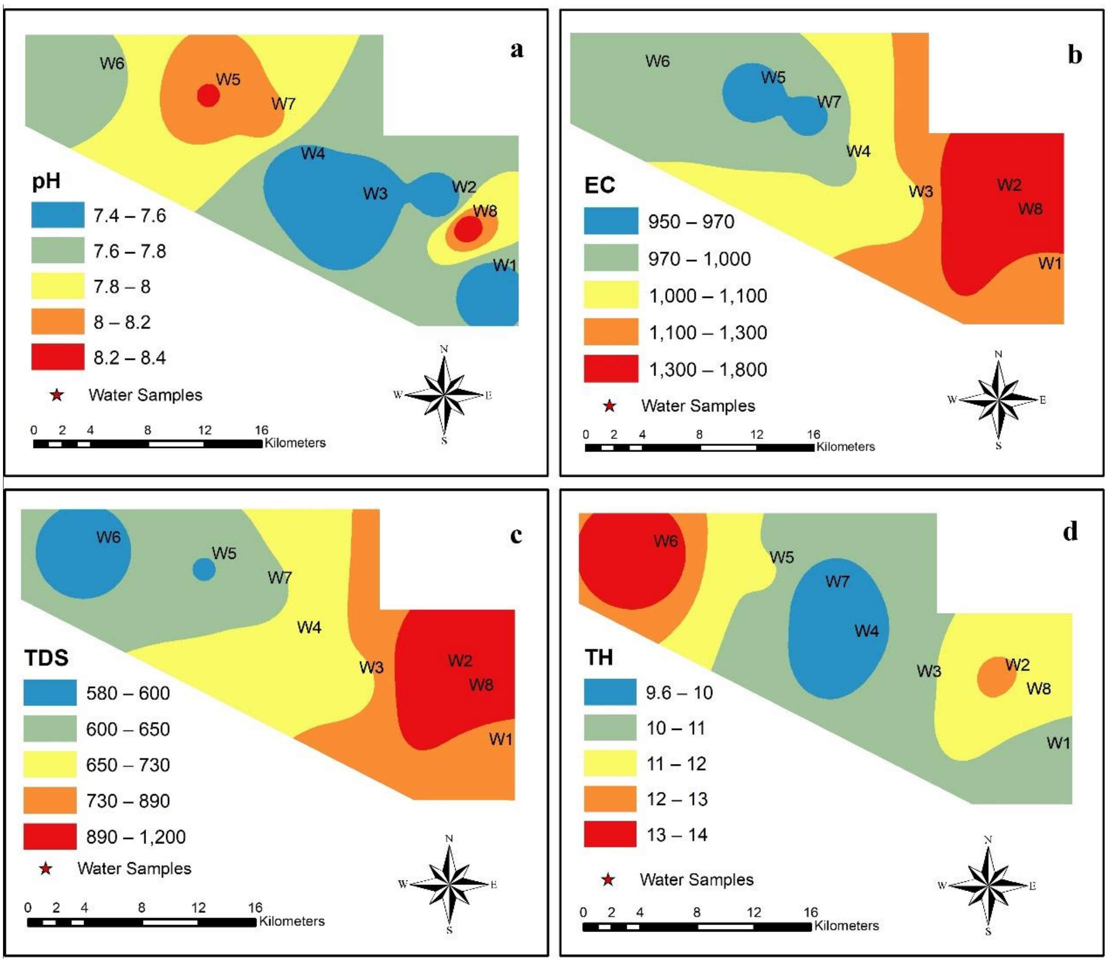

Fig 2. Spatial distribution of pH, EC, TDS and TH values of the groundwater samples in the study area.

The Schuler diagram revealed that all parameters were in good range (Fig. 3). The Schuler diagram is a semi-logarithmic diagram indicating the concentration of the main ions in mEqg/L. In this diagram, based on the chemical parameters of potassium, sodium, magnesium, calcium, chlorine, sulfate, and bicarbonate, water types are classified in terms of the drinking uses. As can be seen in this diagram, Sample W2 is seen in the highest values compared to other samples (Fig.3).

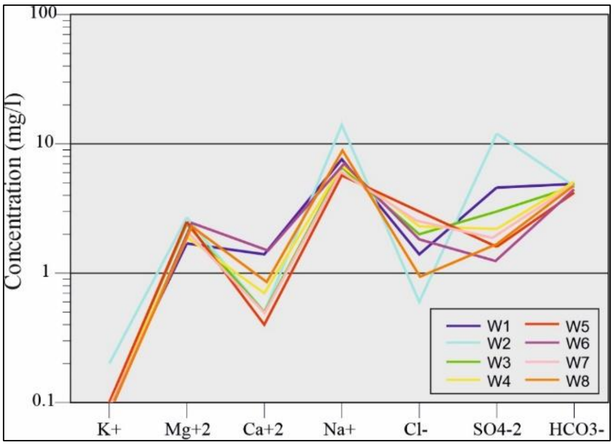

Fig 3. Schuler diagram for the groundwater samples of the Konaro ophiolitic area.

3.2. Hydrogeochemical Facies

The hydrochemical evolution of groundwater can be understood by plotting the major cations and anions in the Piper trilinear diagram (Piper 1944). This diagram is useful in bringing out chemical relationships among waters in more definite terms. The plot reveals similarities and differences among water samples because those with similar qualities will tend to plot together as groups (Todd 1980). Groundwater and surface water chemistry relies on different geological factors of the area and the supply and discharge rates of water from sedimentary and rocky beds. Due to the large variety of rocky composition and intense tectonization, the area has a variety of water types in such a way that they have laid in 2 fields of the Piper diagram (Fig. 4). The results of Piper diagram indicated that the water type in most of the studied samples were of the bicarbonate type (Fig. 4).

3.3. Suitability for drinking and domestic purposes

Water quality varies depending on soil types, geological formations, natural and anthropogenic processes. The types and concentrations of different elements present in the groundwater depend on the associated rock bodies and the time it has been in contact with geological materials. Parameters, such as Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, SO_4^{2-}, F^-, pH, EC, TDS and TH are regarded as critical determinants for most development studies of water quality (Kumar et al. 2007; Sappa et al. 2015). Measurement of groundwater pH is essential because many of the solution processes, such as aqueous complexation, water-rock interactions, mineral solubility and adsorption properties, gas solubility, and biochemical reactions are pH sensitive (Shube 2011). The pH of the groundwater was within permissible value of 6.5 to 8.5 (WHO 2006).The pH of most of the groundwater samples were nearly neutral and about 63% of the samples have pH less than 8 which indicates the absence of carbonate in the water and this could indicate that the area is discharge area.

The evolution of chemical composition of groundwater from recharge areas to discharge areas is characterized by increasing sodium, chloride and sulfate contents as a result of leaching of evaporate rock (Jameel and Sirajudeen 2006). Na^+ is an essential macro mineral for our body. But excess consumption of Na^+ is related with hypertension. The concentration of Na^+ in all groundwater samples are lower than the permissible value according to WHO (200 mg/l) (Table 1). Generally, groundwater quality varies from place to place, depending on seasonal changes (Patel and Parikh 2013), the types of soils, rocks and surfaces through which it moves (Seth et al. 2014). Naturally occurring contaminants present in rocks, soils and sediments.

General quality of groundwater can be determined by the total ionic composition denoted by EC. Range of EC in Konaro groundwater samples was 948–1842 µS/cm with a mean of 1188 µS/cm. Table 2 gives the suitability of groundwater and surface water for drinking use. Most of the Konaro groundwater samples were suitable for drinking based on the EC (Table 2). Large part of the groundwater samples was fresh (75 %) as well as brackish (25 %) in nature based on TDS classification of Freeze and Cherry (1979) (Table 2). High EC and TDS of groundwater make it unsuitable for domestic use and to some extent for irrigation.

3.4. Suitability for irrigation purpose

All of the irrigation activities in the study area depend on the groundwater. The concentration and composition of dissolved substances in the water determines the suitability of the water for agricultural uses. The characteristics of water most important in determining its quality for irrigation purpose are: total concentration of soluble salts; relative proportion of Na^+ to other cations; and concentration of elements that may be toxic (Dessie 2010).

3.4.1. Salinity index

Salinity indices of groundwater samples were calculated using the measured electrical conductivity (Singh et al. 2012). Salinity determines suitability of water for its intended use according to the classification given by Mills (Singh et al. 2012). All of the samples were categorized under Class III (100 %). These samples showed high salinity and may be considered as suitable for irrigation. No sample was fallen into very high salinity hazard category (Fig. 5).

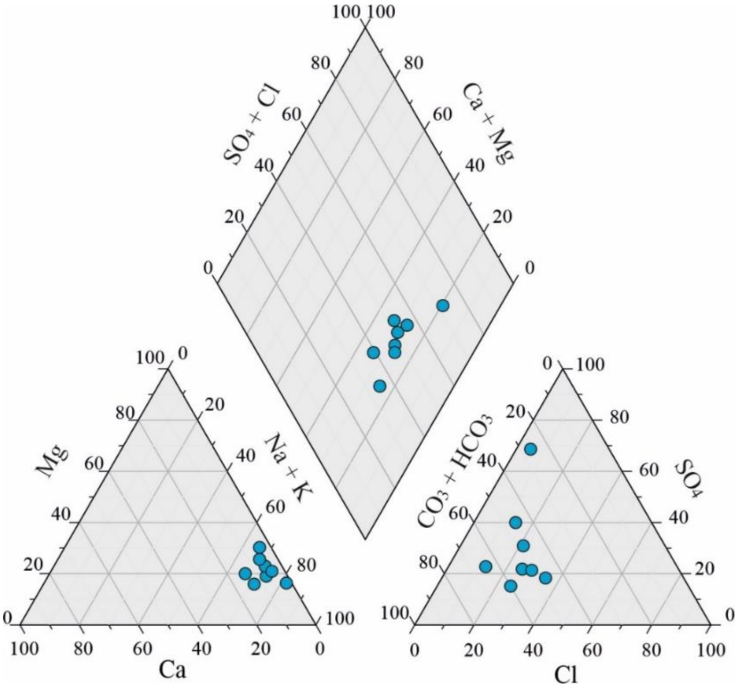

Fig. 4. Piper diagram for the groundwater samples of the Konaro ophiolitic area.

Table 2. Water type and suitability based on EC and TDS.

Parameter	Classification	Water type/suitability	Number of samples
EC (µS/cm) (WHO 1993)	<750	Desirable	
	750-1500	Permissible	6
	1500-3000	Not permissible	2
	>3000	Hazardous	
TDS (mg/l) (Freeze and Cherry 1979)	<1000	Fresh	6
	1000-10000	Brackish	2
	10000-100000	Saline	
	>1000000	Brine	
TDS (mg/l) (Davis and DeWiest 1966)	<500	Desirable for drinking	
	500-1000	Permissible for drinking	6
	1000-3000	Useful for irrigation	2
	>3000	Unfit for drinking and irrigation	

3.4.2. Sodium Absorption Ratio (SAR)

Water is valuable only when its quality is suitable for a variety of purposes. Water for irrigation should satisfy the needs of soil and the crop as the liquid phase in soil water plant growth and crop production. Sodium concentration is an important criterion in irrigation-water classification because sodium reacts with the soil to create sodium hazards by replacing other cations (Raju 2007). The extent of this replacement is estimated by Sodium Absorption Ratio (SAR). The SAR is computed using the following Eq (1) (Hem 1991):

$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\sqrt{\frac{\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}}{2}}} \qquad (1)$$

Concentrations of ions are expressed in meq/l. There is a close relationship between SAR values in irrigation water and the extent to which Na^{+} is absorbed by soils (Rao 2006). SAR contents in the groundwater sampled ranged from 4.73 to 11.07 (average 6.39). The US Salinity Laboratory's diagram (USSLD) is widely used for rating irrigation waters (Salinity Laboratory Staff 1954). SAR was plotted against EC (Fig. 5). The resulting diagram was divided into 16 areas which are used to rate the degree to which a particular water may give rise to salinity problems and undesirable ion-exchange effects in soil. In the USSL plot 50% of groundwater samples falls in C3S1 area, indicating high salinity and low sodium water, which can be used for irrigation in almost all types of soil with little danger of exchangeable sodium (Kumar et al. 2007). Also, 37.5% of the total samples fall in the C3S2 area, indicating water having high salinity and medium sodicity. High salinity, medium sodicity water cannot be used on fine-grained soils with restricted drainage (Vasanthavigar et al. 2010). Approximately 12.5% of the total samples fall in the C3S3 area of the US salinity diagram, indicating samples not suitable for irrigation due to high salinity and sodium hazards which affects the plant growth (Table 3). As shown in Fig. 7a, the maximum value of the SAR is related to sample W2 and its surroundings.

Table 3. Suitability classes of groundwater for irrigation (Salinity Laboratory Staff 1954).

Quality Class	Salinity and Na^+ Hazard	Suitability for irrigation	Samples	
			No.	%
C3S1	High salinity low Na^+ water	used for irrigation in all types of soil	4	50
C3S2	High salinity medium Na^+ water	cannot be used on fine-grained soils	3	37.5
C3S3	High salinity high Na^+ water	not suitable for irrigation	1	12.5

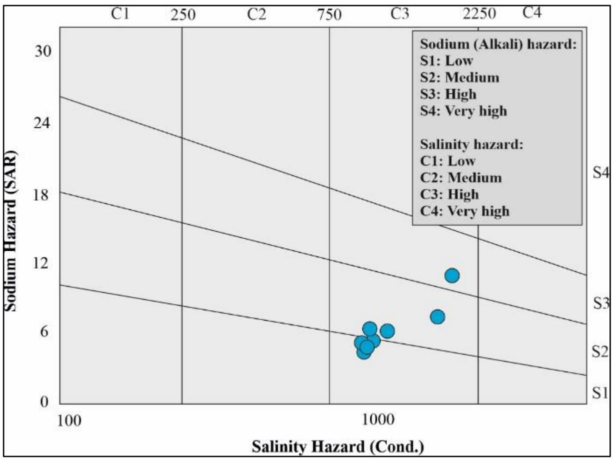

Fig. 5. Wilcox diagram for irrigation water classification

3.4.3. Na% index

EC and Na^+ concentration are also very important in classifying irrigation water. The Na% is computed with respect to relative proportions of cations present in water using Eq. (2), where ions concentrations are expressed in meq/L.

$$\mathrm{Na\%} = \frac{(\mathrm{Na^+ + K^+})}{(\mathrm{Ca^{2+} + Mg^{2+} + Na^+ + K^+})} \times 100 \qquad (2)$$

Wilcox's diagram, where EC is plotted against Na%, is used to further classify groundwater for irrigation. The Na% ranges between 64.86 and 81.61% (average 71.53%). A high Na% causes deflocculation, soils tilt and permeability impairment (Singh et al. 2012). Plot of EC versus Na% is important in classifying groundwater into different irrigation suitability classes. About 87.5% of the samples belonging to permissible to doubtful and 12.5% of the samples fall into doubtful to unsuitable category for irrigation use (Fig. 6). As shown in Fig. 7b, the maximum value of the Na% is related to sample W2 and its surroundings.

3.4.4. Magnesium hazard (MH)

Mg^{2+} is an important parameter in determining the water quality for agricultural uses. In general, Ca^{2+} and Mg^{2+} maintain a state of equilibrium in most waters. MH value is proposed to evaluate water for irrigation (Rao 2006), which can be calculated as a percentage using Eq. (3), where all the ions are expressed in meq/l.

$$\mathrm{MH} = \frac{\mathrm{Mg^{2+}}}{\mathrm{Ca^{2+} + Mg^{2+}}} \times 100 \qquad (3)$$

The calculated MH ratio ranged from 54.84 to 86.21% (average 74.72%) for groundwater samples in the Konaro area. All water samples in Konaro area have high MH than the acceptable Mg^{2+} ratio limit of 50% (Salinity Laboratory Staff 1954), that it originates from ophiolitic rocks of the study area. Such high Mg^{2+} content in water unfavorably affects crop productivity as the soil becomes more saline. As shown in Fig. 7c, the maximum value of the MH is related to samples W2 and W5 and their surroundings.

3.4.5. Total hardness (TH)

Depending on pH and alkalinity, hardness above 200 mg/L can result in scale deposition, particularly on heating. Soft waters with hardness of less than 100 mg/L have a low buffering capacity and may be more corrosive to water pipes. A number of ecological and analytical epidemiological studies show a statistically significant inverse relationship between hardness of drinking water and cardiovascular disease. There is some indication that very soft waters may have an adverse effect on mineral balance, but detailed studies were not available for evaluation. Total hardness has been estimated from Ca^{2+} and Mg^{2+} concentrations and calculated as mg/l $CaCO_3$ using Eq. (4) (Ayers and Westcot 1985; Apha 1995).

$$\mathrm{TH} = 2.497\mathrm{Ca^{2+}} + 4.118\mathrm{Mg^{2+}} \qquad (4)$$

Hardness is commonly classified in terms of degree of hardness as (1) soft: 0 to 75 mg/L; (2) moderate: 75 to 150 mg/L; (3) hard: 150 to 300 mg/L; and very hard > 300 mg/L. The results of the study show the total hardness ranges from 9.57 to 13.63 (Table 1). All groundwater samples of the Konaro area were identified as soft water.

3.5. Determination of pollution indices

3.5.1. Groundwater quality index (GQI)

In order to calculate quality index (GQI), average concentrations of magnesium, calcium, chlorine, SO4, total dissolved solids (TDS), and Na were compared with the standard value of the major ions for drinking water according to the World Health Organization (WHO) report. In ArcGIS, the Map Algebra expression was used to aggregate several input raster layers and create a raster output. First, the raster layers of the concentration of each parameter were applied to create six new maps using Eq. (5), with their new pixel values varing from -1 to 1. Then, the maps were reclassified using Eq. (6) to achieve the new values of 1 to 10.

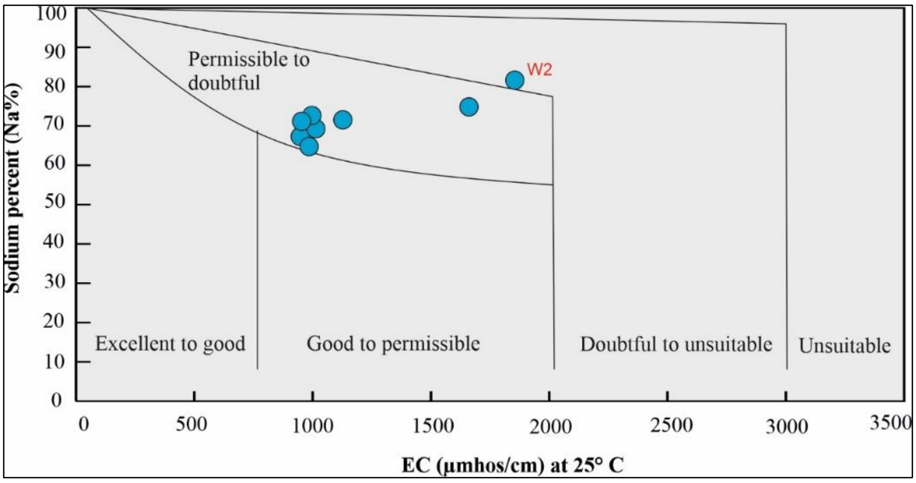

Fig. 6. Rating of the groundwater samples on basis of EC and %Na^+.

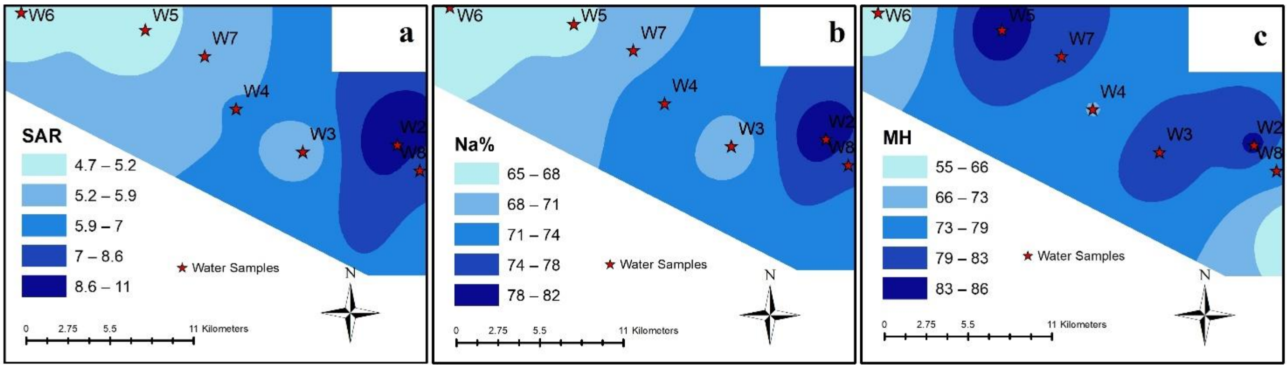

Fig. 7. Distribution of suitability for irrigation purpose based on SAR, Na% and MH values.

Finally, to create the final map that indicates the status of the GQI, the six reclassified layers were combined using the Map Algebra expression and Eq. (7) (Babiker et al. 2007):

$$C = \frac{C_i - C(WHO)_i}{C_i + C(WHO)_i} \tag{5}$$

where C_i is the concentration of the parameter and $C(WHO)_i$ is the maximum allowable concentration provided by the World Health Organization. C is the concentration obtained from Eq. (5) and R is the rating assigned to each of these concentrations.

$$R = 0.5C^2 + 4.5C + 5 \tag{6}$$

$$\mathrm{GQI} = 100 - \left[\frac{\sum_{i=1}^{n} W_i R_i}{n}\right] \tag{7}$$

where R_i is the rating of each ion obtained from Eq. (6) on the basis of the raster layer; W_i is the relative weight of each of these parameters, which is equal to the average concentration of each of the rated parameters, and n is the number of raster layers that should be combined in this method (here it is 6). The GQI values obtained lay between 0 and 100, hence the water quality (Babiker et al. 2007) is classified based on Table 4.

Table 4. Water quality classification based on groundwater quality index (GQI) (Babiker et al. 2007).

Water quality	GQI
Appropriate	91-100
Acceptable	71-90
Average	51-70
Inappropriate	26-50
Totally inappropriate	0-25

The GQI and ranked maps for each variable in groundwater samples of the Konaro area were calculated and prepared. These maps show the aquifer's critical areas relative to each of these variables (Fig. 8). Calcium, magnesium, sodium, chlorine, and sulfate laid in the range of 1 to 1.5, indicating the lower values of the above-mentioned variables in the water and its appropriate quality in terms of the above variables. The presence of sulfate, chlorine, and sodium in the area was very likely to be associated with the brines transmitted through faults. However, the amount of TDS was in the range of 5 to 7. Water quality can vary greatly given the length of the path and the amount of solids dissolved in the path (Mahdavi 2005).

Regarding the calculations, the GQI varied between 89% and 91%, indicating that in total, the underground waters in the studied area laid in the appropriate to acceptable range in accordance with the standards of portable water based on the quality rating tables (Fig. 9). During passing through the layers and their forming materials, the groundwater solves some of the salts in the path, and because of flowing in the direction from the upstream to downstream in the study area. The water quality has increased in the direction of flow of the underwater, except for the second station, in which the quality has declined drastically.

3.6. Multivariate statistical processes

Multivariate statistical processing through principal component analysis (PCA), correlation analysis, and cluster analysis (CA) to determine the interdependence between the various parameters as well as the most influential factor affecting groundwater quality assessment were performed.

3.6.1. Principal component analysis (PCA)

PCA was carried out with Varimax rotation and Kaiser Normalization on groundwater samples data that clarified the observed relationship of cluster variables by simple methods, represented in variance and covariance patterns and the similarity between observations. In this study, in order to increase the number of extracted components to more than two, the values of eigenvalue were considered to be higher than 0.5. As can be seen in Fig. 10a and b, four parameters were extracted for groundwater quality data sets having eigenvalues higher than 0.5 expressed 96.92% of the total variance in the Konaro area. Furthermore, to determine the number of retained PCs for understanding the underlying factors structure, the scree plot (Fig. 10a) was applied. Table 5 presents the measured factor loadings, each parameter cumulative percentages and percentages of variance. According to the PC1, PC2, PC3 and PC4 for groundwater quality data, the total variance of 46.39%, 21.24%, 14.97 and 14.33%, were calculated, respectively. It is evident that PC1 is profoundly very highly positively loaded on Na^+, K^+, TDS, EC and SO_4^{-2} and while highly negatively loaded with Cl^-. The sources of which are either natural from weathering and leaching of silicate minerals such Na and K bearing minerals. Therefore, the clay minerals possibly resulting from the dissolution or weathering of sodium and potassium silicates in the water path have been abundant. PC2 is influenced by highly positively loaded Mg^{2+} and TH, while highly negatively loaded with HCO_3^-, their sources could be from leaching from mafic rocks such peridotites, gabbros, presence of clay minerals and oxidation processes induced by rain or percolating water. PC3 is positively loaded with SO_4^{-2} while highly negatively loaded with pH. PC4 is highly positively loaded with Ca^{2+} (0.973). Sources of the Ca^{2+} are mainly from leaching of carbonate rocks. It is assumed that PC1, PC2, PC3 and PC4 are indicative of the water-rock interaction and natural processes.

3.6.2. Cluster Analysis (CA)

Cluster analysis of the R mode is conducted to describe various groupings of elements in the dataset affecting the total quality of groundwater. As can be seen in Fig. 11, cluster analysis reveals that Na^+, K^+, TDS, EC and SO_4^{-2} are categorized in a single cluster and Mg with TH, Ca with HCO_3^- and pH with Cl^- were added in next steps. According to the mentioned parameters clustering, all parameters have the same origin in the region.

3.6.3. Correlation matrix (CM)

The correlation matrix is used to determine the degree of correlation among the different physicochemical water quality parameters. It shows the dependency of variables with each other. The Karl Pearson’s correlation matrices are used to recognize the relationship of different variables (Table 6). The variables showing correlation coefficient ($r > 0.7$) are considered to be strongly correlated where (r) values between 0.5 and 0.7 indicate moderate correlation while $r < 0.3$ is weak. The correlation matrix was analyzed with cluster analysis using the SPSS (21.0) software. It is observed from Table 6 that there is high positive correlation between TDS and EC. It is also illustrated that EC and TDS show high positive correlation with SO_4^-, Na^+ and K^+. The potassium (K) and sodium (Na) are also significantly correlated ($r = 0.928$); SO_4^- is highly correlated with K ($r = 0.955$) and sodium ($r = 0.902$). Cl^- is negatively correlated with Na ($r = -0.843$) and SO_4^- ($r = -0.644$).

Table 5. Principal component analysis of groundwater quality parameters.

Parameters	Component			
	1	2	3	4
TDS	**0.993**			
EC	**0.991**			
Na^+	**0.942**			
Cl^-	**-0.903**			-0.384
K^+	**0.773**	0.305	0.463	
SO_4^{-2}	**0.762**		**0.562**	
Mg^{+2}	0.330	**0.870**		
HCO_3^-		**-0.845**	0.357	
TH		**0.805**		**0.510**
pH			**-0.943**	
Ca^{+2}				**0.973**
Eigen values	5.103	2.336	1.646	1.576
% of Variance	46.389	21.239	14.964	14.331
Cumulative %	46.389	67.628	82.592	96.923

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 5 iterations.

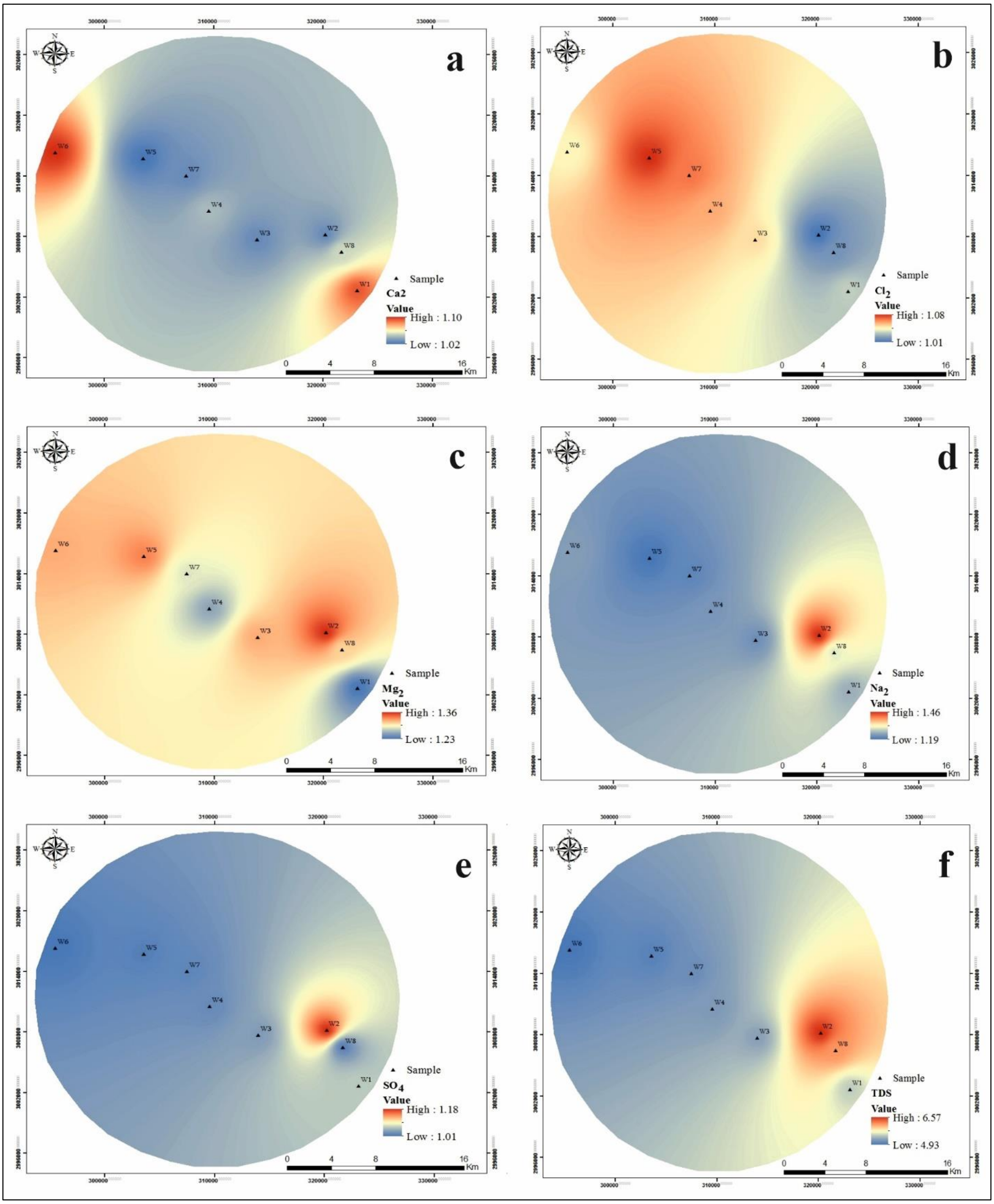

Fig. 8. Zoning map of calcium, chlorine, magnesium, sodium, sulfate and TDS.

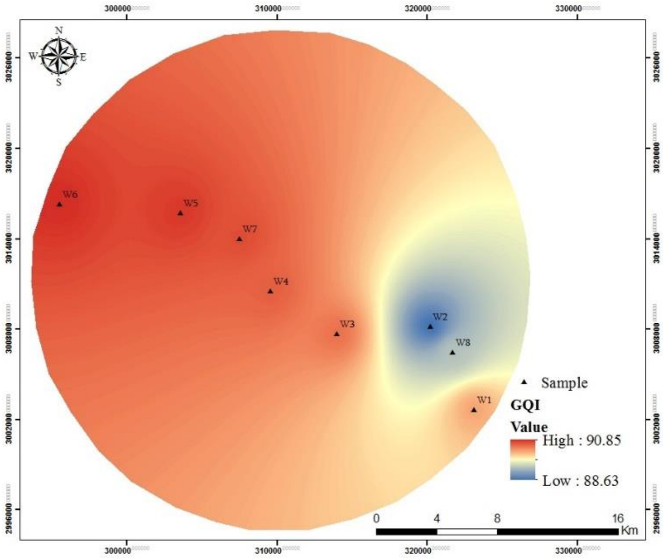

Fig. 9. Water quality zoning map based on global quality index (GQI)

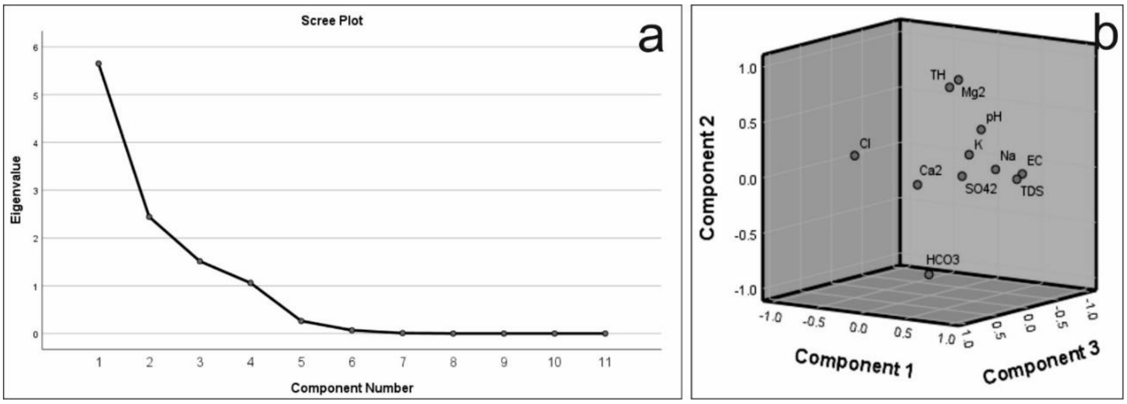

Fig. 10. Principal component analysis by (a) scree plot of the characteristic roots (eigenvalues), and (b) component plot in rotated space.

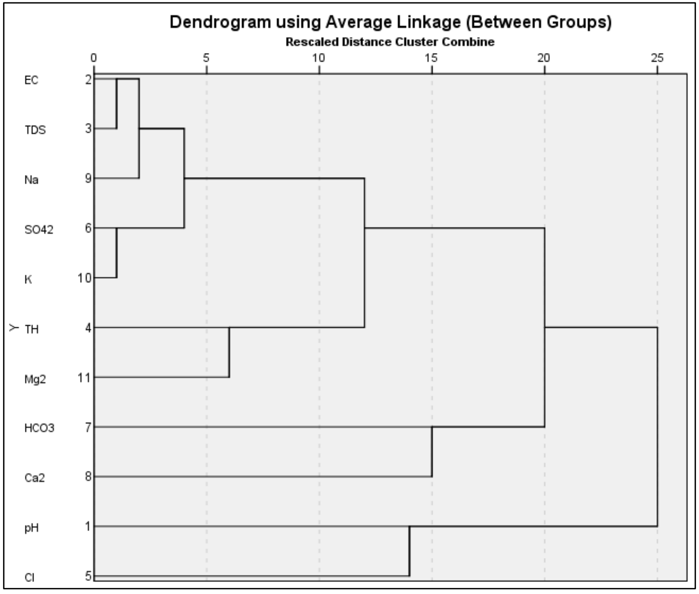

Fig. 11. Groundwater quality parameters cluster analysis tree.

Table 6. Correlation analysis of groundwater quality parameters.

	pH	EC	TDS	TH	Cl-	$SO4^{-2}$	HCO_3^-	Ca^{+2}	Na^+	K^+	Mg^{+2}
pH	1										
EC	0.023	1									
TDS	-0.059	**.992****	1								
TH	0.031	0.310	0.248	1							
Cl^-	0.233	**-.874****	**-.859****	-0.411	1						
$SO4^{-2}$	-0.507	**.713***	**.784***	0.219	-0.644	1					
HCO_3^-	-0.605	0.150	0.191	-0.482	-0.361	0.190	1				
Ca^{+2}	-0.208	-0.138	-0.191	0.372	-0.285	-0.181	0.210	1			
Na^+	-0.276	**.919****	**.941****	0.390	**-.843****	**.902****	0.186	-0.085	1		
K^+	-0.356	**.748***	**.801***	0.348	-0.599	**.955****	0.038	-0.271	**.928****	1	
Mg^{+2}	0.196	0.410	0.392	0.679	-0.173	0.355	-0.636	-0.429	0.445	0.552	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

4. Conclusion

The groundwater quality of Konaro ophiolitic area in Iranshahr sity, was evaluated for domestic and agriculture purposes. The interpretation of hydrogeochemical analysis results of 8 representative groundwater samples from wells and qanat in the study area reveals that groundwater is fresh to brackish and alkaline in nature. The order of dominance of cation and anions are Na> HCO_3> SO_4 > Mg> Cl> Ca> K, respectively. The all groundwater samples are classified as soft water base on the total hardness (TH). The all groundwater samples have high MH and also based salinity index categorized under class III. According to Na% and SAR, 87.5% of samples are suitable for irrigation use. All groundwater samples in the Konaro area, except samples W2 and W8, have the necessary standards for drinking purpose. Also, based on the parameters examined for suitable water for irrigation, 87.5% of the samples (except sample W2) obtained from groundwater in the Konaro area have ideal conditions. Many of the quality parameters in Sample W2 are lower than ideal and have the greatest impact on ophiolitic units and chromite mining in the region due to their high MH values. Near-mine samples were enriched in terms of magnesium and samples near calcareous units, had higher calcium content. The GQI varied between 88% and 91% in the Konaro area, which laid in appropriate to acceptable range. Moreover, based on examining the zoning map, the GQI indicated the least amount of this index in the east, which is likely to be affected by the existence of the chromite mine in the Konaro region, with its highest values being in the northwest direction, indicating an increase in water quality due to its self-purification. Thus, the present work reveals that the most of the groundwater samples show their suitability for domestic, agriculture, and irrigation purposes.

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