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Using of Fuzzy Models to Prepare Water Quality Map in Bahadoran Region, Iran

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Abstract. One of the most important factors affecting sustainable management of ecosystems is maintenance of water quality. Hence, knowing the spatial distribution of water properties can be so useful. Geostatistics is one of the valuable techniques in estimation of water properties. Several interpolation and prediction methods have been proposed yet. Therefore, the main objectives of this research are to evaluate, recognize and introduce the best interpolation methods for prediction of Boron in ground water of bahadoran watershed. Results showed that the hybrid method including fuzzy kriging reduced the error of prediction compared with the other methods. The results also revealed that increasing the number of data by means of the best pedotransfer functions (created by ANFIS) would enhance the accuracy of prediction. In general, combination of the best pedotransfer functions with the best mapping method increased the accuracy of Boron prediction in the study area.

Keywords: Interpolation Techniques, Geostastical methods, Pedotransfer Function

Introduction

In arid and semi-arid area, underground water is a vital source of water. Unfortunately, pollution has contaminated these resources. Hence, conserving quality and quantity of groundwater must be considered as a trivial matter in arid areas. Groundwater quality mapping over extensive areas is the first step in water resources planning (Todd, 1980). Geostatistical analysis is one of the best interpolation methods for

mapping. Geostatistic is presenting a suitable model for description of regional parameters (variables), by considering complications of spatial statistic. In geostatistic, we can develop a relationship between values of quantity in samples society, distance and orientation of sample places in relation to each other. Therefore, geostatistics is an instrument that is able to determine the spatial changes of water characteristics. This method can also be used easily in areas in which sampling is costly and time-wasting.

There are different estimations and interpolation methods could be done by the help of geostatistics such as ordinary kriging, cokriging, fuzzy kriging and regression kriging methods. Nazari zade *et al.* (2006) used geostatistical method to study spatial distribution of groundwater quality in Ballarood plain. The spherical model was the best to fit an experimental variogram of salinity, Chlorine and Sulfate. Investigation on temporal and spatial distribution of groundwater Nitrate *via* kriging and co-kriging methods by Dagostino *et al.* (1988) showed that co-kriging method increased accuracy in the estimation of nitrate concentration. Finke *et al.* (2004) used simple kriging method to estimate distribution of water level in the Netherlands and it is considered as a suitable method for monitoring and mapping groundwater levels. Barca and Passarella (2007) made Nitrate risk maps in Modena plain (northern Italy) using disjunctive kriging and simulation methods for the two thresholds of 10 and 50 mg. The results indicated that disjunctive kriging method is suitable to investigate underground water degradation.

In recent years, in order to apply fuzzy logic in mapping, fuzzy kriging method was used. Fuzzy kriging method was applied by Rahimi and Saghfian, (2007) to estimate the spatial distribution of precipitation and their results showed that this method decreased the estimation error up to 10% in comparison with kriging, thin plate smoothing splines (TPSS) and cokriging. In addition, it provides the possibility of using auxiliary points without increasing the estimation error. In a comprehensive study on soil characteristics related to fertility (organic matter in soil (%), soil pH value, soil texture, phosphorus and phosphorus) by Hegedus (2006), it was asserted that combination of kriging with the theory of fuzzy set, improved management outcomes, especially in the field where uncertainty of the available data is high. Vice versa, Sunila (2004) indicated that fuzzy kriging method had no higher performance than ordinary kriging method.

The present study was therefore, carried out with objectives to evaluate the accuracy of different interpolation methods, kriging, cokriging, fuzzy kriging and inverse distance weighting (IDW), for prediction of Boron concentration in groundwater of Bahadoran region.

Materials and Methods

Study Area

This research was conducted in Yazd-Ardakan plain (31°2′ to 31°30′ N, 54°1′ to 54°58′ E), in the Iranian central plateau. The predominant crops are pistachio nuts, followed by wheat.

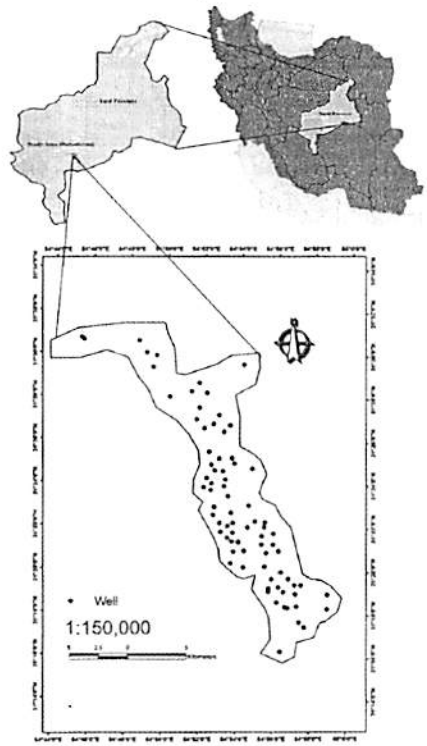

Fig. 1. Study area and sampling points distribution.

The climate of the study area is arid with a mean annual precipitation, mean annual temperature, and annual potential evaporation of 75 mm, 18.5°C, and 3483 mm, respectively. Precipitation is very rare and is received mainly during the winter season. The soil moisture and temperature regimes are aridic and thermic, respectively. Topography of the land is mostly flat.

Data Collection and Samples Analysis

In this study 73 samples from wells of Bahadoran area were used to predict spatial distribution of underground water quality. Boron concentration measured only from 60 samples. Our study was conducted in two stages (Fig. 2 & 3):

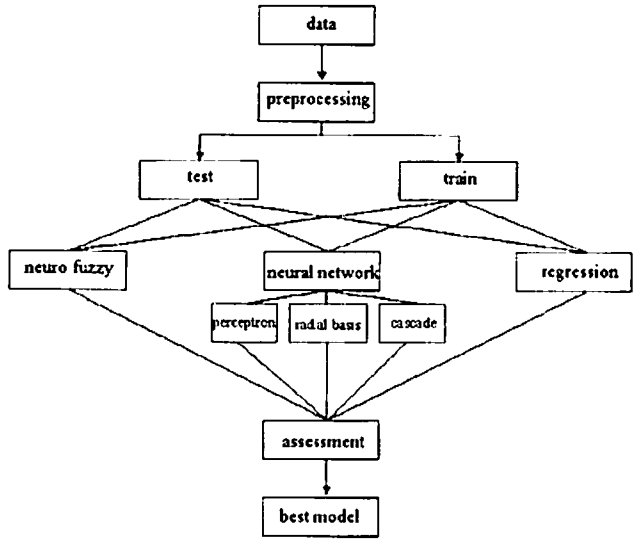

Fig. 2. Layout of best pedotransfer function determination process.

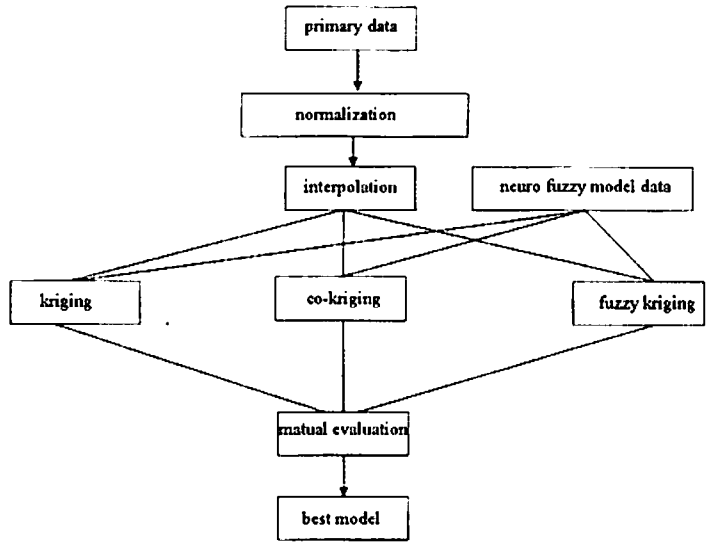

Fig. 3. Layout of best mapping method determination process.

1) Using best conversion functions to increase the data. In this step, we applied different modeling approaches such as: Multivariate regression, artificial neural network and Adaptive neuro fuzzy inference system (ANFIS) to reconstruct the 13 missing data of Boron.

2) Compare various methods of geostatistical analysis such as: Kriging, cokriging and fuzzy kriging to prepare the distribution of Boron in groundwater.

Methods to fit Pedotransfer Functions

Multivariate Regression

The most common method used in estimation PTFs is to employ multiple linear regressions. For example:

$$Y = aX_1 + bX_2 + cX_3 + ...$$

Where Y (*i.e.* Boron) is depended variable, Xn (*i.e.* Water quality parameters) is in depended variable and a,b, ... are coefficients.

Artificial Neural Network (ANN)

An ANN normally consists of three layers, an input layer, a hidden layer, and an output layer. In a feed forward network, the weighted connections feed activations only in the forward direction from an input layer to the output layer. On the other hand, in a recurrent network additional weighted connections are used to feed previous activations back into the network. In this study, the training process was performed by the commercial package MATLAB, which includes a number of training algorithms including the back propagation training algorithm. This is a gradient descent algorithm that has been used successfully and extensively in training feed forward neural networks.

Adaptive Neuro-Fuzzy Inference System (ANFIS)

Fuzzy inference system is a rule based system consists of three conceptual components. These components are: (1) A rule base, contains fuzzy if–then rules, (2) a database, defines the membership function and (3) an inference system, combines the fuzzy rules and produces the system results. First phase of fuzzy logic modeling is the determination of membership functions of input–output variables, second is the construction of fuzzy rules and the last is the determination of output characteristics, output membership function and system results. To determine the membership function of the input–output variables, two

methods, named as backward propagation algorithm and hybrid-learning algorithm, provide learning of the ANFIS and construction of the rules, are used.

Spatial Prediction Methods

Geostatistical prediction includes two stages which is first identification and modeling of spatial structure. At this stage continuity, homogeneity and spatial structure of a given variable is studied using variogram. Second stage is geostatistical estimation using kriging technique which depends on the properties of the fitted variogram which affects all stages of the process. The geostatistical methods used in the present study were: (1) Kriging, (2) Cokriging (3) Fuzzy Kriging and (4) IDW.

Kriging

The experimental variogram measures the average degree of dissimilarity between sampled points and a nearby data value (Ayoubi *et al.*, 2007), and thus can depict autocorrelation at various distances. From analysis of the experimental variogram, a suitable model (*e.g.* spherical, exponential) is then fitted, usually by weighted least squares, and the parameters (*e.g.* range, nugget and sill) are then used in the Kriging procedure.

Inverse Distance Weighting (IDW)

In interpolation with IDW method, a weight is attributed to the point of measurment. The amount of this weight is depended to the distance of the point to another unknown point. These weights are controlled on the bases of power of ten. With increase of the power of ten, the effect of the points that are farther diminishes. Lesser power distributes the weights, more uniformly between neighboring points. We should keep in mind that in this method the distance between the points count, so the points of equal distance have equal weights (Bregt *et al.*, 1992).

Cokriging

The "co-regionalization" (expressed as correlation) between two variables, *i.e.* the variable of interest, groundwater quality in this case, and another easily obtained and inexpensive variable, can be exploited to advantage for estimation purposes by the co-kriging technique. In this sense, the advantages of co-kriging are realized through reductions in costs or sampling effort. The cross-semivariogram is used to quantify

cross-spatial auto-covariance between the original variable and the covariate (Finke *et al.*, 2004).

Fuzzy kriging

This is also one of the hybrid interpolation method in which two simultaneous kriging and fuzzy set theory are used. Fuzzy kriging is a modification of the conventional kriging procedure; it utilizes exact (crisp) measurement data as well as imprecise estimates (defined as fuzzy numbers) obtained from an expert. The fuzzy kriging procedure can be used *e.g.* for the regionalization of ecological parameters. In comparison to the conventional interpolation methods, the results of the regionalization based on this modified kriging procedure reflects better the imprecision of input data (Sunila, 2004).

Finally, the best selected mapping model in the two cases was studied: (a) With 60 initial data (b) predicted data using ANFIS and rerun mapping model with 73 data.

Model Assessment

In order to compare the performance of pedotransfer functions as well as different methods of mapping, Root Mean Square ErrorMethod (RMSE) is used,

$$RMSE=\sqrt{\frac{1}{n}\sum_{i=1}^{n}(Z_0-Z_p)^2}$$

Where Z_0 is measured variable, Zp is predicted value and n is the number of measured variables.

Results and Discussion

Preprocessing

At first, using stepwise regression (step by step), the effective parameters for each model was determined (Table 1). According to Table (1), bicarbonate, sodium adsorption ratio and salinity were the most important factors affecting changes in boron concentration. The data were divided randomly into two categories which do not significantly differ ($p>0.05$), so that 80% data for training data and the remaining (20%) were allocated to validation (Amini *et al.*, 2005). Table 2 shows water quality results. The normality of data was tested by Kolmogorov-Smirnov method ($P>0.05$).

Pedotransfer Functions

Multivariate Linear Regression

To determine multiple regression of the studying parameter, the regression equation using the training data was determined. Then, this equation was applied on the test data.

Multi-Layer Perceptron Neural Network

The test and training data determined, and then normalized. Next, neural network model with a hidden layer which neurons number is 2 - 20, set and optimized structure of the network using the RMSE criterion through trial and error was determined.

Table 1. Characteristics of correlation coefficients between ground water.

	Boron (ppm)	Salinity (106)	Bicarbonates (ppm)	sodium adsorption ratio
Boron (ppm)	1			
Salinity (160)	0.61**	1		
Bicarbonates (ppm)	0.38*	0.32*	1	
sodium adsorption ratio	0.59**	0.66**	0.18	1

*Significant at the level of 0.01
**Significant at the level of 0.05

Table 2. Statistical analysis of groundwater.

Parameters	min	max	mean	Standard deviation	Kurtosis	skew
Boron (ppm)	0.08	2	0.6	0.46	1.14	0.37
Boron (ppm)	0.47	0.69	0.6	0.68	0.05	0.14
Salinity (µS/m)	923.6	85974	8128.8	11672.6	4.4	25.6
Salinity (µS/m)	6.8	11.4	8.4	0.95	0.6	-0.2
Bicarbonate (ppm)	1.2	5	2.72	0.72	0.73	0.76
Bicarbonate (ppm)	0.18	1.61	0.96	0.26	0.18	0.57
Sodium adsorption ratio	4.35	45.57	14.26	8.79	1.19	0.92
Sodium adsorption ratio	1.47	3.82	2.49	0.57	0.36	0.54

$$B= +0.0213SAR -0.269+0.000026EC+0.178HCO_3$$

Where, B is Boron, SAR is sodium adsorption ratio, EC is electrical conductivity, and HCO_3 is Carbonate.

The results indicated that the network with fourth number of neurons is the best network structure .

Adaptive Neuro-Fuzzy Inference Systems (ANFIS)

ANFIS is integration of neural networks and fuzzy logic and has the potential to capture the benefits of both these fields in a single framework. ANFIS utilizes linguistic information from the fuzzy logic as well learning capability of an ANN (Artificial Neural Network) for automatic fuzzy if-then rule generation and parameter. In this system, fuzzy sets interpreted as connection's weights and input and output variables as neurons. To create this network several parameters including the type of membership functions, number functions, learning methods and the number epoch should be optimized. In this study, all states were determined by trial and error. Use of ANFIS model for Boron prediction showed that the membership number 4 and the law number 8 gives the best structure based on the RMSE. It is also obtained in replication number of 450 through learning feedback method and weight average de-fuzzing .

Models Assessment to Determine the Best Transfer Function

Results showed that the artificial neural network with two neurons in hidden layer had better performance in predicting Boron than multivariate regression which is in the line with the work done by Amini *et al.* 2005, Tamari and Wösten (1996), Minasny & McBratney (2002) and Schaap *et al.* (1998). Amini *et al.* (2005) found that the neural network-based models provided more reliable predictions than the regression-based PTFs. Schaap *et al.* (1998) confirmed the applicability of ANNs and concluded that accuracy of these models depend on number of inputs. Koekkoek and Booltink (1999) found that ANN performed slightly better, but the differences were not significant. The network models for three parameters were more suitable for capturing the non-linearity of the relationship between variables. One of the advantages of neural networks compared to traditional regression is that they do not require a priori regression model (Schaap and Leij, 1998).

Results also indicated that the neuro fuzzy is the technique with the highest accuracy (Table 3). Recent studies confirmed better performance ANFIS model than other methods. Aali *et al.* (2009) showed that the ANFIS model was more accurate than the artificial neural network model. ANFIS model was also more appropriate than the regression models (Azamathulla *et al.*, 2008) and was the best method in the surface evaporation predicting (Terzi *et al.*, 2006).

The scatter plots of the measured against predicted Boron for the test data set are given in Fig. 4, for the ANFIS model, which we identified as being the best model for predicting Boron. The best fitted line was one with 45° that indicated the show High estimation accuracy by the ANFIS model.

Table 3. comparison of assessment error results in different methods.

Model	RMSE
Multivariate linear regression	0.74
Multi-layer perceptron neural network	0.57
Adaptive Neuro-Fuzzy Inference Systems (ANFIS)	0.55

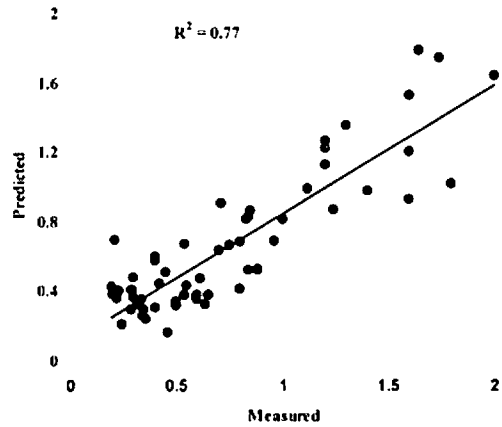

Fig. 4. Scatter plot for values of observations and simulated Boron data in ANFIS model.

Mapping Methods

Inverse Distance Weights (IDW)

Using ArcGIS software and cross validation method, Inverse Distance Weights (IDW) was run and its parameters such as power and radius of the neighborhood were optimized.

Kriging

At first concerned variable semi-variogram using Variovain software diagrammed, then the parameters were optimized using the cross validation (Fig. 5). Therefore, the exponential model was found suitable. Radius effect in this model is the distance in which variogram reached to 95% of the threshold. Low slope of variogram in near of starting point indicates spatial variable correlation. The leap of variogram (middle of

variogram) designates medium correlation rate. Curve slope is more. Through spatial correlation analysis, primary selection of interpolation methods is possible. To apply geostatistical methods data must be static. Stationary means parameters of a random distribution function donot change from one point to other. Variogram analysis is one of the stationary data specification methods. If variogram does not reach a certain threshold and not fixed as well as pair of points have a sinusoidal mode, indicating lack of data stationary. In this research, salinity and Sodium parameters were static. Variogram of these parameters are given in Table 4.

Table 4. The best model fitted to the variogram and its parameters.

Model	Nugget effect (C_0)	threshold (C_0+C)	Radius effect (m)	Nugget effect on threshold (C_0/C_0+C)
Exponential	0.03	0.51	2463	0.05

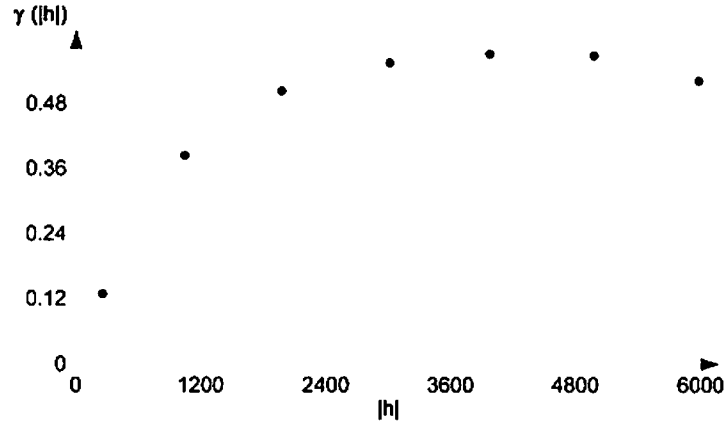

Fig. 5.Semi- variogram of Bohr through kriging method.

Co-Kriging

In the present study the amount of salinity is highly correlated with the Boron levels so, it was considered as auxiliary variable in the Cokriging method.

Fuzzy Kriging

At first a number of sampling points should be set in fuzzy logic. Therefore kriging error map was drawn; the data (points) in the range of maximum error was selected and set in fuzzy logic using triangular membership functions. Domain membership functions according to the

variogram) designates medium correlation rate. Curve slope is more. Through spatial correlation analysis, primary selection of interpolation methods is possible. To apply geostatistical methods data must be static. Stationary means parameters of a random distribution function donot change from one point to other. Variogram analysis is one of the stationary data specification methods. If variogram does not reach a certain threshold and not fixed as well as pair of points have a sinusoidal mode, indicating lack of data stationary. In this research, salinity and Sodium parameters were static. Variogram of these parameters are given in Table 4.

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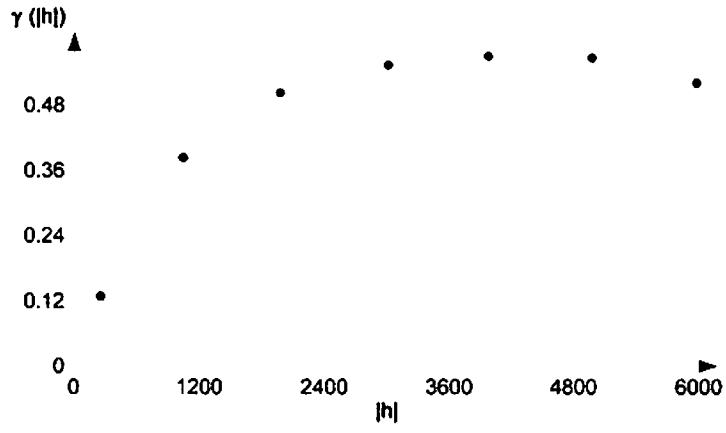

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At first a number of sampling points should be set in fuzzy logic. Therefore kriging error map was drawn; the data (points) in the range of maximum error was selected and set in fuzzy logic using triangular membership functions. Domain membership functions according to the

standard deviation variable, was selected. Theoretical variogram model were fitted on the fuzzy data using the FUZZEK software. The area was conducted on a regular lattice to use the software for kriging mapping on the grid points. Output of FUZZEK for grid points converted to raster image using ArcGIS. To calculate the estimation error, amounts of sampling points extracted, compared with real data and values of RMSE obtained (Sunila, 2004).

Models Assessment to Determine Best Mapping Method

Correlative estimation results of IDW, Kriging, Cokriging and fuzzy kriging methods to predict Boron special variations are given in Table 5. Four methods assessment used the RMSE. Fuzzy kriging is the most appropriate interpolation method based on the RMSE to predict the studied variables. Fuzzy kriging was appropriate for air pollution mapping (Guo *et al.*, 2007). Hegedus (2006) indicated that combination of kriging with theory fuzzy set, improved management outcomes, especially in the field which uncertainty of available data is high. However, the use of kriging compared with fuzzy kriging resulted in better findings (Sunila, 2004).

Table 5. Error of the different interpolation method for Boron estimation in groundwater.

kriging	Cokriging	fuzzy kriging	Inverse Distance weights (IDW)		
			Power ^{1}	Power ^{2}	Power ^{3}
0.88	0.87	0.73	0.91	0.95	0.97

Pedotransfer Functions and Geostatistical Approach Combination

Some of the missing Boron data were reconstructed by ANFIS model. In the next step, we interpolated all Boron data (*i.e.* Measured and reconstructed data)by using fuzzy-kriging. Overall the results of the present study demonstrated that the use of hybrid methods such as fuzzy-kriging and neuro-fuzzy compared to other methods, significantly decreased the estimation error and also increased the mapping accuracy (RMSE = 0.62). So, we recommended researchers apply combination of different models (*i.e.* Pedotransfer function and interpolation methods) to prepare water quality map across the the area of interest. Finally, water quality map, was prepared by fuzzy-kriging and GIS technique (Fig. 6).

The use of of hybrid methods such as kriging fuzzy compared to other methods significantly decreases the estimation error. Also increase the number of data through the best conversion functions (generated by ANFIS), increased estimator accuracy. Finally, combination of the best

conversion functions and the best mapping method, greatly contributed to accurately predict Boron in the study area.

With regard to the map (Fig. 6), the highest concentration of Boron is shown with red color (i.e. North, East, and the South).

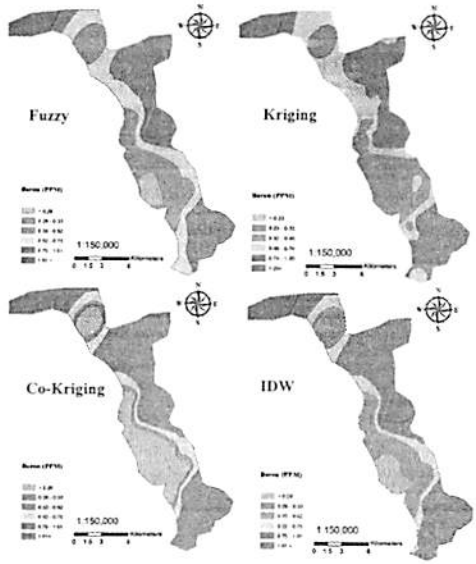

Fig. 6- Boron concentration mapping using fuzzy-kriging and Neuro-fuzzy.

Conclusion

With respect to spatial distribution map of Boron it seems that pollution of water quality is not very serious problem but agricultural activities without consideration to cultivation potential of this area and irregular extraction of groundwater with exceeding use of groundwater can devastate ground water quality in the near future. So it is highly recommended that exploitation policy of water and soil sources should be changed very quickly.

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استخدام النماذج المشوشة (المزخرفه) لتجهيز خريطة لنوعية المياه في بهدوران – إيران

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المستخلص. أحد أهم العوامل التي تؤثر على إدارة الاستدامة في الأنظمة الإيكولوجية هو صيانة نوعية المياه، لذلك معرفة التوزيع المكاني لخصائص المياه يمكن أن يكون من الأشياء المفيدة. ويعتبر الإحصاء الأرضي واحدًا من التقنيات القيمة في تقدير خصائص المياه. تم اقتراح العديد من طرق الاستكمال والتنبؤ لمعرفة التوزيع المكاني لنوعية المياه. لذلك كان من الأهداف الرئيسية لهذا البحث هو تقييم وملاحظة وتقديم أحسن الطرق للاستكمال للتنبؤ بعنصر البورون في المياه الجوفية لحمض وادي بهدوران. ولقد أوضحت النتائج أن الطريقة المهجنة والتي تشمل طريقة كريجنج والنماذج المزخرفة تقلل الخطأ في التنبؤ عندما قورنت بالطرق الأخرى. كما أوضحت النتائج أيضًا أن زيادة عدد البيانات والمولدة باستخدام الشبكات العصبية (ANFIS) قد تحسن من دقة التنبؤات. وبصفة عامة الجمع بين أحسن دوال تحويل مع أحسن طرق لعمل الخرائط تزيد من دقة التنبؤ بعنصر البورون في منطقة الدراسة.