Classification of drinking water quality using Schoeller diagram in GIS

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Abstract Drinking water with high quality is one of our most vital resources, and when our water is polluted it is not only devastating to the environment, but also to human health. So the aim of the research is investigation groundwater quality using Schoeller diagram method in north of Fars province, southeast Iran. For determination of groundwater quality, parameters of chlorine (Cl), sodium (Na), sulfate (So4), total dissolved solids (TDS) and total hardness (TH) were used. Using Inverse Distance Weighting (IDW) interpolation maps of each parameters using inverse distance weighting (IDW) method and then fuzzy and AHP method were determined. The results of fuzzy method showed that, except the parts of south, all of the area was not suitable for So4, Cl, and Na that had the value close to 0. Also except the some parts of north was suitable for TDS and TH that had the value close to 1.

Keywords: Groundwater quality; Inverse Distance Weighting (IDW); Schoeller; Fuzzy-AHP method

1. Introduction

The availability of high-quality water is a key determinant for human, animal and plant survival. Without water, living things could not survive, making water quality one of the most important factors in whether anything can inhabit an area. Understanding relations can improve management and utilization of the groundwater resource by clarifying relations among groundwater quality, aquifer lithology, and recharge type (Ostovari et al. 2013). Recently by using geography information system (GIS) and sample data of well, prepare interpolation map. The GIS is an effective tool the estimation of the spatial distribution of environmental variables (Ordu and Demir, 2009; Rabah et al. 2011; Ritchie and Charles, 1996; Dekker et al., 2002 and Schalles et al., 1998). The use of GIS
and remote sensing in water quality monitoring have improved observation and detection, which have increased public and scientific awareness of water quality related issues and threats (Heisler et al. 2008). GIS can also be used to assess relationships between water quality and land use and land cover (Sharma et al. 2016; Zheng et al. 2016a). Zheng et. al assessed ground water contamination vulnerability from agricultural non-point source contamination using a GIS-base groundwater contamination risk assessment model (2016).

Spatial prediction and surface modeling of water properties has become a common topic in water science research. Interpolation can be undertaken utilizing simple mathematical models (e.g., inverse distance weighting, trend surface analysis and splines), or more complex models (e.g., geostatistical methods, such as kriging) (Negreiros et al. 2011).

Ordinary Kriging (OK), Universal Kriging (UK), Inverse Distance Weighting (IDW) and Radial Basis Function (splines) are four ways to interpolate water quality. Some researchers found that kriging methods out performed IDW or Radial Basis Function (Splines) (Kravchenko and Bullock 1999; Panagopoulos et al. 2006). IDW (Panagopoulos et al. 2006) and Splines (Kravchenko 2003; Keshavarzi and Sarmadian 2010) are also commonly used classical interpolation methods to analyze the spatial variability of water quality.

The fuzzy set theory concept was introduced by Zadeh (1965). To some extent, fuzzy method is a mathematical language that translate vague statements into a mathematical formalism (McNeil and Thro 1994). Sadiq et al. (2004) used fuzzy method to risk management for drilling waste discharges. Fuzzy method was also employed to evaluated urban air quality in Istanbul (Guleda et al. 2004). Wang used fuzzy method to assess the quality of air, water and soil in Zhuzhou City (Wang 2002).

The aim of this research is to employ the geostatistic analysis (IDW) and fuzzy AHP for prediction of water quality in North of Fars province, southeast Iran.

2. Material and method

2.1. Case study

This study area was located in north of Fars province, southeast of Iran. It has an area of about 6657.25 km², and is located at longitude of N 29° 18´- 30° 25´ and latitude of E 52° 04´ to 53° 26´ (Figure 1). The altitude of the study area ranges from the lowest of 1,530 m to the highest of 3,099 m.
For prediction the variability of groundwater quality, chlorine (Cl), sodium (Na), sulfate (So4), total dissolved solids (TDS) and total hardness (TH) were prepared (Table 1). For making the spatial distribution map of each parameters was used 122 wells that local position of the wells show in Figure 2.

Table 1. Statistic characteristics of chemical compositions (mg/l) in the groundwater’s of the study area

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Maximum</th>
<th>Average</th>
<th>STDV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>0.12</td>
<td>122.77</td>
<td>14.06016</td>
<td>21.96956</td>
</tr>
<tr>
<td>So4</td>
<td>0.15</td>
<td>56.35</td>
<td>6.923279</td>
<td>8.715891</td>
</tr>
<tr>
<td>Cl</td>
<td>0.25</td>
<td>173</td>
<td>21.76066</td>
<td>37.98701</td>
</tr>
<tr>
<td>TDS</td>
<td>315</td>
<td>11540</td>
<td>2040.91</td>
<td>2581.938</td>
</tr>
<tr>
<td>TH</td>
<td>200</td>
<td>6750</td>
<td>965.1</td>
<td>1250.4</td>
</tr>
</tbody>
</table>
2.2. Method
Preparing interpolation map

In the study for preparing interpolation maps for each parameter was used inverse Distance Weighted (IDW). To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location. Assumes value of an attribute $z$ at any unsampled point is a distance-weighted average of sampled points lying within a defined neighborhood around that unsampled point. Essentially it is a weighted moving average (Burrough et al. 1998):

$$
\hat{f}(x_0) = \frac{\sum_{i=1}^{n} f(x_i) d_{ij}^{-r}}{\sum_{i=1}^{n} f_{ij}^{-r}}
$$

(1)

Where $x_0$ is the estimation point and $x_i$ are the data points within a chosen neighborhood. The weights ($r$) are related to distance by $d_{ij}$.

Fuzzy and AHP method

A fuzzy membership function is described by a membership function $\mu A(T)$ of A. Each element $t \in T$ a number as $\mu A(T)$ in the closed unit interval $[0, 1]$ associates for membership function. The number $\mu A(T)$ shows the degree of membership of $t \in A$. The attention used for membership function $\mu A(T)$ of a fuzzy set A is $A: T \rightarrow [0, 1]$. The following function was used for all parameters of the water.
\[ T = f(t) = \begin{cases} 0 & t \leq a \\ t - a / b - a & a < t < b \\ 1 & t \geq b \end{cases} \]  

(2)  

Where \( t \) is the input data and \( a, b \) are the limit values.  

In order to define the fuzzy rules was used Schoeller diagram (Table 2).  

<table>
<thead>
<tr>
<th>( \text{SO}_4 )</th>
<th>CI</th>
<th>( \text{Na} )</th>
<th>TH</th>
<th>TDS</th>
<th>The degree of water quality for drinking</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5</td>
<td>&lt;5</td>
<td>&lt;10</td>
<td>&lt;190</td>
<td>&lt;280</td>
<td>High</td>
</tr>
<tr>
<td>5-10</td>
<td>5-10</td>
<td>10-15</td>
<td>191-250</td>
<td>281-500</td>
<td>Medium</td>
</tr>
<tr>
<td>11-15</td>
<td>11-20</td>
<td>16-20</td>
<td>251-600</td>
<td>501-1000</td>
<td>Low</td>
</tr>
<tr>
<td>16-25</td>
<td>21-30</td>
<td>21-30</td>
<td>601-1550</td>
<td>1001-3500</td>
<td>Very low</td>
</tr>
<tr>
<td>&gt;26</td>
<td>&gt;31</td>
<td>&gt;31</td>
<td>&gt;1551</td>
<td>&gt;3501</td>
<td>Non-Drinking</td>
</tr>
</tbody>
</table>

Using overly five factors for preparing water quality was used AHP method. These values are given by a scale from 1 to 9, where 1 means that the two elements being compared have the same importance and 9 indicates that of the two elements one is extremely more important than the other.  

3. Results  

In order to interpolation maps for each parameter was used IDW method that shows in Figure 3. The lowest and the maximum output in IDW is 1.5 and 79.93 mg/l for Ca. 0.28 and 172.25 mg/l are lowest and maximum value for Cl. The minimum value for Na and \( \text{SO}_4 \) are 0.12 and 0.21 mg/l respectively. While the maximum value for Na and \( \text{SO}_4 \) are 120.94 and 56.31 mg/l respectively. So the north of the study area is better quality than the south of the study area. Based on permissible limits for each parameters were defined membership function and then were created fuzzy maps for chlorine (Cl), sodium (Na), sulfate (\( \text{SO}_4 \)), total dissolved solids (TDS) and total hardness (TH) in ArcGIS software (Figure 4).
According to whatever of the So4, Cl, TDS, Na and TH value in the water have fewer, water quality is higher, lower value had given 1, high value had given 0 and other value had given between 0 to 1. Results of fuzzy method showed that, except the parts of south,
all of the area was not suitable for So4, Cl, and Na that had the value close to 0 (Figure 4). Also except the some parts of north was suitable for TDS and TH that had the value close to 1 (Figure 4).

Figure 4. Fuzzy maps for each parameter for determining the water quality in the study area. (a): So4; (b): Cl; (c): TDS; (d): Na; (e): TH
The AHP method was applied on the fuzzy parameter maps and the pairwise comparison matrix which was used for preparation of the weights for each parameter was given in Table 3. Results showed that the most important factor in water quality was Na with weights of 0.39. While the least important water parameters was So4 with weights of 0.090 (Table 3).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Na</th>
<th>TDS</th>
<th>Cl</th>
<th>TH</th>
<th>So4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>TDS</td>
<td>1/2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Cl</td>
<td>1/3</td>
<td>1/2</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>TH</td>
<td>1/4</td>
<td>1/3</td>
<td>1/2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>So4</td>
<td>1/5</td>
<td>1/4</td>
<td>1/3</td>
<td>1/2</td>
<td>1</td>
</tr>
</tbody>
</table>

Finally based on the fuzzy maps for each parameters (Figure 5) and weight of each parameter that was calculated using AHP method (Table 1), the final fuzzy map was determined (Figure 5). The value of final fuzzy map was between 0 to 0.98 where showed the some parts of the study area had high quality (for value more than 0.75), medium quality (for value between 0.5 to 0.75), low quality (for value between 0.25 to 0.5) and very low quality (for value between 0 to 0.25) the results show that only some parts of south had good water quality with value close to 1 (Figure 5). Then, the fuzzy map reclassified in four classes consisted of very low (2624.64 km²), low (533.41 km²), medium (1478.64 km²) and high (2020.55 km²) (Figure 5 and Table 2).
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After reclassifying the fuzzy map prepared in the four classes that show in Figure 6 and Table 4.

Figure 5. Fuzzy-AHP combination map for water quality.

Figure 6. Map of the fuzzy classification.
Table 4. The area (%) for each of the classes for water quality

<table>
<thead>
<tr>
<th>Class</th>
<th>Area (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>2624.642</td>
</tr>
<tr>
<td>Low</td>
<td>533.4191</td>
</tr>
<tr>
<td>Medium</td>
<td>1478.64</td>
</tr>
<tr>
<td>High</td>
<td>2020.55</td>
</tr>
</tbody>
</table>

4. Conclusion
This aim of the study was determination of the groundwater quality in north of the Fars province, southeast of Iran. The results of spatial distribution each of parameters by IDW show that the maximum value of parameters is located in south of the study area. The results of fuzzy method showed that, except the parts of south, all of the area was not suitable for So₄, cl, and Na that had the value close to 0. Also except the some parts of north was suitable for TDS and TH that had the value close to 1.
The major difference between this study and other studies is that we combine two methods (fuzzy and AHP) for determination of water quality. Similar research was done by Shobha et al. (2013). Shobha et al. (2013) used fuzzy-AHP for determination of water quality. In the study, a membership function for the fuzzy rule based system for each salt was developed and the weights for each parameter was calculated using Analytic Hierarchy Process (AHP) that relies on pair wise comparison. The system showed that out of 24 districts of Karnataka state, ground water from 51.78% bore-wells was not feasible for consumption.

References
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