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ASSESSMENT OF GROUNDWATER VULNERABILITY TO POLLUTION USING GOD METHOD IN THE SOUMMAM CATCHMENT AREA (NORTHERN ALGERIA)

*** Selma KISSAR [1], Kaddour KHAMMOUDJ [1]**

[1] *Laboratory of Applied Zoology and Animal Ecophysiology, Faculty of Life and Nature Sciences, University of Béjaia, Béjaia 06000, Algeria*
sansaw48@gmail.com
*Corresponding author
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Abstract: *Aquifer vulnerability maps are useful to contribute to the protection of groundwater resources against possible contamination. The objective of this study is to determine the vulnerability to pollution of groundwater in Soummam catchment area (Northern Algeria) based on the GOD method by applying these three parameters: Groundwater occurrence (G), Overall aquifer class (O) and Depth to groundwater table (D). The mapping of these different parameters allows, after their superposition, the establishment of the vulnerability map. The map obtained highlights five zones with different degrees of vulnerability: extreme (0.7-1.0), strong (0.5-0.7), moderate (0.3-0.5), weak (0.1-0.3) and very weak (0.0-0.1). Occupy respectively (3%, 40%, 15%, 7%, and 35%) of the total basin area. The use of the vulnerability map contributes to the sustainable protection of natural resources. The projection of the pollution sources on the vulnerability map allowed us to establish the risk map.*

Keywords: *Vulnerability, GOD, watershed, Pollution, Risk map, Groundwater.*

1. Introduction

In Algeria, a predominantly semi-arid country where water is at the heart of the concerns of society and public authorities, the notion of watershed is increasingly becoming part of the everyday language of engineers and decision-makers. The watershed is defined as a topographic and hydrographic entity in which water inflows occur, mainly in the form of precipitation, but also underground inflows from other basins, and where the flow (and the transport of materials mobilized by erosion) follows a system of slopes and natural drains towards the outlet or mouth of the collecting watercourse [1]. A detailed study of the catchment area of a watercourse is essential before any study. According to the division of the National Water Resources Agency [2], the Soummam watershed is one of the 17 large hydrological basins of Algeria, numbered 15, located in the central part of northern Algeria with a surface area of 9125 km^2 and composed of ten sub-basins corresponding to hydrological units. The preservation of water resources in this country is essentially based on a national multi-sectoral programme to fight against the pollution of the water resources. In the Soummam watershed, groundwater has been a source of drinking water for the centuries. This non-renewable resource has been the subject of several analytical studies aimed mainly at determining its quality. Mapping the vulnerability of groundwater to pollution plays an important role in the implementation of environmental policies. Vulnerability is

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strongly determined by the properties of the soil that protects the groundwater [3]. Several methods of studying and assessing vulnerability have been studied worldwide by [4-7]. In Algeria, the study of pollution vulnerability is carried out by several workers [8-12]. The objective of this study is to evaluate the degree of vulnerability and the risk of pollution of the groundwater resources of the aquifers in the Soummam catchment area (North of Algeria) by the GOD method: Groundwater occurrence, Overlying lithology, Depth to groundwater [13]. It is, therefore, possible to define the sensitive areas in which pollution can seriously affect a water table, which will help us to find solutions to protect this water table. The reason for using this method exclusively without the rest of the other methods in our work is that the GOD method allows a quick estimation of the vulnerability because it contains only three parameters.

2. Matherials and methods

2.1. Study area

The Soummam catchment area is located in the central part of northern Algeria, and covers 9125 km^2, as shown in Fig. 1 This area is irregularly elongated along the direction of the parallel (35° 45' and 36° 45'). In the north, this basin is bounded mainly by the Djurdjura mountain range, whose highest peak is 2,308 m, above mean sea, amsl level (Lalla Khedidja), while its southern limit is the Hodna Mountains. Less high than the Djurdjura (the maximum altitude is 1862 m, amsl). Towards the east and west the Soummam basin is open; it is in this part of the basin that the high plateaus of Sétif and Bouira are located. The greatest length of the Soummam basin is about 176 km while its width, measured on the line that links the crests of the mountains of Hadjar el Abiod and El Ktef, is about 118 km.

2.2. Geology

The geological map shows the geological complexity of the terrain forming the Soummam catchment area, representing that this terrain is of sedimentary origin (Oligocene, Cretaceous, etc.): limestone, marl, sandstone, dolomite, etc., and is often rather impermeable, which, coupled with the steep slopes, favours run-off.

(Fig. 2) represents the different geological formations of the Soummam watershed, including [14].

Quaternary: represented by alluvium along the wadis and on the high plains.

Continental Pliocene: the hillside of the Sahel is crowned by siliceous and fluvial gravel. Elsewhere, it is conglomeratic or stony.

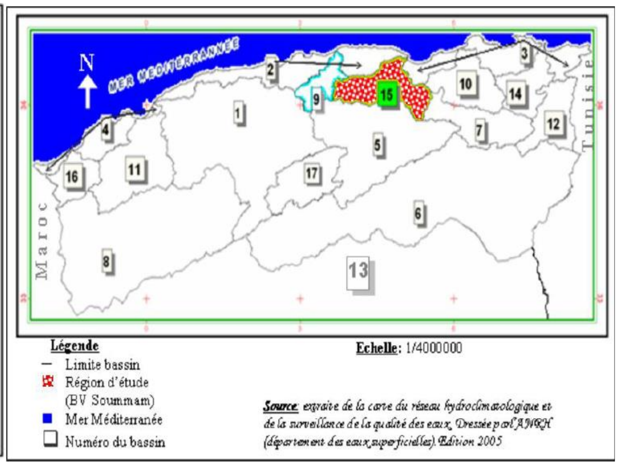
Miocene: this is essentially the Lower Miocene. It is continuous from the west of Bejaia to the surroundings of Sidi-Aich. It also outcrops on the side of Dj. Mansourah in the form of sandstone.

Oligocene: it is generally clayey-sandstone. It is abundant from Tazmalt and on both sides of the Soummam valley, going westwards. Its presence is also noted in the Gouraya chain and the Béni-Mansour region.

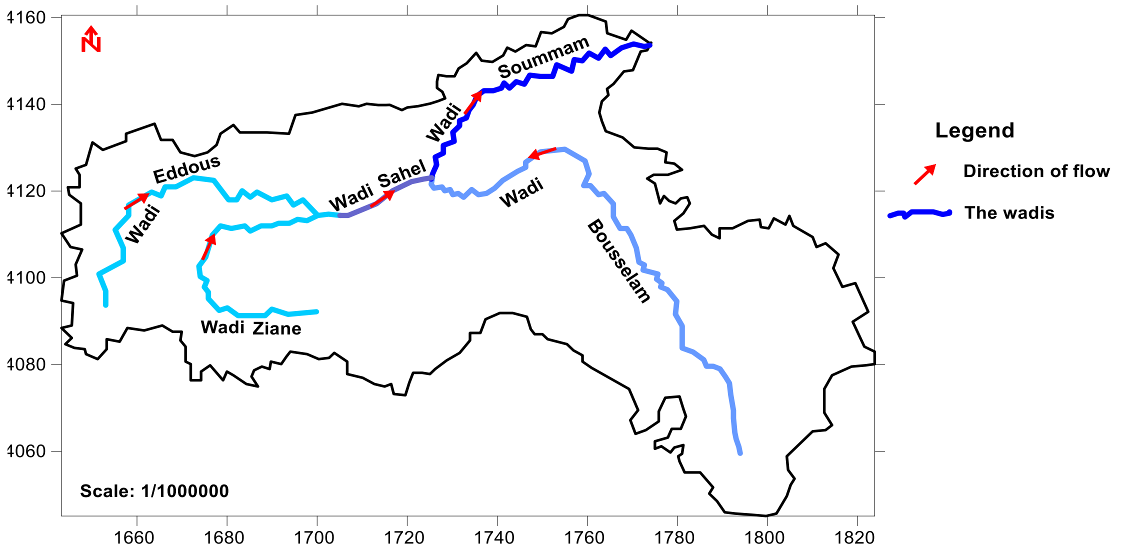
Eocene: it is almost marly, sometimes calcareous-marly. It is mostly found in the high plains.

Cretaceous: is generally in the form of flysch. It is extensive and continuous from the Biban chain to the mountains of Little Kabylia. The facies are marly in the Upper Cretaceous (Senonian). It is schistose, in the form of banks several hundred metres thick with some sandstone intercalations in the middle Cretaceous (Albian) and appears in the Beni-Mansour region and the Bibans range. It is sandstone pelitic, sometimes carbonate-sandstone in the lower cretaceous.

a. Algeria



b. The major watersheds of Algeria



c. Soummam watershed

Fig. 1 Location map of the Soummam watershed

Jurassic: it is mostly found in the limestone chain and along its continuity towards the east. It is mainly calcareous-dolomitic.

Triassic: it is of gypso-saline facies and appears along anomalous contacts (nappes de charriage contact) in the Southern Tell and is presented by conglomerates and reddish sandstones in the Northern Tell.

2.3. Characteristics of the drainage network

The drainage network is the set of natural or artificial, permanent or temporal watercourses that participate in the flow.

2.3.1. The main collectors in the hydrographic network

The oued Boussellam in the East, together with the oued Sahel in the West, constitutes one of the two main tributaries of the Soummam; it drains about 54.9% of the total surface area of the basin to the sea [15]. The oued Boussellam, which has its source in the djebel Meghris, to the north of Sétif, flows initially North-South and then turns abruptly to the North-West. It escapes from the high plains through the gorges carved in the limestone of Guergour, in the region of Bougaa. Further north, it describes a large curve and joins an important tributary, Oued El Main, coming from the South.

After its confluence in the region of Akbou with the Oued Sahel, which drains the waters of Oued Azrou, Oud Ziane and Oued Eddous, it flows into the Oued Soummam, the main collector, which in turn flows into the sea (in Fig. 3). This hydrographic route had attracted the attention of Gautier E F. (1910) who saw in the course hooked, folded on itself, as an indication of a phenomenon of capture. According to this author, at a given time in the past, the Boussellam took the path of Hodna to end in a closed basin until it was captured by the erosion of the head of a torrent Tellien [15].

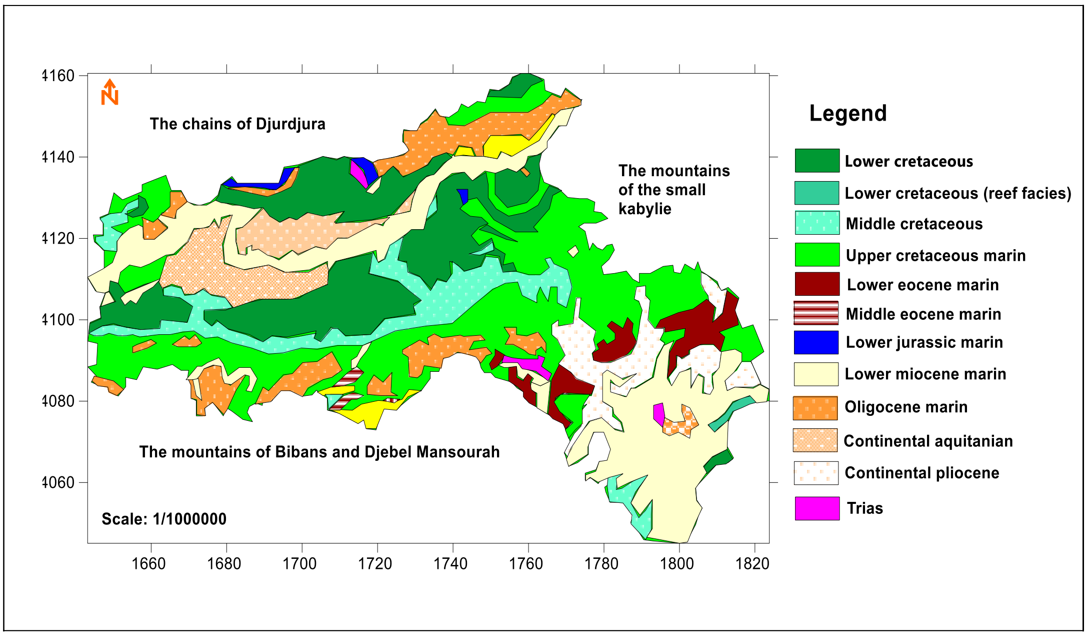


Fig. 2. The geological map of the Soummam watershed (made with the help of software: Surfer)

2.4. Soil

In the Soummam watershed, ancient soil types of paleo-swamp formation are found, which are characterized by well accentuated formations.

The soil map of the Soummam basin was extracted from the soil map of Algeria made by J. Durand in 1954 [14] and produced by the Surfer software (Fig. 4).

The majority of the soils in the Soummam basin are calcareous soils (rich in limestone). These soils generally have a light texture and are therefore permeable.

In the northern part of the basin, unsaturated soils that do not contain limestone are found, where clay may be more abundant at the surface than at depth; their parent rocks are generally impermeable or yield impermeable decomposition products. Along the wadis, the existing soils are alluvial deposits called alluvial soils. In addition, one meets, in small quantities, calcareous soils and soils in balance not very thick, more or less rich in limestone and very poor in soluble salts.

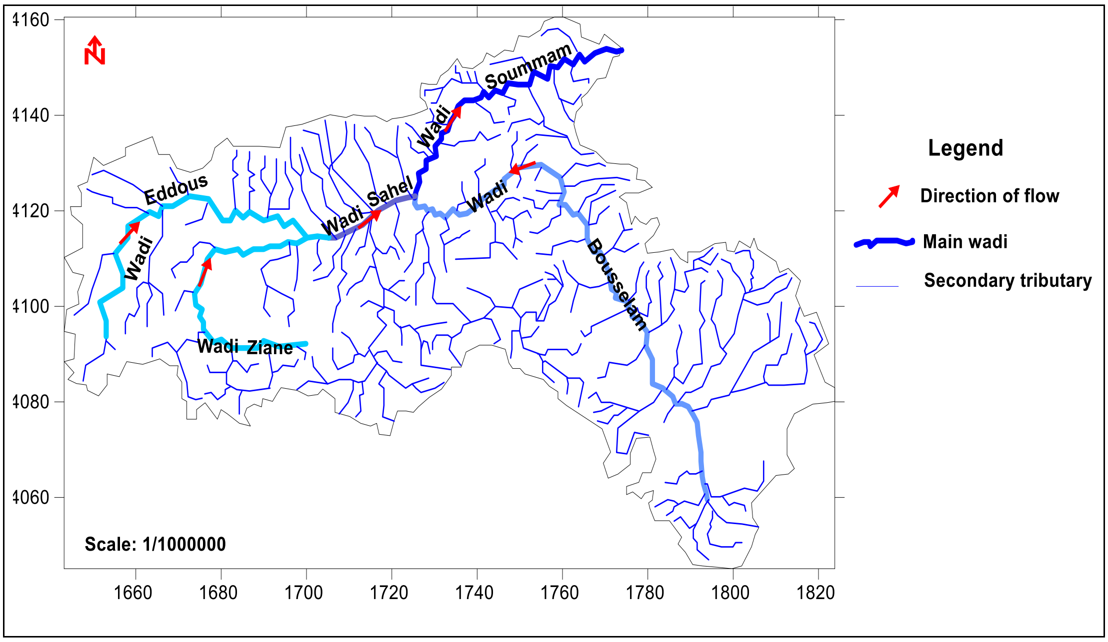


Fig. 3 Map of the hydrographic network of the Soummam watershed (made with the help of Software: Surfer)

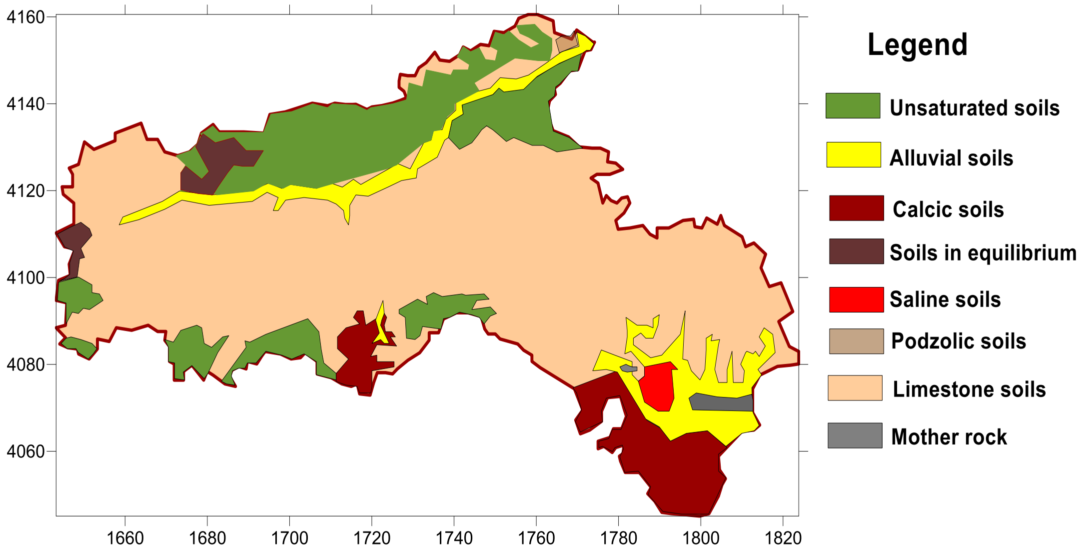


Fig. 4 Soil map of the Soummam watershed (made with the help of software: Surfer)

2.5. Basin Characteristics

The fundamental characteristic of the watershed's relief is reflected in its pronounced plasticity. Numerous streams and their tributaries, most frequently with steep slopes, have carved their beds deep into the weak geological layer (Fig. 5). [14].

The relief of the Soummam is characterized by: the hypsometric curve (Fig. 6) and the characteristic altitudes.

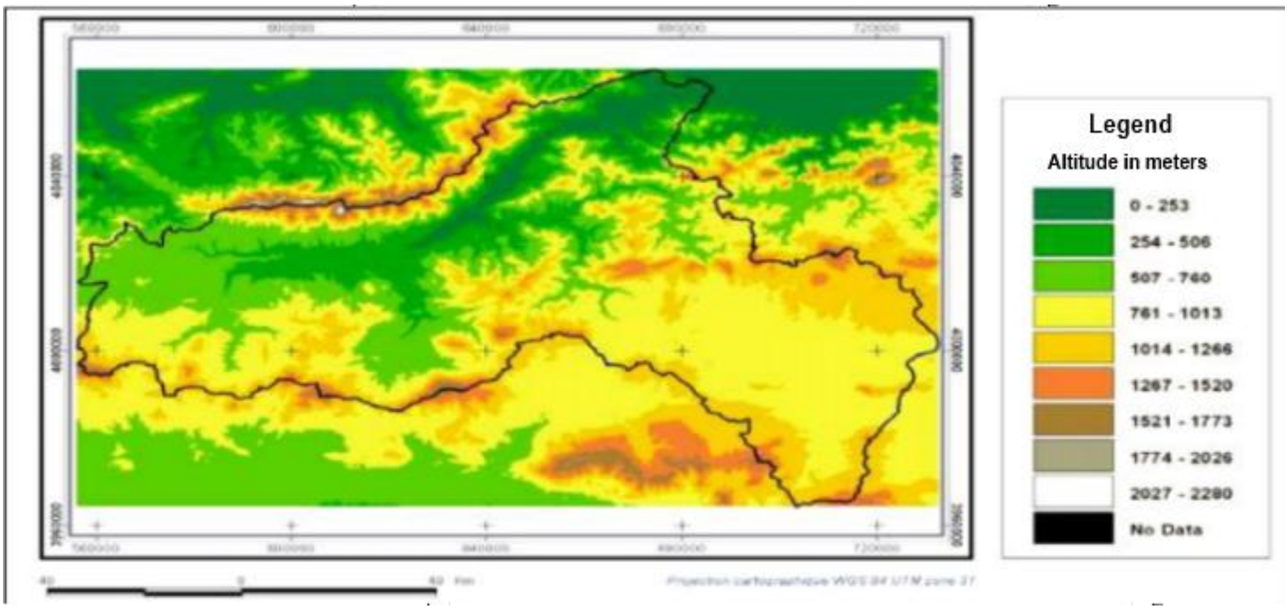


Fig. 5. Relief map of the Soummam watershed.

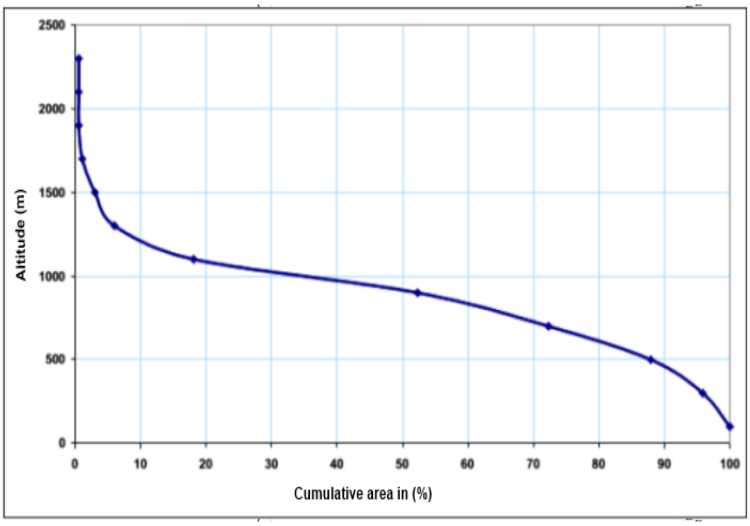


Fig. 6. Hypsometric curve of the Soummam basin.

From Fig. 6 we observe that the curve relates altitudes and surface areas in a basin, in the form of frequencies of surface areas below a given threshold. In a context of geomorphological evolution according to the Davis model (Fig. 6), this curve provides information on the maturity level of a watercourse. It is obtained by summing the histogram of altitudes. [14]

Characteristic altitudes: the minimum altitude of the Soummam watershed is Hmin = 2 m; the maximum altitude is Hmax = 2308 m; the mean altitude is Hmoy = 785 m and the median altitude is Hm = 900 m.
Note that the median altitude is higher than the mean altitude, which means that the basin is slightly asymmetrical towards higher altitudes.

2.6. GOD method

The GOD method is a method for assessing the vulnerability of the aquifer to vertical percolation of pollutants through the unsaturated zone and does not address the lateral migration of pollutants into the saturated zone.
This method was developed by Foster in England in 1987 [13].

It allows for a rapid estimation of vulnerability [16] and takes into account three parameters, which are: G: Groundwater occurrence; O: Overall aquifer class; D: Depth to groundwater table. The classes of the different GOD parameters are assigned scores less than or equal to 1 depending on the particularity of the environment. The GOD index (GI), which allows vulnerability to be assessed, is calculated by multiplying these three parameters according to the following equation:

$$GI = Ca * Cl * Cd \qquad (1)$$

with Ca: rating of the aquifer type; Cl: rating of the lithology and Cd: rating of the depth of the water table. The GOD index (GI) has a minimum value of "0" and a maximum value of "1". The vulnerability increases with the index. After calculating the index, vulnerability classes from "very low" to "extreme" are assigned (Table 1).

Table 1
God Index value ranges and vulnerability classes [16].

Interval	GOD class
0.0-0.1	Very low vulnerability
0.1-0.3	Low vulnerability
0.3-0.5	Moderate vulnerability
0.5-0.7	High vulnerability
0.7-1.0	Very high vulnerability

The vulnerability is a function of the calculated index. Taking this into account, the classification of the different indices must take into account the intervals defined by the GOD method. The boundary values of the GOD index ranges are relative (in Fig. 7). In fact, if the calculated indices do not oscillate between the fixed extremes (0: minimum value; 1: maximum value), another classification adapted to the study is performed. This other classification makes it possible to set the limits of the ranges of the calculated indices and to match the vulnerability classes to these indices. This was the case in the work carried out by a several workers [17-21].

3. Results and discussion

3.1. Description of parameters and maps making:

(1). Parameter types of aquifer "G":
An aquifer type map was made which consists of three zones (Fig. 8):

- Free aquifer around the wadis which induces a vulnerability index of order 1.
- Semi-captive aquifer in the extreme north and south of the catchment area, which has a vulnerability index of 0.3.
- Artesian Captive aquifer occupies a large part of the catchment area with a vulnerability index of around 0.1.

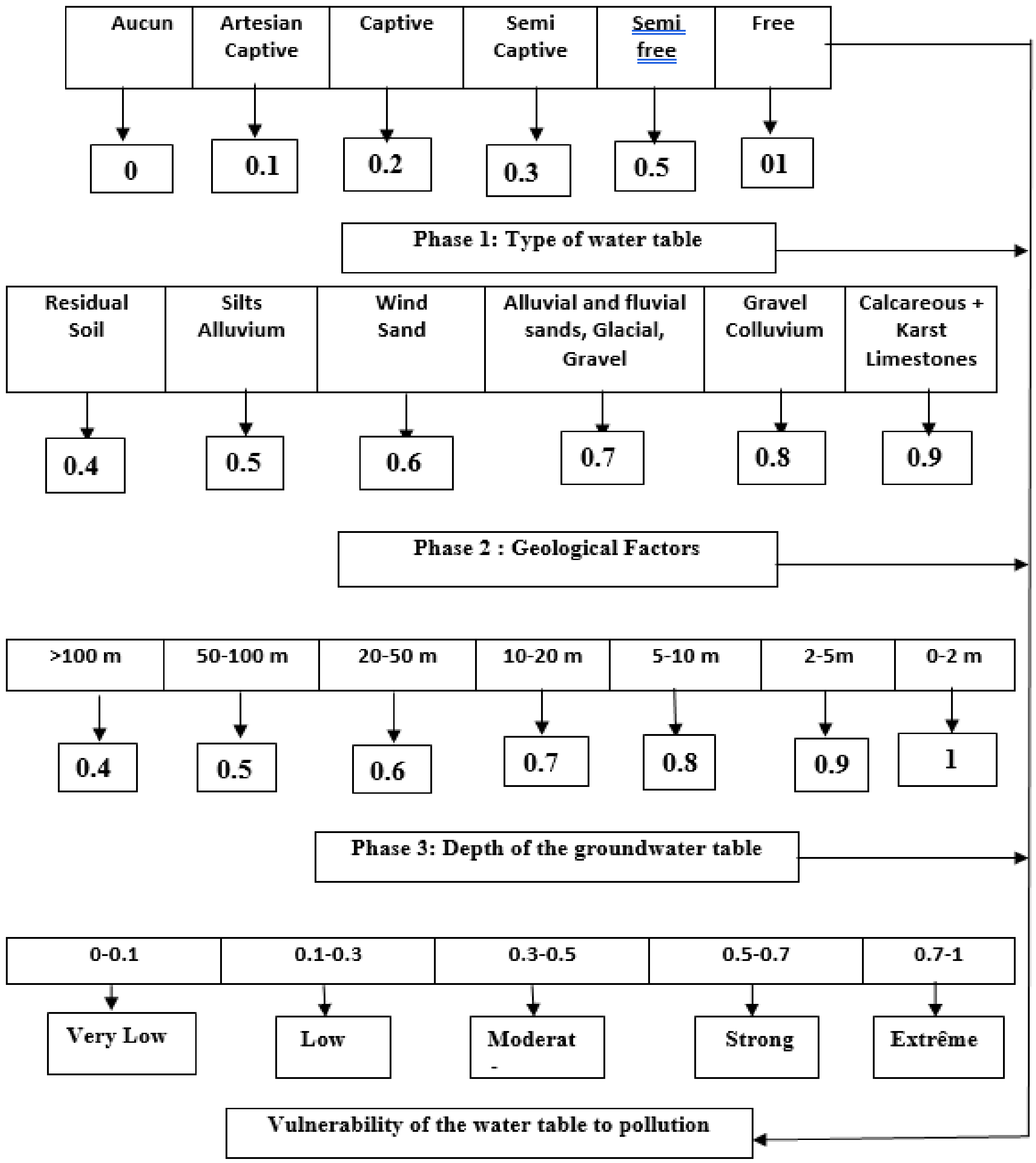


Fig. 7. Empirical GOD system for rapid estimation of aquifer vulnerability [13].

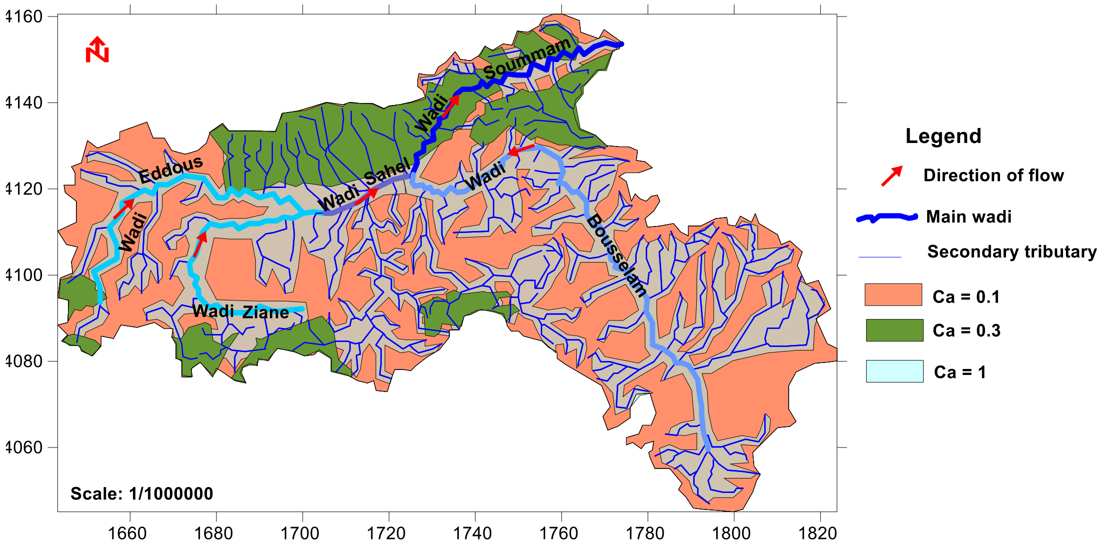


Fig. 8. Aquifer type map "G" (made with the help of software: Surfer)

(2). Lithological nature parameter "O":

The lithological nature parameter has brought out three zones: (Fig. 9)

- The alluvial formations located along the Eddous, Ziane, Sahel and Soummam wadis up to Boussalem with vulnerability index of about 0.5.
- The sandstone formations in the north and south of the basin with vulnerability index of around 0.7.
- The limestone formations which occupy almost the entire basin with vulnerability index of around 0.9.

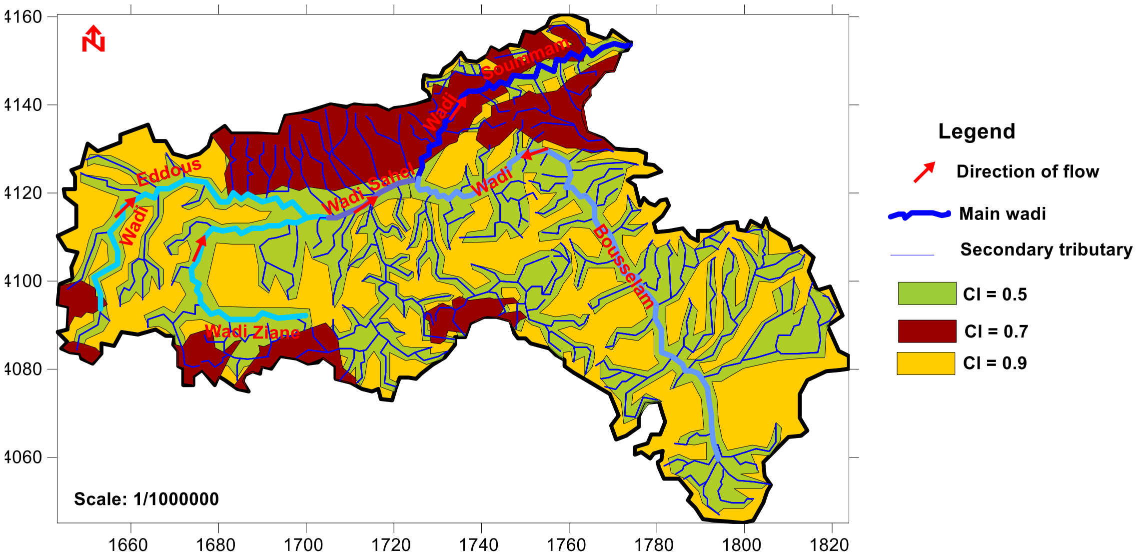


Fig. 9. Aquifer lithology map "O" (made with the help of software: Surfer)

(3). Depth to groundwater table "D"

This parameter has brought out four zones: (Fig. 10)

- Depths vary between 2 to 5 m located along the entire length of the wadis inducing a vulnerability of order 0.9.
- Depths between 10 and 20 m with a vulnerability index of 0.7.
- Depths between 50 and 100 m located at the extreme north of the basin induce an index of order 0.5.
- Depths > 100 m give a vulnerability index of 0.4.

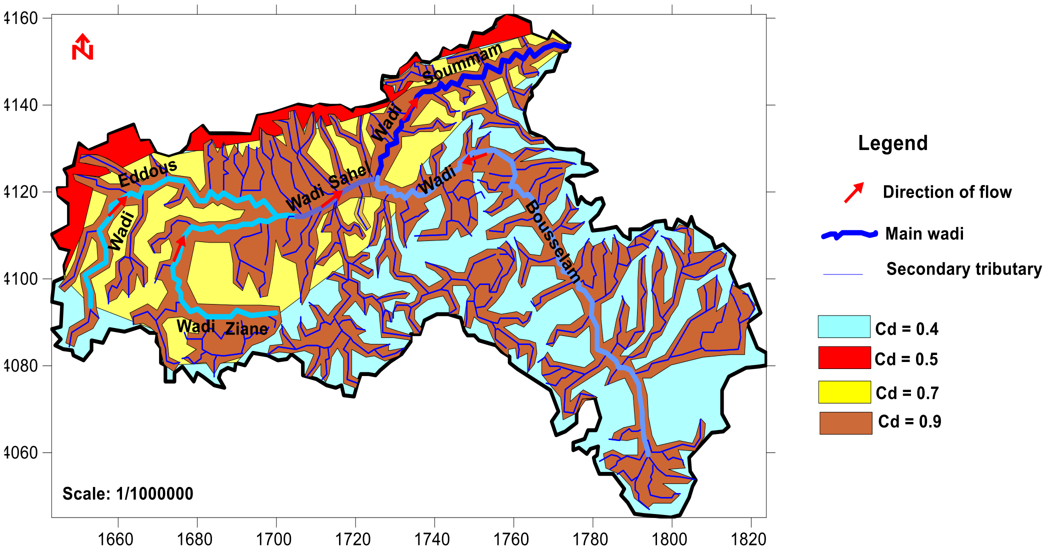


Fig. 10. Map of Depth to groundwater table "D" (made with the help of software: Surfer)

3.2. Vulnerability map

The vulnerability map to groundwater pollution of the Soummam catchment area was carried out by the GOD method using Surfer version 11 software. The calculation of the vulnerability indices by the GOD method is done directly by the multiplication of these three parameters.
The result of this calculation is the elaboration of a vulnerability map (Fig. 11).
Based on the results obtained, five parts are distinguished as follows:

- The very low part: at a degree of vulnerability that occupies 35% of the total area of the basin, with a depth > 100 m.
- The low part: with a degree of vulnerability that occupies 7% of the study area, the depth of the aquifer is between 50 and 100 m.
- The moderate part: at a degree of vulnerability that occupies 15% of the study area, the depth of the aquifer is between 10 and 20 m.
- The strong part: at a degree of vulnerability that represents the area surrounding the wadis (Soummam, Boussellam, Sahel, Eddous and Ziane) it occupies 40% of the total area of the basin with a depth of 2 to 5 m.
- The extreme part: This degree of susceptibility represents the meeting point of the three valleys; this area is very low which facilitates the propagation of contaminants to the groundwater; it occupies 3% of the study area.

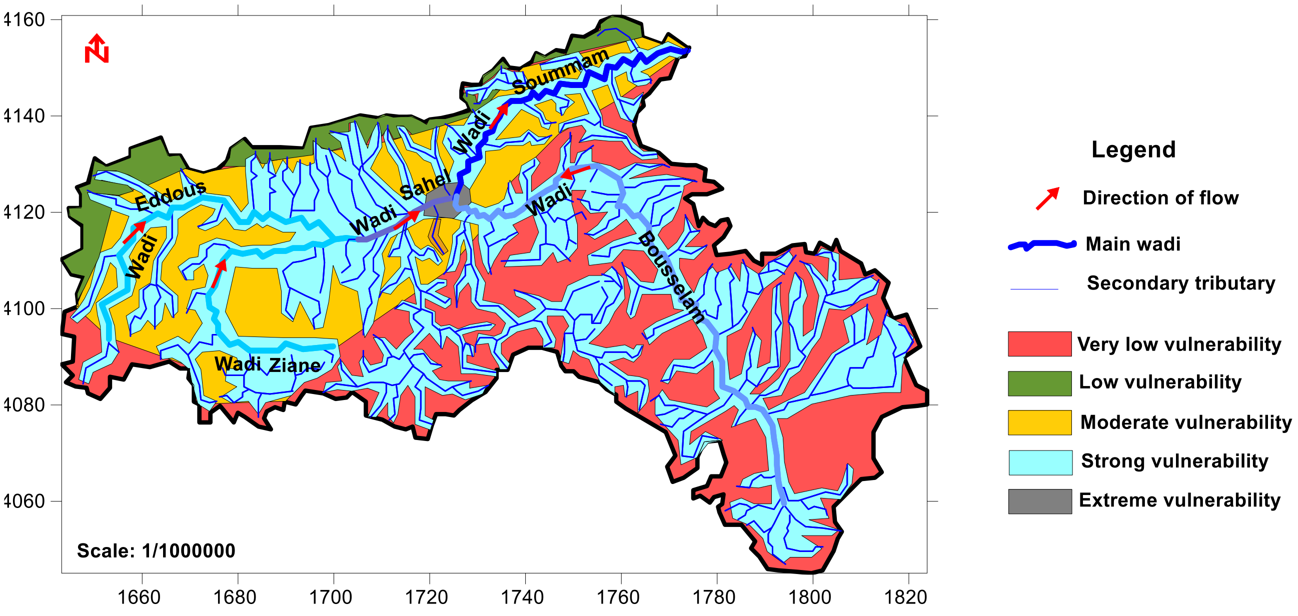


Fig. 11. Vulnerability map (made with the help of software: Surfer)

3.3. Sources of pollution in the study area

Wild dump: The waste dumped in the streets of the regions of our study area is household waste. This waste is dumped without any control, which represents a danger for the ecosystem, fauna and flora. During our work we have marked several points of wild dumps that pollute our basin from Béjaia (El-Kseur, Sidi Aiche, Amizour, Tibane, Akbou), passing to bouira (the dumps of mechedellah that pollute oued sahel until the waste disposal of sour el ghozlane that pollute oued eddous), Bordj bou arreridj (Medjana), Sétif (the dumps of ain oulman, bougaa. which pollute oued bousselam).

Agricultural pollution: The agricultural activity strongly modifies the quality and the dynamics of water in the environment by the contribution of fertilizers and pesticides. (We have many agricultural areas in our basin: The area of the Upper Valley of the Soummam and the area of the Lower Valley of the Soummam (akbou, tazmalt, tibane, amalou, seddouk), the area of oued eddous (tourmente, sour el ghozlane), the area of oued bousselam .

Industrial pollution: remains the most famous and dangerous of all forms of pollution, as its consequences affect even non-industrialized areas. This type of pollution is worsening and taking on alarming proportions, which is why the international community is working to find adequate solutions to limit its damage and prevent the planet from being damaged. The industrial zones: Bejaia, El-Kseur, Akbou, Beni Mansour, Boudjellil, Sidi Khaled in Bouirathe industrial zones of sétif.

3.4. Risk map

The projection of the pollution sources on the vulnerability map gives us a risk map (Fig. 12)

$$Risk = Vulnerability * Hazard \qquad (2)$$

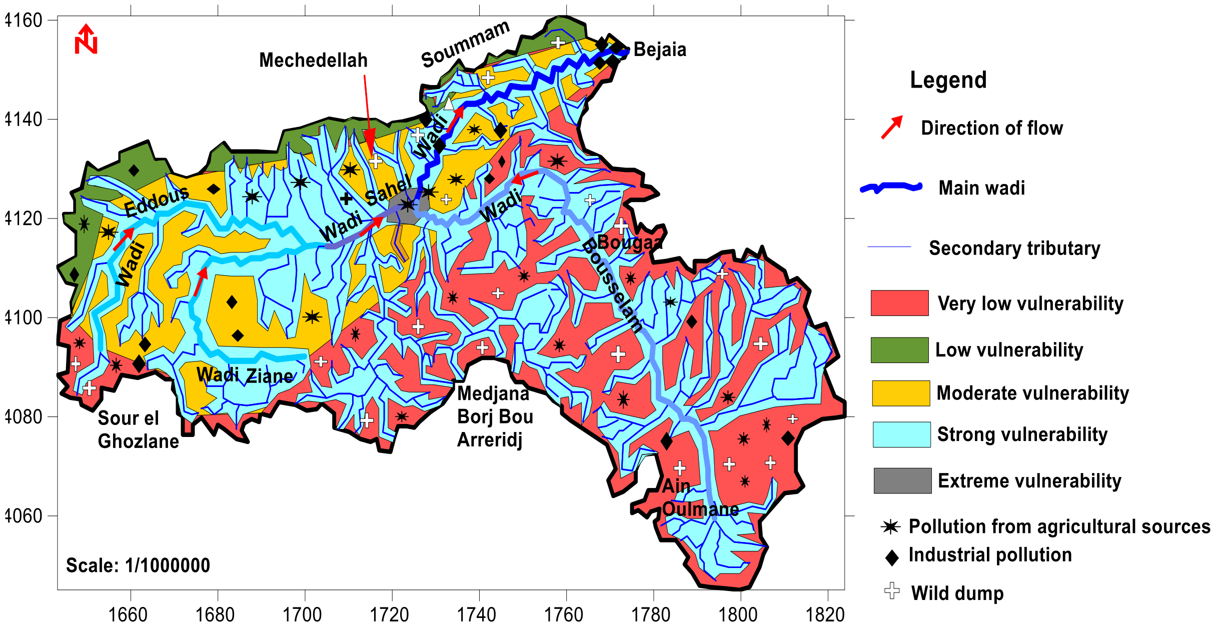


Fig. 12. Risk map (made with the help of software: Surfer)

4. Conclusion

Mapping the vulnerability and pollution risks of groundwater is a methodology that has become necessary in order to ensure the qualitative management of water resources in relation to various human activities, and therefore appears to have potential pollution risks. In this study, we assessed the vulnerability to groundwater pollution using the GOD method. This method led to the following results:

- The waters of the study area are exposed to various types of pollution (agricultural pollution, landfill and industrial pollution).
- The vulnerability map for groundwater pollution using the GOD method revealed five different vulnerability zones: extreme, high, moderate, low and very low).
- Occupy respectively (3%, 40%, 15%, 7%, and 35%) of the total basin area.
- The projections of pollution resources on the vulnerability map give use the risk map.

For this we must to:

- ➢ Development and apply methods to control pollution assessment;
- ➢ Avoiding illegal dumping;
- ➢ Protect groundwater from possible pollution infiltration;
- ➢ Raising awareness among citizens to protect the environment;
- ➢ Treatment of industrial and domestic wastewater discharges that are piped planned;
- ➢ Controlling the development of urbanization in the catchment area;
- ➢ Control the use of fertilizers which constitute a risk of contamination.

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