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Groundwater Vulnerability Assessment by Using Drastic and God Methods

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Abstract: Vulnerability of groundwater to pollution was investigated for the optimum decision to provide the best options for stakeholders to use the suitable lands for plants and crop cover, in addition to establishing factories and industrial development areas based on the results of vulnerability maps. The aim was to choose the best method of assessment groundwater vulnerability in Teeb area, Missan province, and south of Iraq. Two models DRASTIC and GOD of vulnerability maps are analyzed using GIS techniques. DRASTIC vulnerability index (DVI) is computed as the weighted sum overlay of the seven layers. The final result of DRASTIC map ranges from 60 to 139, which represent very low to medium while the GOD vulnerability Index (GVI) is based on three parameters. GVI ranges from 0 to 1. The output of GOD map ranges from 0 to 0.6, which represent very low to high. The DRASTIC method includes three classes, for which the low class dominated most of the study area by 80.29% of the total area, while the GOD method represented four classes (very low, low, medium and high), the medium is the most prevalent in the study area with 54.12 % of the total area. Pearson correlation coefficient for DRASTIC and GOD were 73.05 and 49.79 per cent respectively. Therefore, the DRASTIC method is better for representing the vulnerability groundwater for contamination than the GOD method.

Keywords: Groundwater vulnerability, DRASTIC, GOD, GIS

The concept of the vulnerability of groundwater to contamination in its broader perspective indicates the extent to which the aquifer can be contaminated with pollutants on the earth's surface and arrival to the aquifer system (Agyemang 2017). If its arrival is easy, this indicates the high vulnerability of groundwater and on the contrary the low vulnerability indicates the difficulty of the arrival of pollutants due to the presence of natural factors provide relatively good protection. Groundwater as an important and supportive resource for surface water, which is declining due to high temperatures, increased evaporation rates in summer and reduced rainfall in winter, in addition to the policies of neighbor countries to construct dams on river sources, This in turn enhances the importance of groundwater and the ability to manage it in the best way. In recent decades, measures to protect this important resource through methods of assessing groundwater, are considered which in turn give optimal decision to decision makers on urbanization or the construction of sewage plants or agricultural land that would degrade the quality of groundwater. The assessment of groundwater vulnerabilities is carried out by Geographical Information System (GIS)-based qualitative methods, process-based methods and statistical methods. GIS-based qualitative methods include GOD, DRASTIC, SINTACS, EPIK, AVI, PI and GLA**.** In this study, qualitative methods such as DRASTIC and GOD are adopted (Ghazavi and Ebrahimi 2015). The study aim is to assess the groundwater vulnerability by choosing the best methods to be more realistic for management of the pollution of the area.

MATERIAL AND METHODS

Study area: The study area is located in the northeastern part of Missan Governorate, which constitutes an area estimated at 2450 km^2 out of the governorate's area of 16072 km^2. It represents the strategic depth of the Amara city, center of Missan Governorate. It is bordered to the north-east by the Iranian mountains, to the west by the administrative borders of Ali-Gharbi district, and to the south by Hor Al-Sanaf between longitudinal-line (47°39 11″- 47°55 '1″) and latitude-line (32°29′ 47″- 31°58' 16″). Mostly, the study area is characterized by its plain nature and the cultivated crops include wheat and barley based on economic return. For irrigation depends on the rainwater of wet seasons and on the wells in the dry seasons. Despite the existence of two rivers, Teeb and Duriage rivers, the receding of waters level, especially in the summer the attention must be paid to assess the vulnerability of groundwater for optimal management.

DRASTIC and GOD which are used in this study to identify the most prone area to pollution and comparison between two methods to choose the best one in real representation of the area pollution represented by the nitrate concentration (Machdar et al 2018 and Oroji 2018).

Drastic method: This method adopts seven layers, each layer represents the first letter of it, and each layer has its own rate ranging from 1 to 10, while the weight for each layer ranges from 1 to 5 representing developed by the US Environmental Protection Agency (USEPA) by (Aller et al 1987). The DRASTIC Vulnerability Index (DVI) is obtained from the assemblage of the rate and weight for each of the seven parameters according to the following linear equation.

$DVI = D_r \times D_w + R_r \times R_w + A_r \times A_w + S_r \times S_w + T_r \times T_w + I_r \times I_w + C_r \times C_w$ (1)

Where D_r, R_r, A_r, S_r, T_r, I_r ^ C_r are rating for the depth to water table, aquifer recharge, aquifer media, the soil media, topographic (slop), vadose zone, and hydraulic conductivity. D_w, R_w, A_w, S_w, T_w, I_w ^ C_w are weights assigned to the depth to water table, aquifer recharge, aquifer media, soil media, topography, vadose zone, and hydraulic conductivity.

The required data are calculated from different sources such as field work, well logs, soil survey and geological maps and hydro-geologic reports available in Groundwater Directorate in Missan province 35 selected wells were measured by the sounder device. The depth ranged from (zero to twenty-nine meter). There groundwater recharge is calculated with WetSpass model (Salih 2020). By finding an average of the 12 input layers for each month and analyzing the resulting layer through the technique within the GIS environment. WetSpass model reduces uncertainty and reliability not only for spatial distribution of recharge but also for hydraulic conductivity and ultimately simulate the transport of pollutants. All the recharge values ranges from (zero to sixteen mm/year) which are less than 50 mm/year so it is classified as one rating.

Based on the geological map of the basin and drilling well logs to produce spatial variation of the aquifer media shows that two classes in the study area sand and gravel and shale. Twenty Soil samples are collected from the al-Teeb area randomly distributed and at a depth of 30 cm and tested by Hydrometer test. Soils are classified to three types (sand, sandy loam and loamy sand). The topography of the area refers to the slope of the surface area by per cent. Topographic map is constructed from digital elevation model (DEM) with accuracy of (30 m). Four classes of topographic map range from 0-2, 2-6, 6-12, 12-18 per cent as in Aller tables. Low slope (0-2) % is occupied most study area by (86%) as rated 10 which more potential of groundwater pollution. Remaining slopes (2-6, 6-12,12-18) are occupied low percentage of study area by (11%, 2% and 1%) respectively. Four segments of vadose zone are (sand, gravel, sand & gravel, and clay) classes. Hydraulic conductivity varies (2.19 to 12.87 m/day) as shown in Table 1, Figure 1.

God method: This method was advanced in England by (Foster 1987) is a swift estimate of groundwater vulnerability

Table 1. Parameters used in drastic

Parameters	Units	Range	Rating	Percentage	Relative weight
Depth to groundwater	m	0-1.5	10	1`	5
		1.5-4.5	9	6	
		4.5-9	7	71	
		9-15	5	18	
		15-23	3	3	
		23-29	2	1	
Net recharge	mm/year	< 50	1	100	4
Aquifer media		Sand & Gravel	8	70	3
		Shale	6	30	
Soil media	-	Sand	9	45	2
		Sandy Loam	6	3	
		Loamy Sand	7	52	
Topography	%	0-2	10	86	1
		2-6	9	11	
		6-12	5	2	
		12-18	3	1	
Impact of Vadose Zone	-	Gravel	9	1	5
		Sand&Gravel	8	6	
		Sand	7	74	
		Silt/ Clay	3	19	
Hydraulic conductivity	m/day	Less than 4	1	31	3
		4.0 -12	2	69	

as a result of its reliance on three hydrogeological parameters of any study area and represents abbreviated three characters GOD, here G represents groundwater occurrence, O lithology of unsaturated zone (overall aquifer class), and D r aquifer depth.

$$GVI = G_r \times O_r \times D_r \qquad (2)$$

Where the symbol r is the rating of the three parameters mentioned above. The ratings used for the parameters range from 0 to 1 (Table 2, Fig. 2).

RESULTS AND DISCUSSION

The final vulnerability DRASTIC and GOD maps are illustrated Figure 3 and 4, respectively. DRASTIC map shows three classes ranges from very low to medium which scores ranged from 60 to 139, respectively, (Fig. 5). The final vulnerability map is obtained by the DRASTIC technique that varies from (60 to 139) (Fig. 3). About 80.29% of study area is classified under low vulnerability; the remaining 7.84 and 11.87% are under very low and moderate vulnerability respectively (Table 3). The DRASTIC parameters mean shows that the highest contribution to the vulnerability index is made by slope and soil media (mean = 10) followed by aquifer media by (mean = 7.40) and depth (mean= 6.58). Hydraulic conductivity and recharge mean of 1.69 and 1, respectively contribute lowest to the contamination of groundwater. The coefficient of variations indicates a high contribution to the variation of vulnerability index is made by hydraulic conductivity (27 %), then by vadose zone (26%) (Table 4). GOD vulnerability map depicts four classes ranges from very low to high which represents scores from 0.0 to 0.6 (Fig. 6). Medium vulnerability zone is dominated in study area occupied by 54.12% of area while the low vulnerability area was occupied by 44.32% and high vulnerability area represents the remaining percentage of study area (Table 5). The means shows that groundwater occurrence and depth to groundwater were the highest by mean of 0.8. Then over all lithology mean was 0.58. The coefficient of variations shows that groundwater occurrence is higher than other parameters by 20%, followed by overall lithology 14% and the remaining represents 8.5% depth groundwater (Table 6). There is no fixed model that meets all the requirements of the hydrological environments due to the different nature and study area. The model must therefore be adjusted to suit the needs of the study area. The choice of the right model depends on several factors, the most important of which is the availability of data, hydrological setting and the final use of the map. Nitrate concentration was used to verify the accuracy of groundwater risk map as a basis for comparison between different models where Pearson coefficient was employed for this purpose. Pearson's correlation coefficients

Table 2. Parameters used in GOD method

Parameters	Range	Rating	Percentage
Groundwater occurrence	Unconfined	1	83
	Semi-confined	0.3	16
	Confined	0.2	1
Overlaying lithology	Unconsolidated sediment	0.4	17
	Consolidates dense rocks	0.7	81
		0.8	2
Depth to groundwater (m)	<2	1	1
	2-5	0.9	21
	5-10	0.8	44
	10-20	0.7	31
	20-50	0.6	3

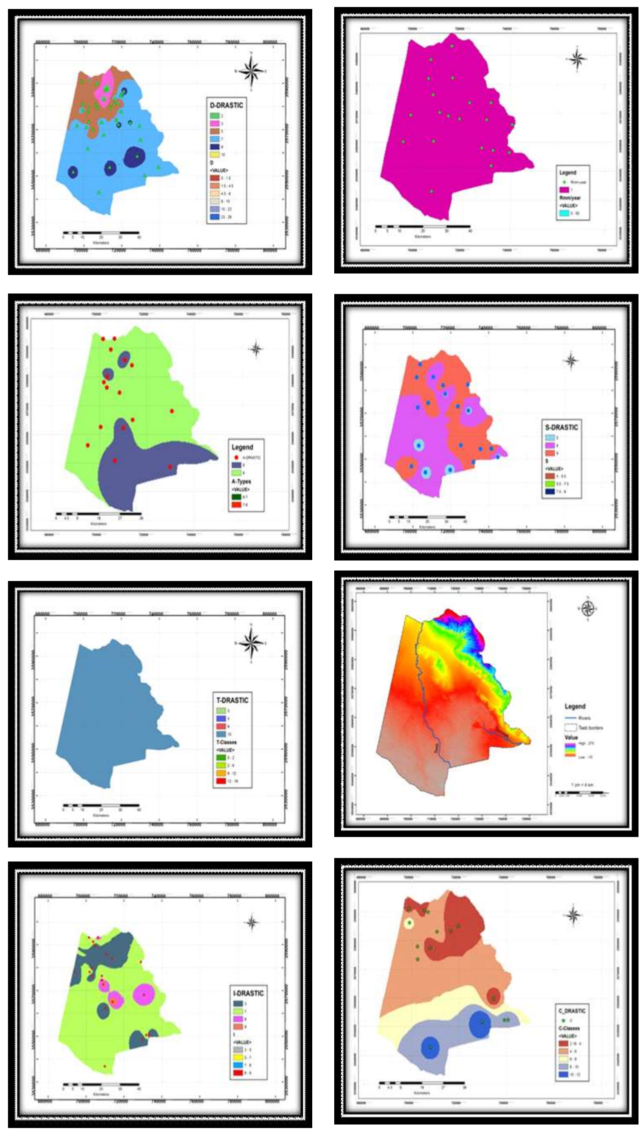

Fig. 1. The range and rating of parameters used in DRASTIC method

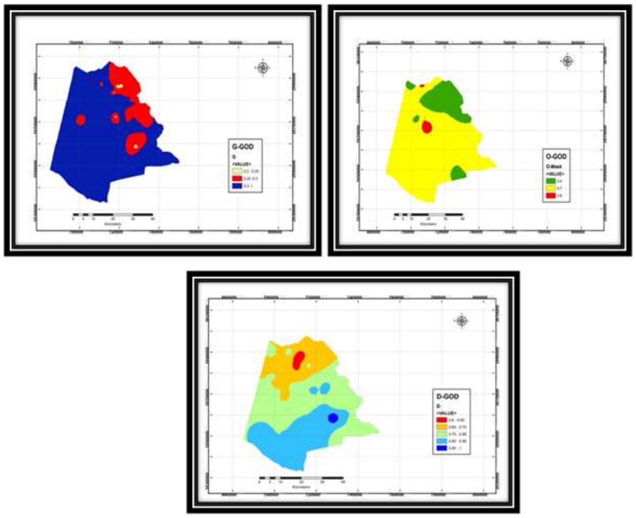

Fig. 2. Parameters of GOD methods

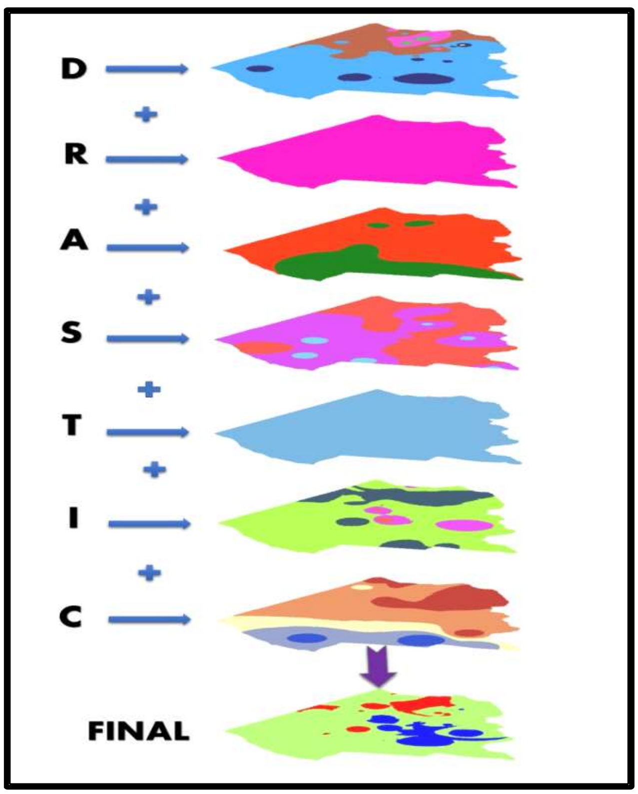

Fig. 3. DRASTIC parameters

for comparing each vulnerability map with the rate of nitrate concentration as spatial distribution map was 73.05and 49.79 per cent for DRASTIC and GOD, respectively. DRASTIC vulnerability map appears more interconnected than GOD and represented the best technique for evaluating vulnerability map in the study area which can be recommended (Fig. 7).

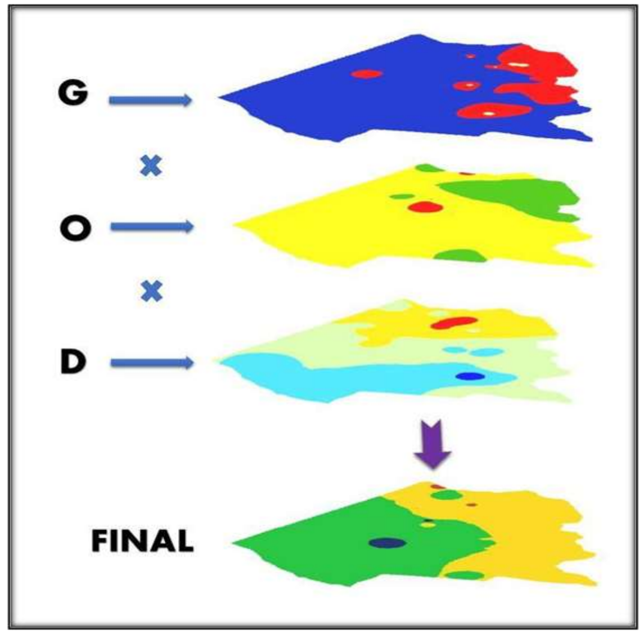

Fig. 4. GOD parameters

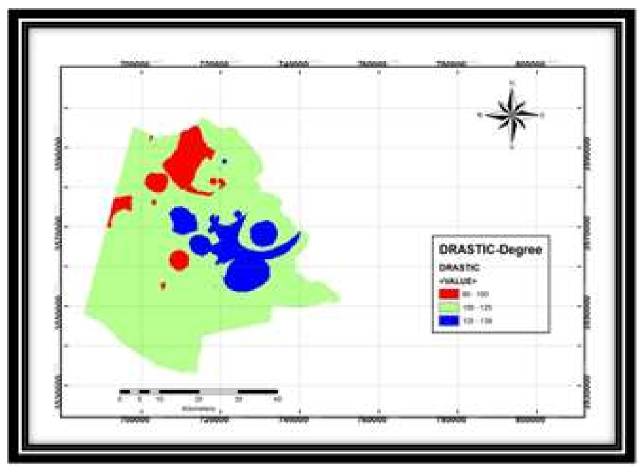

Fig. 5. DRASTIC vulnerability map

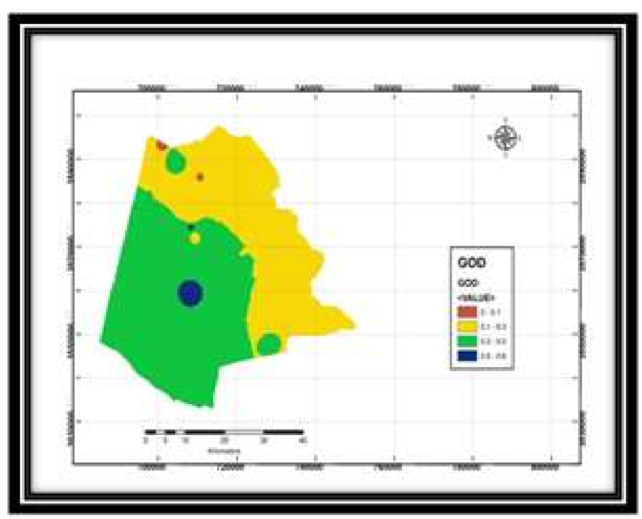

Fig. 6. GOD vulnerability map

Table 3. Percentage of each zone of DRASTIC vulnerability

Vulnerability zone	From	To	Area (Km^2)	Percent
Very low	60	100	190.17	7.84
Low	100	125	1948.5	80.29
Medium	125	139	288	11.87

Table 4. Statistical analysis of the seven parameters

Parameters	Weights	Minimum	Maximum	Mean	SD	Cv (%)
D	5	2	10	6.58	1.25	19
R	4	1	1	1	0	0
A	3	6	8	7.4	0.92	12
S	2	3	10	10	0	0
T	1	3	10	10	0	0
I	5	3	9	6.3	1.63	26
C	3	1	2	1.69	0.46	27

Table 5. Percentage of each zone of GOD vulnerability

Vulnerability zone	From	To	Area (Km^2)	Percent
Very low	00	0.1	7.21	0.29
Low	0.1	0.3	1086.18	44.32
Medium	0.3	0.5	1326.4	54.12
High	0.5	0.6	31.98	1.3

Table 6. Statistical analysis of the GOD parameters.

Parameters	Minimum	Maximum	Mean	SD	Cv
G	0.2	1	0.8	0.16	20
O	0.3	0.9	0.58	0.08	14
D	0.6	1	0.8	0.068	8.5

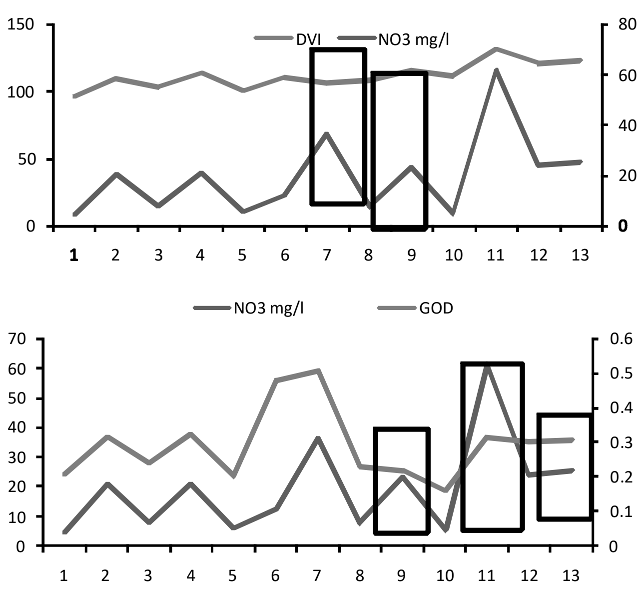

Fig. 7. Spatial variability of nitrate

CONCLUSION

DRASTIC technique that varies from 60 to 139. The area under low vulnerability was 80.29 prevent followed by 7.84 and 11.87 per cent under very low and moderate vulnerability respectively while the final vulnerability map obtained by the GOD technique t varies from 0.0 to 0.6. About 54.12% of study area is classified under moderate vulnerability, the remaining 44.32% and 1.3% are under low and very low vulnerability, respectively. Pearson's correlation coefficients for comparing each vulnerability map with the rate of Nitrate concentration as spatial distribution map as follows 73.05, 49.79 per cent for DRASTIC and GOD, respectively. So, that DRASTIC is the best technique for evaluating Vulnerability map is recommended in the study area.

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