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ORIGINAL ARTICLE

Spatial variation of corrosion and scaling potential of groundwater using kriging (Dezfoul – Andimeshk Plain)

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ABSTRACT
Water quality has great importance in water resources planning. Lack of control of chemical water quality in distribution systems led to the phenomenon of corrosion, scale formation and economic damage.If the water has a tendency to scale, over time, creating layers of sediment in the inner pipe, reducing the inside diameter of the pipe and the water flow will reduce transmission. Corrosion causes dissolution of pipes, which eventually led to the entry of pollutants into water. Corrosion and scaling Potential is determined using the Langelier Index (LSI) and Ryznar index (RI).In this paper we use data of water quality analysis samples from 105 wells in the Dezfoul – Andimeshk Plain, spatial analysis of Langelier Saturation Index (LSI) was performed using kriging gaussian model. Langelier index was negative for only two wells and the rest of the Langelier index value is greater than zero. These values vary from - 0.15to 1.05 with a .535 average, which shows the scaling conditions. Langelier index shows increasing scale forming tendency from north to south of plain. The spatial analysis Ryznar index (RI) was modeled using kriging exponential which the status of groundwater in parts of the northern plains, slightly corrosive, neutral in middle and southern part is slightly scaling form. Generally Ryznar index varies from 5.4 to 7.68 with the average 6.41.
Key words: *water quality, scaling, corrosion, Langlier and Ryznar indices.*

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INTRODUCTION

Corrosion is the physical and chemical reaction between the substance and its surroundings, which leads to changes in the material properties. In the area of engineering materials, due to the nature of the corrosion process, this phenomenon is examined in two major categories, which include corrosion caused by erosion and electrochemical corrosion. The first type includes material damage dealt by physical factors such as suspended solids in water or sewage pipes. Due to the nature of the factors in the occurrence of this phenomenon in metallic and non-metallic pipes such as concrete is likely. The second type includes electrically powered and electrochemical reaction between the environment and the materials in it which due to the nature of the metal material such as steel pipes used in water distribution and transmission lines to occur [1].

Cause corrosion of metal pipe materials being released into the liquid to be transitional. If corrosion occurs rapidly, causing a hole in the pipe and the pipe is punctured and when negative suction pipe will cause contaminants to enter and the water tends to be deposited layers of sediment over time, inner tubes, reducing the inside diameter of the pipe and the pipe is lowered into the water stream transmission [2].

Corrosion can affect public health, public acceptance and cost of providing a water source for drinking water influence. Decomposition of the material from corrosion can be a big annual spending on scarce resources of money to repair, replace and maintain a distribution system [3].

Studies show that most deposits formed in water distribution systems consisting of calcium carbonate, magnesium carbonate, calcium sulfate and magnesium chloride. So some of the above factors, the uncontrolled deposition, causing tubal obstruction and operation costs increase [4].

Various indicators exist to assess the status of water corrosion and scale formation. Langelier Index and Ryznar are two of the most recognized and the most plausible of those indices. The point calculation of these indicators in the groundwater samples and sampling locations without interpolation, determines the spatial distribution of the values of these indices. There are several methods for interpolation. Interpolation methods can provide different results. One of interpolation methods is kriging as a geostatistical method. In terms of spatial position and spatial dependence between samples, it helps to a better understanding of the community. The geostatisticsis actually trying to communicate between different values of a variable and distance and position them relative to each other that is called the spatial structure. The geostatistical approach, each sample is associated with a maximum distance of surrounding samples [5].
Several researchers have investigated the water situation in terms of scaling and corrosion. Mazloumi et al.[6] studied the corrosion potential of the Shiraz city's drinking water and according to the Langelier Index and Ryznar determined that Wells that supply drinking water to the Shiraz and Doroudzan are relatively scale forming. Sadeghiet al. [7] assessed the potential for corrosion and scaling for sources, reservoirs and water distribution networks of Qian using the Langelier index and Ryznar. Results showed that water has a corrosive situation (with minor to severe conditions). Sefidian et al. [8] studied the Kahou village water resources (KhorasanRazavi) based on the corrosion and scale formation using the Langelier Index. Finally, it determined the samples of the neutral, corrosive and scaling water. Ghanizadeh and Ghaneian [9] studied the corrosion and scaling potential of drinking water of supply systems for military facilities. The results showed that the water used in the three studied centers has the corrosion potential. In other centers, there is scaling potential. Savari et al. [10] evaluate corrosion in distribution network of drinking water of Ahwaz. The results of corrosion indices, Langelier (0.56-), Ryznar (8.43), showed that the city's drinking water tends to be corrosive conditions. The purpose of this study is to investigate the corrosion and scaling potential of Dezfoul – Andimeshk Plain groundwater using the Langelier Index and Ryznar which Using kriging to assess the spatial distribution of both indices.

Study area

Dezfoul – Andimeshk Plain - an area of about 2070 square kilometers - is located between latitudes 48° 9' to 48° 47' East Longitude and 32° 2' to 32° 36' North latitude. Plain is located in North West of Khouzestan province, Iran. The studied Aquifer Unlike most plains of Iran is seen the maximum water level in the months of September and October and a minimum balance in the months of February and March. Due to the hot dry climate of the region, crops are grown in all seasons. Average annual rainfall is 400 mm of rain. Average temperature of 3 ° C is in winter and 49 degrees Celsius in summer. Hottest and coldest months are January and July respectively.

METHODOLOGY

This study aimed to determine the potential for Dezful corrosion and scale groundwater in plain of Dezfoul - Andimeshk using the Langelier Index and Ryznar. To this purpose, the values Ca, Mg, Na, K, HCO_3 and CO_3 for 105 wells in region was used.
To calculate the Langelier Index and Ryznar, the PH and PHc must be calculated:

$$PHc = P(Ca+Mg+Na+K) + P(Ca+Mg) + P(CO_3+HCO_3)$$

P(Ca+Mg+Na+K): is a parameter whose value depends on the sum of the cation concentrations of calcium, magnesium, sodium and potassium.
P(Ca+Mg): is parameter whose value depends on the volume concentration of calcium and magnesium ions (Ca + Mg).
$P(CO_3+HCO_3)$is a parameter whose value depends on the sum of carbonate and bicarbonate anion concentration and the concentration (CO_3 + HCO_3) value is obtained.

Langelier Saturation Index

Called the Langelier Saturation Index (LSI) on water acidity (PH) and the pH adjusted (pHc) is obtained:

$$LSI = PH-PHc$$

If it is positive (LSI> 0) there is a risk of carbonate precipitation, if the index is negative (LSI <0) then the water would be problematic in terms of corrosion [11].

Ryznar Index

Using the following equation can be used to calculate the index value [11]:

$$RI = 2PHc -PH$$

Using Table 1, the water situation is characterized in terms of corrosion and scaling.

Table 1- Ryznar Index classification

RI	Water situation
< 5.5	Heavy scale
5.5 – 6.2	Scale
6.2 – 6.8	Neutral
6.8 – 8.5	Corrosive
> 8.5	Very corrosive

Interpolation

After calculating the Langelier index and Ryznar using software ARC GIS, spatial distribution maps were prepared for the Langelier Index and Ryznar using kriging. Kriging is a geostatistical estimation method based on weighted moving average. So that it can say this method is the best linear unbiased estimator. The Estimator is defined as follows:

$Z^*(x_i) = \sum \lambda_i . Z(x_i)$

$Z^*(x_i)$ is predicted value at point x_i, $Z(x_i)$ observed value at point x_i, λ_i weight or importance of i sample. This type is called a linear kriging because it is a linear combination of n data. The condition of this estimate is that the variable Z is normally distributed. Otherwise, or the use of non-linear kriging or somehow be transformed to the normal distribution of the variables [12].

The most important part of kriging is determination of weights λ_i to be unbiased estimates, the weights should be specified so that their sum is equal to 1 [12].

$$\sum \lambda_i = 1$$

To investigate the spatial correlation and structure of LSI and RI indices using the software ARC GIS, variogram of data were analyzed.

RESULTS

According to the data in Table 2 and plotted the histogram (fig. 1 and 2), it is characterized that both LSI and RI indices have low skewness therefore the data are normal.

Table 2 - Descriptive statistics of variables

Variable	Min	Max	Mean	Standard deviation	Coefficient of variations	Med	Skewness	Kurtosis
LSI	0.15	1.05	0.5350	0.2384	0.4456	0.57	-0.313	2.9037
RI	5.4	7.68	6.4171	0.4531	0.0706	6.36	0.378	3.0333

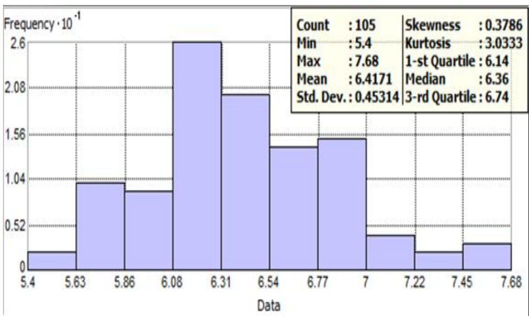


Figure 1- Frequency Histogram of RI

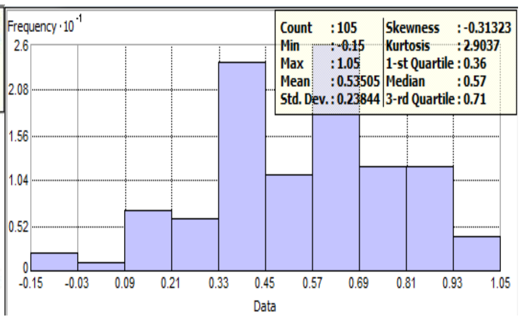


Figure 2- Frequency Histogram of LSI

In this study, the kriging method for interpolation was used. To uses this method, first variography operation is performed and the theoretical model is fitted to the experimental variogram. Then according to the fitted model interpolation is done. Studied models included: circular, spherical, exponential, and a gaussian. Finally, with respect to the values of the RMSE, the spatial distribution was obtained using the Langelier index Gaussian kriging model and the exponential model using kriging Ryznar. According to Table 3, the Gaussian model with the least amount of errors equal to RMSE = 0.1972, was selected to evaluate the spatial distribution of LSI Langelier Index. To assess the spatial distribution of Ryznar Index (RI), the exponential model is used with RMSE = 0.340 compared to three other models with the highest accuracy and the lowest error.

Table 3- values of RMSE for Langelier and Ryznar indices

Model	Kriging (LSI)	Kriging (RI)
Circular	0.1981	0.343
Spherical	0.1977	0.342
Exponential	0.1990	0.340
Gaussian	0.1972	0.360

Nugget effect than the sill (C0/C0+C) is an indicator of the strength of the spatial variables. If this ratio is less than 0.25, which is indicative of strong spatial correlations and if this ratio is between 0.25 - 0.75 moderate spatial dependence can be represented as the ratio greater than 0.75 would be indicative of a weak spatial dependence [13].According to Table 4, Ryznar and Langelier indices data have weak and moderate spatial dependence, respectively. Effect range of the Langelier and Ryznar indicesis 19464 meters and 61589 meters that due to the spatial dependence of the two parameters is justified. Table 4 shows characteristics of fitted kriging model. Variograms of indices data are presented in figures 3 and 4.

Table 4 - Results of the geostatistical analysis of Langelier and Ryznar indices in kriging

Variable	Model	Nugget (C0)	Sill (C0+C)	Range (m)	C0/C0+C	Spatial correlation
LSI	Gaussian	0.02844	0.02653	19464.12	1.071	weak
RI	Exponential	0.06279	0.20988	61589.56	0.299	moderate

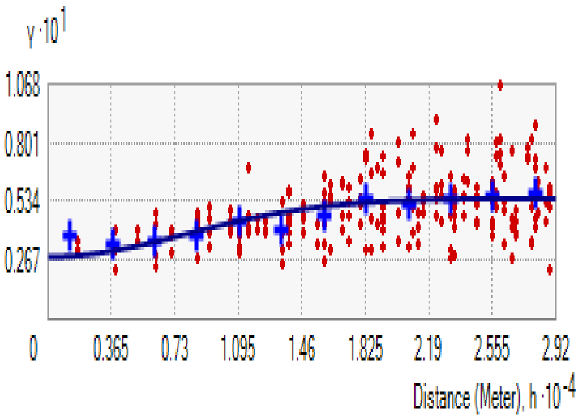


Figure 3- Variogram of RI

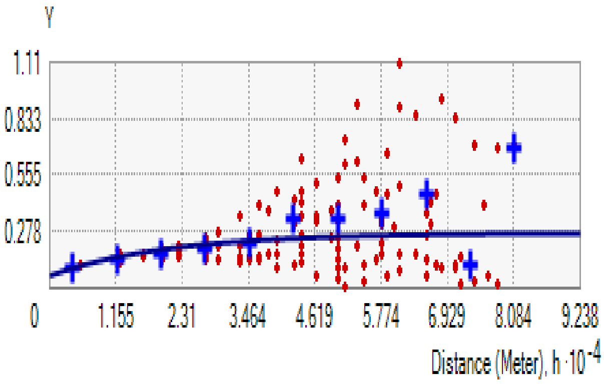
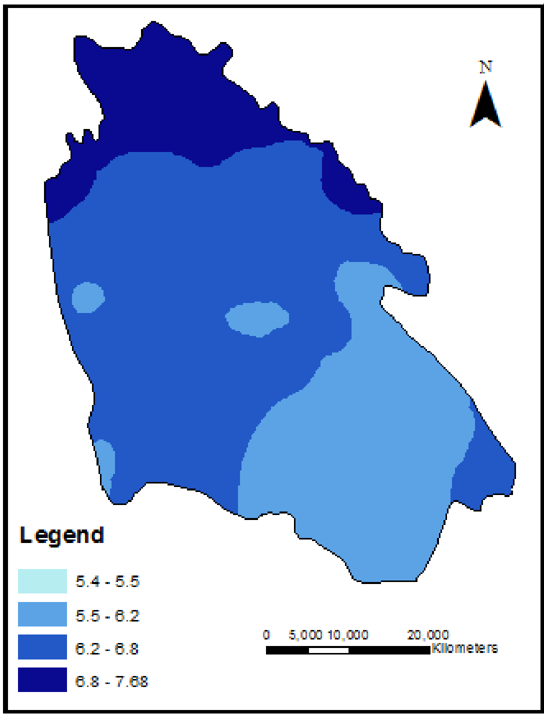


Figure 4- Variogram of LSI

Spatial distribution maps of Langelier and Ryznar indices of ground water

Using data obtained from the analysis of groundwater quality of Plain, Langelier index was calculated. Results showed that Langelier index is negative only for 2 Wells, Given the negative Langelier index points and the classification criteria, corrosive water conditions for these two wells are reported. The rest of the amount is greater than zero and is positive Langelier Index (LSI> 0).Given the positive Langelier index, water tends to be characterized by carbonate precipitation at these points. Using Gaussian kriging model, the spatial distribution of Langelier index was developed. According to Figure 5, the tendency to scale forming of groundwater from the North to the South of Plain shows an increasing trend. Langelier index varies from -0.15to 1.05 and in terms of this indicator, groundwater of most area of plain is scaling.

Ryznar index results showed that for most of the plain area between Ryznar index value is 6.2 to 6.8 that according to Table 1, the water has a neutral situation. Ryznar index is 5.4 only for one well and water is high scaling. Water situation to nine points with respect to the Ryznar classification is 5.5 – 6.2 that is slightly scaling. According to fig. 6, the spatial distribution of Ryznar index shows that the northern plains due to being in the range of 6.8 to 8.5, the water is slightly corrosive. Range 6.2 to 6.8 the maximum area in the middle of the plain into account that water situation in this area is neutral. Due to exposure to the southern part of the plain in the range of 5.5 to 6.2, the water situation in terms of Ryznar at this section is slightly scaling.



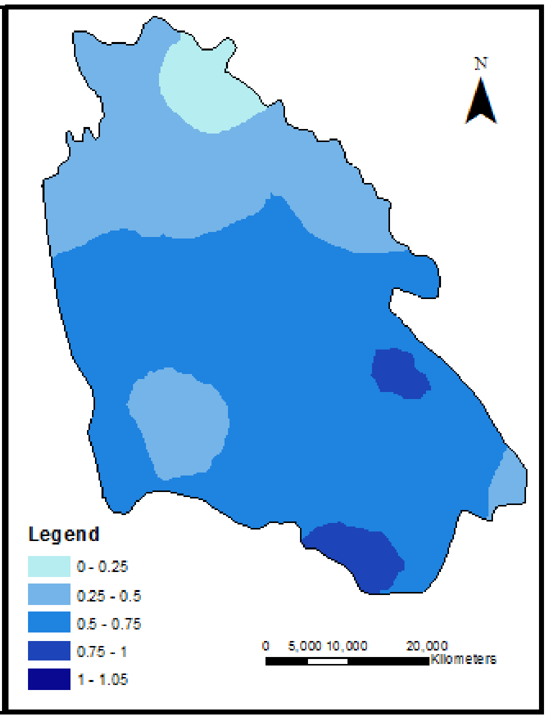


Figure 5 - Zoning map of RI Figure 6- Zoning map of LSI

CONCLUSION

Groundwater quality assessment of Dezfoul – Andimeshk Plain on Langelier Index (LSI) and Ryznar (RI) was performed. Average Langelier index is 0.535, which has scaling conditions. Langelier index indicates that in most area of plain LSI> 0 that is indicator of tendency of water to carbonate precipitation. For controlling and eliminating the tendency of scale formation must utilize methods that are leading to pH reduction. In other words, pH changes from alkaline to acidic. Among the proposed solutions can be pointed to inject CO2 into the water, adding sediment maker materials such as ortho phosphats and Meta phosphats, adding mineral acids into the water.

Langelier index was created using the spatial distribution of Gaussian kriging model which tend to show increased scaling of groundwater from the north to the south of plain. Average of Ryznar index was 6.41 which indicate a neutral condition. Most well studied was in the range of 6.2 to 6.8 which indicates the water is neutral. Only at the one well, Ryznar index is 5.4 indicator of high scaling and 9 wells are placed in the category of slight scale forming. The spatial distribution for Ryznar index was prepared using a kriging exponential model. Zoning maps Ryznar index can be concluded that the status of groundwater resources in the northern part of the plain is slightly corrosive. Middle part on the plain, with the largest area being in the range 6.8 to 6.2 is neutral status. Groundwater in the southern part of the plain, according to exposure in the range of 5.5 to 6.2, is slight scaling. Finally, according to the Langelier index and Ryznar can be concluded that although the status of groundwater in plain at low scale and corrosion is low, but the most of plain area is scaling.

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