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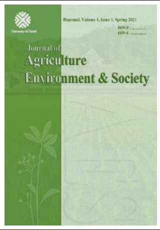

Scaling and corrosion quality zoning of groundwater in the aquifer of the ghorove–dehgolan plain

Eebrahim Yousefi Mobarhan [*a], Ebrahim Karimi Sangchini [b], Sakineh lotfinasabasl [c]

[a] Soil Conservation and Watershed Management Research Institute, Semnan Agricultural and Natural Resources Research and Education Center, Agricultural Research, Education and Extension Organization (AREEO), Semnan, Iran.
[b] Soil Conservation and Watershed Management Research Institute, Lorestan Agricultural and Natural Resources Research and Education Center, Agricultural Research, Education and Extension Organization (AREEO), Lorestan, Iran
[c] Desert Research Department, Research Institute of Forests and Rangelands, Agricultural Research, Education and Extension Organization (AREEO), Tehran, Iran

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ABSTRACT

Chemical quality is a significant and determining factor in a variety of water applications. Understanding the characteristics of subterranean water is regarded as a viable instrument for assessing water resource management. o determine the chemical quality of the groundwater in the Ghorove– Dehgolan aquifer, as well as to examine changes over three statistical periods (2001–2018), the basin was sampled for the following chemical parameters: electrical conductivity, total dissolved solids, sodium absorption ratio, bicarbonate, carbonate, chlorine, sulfate, calcium, magnesium, sodium, and potassium. Information from 276 exploitation sources on an annual scale pertaining to an 18-year statistical period was utilized to accomplish the objectives. The geographic information system (GIS) and the geostatistical interpolation method were utilized to determine the distribution of effective variables in the quality of industrial consumption in order to generate quality zoning maps of water consumption utilizing the Langelier index and the available data for the study area. The analysis of water quality variables revealed that the aquifer exhibited the highest values of electrical conductivity (669 µS/cm), total dissolved solids (430 mg/l), and sodium absorption ratio (0.95%) for groundwater quality during the period 2013–2018. In comparison to the other courses, they are lower. The assessment of industrial water quality revealed that scaling affected 22% of the water samples, while corrosion affected 78%. The examination of qualitative zoning maps intended for industrial applications revealed that the aquifers in the southern portion of the Ghorove–Dehgolan plain, along with a restricted region in the aquifer's northern section, exhibit sedimentation characteristics. Conversely, the majority of the aquifers in the area demonstrate corrosive attributes. Thus, it is imperative to exercise utmost caution when utilizing these resources in pressurized irrigation systems and industrial, urban, and agricultural water supply systems in order to mitigate potential harm to pipelines and metal connections.

Highlights

- The study provides a comprehensive assessment of groundwater chemical quality over an 18-year period for industrial use in the Ghorove–Dehgolan aquifer.
- The study found the highest levels of electrical conductivity, total dissolved solids, and sodium absorption ratio in the aquifer during 2013–2018.
- The finding revealed that 22% of water samples are affected by scaling, while 78% are prone to corrosion, with qualitative zoning maps indicating sedimentation in the southern and a portion of the northern aquifer.
- The study highlights the need for caution in using these water resources to prevent damage to pipelines and metal connections in various systems

[*] Corresponding author.
E-mail address: e.yousefi.m@gmail.com
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1. Introduction

As one of the most vital elements, water plays a critical role in all aspects of human life, including human well-being, social economic development, and ecosystem life (An et al., 2014). In addition to being essential for human life, water is also one of the determining factors in the quality of human life (Raju et al., 2011; Raju et al., 2014 and Toumi et al., 2014). One of the important sources of fresh water needed by humans is groundwater, which is the largest fresh water reserve on earth after glaciers (Yousefi Mobarhan and Peyrowan, 2022 and Todd and Mays, 2005). Groundwater is a renewable, limited, and vital resource for human life, social, and economic development, a valuable component of the ecosystem, and vulnerable to natural and human impacts (Singh et al., 2011). In recent years, because of the sharp decrease in the volume of groundwater, it has been important to check its quality and protect it accordingly. Water quality is a function of physical, chemical, and biological variables and is mainly controlled by two natural and human factors.

Natural processes such as the geology of the region, the speed of groundwater movement, recharge of water quality, the interaction of water with rock and soil, the reaction with other aquifers, and activities related to human intervention, including agricultural, industrial, and urban development activities and increasing the use of water resources (Chan, 2001) Currently, understanding the quality of groundwater is one of the most important and vulnerable sources of water supply (Shokuhi et al., 2011), and a better understanding of the spatial and temporal relationships between water quality and variables Geography and environment can play an important role in the effective and efficient planning of resources. Many industries use water for various purposes, such as cooling devices, producing materials, and using steam boilers and hydroelectric power plant.

Waters can undergo corrosion or scaling, both of which have adverse effects on the industry (Lotfinasabasl et al., 2020). The effects of corrosion and scaling in water supply systems, transmission, and distribution can increase operating costs and create negative effects on human health (Bamdad Machiani et al., 2014; Ehsani et al., 2013). Therefore, the science of water quality will remain an important issue for engineers and scientists in the coming years (Arand et al., 2008). Several methods have been invented and developed to investigate the chemical quality of water (Kelly et al., 1940; Najafzadeh and Tafaroj, 2016; Najafzadeh and Zahiri, 2015; and Nouri et al., 2012).

The hydrogeochemistry of the Sahand watershed using the Piper diagram by Naseri et al. (2010) was evaluated. They introduced the facies and groundwater type of this basin as calcium/sodium bicarbonate. They also assessed water quality as suitable for drinking and agriculture. In the study of the quality of water resources in the Koh-Zar mineral area in the west of Torbat Heydarieh, Khmer et al.(2011), after measuring the cations and anions of the water samples taken from the groundwater sources, determined the type of water in the area as Cl– Na and HCO3–Na and the water quality based on Schuler and Wilcox diagrams in terms of inappropriate drinking and agriculture.

Sahbaei Lotfi (2013) investigated the condition of the Baba Aman River from the headwaters of the Etrak River for drinking, industrial, and agricultural purposes, as well as its long-term quality changes. The results of the study were drawn on the basis of the Wilcox and Schuler charts. The results showed that the water in this river at the site of the station is suitable for agricultural and drinking purposes and that the water salts are increasing at the site of this station. Hoseinsarbazy and Esmaili (2014), by examining the indicators of corrosion and scaling of groundwater quality, concluded that all the samples in the Neyshabur Plain have scaling properties. Investigating the hydrogeochemical quality of groundwater in the Siyahu Basin by Gholamdokht Bandariet al.(2018), they showed that according to the quality index of Wilcox and Schuler, the groundwater for agricultural purposes was at the average level, and in terms of potability and Langelier saturation coefficient, they evaluated the available water sources as Corrosion to Scaling. Aghdam et al. (2019) investigated the qualitative zoning of groundwater resources in the Naghade plain for drinking, agriculture, and industry. The evaluation of industrial water quality showed that 61% of the water samples in the study area were scaled and 39% were corrosive.

The water quality assessment of the Kopal River by Lotfinasabasl et al. (2020) was investigated, and the results showed that the quality of water for three purposes (drinking, agriculture, and industry) has been greatly reduced by moving toward the final years, especially the last five years under study, and industrially, the water of this river has sedimentation effects. Jiang et al. (2020) investigated the hydrochemical characteristics and water quality assessment of rivers in different areas of cities. The results of the irrigation water quality evaluation showed that the Tuo River samples have high salt and low alkalinity and can be used for irrigation under suitable soil washing conditions, whereas the Bian River water samples have high salt content and are suitable for watering saline plants.

Chai et al. (2020) investigated hydrogeochemical properties and assessed the quality of groundwater in Dahui city, China, using multivariate statistical analysis. The results will be useful for the development and management of groundwater resources. The quality of water resources in the Ruin Esfrain karst aquifer in North Khorasan province was reviewed by Motamedi Rad. The water quality of springs in the region in terms of industrial use also showed that all water samples in the region have scaling properties, except for the Sengua spring, which has scaling water. Also, in research by Yousefi et al. (2022), they evaluated the water quality of aqueducts for different uses in Nain, drew the charts of Shuler, Wilcox, and Piper, and determined the quality of aqueducts for drinking, agriculture, and industry. most of the Qanats under study were part of the Scaling group, and only two Qanats from Hyderabad and Arend were in the corrosive category in terms of water quality for industrial use.

By reviewing the sources, it was found that the Langelier index is one of the most useful and reliable indicators in determining the quality of groundwater for industrial purposes, and the researchers' use of this index confirms this. Since excessive harvesting, meteorological droughts, and the climate change trend have become more intense in recent decades and have changed the quality of groundwater, a comprehensive study of the quality is still needed. Groundwater for various uses, especially for industrial purposes, has not been used in the Ghorveh–Dehgolan plain. Therefore, this research tries to investigate the trend of variables affecting the quality of groundwater in the time periods and spatial areas of the Ghorveh–Dehgolan aquifer. Using GIS to zone the spatial changes in groundwater quality in the study area for industrial uses with the Langelier index, the results can be used to plan for the proper exploitation of groundwater resources.

2. Materials and Methods

2.1 The study area

The Ghorveh-Dehgolan is one of the 11 areas or plains of the Sefidroud basin, which has an average annual rainfall of 352 mm and a semi-arid and cold climate. It is located to the east of Sanandaj city and northwest of Hamedan. The geology of the Ghorveh-Dehgolan plain is part of the Sanandaj-Sirjan construction zone, which is considered to be one of the most active construction zones in Iran (Rahmati et al., 2016). The southern elevations of the Ghorveh plain consist of metamorphic rocks such as Schist, Marble, Amphibolite, and Gneiss, along with igneous masses with different compositions. The intensity of tectonic forces in the northern parts of the region is less than that in the southern parts. In the northern half of the plain, from the Miocene to the beginning of the Quaternary, magmatic activities have caused the formation of basalt and andrite volcanic formations in the region.

This plain is bounded from the west by red sandstone heights and early dolomitic limestones, from the east by dolomitic limestones, from the north and northeast by Plio-Pleistocene formations, and from the south by internal igneous and metamorphic formations. the highlands of Bi-Khair are separated from the Ghorve plain (Abassi et al., 2015). Its minimum and maximum temperatures are -23 and 41 °C, respectively; the average annual relative humidity is 45%; and the maximum evaporation in July is more than 350 ml. The soil of these lands has great talent and ability in terms of irrigation and agriculture, and the cultivation of all kinds of agricultural and native plants has good performance at low cost. These lands have deep - surface soils with medium- to heavy texture and high water retention capacity. The study area is shown in Figure 1.

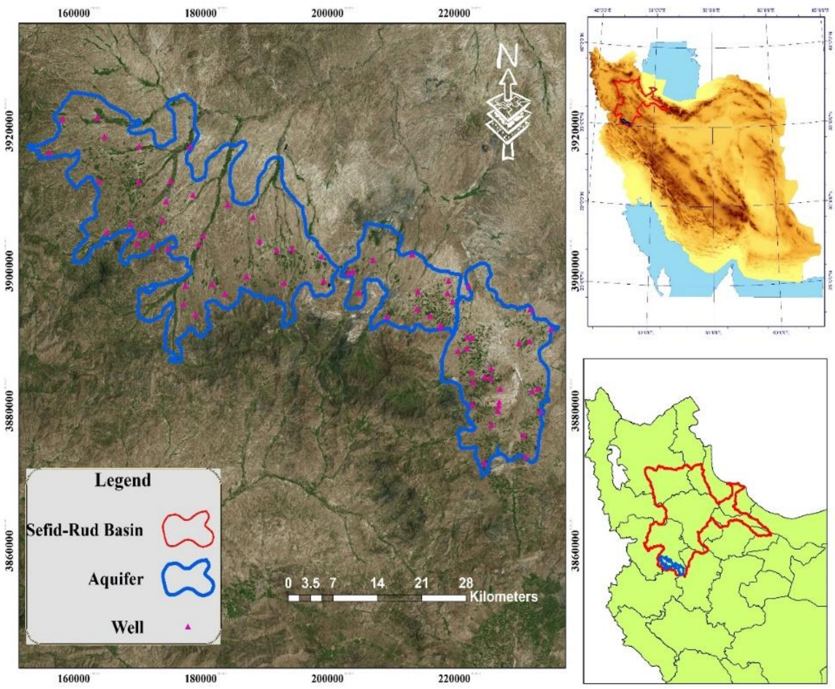

Figure 1. Geographical location of the study area

2.2 Statistics and qualitative information

The first step in using water quality data is to check the accuracy of the collected data. In the investigation of the quality data of the underground water, after preliminary checks of the data from the last sampling period and elimination of the existing errors, samples with an ion error percentage higher than 5% of the total anions and cations in the analyses were not used. Note that in the analysis of the water quality parameters of the Ghorveh-Dehgolan plain, 276 water samples were taken to measure the water quality in the Ghorveh-Dehgolan aquifer. In the current research, the chemical quality of groundwater sources in the plains has been investigated using the results of qualitative analysis of water samples in deep and semi-deep wells from three periods (periods 2001–2008, 2008–2013, and 2013–2018), and it has been analyzed according to the common statistical period of 18 years (2001–2018). The analyzed statistics and information include the results of a complete chemical analysis of water and variables such as electrical conductivity (EC) values, total dissolved substances (TDS), pH, cations (calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), and potassium (K^{+}), anions (chloride (Cl^{-}), sulfate ($SO4^{2-}$), bicarbonate (HCO_3–), and carbonate (CO_3^{2-}), sodium percentage (%Na), and sodium absorption ratio (SAR).

2.3 Water quality index based on industrial use

The Langelier index was used to measure water quality for industry based on equations 1 and 2 (Llyod and Heathcote, 1985; Rahimi et al., 2016; Sadeghi Aghdam et al., 2019).

$$LI = PH_a - PH_s \quad (1)$$

$$PH_s = A + B + C \quad (2)$$

In the above equations, pH is the measured acidity of water, pH is the modified acidity, A is the negative logarithm of the total concentration of Ca, Mg, Na, and K ions, B is the negative logarithm of the total concentration of Ca and Mg ions, and C is the negative logarithm of HCO_3^- and CO_3^{2-} ions. In this regard, the concentration of the ions is expressed in terms of equivalents per liter. In this regard, LI is the Langelier index, which is an index for corrosion and sedimentation. Table 1 shows the classification of water quality for industrial uses based on the Langelier Index (LI). Water with a negative saturation index is corrosive and can adversely affect wells and water supply facilities. Waters with a positive saturation index are sedimented, and their use in steam boilers and low-pressure heaters is not allowed. Waters with a zero-saturation index are in a state of equilibrium and do not have corrosive or sedimentation properties (Gholamdokht Bandari et al., 2018).

Table 1. Quality of groundwater in the Sefid– Rud Basin based on Langelier indices (Lotfinasabasl et al., 2020)

(LI)	Quality (Langelier)
LI<0	Water is supersaturated and tends to scale $CaCO_3$.
LI=0	Water is saturated with CaCO3 and does not tend to form or decompose $CaCO_3$.
LI>0	The water is undersaturated, and the decomposition of solid $CaCO_3$ is not expected.

Zoning is used to display water quality data and the trend of changes in parameters affecting the quality of underground water for industrial purposes (Yousefi Mobarhan and Karimi Sangchini, 2021; Yang et al., 2004). The distribution map of each of the effective parameters in the classification for 65 sampled points was prepared in the ArcGIS 10.5 software environment using the Kriging method. The Kriging interpolation method is calculated on the basis of the weighted moving average and is the best unbiased linear estimator with the minimum estimation variance (Nadiri et al., 2015). Each of the effective parameters in the water quality classification according to the type of use for drinking, agriculture, and industry was prepared by the normal Kriging interpolation method and the Gaussian model. Each layer was classified based on the Langelier (industrial) index.

3. Results and discussion

3.1 Statistics and qualitative information

In the statistical analysis of groundwater in the Ghorveh-Dehgolan aquifer plain, while determining the maximum, minimum, and average values of the qualitative variables at the level of the study areas and the trend of qualitative changes in the aquifer level according to the water electrical conductivity map, groundwater was investigated and analyzed.

According to Figure 2, it can be seen that the salinity value in the Ghorveh-Dehgolan aquifer in all three-time scales is lower than the maximum value given by Wilcox (2250), and it can be said that the plain is in a good state in terms of salinity. The average values of EC and TDS in the border of the Ghorveh-Dehgolan plain during the 3 time periods under study have had an increasing trend, which indicates that the plain has a trend toward salinity and its quality has decreased over time (Figure 3).

Note that the increasing trend of the electrical conductivity of the Ghorveh-Dehgolan aquifer in all three statistical periods is consistent with the findings of Abbasi et al. (2016), who stated that the quality of underground water in the Ghorveh-Dehgolan plain is decreasing, and if the current trend continues in the near future, it can cause many crises in terms of various uses.

The maximum electrical conductivity (EC) and total dissolved solids (TDS) were observed in the period of 2013–2018 in the Ghorveh– Dehgolan aquifer (669 µS/cm and 430 mg/l), respectively. In addition, the results showed that the increase in TDS had a significant effect on the increase in electrical conductivity, especially in the last years of the study. Figure 3 shows that the sodium absorption ratio (SAR) in the plain has an upward trend, and the maximum sodium absorption ratio in the third period (2018–2013) in the plain is 0.95%. According to Figure 4, among the cations, the highest amount is related to the calcium ion, followed by the sodium ion. It is possible that the presence of calcium ions is due to the dissolution of carbonate minerals in the geology of the region. In addition, the dissolution of carbonate minerals such as dolomite and calcite and minerals containing magnesium ions may be the reason for the increase in magnesium in water. It has been a study that has had a relatively constant trend in the years under review (Figure 5).

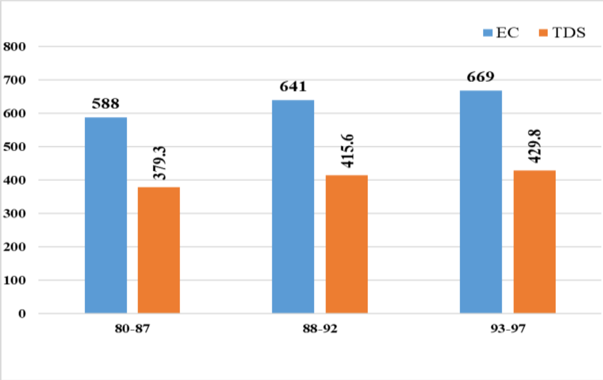

Figure 2. EC and TDS values in the groundwater of the Ghorveh– Dehgolan aquifer

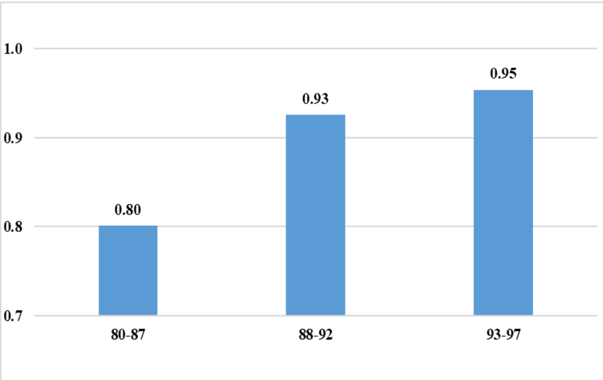

Figure 3. SAR values in the groundwater of the Ghorveh– Dehgolan aquifer

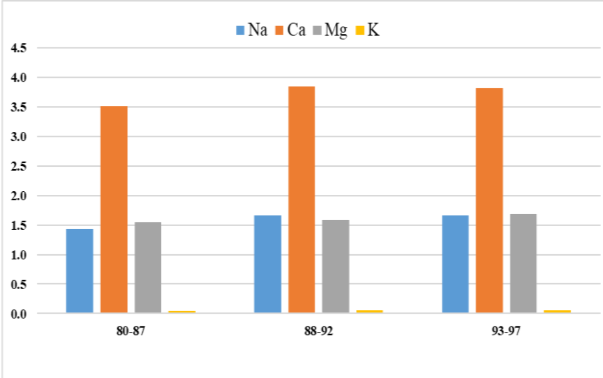

Figure 4. Values of cations (Na, Ca, Ma, and K) in the groundwater of the Ghorveh– Dehgolan aquifer

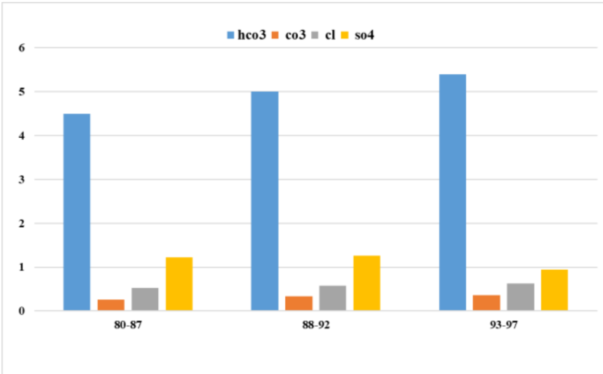

Figure 5. Values of anions (Hco3, Co3, Cl, and So4) in the groundwater of the Ghorveh– Dehgolan aquifer

3.2 Analysis of water quality based on industrial use

In the classification of water for industrial use, salinity, number of solutes, degree of hardness (permanent and temporary), and its reaction environment are essential. Therefore, first, after calculating the hardness of alkalinity, TDS, pH, and temperature, the pH value of water in the saturated state of calcium carbonate (pHs) was calculated from equation (2), and finally, using equation (1), the values The Langelier Index (LI) was determined to determine the corrosion and scaling properties of the Ghorveh-Dehgolan aquifer for the statistical periods under study. Figure 6 shows the zoning of the industrial uses of the Ghorveh-Dehgolan aquifer in three periods (2001–2008, 2008–2013, and 2018–2013).

Table 2. Quality classification of industrial water based on the Langelier index (LI)

Water quality for industrial use	Langelier index	Percentage of samples
Corrosion	LI<0	78
Scaling	LI>0	22

As Figure 6 shows, in all three time periods investigated based on the Langelier index, the spatial distribution of parameters affecting the quality of corrosion and scaling in the plain's groundwater is such that the zoning maps divide the quality of the plain into two scaling groups in the southern and some northern parts and corrosion in most of the other areas. The zoning results presented in Figure 6 show that the scaling property of the plain's groundwater has decreased, and in the third period (2013–2018), the quality of the groundwater in most of the plain's area has become corrosive. In general, the quality of underground water and its corrosion and sedimentation properties depend on the geological context of each region. In addition, according to Langelier classification, 78% of the samples are corrosion and 22% are scaling (Table 2), and the findings of this study are in agreement with the results of Motamedi Rad et al. (2021), Rahimi et al. (2016), and Gholamdokht Bandari et al. (2018).

In their study, they found that the quality of the groundwater in the studied areas, in terms of the industrial uses of the area, often has corrosive properties.

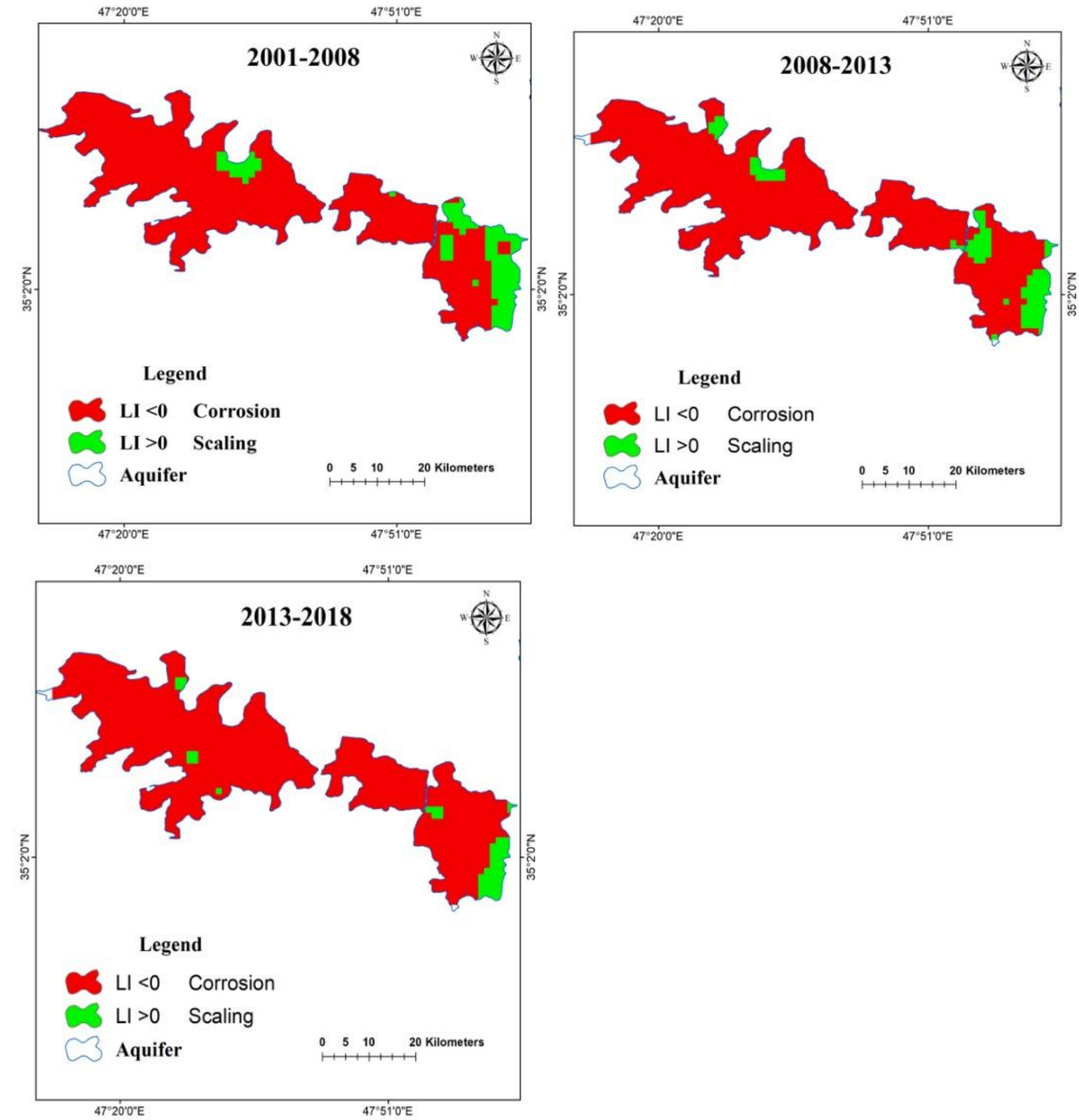

Figure 6. Zoning industrial uses the Ghorveh– Dehgolan aquifer, separated by 3 statistical periods

4. Conclusion

Surface waters, especially rivers, are one of the most important water sources that are used to resolve the needs of human societies and for various purposes, including drinking, industry, and agriculture. Therefore, water quality, like its quantity, is one of the most important determining factors. It is considered effective for its use for various purposes. The chemical variables of water play an important role in the classification and evaluation of water quality; therefore, measuring and examining these variables is one of the necessities of their study. In this study, to investigate the water quality of the Ghorveh-Dehgolan aquifer and the change process, the chemical variables of the water were investigated. The results of the study showed that, in the 18-year statistical period, the average values of EC, TDS, and sodium absorption ratio (SAR) in three statistical periods limited to the plain had an increasing trend, and the increase in TDS had a significant effect on the increase in electrical conductivity, especially in the last years of the study. It shows the highest values of cations, respectively, for Ca^{2+}, Na^{+}, Mg^{2}+, and K^{+} ions in the boundary of the aquifer. The highest numbers of anions included HCo_3^-, SO_4^{2}-, and Cl^-. The qualitative evaluation of the groundwater resources of the Ghorveh-Dehgolan plain for industrial purposes based on the Langelier index showed that the change trend of this index was toward corrosiveness, and out of 276 sources in the basin, 214 sources had corrosion characteristics and 62 sources had scaling characteristics. The results also showed that the groundwater in most of the aquifer area of the Ghorveh-Dehgolan plain has corrosive properties, and its use in urban water supply systems will cause disease in humans and various problems caused by the corrosion of pipes. Therefore, in the use of these resources in industrial, urban, and agricultural water supply systems, especially in pressurized irrigation systems, the necessary measures should be considered to minimize damage to pipes and metal connections. In addition, by reducing the extraction of underground water and reducing the area of cultivation in areas where the required water is supplied only through aquifers, the quality of the underground water can be managed even in dry years.

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