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Assessment of groundwater vulnerability and sensitivity to pollution in Berrechid plain, using drastic model

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Abstract: *The Groundwater protection and management is vital for human evolution, socio-economic development and ecological diversity, because it is one of the most valuable natural resources. Agricultural and industrial activities, more and more intensive and significant population growth, have contributed to the degradation of Berrechid Groundwater quality. The present study aimed to assess the vulnerability of Berrechid aquifer using the DRASTIC models. The application of the methodology developed has needed the establishment of a Geographical Information System synthesizing a considerable mass of data (geological, hydrogeological, geophysical, etc.), constitutes a real tool to aid in the decision for the managers of water resources in the region of Chaouia. The results show that three classes of vulnerability are observed in the study area: the higher drastic indices appear at the areas with low groundwater table depth and the areas which are not protected by the clays, and the areas less vulnerable are located in areas where the water is deeper and the clays recovery is important.*

Keywords*: Groundwater vulnerability / DRASTIC / Berrechid plain.*

I. Introduction

The Berrechid plain extends to the south of Casablanca on an area of 1600 km2. It is at the surface as a pit of subsidence, limited to the south by the limestone of the Cretaceous, and elsewhere by primary formations consisting of shales and quartzites. The land of filling is formed of marine sandstone dune and the Pliocene **[1] (Fig.1),** its main aquifer is located between 5 and 30 m depth **[2].**

This groundwater has an underground hydraulic potential which represents the sole and unique water resource in the region; it is the source of the drinking water supply of a large part of the rural areas of the province and a part of Settat city.

Berrechid City of has known these past fifteen years a development of industrial and agricultural activities with a use of more and more exaggerated chemical fertilizers. To which is added the pressure of Demographic growth. This is reflected by the growing risks of groundwater pollution.

Berrechid groundwater is generally of a very bad quality for the whole of the sampling points. This state of quality is due: to the strong mineralization, elevated chloride and nitrate [**3].**

The prevention of groundwater pollution is an important step, to which scientists must deploy more effort, including the discovery of the groundwater vulnerability.

The main objective of this study is the assessment of the vulnerability of the Aquifer using the DRASTIC model **[4]** and the combination of the data of the hydrogeological layers in the GIS.

Seven parameters are taken into account: the depth of the water, the annual recharge of the Aquifer effective, aquifer lithology, the type of soil, topography, the impact of the unsaturated zone and the hydraulic conductivity of the aquifer.

II. Presentation of the study area

The Berrechid groundwater: Located in the south of the city Casablanca, it is characterized by the importance of its extent around 1500km^2. It fits in the quadrangle formed by the cities of Settat, El Gara, Mediouana and the center of Bousakoura. This groundwater is developed in formations sandstones of age plio-Quaternary, under a silty Coverage with average thickness of 20m. Geologicaly, this plain is composed of sedimentary rocks formed Cretaceous limestone (Cenomanian) with intercalations of clays and marls and sedimentary rocks formed of calcareous sandstone to cemented conglomerates toward the base .The whole is surmounted by a coverage of clayey silts of the quaternary recent. This part of the low Chaouia, receives of the upstream elements of varied erosion from the high Chaouia (Plateau of Settat - Ben Ahmed) from which it is separated by the flexure of Settat **[1]**.

The recharge of the aquifer is mainly done in the marginal areas. The deposits are covered by location of clays whose thickness can reach approximately 50 m; clays that form the more important accumulations of Quaternary deposits offering a natural protection to the Pliocene aquifers. The areas where the thickness of sediment is more low (less than 5 m) or the sectors where the Quaternary deposits are mainly trained of sands would constitute the areas most vulnerable to infiltration of pollutants. **[5]**.

The Berrechid Groundwater is limited: in South and Southeast: by the Settat plateau who plunges in the plain through flexures and defects and forming the bedrock Eocene; in the north-east: the valley of the Oued El Mellah; in the north: the plain of the Chaouia which is the natural extension of plain of Berrechid and to the west and to the north-west by the primary outcrops **(Fig.1),**.

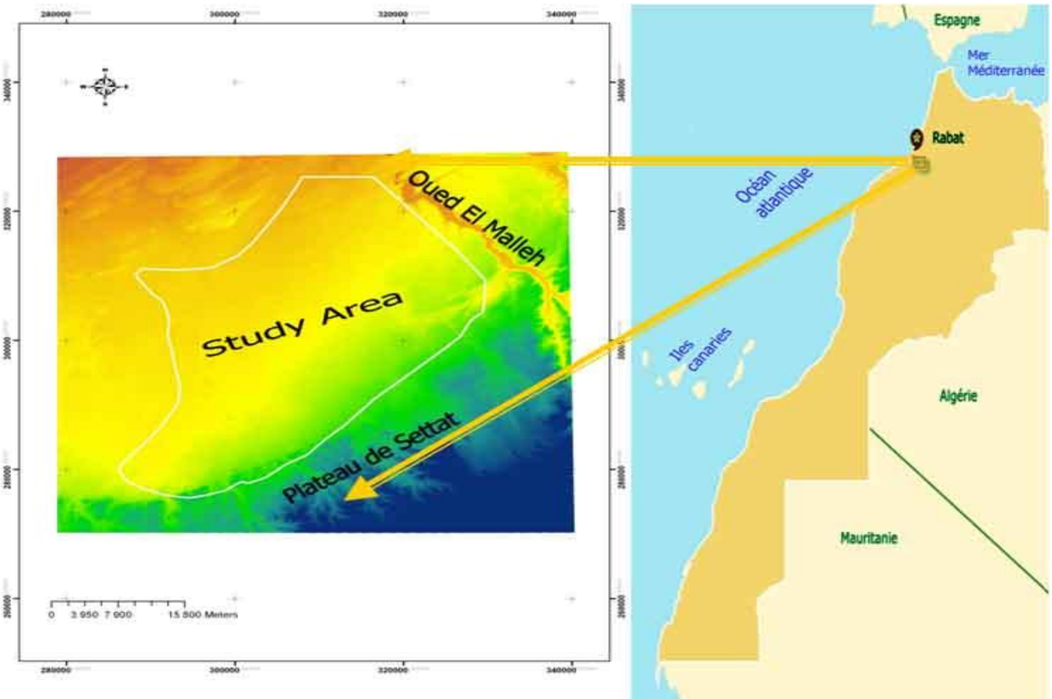

Fig. 1: The study area location

III. Data and Methodology

The DRASTIC model was developed in USA for the purpose of protecting the groundwater resources; it is an empirical groundwater model that estimates groundwater contamination vulnerability of aquifer systems based on the hydrogeological settings of that area **[1]**. The DRASTIC method is based on a weighting and indexing system of parameters **[4],** based on ratings and weights given to the criteria chosen to study, classify and represent in the horizontal plane; the protective role of the interface between water resources of the source of pollution **[6].**

The DRASTIC hydrogeologic vulnerability ranking method uses a set of seven hydrogeologic parameters to classify the vulnerability or pollution potential of an aquifer. The parameters are: **[7]**

- **Depth of groundwater (D):** is subdivided into seven vulnerability classes. More depth to the top of the table, the less the area is vulnerable;
- **Recharge rate (R):** is expressed as depth of water seeped into the water table over a year. It is divided into 5 classes. More charging, the higher the vulnerability is too. The assumption made here is that the importance of charging is a factor aggravating the pollution as it pushes into the system. This assumption does not take into account that most charging is more important pollution is diluted;
- **The Aquifer media (A)** is established according to ten major lithological units as massive limestones, karstified limestone, metamorphic rocks, moraines, sandstone ... Each type of lithology is assigned varying degrees of vulnerability which is defined by the expert according to the reactivity of the aquifer, its fracturing and sorption phenomena which may occur therein;
- **The Soil media (S)** are subdivided into eleven classes according to their composition, their texture and structure. More soils are permeable, more they are considered vulnerable because they promote the infiltration

of pollution. The possibility that the water flows on impermeable soils and contaminants then infiltrating in a concentrated way downstream ,is not considered in this approach;

- **Topography (T)** or more exactly the percentage of slope is divided into five classes. The assumption made here is that more the slope is steeper, more there is infiltration and the area is vulnerable. As for the "soil" parameter, the issue of re-infiltration of water into slope foot area is not addressed. As the issue of soil erosion favored by the slope and transporting fine solids in the resulting aquifer;
- **The Impact of the vadose zone (I)** is divided into eleven classes according to the lithologies within it. As for the criterion "geology of the aquifer rock", each lithology has varying degrees of vulnerability which are defined by the expert based on his knowledge of the system. Generally, lithology wherein the water circulates rapidly is considered more vulnerable than lithology wherein the water flows slowly. This classification does not consider the superposition of different lithologies, such as, for example, the plating on karst moraine;
- **The hydraulic Conductivity of the aquifer (C)** is divided into six different classes. More it is higher, more the medium is considered vulnerable because the mechanisms to mitigate pollution have less time to occur. This criterion is closely related to the geology of the aquifer rock.

Table 1 Drastic parameters assigned weights [4]

Factor	Weight
D Depth to top the of the Aquifer	5
R Net Recharge	4
A Aquifer Media	3
S Soil Media	2
T Topography	1
I Impact of the Vadose Zone	5
C Hydraulic Conductivity of the Aquifer	3

Drastic sensitivity index was computed based on the following formula.

Drastic index =(Dr×Dw)+(Rr×Rw)+(Ar×Aw)+(Sr×Sw)+(Tr×Tw)+(Ir×Iw)+(Cr×Cw) (1)

Where letters indicate the name of the layer, the sub-letter *w* indicates the weight of the layer, sub-letter *r* indicates the ranking number as weighting factor based on sensitivity of parameters.

The vulnerability degree is assessed on the basis of the DRASTIC index classes. The vulnerability is even more important than the calculated index is high**. [8]**

Table 2. (a) Classes and notes used for Depth of water (D); (b) Classes and notes used for net recharge (R); (c) Classes and notes used for aquifer lithology (A); (d) Classes and notes used for soil (S); (e) Classes and notes used for topography (T); (f) Classes and notes used for unsaturated zone (I); (g) Classes and notes used for permeability (C).

Class(m)	Note
0 -1.5	10
1.5 - 4.5	9
4.5 - 9	7
9.0 -15.0	5
15 – 23	3
23 – 30	2
>30	1

(a)

Class(mm)	Note
0 – 50	1
50 - 100	3
100 – 175	6
175 - 225	8
>225	9

(b)

Class	Typical Note
Massive shale	2
Metamorphic	3
Metamorphic altered-Sandstone	6
Limestone massive	8
Sandstone	6
Sand and gravel	8
Basalt	9
Limestone	10
(c)	

Class	Note
Thin or absent	10
Gravel	10
Sands	9
Sandy loam	6
Silts	4
Silty loam	3
Clays	1
(d)	

Range of slope (in degrees)	Note
0 - 2	10
2 – 6	9
6 – 12	5
12 – 18	3
> 18	1
(e)	

Lithological Nature	Typical Note
Silt and clay	3
Shale	3
Limestone	3
Sandstone	6
Sand and gravel with silt and clay pass	6
Sand and gravel	8
Basalt	9
Limestone karst	10
(f)	

Range of permeability (m/s)	Note
$1.5*10^{-7} – 5*10^{-5}$	1
$5*10^{-5} – 15*10^{-5}$	2
$15*10^{-5} – 33*10^{-5}$	4
$33*10^{-5} – 5*10^{-4}$	6
$5*10^{-4} – 9.5*10^{-4}$	8
$>9.5*10^{-4}$	10

IV. Results and Discussions

a. Drastic settings and the aquifer vulnerability

- **Depth of groundwater (D):** has been developed by the interpolation of data on the water level **[9].** The interpolation is performed by the ordinary kriging method **(Fig. 2a).**
- **Recharge rate:** The values of this parameter are acquired by the application of the Thiessen polygons on the data of effective rainfall **(Fig. 2b).**
- **The Aquifer media:** The development of the matrix Card “aquifer media” has been based, essentially, on the interpretation and the correlation between drilling in the study area **(Fig. 2c).**
- **The Soil media**: The study area map “Soil media” has been developed by the digitalisation of the card national soil, conducted by the Department of Agriculture and the Agricultural Development. This map shows a dominance of Clay textures and loam-Clay **(Fig. 2d).**
- **Topography**: The matrix slope map is carried out from the digital model of terrain SRTM (Ftp://e0srp01u.ecs.nasa.gov) **(Fig. 2e).**
- **The Impact of the vadose zone**: The evaluation process of the impact parameter of the vadose zone is based on the interpretation of the lithological drilling slices. The correlation shows that the unsaturated zone is constituted essentially by the clayey facies , sand and gravel **(Fig. 2F).**
- **The hydraulic Conductivity of the aquifer**: This card has been developed by the digitalisation of the hydraulic conductivity map of (ABHBC, 20012) **(Fig. 2g).**

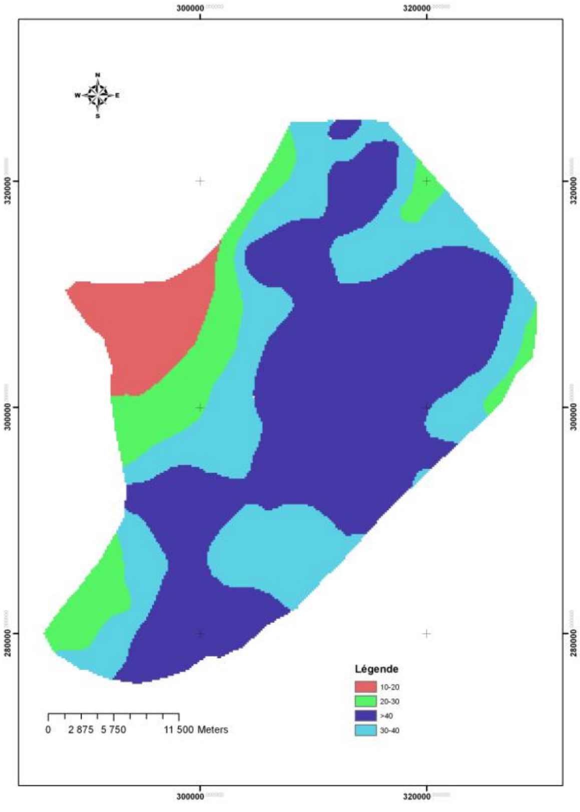

Fig. 2a : Map of groundwater depth (D)

Fig. 2b: Map of groundwater net recharge (R).

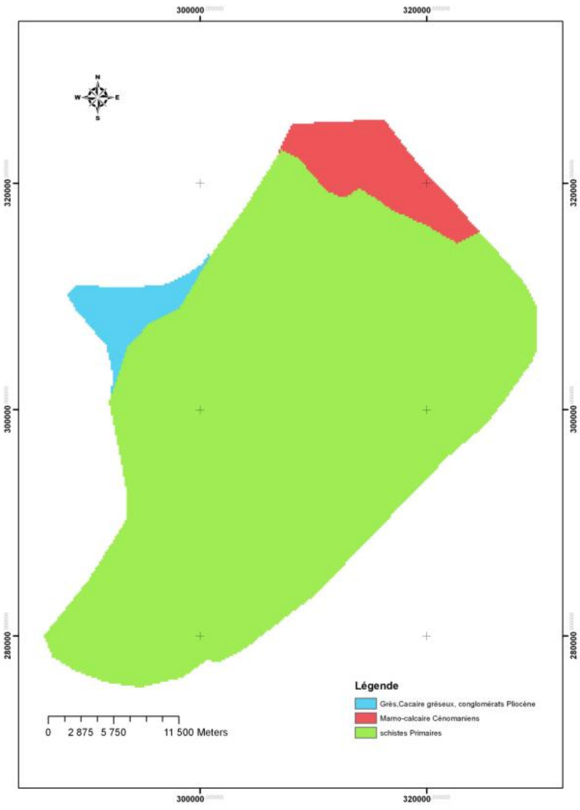

Fig. 2c: Map of aquifer lithology (A).

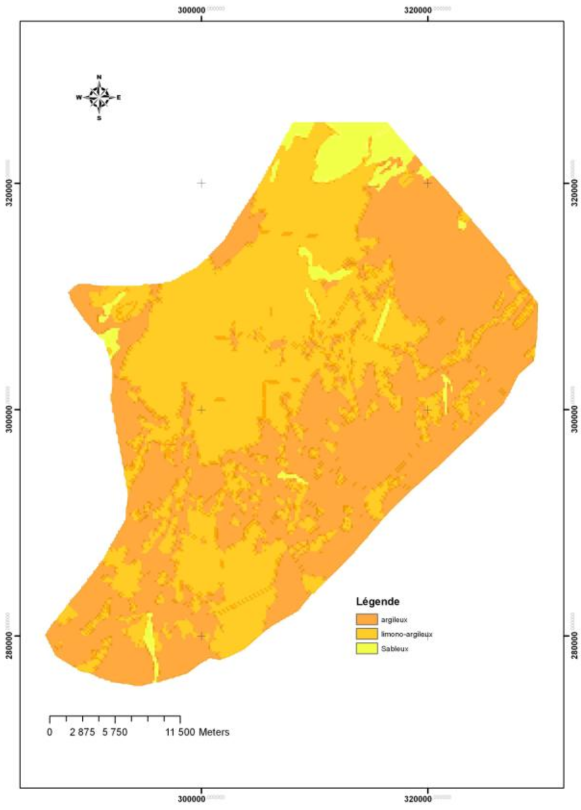

Fig. 2d : Map of groundwater pedology (S)

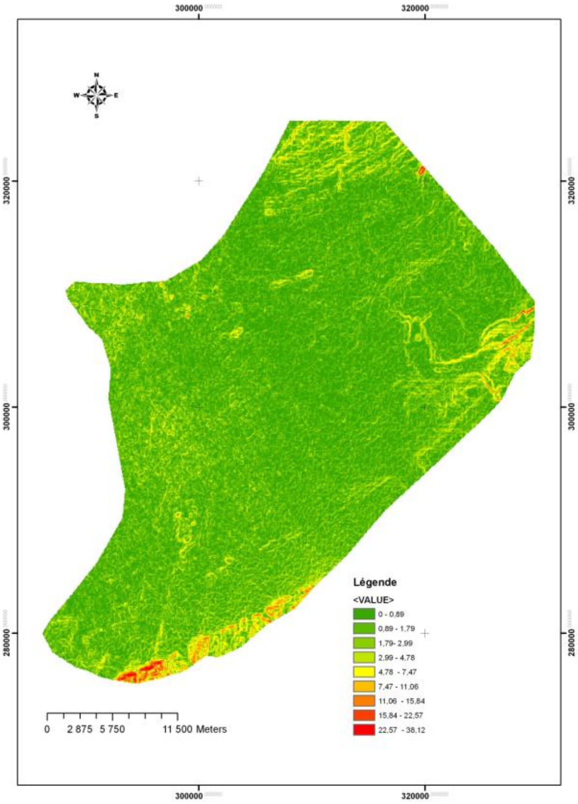

Fig. 2e: Map of aquifer topography (T).

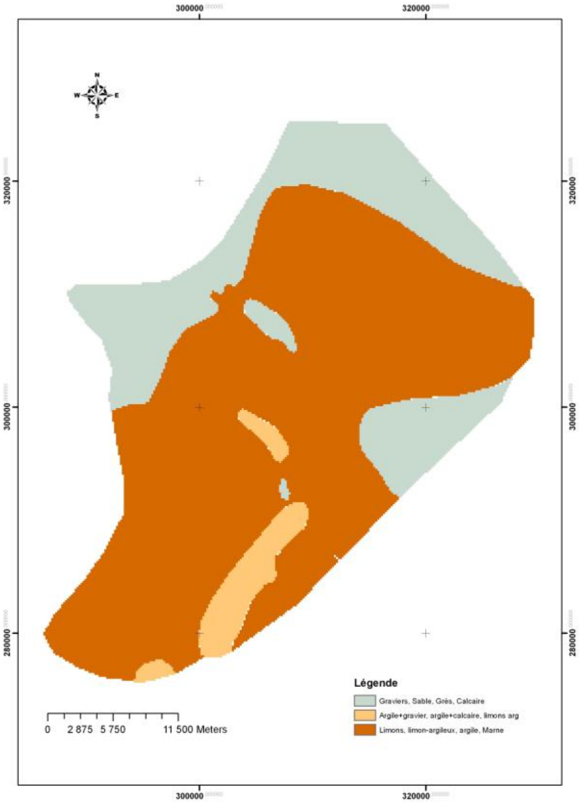

Fig. 2f: Map of groundwater unsaturated zone (I).

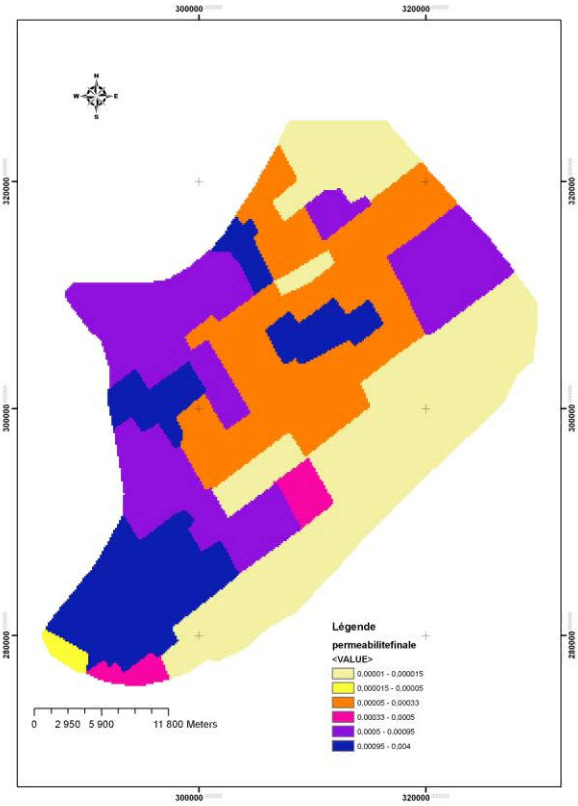

Fig. 2g: Map of ground water permeability (C).

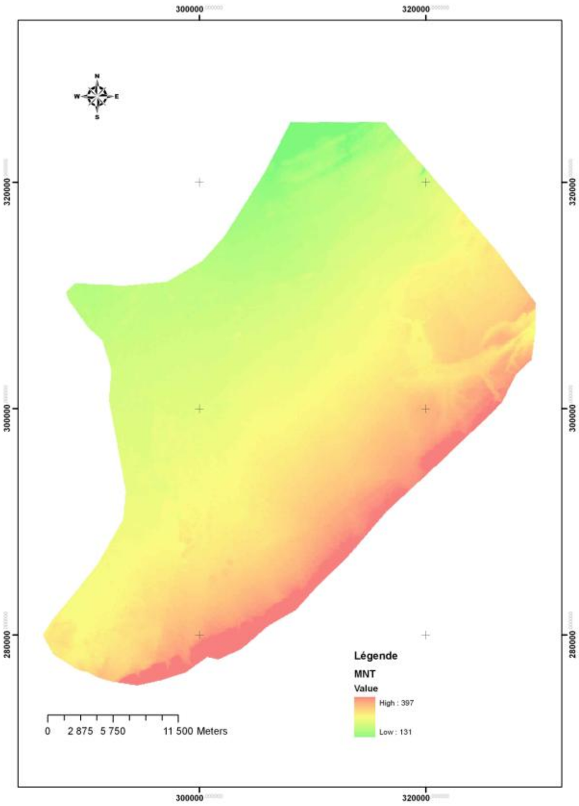

Fig. 2h : MNT of the study area

Fig 2: Maps used for the development of the vulnerability map (drastic).

All the maps of the figure 2 are classified; depending on the rating system of the DRASTIC method (Table 2). The figure 3 represents the classified maps.

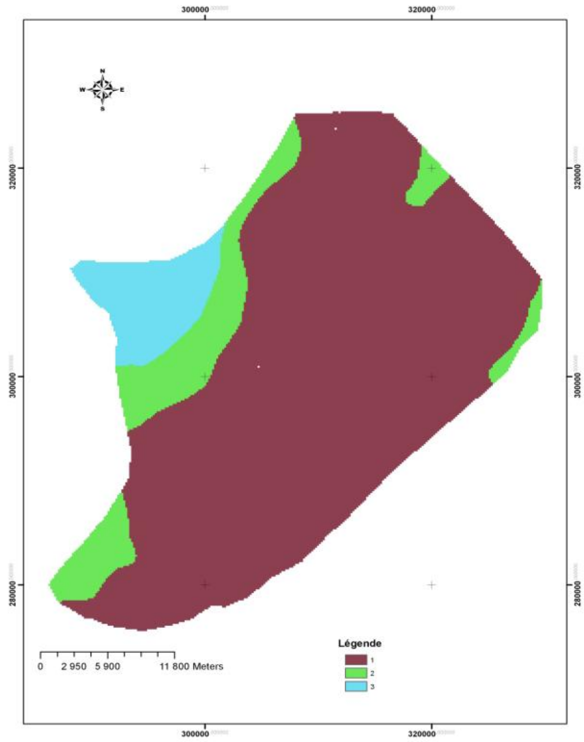

Fig. 3a : Map of groundwater depth after reclass

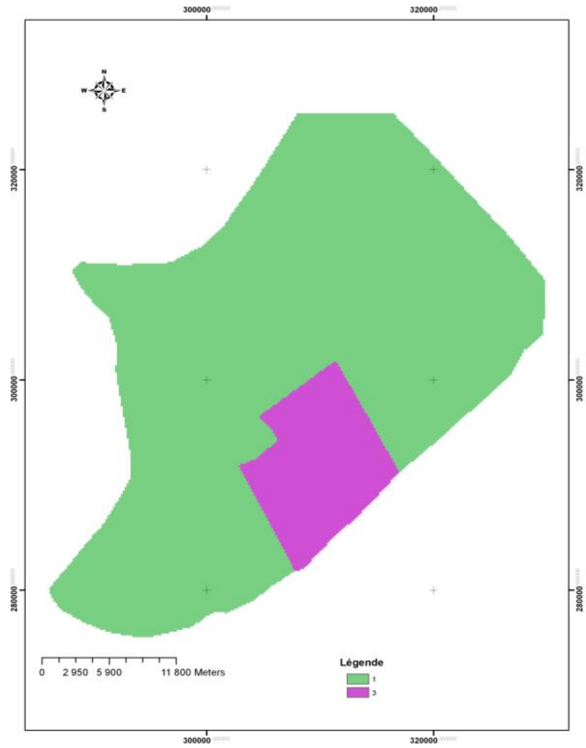

Fig. 3b: Map of groundwater net recharge after reclass.

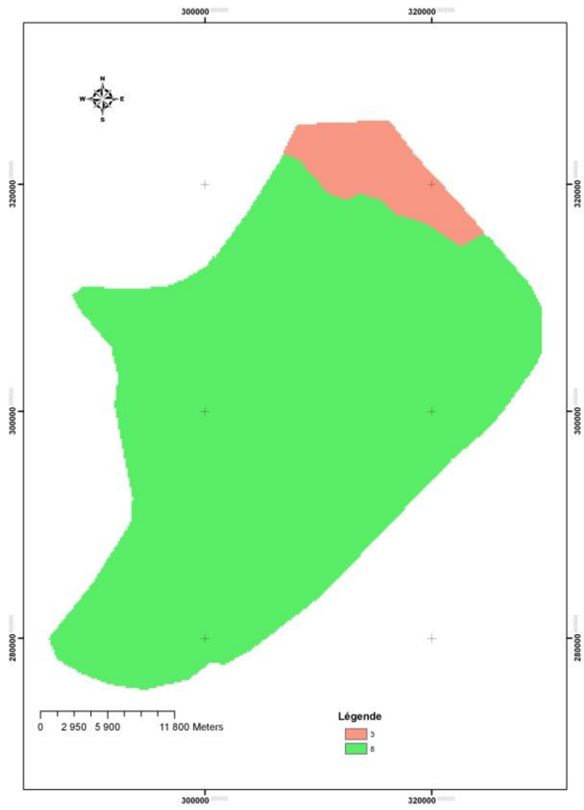

Fig. 3c: Map of aquifer lithology after reclass.

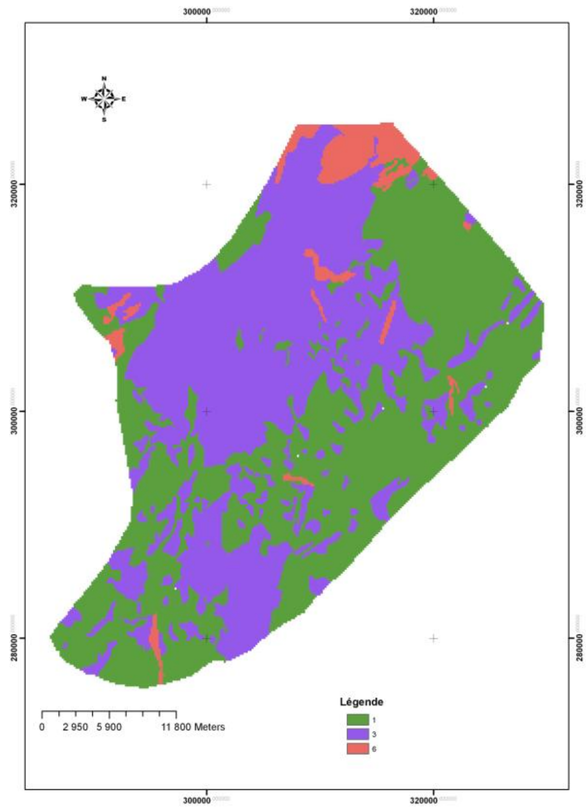

Fig. 3d: Map of groundwater pedology after reclass.

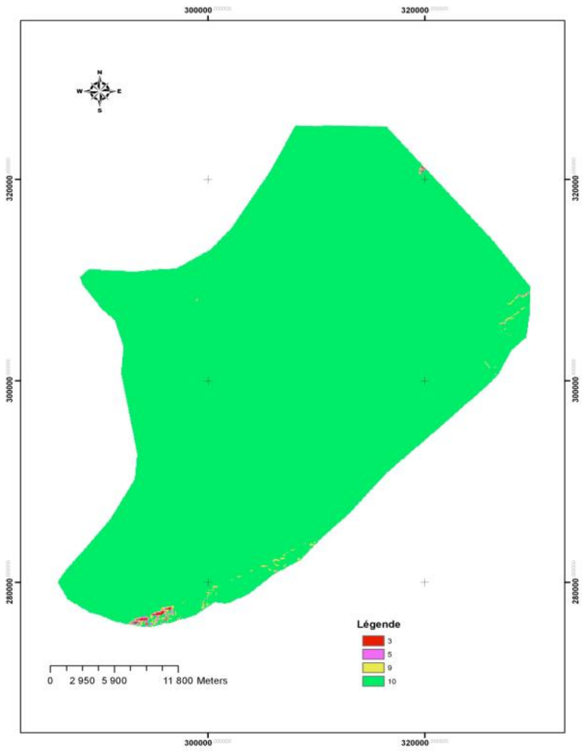

Fig. 3 e : Map of aquifer topography after reclass

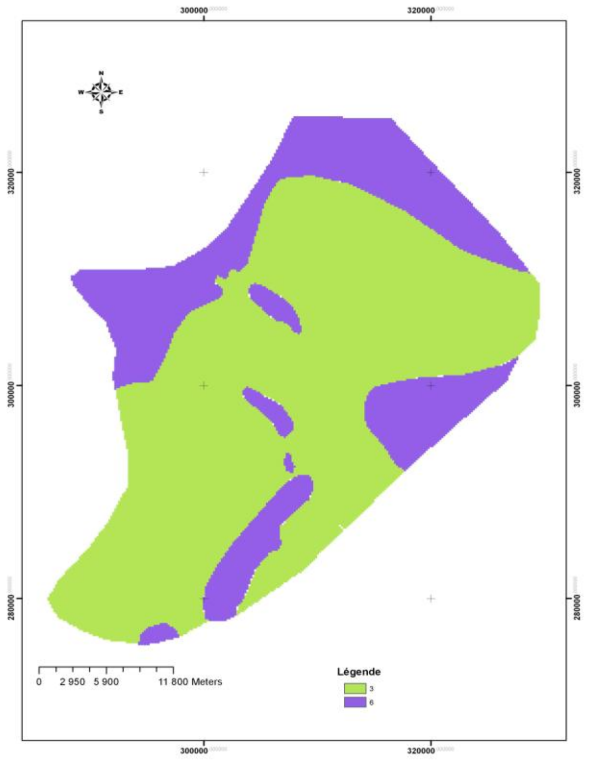

Fig. 3f : Map of groundwater unsaturated zone after reclass

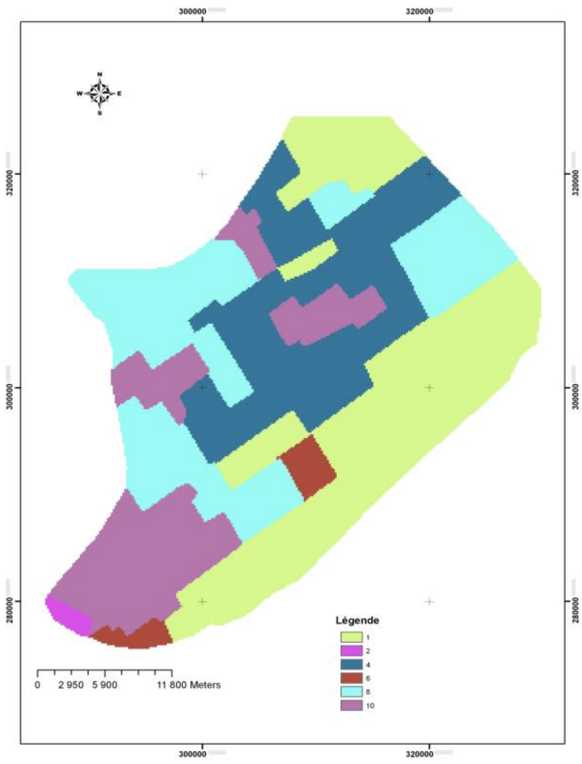

Fig. 3g: Map of ground water permeability after reclass

Fig 3: Maps used for the development of the vulnerability map (drastic) after reclass.

The vulnerability map of Berrechid plain (Drastic) thus obtained by the Formula 1 is the following **(Fig. 4)**

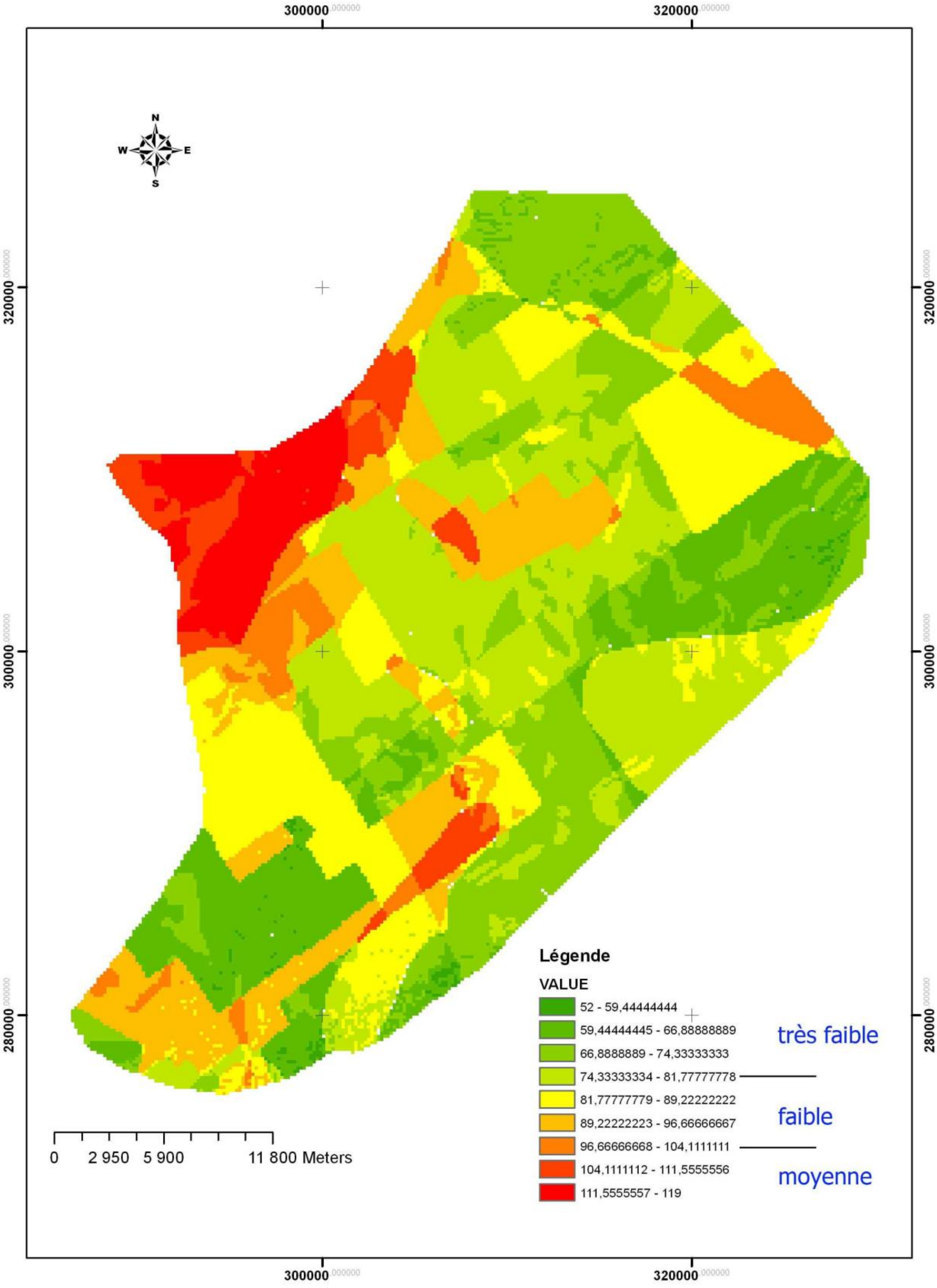

Fig. 4: Map of vulnerability of Berrechid groundwater (DRASTIC)

Any vulnerability map developed is tested and validated by the measurement and analysis of chemical data of groundwater [10 -12].

The validity of the vulnerability assessment to pollution by drastic methods in the case of this study has been tested by the pollution by nitrates in the water. So we compare the distribution of nitrate in groundwater and the distribution of vulnerability classes. The Figure 5 shows the map of the nitrate distribution in Berrechid groundwater [9]

We note that the area NW with high drastic index shows elevated levels of nitrates.

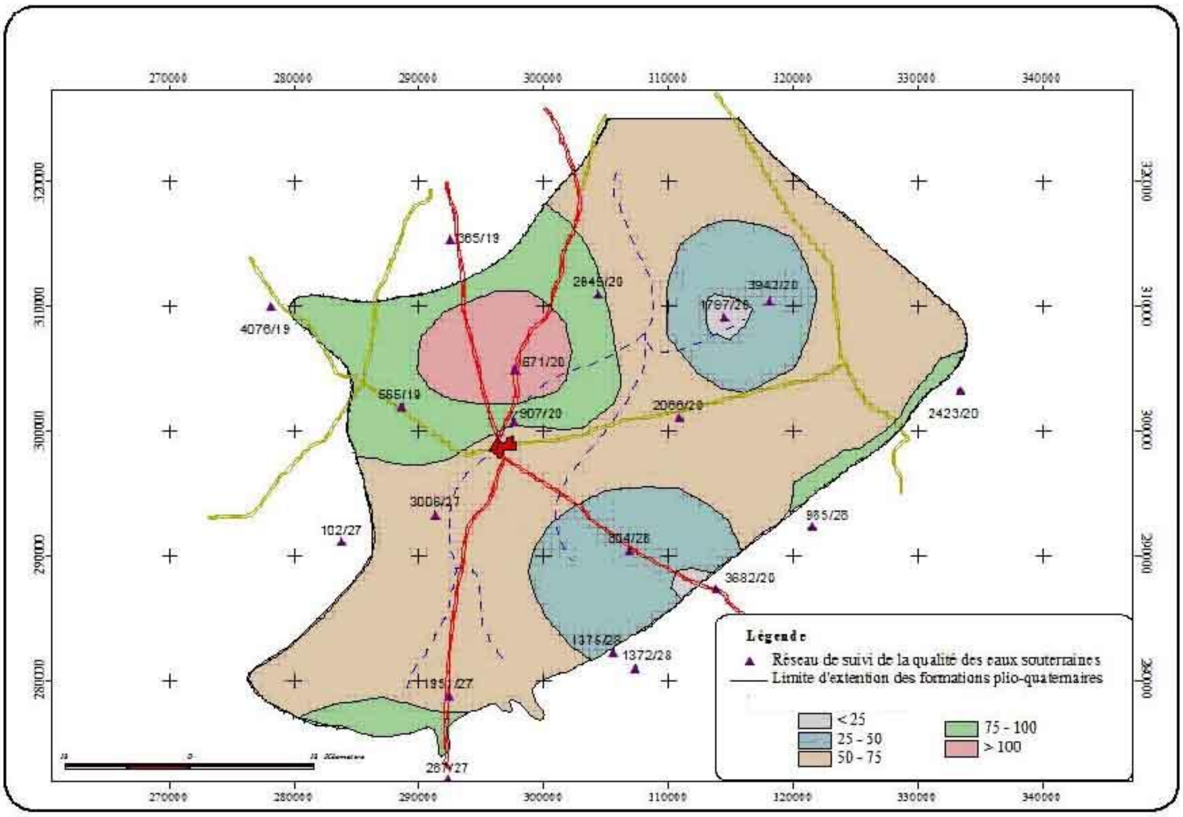

Fig. 5 Map of distribution of nitrates in Berrechid groundwater (ABHCB)

The analysis of the drastic card allows you to distinguish 3 classes of vulnerabilities: very low, low and average.

The spatial distribution of vulnerability classes of Berrechid groundwater is generally low to medium vulnerability with a drastic index between 52 and 119.

The highest drastic indices are located mainly in areas n and NW of Berrechid city. These areas are characterized by low slopes, low depth of the Plan of water and the nature of the rock formations permeable.

While the areas with vulnerability very low occupy the borders NE and E of the study area. These areas are characterized by a low permeability and the nature lithological little permeable “clay”, offering to the aquifer a natural protection.

b. Sensitivity of the drastic Model

Table 3 shows the summary data statistics of the seven parameters used to calculate the index drastic in the Berrechid plain. The analysis of the medium sized shows that the greatest risk of groundwater contamination of the plain of Berrechid is favored by the parameters "**topography**, **Aquifer media and hydraulic conductivity**" (whose averages are respectively: 9.87, 7.64 and 5.04). However the parameters "**unsaturated zone and soil**" participates with a moderate risk (averages is 3.89 and 2.14), and the parameters **Depth of groundwater and** recharge promotes a low risk (medium: 1.27 and 1.24).

The coefficient of variation shows that the great contribution to variations in the index of vulnerability is due to the parameter "**hydraulic conductivity**" (CV: 68.45%). The parameters **"soil, unsaturated zone, recharge, depth of the groundwater and unsaturated zone"** show an average contribution (CV: 60.28%, 52.42%, 45.67% and 35.22%) however **the aquifer and topography** represent a contribution to the variation of the index of vulnerability medium to low (CV: 16.75 and 5.98).

Table 3. The summary statistics of drastic parameters

	D	***R***	***A***	***S***	***T***	***I***	***C***
Min	***1***	***1***	***3***	***1***	***3***	***3***	***1***
Max	***3***	***3***	***8***	***6***	***10***	***6***	***10***
Moy	***1,27***	***1,24***	***7,64***	***2,14***	***9,87***	***3,89***	***5,04***
SD	***0,58***	***0,65***	***1,28***	***1,29***	***0,59***	***1,37***	***3,45***
CV	***45,67***	***52,42***	***16,75***	***60,28***	***5,98***	***35,22***	***68,45***

V. Conclusion

In this study, we have attempted to assess the vulnerability of the ribbon cable for Berrechid and to identify and classify the vulnerable and the areas not vulnerable to contamination of groundwater in order to provide the zoning in the protection of the groundwater table and the implementation of effective strategies for the management of groundwater. We used for this objective, the GIS through the DRASTIC method. In effect, the SIG has provided an effective environment for analyzes and a strong capacity of handling of large quantities of spatial data. The Seven Parameters of the model have been built, classified and coded using the GIS tool and its features. The vulnerability index was easily calculated. The Berrechid groundwater is polluted with high values of nitrates due to several phenomena: the discharge of solid and liquid wastes of the industry, domestic, and also by the use of large quantities of fertilizers in agriculture. This study has produced a very important tool for the management and development, because it gives full details on the vulnerability of groundwater, it is now high time that the stakeholders in the water sector, the environment and the local authorities, use this approach to the vulnerability as a tool to aid decision making, and reflect on solutions and facilities promoting a sustainable protection of this resource.

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