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# Using the AHP method to evaluation of aquifer potential pollution in geographical information system (GIS)

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**Key words:** Aquifer Vulnerability, GIS, DRASTIC Model, Analytic Hierarchy Process (AHP).

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## Abstract

In this paper, Eshtehard plain pollution potential calculated by the AHP method and compared with the results of DRASTIC method. Seven parameters data were prepared and entered in GIS system. This data include the depth to water table, net recharge, aquifer media, soil, topography, De saturated media and conductivity. In this investigation, with slight changes in this method's parameters to calculate net recharge (called Piscopo), better results have been obtained for the study area in Iran. The results of performance the DRASTIC model, shows that aquifer vulnerability index which got from ranks and weights each parameters sum, minimum is 74 and the maximum is 185.The average of index is calculated 129 in the plain. Also by AHP method, with consideration of four parameters, such as: conductivity, depth to water table, precipitation, slope and comparison the parameters two by two, the weight of each parameter had obtained. So accordingly, a new model had present to evaluation the aquifer vulnerability. The average of vulnerability in Eshtehard plain is 56 percent by this model.

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**Introduction**

Our country due to being in arid and semi-arid climate has limited water resources. These resources are groundwater that natural contaminants always threat them. The models of evaluation groundwater vulnerability are the models to calculating pollution potential index or vulnerability index by consideration of influence factors and criterions on contaminants transfer to aquifers (Alwathaf Y *et al.*, 2011).

Various methods have already been proposed to calculate aquifer vulnerability index. The most famous useful methods is parametric model which called DRASTIC, that by seven hydrological, hydrogeological parameter and assigned rank and specific weights to them, presents an index to aquifer vulnerability. These seven parameters are: depth to water table (D), net recharge (R), the aquifer media (A), soil (S), and topography (T), De saturated media (I) and conductivity (C).

**Table 1**. Parameters of DRASTIC model.

| Weight | Parameter |
|---|---|
| 5 | Depth to water table (D) |
| 4 | Net recharge (R) |
| 3 | The aquifer media (A) |
| 2 | Soil (S) |
| 1 | Topography (T) |
| 5 | De saturated media (I) |
| 3 | Conductivity (K) |

In this table, depth to water table and de saturated media has the maximum weight and topographic parameter has lowest weight. To calculate the DRASTIC index at any point of the study area, rank of each parameter multiplied to its weight that the sum gives the DRASTIC index. As regards the ranks can be 1 to 10 and the total of DRASTIC coefficient is 23, so the minimum of index is 23 and the maximum is 230.

This means the area that its vulnerability index is 23, is in the lowest risk of infection. In contrast, the area that its vulnerability index is 230 is in the highest risk of infection. There are four assumptions in DRASTIC model:

Pollution entered from the water table to aquifer. The factor of contaminants transfer is absorbed water from precipitation. Mobility of contaminants is equal to mobility to water (Abdulla Rawabdeh *et al.*, 2013). They are assessment using DRASTIC model, is at least 40 hectares.

Vulnerability index map: After entering data into the GIS system and calculate the rank for each parameter according to Table 1 and the equation (1), prepared DRASTIC index map:

$$DRASTIC\ Index = D_R D_W + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W \quad (1)$$

In this equation, total multiplied of parameters rank and weights is calculated as vulnerability index (Rahman, 2008).

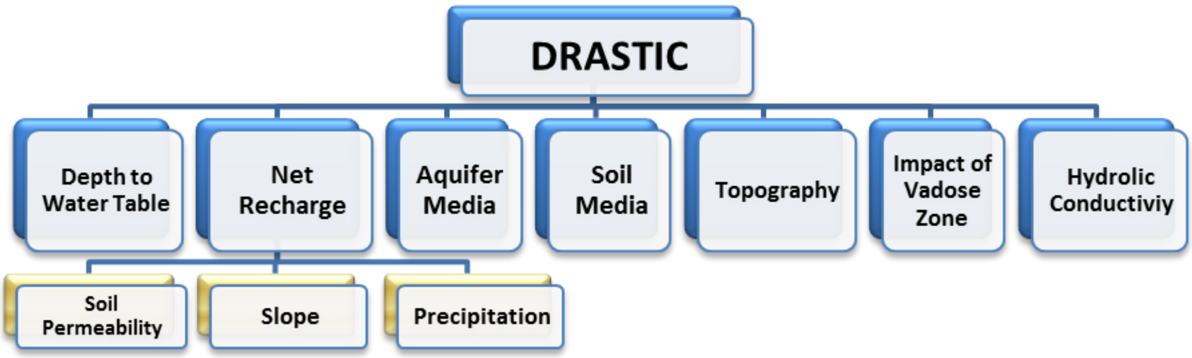



**Fig. 1**. DRASTIC Model Parameters.

DRASTIC model includes the parameters that the hydro-geological are correlated. This will lead to data redundancy and maybe inconsistency in the comparison. So to enhance the parameters accuracy and weighting them is suggested to use the analytic hierarchy process (AHP) to evaluation the aquifer vulnerability. In this way various experts' opinions have to enter into the method's matrix calculated the value of each criterion. DRASTIC model only estimates the pollution potential, so it is worth considering the pollution distribution data in the study aquifer, developed this model and evaluated the accuracy. Given the multiplicity of industrial and pollution distribution by them in the study area, in addition to considering Nitrate pollution from fertilizers of land acreage, survey sulphate pollution over two years (Wang *et al.*, 2007).

In the analytic hierarchy process after the formation of the tree diagram and determine the indexes, the parameters compared two by and each parameter's relative weight is given from resulting matrix. Redundancy and parameters dependency is the facing challenge to use this method which the effect will determinate after calculating the inconsistency coefficient. If to calculating net recharge layer use Piscopo method as described, due to the involvement of the slope layer, redundancy and data dependency will be more, also the parameters of the conductivity and permeability not independent of aquifer media, de saturated media even soil. So to obtain an accuracy result of aquifer vulnerability offered to use independent criterions in AHP method and combined them DRASTIC model criterions (Mendoza *et al.*, 2006). The purpose of this study is using the independent parameters to estimate of the aquifer vulnerability with assigning new weights based on comparison of the parameters two by two to obtain a more accurate model.

## Materials and methods

*Study area*

The Eshtehard plain is a part of the top notch drainage basin of the central plateau and second-rate drainage basin of the salt lake and is adjacent two major basins of Tehran-Karaj and Qazvin. City Eshtehard Industrial nature and number of large industrial centers in the area is a threat to the aquifer of this area. Eshtehard plain alluvial aquifer is one of the most important groundwater sources of Tehran which has been a decisive role in the provision of water supply to drinking, agriculture and industry.

In Eshtehard plain on the on hand because of the In Eshtehard plain, on the on hand because of the geographical specific location, adjacent two metropolises of Tehran and Karaj, the growing population of these cities and adjacent of satellite towns which outcome of it, is increasing need to water, so uncontrolled exploitation of aquifer has intensified through deep wells.

On the other hand, despite of announced the ban to operation of aquifer to agriculture since 1374, unfortunately illegal operation of aquifer is go on and the surveys show the imbalanced status and persistent decline in resource volume.

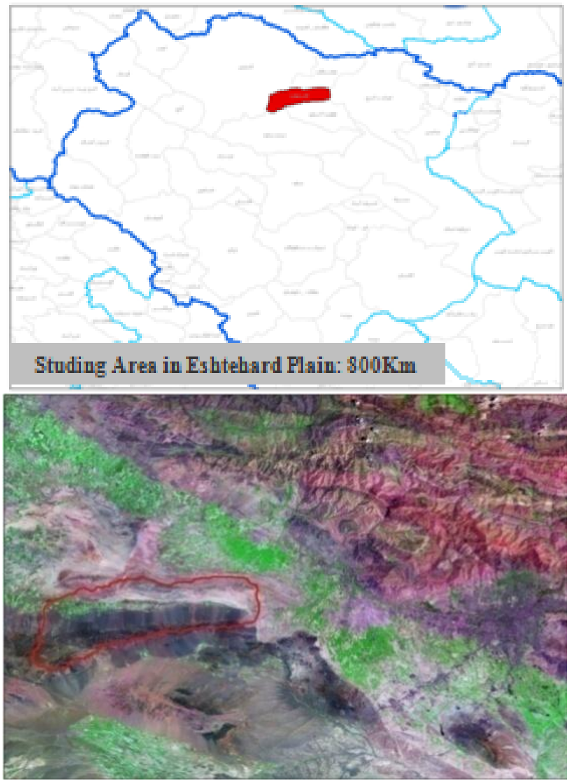



**Fig. 2**. Location of the study area – The Eshtehard Plain.

**Results and discussion**

*The Data Used*

The parameter of depth to water table can be achieved by the data were taken from wells or drilling logs. This data must be converted from the spot to Polygon and subsequently raster. To do this can be used Thiessen Polygon.

The aquifer media and de saturated media data extracted from drilling logs. The drilling log is the soil profile of ground lower layer where type is specified in the each depth to bedrock. Depth of water table can also be obtained from drilling logs. Topographic layers can be extracted from the digital elevation model.

To provide net recharge layer can be used the equation below:

Net recharge = the difference of Evapotranspiration and Precipitation × recharge coefficient (2)

In this equation is used annual rainfall data of thirty years at seven stations in the country of study (Japan). Recharge coefficient considered 20% for urban areas and 85% for other areas (Al-Adamat *et al.*, 2003).

The other methods to calculating the aquifer net recharge is using Piscopo. In this method, according Table 2, to directly calculating of net recharge in DRASTIC model is used the total weight of three values of the slope, Precipitation and permeability:

Net recharge = Precipitation + slope + permeability (3)

**Table 2**. Ranking by Piscopo method table.

| Net recharge | | permeability | | Precipitation | | slope | |
|---|---|---|---|---|---|---|---|
| **Rank** | **Range** | **Rank** | **Classification** | **Rank** | **Precipitation (mm)** | **Rank** | **Slope (%)** |
| 10 | 11-13 | 5 | High | 4 | >850 | 4 | <2 |
| 8 | 9-11 | 4 | Moderate to high | 3 | 700-850 | 3 | 2-10 |
| 5 | 7-9 | 3 | Average | 2 | 500-700 | 2 | 10-33 |
| 3 | 5-7 | 2 | Low | 1 | <500 | 1 | >33 |
| 1 | 3-5 | 1 | Very little | | | | |

Also to provide the net recharge layer is used Iso-Rain layer multiplied by permeability layer. Permeability rate is the percentage of rainfall that Penetrates into the ground. Also it can estimate aquifer conductivity with the data of water table level in different months (Thirumalaivasan *et al.*, 2003). Thus the aquifer net recharge map is acquired of subtracting the map of water table level in the dry months from the wet months and multiplied the result by the permeability map.

There are different ways to provide and calculating the conductivity layer.

The conductivity layer is related to the aquifer permeability or the ability of the aquifer to transferring water or solutes. The conductivity presented by capital K in the hydrology problems and its dimension is the speed. Indeed the intensity of groundwater flowed by hydraulic slope. The conductivity is a controller to movement and the pollutants shelf life from entering the soil to the aquifer. Because of it, increasing K is causing to more or high pollution potential (Al-Zabet, 2002).

The exact value of conductivity can be obtained of pumping tests with the constant rotation, in terms of $m^3$/ day (Melloul *et al.*, 1998).

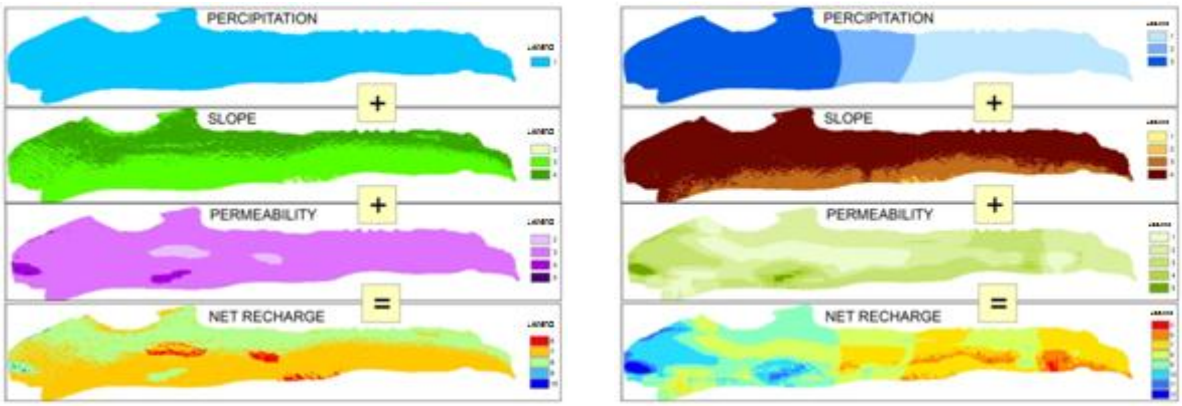
The other way to providing conductivity is using the saturation layer thickness map (or the aquifer thickness) and transmissibility. The conductivity map is obtained from divided by transmissibility map to saturation layer thickness (Wang *et al.*, 2007).

*The Data Preparation and Maps Production*

To providing the depth to water table map used the data of 22 wells, drilling logs and their soil. The depth to water table parameter obtained by sampled wells data of Iran Water Resources Management Company. This data must be converted from the spot to Polygon and raster subsequently. To do this, can be used the interpolation methods as inverse distance weighted (IDW) or Kriging.

To providing the net recharge layer used Piscopo method as described in the previous section. However in this study, due to the specific condition of weighting in this method, the prepared map is with great uniformity all over the study area.

For example, the precipitation parameter that has important role to aquifer net recharge is from 180 mm to 245 mm that in the classification of rainfall is placed the range of "very low" (precipitation less than 500 mm) throughout the study area. In this classification the diversity and distribution of permeability disregarded as seen in the conductivity map in the Fig. 3. The result of performance the Piscopo method by 3 parameters of precipitation, slope and permeability with the weighting according the Table 3 is like the right map in Fig. 2. But with minor changes in the weighting parameters and reclassified with new coefficients can obtained the result the left map in Fig. 3.




(Weighting by new method) (Weighting by Piscopo method)

**Fig. 3**. Calculating the net recharge rank by Piscopo weighting and new weighting.

As seen in the results, the topography has a significant effect on the results of the old weighting method. In reality the effect of precipitation and permeability on the net recharge is greater than the effect of slope and topography has less important role in the net recharge. Thus can be concluded, using the weights of the Piscopo method is not efficient in the study area. Maps of the aquifer media and de saturated media were extracted and prepared from soil profiles of sampled wells (Drilling logs). This data exist as points that were converted to layers of raster and surface by Thiessen.

The slope layer was prepared by digital elevation model (DEM). Also to providing the soil layer used the soil type map. The quantity of conductivity can be obtained from divided by the transmissibility to aquifer thickness, according to equation (4).

$$\text{Conductivity (K)} = \frac{\text{transmissibility (T)}}{\text{aquifer thickness (d)}} \quad (4)$$

Conductivity layer obtained of the division transmissibility map ($m^2$/day) to aquifer thickness map (m) as Fig. 4.

Maps collection of primitive parameters affecting on the aquifer vulnerability is presented in Fig. 5.

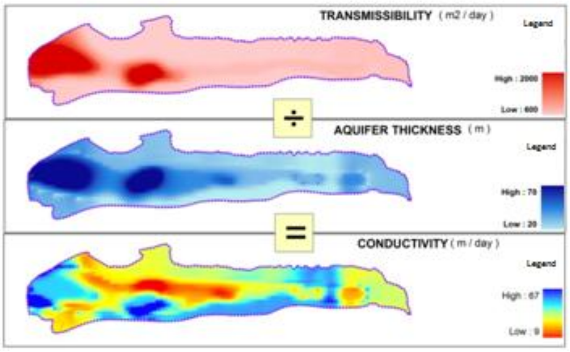



**Fig. 4**. Providing the Conductivity Map.

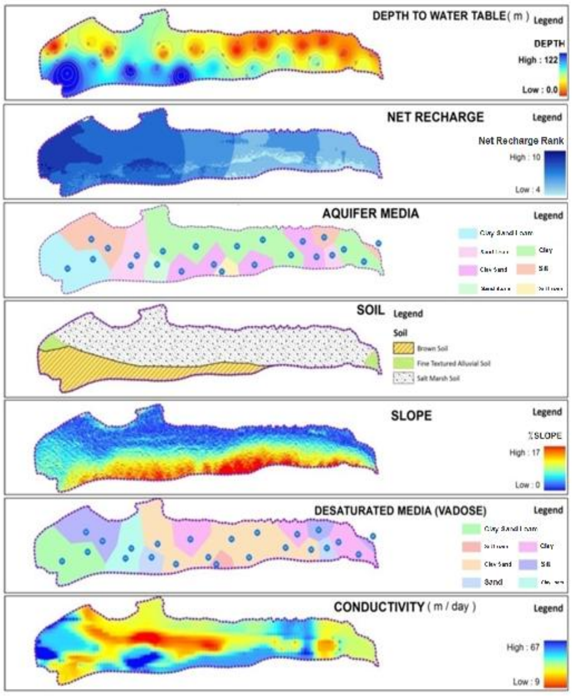



**Fig. 5**. The Aquifer Vulnerability Parameters Map.

*Weighting Parameters*

*1. The Parameters Weighting by DRASTIC Assumptions*

To considering of assigned weights to parameters in the DRASTIC theory (Table 1) and apply them on maps of seven, index DRASTIC map and zoning risk in the study area is like Fig. 6. Indeed the following maps have been prepared of the weighting to seven parameters by the DRASTIC theory assumptions.

The average of vulnerability index is 129 in the area that is placed in range of the "low to moderate" in the category of risk.

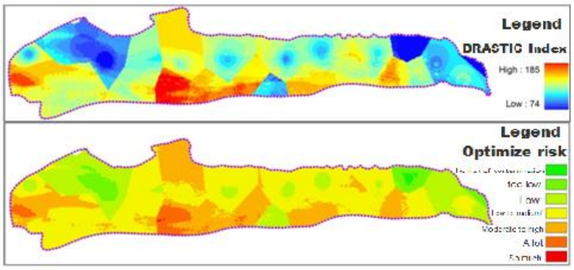



**Fig. 6**. Aquifer vulnerability Map based on the DRASTIC Model Weighting.

*2. Advantages and Disadvantages of the DRASTIC Method*

There are seven parameters in the DRASTIC method that seems significant numbers of them overlap with each other in terms of conceptual. For example, the parameter of conductivity which is directly affected by the parameters of de saturated media, aquifer media and soil (Gogu *et al.*, 2000). In other words, this parameter is dependent on the aquifer geological features. It is worth noting, this parameter weight is 13 out of the total weight in the DRASTIC model, which is so high weight. While the two layers of the de saturated media and aquifer media are correlated a lot. The correlation coefficient between these two parameters according to equation (5) is 62.8%.

$$r = \frac{\mathrm{cov}(x, y)}{\sigma_x \sigma_y} \qquad (5)$$

Generally the permeability or conductivity is the ability of aquifer to transmission particles from the surface to depth. The other important factor in the transfer of pollutants from surface to depth is the aquifer thickness parameter that in the transmitting parameter, is considered this item too. Therefore in researches conducted as AVI transmissibility or reverse number of it, the hydraulic friction, presented as an index to evaluation of assessing the aquifer vulnerability (Doerfliger *et al.*, 1999).

*3. The Method of Analytical Hierarchy Process (AHP)*

Analytical Hierarchy Process based on the separation and break down complex problems into simpler parameters. In this method, the parameters to be measured and valued two by two, and the relative weight of each parameter is calculated by the resulting matrix. Redundancy and parameters dependency is the facing challenge to use this method which the effect will determinate after calculating the inconsistency coefficient (Vias *et al.*, 2005).

*Using the AHP Method to Evaluation of Aquifer Pollution Potential*

As described in the previous section. Used Piscopo method to calculating the net recharge layer. Due to the involvement layers of the slope and permeability in this method, redundancy and data dependency will be more. Also the conductivity parameter not independent of aquifer media, de saturated media even soil. So using the AHP method and combining it with the DRASTIC theory is not reasonable as the parameters are dependent of each other. So to using the AHP method, it is better to considered less parameter with more independence. As described, conductivity parameter itself contains the parameters such as: soil, de saturated media, aquifer media, aquifer thickness, transmissivity. Among of the four parameters such as: conductivity parameters in DRASTIC model (which obtained from aquifer thickness and transmission maps), depth to water table, slope and precipitation were considered as four independent parameters. Table 3 was prepared to comparison of these four parameters two by two and calculation of the relative weight of each parameter subsequently. In this method, the inconsistency coefficient calculated 0.04 using the follow weighting.

**Table 3**. Parameters weighting table by AHP method.

| Weight toward the DRASTIC | Weight | Geometric average | S | C | R | D | Abbreviations | Parameters |
|---|---|---|---|---|---|---|---|---|
| 7.1 | 0.31 | 1.41 | 4.00 | 0.50 | 2.00 | 1.00 | D | Aquifer depth |
| 4.2 | 0.18 | 0.84 | 2.00 | 0.50 | 1.00 | 0.50 | R | Precipitation |
| 9.4 | 0.41 | 1.86 | 3.00 | 1.00 | 2.00 | 2.00 | C | Conductivity |
| 2.3 | 0.1 | 0.45 | 1.00 | 0.33 | 0.50 | 0.25 | S | Topography |
| 23 | 1 | 4.57 | | | Total | | | |

As seen, in comparison of the parameters two by two, the influence of a parameter is a little different than another parameter on aquifer pollution. For example, the influence of the aquifer depth is 2x more than precipitation that mean aquifer depth effect on pollution transfer more than precipitation. Most different amount is between these two parameters: aquifer depth and slope, that shows influence of aquifer is more than slope. So by calculating this table, the weights of parameters obtained as:

Conductivity (0.41) - aquifer depth (0.31) - precipitation (0.18) – slope (0.1). By applying the new weights, aquifer vulnerability map by the new method obtained as Fig. 7.

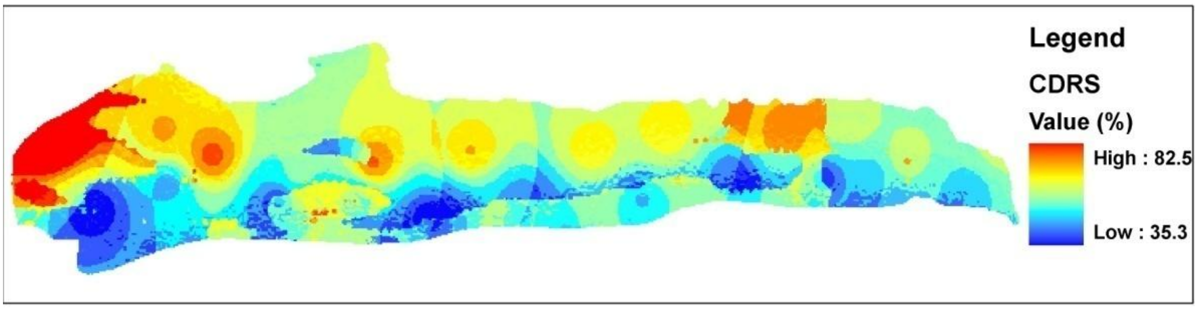



**Fig. 7**. Aquifer Vulnerability Maps by the New Model (CDRS).

According to normalization of total weights in AHP method the obtained indices of 10 in this method is mentioned by percent. As seen, the minimum vulnerability of the map is 35% and maximum is 83%. The average o vulnerability had calculated 56% in Eshtehard.

**Conclusion**

Using of DRASTIC model showed the vulnerability of the study area, is at least 74, at most, 185 and the average of vulnerability is 129 that it set in the "low to moderate" in the category. DRASTIC model contains multiple and overlapping factors that leads data to redundancy, such as Such as these two parameters: aquifer media and de saturated media that the correlation coefficient between them had calculated as 62.8%. In the AHP method, interrelated and interdependent parameters removed as possible and four parameters were considered such as: conductivity, depth to water table, precipitation and slope which compared and weighting by AHP method, the model of this method called CDRS model. The index that expressed by the percent, in study area had calculated 35% in minimum and 83% in maximum.

It seems, in the aquifer vulnerability there are more parameters such as vegetation and land-use are effective too, that will be the subject of study in the Future.

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