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AQUIFER SUCEPTIBILITY AND AGRICULTURAL ACTIVITIES EFFECT ON WATER QUALITY IN SEMIARID ZONE: EL MA LABIOD PLAIN, NORTH EAST OF ALGERIA

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Abstract: *For more than three decades, many agrarian systems have been intensified in an attempt to reduce the widening gap in food deprivation. The concern to feed the population has meant that the consequences have not been well studied, especially the degradation of groundwater, which was not yet among the issues discussed in developing countries.*
The study of piezometric measurements shows that the groundwater level of the plain of El Ma Labiod decreases on average by one meter per year. The chemical analysis shows that few of the 40 representative water points sampled, in the study area, exceed drinking water standards for nitrate and chloride concentrations, making 5 wells unsuitable for drinking water production and 8 others unfit for human consumption without prior treatment. It was found that Nitrate was the main component that degrades the quality of groundwater.
The application of the DRASTIC and GOD methods to estimate the susceptibility of aquifers has made it possible to highlight three classes of vulnerability from very low to moderate.
The mapped results using GIS data and ArcGis tools show a large similarity in the spatial distribution of vulnerability classes and the alteration of water quality. The purpose of this study is to take stock of the state of groundwater and create a basic document for decision-making to ensure healthy environment development in the study area.

Keywords: *El Ma Labiod, groundwater vulnerability, DRASTIC, GOD, Arcgis, Water quality SEQ-Eau.*

1. Introduction

Food needs are the main factor which induces the extension and intensification of agricultural practices; intensification which is done by providing enough water for irrigation and non-organic nitrogen fertilizers and pesticides. Following a spread, the fraction of pesticides and fertilizers that reaches the ground contaminates the groundwater with water infiltration [1]. Contamination is defined as the presence of something harmful in food or drink that creates a risk of illness, injury or discomfort [1].

The increasing urbanization, Industrialization, agriculture and climate change make the quantity and quality of water available rapidly diminishing [2]. Indeed, in the semiarid zone, where surface water is very insufficient, if not null, the irrigation water and all other needs are withdrawn from a groundwater reducing its reserves by overexploitation.

This contributes, in the long term, to the depletion of the water resource [3] so the knowledge of regional hydrogeological circumstances [4] becomes a priority.

Phosphorus and nitrogen-based pollutants are a persistent problem of surface and groundwater pollution in rural and urban environments, from point and diffuse sources. Diffuse sources are mainly of agricultural origin [5]. All groundwater is vulnerable! [6]. Therefore, agricultural system must be continually evaluated and corrected during this transitional period which lasts.

The compromise "food production - environmental impact" must not trample health standards, especially those relating to the air near homes or to water intended for human and animal consumption.

Drinking water becomes increasingly scarce under inefficient management in a semiarid environment [7], thus it is imperative to protect the public health by ensuring water and its housing environment safety [8]. The awareness of the vitality of this resource imposes some precautionary measures the first of which is the evaluation of the current quality of groundwater and the vulnerability of the aquifer. This study was undertaken due to the lack of recent studies on the effects of strengthening agricultural practices on the quality and quantity of groundwater in the study area. The last study dates from 2006 [9]. The Algerian legislation concerning the standards of drinking water is, apart from a few elements, very close to the lists of those issued by the WHO [10, 11].

The aim of this paper is to check the water quality, applying the “SEQ-Eau” (Water quality assessment system) to 40 representative sampled wells in the studied area and to compare its spatial distribution with the vulnerability map of the aquifer under El Ma Labiod plain.

Groundwater vulnerability maps are expected to draw the attention of land-use planners and decision-makers to the effects to groundwater of human activities on the soil [12] and allow the district to readily assess potential groundwater quality impacts of future changes in land use [13].

The analysis of groundwater is centered on its components, as they are the main indicators of the social and environmental problems [14] and the aquifer vulnerability assessed by two intrinsic overlaid methods is mapped using ArcGis tools in GIS environment.

2. Matherials and methods

2.1 Presentation of the study area: El Ma Labiod plain is situated at 15 kilometers south of Tebessa-town in the Northeast of Algeria. It is limited by the parallels 35°05’ and 35°25’ north and by meridians 7°57’ and 8°25’ east (Figure1). The studied watershed covers 582.33 square kilometers. The elevation from sea level goes from 1650 m in the North West (Dj. Doukane) to 980 m at the outlet. The plain presents an average slope of 3%. It has a semiarid climate and an enough developed drainage which streams feed the big watershed of Melghigh which concentrates southward. The studied zone is an unconfined covered aquifer in a negative form with a Miocene filling of sand and clayey sandstone in abnormal contact with a Cretaceous border. The alluvial deposit thickness varies from 0 to 10 meters [9]. The Geo-electric study titled “Geophysical prospecting of the El Ma Labiod basin” carried out by UGF BRNO (geophysical and drilling unit, non-destructive reconnaissance office) in 1971 for the State Secretariat of Hydraulics. (Unpublished report). Geophysical Unit, archives of

ANRH Tebessa, shows two pairs of faults which limit the aquifer area in the plain.
The lithology and the structural built share the plain in water-bearing and non-water-bearing zones and give the watershed varied hydrogeological characteristics.

With almost 400 wells and drillings the wound is exploited in more than 25 Million of cubic meters per year [15]. The aquifer of El Ma Labiod provides the sole resource to cover all water needs (drinking, industrial and irrigation) for more than 70% of the population of Tebessa region.

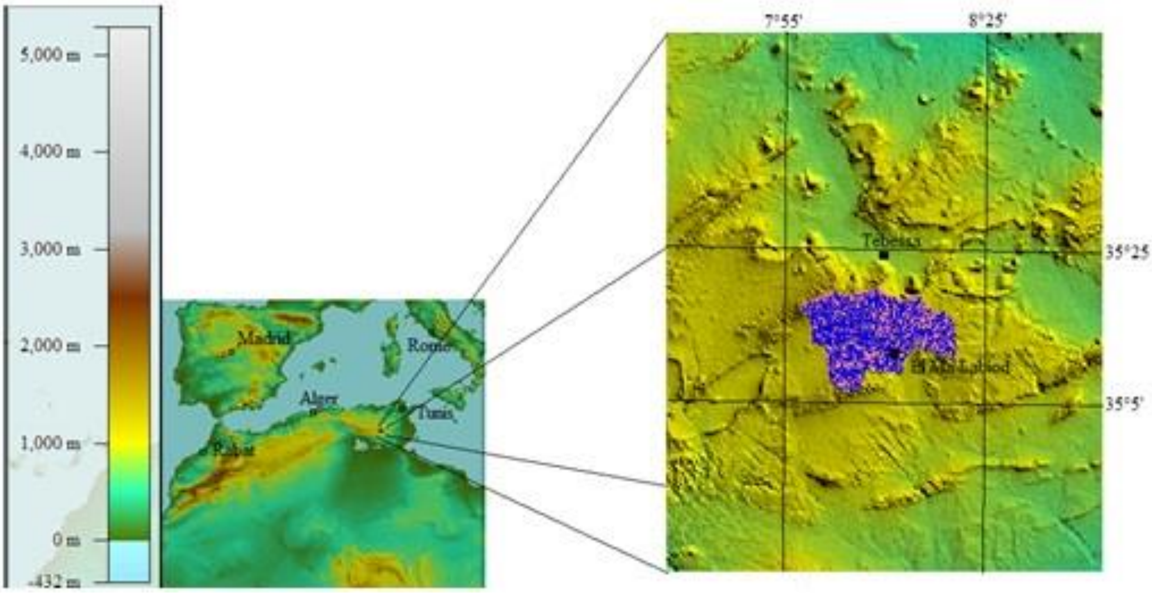

Fig.1 Geographic setting of study area

The plain of El Ma Labiod presents a negative water balance despite the reported contributions from the karstified limestone of the North East and South West limits as in [9] confirmed by Boughanem M. In his Master work (2011). Referring to data from the last three decades, the piezometric level decreases, in the study area, with an average of 1m per year.

2.2. Aquifer vulnerability assessment: Both of used methods; DRASTIC [16], [17], [13] and [18] and GOD [10], [19], [20] and [21] have been widely applied around the world and became notorious.
The requested parameters for the DRASTIC method and the GOD method, their sources, their mode of acquisition, the formulas to calculate the vulnerability indexes and their mapping modes are summarized in the respective operating diagrams Figure 2 and Figure 3.

2.2.1. DRASTIC method: DRASTIC is the acronym formed by the initials of the seven parameters required by the method [16]:
"D" for depth to water table,
"R" for net recharge,
"A" for aquifer media,
"S" for soil media,
"T" for topography,
"I" for the impact of unsaturated zone and
"C" for hydraulic conductivity.
The DRASTIC Groundwater Vulnerability Index (Drastic GVI) is obtained by summing the parameters as following:

$$\text{Drastic GVI} = D_r.D_w + R_r.R_w + A_r.A_w + S_r.S_w + T_r.T_w + I_r.I_w + C_r.C_w$$

or:

$$\text{Drastic GVI} = \sum(i_r i_w) \quad (1)$$

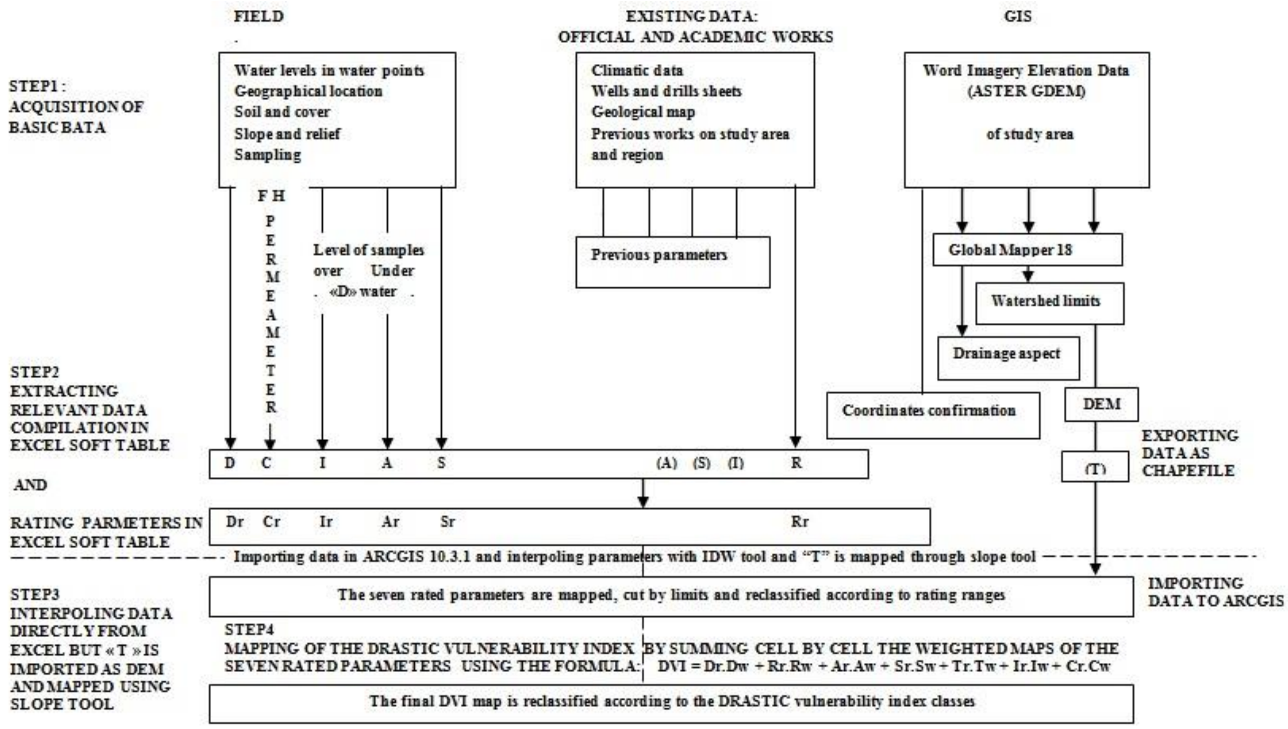

Fig.2 The operating diagram of DRASTIC method

Where: "i" ϵ {D, R, A, S, T, I, C} the seven parameters.

"i_r" and "i_W" are respectively the rated and the weighted parameters in each measured area, the first evaluates the state of the parameter on a scale of 1 to 10 and the second represents the weight assigned by the authors to each parameter according to its importance in the Drastic GVI formula (1).

2.2.1. GOD method: GOD is the acronym formed by the initials of the three required parameters [19]; [20]:

"G" for Groundwater occurrence,

"O" for Overall lithology; aquiperm – aquitard and

"D" for Depth to water table.

The GOD Vulnerability index (GOD GVI), is obtained by multiplying the three parameters between them as in formula (2) [19].

$$\text{GOD GVI} = cG \,.\, cO \,.\, cD \quad (2)$$

Where: cG, cO and cD are the respective rates assigned to parameters G, O and D. Its map is shown in figure 7B.

2.3. **Data acquisition:** Each datum was acquired at its source:

The depth to the water table "D" was directly measured with a piezometric probe.

The net recharge "R" was calculated applying the formula (3) of Tixeront - Berkaloff [9] in Thornthwaite's water balance for four decades (1975 to 2015):

$$R = P - ETR - \frac{P^3}{3.(ETP)^2} \quad (3)$$

With:

-R as a net recharge,

-P as precipitation,

-ETP as a potential evaporation-transpiration and

-ETR as a real evaporation-transpiration.

The saturated media and unsaturated aquifer media "A" and "I" were evaluated applying authors' tables [16] according to their lithology using logs of wells and drills from archives of National Agency of Hydraulic Resources (ANRH) and Water

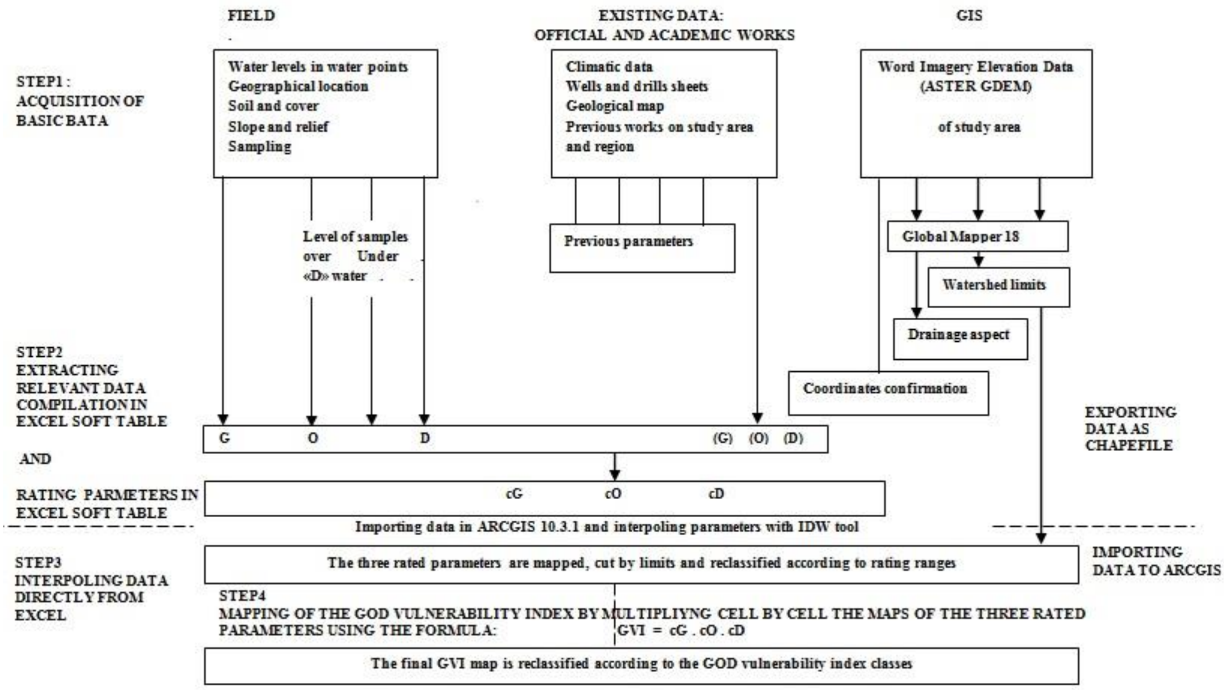

Fig.3 The operating diagram of GOD method

Direction of Wilaya (DEW) and geoelectric data from ANRH archives.

The soil media "S" was directly evaluated, supported by land use scheme obtained from the local subdivision of agriculture.

The slope (Topography) "T" map was prepared with Arcgis using a global mapper-v18 exported shape file of an STRM GDEM V2 worldwide elevation data (1 arc-second resolution).

The hydraulic conductivity "C" was determinate through a falling head permeameter [22] with 12 samples of materials extracted during new drilling and from other representative points applying the formula (4):

$$C = 2{,}3al\,\frac{\log(h0/h1)}{A.t1} \qquad (4)$$

Where:

-*T1* is the necessary time that water goes from level "*h0*" to "*h1*" in the tube with diameter "*a*" through the cylinder with "*A*" diameter and "*l*" thickness.

The coordinates of the water points were determined by Garmin "nuvi" personal GPS, and confirmed by an imagery world satellite image downloaded through "popular sources" then reported on a map at 1/50.000.

2.3.1 The DRASTIC GVI assessment:

The six parameters D, R, A, S, I and C: The collected data compiled under excel, were rated and weighted [16], then interpolated and cut through the study area limits by ArcGis tools in 2D analysis. (Figures: 4A, 4B, 4C, 4D, 4F and 4G.).

The "T" slope map (Figure 4E) was directly drawn by the "slope" function in 3D analysis of Arc map using the TIN created with Global mapper v. 18 tools.

Table 1 shows the DRASTIC parameters ranges in field their rates and weights.

The limits of the study area, data required to download image and elevation data map, were extracted from the topographic map of El Ma Labiod sheet n° 235.

The DRASTIC vulnerability index map was obtained by applying the formula (1) with maps of rated parameters as shown in formula (5):

$$\text{mDRASTIC GVI} = 5\text{mDr} + 4\text{mRr} + 3\text{mAr} + 2\text{mSr} + 1\text{mTr} + 4\text{mIr} + 3\text{mCr} \quad (5)$$

Where: m is used for mapped item.

Table 1 The rated and weighted parameters of the DRASTIC method.

Parameter	State and measures	Rates	Weighted rates
Depth “D”	18 – 30,5m and d >30,5 m	1 – 3 and 6	5 to 15 and 30
Net Recharge “R”	10 mm/y	1	4
Aquifer media “A”	Sand, gravel, clayey sandstone, marl and limestone	3 to 10	9 to 30
Soil media “S”	Thin, sand, gravel and clayey	7 to 10	14 to 20
Slope “T”	0 - 18%	3 to 10	3 to 10
Vadose Zone media “I”	Sand, gravel, clayey sandstone, marl and limestone	7 to 10	28 to 40
Hydraulic Conductivity “C”	(0.13 and 65) $*10^{-5}$ m/s	1 to 6	3 to 24

The seven maps were summed cell-by-cell [16] using the “Raster calculator” of "map algebra” in “spatial analyst tools” of ArcGis 10.3.1. (Figure 2).

The table 2 shows the ranges for the DRASTIC vulnerability index classification [23].

Table 2 DRASTIC vulnerability index ranges for classification

Value	0 – 75	75 – 100	100 - 125	125 – 150	150 – 204
State	Very low	Low	Medium	High	Very high

2.3.2- The GOD GVI assessment: Table 3 shows the ranges of classification for the groundwater vulnerability index assessed by GOD method [19].

Table 3 The rated parameters of GOD method

Parameter	Rate ranges	State	Rated	Process
(G)groundwater occurrence	0 – 1	Unconfined (covered)	0.6 – 1	Field and well logs
(O) Overall lithology	0.4 to 1	Sands, gravel, Sandstones and limestone	0.5 – 0.7	Well logs and geophysics sheets
(D) Depth to water table	0.4 to 1	28,6 m – 82,8 m	0.5 – 0.6	Piezometric probe

The GOD GVI map was produced by similarity to the DRASTIC GVI map using the formula (6) as shown in Figure 3:

$$(\text{GVI})\text{map} = \text{mcG} * \text{mcO} * \text{mcD} \quad (6)$$

Where: m is used for mapped item.

Table 4 shows the classification ranges of GOD GVI [19].

Water quality assessment: The SEQ-Eau system (Water quality standards for natural water bodies) used to estimate the quality of groundwater in the plain of El Ma Labiod (groundwater quality assessment system) Adopted by ABH (Hydrographic Basin Agency) for the Constantine region, Seybousse and Mellègue [24].

Table 4 GOD vulnerability index ranges classification.

Value	0	0 - 0.1	0.1 - 0.3	0.3 - 0.5	0.5 - 0.7	0.7 – 1.0
State	None	Negligible	Low	Moderate	High	Extreme

Table 5 shows the ranges for eachparameter for classification of water quality according to SEQ-Eau ABH (Constantineregion- Seybousse- Mellegue).

Table 5 The parameters and classes of SEQ-eau

Deterioration by Mineralization:					
Parameters	Unit				
Conductivity	µS/cm	[180 – 400]	] 400 – 2500]	<180 or]2500 – 4000]	>4000
Chlorides	mg/l	<25	200	/	>200
Sulfates	mg/l	<25	250	/	>250
Deterioration by nitrogenous materials except Nitrates:					
Parameters	Unit				
Ammonium	mg/l	<0,05	0,5	4	>4
Nitrites	mg/l	<0,05	0,1	0,7	>0,7
Deterioration by Nitrates:					
Parameters	Unit				
Nitrates	mg/l	<25	50	100	>100

Legend

Color	Meaning
	Safe water : don't need any treatment
	Drinkable but would be better if treated
	Not drinkable without treatment
	Unfit for human drink even after treatment

3. Results and discussion

3.1. DRASTIC Parameters maps: The seven maps induced by the seven rated and weighted parameters are shown in Figure 4.

Figure 5 shows the histogram of GOD and DRASTIC GVI class areas in km^2 through the studied watershed and figure 6 shows the areal rates (%) of GVI classes referred to the plain area (Watershed without mountains area) and to the aquifer area (Plain without aquitard area).

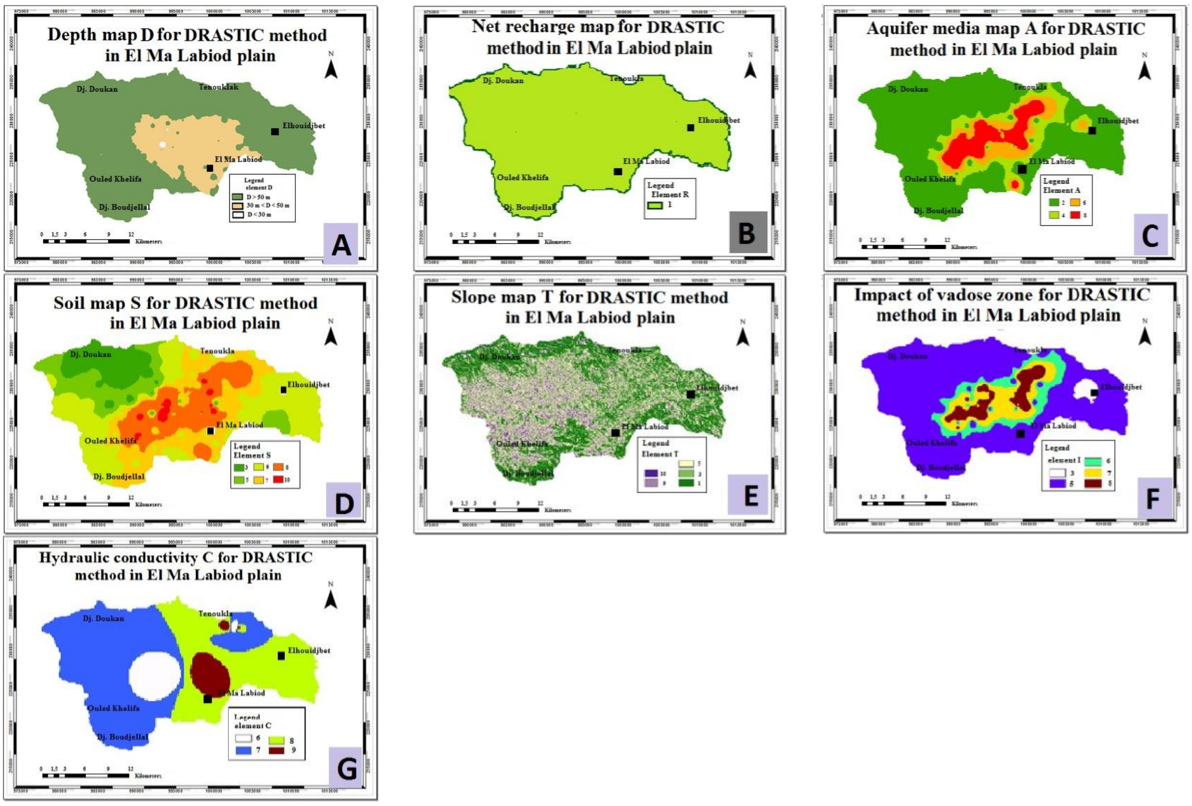

Fig.4 Maps of the seven parameters overlaid classes in El Ma Labiod plain:

A – Depth map "D" for DRASTIC method. B – Net Recharge map "R" for DRASTIC method. C – Aquifer medium map "A" for DRASTIC method. D – Soil map "S" for DRASTIC method. E – Slope map "T" for DRASTIC method. F – Impact of vadose zone "I" for DRASTIC method. G – Hydraulic conductivity map "C" for DRASTIC method.

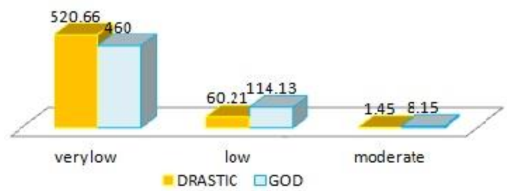

Fig.5 The areas of GVI classes in the studied watershed in km^2.

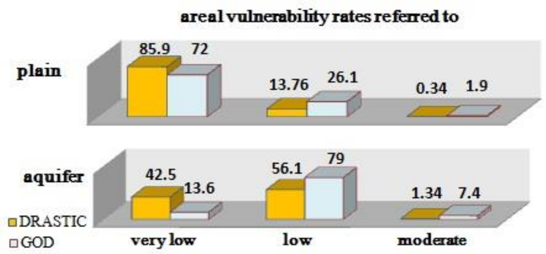

Fig.6 The areal rates (%) of GVI classes referred to the plain area and to the aquifer area.

3.2. DRASTIC GVI map: The DRASTIC groundwater vulnerability index, which ranges from 28 to 124 highlights three levels of susceptibility:

- Referring to the studied zone, it shares the plain of El Ma Labiod in very low vulnerability 85,9%, low vulnerability 13,76%, and medium vulnerability 0,34%. Its map is shown in Figure 7A.

-Referring to the aquifer area, the low vulnerability class covers 56% around the central axe of exploited part of the plain, and the moderate one covers 1.34% in two little areas. The eastern one is probably due to the high value of "C" induced by the longtime of over pumping and the relatively low value of the depth to the water table.

3.3. GOD GVI map: The GOD vulnerability index ranges from 0 to 0.43, and highlights three levels of suscep-tibility. It divides the plain of El Ma

Labiod as follows: none to negligible vulnerability 72%, low vulnerability 26.1% and moderate vulnerability 1.9%. Its map is shown in Figure 7B.

Referring to the of aquifer area, the low vulnerability range occupies practically the complete aquifer area with 1.3% of the very low class and 7.6% for the moderate one with two little areas at the north which don't rise in DRASTIC GVI map. These are situated in non-covered sand dunes with clean sand. The extend areas are so large because the range of parameter D (0 to 100 m) which covers all measured water points.

3.4. Water quality: Table 6 shows the distribution (in %) of the 40 water points sampled across the quality classes according to the SEQ-Eau system.

3.5. Findings: Nitrates, with five water points unsuitable for drinking water production and eight others unfit for human consumption without prior treatment, are practically the cause of deterioration in the quality of El Ma Labiod groundwater.

Three of the four water points which appear with a high level of chlorides are among those which are unsuitable due to nitrates and the fourth one is a 32 m deep well which has a water height of less than two meters above a clay substratum.

Thus, the map of nitrate concentrations reclassified according to the SEQ-Water margins had been used as a map of water quality.

Table 6

Water points classified according to the SEQ-eau system

Deterioration by mineralization:				
Parameters				
Conductivity	/	100%	/	/
Chlorides	/	90%	/	10%
Sulfates	2.5%	97.5%	/	/
Deterioration by nitrogenous materials except Nitrates:				
Parameters				
Ammonium	/	100%	/	/
Nitrites	95%	5%	/	/
Deterioration by Nitrates:				
Parameters				
Nitrates	22,5%	45%	20 %	12,5 %

3.6. Maps confrontation: The comparison of the two groundwater vulnerability indexes (GVI) maps themselves and with he map of Nitrate concentrations in the groundwater of the of El Ma Labiod plain shows:

•A perfect spatial concordance of the maximums of the three items.

•That both GVI share the study area in three classes and went to moderate one.

•The space occupied by the GVI assessed by the GOD method for the moderate and low classes is greater and cover integrally those resulting from DRASTIC method.

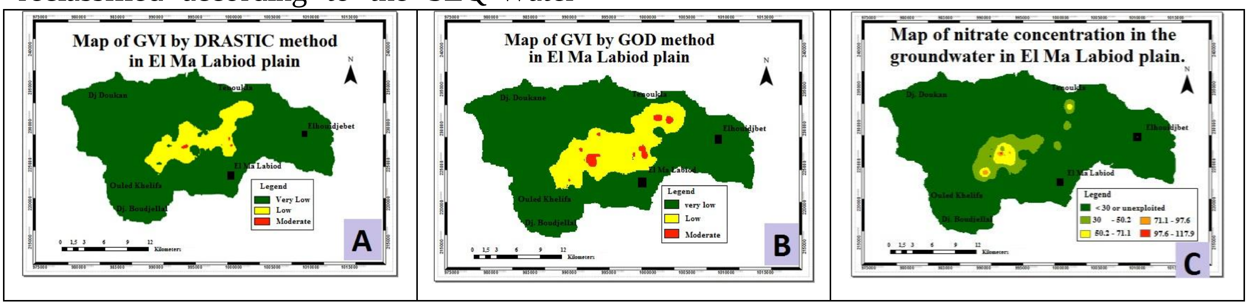

Fig. 7 Confrontation of vulnerability indexes and nitrate concentration maps: A– Map of GVI assessed with the DRASTIC method. B- Map of GVI assessed with the GOD method. C- Map of nitrate concentrations in the groundwater of the plain of El Ma Labiod.

•The low GVI class of both methods includes all nitrate values over 30 mg/l and all high values of the red quality class are located in the moderate GVI class areas.

The difference observed in these spatial extents (Figure 5) is probably due to the operating mode of the two assessing approaches:

•The parameter D covers more important fields of rated depth, up to 100 m, for GOD method, whereas DRASTIC method is limited to the first 30 meters.

•The rating systems use different scales and number of parameters.

•The calculation methods of GVI are different.

•The spatial distribution of values that exceed the drinking water standards confirms the results obtained by the two used methods to assess the vulnerability of the aquifer.

4. Conclusion

The effect of agricultural activities on groundwater is no longer to be proven; the level of the water concerned is seriously reduced by irrigation needs and its quality is deteriorated by pollutants from the fields. Referring to data from the last three decades, the water table level is decreasing in the study area, with an average of 1m per year, despite the inflow from the North and the South West limestone borders.
The contamination of certain areas of El Ma Labiod plain is concrete and it exceeds drinking standards, with five water points unsuitable for drinking water production and eight others unfit for human consumption without prior treatment.
The analysis of the samples designates Nitrates and the agricultural activities as an essential cause of the water quality deterioration in El Ma Labiod plain.
Both resulting DRASTIC and GOD vulnerability index maps are spread over three levels with a larger "susceptibility" areas for the GOD method which has a "D" parameter ranging from 0 to 100 m.
Thus, the GOD method is better suited to the arid and semi-arid climate zones which are characterized by deep water tables.
The comparison of the map of the nitrate concentrations with DRASTIC and GOD GVI maps shows a perfect match of the respective maximum values confirming the preferential pathways for surface contaminants to reach the water table.

Whatever the gap between the needs and the availability, consideration must be given to the safety of other vital resources and the environment before the start of any agricultural or industrial food production project.

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