Journal homepage: www.fia.usv.ro/fiajournal
Journal of Faculty of Food Engineering,
Ştefan cel Mare University of Suceava, Romania
Volume XXI, Issue 1 - 2022, pag. 62 - 75

FOOD AND ENVIRONMENT SAFETY

EVALUATION AND COMPARISON OF GROUNDWATER VULNERABILITY TO POLLUTION BY THE DRASTIC AND GOD METHODS: A CASE OF WADI NIL ALLUVIAL PLAIN (JIJEL, NE ALGERIA)

***Souhil MAHDID[1, 2], Nabil CHABOUR[3], Taha-Hocine DEBIECHE[1], Abdelmalek DROUICHE[1], Faouzi ZAHI[1], Séverin PISTRE[4]**

[1]University of Mohamed Seddik Benyahia - Jijel, Ouled Aissa, Jijel, Algeria,
[2] University of Mentouri Brothers - Constantine 1, Algeria
mahdidsouhil@yahoo.com
[3]University of Mentouri Brothers - Constantine 1, Constantine, Algeria,
[4]University of Montpellier, Montpellier, France
*Corresponding author:
Received 13th December 2021, accepted 25th March 2022

Abstract: *The current research aims to compare the results of two vulnerability estimation methods (DRASTIC and GOD) in superficial and deep aquifer of Wadi Nil alluvial plain (NE Algerian). Analysis of the obtained results showed that the vulnerability of the superficial aquifer is divided into three classes of vulnerability according to the DRASTIC method, and only into two classes according to the GOD method. In deep aquifer, the study of vulnerability using DRASTIC method has shown us a dominance of the middle and high classes. On the other hand, GOD method shows an equitable distribution of high, low and middle classes. The statistical study of the agreement between the two methods shows a weak agreement in superficial aquifer and a strong agreement in deep aquifer. The surface analysis per class of the two methods shows an identical index of superficial and deep aquifers. In this study, we find that the DRASTIC method provides better results in both aquifers (superficial and deep). It provides better information and gives the necessary amount of information required in the vulnerability assessment compared to the GOD method.*

Keywords: *Vulnerability methods, aquifer, classes, statistical study, surface analysis, Wadi Nil.*

1. Introduction

The quality and availability of water resources present major issues of our century, and a major source of concern throughout the world. The preservation of water requires better management of pollutants originated, mainly from anthropogenic activities; industrial, agricultural or domestic as a result of, an over-growing population. Pollutants alter the quality of water resources and threaten our ability to use these resources in various purposes; including drinking and irrigation agricultural lands. Mapping the vulnerability and contamination risks of groundwater resources is an effective tool to protect these resources, and to guide local and regional public policies to optimize land management.

The notion of water vulnerability to pollution is defined as the possibility of percolation and propagation of different pollutants from the soil surface to the groundwater [1]. Several methods for determining the vulnerability of aquifers have been developed around the world using physical or semi-physical approaches.

DOI: https://doi.org/10.4316/fens.2022.007

Ranging simplest to the most complex, they took into account the concentration of pollutants [2], physical, chemical and biological processes in the unsaturated zone [3], or different criteria affecting vulnerability [4] that are weighted according to the hydrogeological context. The latter, known as "indexing methods", are often preferred because they are easier to implement on a regional scale.

Several authors proposed indexing methods to establish vulnerability maps to protect and conserve of aquifers from pollution, such as DRASTIC [1], GOD [5], AVI [6], SINTACS [7], EPIK [8], GALDIT [9], DRISTPI [10], PI [11], COP [12], and DISCO [13]. However, there are few comparative studies of these different vulnerability mapping methods.

DRASTIC and GOD methods were used for this study because, they are the most suitable to comparably assess vulnerability in granular aquifers, due to the fact that they use the same parameters allowing a certain stability of the final results [14].

They are also characterized by low implementation efforts, fast interpretation and limited minimum hydrogeological datasets to estimate the overall vulnerability of the aquifer [15], [16]. Nevertheless, the accuracy of this estimate will be conditioned by the quantity and the quality of the data.

2. Materials and methods

2.1. Study area

The alluvial plain of Wadi Nil is a part of the coastal plains of North-east Algeria (Fig. 1). It is located 260 km east of the capital Algiers and 20 km east of Jijel city, covering an area of 58 km^2.

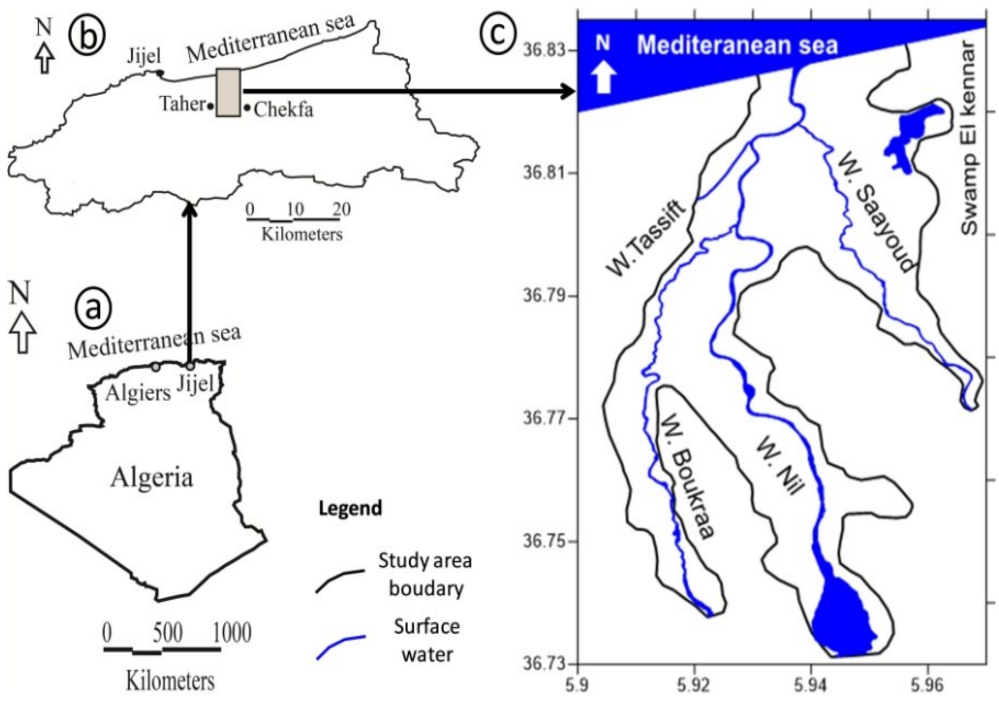

Fig. 1. Location of the study area. a) Map of Algeria, b) Wilaya of Jijel, c) Wadi Nil Alluvial plain

The study area is characterized by a Mediterranean climate considered as hot and dry in summer, cold and humid in winter. The annual average of rainfalls is around 1000 mm/year and the maximum and minimum monthly temperatures are respectively 28.1°C (August) and 13.4°C (January), according to the Achouat weather station (1988 to 2015).

The hydrographic network is mainly represented by Wadi Nil and its three tributaries: WadiBoukraa, WadiSaayoud and WadiTassift. In addition to these Wadis, there are marshes (wetlands) including El Kennar swamp (Ghdir Ben Hamza) in the eastern part of the plain (Fig. 1).

2.2. Geological overview

In terms of hydrogeology, the alluvial plain of Wadi Nil is mainly composed of two formation typesof formation: (i) Permeable formations dating back to the Quaternary age, which occupy the littoral area. These formations are constituted of fine sands (recent dunes), fine silty sands (old dunes), and, along the main Wadis, of alluvial deposits (sand, gravel, pebbles and conglomerates) forming the alluvial aquifer. (ii) Impermeable formations, which outcrop in the center of the plain, on the right bank of Wadi Nil.

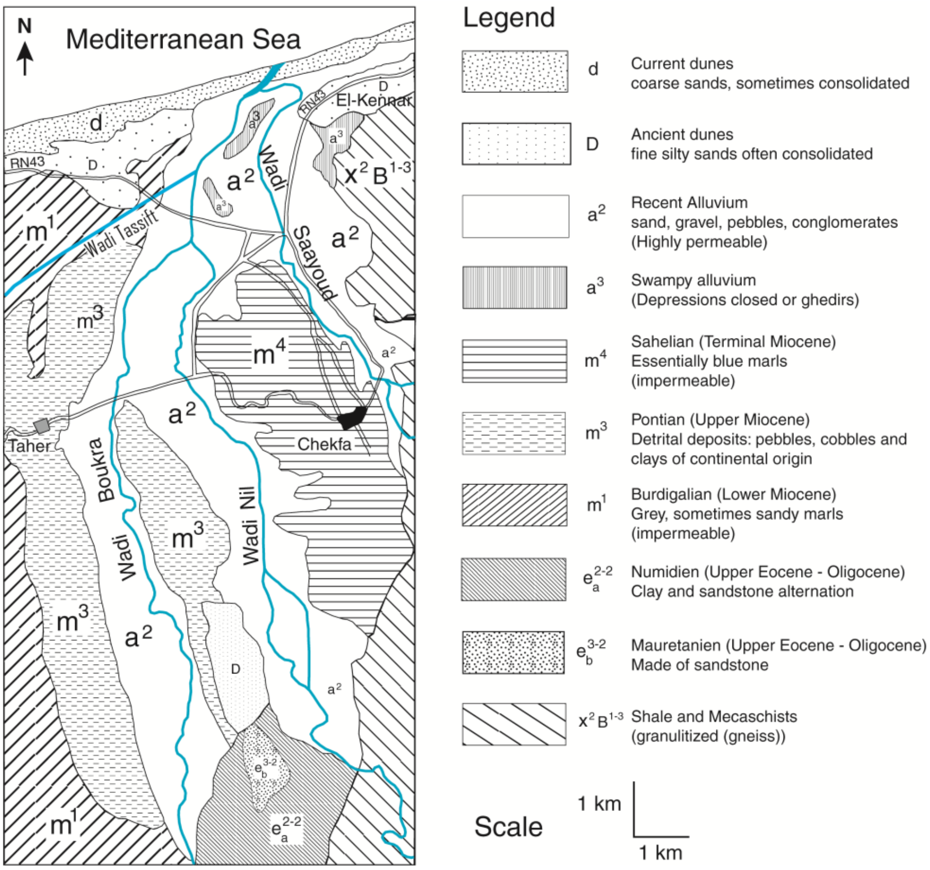

Fig. 2. Geological sketch of Wadi Nil plain [17]

They are principally made up of blue marls dating back to the upper Miocene age. However, in the western part of the plain, they are mainly made up of grey marls, sometimes sandy, dating back to the lower Miocene age. These formations constitute the impermeable limits of the aquifer.

According to the log-lithostratigraphy, three lithological cross-sections obtained in the plain (Fig. 3), they show that the Wadi Nil plain is vertically composed of a single aquifer, locally separated by clay lenses which give rise to a surface aquifer exploited by wells and a deep aquifer exploited by boreholes. In the absence of a clay lens, the two aquifers merge together to form hydraulic exchanges. The permeability of the aquifer varies between 10^{-3} and 10^{-4} m/s. The thickness of the alluvium increases from up to downstream, it can reach around 100m near the confluence of WadiBoukraa and Wadi Nil. The substratum consists of grey plastic marl dating back to the Miocene age.

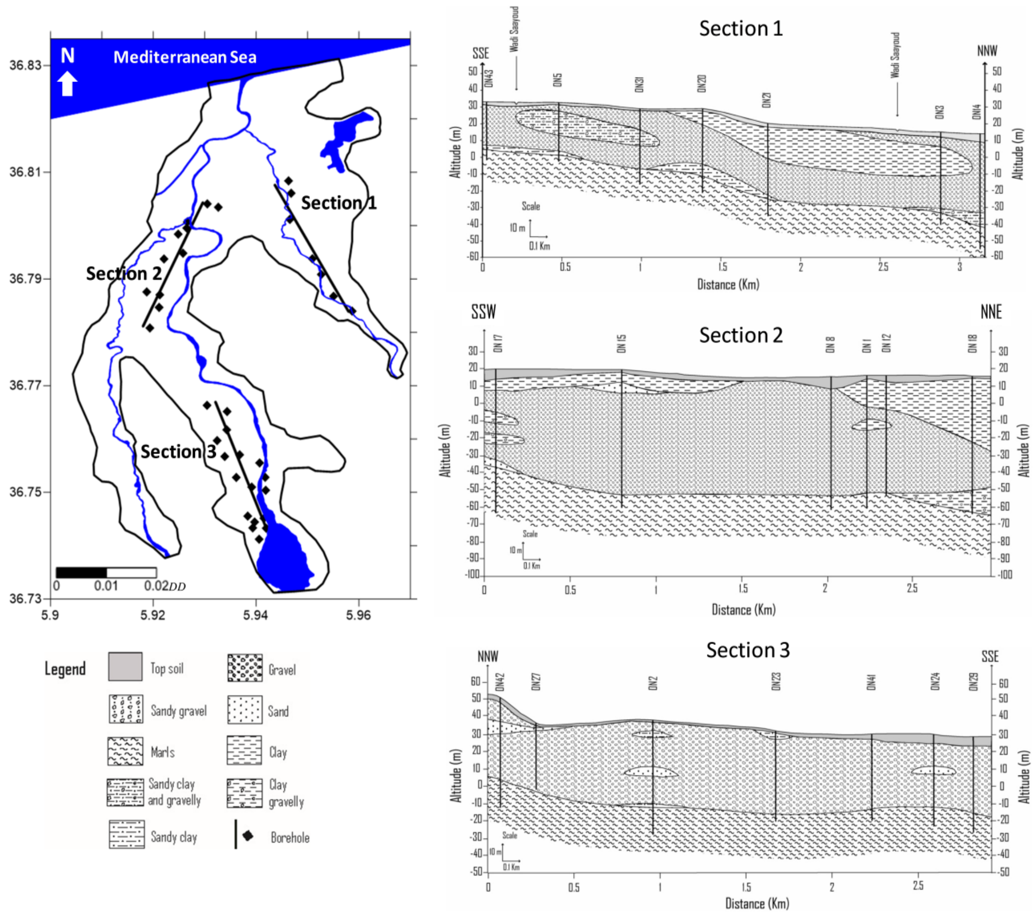

Fig. 3. Lithological cross-sections made from the stratigraphic logs of the drillings

2.3. Data

Creation of a vulnerability map using DRASTIC and GOD methods requires the determination of several parameters: geological (aquifer environment), hydrogeological (aquifer type, aquifer depth, vadose zone impact and hydraulic conductivity), pedological (soil type), topographical (topography) and meteorological (recharge) (Fig. 4).

The aquifer environment data was taken from the geological sketch of the Wadi Nil alluvial plain (Fig. 2). The aquifer depth was obtained from the piezometriccampaign carried out during high water period (28 - 29 April 2012) from 106 water samples (64 wells, 35 boreholes and 7 piezometers) distributed across the plain.

The aquifer type and the vadose zone impact were obtained from the litho-stratigraphic logs of the mechanical drillings carried out, by the Jijel wilaya's Water Resources Department (DRE) in the Wadi Nil alluvial plain. The hydraulic conductivity was obtained from long-term pumping tests carried out on the boreholes. Rainfall data provided by the National Agency for Hydraulic Resources (ANRH) of the wilaya of Jijel was used to estimate the aquifer recharge.

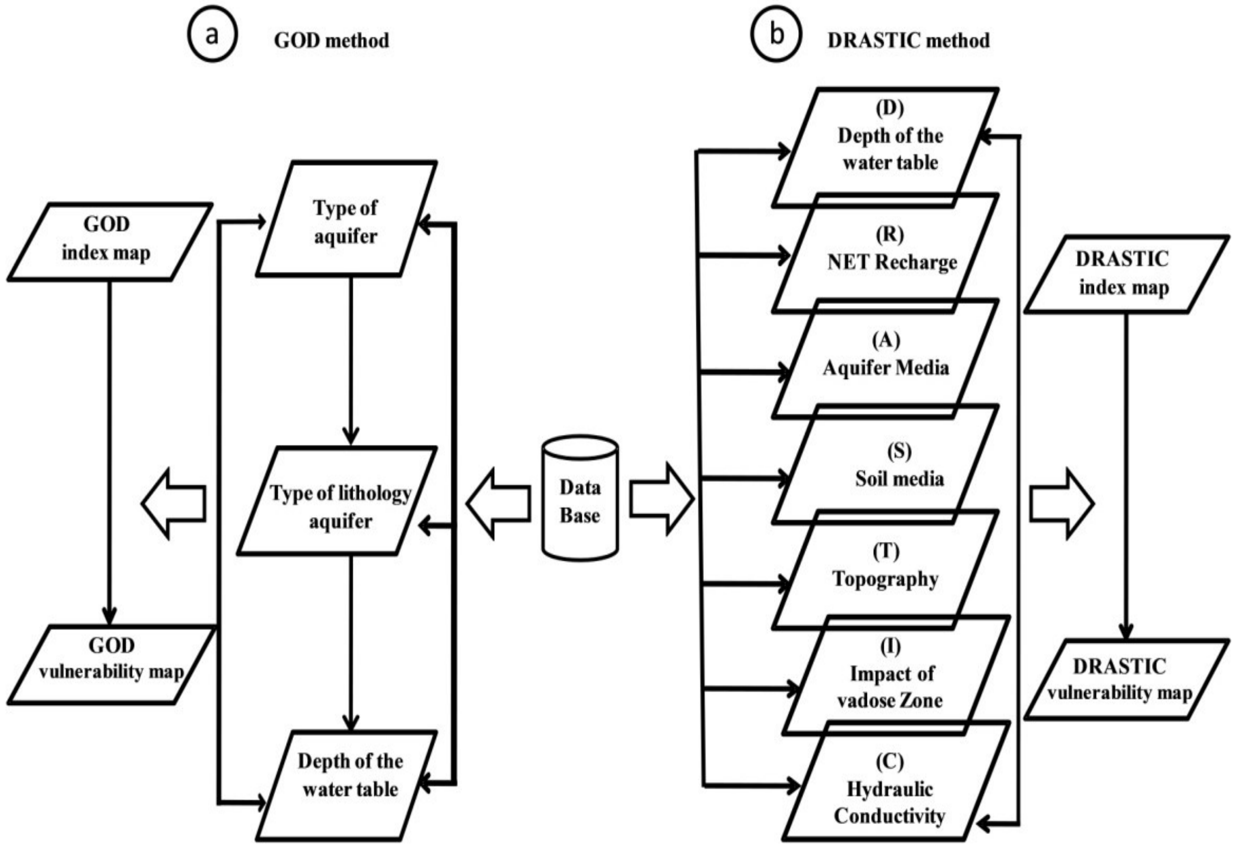

Fig. 4. Vulnerability map parameters. a) DRASTIC method, b) GOD method

2.4. The DRASTIC method

The DRASTIC method was developed mainly by the scientific research of the Environmental Protection Agency (EPA) in the USA in 1985 [1]. The purpose was to estimate the potential pollution of groundwater. It allows an assessment of vertical vulnerability based on seven parameters, which are; Aquifer depth (D), net Recharge (R), Aquifer lithology (A), Soil type (S), Topography (T), vadose zone Impact (I) , and aquifer hydraulic Conductivity (C). Each parameter assigned a fixed weight ranging from a value of "5" in the most important parameters in the pollutants propagation in the aquifers to a value of "1" in the least important ones [18] (Tab. 1).

Table 1

DRASTIC parameter weights [1]

Parameters	Symbol	Weight
Aquifer Depth (D)	D	5
Net Recharge (R)	R	4
Aquifer Medium	A	3
Soil Type	S	2
Topography	T	1
Impact of vadose zone	I	5
HydraulicConductivity	C	3

Vulnerability is calculated using a DRASTIC index, which is the weighted sum of the seven parameters according to the following formula:

$$ID = D_r D_W + R_r R_W + A_r A_W + S_r S_W + T_r T_W + I_r I_W + C_r C_W$$

Where; ID is the DRASTIC index (D, R, A, S, T, I, C), r is the score or parameter coefficient which varies from 1 to 10,w is the weight of the DRASTIC parameter, which ranges from 1 to 5 [1]. The calculated index thus represents a measure of the level of contamination vulnerability in the hydrogeological unit of the study area. This risk increases with the value of the ID index, which therefore oscillates between 23 and 230 (Tab. 2).

In practice, the study area is divided into grids where every parameter is estimated. The user of the method assigned an index for each parameter, which is defined in a range of values altering from 1 to 10. A parameter with a high index indicates that the aquifer in question is vulnerable regarding this criterion and vice versa. The use of GIS allows each parameter to be mapped from topographical, hydrogeological, pedological and meteorological data. Based on this data, it is possible to automatically assign an index to each parameter in each grid cell of the studied area. The ID cartographic distribution is obtained by "superimposing" the maps associating to each parameter.

Table 2

Ranges of vulnerability in dex values and corresponding DRASTIC classes

Vulnerability index	Vulnerability Classes
23 – 70	Very low
70 – 110	Low
110 – 150	Medium
150 – 190	High
190 – 230	Very high

2.5. The GOD method

The GOD method was developed in England by Foster [5]. Estimation of water vulnerability to pollution is obtained from the combination of three parameters: Groundwater type (G), Overlying strata (O) and groundwater Depth (D). Each parameter evaluated by the user in a range varying from low to high effect on vulnerability (0 to 1) [17] provides standard values for

estimating these parameters according to hydrogeological characteristics.
The GOD index (GI) is obtained by multiplying the indices of each of these three parameters [19]:

$$GI = Ca \times Cl \times Cd$$

Where; Ca is the aquifer type, Cl is the aquifer lithology and Cd is the aquifer depth.
According to the geological and piezometric maps, each grid cell in the study area assigned a value for each of the three parameters.

After calculating the index in each grid cell, the vulnerability classes corresponding to the obtained index intervals are determined. These indices are classified into five classes ranging from very low to very high vulnerability (Tab. 3). The final cartographic result is based on the GI value in each domain grid cell.
In case where the calculated indices do not oscillate within the set limits ("0": minimum value; "1": maximum value), another more suitable classification can be used [20], [21].

Table 3

Range of vulnerability index values corresponding to GOD method classes

Vulnerability Index	Vulnerability Classes
0 – 0.1	Very low
0.1 – 0.3	Low
0.3 – 0.5	Medium
0.5 – 0.7	High
0.7 – 1	Very high

3. Results and discussion

3.1. Vulnerability map according the DRASTIC method

Calculating the DRASTIC vulnerability index enabled us to draw up a vulnerability map for each aquifer (Fig. 5). These maps show the main areas that are vulnerable to pollution. The spatial distribution of the vulnerability index of superficial aquifer to pollution (Fig. 5a) highlights three classes; (i) A very high vulnerability class which covers 20% of the study area, mainly located near the coastal zone and to the south of the plainwhere the pollutants propagation from the soil surface is facilitated within the high permeability of the sandy formations and the flat topography. (ii) A high vulnerability class, which represents 43% of the study area, located in the center, the east, the west and the south of the plain. (iii) A medium vulnerability class representing 37% of the study area, situated in the center and the southern end of the plain. It is characterized by a fairly deep aquifer, moderate permeability, and low slope. Moreover, the spatial distribution of the pollution vulnerability index of the deep aquifer shows the existence of four vulnerability classes (Fig. 5b): (i) A very high vulnerability class occupying 0.6% of the plain's surface, located in the southeast of the plain. This class is linked to the nature of the geological formations made up of recent alluvium (pebbles, sand and gravel) and the shallow depth of the aquifer (ranging from 0 to 1.15 m). (ii) A high vulnerability class representing 28.2% of the surface area, which is located in the north of the plain, where dune formations (sand) dominate, and to the south with mainly alluvium (gravel, sand and pebbles), favoring the transfer of contaminants.

These areas are characterized by low slope and high hydraulic conductivity. (iii) A medium vulnerability class covering 68.6% of the study area, which occupies the center and the extreme south of the plain. It is characterized by moderate permeability and low slopes. (iv) A low vulnerability class representing 2.6% of the study area and, occupying the north-eastern part and the confluence zone of Wadi Nil and Wadi Boukraa. It is marked by a relatively low permeability and a significantdepth of the aquifer.

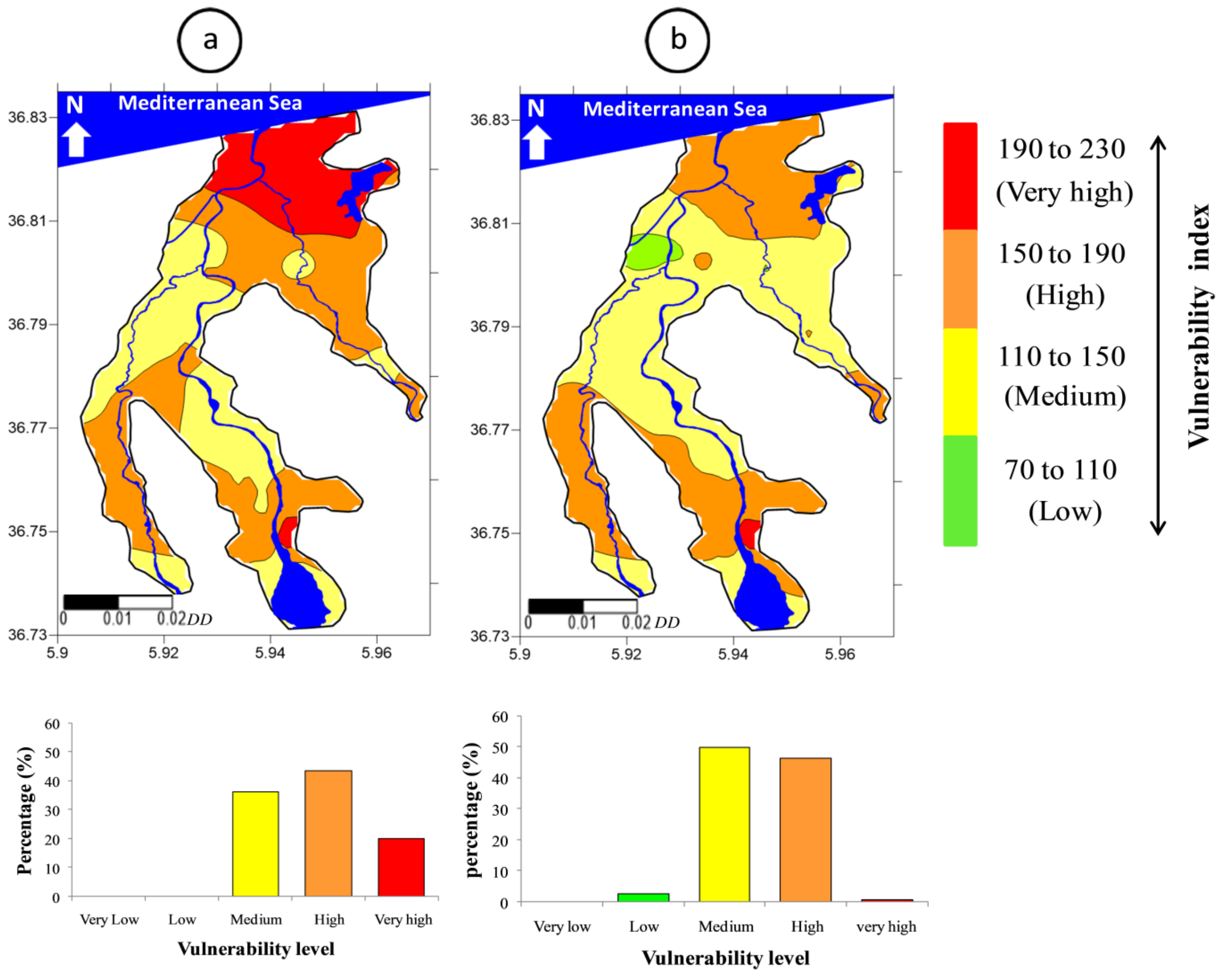

Fig. 5. Pollution vulnerability maps of Wadi Nil plain using DRASTIC method.
a) Superficial aquifer, b) Deep aquifer

3.2. Vulnerability map using the GOD method

The GOD method differs from the DRASTIC method in its approach wherevulnerability is defined in terms of the difficulty of the pollutant to reach the saturated zone, and the degree of attenuation, which represents the layer above the saturated zone [22].

The vulnerability index evaluated by GOD method in the Wadi Nil plain (superficial and deep aquifers) varies between 0 and 0.72, representing five classes ranging from very low to very high (Fig. 6).
The GOD vulnerability map of the superficial aquifer highlights two classes (Fig. 6a): (i) A high vulnerability class, which occupies the north-eastern part and the center of the plain (53% of the area). The high degree of vulnerability is explained by the shallowness of the aquifer, which means that, the water level is very close to the ground surface. (ii) A medium vulnerability class, found in the northern parts (near the sea), the northwest, the south and southwest of the plain (47% of the study area). This is due to the average depth of the water table (about 2 m) and the lithology of the aquifer, which is mainly sand, gravel and clay.On the other hand, the vulnerability map of the deep aquifer according to the GOD method (Fig. 6b) shows five classes: (i) A very high vulnerability class affecting the southern and the eastern parts in the form of small islands (3.5% of the area).

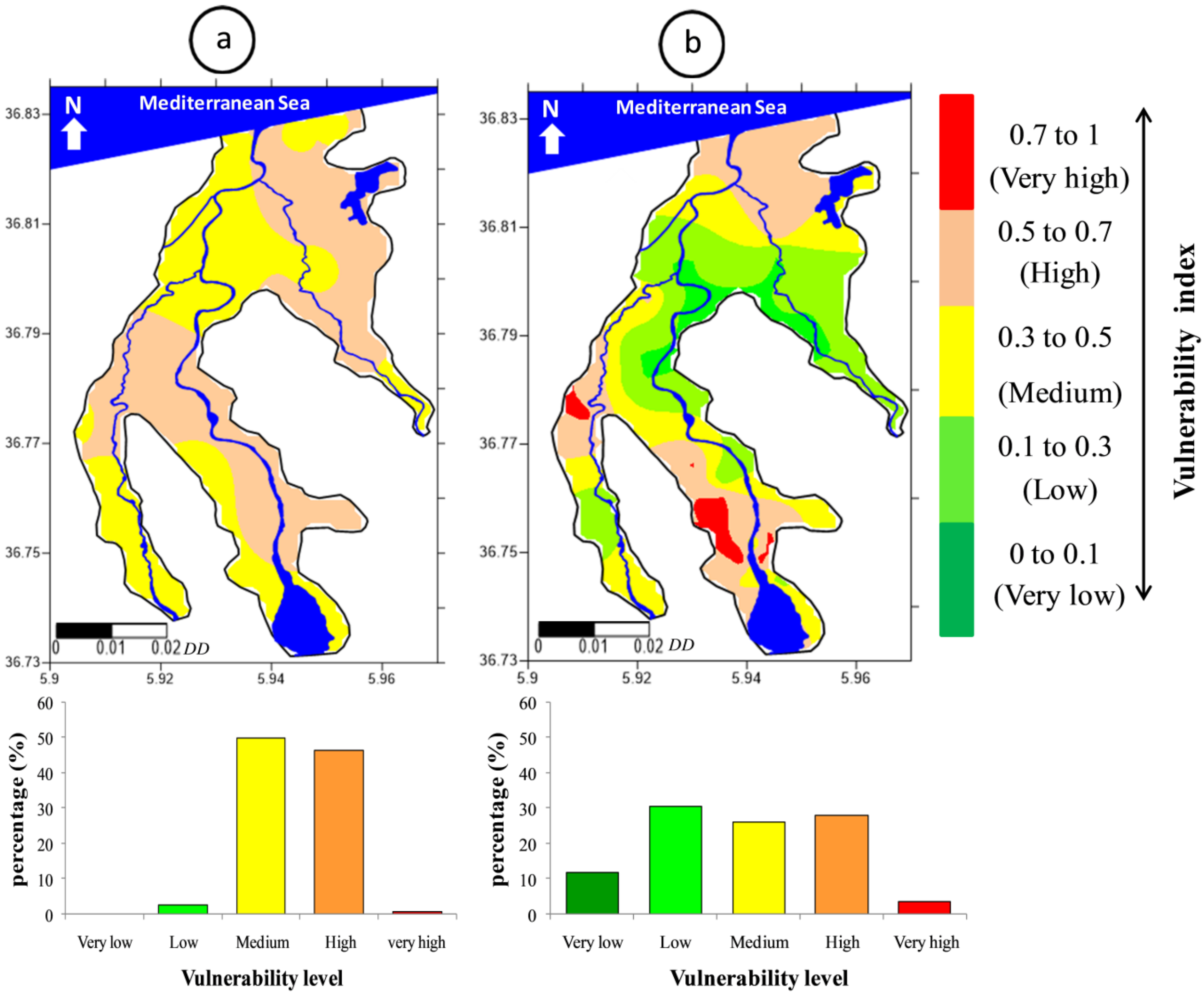

Fig. 6. Pollution vulnerability maps of Wadi Nil plain using the GOD method. a) Superficial aquifer, b) Deep aquifer

The very high index is attributed to the lithological nature of the aquifer zone, mainly sand and gravel. (ii) A high vulnerability class found in the north and the south of the plain (30.8% of the study area). The high vulnerability index is explained by the shallowness of depths and the lithology, which is made up of sand, gravel and clay. (iii) A medium vulnerability class, found in the north, the center and the south of the plain (28.1% of the study area). It is characterized by lower vulnerability to pollution due to the depth of the water table (0 to 2m). (iv) A low vulnerability class, located mainly in the center of the plain (30.7% of the study area). The low vulnerability index is linked to the aquifer depth in this area, which varies between 10 and 25 meters. (v) A very low vulnerability class found, mainly in the center of the plain near theNil and Saayoud Wadis. The very low vulnerability index is explained by the significant aquifer depth in this location (over 20 meters). This class represents 6.9% of the study area.

3.3. Comparison between DRASTIC and GOD methods

Water pollution vulnerability mapping methods should be validated in different ways (field observations, statistics of the existing data, mathematical modelling) in order to be considered as a credible scientific tool.

To carry out this comparison, we have opted for the statistical method through the Kappa test (or proportion test) and the surface analysis. The former is a correlation coefficient based on the comparison of the vulnerability classes determined by the two methods DRASTIC and GOD. It thus makes it possible to determine the degree of association and concordance between the two methods [23]. The second method estimates the differences in the vulnerability assessment of the same area by the two methods DRASTIC and GOD, while determining the association between each method. These two statistical methods make it possible to determine which method offers the most stability. It should be noted that this type of comparative validation is completely site dependent.

3.3.1. The Kappa test

The non-parametric Kappa test (K) is used to evaluate the degree of agreement or concordance between two judges, assessors or observers (vulnerability estimation methods in this case). The level of agreement is higher when its value is close to "1".

The Kappa coefficient is calculated by applying the following formula:

$$K = \frac{P_0 - P_e}{1 - P_e}$$

Where: Po: proportion of the observed and calculated agreement that corresponds to the proportion of cases where both assessors have assigned the same categories, it is calculated by the following formula:

$$P_0 = \sum_{i=1}^{K} P_{ii}$$

Where: Pii: each value on the diagonal of the two-entry table, Pe: proportion of random agreement; which is the sum of the products of the marginal proportions of rows and columns. It is calculated by the following formula:

$$P_e = \sum_{i=1}^{K} P_{+i} P_{+i}$$

Where: $P_{i+} = \sum_j P_{ij}$, and: $P_{+i} = \sum_i P_{ij} P_{ij}$.

The Kappa coefficient (K) is a real, dimensionless number between -1 and +1. The more agreement is higher the closer the Kappa value is +1, in the case of disagreement between assessors, the Kappa value will be close to -1.

When the assessments are independent, the Kappa coefficient is equal to "0" (P0 = Pe).

In the case of the superficial aquifer, the Kappa coefficient calculated by both methods in each domain grid cell is equal to 0.31.

The current low agreement can be explained by the influence of the aquifer depth parameter, where the index is high (score (7 to 10) * weight (5)) in DRASTIC method and low in GOD method (score (0.9 to 1) * weight (1)). In deep aquifer, the Kappa coefficient is equal to 0.71; indicating that the two methods strongly agree. This can be explained by the decrease of depth index in DRASTIC method; where the index rating from (2 to 10) * weight (5)) is closer to GOD method (rating (0.6 to 1) * weight (1)).

3.3.2. Surface analysis

The area's analysis test allows the visualization of variations in the pollution vulnerability assessment of the same area through the two used methods, DRASTIC and GOD, and enable us to determine the association between the two methods. In order to compare the pollution vulnerability maps produced by both methods, the relative area of each class was compared with another one. Calculation of the surface area and its percentage of each vulnerability class was performed in the two aquifers (superficial and deep). The comparison of the areas per class for both DRASTIC and GOD methods is shown in Tables 4 and 5.

The values 1, 2, 3, 4 and 5 were attributed to the different classes characterizing the vulnerability obtained by DRASTIC and GOD methods (very low, low, medium, high and, respectively very high), calculation the difference between the two maps (DRASTIC-GOD) made it possible to obtain maps of the differences between the two methods (Fig. 7). The superficial aquifer (Fig. 7a) shows that the "-1" deviation gives a percentage of (16%); while the "0" deviation gives a percentage of (46%). The gaps "1" and "2" show a percentage equal to 31% and 7%.

The majority of the study area is considered to have a dominant percentage of 38%, representing an overestimation of the DRASTIC method index compared to the GOD method, while the "0" gap is represented with a percentage equal to 46% where both methods are in agreement. They have identical indices; and an under-assessment of about 16%.

This difference is explained by the number of parameters used in the two methods; the DRASTIC method uses seven parameters to establish the vulnerability map. However, the GOD method establishes its vulnerability map with only three parameters; explaining why the GOD method tends to underestimate the vulnerability of the study area. In the case of deep aquifers (Fig. 7b) the deviations "1", "2" and "3" represent the highest percentage (43.49 %); indicating the overestimation of the DRASTIC method compared to the GOD method. The deviation class "0" in which the two methods agree is presented by a percentage equal to 40.5%. In the "-2" and "-1" deviations, the lowest noted percentage is (16%) indicating an underestimation of vulnerability in the DRASTIC method compared to the GOD method.

As in the superficial aquifer, this variation is related to the number of parameters used in both methods. Finally, the DRASTIC method appears to be more suitable into assessing vulnerability to pollution than the GOD method; especially in superficial aquifer; where the thematic map of the parameter "aquifer depth" has heavier weight. The two other thematic maps (aquifer type and aquifer lithology) of both methods show similar variation in the classes; and slightly influence the vulnerability map.

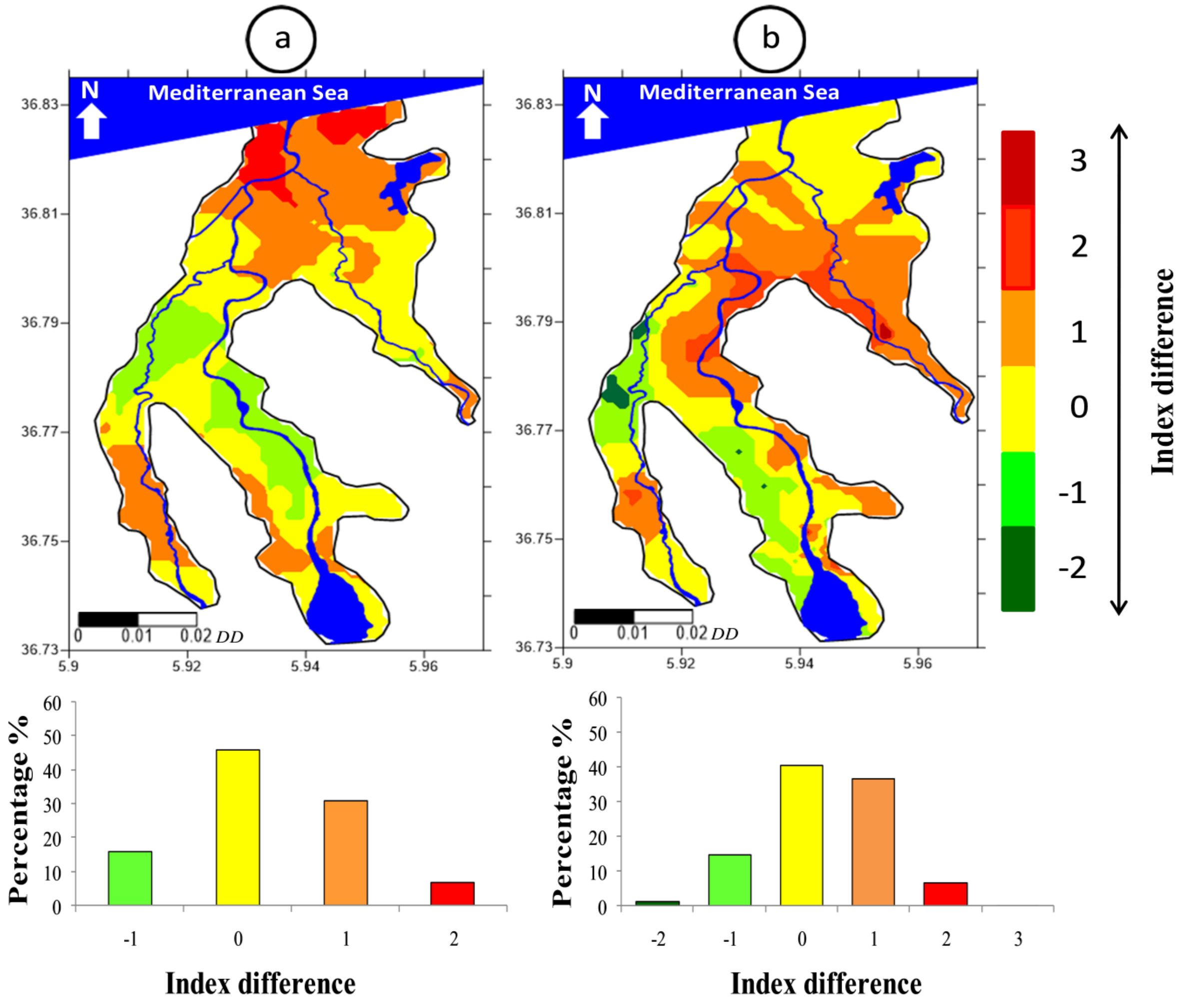

Fig. 7. Gap of Vulnerability map (DRASTIC-GOD) in Wadi Nil plain. a) Superficial aquifer , b) Deep aquifer

Table 4
Comparison between grid cells and classes of DRASTIC and GOD methods in the superficial aquifer

		DRASTIC					
		Very low	Low	Medium	High	Very High	Total
GOD	Very low	**0**	0	0	0	0	0
	Low	0	**0**	0	0	0	0
	Medium	0	0	**512**	480	135	1127
	High	0	0	373	**565**	349	1287
	Very high	0	0	0	0	**0**	0
	Total	0	0	885	1045	484	2414

Table 5
Comparison between grid cells by class of DRASTIC and GOD methods for the deep aquifer

		DRASTIC					
		Very low	Low	Medium	High	Very High	Total
GOD	Very low	**0**	64	103	0	0	167
	Low	0	**0**	741	0	0	741
	Medium	0	0	**679**	0	0	679
	High	0	0	133	**611**	0	744
	Very high	0	0	0	69	**14**	83
	Total	0	64	1656	680	14	2414

Authors should discuss the results and their manners of interpretation in perspective of previous studies and working hypotheses. The findings and their implications should be discussed in the possible broadest context. Future research directions may also be highlighted.

4. Conclusions

The analysis of the vulnerability maps of Wadi Nil alluvial plain by the DRASTIC and the GOD methods shows the existence of three vulnerability classes (medium, high and very high) in the superficial aquifer; and five vulnerability classes (very low, low, medium, high and very high) in the deep aquifer.The comparison between the two vulnerability maps, established by the DRASTIC and the GOD methods; using the Kappa's test, shows a weak agreement (K = 0.31) in the superficial aquifer and a strong agreement (K = 0.71) for the deep aquifer. This is mainly due to the high index of low depths in the DRASTIC method.
The analysis of the areas per class of the two methods (DRASTIC and GOD) in the superficial aquifer indicated an underestimation of 16% by the DRASTIC method and an overestimation of 38% by the GOD method.While in the deep aquifer, the DRASTIC method showed an underestimation of 16% and an overestimation of 43% of the index by the GOD method.

This allowed us to deduce that the DRASTIC method overestimates the aquifer vulnerability compared to the GOD method. This is due to the weight given it gives to the seven parameters used in the vulnerability calculation and especially to the weight of the depth.
This study indicates that the DRASTIC method is improved over the GOD method, because of using, seven parameters in the vulnerability assessment and additionally assigns different weighting to each parameter depending on the pollution risk. The GOD method underestimates the vulnerability values compared to the DRASTIC method because of using, only three parameters and assigns them identical weights. This method is recommended in cases where only a few parameters of the DRASTIC method are available.

5. Acknowledgments

The authors of this paper thank the General Directorate of Scientific Research and Technological Development (DGRSDT), the "AgenceNationale des Ressources en eau" (ANRH) et the"direction des ressources en eaux" (DRE) of the wilaya of Jijel for their help in carrying out the present scientific research.

6. References

[1]. ALLERL, BENNET T, LEHR JH, PETTY RJ, HACKETT G., "DRASTIC : a standardized system from evaluating groundwater pollution potential using hydrogeologic settings, *Prepared by the national Water Well Association For the US Environement Protection Agency,*2 : 87-035, (1987)

[2]. ZWAHLEN F., "Vulnerability and risk mapping for the protection of carbonate (Karst) aquifers". *European commission, Directorate – general XII, Science, Research and development, Cost action* 620, 279p, (2004)

[3]. SCHNEBLEN N, PLATEL JP, LE NINDRE Y., "Management of groundwater in Aquitaine Year 5. Sector operation. Oligocene aquifer protection in the Bordeaux region". (Eric Document Reproducion Service No ED 98-01), (2002)

[4]. GOGU RC, DASSARGUE A., "Current trends and future challenges in groundwater vulnerability assessment using overlay and index methods". *Environ Geol,* 39: 549-559, (2001)

[5]. FOSTER S.,"Fundamental concepts in aquifer vulnerability, pollution risk and protection strategy".in:W. van Duijvanbooden and H.G. van Waegeningh(eds.),Vulnerability of Soil and Groundwater to Pollution, *Committee on hydrogeological Research,* 69-86,(1987)

[6]. VAN STEMPVOORT D, EWERTWASSENAAR LL. "Aquifer Vulnerability Index (AVI): A GIS Compatible Method for Groundwater Vulnerability Mapping". *Canadian Water Resour J*, 18, 1: 25-37, (1993)

[7]. CIVITA M., "Vulnerability mapping of the aquifer; theory and practice, Quaderni di Techniche di protezioneAmbientale, Pitagora, Italy", (1994)

[8]. DOERFLIGER N, ZWAHLEN F., "Practical guide, vulnerability mapping in karstic regions (EPIK)", published by the OFEFP, Federal Office for the Environment, Forests and Landscape (Order No.: VU-2505-F), (1998)

[9]. CHALCHADI AG, LOBO-FERREIRA JP., "Sea Water Intrusion Vulnerability Mapping of Aquifers Using GALDIT Method. *Coasting-A Coastal Policy Res Newsl,*4: 7-9, (2001)

[10]. JIMÉNEZ-MADRID A, CARRASCO F, MARTINEZ C, GOGU RC., "DRISTPI, a new groundwater vulnerability mapping method for use in Karstic and non-Karstic aquifers", *QJ of EngGeol and Hydrogeol,* 46: 179-194,(2013)

[11]. GOLDSCHEIDER N, KLUTE M, STURM S., "The PI method – a GIS-based approach to mapping groundwater vulnerability with special consideration of Karst aquifers". *ZeitschriffürAngewandteGeologie*, 3: 157-166, (2000)

[12]. VIAS JM, ANDREO B, PERLES MJ, CARRASCO F, VADILLO I, JIMÉNEZ P., "Proposed method for groundwater vulnerability mapping in carbonate (Karstic) aquifers: the COP method". *Hydrogeology Journal,* 14: 912-925, (2006)

[13]. MEERKHAN H, TEIXEIRA J, ESPINHA MARQUES J, AFONSO MJ, CHAMINÉ H.I., "Delineating GroundwaterVulnerability and Protection Zone Mapping in Fractured Rock Masses": Focus on the DISCO,*water,* 8: 1-20, (2016)

[14]. MURAT V, PARADIS S, SAVARD MM, NASTEV M, BOURQUE E, HAMEL A, LEFEBVRE R, MARTEL R., "Vulnerability to the groundwater table of fractured aquifers in Southwestern Quebec: Evaluation by the DRASTIC and GOD methods". *Natural Resources Canada, GeologicalSurvey,* 3: 1-14, (2003)

[15]. ASHOKRAJ C, KIRUBAKARAN M, COLINS JOHNNY J., "Estimation of Groundwater Vulnerability using Remote Sensing and GIS Techniques". *IJIRST,* 9: 2349-6010, (2015)

[16]. AL-ABADI AM, AL-SHAMMA'A AM, ALJABBARI MH., "A GIS-based DRASTIC model for assessing intrinsic groundwater vulnerability in northeastern Missan governorate, southern Iraq". *Appl Water Sci,* 7:89-101, (2014)

[17]. EHRMANN F., "Geological map of El Milia", Map N°29, 1/50 000. Geological Survey of Algeria, (1928)

[18]. CHENG Y, BAOXIANG Z, YINGYING Y, FANHAI M, CHUNMIAO Z., "A field demonstration of the entropy-weighted fuzzy DRASTIC method for groundwater vulnerability assessment", *Hydrological Science Journal – Journal des Sciences Hydrogéologiques,*7: 1420-1432,(2012)

[19]. AKE GE, KOUASSI D, KOUADIA BH, DIBI B, SALEY MB, BIEMI J., "Contribution of DRASTIC and GOD autonomous vulnerability methods to the study of nitrate pollution in the Bonoua region (South-East of the Côte d'Ivoire)". *European Journal of Scientific Research,* 31: 157-71, (2009)

[20]. NAVALUR KCS, ENGEL BA., "Predicting spatial distribution of vulnerability of Indiana state Aquifer system to nitrate leaching using a GIS", 18p, (1997)

[21]. MOHAMED RM., "Evaluation et cartographie de la vulnérabilité à la pollution de l'aquifère alluvionnaire de la plaine d'El Madher, Nord-Est algérien, selon la méthode DRASTIC", *Science et changement planétaires. Sécheresse,* 2 : 95-101, (2000)

[22]. SINAN M, MASLOUHI R, RAZACK M., "An extension to the DRASTIC model to assess groundwater vulnerability to pollution: application to the Haouz aquifer of Marrakech (Morroco)", *special issue: environment: Survival and Sustainability,* 247-348, (2007)

[23]. MURAT V, MARTEL R, MICHAUD Y, THERRIEN R, "Comparative study of methods for assessing the vulnerability of aquifers to pollution: application to granular aquifers of the Laurentian foothills, Quebec", *AIH-CNC*, 411-418, (2000)