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ORIGINAL ARTICLE

Spatial analysis of Ardabil plain aquifer potable groundwater using fuzzy logic

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Abstract The purpose of this study is to evaluate the quality of drinking water and qualitative classification of potable water in Ardabil plain aquifer. To determine the chemical properties 58 water samples were collected from wells and analyzed. Distribution of each quality parameter was estimated using data driven techniques of kriging and fuzzy logic modeling. According to the obtained results, the fuzzy model provides better results compared to kriging. Different water quality standards are used for assessment of drinking water. The quantitative limits specified in these standards and also water quality data are associated with uncertainty. To reduce the uncertainty a fuzzy based decision making approach was applied for interpretation of groundwater quality. Final output was presented in the form of a zoning map with three categories as 'Desirable', 'Acceptable' and 'Not acceptable'. This map indicates that most parts of the aquifer have acceptable and desirable water quality for drinking; but the groundwater in the Southwest and North of the plain, being in conformity with Miocene formations, is undesirable (Not acceptable). This spatial distribution map can help a lot for groundwater supply and offers a good insight of groundwater qualitative trend in this study area.

1. Introduction

Sustainable management of groundwater resources in underdeveloped regions is one of the essential objectives for future, especially when the rising demand for clean drinking water by these fast communities is considered (Mende et al., 2007). Understanding the hydrochemical properties of aquifer is very important for groundwater planning and management.

In Ardabil plain the main source for drinking water is ground water. Low quality water supply can cause health problems, therefore determining the quality of water in the study area is important. Map of water quality can be obtained from estimation of element concentration of the whole aquifer based on measurements of some localized samples.

Many researchers have tried to use different data driven interpolation methods for modeling separate samples of

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element concentrations (Molenat and Gascuel-Odoux, 2002; Flipo et al., 2007; Tutmez and Hatipoglu, 2010; Wang and Huang, 2012; Wei et al., 2012).

Making use of geostatistics, especially kriging, is one way to interpolate in geological media. Numerous literatures can be found about interpolation via kriging in water sciences (Wang et al., 2001; Desbarats et al., 2002; Sepaskhah et al., 2004; Jang and Liu, 2004; Shen and Wu, 2013).

Although kriging produces good results, it encounters problems when the number of measurements is insufficient for the calculation of acceptable variograms (Deutsch and Journel, 1998; Bardossy and Fodor, 2004; Tutmez and Hatipoglu, 2010).

Another method for interpolation is using fuzzy modeling. Two major uses of fuzzy logic are decision making and modeling. Fuzzy logic is an effective tool for handling the ambiguity and uncertainty of real world systems. Fuzzy logic can be particularly suited when relationships between variables in the environment are either ill defined or very complex (Kavitha Mayilvaganan and Naidu, 2011). This method was applied to estimate the values of variables at unsampled sites by many researchers (Burrough, 1989; Bogardi et al., 2003; Amini et al., 2005; Tutmez and Hatipoglu, 2010; Kholghi and Hosseini, 2008).

Numerous studies have been made in the field of water quality assessment. Some of them are mentioned in the following. Chang et al. (2001) in a comparative study, compared the performance of the fuzzy synthetic evaluation approach in identification of water quality with results obtained from traditional methods.

Muhammetoglu and Yardimci (2006) utilized the fuzzy logic approach to assess groundwater pollution levels in the area by developing Water Pollution Index values. They concluded that the fuzzy logic approach presents a more understandable and objective way of water quality classification.

Taheriyoun et al. (2010) developed an Entropy based Fuzzy Eutrophication Index model for classification of the trophic level of Satarkhan Reservoir in the North western part of Iran.

Samson et al. (2010) evaluated the application of fuzzy set theory for decision making in the assessment of groundwater quality for drinking and they used the kriging method to interpolate the physical and chemical water quality parameters.

Tayfur et al. (2003) used fuzzy logic algorithms for estimating sediment loads from bare soil surface. Dahiya et al. (2007) reported the application of fuzzy set theory for decision making in the assessment of physicochemical quality of groundwater for drinking purposes and expressed the view that a fuzzy synthetic evaluation model gives the certainty levels for the acceptability of water based on the prescribed limits of various regulatory bodies, quality class, and perception of the experts from the field of drinking water quality.

In recent years, several works have been performed in quality classification of surface water by fuzzy logic (Gharibi et al., 2012; Duque et al., 2013; Scannapieco et al., 2012). Gharibi et al. (2012) developed a novel water quality index based on fuzzy logic for routine assessment of surface water quality, particularly for human drinking purposes. They deduced that the fuzzy-based index proposed by them produced more stringent outputs compared to the traditional methods. Duque et al. (2013) also used a fuzzy logic hybrid model to assess river water quality. They concluded that the main advantage of their proposed method in comparison with traditional methods is that it considers flexible boundaries between the linguistic qualifiers used to define the water status, being the belongingness of water quality to the diverse output fuzzy sets or classes provided with percentiles and histograms, which allows to classify better the real water condition.

According to the census 2011, approximately 564,000 people live in Ardabil plain inhabiting 2 major cities and 88 villages (Statistical Center of Iran, 2011). The average use of drinking water in Ardabil plain is about 26 (million m3/y), which accounts for 89% of total water demand that is supplied by groundwater and the remaining 11% is obtained from surface water (Kord et al., 2013). Due to this significance, the quality mapping of potable groundwater for this plain is indispensable. In this regard, the use of appropriate methods has a direct influence on the accuracy of obtained results and consequently on proper management of the aquifer. In previous studies which are mentioned above, the fuzzy logic has been used just as a data driven or decision making method.

The purpose of this study is to evaluate the quality of drinking water and qualitative classification of potable water in Ardabil plain aquifer using special abilities of fuzzy logic in modeling and decision making. Therefore the unknown component concentration values of groundwater at a location with no wells have been estimated through kriging and fuzzy logic techniques from known element concentrations measured at sample points in the aquifer. Then, to assess the quality of drinking water, fuzzy logic has been used as an expert system suited for decision making.

2. Materials and methods

The Ardabil plain aquifer is located in Northwest Iran in the Province of Ardabil. This plain is found bounded between 38°00′–38°30′ N and 48°00′–48°40′ E, and has an aerial coverage of about 990 km^2. The region experiences pleasant summer and relatively long winters with an average annual precipitation of about 300 mm.

The Ardabil plain is surrounded by elevations which are parts of Alborz Mountains. In West of the plain, conglomerate with some tuff, volcanic ashes and lahars are outcropped. These rocks due to the abundant springs originate from the Sabalan Mountain, affect aquifer recharge.

The rock units consisting of conglomerate with some sandstone, marl, fresh water limestone, pumice, tuff and lahar of Neogene age are located in Southwestern Ardabil plain. These formations have a very low effect on aquifer recharge. Other unit rocks including cherty limestone, cherty dolomite, sandstone and conglomerate with thin beds of gypsum in Northeast and megaporphyric trachy andesite, trachy basalt, volcanic breccias, olivine basalt, tuff and sandy tuff located in the South, East and North of the plain have a moderate potential from aquifer recharge point of view.

The Ardabil plain that has been formed out of Quaternary alluvial deposits originated from alteration of surrounding mountains. Based on the results of geophysical studies of pumping test data and drilling logs, the aquifer with a maximum thickness of about 220 m, is mainly composed of gravel, sand and a little amount of clay. The transmissivity of the aquifer varies between 50 and 2200 m2/day and the specific yield ranges from 0.021 to 0.14. The general direction of groundwater flow is from other directions to the North–West of the plain (Kord et al., 2013).