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ORIGINAL ARTICLE

Assess the Potability of groundwater in terms of TDS and TH (case study: Dezfoul – Andimeshk Plain)

Fereshteh Zarif[1], Hossein Eslami[2]
1 -Msc student of Department of Water Engineering, Shoushtar Branch, Islamic Azad University, Shoushtar, Iran
2-Department of Water Engineering, Shoushtar Branch, Islamic Azad University, Shoushtar, Iran
Corresponding Author email: eslamyho@gmail.com

ABSTRACT
Groundwater is an important source of drinking water in many areas, including Iran. Groundwater is usually free of physical and organic impurities and main problem is related to chemical impurities. This study was conducted to investigate the ground Water Quality of Dezfoul – Andimeshk Plain in terms of potability and the effects on human health. To understand the distribution of ground water quality data relating to TDS and TH samples taken from 105 wells were used for variables. Geostatistical interpolation methods were assessed for TDS and TH variables. The results showed that the cokriging is suitable for both variables. Cokriging with fitted gaussian model with RMSE 384.7 was selected for mapping the spatial distribution of TDS. Map shows the TDS increases from north to south plain. Classified according to Schoeller for TDS, groundwater is on moderate quality. The spatial distribution of a variable TH was developed using an exponential cokriging model that represents the increase of TH from the north to the south plain. Due to exposure to most areas of the plain in the 250-600 range Schoeller classification, the quality in terms of potability is moderate.
Keywords: *Water quality, Geostatisics, TH, TDS, Kriging*

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INTRODUCTION

Today, the population growth in most regions of the world, drinking water supplies from groundwater sources is important. In cases where groundwater use is associated with the occurrence of diseases. One of the most important studies is to assess the quality of groundwater resources. If impurities in the water does not exceed certain limits does not preclude its use, because each consumption type has its own water standards. For example, quality standards for drinking water and agriculture are different. This criterion also did not specify the number or numbers that make up a wide range, which varies depending on usage conditions. For example, in the case of drinking water quality standards may limit the carbonate hardness of 200 mg per liter, but in some places due to water restrictions, water hardness of 500, and even more will also be taking [1].Using GIS, it can determine the zoning of the variable quality of drinking water. There are several methods to evaluate and interpolate of characteristics of groundwater. Each of the methods has different accuracy depending on local conditions, variables type and adequate data. Including interpolation methods for the preparation of maps of groundwater quality changes can be noted geostatistical methods (kriging and cokriging) and inverse distance weighted (IDW).In recent years, many studies on groundwater quality and its potential for agriculture and drinking is done using GIS.

Abdi [2], the Zanjanrood River basin water quality analysis, quality zonation map of kriging in GIS based on classification criteria Schoeller and wilcox provided. Entezari et al. [3] examined the quality of drinking water from groundwater sources and the impact on human disease in recent decades for Mashhad city. The results indicate a decreasing trend and especially in the southern part of the plain is unfavorable situation.

Mehrjardiet al. [4] conducted a spatial analysis of groundwater quality features such as TDS, TH, EC and SAR using geostatistical methods for Ardakan Yazd plain. The results showed that kriging is preferred having the lowest RMSE comparison kriging and IDW. Maanavi et al. [5] looked for changes in the quality of Isfahan city aquifer parameters electrical conductivity, hardness, alkalinity, sodium, potassium, sulfate, chloride, nitrate and nitrite from 79 to 82 in 57 wells in GIS. Adhikaryet al. [6] investigated the quality of groundwater for irrigation and drinking on the outskirts of Delhi, India using GIS and geostatistics. In this study, to evaluate the quality of groundwater Dezfoul – Andimeshk Plain terms of usability for drinking and the effects on human health, the spatial distribution of TDS and TH were prepared using geostatistical methods. Plain water quality for drinking was reviewed based on schoeller classification and national standards.

STUDY AREA

Plain of Dezfoul – Andimeshk 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. Plain area is about 2070 square kilometers. 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 warm dry climate of the region, crops are grown in all seasons. Average annual precipitation is 400 mm. Average temperatures is 3 ° C in winter and 49 degrees Celsius in summer. Hottest and coldest months are January and July respectively.

Methods

TDS

Total dissolved solids (TDS), refers to the total amount of all inorganic and organic substances – including minerals, salts, metals, cations or anions – that are dispersed within a volume of water. By definition, the solids must be small enough to be filtered through a sieve measuring 2 micrometers. TDS concentrations are used to evaluate the quality of drinking water systems. TDS concentrations are equal to the sum of cations and anions. Sources for TDS include agricultural and urban run-off, industrial wastewater, sewage, and natural sources such as leaves, silt, plankton, and rocks. Piping or plumbing may also release metals into the water.

While TDS is not considered a primary pollutant, high TDS levels typically indicate hard water and may lead to scale buildup in pipes, reduced efficiency of water filters, hot water heaters, etc., and aesthetic problems such as a bitter or salty taste. The United States Environmental Protection Agency (EPA) recommends treatment when TDS concentrations exceed 500 mg/L, or 500 parts per million (ppm). The TDS concentration is considered a Secondary Drinking Water Standard, which means that it is not a health hazard [7].

TH

Hardness is most commonly associated with the ability of water to precipitate soap. As hardness increases, more soap is needed to achieve the same level of cleaning due to the interactions of the hardness ions with the soap. Chemically, hardness is often defined as the sum of polyvalent cation concentrations dissolved in the water. The most common polyvalent cations in fresh water are calcium (Ca^{++}) and magnesium (Mg^{++}).

Hardness is usually divided into two categories: *carbonate hardness* and *noncarbonate hardness*. Carbonate hardness is usually due to the presence of bicarbonate [$Ca(HCO_3)_2$ and $Mg(HCO_3)_2$] and carbonate ($CaCO_3$ and $MgCO_3$) salts. Noncarbonate hardness is contributed by salts such as calcium chloride ($CaCl_2$), magnesium sulfate ($MgSO_4$), and magnesium chloride ($MgCl_2$). Total hardness equals the sum of carbonate and noncarbonate hardness. In addition to Ca^{++} and Mg^{++}, iron (Fe^{++}), strontium (Sr^{++}), and manganese (Mn^{++}) may also contribute to hardness. However, the contribution of these ions is usually negligible.

Hardness is usually reported as equivalents of calcium carbonate ($CaCO_3$) and is generally classified as soft, moderately hard, hard, and very hard. It is best to report results as the actual equivalents of $CaCO_3$ since the inclusive limits for each category may differ between users of the information. The classification scheme used by the U.S. Environmental Protection Agency (EPA) is shown in Table1.

Table 1- Water hardness classifications (reported as $CaCO_3$ equivalents) [7].

Classification	$CaCO_3$ equivalent (mg/L)
Soft	<75
Moderately hard	75–150
Hard	150–300
Very hard	>300

Standard and Industrial Research Institute Iran determine optimal and allowed limit for total hardness in drinking water 200 and 500 milligrams per liter, respectively. Assessment and classification of groundwater quality variables and parameters suitable for drinking was classified according to Schoeller(Table 2).

Table 2- classification of water quality based on Schoeller [1].

Water quality	TH	TDS
Good	< 190	< 280
Acceptable	190 - 250	280 - 500
Moderate	250 - 600	500 - 1000
Inappropriate	600 - 1000	1000 - 2000
Completely unpleasant	1000 - 20000	2000 - 4000
undrinkable	> 2000	> 4000

Interpolation methods

IDW

IDW interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location. Those measured values closest to the prediction location will have more influence on the predicted value than those farther away. Thus, IDW assumes that each measured point has a local influence that diminishes with distance. It weights the points closer to the prediction location greater than those farther away, hence the name inverse distance weighted and the general formula is as follows:

$Z(S_0) = \sum_{i=0}^{n} \lambda i.\ z(si)$

$Z(S_0)$ is estimated values in S_0; $Z(S_i)$ is observed values in S_i, λi: Weights assigned to each measurement point, n: The number of measurement points around the area. Weight equation is:

$\lambda_i = d_i^{-p} / \sum_{i=1}^{n} d_i^{-p}$

That d_i is the distance between observed and estimated points, P; the optimal power (p) value is determined by minimizing the root mean square prediction error. Geostatistical prediction includes identification and modeling of spatial structure. Continuity, homogeneity and spatial structure of studied variables are studied using variogram. Next stage is geostatistical estimation using kriging technique which depends on the properties of the fitted variogram which affects all stages of the process.

Variogram analysis

Variogram method is a suitable technique for estimating spatial variability of a variable. Calculation of variogram graph is one of essential stages in geostatistics which is defined as follow:

$$2\gamma(h) = 1/n \sum_{i=1}^{n} \left[Z(xi+h) - Z(xi)\right]^2$$

Where: γ (h): value of variogram for pair points with distance h, n (h): Number of pair points with distance h, Z (xi): observed value of variable x and Z (xi+h): Observed value of the variable with distance h from x. Variogram is the variance of different points with distance h. The obtained variograph of measured samples is called experimental variogram which is a vector value that is a dependent of distance and direction. The properties of variogram include threshold (sill=C0). The threshold is the maximum value of variogram which is spatial variance of the variable. The lowest value of variogram includes spatial effect which shows variance of errors of measurements. The effective range demonstrates the distance that variogram has the highest value [8].

Kriging

Kriging is a prediction method that considers values of a variable in un sampled points as a linear composition of the values of surrounding points. Considering the values of variable Z in n measured points as follow:

$Z = (Z(x_1), Z(x_2) \ldots Z(x_n))$

Estimation of Z in point X_0 using kriging estimation is defined as:

$Z^*(x_0) = \sum \lambda_i.\ Z(x_i)$

The most important part of kriging is statistical weighs assigned to λi. To avoid bias of estimation, the weights should be determined in a way that summation is equal to one and the variance of estimates should be minimized.

Cokriging

As in classical statistics, multivariate methods, there can be kriging based on correlations between variables, can be used for estimator. Co-kriging equations are as follows [8]:

$Z^*(x_i) = \sum\lambda_i.\ Z(X_i).\ \sum\lambda_k.\ y(x_k)$

That $Z^*(x_i)$ is estimated value for x_i , λ_i is weight that related to Z variable, λ_k is weight of secondary variable, $Z(x_i)$ is value of observed main variable and $y(X_k)$ was observed value of secondary variable.

To choose the best interpolation method to convert point data to regional data, Cross-Validation technique is used. In this method in every stage, one observing point is omitted and with rest of observing point, that unknown point will estimated. For estimating carefulness RMSE criteria are used that consist of:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left[Z^*(xi) - Z(xi)\right]^2}{n}}$$

RMSE: Root Mean Squared Error, Z*(Xi): The estimated values, Z (Xi): The observed values, n: The number of observed samples.

RESULTS

In this study, three methods of interpolation kriging, cokriging and inverse distance weighted for spatial analysis of TDS and TH variables were evaluated. In order to study of spatial correlation and structure of TDS and TH variables using ARC GIS software, variograms of the data were analyzed. According to the data in Table 3 and plotted the histogram (figures 1 and 2), it is clear that both TDS and TH variables with high skewness and non-normal data. Therefore to normalize the data, a logarithmic function was used.

Table 3 - Descriptive statistics of variables

Vaiable	Min	Max	Mean	Standard deviation	Coefficient of variations	Med	Skewness	Kurtosis
TDS	128	2600	696.06	462.97	0.6651	543	2.1876	8.4159
TH	108.5	1012	360.37	147.51	0.4093	333.5	1.7713	7.6306

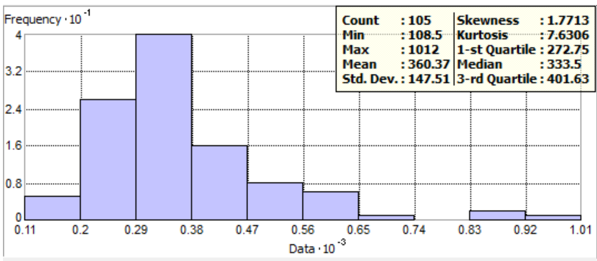

Figure 1- Histogram of TH

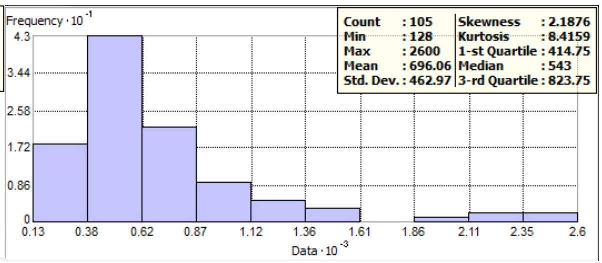

Figure 2- Histogram of TDS

To use geostatistical method, first variography operation is performed and the theoretical model is fitted to the experimental variogram. Then according to the fitted model interpolation is performed. Selected models included: circular, spherical, exponential, and Gaussian. According to Table 4, the Gaussian cokriging model with the least amount of errors equal to RMSE 384.7 was selected to evaluate the spatial distribution of TDS. To assess the spatial distribution of TH, the exponential cokriging model is used with RMSE 108 compared to other models with the highest accuracy and the lowest error.

Table 4 - Evaluation of interpolation methods for mapping groundwater quality parameters

Interpolation method	Kriging	Cokriging	IDW			
			Power 1	Power 2	Power 3	Power 4
TDS	396.83	384.7	396.970	418.928	447.838	471.7007
TH	111.28	108.9	115.2164	115.5007	133.2943	142.4388

Auxiliary variable is used for cokriging interpolation method. To select the auxiliary variables, each variable has a higher correlation with the original variables is selected. Cl variable having the highest correlation (R = 0.91) with the TDS is selected as auxiliary variable. Ca as well as the variable having the highest correlation (R = 0.90) were considered as auxiliary to the TH.

The ratio of nugget variance to sill expressed in percentages can be regarded as a criterion for classifying the spatial dependence of ground water quality parameters. If this ratio is less than 25%, then the variable has strong spatial dependence; if the ratio is between 25 and 75%, the variable has moderate spatial dependence and greater than 75%, the variables shows only weak spatial dependence [9].According to Table 5, TDS and TH data have moderate spatial dependence. Effect range of the TDS and TH is 78903 meters and 93433 meters. Table 4 shows characteristics of fitted cokriging model. Variograms of variables are presented in figures 3 and 4.

Table 5 - Results of the geostatistical analysis of water quality parameters in cokriging

Variable	Model	Nugget (C0)	Sill (C0+C)	Range (m)	C0/C0+C	Spatial correlation
TDS	Gaussian	0.1709	0.5272	78903.9	0.32	Moderate
TH	Exponential	0.05566	0.1489	93433.5	0.37	Moderate

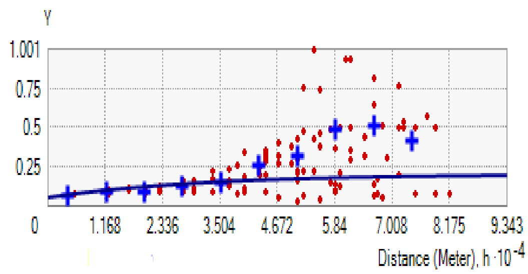

Figure 3- Variogram of TH

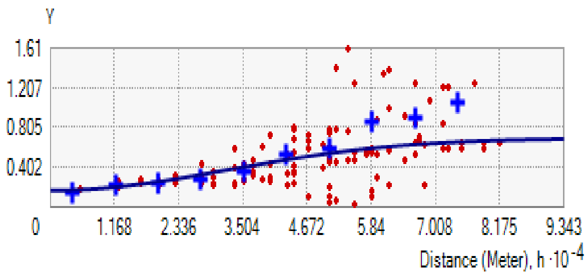

Figure 4- Variogram of TDS

Spatial distribution of TDS and TH

The spatial distribution of TDS values of plain groundwater, cokriging interpolation method and auxiliary variables of Cl in the fig. 5 is shown.TDS amount from the north to the south is rising and given in Table (2) most of the plains due to being in the range 500-1000 Schoeller classification for TDS, potability quality is moderate. Southeastern part of the plain, according to the classification being in the range 1000-2000 Schoeller, unsuitable for drinking will be assessed. Also, it can be concluded that the observed spatial distribution of TH, it increases from north to south, and most plain areas in the range 250-600 are classified that is moderate quality for drinking. According to fig. 7, the southeastern plains being in the range 600-1000Schoellerclassification are assessed inappropriate.

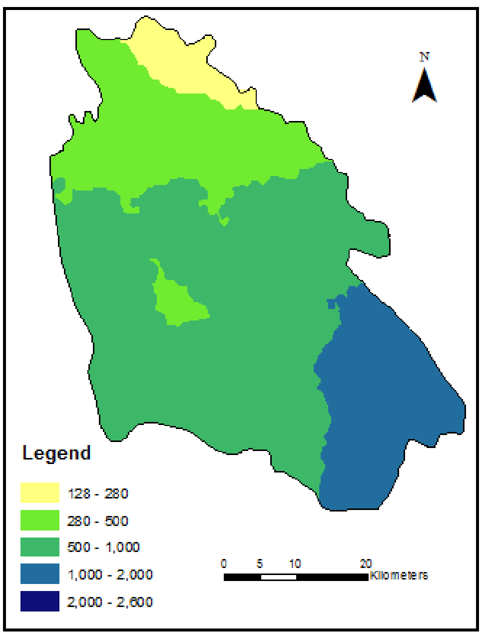

Figure 5- Spatial distribution map of TDS

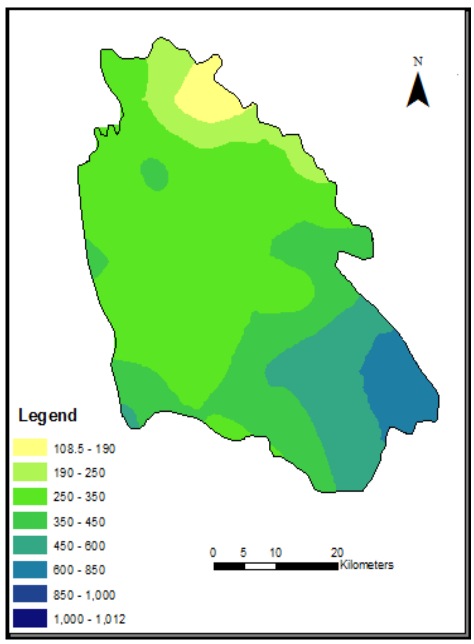

Figure 5- Spatial distribution map of TH

CONCLUSION

Variable TDS results showed that only 6 wells had more than 1,500 more than the allowed amount set by the national standard that In terms of drinking is inappropriate.TH also showed that only 12 wells have a value greater than 500 that are not suitable for drinking but the rest of the wells in the area are suitable.
Gaussian model cokrigings having the lowest RMSE 384.7 for the variable TDS also exponential model cokrigings with RMSE108 for the variable TH was selected as a method with higher accuracy rate than kriging and IDW for mapping the spatial distribution. Map prepared by the TDS using cokriging method and Cl auxiliary variable, the incremental amount of TDS from the north to the southern Plains shows. Given that most plain areas classified as being in the range 500-1000 for TDS, moderate drinking is evaluated in terms of quality, southeastern part of the plain, being in the range 1000-2000 are classified according to Schoeller, the assessment is unsuitable for drinking.
The TH map was produced using cokriging with auxiliary variable of Ca, it can be concluded that the increase in plain is from north to south, the majority of plain in terms of Schoeller classification placed in the range of 250 - 600, which is of moderate quality for drinking. Southeastern part of the plain, according to the Schoeller, is evaluated in terms of inappropriate drinking.

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