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ASSESSING GROUNDWATER VULNERABILITY TO AGRICULTURE CONTAMINATION IN A SEMI-ARID ENVIRONMENT USING SI AND GOD MODELS, CASE OF BABAR BASIN, ALGERIA

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Abstract: The aquifer of the plain of Babar, with a very large area of around 355,000 ha, is of a great economic importance because it is used for irrigation and domestic consumption. The aquifer zone is mainly occupied by agricultural areas characterized by an increasing use of chemical fertilizers, threatening the quality of groundwater. The study of the vulnerability to pollution of this water table was carried out by applying the GOD and SI methods in a GIS environment. The comparison of the vulnerability maps obtained shows that the recovery rates are very different, but they have a certain degree of similarity in space, both methods show a low vulnerability to agriculture pollution. In terms of vulnerability characterization, the GOD method provides more representative information.

Keywords: vulnerability map, agricultural pollution, GOD and SI methods, aquifer.

1. INTRODUCTION

In the beginning of the 19th century, agriculture experienced enormous progress with the introduction of new technologies and techniques to increase yields and accelerate this process. Farmers were beginning to use machinery instead of animals, and chemicals replaced natural fertilizers.

The southern region of Babar is characterized by an arid climate with rainfall which does not exceed 60 mm annually in most of the region; the main activity of this region is the cereal crop which is accompanied by the cultivation under agricultural greenhouse which takes place over the last few years. The soil in this region is sandy, low in organic matter. Farmers use nitrogen fertilizers to meet their crop needs.

Water resources are scarce and under strain in the world's arid and semi-arid regions owing to pollution, irrigation, increasing per capita water usage and population development. The management of water resources, especially groundwater, has become an increasingly pressing issue in these areas (Ghazavi et al., 2010).

Because groundwater is the primary supply of drinking water in arid and semiarid areas, determining its sensitivity and identifying locations that are more vulnerable to contamination is crucial (Ighbal et al., 2014).

The excessive use of chemical fertilizers, irrational irrigation and the high permeability of the soils of this plain make its waters very vulnerable to external aggressions and facilitate the leaching of pollutants to deep waters. Infiltration of industrial and urban wastewater can recharge groundwater, but can also pollute aquifers used for potable supply (Oiste 2014; Odukoya & Abimbola 2010; Lăcătușu et al., 2019; Domnariu et al., 2020).

Groundwater vulnerability (the degree of protection that the natural environment provides against the spread of pollution in groundwater) is classified into intrinsic and specific vulnerability (National Research Council 1993).

To assess groundwater vulnerability, many techniques have been developed. Three broad categories may be used to group these techniques: process-based simulation models, statistical methods, and overlay and index methods (Harbaugh et al., 2001). Overlay and index methods are based on combining different maps of the region. The more popular types of the overlay and index methods are GOD (Foster, 1987), SI (Ribeiro, 2000), IRISH (Daly & Drew 1999), AVI (Van Stemproot et al., 1993), and DRASTIC (Aller et al., 1987).

In our case we chosed the two models GOD and SI, they was especially developped for large areas with important agriculture activities to quantify the behavior of pollutants of agricultural origin, (Rizka, 2018)

The aims of this study is to determine the vulnerability of aquifer water using two methods, GOD and SI, and to study the correlations that can be established between this and the nitrate concentrations level present in Babar plain groundwater. SI and GOD have been used in several regions (Păltineanu, et al., 2022) (Ghazavi & Ebrahimi 2015) (Lobo-Ferreira, 2004), it takes benefit of a GIS-based cartography.

2. MATERIALS AND METHODS

2.1. Study area

The study area is located in the south of the commune of Babar, which is approximately between latitudes of 34°30' to 35°00' N and 6°78' to 7°30' E longitude, south of the Saharan Atlas. The Babar plain covers about 2350 km^2, with altitudes varying between 1248 and -12 m from northeast to southwest (Figure 1).

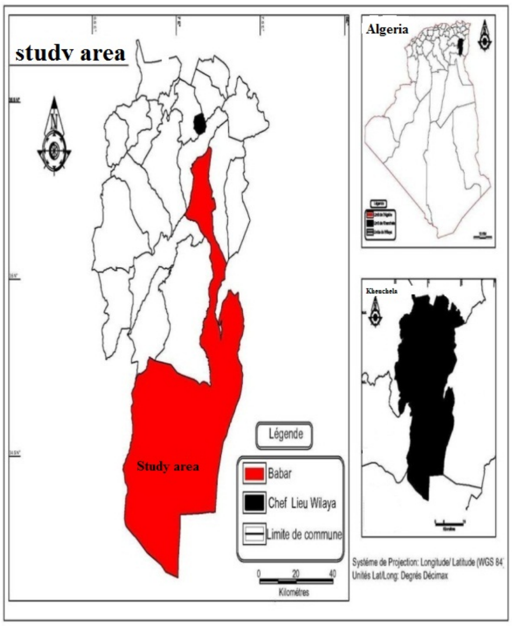

Figure 1 Geographical location of the Babar Plain - Algeria

The area under study has an arid to semi-arid climate, the maximum temperatures are recorded between May and October; however, in winter, the lowest temperatures reach 5°C, and with an annual average of 22°C (Office National De La Météorologie). Annual precipitation is around 200 mm (semi-arid climate) in the north and 60 mm in the south (arid climate).

The main rivers draining the plain are: Wadi Mehane, Wadi Ouzzern and Wadi Elarab. Temporary in appearance, they arise in the north to flow into the endorheic depression of Chott Melghir downstream. The main activity of the region is agriculture, especially the cultivation of cereals (wheat, barley and flour) which uses groundwater as the only source of irrigation.

The boreholes used for irrigation have depths that vary between 30 and 200 m, they are all located in the Plio-Quaternary aquifer. The Plio-Quaternary stage, which is composed of alluvium made up of gravel, sand and clay with a thickness that reaches 525 m, constitutes the first aquifer of the terminal complex resting on a layer of impermeable marl. There is a deeper aquifer, the captive Mio-Pliocene aquifer (second aquifer of the terminal complex).

The study is based on the obtained measurements from the field surveys that were conducted during Mai 2016 and supplemented by the compilation of the information collected from various technical studies established by the direction of the Water Resources of Khenchela.

We collected the parameters necessary for the realization of the vulnerability map according to the GOD model (depth of the aquifer, type of aquifer and geological nature) and SI (depth of the aquifer, recharge, lithology of the aquifer, topography, and land use). Then, we integrated the data into the ArcMap 10.3 software in the environmental laboratory of the Faculty of Sciences of the University of Iasi in Romania. The method consists of making maps using the kriging tool in the spatial analysis tools pane then interpolation. This allows maps to be created from the integrated points and data.

2.2. GOD Method

This system was developed by Foster, (1987) it is illustrated in (Table 1). It presents the aquifer's vulnerability to vertical percolation of pollutants through the unsaturated zone and does not address the lateral migration of pollutants into the saturated zone. This method is based on the identification of three criteria:

- Groundwater occurrence.
- lithology rating.
- Depth to aquifer.

The vulnerability index (I) is obtained according to the following equation:

$$I = GO*Li*D$$

Where: GO = Groundwater occurrence, Li = lithology rating, D = depth to aquifer rating. Vulnerability increases with the classification index, it is done in five classes ranging from 0 to 1 as shown in Table 1.

Table 1. GOD index (after Foster, 1987)

Class vulner-ability	Very low	Low	average	High	Very high
Index	0.1	0.1-0.3	0.3-0.5	0.5-0.7	0.7-1

2.3. SI Method

The susceptibility index (SI) method is a specific vertical vulnerability method, developed in Portugal by (Ribeiro, 2000) (Table 2), which takes into account pollutants of agricultural origin, notably nitrates and pesticides.

This method takes into consideration five parameters; the first four are identical to that of the DRASTIC method by multiplying the dimensions by 10 (D: Depth to aquifer; R: Effective Aquifer Recharge; A: middle aquifer; T: Topographic slope). And the fifth new parameter has been introduced: land cover parameter (L). A rating ranging from 0 to 100, ranging from least vulnerable to most vulnerable, is assigned to each land cover class (Table 3).

The weights assigned to the SI parameters vary from 0 to 1 depending on the importance of the parameter in the vulnerability. The vulnerability index SI is calculated by summing the products of the rating by the weights of the corresponding parameters:

$$SI = Dr*Dw + Rr*Rw + Ar*Aw + Tr*Tw + Lc*Lp$$

Where D, R, A, T, and L are the fifth parameters and subscripts w and r are the corresponding weights and rating respectively.

Table 2 Parameters of the SI method and their weights (Ribeiro, 2000)

Parameters	Weight
Water depth	0.186
Effective Recharge	0.212
Middle aquifer	0.259
Topography	0.121
Land Use	0.222

Table 3. SI index (Ribeiro, 2000)

Class vulnerability	Low	Average	High	Very high
Index	< 45	45 - 64	65 – 84	85 - 100

3. RESULTS AND DISCUSSIONS

3.1. GOD Method

3.1.1. Depth to aquifer

The depth of the water table is an important parameter, which constitutes a determining factor of vulnerability. The greater this depth, the longer the contaminant takes to reach the piezometric surface. For the Babar plain aquifer, this parameter was determined during the piezometric surveys. The results for the indices of the GOD method are presented in the Figure 2.

The map displaying the depth of the El-Meita aquifer (Figure 2) shows that the depth of the aquifer increases from north to south. The depth is between 50 and 200 meters, these depths have a low index in the empirical system of evaluation of GOD which is between 0.4 and 0.6. There is also a shallow depth to the southwest near the Chott.

3.1.2. Lithology Rating

The geological nature of the unsaturated zone is an important parameter in the estimation of vulnerability because it influences the rate of propagation of pollutants. Its impact is determined

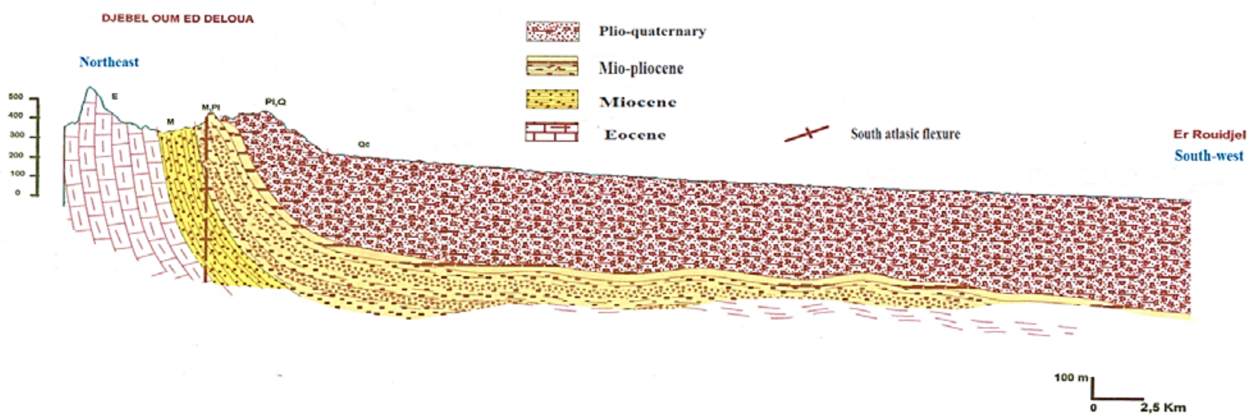

Figure 2. Northeast southwest cross section of the study area

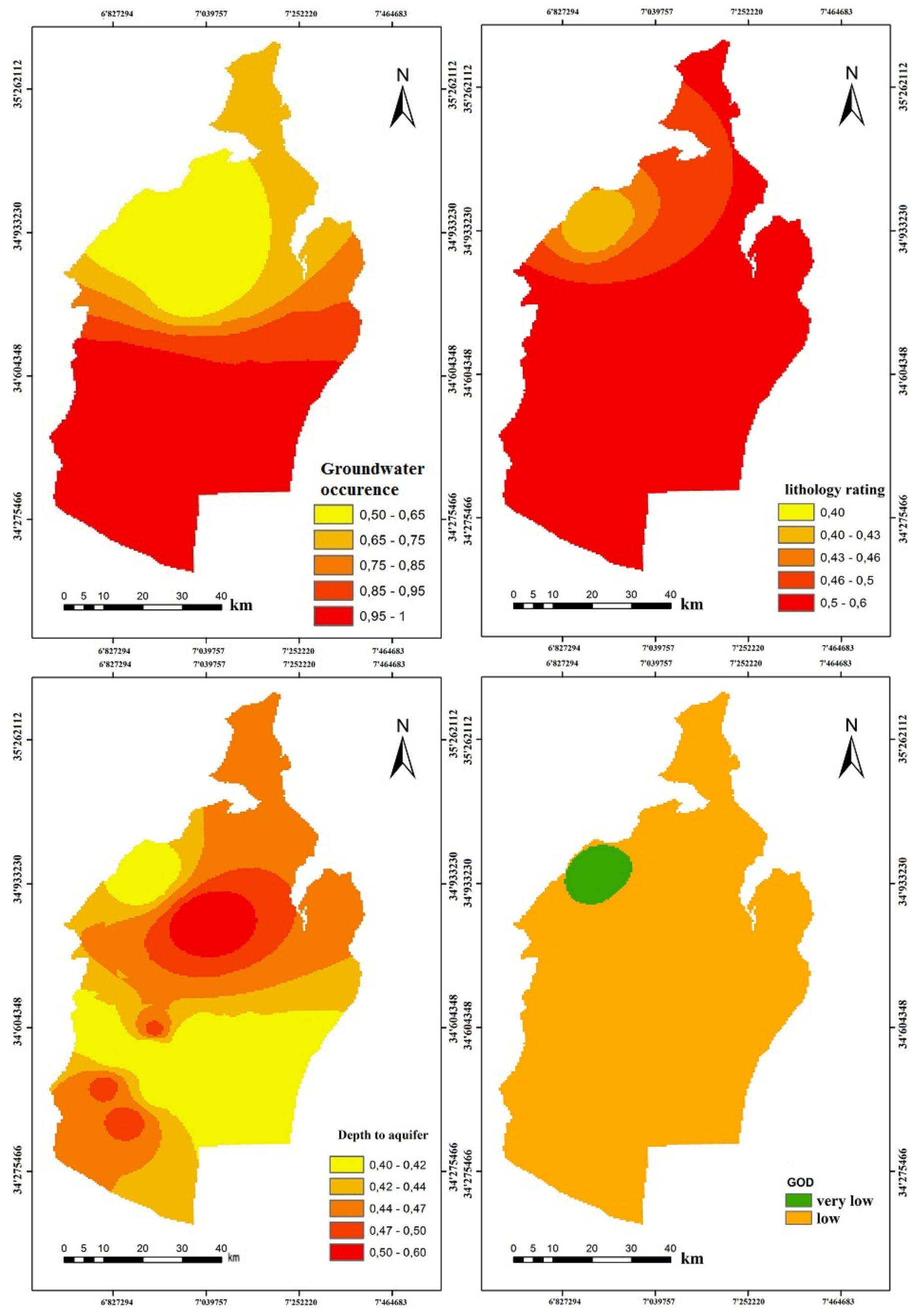

Figure 3. GOD maps (IN Groundwater occurrence, ZNS lithology rating, IP Depth to aquifer, vulnerability GOD index)

from the lithology of the land that constitutes it. The percolation of contaminants to the piezometric surface is greater when this lithology is favorable (Zair, 2017).

For the El-Meita aquifer, the unsaturated zone is essentially composed of alluvial silts and alluvial sands. The geological nature index is average for these soils; the latter allow a rather easy passage for pollution towards the water table.

3.1.3. Groundwater Occurrence:

This parameter designates the type of aquifer. Its identification was based on the North-south cross section of boreholes and dug wells for groundwater collection (Figure 2)

Observation of the groundwater index map shows that the lowest indices are located in the south in the plain (Figure 2), unconfined aquifer (groundwater index equal to 1). For the northern region, the water table is unconfined.

3.1.4. Vulnerability by GOD

The analysis of the vulnerability map (Figure 3), established using the GOD model, allowed the researchers to distinguish two different classes of vulnerability.

The vulnerability index is between 0.08 and 0.3. These two classes are distributed in the area as follows:

- This corresponds to the lithological nature of the semi-confined aquifer.

- The second class with low vulnerability extends from the northeast to the south of the plain and represents 96.8% of the region. This is explained by unconfined nature of the water table and the high depth.

3.2. SI method (Susceptibility Index).

3.2.1. Water depth "D"

The depth of the water table represents the vertical distance crossed by a contaminant on the surface of the ground to reach the water table. Generally, the potential protection of the aquifer increases with the depth of the aquifer. This parameter was obtained by interpolation of piezometric levels of 25 wells.

The depth in the study area ranges from 30 meters as a minimum to a depth greater than 200 meters. The groundwater depth map shows (Figure 4). The > 30m class: represents 100% of the region's total area.

3.2.2. Effective Recharge "R"

Aquifer recharge is the main vector of contaminants to groundwater. The contaminant can solubilize better and reach the water table in greater quantity when the recharge is high. The recharge "R" is calculated based on DRASTIC method according to different hydrological groups of soils: Our study region is characterized by two recharge zones, with a rating of 3 and 6.

3.2.3. Middle Aquifer "A"

The circulation and propagation of a contaminant in the saturated zone depends on the texture and lithological distribution of the aquifer layers. This is always controlled by the granulometry, porosity, permeability and lithology of the geological formations (Smida, 2010). This parameter is determined by the correlation of lithostratigraphic sections.

The spatial distribution of the reservoir levels of the El Meita aquifer shows two lithological classes: To the north, the aquifer is formed mainly by massive sandstone and a score of 6 is assigned. To the south, the aquifer is mainly composed of sand and gravel and a score of 8 is assigned.

3.2.4. Topography "T"

Topography refers to the slope of the ground surface. Slopes that favor infiltration are generally associated with high vulnerability. The steeper the slope, the lower the potential for pollution due to increased runoff and the rate of erosion.

For the topography parameter, a topographic map that has been established by the hydraulic services is used as a reference.

3.2.5. Land Use "OS"

The land cover map of the study area was extracted from the global land cover map of Algeria. This map shows that the El Meita region is an essentially agricultural area with irrigated perimeters and irrigated and non-irrigated annual crops.

3.2.6. Sensitivity analysis

The data of the doctoral thesis of (Sedrati, et al., 2017) has been taken into consideration in order to reach such results. This method was used by (Debernardi, et al., 2008, Neshat et al., 2014).

The results of the two GOD and SI models were compared with the results of the nitrate concentration of water to verify the most appropriate method for our study area (Figure 5). The results showed the following:

- r_{GOD} = 0,69 - r_{SI} = 0,64

The both correlation coefficients are representative of the groundwater pollution of the Babar plain aquifer. This tells us that the two models GOD and SI are suitable for studying the vulnerability of the aquifer in this region, where rainfall is rare, the depth very great and the agriculture activity is important.

4. CONCLUSION

From this study, it appears that the intrinsic methods, especially the GOD method, provide better results of vulnerability assessment compared to the SI method. Their application on the plain of El-Meita showed that the aquifer is vulnerable to pollution as a whole. This vulnerability is accentuated at the level of the zones which have a strong agricultural activity and a weak depth and present a very weak risk of pollution because of the weak precipitation and the important depth in other zones. These areas of low vulnerability represent 96.8% of the basin. As for the map of vulnerability to pollution of agricultural origin established by the SI method, it overestimates the vulnerability to pollution of the Babar Plain with 9.7% of highly vulnerable areas.

The most favorable areas to recharging are also the most vulnerable. It, therefore, appears necessary to undertake measures for the management of water resources in the Babar Plain. This experience has shown that GIS are of a major contribution on several levels. The automation, the analysis, the pace of manipulation and the storage of the data with the capacity for updating provided full satisfaction.

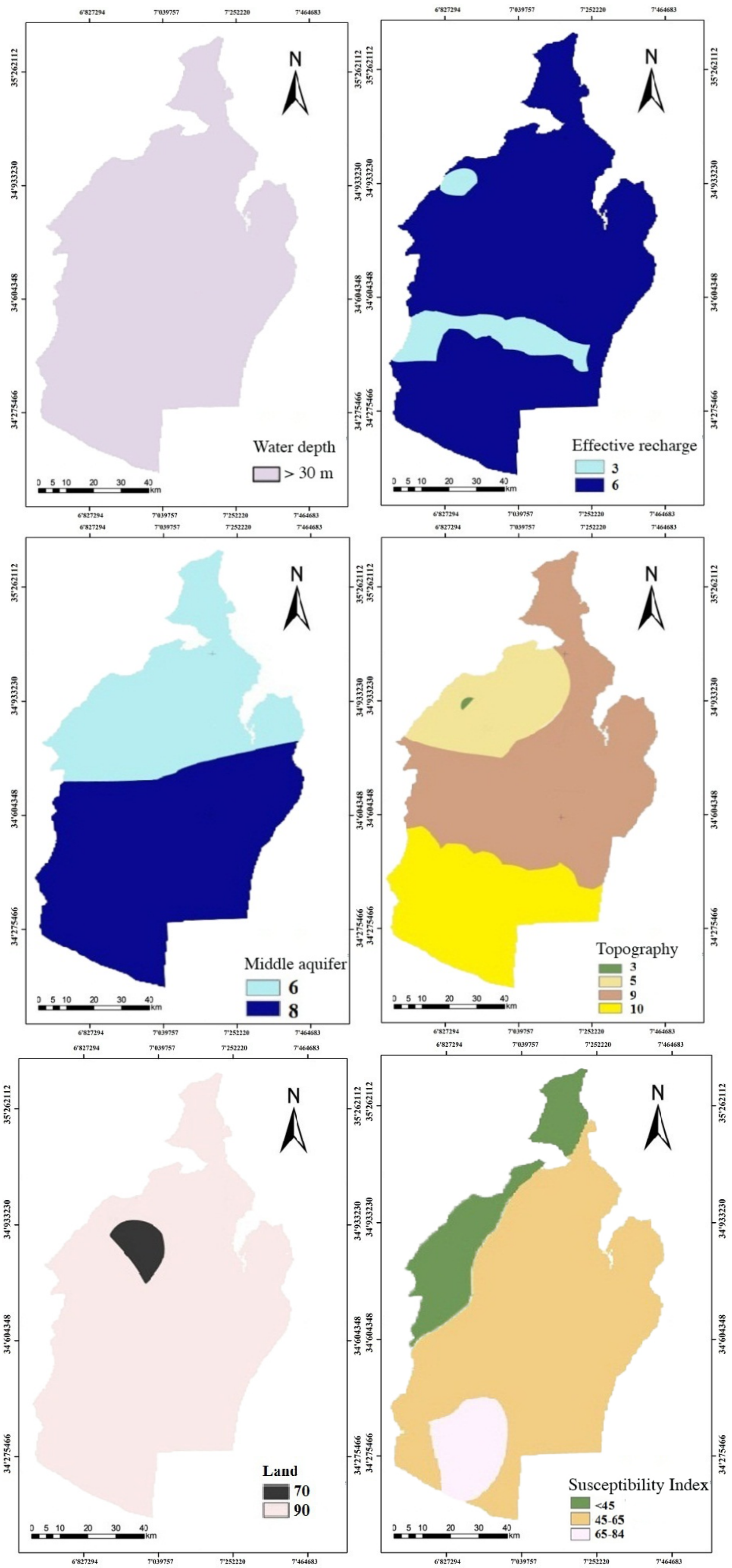

Figure 4. SI method (water depth, effective recharge, middle aquifer, topography, land, SI index)

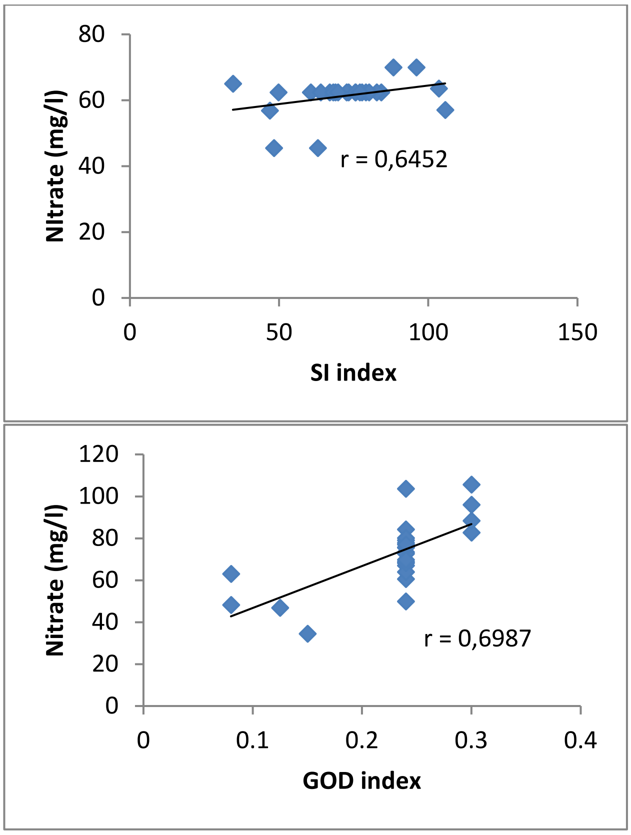

Figure 5. Correlation between Vulnerability Index and Nitrate Concentrations.

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