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Assessment of groundwater contamination by using numerical methods

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A B S T R A C T

Groundwater vulnerability maps by numerical methods help to set priorities for identifying areas that are most affected by pollutants, enabling decision makers, departments and government agencies to save additional funds in the event of a groundwater monitoring and protection system for the entire study area.Numerical methods as SINTACS and Modified DRASTIC with GIS technologies are depended in this study. SINTACS Vulnerability Index (SVI) is based on seven parameters while Modified DRASTIC Index (MDI) is based on eight parameters but both methods are adopted weighted sum overlay of the parameters. Final results of SINTACS Vulnerability map depicts four classes from very low to high which varies from (77 to 144). About 82.81% of study area is classified under moderate vulnerability; the remaining 15.08% and 1.75% are under high and low vulnerability respectively. MD- DRASTIC vulnerability map ranges (85–179). This range of index values is divided into four classes including very low to high vulnerability classes. About (72.35%) of the study basin has moderate vulnerability. High vulnerability measured as a second effective class of the studied area with (20.5%). While low and very low areas comprise (6.45% and 0.6%) respectively. Comparative study of two vulnerability maps with water quality data represented by nitrate concentration showed that MD- DRASTIC method is more suitable to represent the real reality of pollution of the area.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Nanoelectronics, Nanophotonics, Nanomaterials, Nanobioscience & Nanotechnology.

1. Introduction

Recently, an urgent need has emerged to invest groundwater as compensation for the shortage of surface water, which has begun to recede gradually due to the phenomenon of desertification and the lack of rain in winter, especially in the regions of the Middle East, including Iraq. Groundwater quality is greatly affected by human, industrial and agricultural activities alike. In arid or semi-arid regions, the investment of groundwater is mostly in agricultural activities, such as the study area in which the research was conducted, where fertilizers are added to increase crop production. The surplus number of nitrates that the plant cannot absorb is thrown into the groundwater through irrigation or rainwater, where it penetrates. Small quantities of nitrates are harmful to human health, so how high rates of more than 10 mg /l cause serious diseases such as stomach cancer, birth defects and other diseases [1]. As a result of vulnerability groundwater pollution with nitrates and other pollutants and the difficulty of removing these pollutants, it was necessary to put in place a system to protect and monitor groundwater from pollution. The most important systems for this protection are to assess the impact of groundwater to pollution and to identify areas exposed to pollution more than others. Various methods used to assess groundwater vulnerability to pollution. One of most important method is Overlay and Index Methods such as SINTACS [2] and Modified DRASTIC where hydrogeological features, slope, soil, rainfall and land use/land cover (LULC) with geographic information system (GIS) and remote sensing data (RS) are employed for these methods [3].

1.1. Study area

The study area is characterized by a variety of surfaces, with mountains and hills in the northern and north-eastern regions, plains in the central regions and marshes in the south between longitudinal-line (47°39 11″- 47°55 ′ 1″) and latitude-line (32°29′ 47″- 31°58′ 16″) In Missan province in southern Iraq with an estimated area (2450 km^2) Fig. 1. Although the region is rich in mineral resources such as oil and gas, as well as the abundance of soil rich of gravel, sand and clay, which is an important resource

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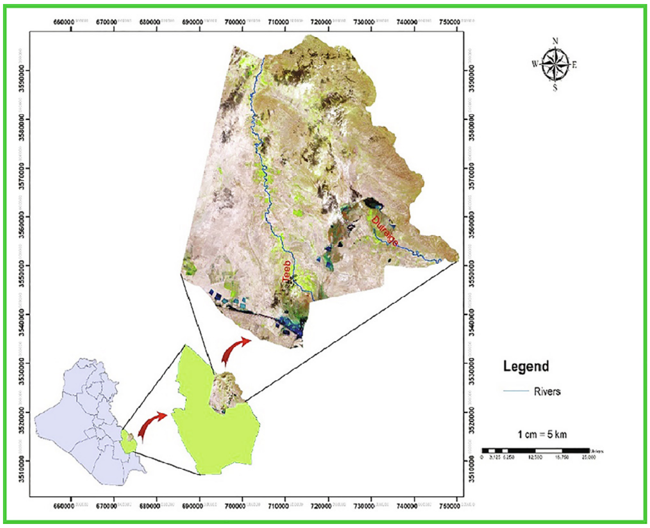

Fig. 1. Location of Study Area in Iraq and In Missan Province.

for many construction industries and the presence of surface water represented by the Teeb and Duriage rivers as well as groundwater also makes it a center for tourism and recreation. Despite the existence of these two rivers, but the region mainly depends on the wells water due to the drying out of the two rivers during the hot summer months, in addition to the absence of reservoirs for the water of the two rivers for the purpose of storage in the winter months when the period of abundance of water. Therefore, the need arose to protect this important resource and monitor its management effectively. By identifying the areas exposed to pollution more than others, and by setting strict laws that are deterrent to any action taken that would pollute the groundwater.

2. Methods of vulnerability assessment

Methods of assessing the vulnerability of groundwater to pollution are considered one of the modern methods in the world to monitor and control the pollution of this important and sustainable resource, which is always dependent on it in case of scarcity of surface water [4]. The overlay and index technique is more widely used than other assessment methods such as statistical and process based techniques due to its reliance on measurable parameters as well as its ease of application. In this study, SINTACS and Modified DRASTIC are employed as overlay and index technology to assess the groundwater vulnerability. All the parameters are rated from 1 to 10 and weighted from 1 to 5 according to their relative importance in groundwater vulnerability with respect to others as well as the type of model assessment. In both methods, the same GIS techniques are taken into account to obtain the final vulnerability maps of the models, so that the comparison is uniform and the difference is a result of the characteristics of the model itself, not the techniques that produced it. Both methods are subjected to the same linear equation by summing the rate multiplications for each of the parameter classes into the weight chosen for each category.

$$Vulnerability\ Index = \sum_{i=1}^{i=n} Ri \times Wi \quad (1)$$

where Ri and Wi represent the rating and weight for each parameter and n represents the number of parameters.

2.1. SINTACS method

This model is introduced by Italian [2] so the model is abbreviated for seven parameters in Italian which **S**,**S**oggicenza means (depth to groundwater), **I** , **I**nfiltrazione is attributed to (effective infiltration), **N**, **N**on saturo (unsaturated zone), **T**, **T**ipologia della copertura which is mean (soil), **A**, **A**cquifero (saturated zone characteristics), **C**, **C**onducibilità (hydraulic conductivity), and **S** **S**uperficie topografica (topograghy). SINTACS Vulnerability Index can be Shortened by (SVI). The first parameter **S,** means the depth from ground surface passing through unsaturated zone to saturated thickness of the aquifer system and it is similar to parameter D in MD-DRASTIC. Field work to measure depth to groundwater levels by sounder device of (35) selected wells distributed over study area shows the water levels ranges from (29)m to (0.0) m. Parameter **I,** is represents effective infiltration so is similar to parameter R in MD-DRASTIC method. This factor plays an important role in the transport of pollutants through the unsaturated zone to the saturation zone, where it depends mainly on direct recharge of rainwater and there are no irrigation practices that use large amount of water. the spatial distribution of net recharge shows the values ranges (0–16) mm/year according to results of WetSpass model [5], Parameter **N,** is same as I in the MD-DRASTIC method and represents the unsaturated layer and it is characterized by its hydro-lithological features which are represented by the texture, grain size, mineral composition and other characteristics that would make it as barrier for all hydro-vectored pollutants to groundwater and is classified into (sand and gravel, sand and silt and clay) depending on geological maps and hydro-geologic reports of MWR archives of groundwater directorate in Missan province. Parameter **T,** is represented soil media as S in MD-DRASTIC method. This layer represents the first line of defense that can prevent or slow the arrival of pollutants destined to aquifers through their characteristics, the most important of which is permeability, which depends mainly on granular size that consists them. By Hydrometer test, soil media is classified in to three classes (sand, sandy loam and loamy sand). Aquifer media **A**, is classified into (sand and gravel, and shale) through geological maps and hydro-geologic reports of MWR archives of groundwater directorate in Missan province. The parameter C which represents the topographic slope is an important factor in vulnerability assessment. slight slopes mean the contaminant stays for longer period under gravity action or even stop in the outlet place favoring percolation and is obtained from DEM with 30 m pixel size Maps. The topography is classified into three classes ranges (0–2, 2–6, and more than 18) percent. The hydraulic properties of aquifers are influenced by processes that occur when pollutants arrive and mix with groundwater. The most important of these processes are dilution, sorption and chemical reactions between the rock and the contaminants. The last parameter **S**, hydraulic conductivity indicates that pollutants can be transported freely within the saturated zone. This parameter determines, the aquifer unit yield and flow velocity and it is similar to C in MD-DRASTIC and it is estimated from pumping test results. The hydraulic conductivity (S) varies between (0.45–12.87) m/day. Table 1 illustrated the rate and weight of each parameter. Figs. 2 and 3 show SINTACS parameters and Fig. 4 illustrates the schematic of SINTACS method.

2.2. md-drastic

Modified DRASTIC method represents construction of land use and land cover map which is normally marked by a short term of (LULC) and add to the original DRASTIC method [6]. One of the most important factors that enhances the choice of this method is the availability of remote sensing data and their compatibility

Table 1
The Parameters Used in SINTACS Method.

No.	Parameters	Units	Range	Rating	Percentage	Relative Weight
1	S Water Table depth	m	0–2	10	1	5
			2–4	9	2	
			4–7	7	58	
			7–10	6	20	
			10–20	5	17	
			20–29	3	2	
2	I Effective infiltration	mm/year	0–50	1	100	4
3	N Unsaturated zone	–	Clay	1	2	5
			Silt/clay	3	16	
			Sand	7	68	
			Sand and gravel	8	14	
4	T Soil Media	–	sand	7	27	4
			Sandy Loam	6	64	
			Loamy Sand	5	9	
5	A Aquifer media	–	Sand and gravel	8	70	3
			Clay	3	30	
6	C Topographic slope	%	0–2	10	89	2
			2–6	9	10	
			> 18	1	1	
7	S Hydraulic conductivity	m/day	0.45–4.89	1	63	3
			4.89–8.3	2	30	
			8.3–12	3	7	

with the application of the studied area and the accuracy that depends on the classification.

Using remote sensing data and field survey of the studied area to confirm the classification according to observations then LULC maps can be drawn. The USGS system of classification consists of five levels, from I to V; The difference between classification is determined the accuracy of remote sensing data available for classification [7].

ArcMap 10.7 software was used to prepare the digital image classification of the study basin. Supervise classification for levels of USGS was done. Analysis was based on field work by selecting several points by GPS and taking images that support the accuracy and validity of the final classification map [8]. Depending on remote sensing system data, the LULC map classifications with percent and the area of land covering in each class are summarized as in Table 2. Fig. 5 depicts the LULC map. LULC map is to be added to DRASTIC parameters maps to establish the final MD-DRASTIC map.

Wetland occupies (4%) with an area of (99.83) km^2 whereas the agricultural Land crops is encompassed 14.49% or (354) km^2. Natural plant land in study area represents by shrubs and grasses which comprises the more percent 31.7% cover an area of (775) km^2 while the desert (barren) and saline land occupies (29% and 20.7%) or (710.6 and 505.5) km^2 respectively of the studied area. Fig. 5 shows the classes of LULC map. After the creation of the final map LULC, the accuracy is verified by taking several points in the field by GPS as well as taking photo of each point to verify the accuracy.

Natural plant and salt areas have been included in the barren areas because the LULC layer takes into account the impact of human activities and natural processes that would contaminate the groundwater [9]. Add LULC layer to the seven layers to obtain the final map as shown in the Fig. 6. Table 3 depicts the details of parameters are used in MD-DRASTIC. Figs. 7 and 8 shows the vulnerability maps of MD-DRASTIC.

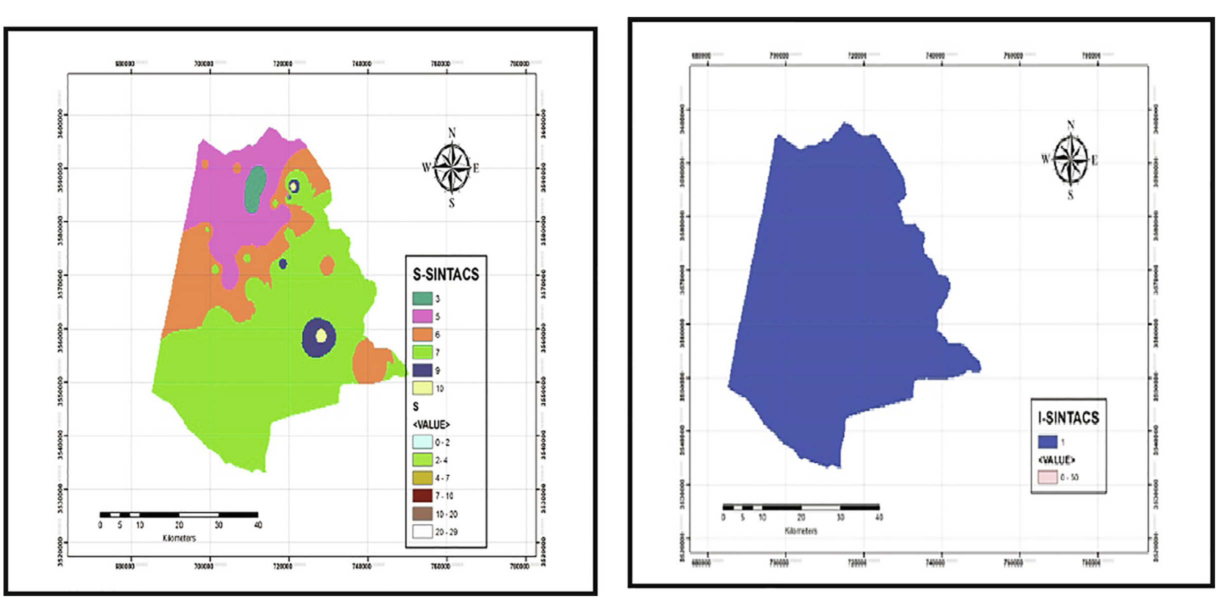

Fig. 2. Maps of parameters S, I in SINTACS Method.

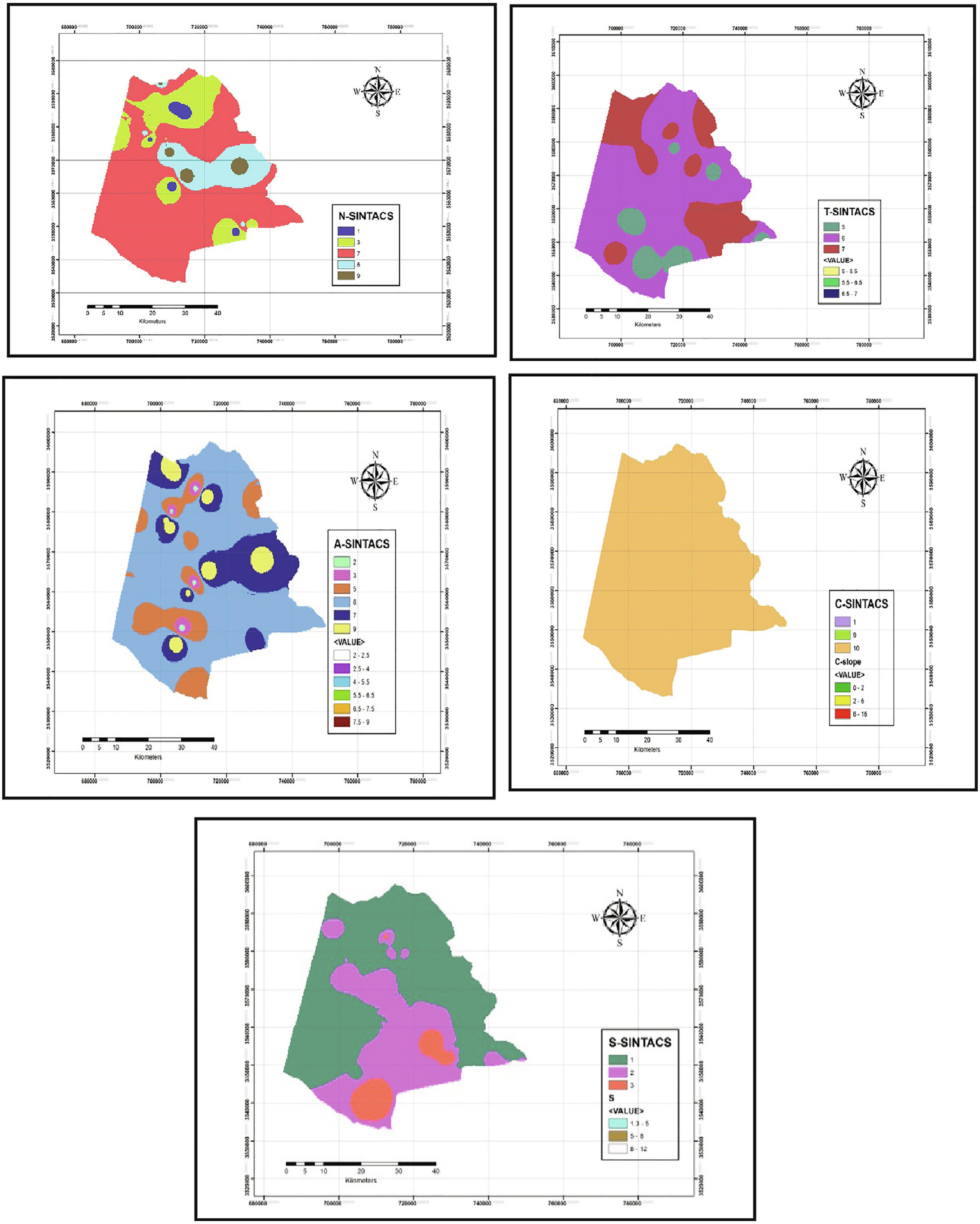

Fig. 3. Maps of parameters N, T, A, C, S in SINTACS Method.

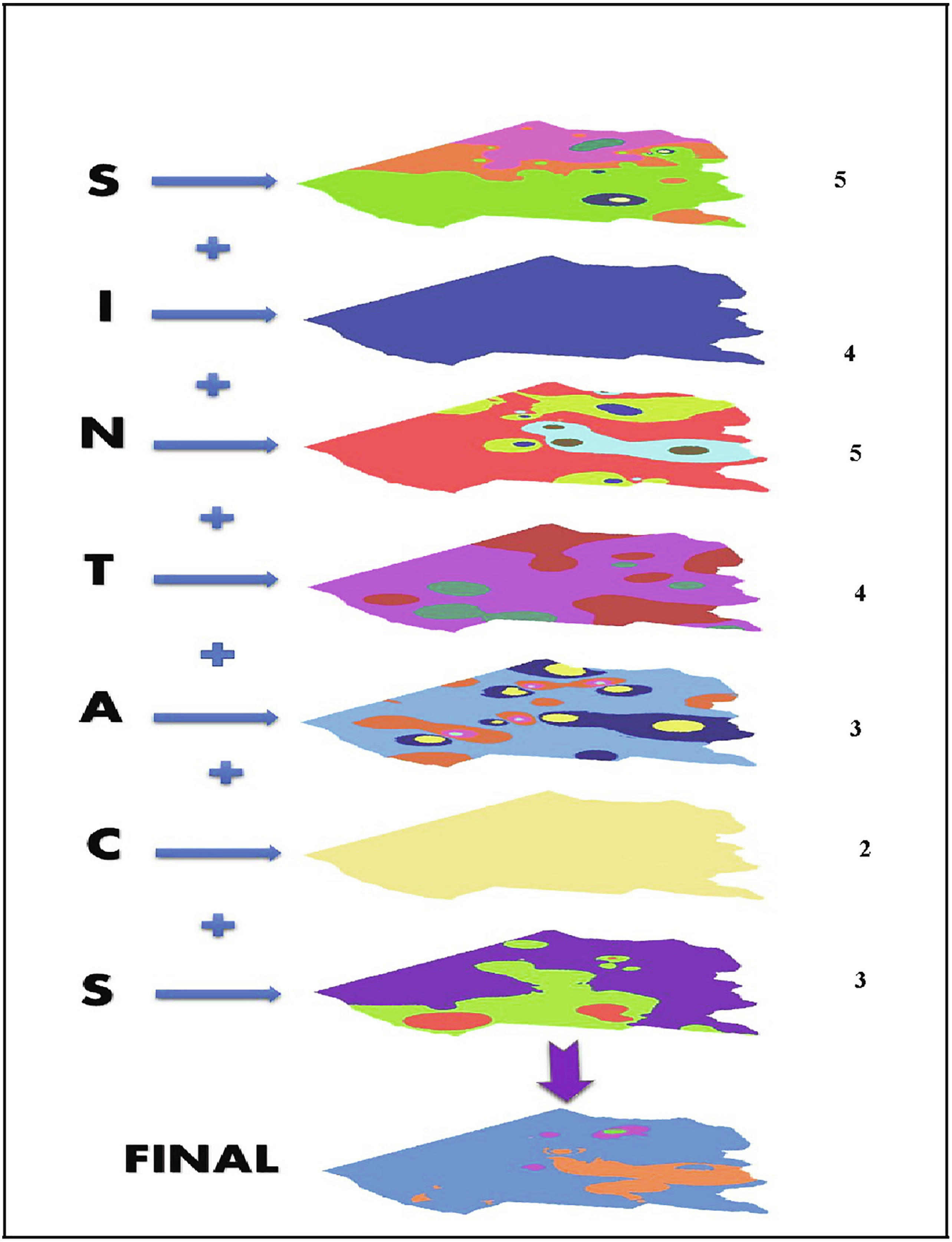

Fig. 4. Maps of parameters S, I, N, T, A, C, S in SINTACS Method.

Table 2
LULC Classes in The Study Area.

Level Classes	Area km^2	Area %
Wetland	99.83	4
Agricultural Land	354	14.49
Natural plant land	775	31.7
Desert land	710.6	29
Saline crust land	505.5	20.7

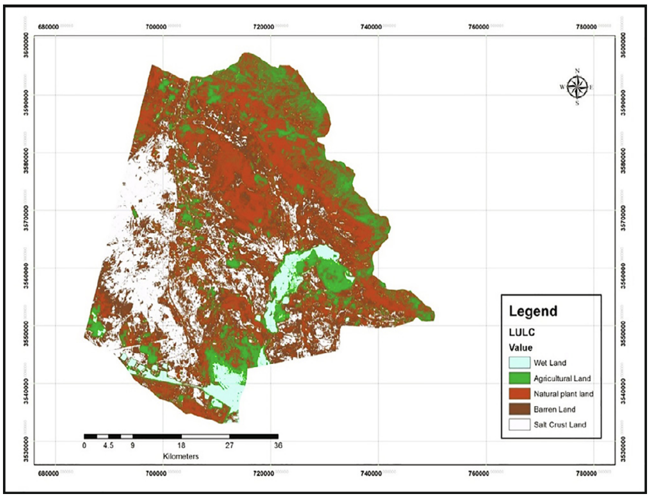

Fig. 5. LULC map of study area.

3. Results and discussion

By using unified GIS techniques in both methods which include obtaining the raster map for each parameter in order to the comparison is clearer which represents the characteristics of model its self. GIS is the best way to create, process and analyze geographical information in a simple and flexible way that is easy to deal with after converting it into layers of information and a large set of data that meets all needs of the concepts of each model and thus it facilitates the assessment of the vulnerability of groundwater pollution from different indices by comparing the obtained results without highlighting the advantages and disadvantages of each method with detailed comparisons of the map of vulnerability also allows to adapt to the indices of vulnerability by changing the factor's weights and ratings [10]. It's obvious that this method is similar to the DRASTIC method of different rates and weights set in a comprehensive manner for all environmental conditions of the seven parameters used in the model. So, all the maps of the parameters of this model will be completely different from the DRASTIC method. The final vulnerability map is obtained by the SINTACS technique which varies from (77 to 144). About 82.81% of study area is classified under moderate vulnerability; the remaining 15.08% and 1.75% are under high and low vulnerability respectively Fig. 8 and Table 4 are showed the results of SINTACS vulnerability map. The most classes of seven parameters occupies high proportions in the study area where Effective infiltration (I) by 100%, the topography (C) class (0–2) % by 89%, (sand and gravel) within Aquifer media (A) class is occupying by (70%), Unsaturated zone (N) within class (sand and clay) by 68%, class (sandy loam) of soil media (T) by (64%), ranges (0.45–4.89) of Hydraulic conductivity (S) is by (63%), while the depth to groundwater (S) ranges between (4–7) m with 58%.

The parameter means shows that the highest contribution to the vulnerability index is made by Slope (C) (mean = 10), then the depth to groundwater (S) (mean = 6.45) and so on for Aquifer media (mean = 6.13), then the Soil media (T) mean is (6). Unsaturated zone (N), Hydraulic conductivity(S), Effective infiltration (I) means are of (4.89, 1.43, and 1) respectively. The coefficient of variations indicates that a high contribution to the variation of vulnerability index is made by Hydraulic conductivity (43%), then the unsaturated zone (N) by (26%) Fig. 9 and Table 5 are showed the statistical results of SINTACS method.

MD- DRASTIC vulnerability map ranges (85–179). The range of index values was divided into four classes including very low to high vulnerability classes Fig. 10 and Table 6 are illustrated the classes of MD-DRASTIC. About (72.35%) of the study basin has moderate vulnerability. High vulnerability measured as a second effective class of the studied area with (20.5%). While low and very low areas comprise (6.45% and 0.6%) respectively Fig. 11 and Table 7 are illustrated the results of statistical of MD-DRASTIC model. MD-DRASTIC method results based on LULC is classified to three classes (Wet Land, Agriculture Land and Barren Land). The category of agricultural land was the highest rate within the study area (55%). The Barren Land and wet land are comprised (30%) and (15%) respectively. Fig. 12 shows the minimum, maximum, and mean values of MD-DRASTIC parameters**.** The vulnerability indexes are ranged between very low to high but both classes show low values in all models, while the moderate class is dominate for all.

4. Validation

Aquifer vulnerability assessment is lacking without validating each model with field data. Field data is carried out with the water quality data with respect to nitrate concentration. To obtain the concentration of nitrates, samples of groundwater are collected for wells distributed within the study area. Before starting the sampling process, the tools used to draw samples and to ensure that the samples withdrawn represent the reality of the aquifer. Nitrate concentration data for the purposes of verifying the validity of each technique by comparing it with a real representation of the reality of the area and selecting the closest ones in representation [11]. Adoption of nitrate concentration as a basis for comparison between different models where Pearson coefficient is employed for this purpose. Fig. 13 and Table 8 and are showed the spatial distribution of nitrate concentration in wet and dry season.

5. Conclusion

Adoption of nitrate concentration as a basis for comparison between different models where Pearson coefficient was employed for this purpose. Pearson's correlation coefficients for comparing each vulnerability map with the rate of Nitrate concentration as spatial distribution map as follows (87.94 and 83.23) percent for MD-DRASTIC and SINTACS respectively. So, it's more identical to real pollution map than SINTACS model.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

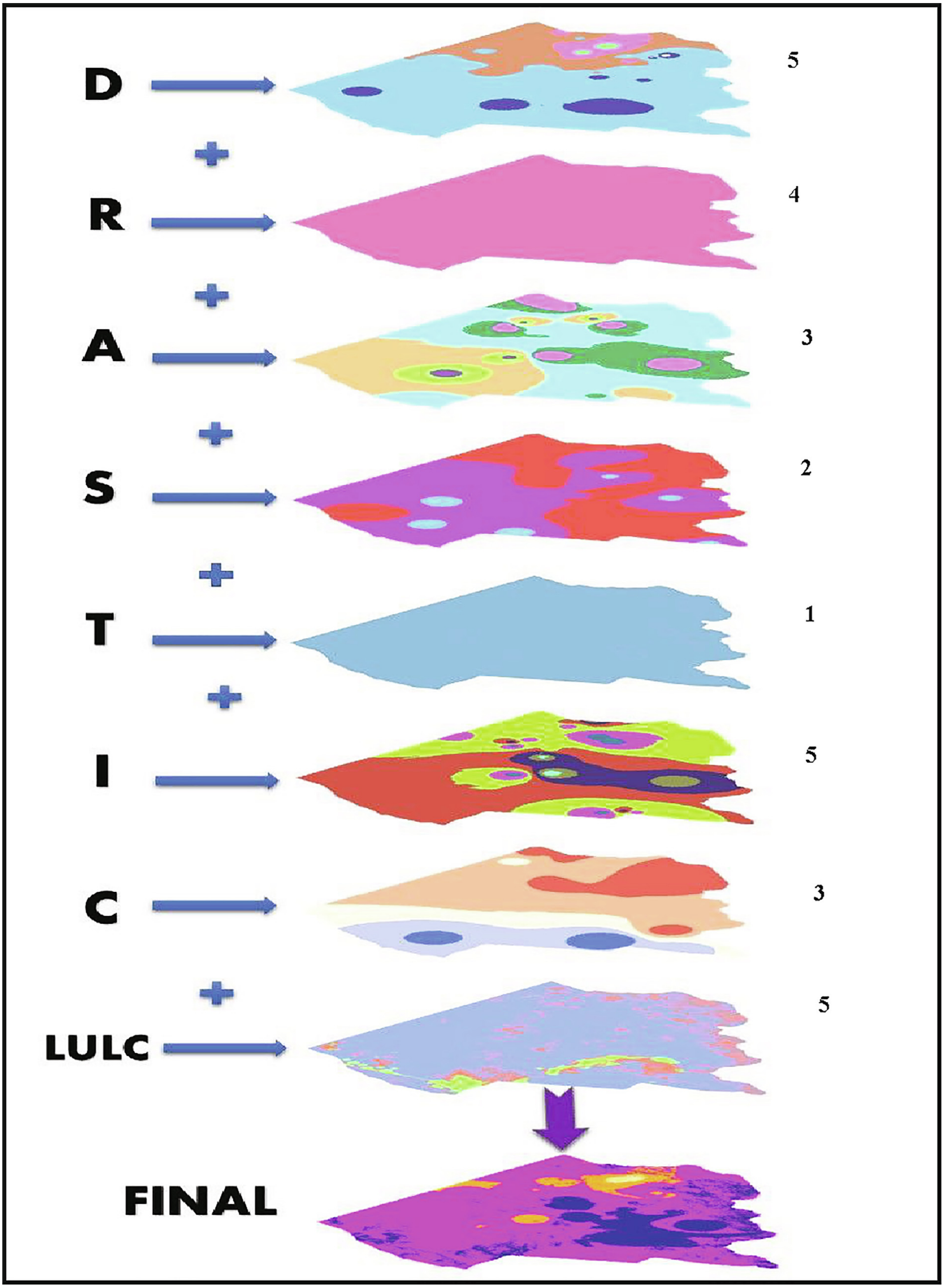

Fig. 6. Maps of parameters D, R, A, S, T, I, C and LULC in MD-DRASTIC Method.

Table 3
The Parameters Used in MD_DRASTIC Method.

No.	Parameters	Units	Range	Rating	Percentage	Relative Weight
1	Depth to Groundwater	m	0–1.5	10	1	5
			1.5–4.5	9	6	
			4.5–9	7	70	
			9–15	5	18	
			15–23	3	3	
			23–29	2	2	
2	Net Recharge	mm/year	less than 50	1	100	4
3	Aquifer Media	–	Sand and gravel	8	70	3
			Shale	6	30	
4	Soil Media	–	Sand	9	44	2
			Sandy Loam	6	52	
			Loamy Sand	5	4	
5	Topography	%	0–2	10	86	1
			2–6	9	11	
			6–12	5	2	
			12–18	3	1	
6	Impact of Vadose Zone	–	Gravel	9	1	5
			Sand and gravel	8	6	
			Sand	7	74	
			Silt/ Clay	3	19	
7	Hydraulic **C**onductivity	m/day	Less than 4	1	31	3
			4.0–12	2	69	
8	LULC	–	Wet Land	7	15	5
			Agriculture Land	8	55	
			Barren Land	5	30	

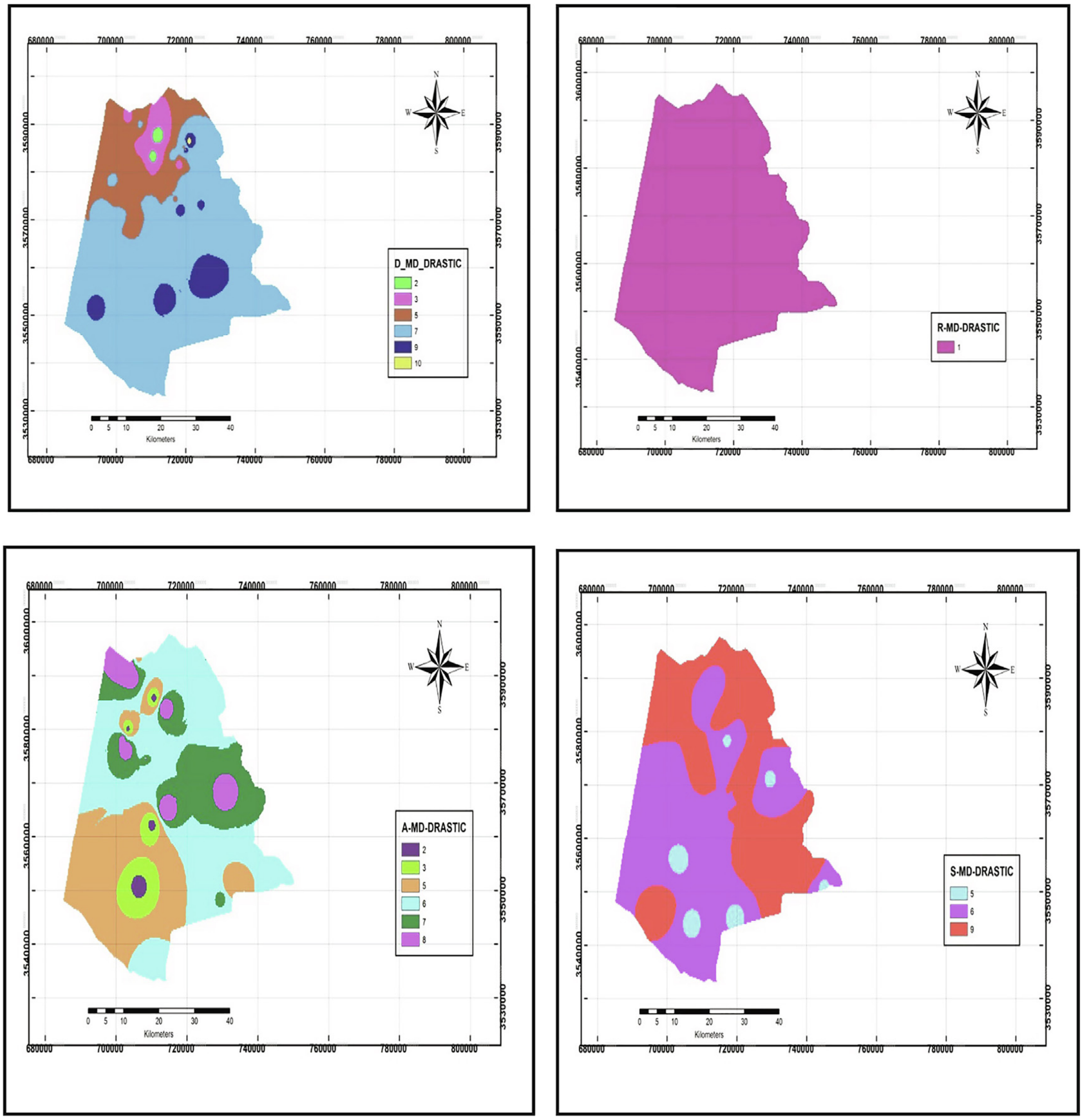

Fig. 7. Maps of parameters D, R, A, S in MD-DRASTIC Method.

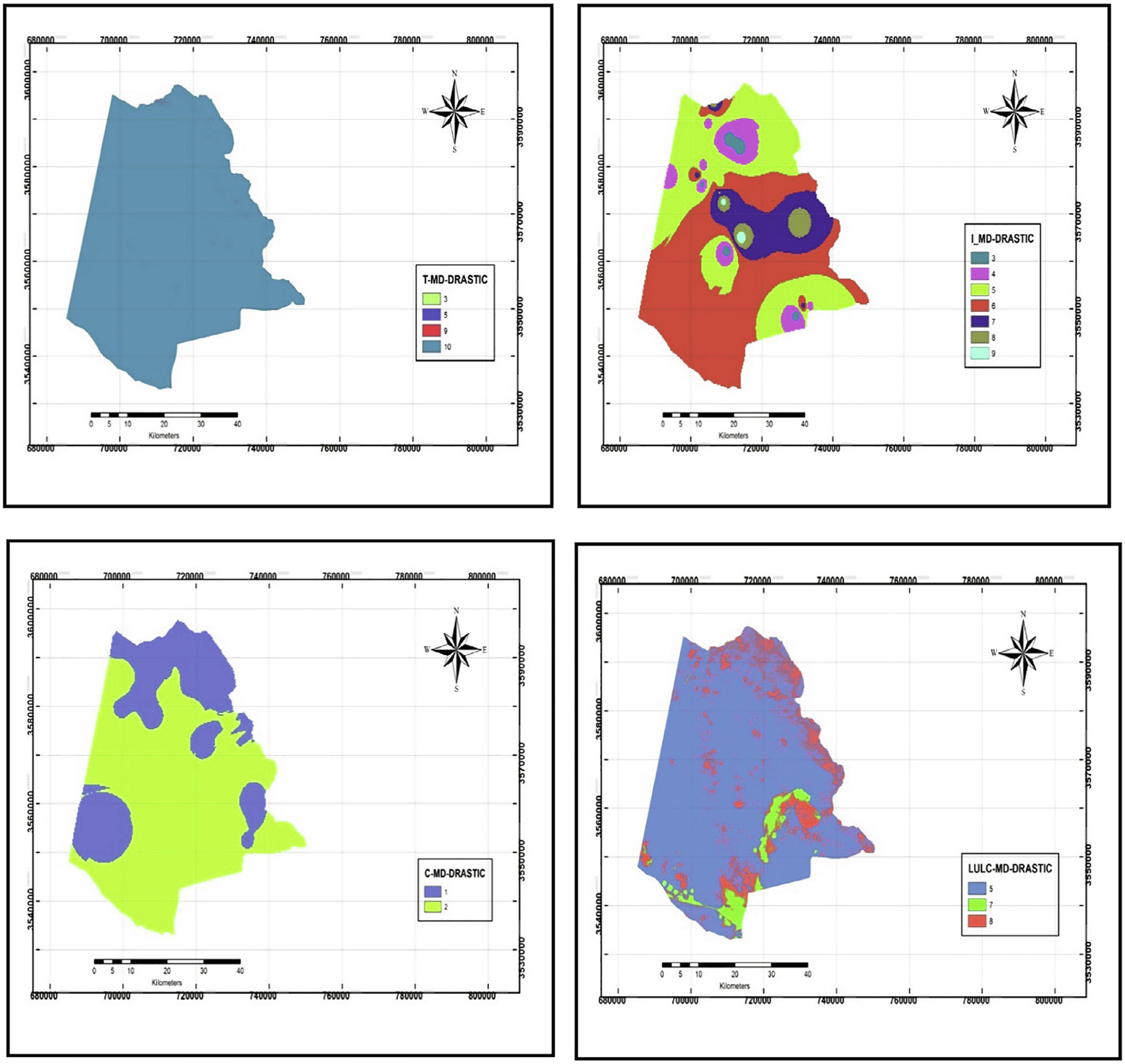

Fig. 8. Maps of parameters T, I, C, LULC in MD-DRASTIC Method.

Table 4
The Percentage of Each Zone of SINTACS Vulnerability.

Vulnerability Zone	From	To	Area (Km^2)	Percent
Very Low	77	80	8.48	0.35
Low	80	105	42.47	1.75
Medium	105	140	2009.83	82.81
High	140	160	366	15.08

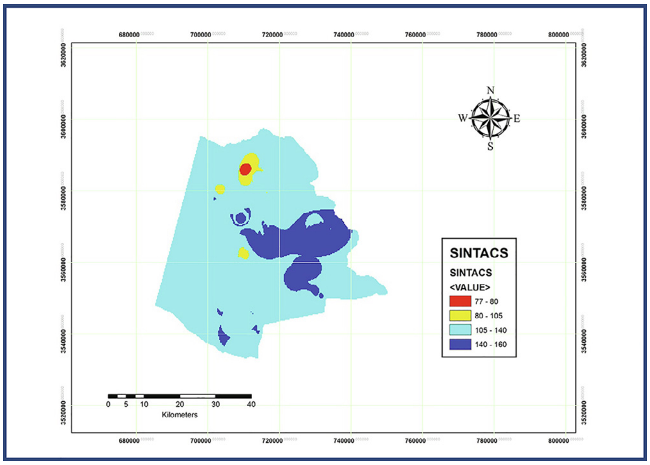

Fig. 9. Final Vulnerability map of SINTACS Method.

Table 5
The Statistical Summary of the SINTACS Parameters.

Parameters	Weights	Min	Max	Mean	SD	Cv
S	5	3	10	6.45	0.97	15%
I	4	1	1	1	0	0%
N	5	1	8	4.89	1.25	26%
T	4	5	7	6	0.57	9.5%
A	3	2	9	6.13	0.95	15.5%
C	2	1	10	10	0	0%
S	3	1	3	1.43	0.61	43%

Table 6
The Percentage of Each Zone of MD-DRASTIC Vulnerability.

Vulnerability Zone	From	To	Area (Km^2)	Percent
Very Low	85	100	14.76	0.6
Low	100	125	156.4	6.45
Medium	125	150	1753.8	72.35
High	150	179	498.5	20.5

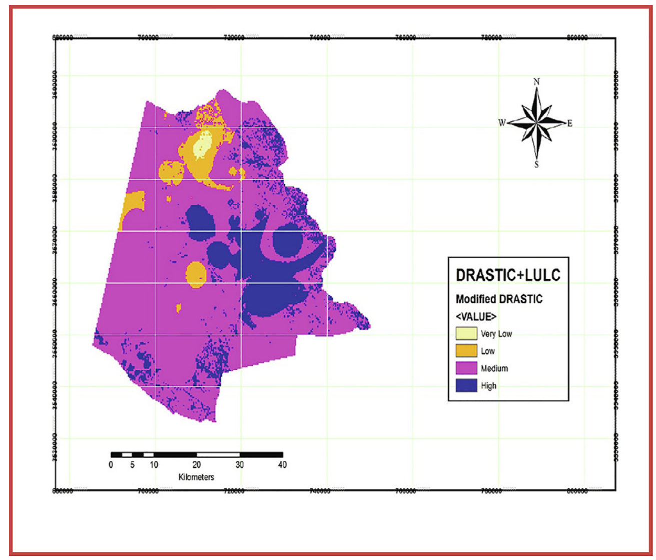

Fig. 11. Final Vulnerability map of MD-DRASTIC Method.

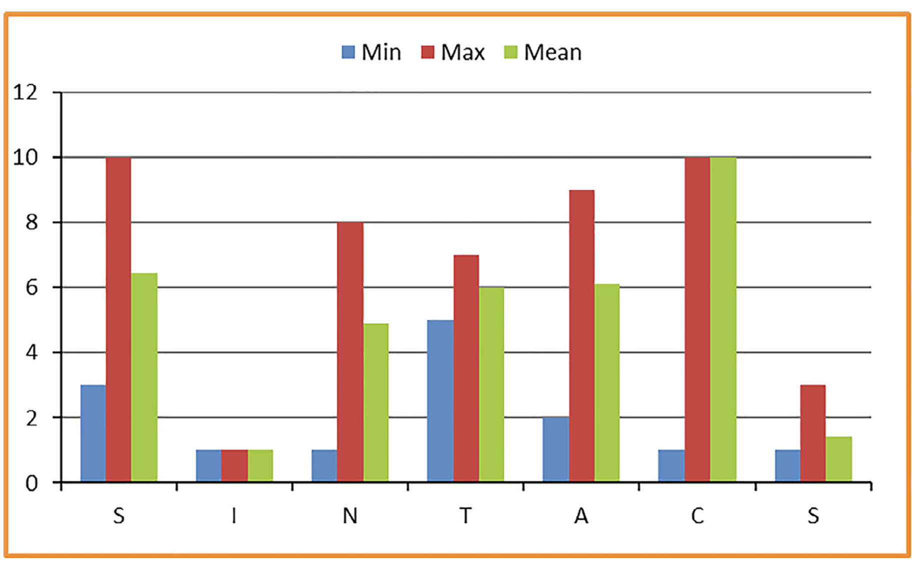

Fig. 10. The Minimum, Maximum, and Mean Values of SINTACS Parameters.

Table 7
The Statistical Summary of the Eight Parameters.

Parameters	Weights	Min	Max	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%
LULC	5	5	8	5.5	1.09	20%

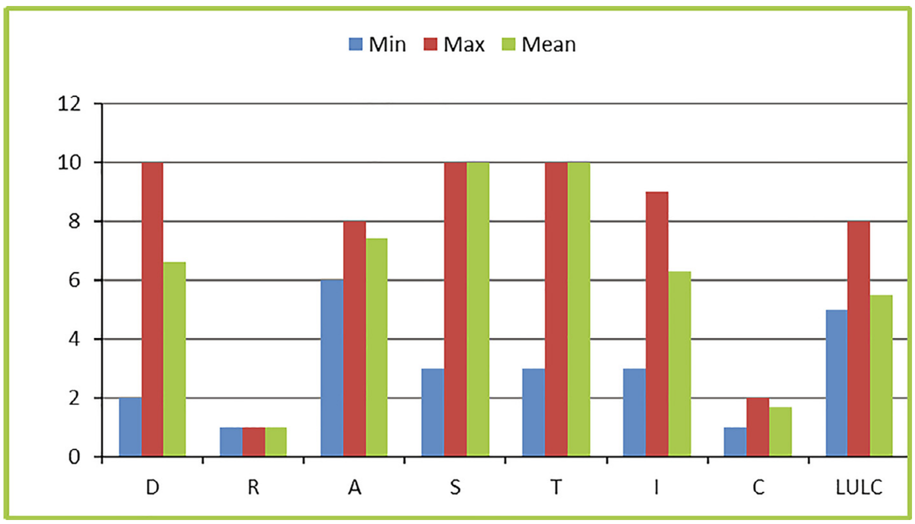

Fig. 12. The Minimum, Maximum, and Mean Values of MD-DRASTIC Parameters.

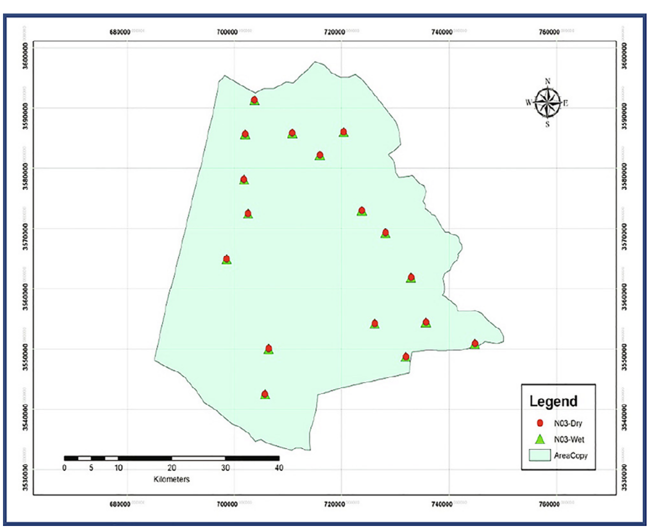

Fig. 13. The Locations of Wells Which Used for Collecting Groundwater Samples.

Table 8
Nitrate Concentrations in Groundwater (mg/l).

well	x	y	Wet	Dry
Well-1	698,565	3,564,920	1.6813	3.455
Well-2	702552.1	3,572,517	1.389	4.356
Well-3	702000.5	3,585,663	20.885	36.758
Well-4	703741.7	3,591,337	18.015	20.555
Well-5	710781.6	3,585,843	11.717	14.705
Well-6	715932.4	3,582,193	3.232	7.456
Well-7	720,347	3,586,048	17.04	20.775
Well-8	701785.2	3,578,141	1.788	5.705
Well-9	705,699	3,542,477	10.26	12.26
Well-10	706386.1	3,550,040	32.19	36.23
Well-11	744784.3	3,550,890	3.532	7.737
Well-12	735674.3	3,554,435	22.237	22.941
Well-13	731948.5	3,548,710	1.863	5.111
Well-14	726156.8	3,554,219	41.596	61.606
Well-15	732906.1	3,561,891	4.172	6.762
Well-16	723748.9	3,572,964	18.727	24.185
Well-17	728151.8	3,569,303	14.212	25.385

References

[1] A. Agyemang, Vulnerability assessment of groundwater to NO3 contamination using GIS, DRASTIC model and geostatistical analysis, Electronic Theses and Dissertations, Paper 3264, 2017, https://dc.etsu.edu/etd/3264.
[2] M. Civita, M. De Maio, Assessing and mapping groundwater vulnerability to contamination: the Italian ''combined'' approach, Geophys. Int. Mexico 43 (4) (2004) 513.
[3] S. Chowdhury, Md. Ferozur, A. Riad, A.Md. Samser, H. Quamrul, Delineation of groundwater potential zones of Atrai–Sib river basin in north-west Bangladesh using remote sensing and GIS techniques, Sustainable Water Resources Management, 2018, 10.1007/s40899-018-0240-x.
[4] I Machdar, T Zulfikar, W Rinaldi, Y Alfiansyah, Assessment of groundwater vulnerability using DRASTIC Model and GIS : a case study of two sub-districts in Banda Aceh city Indonesia, . IOP Conf. Series: Mater. Sci. Eng. 334 (2018) 012032, https://doi.org/10.1088/1757-899X/334/1/012032.
[5] A.H. Salih, Estimation of spatial groundwater recharge using wetspass model in teeb area, Missan Province. M. Sc. dissertation presented to the University of Basrah, College of Engineering, 2020.
[6] L. Aller, T. Bennett, J.H. Lehr, R.J. Petty, G. Hackett, DRASTIC, a standardized system for evaluating ground water pollution potential using hydrogeologic settings - National Water Well Association, 1987.
[7] A.K.S. Bety, Urban geomorphology of Sulaimani City, Using Remote Sensing and GIS Techniques. Kurdistan Region, Iraq. Unpublished PhD thesis, Faculty of Science and Science Education, University of Sulaimani, P.125, 2013.
[8] J.F. Mas, Monitoring land-cover changes: a comparison of change detection techniques, Int. J. Remote Sensing. 20 (1999) 139–152.
[9] L.W. Canter, Nitrates in groundwater from agricultural practices - causes, prevention, and clean – up, Report to united Nation Development program, University of Oklahoma, Norman, Oklahoma, 1987.
[10] L. Duarte, J.E. Marques, A.C.Teodoro, 2019.
[11] An Open Source GIS-Based Application for the Assessment of Groundwater Vulnerability to Pollution, University of Porto, 4169-007 Porto, Portugal.

Further Reading

[1] S. Javadi, N. Kavehkar, M.H. Mousavizadeh, K. Mohammadi, Modification of DRASTIC model to map groundwater vulnerability to pollution using nitrate measurements in agricultural areas, J. Agri. Sci. Technol. 13 (2011) 239–249.