Quantitative Modeling of Nitrate Distribution in Ardabil Plain Aquifer Using Fuzzy Logic

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Received: March., 2014 Accepted: Sep., 2014

Extended Abstract

Introduction

Environment as a great and complex collection is composed of a process and evolution of live existences and the Ardabil Plain aquifer, with an area about 900 km^2, has high concentration of nitrate in some parts. Nowadays, nitrate pollution in groundwater due to the widespread application of fertilizers and increase of drinking water demand, has problems for consumers. The adverse health effects of high nitrate levels in drinking water have been well documented.

In the last two decades use of fuzzy logic has considered as a simulation for environmental process because of complexity in modeling domain and uncertainty in data. Most of these research studies have been profited from advantages of fuzzy logic beside other scientific methods. In previous published academic researches investigating vulnerability of aquifer by fuzzy logic, it has been concluded that data clustering and determination of bounds between these clusters is a matter of importance and the efficiency of fuzzy logic is higher than traditional methods.

Reviewing the previous records indicates that there is not any literature about modeling of nitrate in Ardabil Plain. Therefore, in this study distribution of nitrate in Ardabil plain aquifer has been estimated using fuzzy logic modeling and the performance of this method has been compared with kriging.

Material and Methods

The study area is located between latitude 38°00′ and 38°30′ and longitude 48°00′ and 48°40′ and it covers an area of approximately 900 km^2. For spatial distribution modeling of nitrate concentration in Ardabil plain, a total of 61 wells were sampled for chemical analyses on November, 2011. In this study, 75% and 25% of samples were used for calibration and verification, respectively.

Fuzzy logic

Contrary to classic sets, that their members are completely belonging to them, in fuzzy sets the members have membership grades between 0 and 1. One of the applications of fuzzy theory is modeling. In order to make modeling by fuzzy logic, the first input data are shown as fuzzy membership functions, then, these membership functions are related to output data via definition of fuzzy rules. Sugeno model is used in process of this kind of modeling which consists of three stages: 1. clustering, 2. identification of rules and 3. parameter estimation.

To determine the optimum number of clusters, the software of FuzME has been employed. After determination of classes, inputs of model were related to the outputs by definition of if-then fuzzy rules. In the last step, least square errors were minimized to calibrate the model.

Kriging

Kriging is a geostatistical interpolation method which is an efficient linear unbiased estimator. After the examination of normality of data and using normalization for data without normal distribution, the best experimental and theoretical variogram basis isotropic or anisotropic properties of data is plotted by GS+ software. As a result, the best chosen variogram was exponential with nugget effect of 0.09 and sill about 0.50.

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Results and Discussion

In this study, longitude and latitude have considered as inputs and nitrate concentrations have kept for output of model. For the reason that the UTM values were large numbers, in the beginning the inputs normalized between 0 and 1, then, they were classified in six clusters by fuzzy c-mean clustering method. Since the number of rules in this type of modeling is equal to the clusters, therefore, the set of inputs was related to the set of outputs via defining six rules. The parameters of model were also estimated by the running of the model. The calibrated parameters of input and output membership functions are given in Table 1.

Table 1. Optimized parameters of input membership functions and output linear functions

cluster	input1		input2		output		
	σ	c	σ	c	α	β	ε
1	0.1672	0.3313	0.1768	0.6902	44.83	9.937	-3.126
2	0.1256	0.5027	0.1243	0.5807	566.4	-317.8	-119.4
3	0.1287	0.6495	0.2049	0.4377	-19.18	66.09	16.72
4	0.1143	0.4066	0.1598	0.6709	127.6	-319.4	242.1
5	0.1369	0.6086	0.1599	0.5013	132.5	-121.5	-105.9
6	0.0492	0.5478	0.08954	0.8856	-244	-265.1	392.4

To verify the model, a total of 16 separated samples were used and its results were compared with that of kriging method. For this purpose, root mean square error (RMSE), mean absolute error (MAE) and coefficient of determination (R^2) were computed. These are presented in Table 2.

Table 2. Statistical characteristics of the data used for verification

Model	mean	std	MAE	RMSE	R^2
Fuzzy logic	7.99	5.063	1.3982	1.6940	0.916
Kriging	5.82	2.594	2.9677	4.3549	0.517
measured	8.65	5.57	-	-	-

According to reported results in Table 2, purposed model showed better results than kriging method. Therefore, to generate the nitrate distribution map, the verified fuzzy model was run and final result is shown in Figure 1.

Conclusion

The reliability of spatial distribution maps of pollutants is very important in water resource management. Basically, the geostatistics interpolation methods, especially kriging, are used to generate spatial distribution data. According to the results, the used fuzzy model was very efficient in estimation of the nitrate concentrations in the study area.

The final output of the model shows that the nitrate concentrations in some areas in north and southwest parts of the plain is higher than 10 mg which these parts occupied about 17% of aquifer area.

The places with high amounts of nitrate around Ardabil city had full conformity with urban waste water. Therefore, it is highly likely that the nitrate pollution could be related to urban waste water. Furthermore, high concentrations of nitrate in the north margin of the plain are in conformity with landfill that can be considered as cause of nitrate pollution at that area.

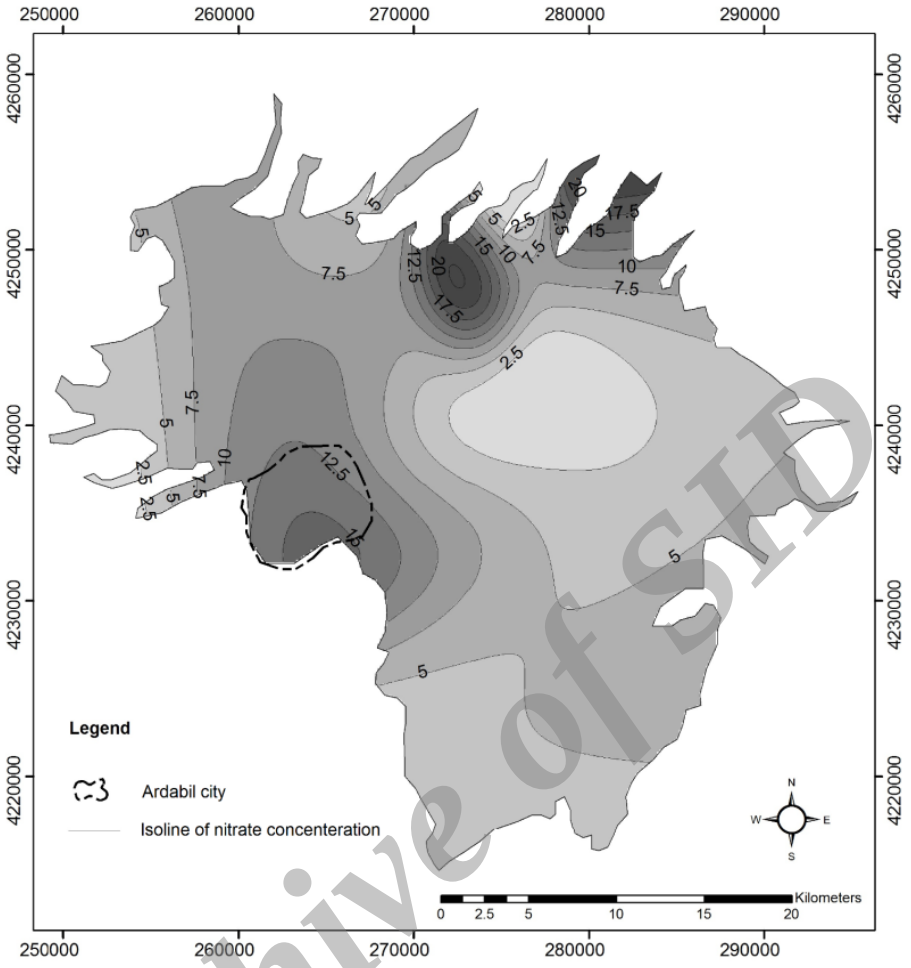

Fig. 1. Spatial distribution map of nitrate in Ardabil Plain aquifer

Keywords: clustering, fuzzy logic, groundwater, nitrate.