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Groundwater vulnerability assessment using GIS-based DRASTIC and GOD in the Asadabad plain

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Abstract

The different models such as DRASTIC and GOD models has been used to map groundwater vulnerability to pollution in very areas. The main purpose of this is to used two methods, DRASTIC and GOD, applied to the basin of the Asadabad plain in determining groundwater vulnerability to pollution. The results showed in models of DRASTIC and GOD respectively 2.1% and 1.6% of the areas are high potential vulnerabilities. According to the model DRASTIC at study area 63.6 % of has a low class of groundwater vulnerability to contamination, whereas a total of 34.2% of the study area has moderate vulnerability, that the value for GOD model was 60.8% and 37.6% respectively.The final results indicate that the aquifer system in the interested area is relatively protected from contamination on the groundwater surface. To mitigate the contamination risks in the moderate vulnerability zones, a protective measure must be put before exploiting the aquifer and before comprehensive agricultural activities begin in the area.

1. Introduction

Groundwater vulnerability is considered an intrinsic property of groundwater and can be defined as the possibility of percolation and diffusion of contaminants from the ground surface into the groundwater system. The term vulnerability is used to explain the degree to which human or environmental systems are likely to experience harm due to perturbation or stress, and can be known for a determined system, hazard, or group of hazards [1]. Vulnerability evaluation of Groundwater aquifer provides a basis for initially protective measurement for important groundwater resources and will normally be the first step in a groundwater pollution hazard assessment and quality, when it interest [2]. Many approaches have been expanded for assessing groundwater vulnerability and con are grouped into three major categories [3]: a. overly and index methods; b. methods using process-based simulation models; c. statistical methods.

In overly and index methods, factors which are controlling movement of pollutants from the ground surface into the saturate zone (e.g., geology, soil, impact of vadose zone, etc.) are mapped depending on existing and/or derived data. Subjective numerical values (rating) are then assigned to each factor based on its importance on controlling pollutants circulation. The rate maps are linearly to produce final vulnerability map of a region. The groundwater vulnerability assessment by such methods is qualitative and relative. The main benefit of such methods is that some of the factors controlling movement of pollutants can be assessment over large area, which makes them appropriate for regional scale evaluation [4]. With the development of GIS digital technology, adoption of such methods for creating vulnerability maps is an easy task. Several overly and index methods have been expanded. The most common one are: the DRASTIC system [5], the GOD system [2], the AVI rating system [6], the SINTACS method [7], the German method [8], the EPIK [9], and the Irish perspective [10]. The prevention against groundwater pollution constitutes an important phase to which scientists are doing their best notably in studying the vulnerability of the groundwater. They therefore, created classical scientific methods and numerical, to facilitate the identification of the state of these groundwater and to control the pollutants in the reservoirs such as DRASTIC and SI. These different methods are presented under the form of numerical quotation systems based on the consideration of the different factors influencing the hydrogeological system [11].

Prevention of aquifers pollution is considered as an important factor in the management of groundwater resources; also, the assessment of aquifer vulnerability by scientists is an essential factor which gives us solutions to protect groundwater resources. To recognize the need to an efficient method to protect groundwater resources from contamination, scientists and managers develop aquifer vulnerability techniques for predicting which areas are the most vulnerable [12]. During the past years the assessment of groundwater vulnerability to pollution has been the subject to intensive research and a variety of methods have been developed. Many approaches have been developed to evaluate aquifer vulnerability and for this objective, the GIS and remote sensing tools are combined to two methods: standard DRASTIC and GOD method. Also, these are used to evaluate aquifer vulnerability to pollution. A comparative study of the vulnerability maps was performed in order to choose the best method [12, 13].In the Asadabad plain intensive agriculture has raised concern over possible contamination drinking water supplies. Often nitrate concentrations in agricultural areas are associated with pesticide and microbial contaminations. Nitrogen fertilizers or manure applied to farmlands can be considered as non-point sources of nitrate. The aim of the present study is to assess the aquifer vulnerability of Asadabad plain and to recognize the sensitive areas against pollution. Recognizing the vulnerability of groundwater will help to manage their quality and protect groundwater resources. Possibility of pollutants reaching and releasing into the groundwater after contaminating the ground, is called the aquifer vulnerability. In this study aquifer vulnerability assessment is to identify areas prone to pollution that were modeled via the DRASTIC and GOD models, and the Maps generated for each parameter were classified and combined based on the models.

2. Materials and Methods

The data was collected including: piezometric level measurements in September 2013; results from pump tests in 30 wells; in fact, these results allow to deduce the transmissivity values and permeability values; data sheets and logs of the geological drilling; results of geophysical interpretations (maps of apparent resistivity, resistance transversal, cuts geoelectrical); cartographic documents on the scale 1:50.000(geological map and soil map, topographic maps of area) and with the 1:25.000 (topographic maps of area); digital maps of land at 1:10.000;slope map and Digital Elevation Model (DEM) and the meteorological data in order to assess the water balance and estimate infiltrated water.The Asadabad alluvial aquifer with an area of 962 square kilometers is situated in western Iran (Figure 1).

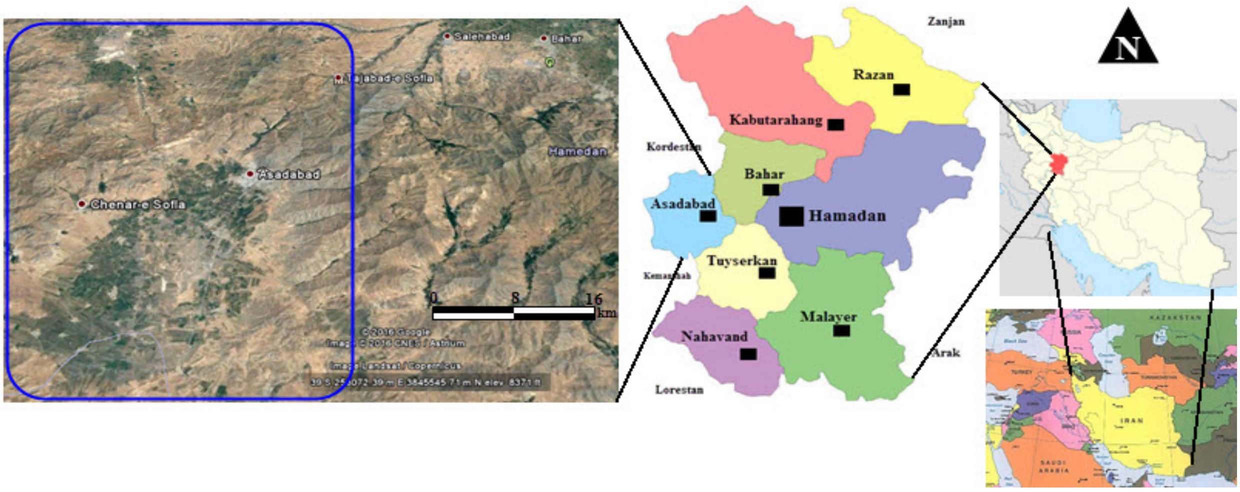

Figure 1: The geographical location of the study area

The location of the aquifer is between 48º 07 to 34º 47 east longitude and 37º 07 to 37º 25 north latitude. Figure 2 shows the geological map of the area. In the region under study, almost 1.5 percent of the irrigation water that is about 4 million cubic meters (MCM) infiltrates into the groundwater per year. In addition part of the municipal wastewater i.e. about 4 MCM, from the cities of Chardoli, and Asadabad, percolates into the groundwater annually [14]. These factors have resulted in the groundwater in some parts of the aquifer being polluted, making it necessary to have an precise plan to prevent more damage to the groundwater resources [14].The Asadabad alluvial aquifer located in the west of Iran selected as a case study to show the applicability of the proposed method. The chosen study region is mostly included of agricultural lands and the use of fertilizers and pesticides are common practices. Before starting detailed data collection, some general information pertaining to the socioeconomic, physical characteristics and demographic, settlement patterns and water supply schemes of the communities under study were gathered. This information has been used as a base for planning the field data collection and determining the selection of the sample population [15].

A comprehensive groundwater vulnerability model must include parameters to describe how much a site is risky to be contaminated and how the contaminant moves from the contamination site to the aquifer, therefore numerous vulnerability modeling approaches is proposed [5]. In this study, the vulnerability rating used is the GOD and DRASTIC. In Figure 3 had shown the flowchart of methodology for groundwater pollution vulnerability analysis.

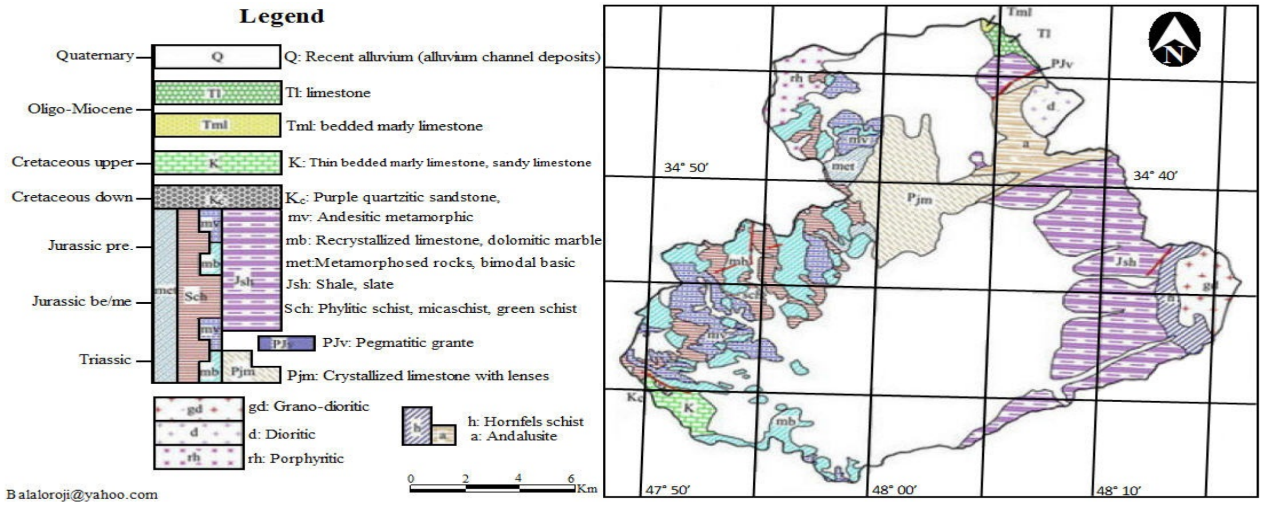

Figure 2: The geological map of the study area – map corrected

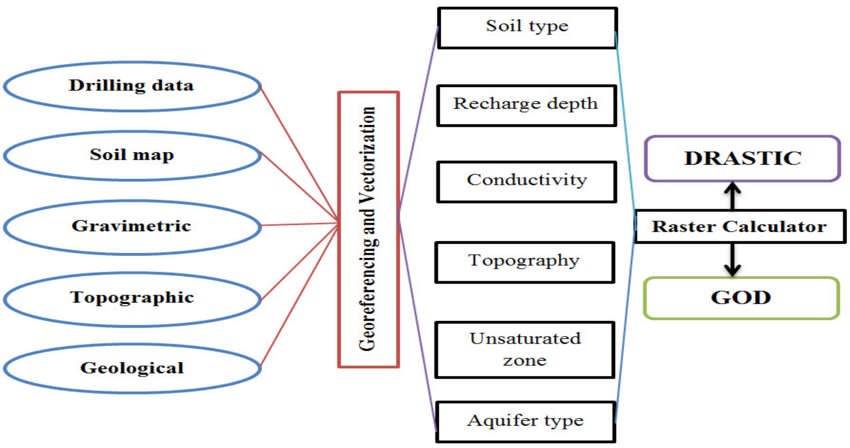

Figure 3: Flowchart of methodology for groundwater pollution vulnerability analysis

The depth (D) index represents the depth from the land surface to the first groundwater aquifer. It determines the thickness of material through in which infiltrating water must move before reaching the aquifer-saturated zone [16]. Consequently, the depth of the groundwater impacts on the interaction degree between the percolating contaminant and subsurface materials and, therefore, on the degree and extent of physical and chemical attenuation, and degradation processes, the depth groundwater distribution (D) was established by subtracting the groundwater level, measured in 30 wells in the Asadabad alluvial aquifer, from the topographic elevation in the corresponding cell location [16]. The soil media (S) index was obtained by digitizing the existing soil maps, with 1:50.000 as a scale required from Hamadan Research and Education Center for Agriculture and Natural Resources which they cover the entire region. The Topography (T) index is to the slope percent of the land surface which was determined directly from the topographic maps of Asadabad area (scale 1:50.000). For calculate the net recharges (R) index distribution, the Water Table Fluctuations method (WTF) was used. One of the major impacts of the integrated watershed management program was on improving groundwater recharge and its availability [21]. It estimates groundwater recharge as the product of specific yield and the annual rate of water table rise added to the total groundwater draft ended by the equivalent permeability, which is found from well logs [18]. The hydraulic conductivity (C) index is defined as the ability of aquifer materials to transmit water which, controls the rate at which groundwater will flow under a given hydraulic gradient. The rate, at which the groundwater flows, also controls the rate at which it enters the aquifer.

3. Results and Discussion

A raster map is made from interpolation of the well data using the GIS software for each indicator. In order to obtain the vulnerability indexes was given the attribution to each indicator the corresponding weight and rating according the formula of each method. All indicators in different models are mapped [19]. The slope map is obtained from the digital elevation model and map of soils is scanned and then processed from the Soil Map. Also each indicator is classified on certain vulnerability classes with values from the DEM. We have been allowed to map the distribution of each indicator using the Kriging interpolation technique. The Asadabad alluvial aquifer is important water resource because it is used for irrigation; therefore the aquifer vulnerability to pollution by generic pollutants has been studied by applying the following methods.After classifications data for each indicator, the spatial mapping in Raster format by interpolation of these indicators is a necessary step in this work. At GIS software; maps are classified by "symbology" and then are cut with the tool "Extract by Mask" then they will be recorded in Raster "Tift" format. The maps are then superposed through "ArcScene," and the final product of vulnerability has been deducted by the "Raster calculator" tool, using the formulas already defined previously and multiplying classified indicators by their equivalent weight.

The DRASTIC model is the most widely method used to assessment intrinsic vulnerability for a wide range of potential contaminants. It is an overlay and index model deliberate to product vulnerability scores by combining several thematic maps. Inherent in each hydrogeological settings are the physical characteristics that affect the groundwater pollution potential. After the factors such as transmissivity, temperature, aquifer chemistry, gaseous phase transport, tortuosity and some others have been evaluated, the most important factors that control the groundwater pollution potential have been determined to be Net Recharge, Soil Type, Depth to Water, Topography, Aquifer Material, impact of the Unsaturated Zone and Aquifer Media of the Hydraulic Conductivity, in short DRASTIC. Figure 4 shows depth to water table in Asadabad aquifer. Using the created maps and based on the rating system recommended in the original DRASTIC model, the depths were divided into different classes.

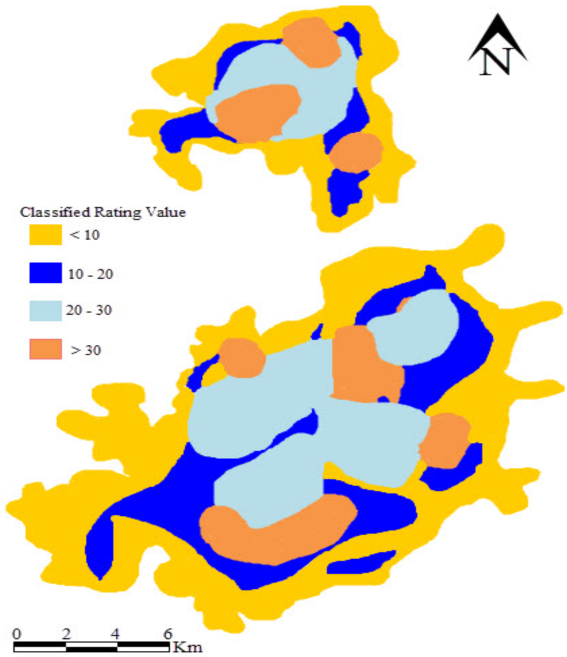

Figure 4: Mapping of depth to water table in the Asadabad alluvial aquifer

In the following, a numerical ranking system to assess groundwater pollution potential in hydrogeological setting has been devised [5]. It assigns a note between 1 and 10 and a weight between 1 and 5 for each used indicator (Table 1).For DRASTIC models used Eq. (1).

$$DI = Cp \times Cc + Ip \times Ic + Tp \times Tc + Sp \times Sc + Ap \times Ac + Rp \times Rc + Dp \times Dc \quad (1)$$

Where, ***DI*** is the vulnerability index based on the DRASTIC model; ***C***: hydraulic Conductivity; ***I***: Unsaturated zone; ***T***: Topography; ***S***: Soil Media; ***A***: Aquifer Material; ***R***: Net Recharge and ***D***: Depth to Water. The results of this model are shown in Figure 5.

The GOD method is an empirical method for the assessment of aquifer pollution vulnerability that developed inGreat Britain; this method uses three indicators: overlying lithology, depth to groundwater and groundwater occurrence. Values from 0 to 1 can be assigned to the indicators (Table 2) [2]. For GOD models used Eq. (2).

$$IGOD = C_i \times C_a \times C_p \quad (2)$$

C_i: Aquifer type; C_a: Saturated zone and C_p: Depth. The results of GOD model are shown in Figure 6.

Table 1: Attribution of notes for DRASTIC model indicators[5].

Range	Rating		Range	Rating		Range	Rating	
Confining Layer	1	**Vadose Zone Material**	0-1.5	10	**Depth to Water (m)**	0.04-4.1	1	**Conductivity (m/d)**
Silt/Clay	3		1.5-4.5	9		4.1-12.3	2	
Shale	3		4.5-9	7		12.3-28.7	4	
Limestone	3		9-15	5		28.7-41	6	
Sandstone	6		15-22	3		41-82	8	
Bedded Limestone, Sandstone	6		22-30	2		>82	10	
Sand and Gravel W. Silt	6		>30.4	1		0-2	10	**Topography (Slope %)**
Sand and Gravel	8		Thin or Absent	10	**Soil Media**	2-6	9	
Basalt	9		Gravel	10		6-12	5	
Massive Shale	2	**Aquifer Media**	Sand	9		12-18	3	
Metamorphic/Igneous	3		Peat	8		>18	1	
Weathered Metamorphic Igneous	4		Shrinking Clay	7		0-50	1	**Recharge (mm)**
Glacial Till	5		Sandy Loam	6		50-100	3	
Bedded Sandstone, Limestone	6		Loam	5				
Massive Sandstone	6		Silty Loam	4		100-175	6	
Massive Limestone	8		Clay Loam	3				
Sand and Gravel	8		Muck	2		175-225	8	
Basalt	9		No shrinking Clay	1				
Karst Limestone	10					>225	9	

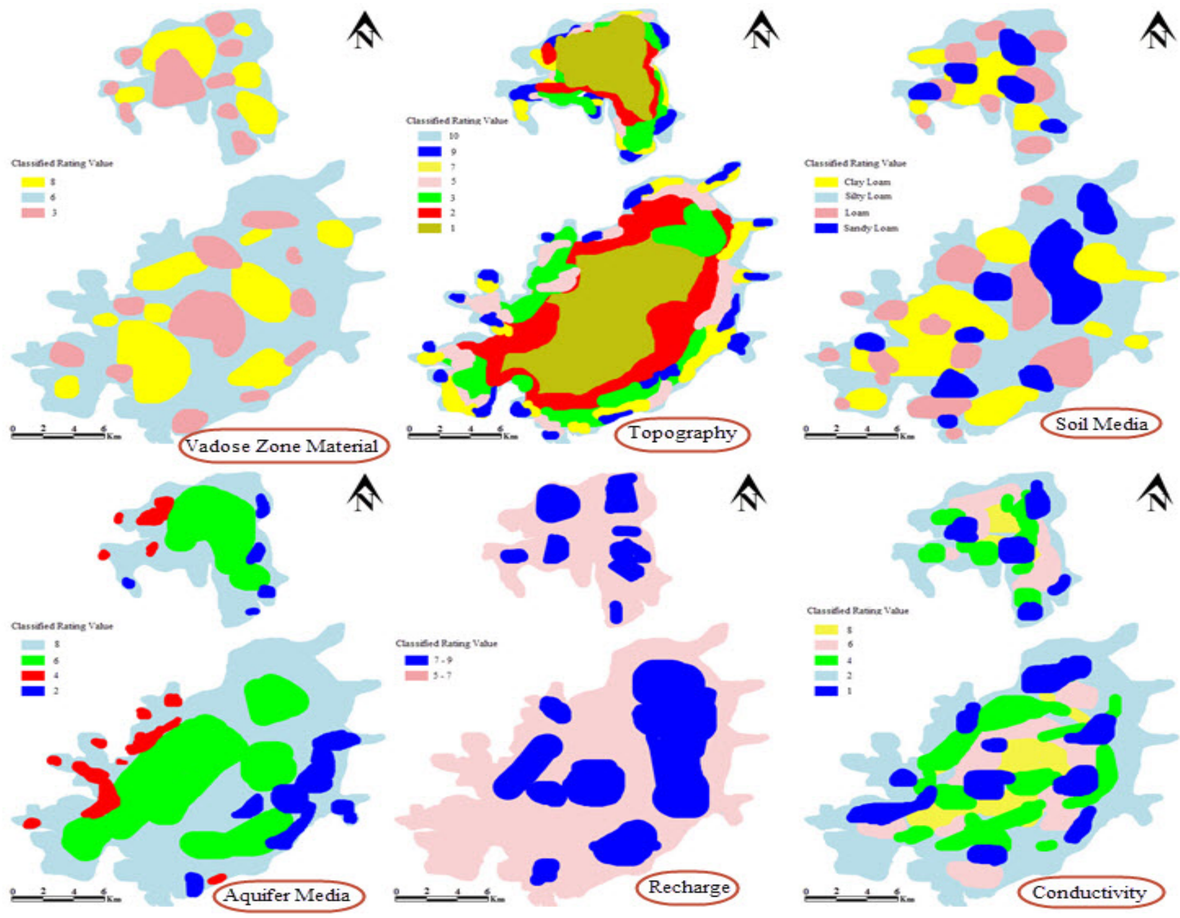

Figure 5: Mapping of DRASTIC model indicators

Table 2: Attribution of notes for GOD model indicators[2]

Range	Rating		Range	Rating		Range	Rating	
None aquifer	0	Aquifer type C_i	<2	1	Depth to C_a (m)	Residual Soil	0.4	Lithology ttype C_a
Artesian	0.1		2-5	0.9		Limon alluvial; Loess; Shale, fine Limestone	0.5	
Confined	0.2		5-10	0.8		Aeolian Sand; Siltite; Tufa; Igneous rock	0.6	
Semi-confined .	0.3		10-20	0.7		Sand and gravel; Sandstone; Tufa	0.7	
Free with cover	0.4-0.6		20-50	0.6		Gravel	0.8	
Free with cover	0.7-1		50-100	0.5		Limestone	0.9	
			>100	0.4		Fractured or karstic Limestone	1	

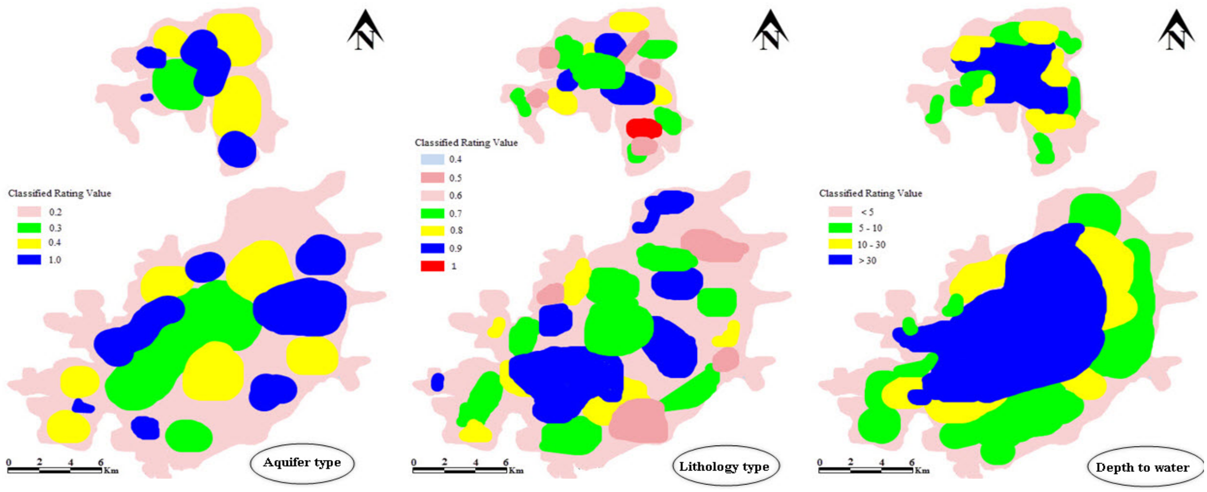

Figure 6: Mapping of GOD model indicators --- map corrected

The data used to generate the vulnerability index map is produced at a variety of scales. Through a function specific to the GIS software the overlay function, the various maps for each index models are combined through the map calculator function from the spatial analyst extension resulting in the vulnerability map of groundwater. After mapping all the indicators, the vulnerability maps were obtained by overlaying the individual maps and calculating the indices on a grid map (Figure 7).

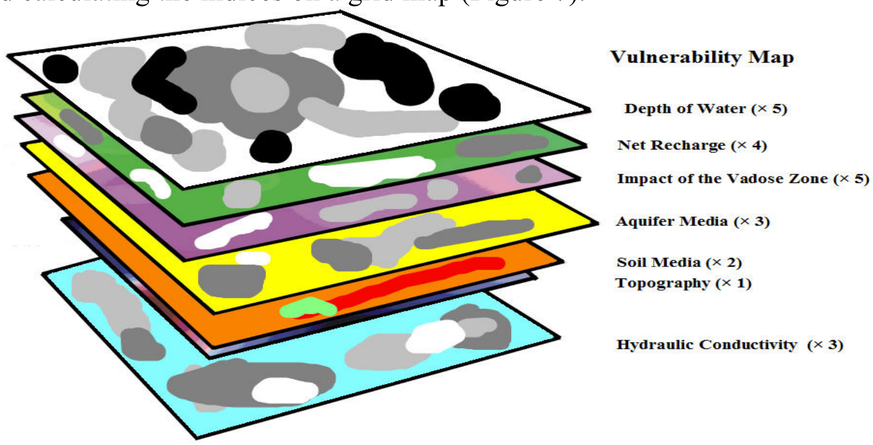

Figure 7: Overlaying of indicators

The vulnerability index for each grid cell was calculated as the weighted sum of the indicators according to equation. In the following, have to evaluate the hydrologic settings which are present on the map. Finally, the areas on the final map are labeled with the appropriate hydrogeologic setting. The vulnerability indexes for all models are calculated and the final vulnerability map was subdivided into classes related to vulnerability degrees of according to the classification of Engel et al. (1996)[20]. In some areas, topography and soil are intimately related, also in other areas, the vadose zone and aquifer media are the same. Values for hydraulic conductivity was frequently extrapolated from only a few points of reference and simply estimated from aquifer media. Groundwater contamination risk mapping is carried out by overlay of layers representing the different indicators in the parametric models. Theoretically an overlay was necessary for each indicator. However some of indicators are frequently closely associated.

The DRASTIC vulnerability map, according to standard classical provides, in turn, more detailed results widely different from other methods (Figure 8). The results showed that the maximum contamination potential in the Asadabad plain groundwater was observed in the central area of the plain. Also there were areas with low potential in the marginal area of the plain. Both techniques were prospected the vulnerability potential in the Asadabad plain with the same accuracy. This region is an area of high agricultural activity with an intense use of chemical fertilizers.The DRASTIC map resulting from overlaying the seven thematic maps shows three classes, as indicated in Figure 8. The highest class of vulnerability index covers 2.1% of the total surface in the central part of the study area (Table 3). This condition, it is due to the high aquifer permeability coming from the vadose zone sediments nature. The aquifer combination was of quaternary alluvium and sandstones, medium recharge, shallow groundwater and medium hydraulic conductivity. This results in a low capacity to attenuate the contaminants.

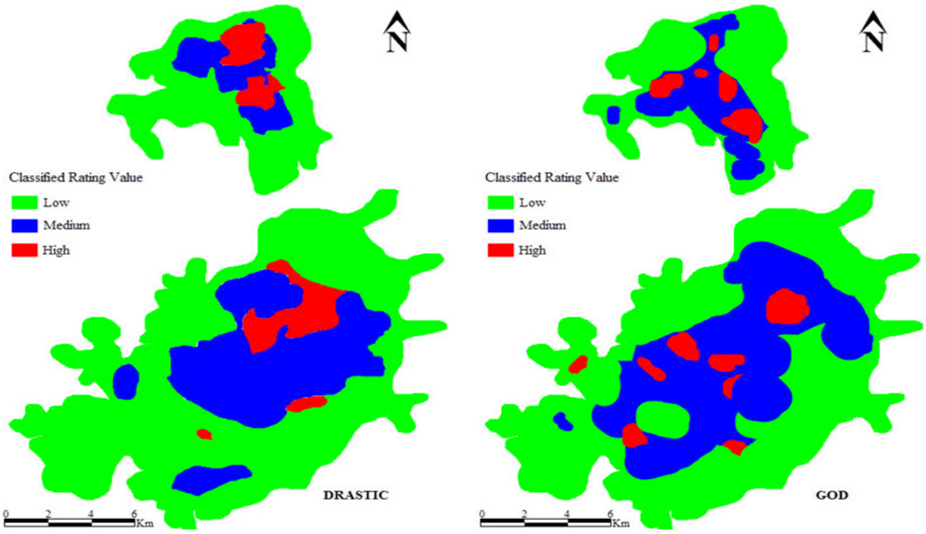

Figure 8: DRASTIC and GOD vulnerability maps of the study area

Also, low vulnerability, which is represented by 63.7% of the total Asadabad plain, are essentially due to the deep groundwater, the vadose zone sediments and the low permeability, added to that the low hydraulic conductivity. As well as the low recharge rate, we assume that these are the same conditions in the case of low vulnerability, with less degree of impact for these indicators. The moderate vulnerability which is represents 34.2% of the study area. Vulnerability pattern is mainly dictated by the variation of the permeability and the vadose zone [19]. The recharge and the depth of groundwater are two indicators having an influence on vulnerability degrees to pollution. The GOD Model application indicates the high vulnerable zones to be contaminated by pollutants (Figure 8). The most vulnerable areas have an index between 0.5 and 0.7 (Table 3).

Table 3: Evaluation criteria of degree of vulnerability in GOD and DRASTIC models

Vulnerability	**GOD** model		**DRASTIC** model	
	Area		Area	
	(Km^2)	(%)	(Km^2)	(%)
Low	181.18	60.8	189.82	63.7
Medium	112.04	37.6	101.9	34.2
High	4.78	1.6	6.25	2.1

Zones which have index value between 0.1 and 0.3 are the less vulnerable. The low and moderate vulnerability which are represents 60.8 and 37.6% respectively of the study area. A statistical comparison among the vulnerability maps generated by each method has been carried out. The Figure 8 shows the difference of classification between the used methods of vulnerabilities [16].Also, the DRASTIC map classification shows different results. We see much more of a class at the DRASTIC method, this method is thus more suitable to use in our case. So, conclude that a specific vulnerability study using the modified DRASTIC method especially in nitrate was more recommended to this type of environment. It helps to protect the most vulnerable areas and to guide investors to have decision.

Conclusions

Vulnerability evaluation of groundwater aquifer provides a basis for initially protective measurement for important groundwater resources and will normally be the first step in a groundwater pollution hazard assessment and quality, when it interest. This study highlighted areas of high vulnerability and medium vulnerability; where special measures can be taken to improve the condition groundwater resources, like sites for artificial rainwater harvesting to restore the discharged resource, and also sites where contamination can cause invariable damage, can be prevented. The highlighted areas must be monitored extensively for further analysis. The purpose of this research was to assess the vulnerability potential of the Asadabad aquifer using the DRASTIC and GOD methods. The area of the aquifer is essentially occupied by agricultural areas characterized by an important use of chemical fertilizers which are in addition to the discharge of industrial zones, an ongoing risk to the groundwater quality; this prompts us to a hydrological study and vulnerability late attributed to improve management of water resources in the study area.

The use of GIS techniques to identify contamination risk by mapping was primarily due to the automatization of certain operations. The databases which are behind all layers can anytime be updated. Also, the use of GIS facilitates the rapid visualization of some elements in the map by selecting them from the attribute table. The vulnerability maps, contamination data and groundwater quality can be used in view of a rapid and correct evaluation of pollution risk. By using this technology, are assured that the information will be used in an efficient manner. The models application showed that Asadabad groundwater was characterized by low to high vulnerability degrees. The results of the all methods showed that the maximum contamination potential in the Asadabad plain groundwater was observed in the west and central area of the plain. According to the sensitivity analysis the depth to water table was the most effective parameter on the vulnerability potential. Waters are easily accompanied by various geochemical elements coming from toxic pesticides and their extensive use in farmland, and wastewater. So, in high vulnerability areas, we shouldn't allow additional high risk activities in order to obtain economic advantage and to reduce environmental pollution hazard.

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