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Groundwater Quality Mapping of an Alluvial Aquifer, Eshtehard, Iran

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ABSTRACT

Eshtehard aquifer located in southwest of Tehran province, Iran, provides a large amount of water requirement for inhabitants of Eshtehard district. Monitoring and analyzing of groundwater quality are important for protecting groundwater as sustainable water resource. One of the most advanced techniques for groundwater quality interpolation and mapping is geostatistics methods. The purposes of this study are (1) to investigate major ions concentration and their relative abundance to provide an overview of present groundwater chemistry and (2) to map the groundwater quality in the study area using geostatistics techniques. In this investigation, ArcGIS 9.2 was used for predicting spatial distribution of some groundwater characteristics such as: Chloride, Sulfate, pH, and Conductivity. These methods are applied for data from 44 wells within the study area. The final maps show that the south parts of the Eshtehard aquifer have suitable groundwater quality for human consumption and in general, the groundwater quality degrades south to north and west to east of the Eshtehard plain along the groundwater flow path.

Keywords: Groundwater quality, GIS, geostatistics, Eshtehard, Iran

INTRODUCTION

Groundwater is the only reliable source for increasing water demand in arid and semi-arid regions around the world. Many regions in Iran are characterized by semi-arid climate. Eshtehard plain, located in west of Tehran, falls in a semi-arid type of climate. This aquifer provided the increasing water demand for irrigation, domestic, and industrial uses over the past century. The quality of water is as important as its quantity in any water supply planning especially for drinking purposes. The chemical, physical and bacterial characteristics of ground water determine its usefulness for municipal, commercial, industrial, agricultural, and domestic water supplies. Therefore, monitoring the quality of water is important because clean water is necessary for human health and the integrity of aquatic ecosystems (Babiker *et al*., 2007). However, due to cost and practicality, it is not feasible to establish monitoring stations in every location of study area to measure the pollutant concentration. Therefore, prediction of values at other locations based upon selectively measured values could be one of the alternatives. There are two main groupings of interpolation techniques: deterministic and geostatistical. Deterministic interpolation techniques create surfaces from measured points, based on either the extent of similarity (e.g. Inverse Distance Weighted) or the degree of smoothing (e.g. radial basis functions). Geostatistical interpolation techniques (e.g. kriging) utilize the statistical properties of the measured points. Using measured sample points from a study area, geostatistics can create prediction for other unmeasured locations within the same area The geostatistical techniques

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quantify the spatial autocorrelation among measured points and account for the spatial configuration of the sample points around the prediction location (ESRI, 2003). The accuracy of interpolation methods for spatially predicting soil and water properties has been analyzed in several studies (Nas and Berktay, 2006; LaMotte and Greene, 2007; Barca and Passarella, 2008). Thus this research has been done to investigate the spatial correlation of groundwater quality data set in Eshtehard aquifer and mapping groundwater quality in this area by using GIS and geostatistics techniques.

STUDY AREA

The study area is in Tehran province, about 100 km southwest of Tehran. This area lies between the longitudes of 48˚16' to 48˚50' and latitudes 35˚34' to 35˚47' (*Fig. 1*). It is surrounded by the Halghehdar Mountains to the north, Karaj plain to the east, Kordha and Ghezelban Mountains to the south and Hajiarab basin to the west. The area is characterized by a warm and dry climate in summer and cold and dry in winter, in way of modified Domartan method with an average annual temperature of 14.7˚C and a rainfall of 227 mm. The Eshtehard groundwater basin consists of the moderately permeable gravel formation and the overlying coarse sediments. The aquifer forms an east–west elongated topography deepening westward. The aquifer thickness ranges from 30 m in the east to more than 130 m in the west. Due to the lack of confining clay layers, the aquifer is considered typically unconfined. The groundwater flow is from west to east.

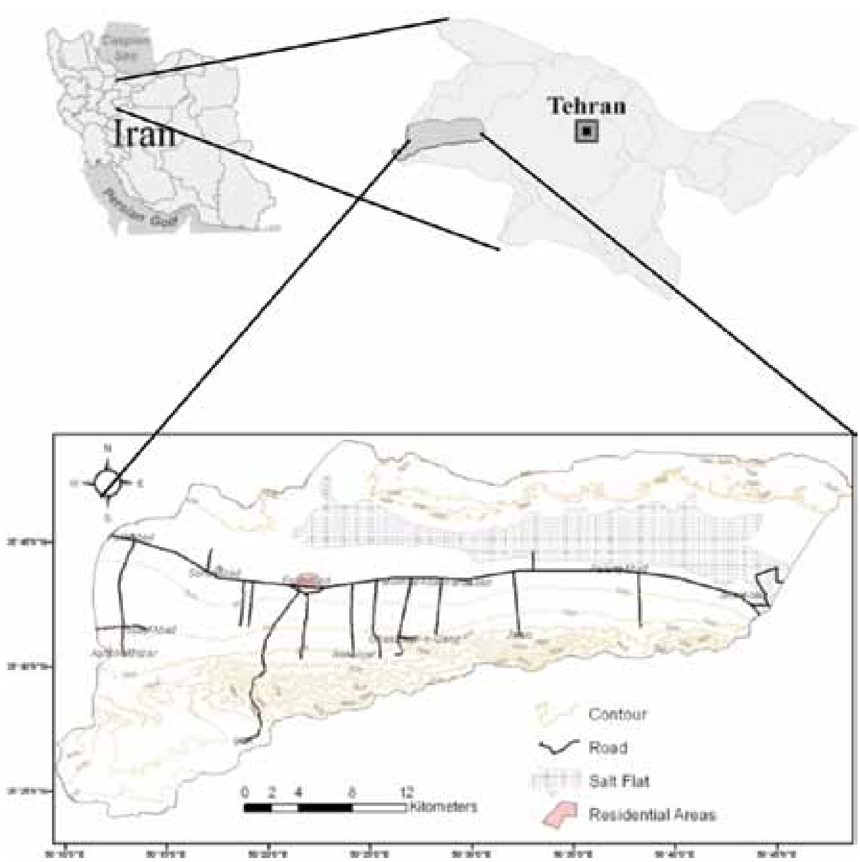

Fig. 1: Location of the study area

MATERIALS AND METHOD

Groundwater samples were taken directly from 44 sample points in May and October 2007. Water quality parameters (chloride, sulfate) were then analyzed in the laboratory of Tehran Regional Water Authority according to the methods given in the 19th edition of the Standard Methods of APHA (Fetouani *et al*., 2008). Sample pH was measured using a glass electrode pH meter. Electrical conductivity was measured using a platinum electrode conductivity meter. The analytical precision for the measured major ions was within ±5%. Summary statistics of the chemical data are listed in Table 1.

TABLE 1
Chemical compositions of groundwater samples

Parameter	Minimum	Maximum	Mean	WHO, 2004
SO4	23.54	1526	420.45	250
Cl	10.64	7332	1089.69	250
pH	7.11	8.54	8/00	6.5-9.2
EC	350	23600	4425.79	1500

In this study geostatistical interpolation techniques were used to obtain the spatial distribution of groundwater quality parameters over the area. As their name implies, geostatistical techniques create surfaces incorporating the statistical properties of the measured data. Many methods are associated with geostatistics, but they are all in the kriging family. Among the various forms of kriging, ordinary kriging has been used widely as a reliable estimation method (Yamamoto, 2003; Fetouani *et al*., 2008). Kriging is divided into two distinct tasks: quantifying the spatial structure of the data and producing a prediction. Quantifying the structure, known as variography, is where a spatial-dependence model is fitted to data set. To make a prediction for an unknown value for a specific location, kriging will use the fitted model from variography, the spatial data configuration, and the values of the measured sample points around the prediction location. According to the theory of regionalized variable, the value of a random variable Z at a point x is given as by Buyong (2007):

$$Z(x) = m(x) + \varepsilon'(x) + \varepsilon'' \tag{1}$$

where $m(x)$ is the deterministic function describing the structural component of Z at point x, $\varepsilon'(x)$ is the term denoting the stochastic, locally varying but spatially dependent residual from $m(x)$ called the regionalized variable, and ε'' is the residual having zero mean. If there is no trend in a region, $m(x)$ equals the mean value in the region. Therefore, the expected difference between any two points x and $x + h$ separated by a distance vector h will be zero. That is:

$$E[Z(x) - Z(x + h)] = 0 \tag{2}$$

where $Z(x)$ and $Z(x + h)$ are the values of the random variable Z at point x and $x + h$. It also assumed that the variance of differences depends only on the distance h between points, so that:

$$\begin{aligned} E[\{z(x) - z(x+h)\}^2] &= E[\{\varepsilon'(x) - \varepsilon'(x+h)\}^2] \\ &= 2\gamma(h) \end{aligned} \tag{3}$$

The term $\gamma(h)$ is called semivariance. We can write equation (1) as:

$$Z(x) = m(x) + \gamma(h) + \varepsilon'' \tag{4}$$

to show the equivalence between $\varepsilon'(x)$ and $\gamma(h)$. Thus, the semivariogram may be mathematically described as the mean square variability between two neighboring points of distance *h* as shown in Eq. 5 [9, 10]:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i + h) - z(x_i)]^2 \tag{5}$$

Where $\gamma(h)$ is the semivariogram expressed as a function of the magnitude of the lag distance or separation vector h between two pints, $N(h)$ is the number of observation pairs separated by distance *h* and $z(x_i)$ is the random variable at location x_i.

The experimental semivariogram, $\gamma(h)$ is fitted to a theoretical model such as Spherical, Exponential, Linear, or Gaussian to determine three parameters, such as the nugget (C_0), the sill (C) and the range (A_0). These models are defined as follow (Adhikary *et al.*, 2009; Isaaks and Srivastava, 1989),

Spherical model:

$$\gamma(h) = C_0 + \left[1.5\left(\frac{h}{A_0}\right) - 0.5\left(\frac{h}{A_0}\right)^2\right] \qquad h \le A_0$$

$$\gamma(h) = C_0 + C \qquad h > A_0 \tag{6}$$

Exponential model:

$$\gamma(h) = C_0 + C\left[1 - \exp\left(-3\frac{h}{A_0}\right)\right] \tag{7}$$

Gaussian model:

$$\gamma(h) = C_0 + C\left[1 - \exp\left[-\left(\frac{3h}{A_0}\right)^2\right]\right] \tag{8}$$

In this study, a geostatistical software package, called ArcGIS Geostatistical Analyst Extension was used for the ordinary kriging estimations. The groundwater quality data has been checked by a histogram tool and normal QQ Plots to see if it shows a normal distribution pattern. For the data which are not normally distributed (SO_4^{2-} and Cl^-), the ArcGIS Geostatistical Analyst provides log transformations for converting skewed distributions into normal distributions.

For each water quality parameter, an analysis trend was made. The trend analysis tool from the ArcGIS Geostatistical Analyst provides a three-dimensional perspective of the groundwater quality data directional trends. This analysis demonstrates that the chloride and electrical conductivity data seem to exhibit a strong trend in the NE-SW direction. Three different semivariogram models (Spherical, Gaussian and Exponential) were fitted on computed experimental semivariograms.

Prediction performances were assessed by cross- validation (*Fig. 2*).

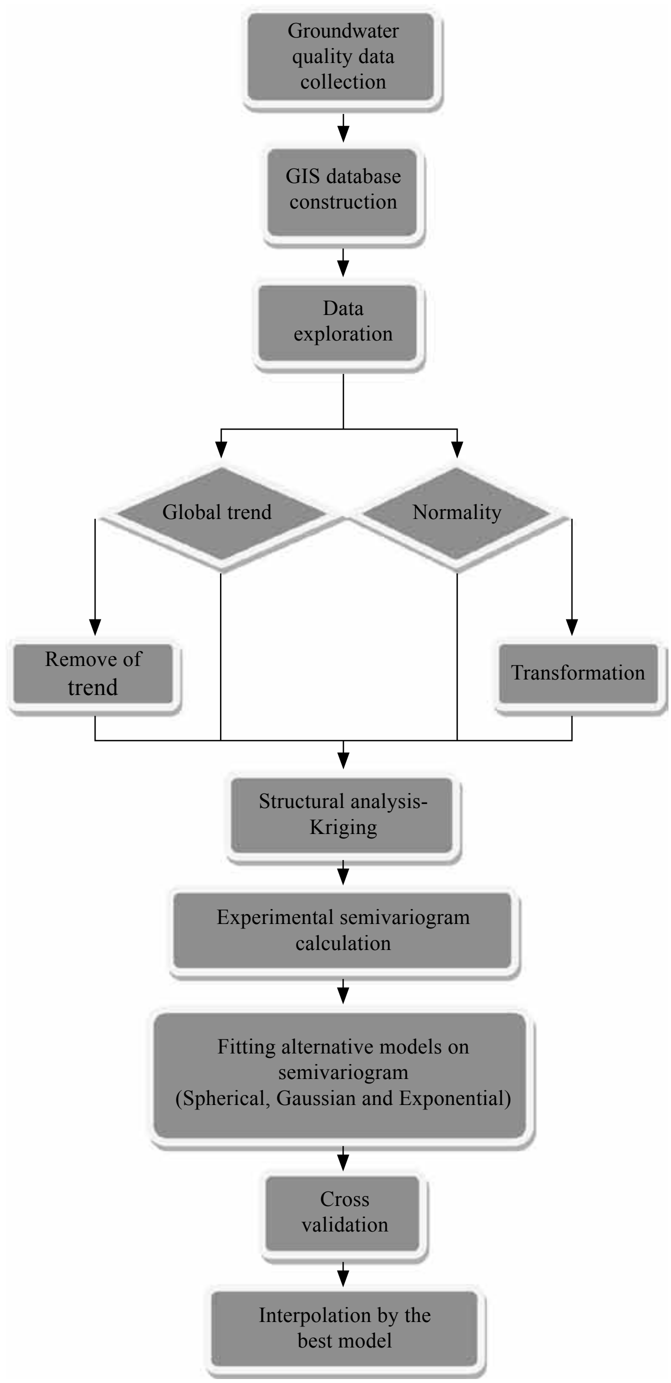

Fig. 2: Methodology flowchart

RESULTS AND DISCUSSION

The water quality evaluation in the area of study is carried out to determine their suitability for different purposes. The permissible limits for presence of different ions in groundwater have been defined by the World Health Organization as the standard quality for drinking water (WHO, 2008).

A statistical summary of the groundwater quality properties is presented in Table 1. In this study, the semivariogram models (Spherical, Exponential, and Gaussian) were tested for each parameter data set. Prediction performances were assessed by cross-validation. The objective of cross validation is to make an informed decision about which model provides the most accurate prediction.

For a model that provides accurate predictions, the mean error should be close to 0, the root-mean-square error and average standard error should be as small as possible (this is useful when comparing models), and the root-mean square standardized error should be close to 1 (ESRI, 2003).

After determination of the most suitable models by comparing the prediction errors, the spatial distribution of different groundwater quality elements were analyzed using Arc GIS. Subsequently, thematic maps for groundwater quality parameters were generated using ordinary kriging. Table 2 shows the best fitted models and their prediction errors using cross validation.

TABLE 2
Summary of best fitted models for different groundwater quality parameters

Parameters	Models	Prediction errors			
		Mean	Root-mean square	Average standard error	Root-mean-square standardized
SO_4	Spherical	-0.391	5.126	6.656	0.778
Cl	Guassian	-5.923	147.3	169.1	0.876
EC	Spherical	-2.007	42.72	47.79	0.935
pH	Spherical	-0.002	0.254	0.261	0.959

Groundwater quality maps resulting from kriging interpolation has been illustrated in *Fig. 3*. This figure shows the spatial distribution of pH, conductivity, sulfate, and chloride concentrations in study area, respectively.

pH

It was observed from the pH value that water samples were varying from 7.1 to 8.5 and these values are within the limits prescribed by WHO (Table 1). There are no water samples with pH values outside of the desirable ranges.

Electrical Conductivity (EC)

EC of the groundwater is varying from the conductivity values ranged from 350 to 23600 µmhos cm-1 at 25°C. The maximum limit of EC in drinking water is prescribed as 1500 µmhos cm-1 (Fetouani *et al*., 2008). In 55% of water samples the conductivity exceeds the permissible limit. As shown in *Fig. 3b*, the EC value increases from south to northwest and northeast along the groundwater flow path with the upper ranges being greater than 5,000 µmhos cm^{-1}.

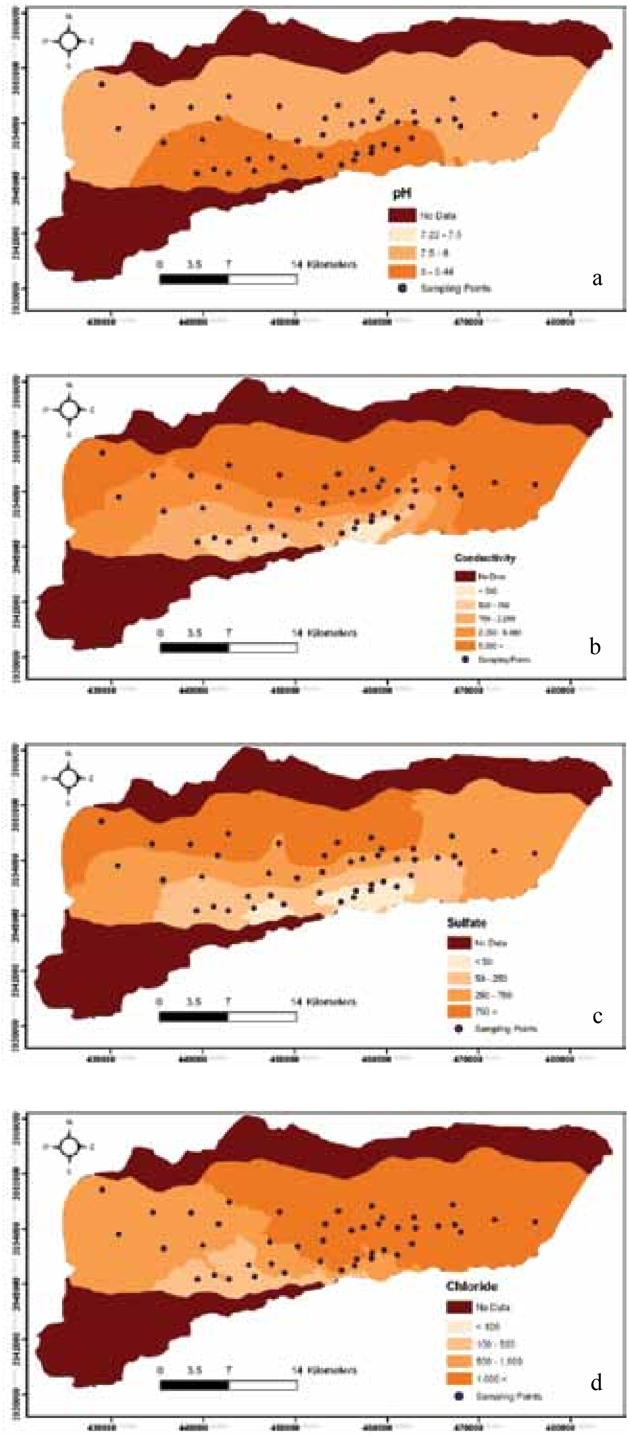

Fig. 3: Spatial distribution of a) pH, b) conductivity, c) sulfate and d) chloride

Chloride (Cl^-)

Chloride concentration is varying from 10.64 to 7332 mg l^{-1}. The large variation in Cl is mainly attributed to lithologic composition and anthropogenic activities prevailing in this region. Chloride concentration is very high in west and northwest of the study area which may indicate influence of geological formation and high rate of evaporation.

Chloride salts in excess of 100 mg l^{-1} give salty taste to water. When combined with calcium and magnesium, may increase the corrosive activity of water.

Sulfate ($SO4^{2-}$)

Sulfate concentration is varying from 23.54 to 1526 mg l^{-1} which exceeded the permissible limits in 50% of water samples. The groundwater samples with high concentration of sulfate are dominantly distributed in north and northeast of the area. It falls in an area of intensive land use (around the Eshtehrad city and cultivation area), that confirms an origin from the waste water discharge and agricultural fertilizers.

CONCLUSION

The groundwater samples have been evaluated for their chemical composition and suitability in Eshtehard aquifer. Spatial distribution map of groundwater quality parameters were generated through GIS and geostatistical techniques (ordinary kriging).

Because geostatistics is based on statistics can give an indication of how good the predictions are. The spatial variability maps showed that southern part of the study area has optimum groundwater quality and in general, the groundwater quality decreases south to north of the region. However chloride concentration in the groundwater was found to be increased from south and southwest to west and northwest.

Recommendations regarding improved cultural practices including the conjunctive use with good quality water, fertilizer and water management, and installation of subsurface drainage system should be taken up as effective practices to prevent soil salinization and provide sustainable water supply.

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