STATE OF VULNERABILITY TO POLLUTION OF THE BIG RESERVOIRS OF GROUND WATER IN THE REGION OF ANNABA-BOUTELDJA(NE ALGERIA)

***Badra ATTOUI*[1], *Nacer KHERCI*[1], *Houria BOUSNOUBRA*[1]**

ABSTRACT:
State of vulnerability to pollution of the big reservoirs of ground water in the region of Annaba-Bouteldja (NE Algeria). Scientists are deeply concerned by the state of vulnerability of groundwater reservoirs. It is a complex task because of the difficulties to determine the degree of pollution of the ground water. Many methods have been adopted like (DRASTIC, GOD, SI, SINTACS…..).Another method (*Kherici, 2010*) is added to identify the vulnerability of groundwater reservoirs and control the evolution of pollutants The present article targets the determination of the vulnerability and risks of pollution of groundwater reservoirs of a climatic Mediterranean region (Annaba-Bouteldja region).The device used is based on the combination of two criteria: natural factors (thickness of the unsaturated zone, geological facies and degree of sel-purification) and the causes of vulnerability and the pollution risks entropic factors(caused by man).
The application of Kherici's method has revealed a distinction between the different degrees of pollution and has allowed a neat classification of the different of the reservoirs study.
The results lead to a vulnerability map and the risks of pollution of Annaba- Bouteldja different aquifers. It has also led to the installation of protection areas sustained by an efficient general evacuation plan of the sewerage net and the construction of treatment station of the sewage effluents in the urbanized areas.

Key-words: *unsaturated zone, self-purification, vulnerability to pollution, risk of pollution.*

1. INTRODUCTION

Groundwater reservoirs are easily affected by pollution. The process is slow but its effects are very dreadful (*Baghvand et al., 2010*) (from the ground to the unsaturated zone). Thus, whatever the nature of the physical pollution (radioactivity), chemical (Mineral pollutants) (*Lain et al., 2007, Lake et al., 2003*), organics (pesticides, *Fred Worrali et al., 2004*) or bacteriological (bacteria, viruses (*Schijven et al., 2010*), the aquifers are affected.

However, the prevention against groundwater pollution constitutes an important phase to which scientists are doing their utmost notably in studying the vulnerability of the groundwater. They therefore, created classical scientific methods (Etienne et al., 2009) and numerical (*Boufekane et al., 2010*), to facilitate the identification of the state of these groundwaters and to control the pollutants in the reservoirs such as (DRASTIC, GOD, SINTACS….). These different methods are presented under the form of numerical quotation systems based on the consideration of the different factors influencing the hydrogeological system (*Rouabhia, 2004*). These methods affect a note that varies at each used parameter and a weight. But the question that arises here is: on which bases had researchers specified these values of weight and quotation?

[1] *University Badji Annaba, Geology Laboratory, BP12 Mokhtar Annaba 23000, Algeria.*

This is because the reliability of these methods have not proved convincing throughout previous studies (*Mohammed et al., 2007*). So, we are adopting a new data processing method suggested by *Kherici 2010*, based on the index of self-purification of the geological formations (*Rehse in Detay, 1997*). The analysis of the vulnerability and the pollution risks of the groundwater reservoirs introduced in this document have been achieved on the bases of the combination of two criteria, the index of self-purification and the contamination index, it consists of a new graphic method under the form of Abacus rapid and simple when used for the characterization of the vulnerability and the pollution risks of the aquifers. The Abacus is composed of two triangular forms connected to a rectangle which permits the identification of the degree of vulnerability and the pollution risks of the groundwater. On one of triangles, the sel-purification of the soil and the thickness of the unsaturated areas index are represented. On the other triangle the index of organic contamination and mineral of the groundwater (*Kherci, 2010*) are represented too and inspired from the numerous applications to the different aquifers (confined and unconfined). Because of the great variability of the thicknesses and the self –purification indices within the unsaturated areas of the studied points, it was judicious to take a logarithmic scale within the first triangle for a better legibility.

2. DESCRIPTION OF THE SITE UNDER STUDY

Annaba–Bouteldja region is situated in the North-East of Algeria. It is about 800 km^2 (**Fig. 1**). It constitutes the lower plain of the Wadis (streams) Ressoul, Seybouse , Bounamoussa and Khebir (*Hani, 2003*) with different geomorphological formations (mountains, lakes, wadis and plains) where it is characterized by intense vegetative cover especially at the mountains' level .

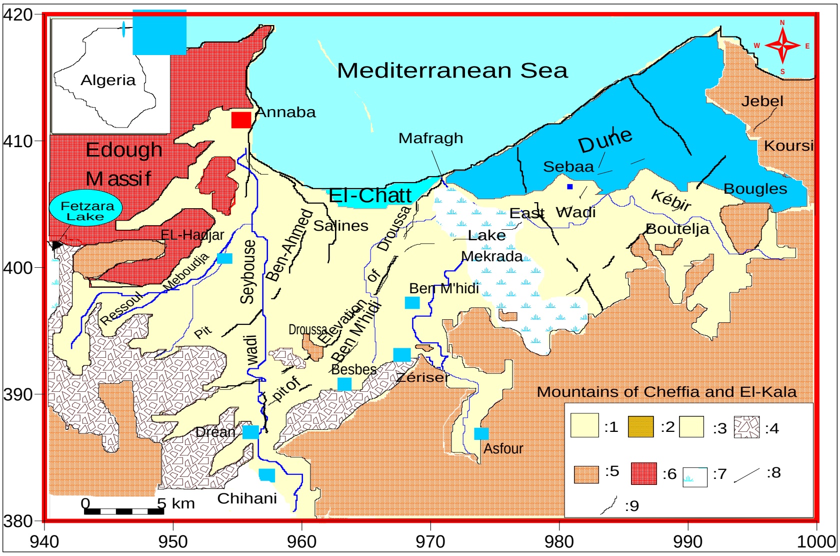

Fig. 1 Extending the different aquifers in the plains of Annaba Bouteldja (*from Gaud, 1976, amended 2009).* 1: Shallow aquifer; 2: Aquifer of massive dune of Bouteldja; 3: Unconfined aquifer of the dune; 4: Aquifer alluvium high level; 5: Numidian sandstones and clays; 6: Metamorphic formations (aquifer of marbles), 7: Swamp; 8: Faults; 9: Septic.

The studied area is known by its intense industrial activity localized in Annaba region at the West (Annaba plain) and is essentially agricultural in the East (El-Tarf plain). Concerning the climate, the region is among the most wet ones in Algeria. It has a Mediterranean climate mild and wet in winter and hot, dry in summer. The annual average rainfall varies between 594 mm and 817 mm under an annual average temperature of 18 C° and with evapotranspiration comprised between 485 mm/year and 581 mm/year.

According to (*Joleaud, 1936, Hilly, 1962, Vila, 1980, Lahondère,1987, Gleizes, 1988, Hammor, 1992*), there are two types of terrain: one metamorphic (cristallophylein) of primary age presented by the Eddough Massif in the West, and the other sedimentary age (Tertiary to Quaternary) almost occupying the totality of Annaba plains .The latter is the seat of permeable aquifers formation constituting important water reservoirs (**Fig. 1**) specially Annaba aquifers (superficial and deep groundwater) aquifers El-Tarf (dunes of El-Chatt, and massive dune Bouteldja).

3. MATERIALS AND METHODS

The work consists of evaluating the vulnerability and the pollution risk of a certain number of water points that represent Annaba-Boutedja region (**Fig. 2**). The water taken samples have been from domestic wells and drillings during a period of 25 years or more and completed by the actual analyses. The flame spectrophotometric absorption has been used for heavy metals, the atomic absorption spectrophotometer (PU8620) for all the nutrients (No_3, No_2). For the proportioning of DBO5 we have used a DBO metre.

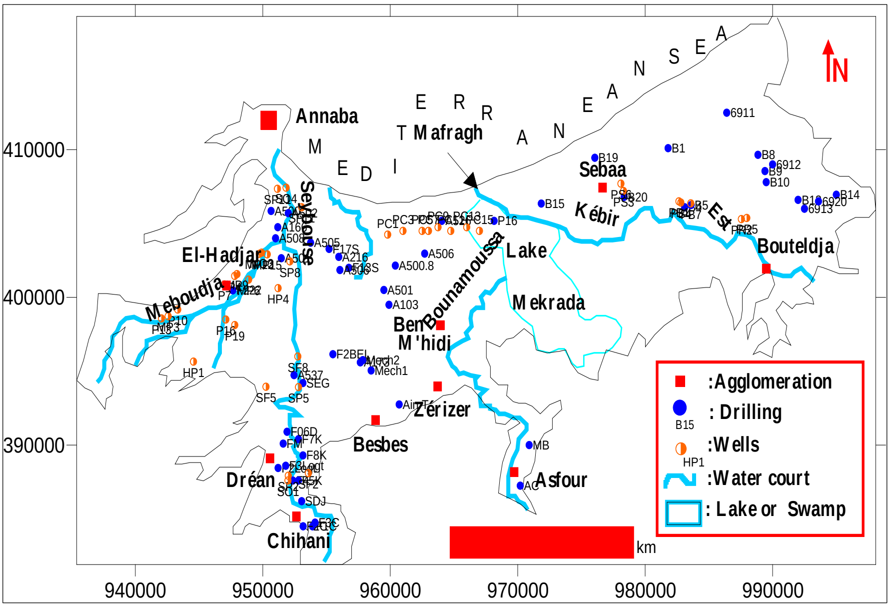

Fig. 2 Map inventory of water points in the region of Annaba-Bouteldja.

For a better protection of groundwater resources we have judged it useful to use pessimistic values in our approach. The data processing is used and studied by the new vulnerability determination method and of the pollution risks of the groundwater (*Kherci*, *2010*). It is represented by an abacus supported on the factors (natural: thickness of the unsaturated zone, geological facies, degree of self-purification) and on the causes of vulnerability of the aquifers to pollution (anthropic factors caused by man).

The abacus is essentially formed of two triangles and a rectangle, the first triangle A represents the natural factors identified by a semi-logarithmic scale (depth of the water surface that sometimes out passes hundreds of meters (lithological type of the ground crossed the product of these factors) accertains the total self-purification index of the unsaturated zone representing the Rehse1977 in detay1996 calculation method (Md = h*i=1m * 0.017 = 0.017). The second triangle B represents the organic contamination index of a side Exp: ICO = 5, the mineral contamination index on the second side Exp: ICM = 4, and the sum of the two índexes represents the total contamination index identified by the third side Exp: ICT = ICO + ICM = 5 + 4 = 9 (**Fig. 3**).

In order to have a better understanding of the use of this abacus we introduce the following:

The data of a drilling the example in (**Fig. 3**) being:

- With an unsaturated zone thickness of a drilling equal to 1meter with sand representation
- As the sand index according to Rehse is equal to the 0.017 therefore, the thickness of the product and of the index give a total sel-purification 0.017*1 = 0.017 (if the sel-purification index is equal or superior to 1 the sel-purification is satisfactory)
- With an organic contamination index ICO equal to 5 and a mineral contamination index ICM equal to 4. The total contamination ICT is equal to 5 + 4 = 9.

The projection of the preceding two triangles (**Fig. 3**) over the rectangle identifies the state of vulnerability and of the risk pollution of the studied water points of the aquifers (*Kherici, 2010*).

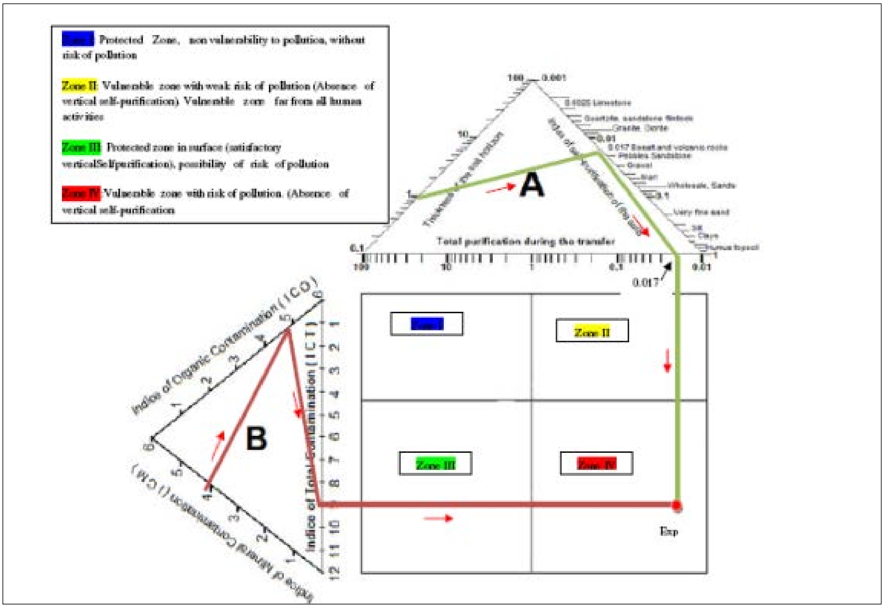

Fig. 3 Determination of vulnerability and pollution risk of water pollution zones (*Kherici, 2010*).

In orther to represent the samples of the different water points taking from the aquifer of the region on the abacus, it is necesssary to calculate the organic and mineral indexes (**Tables 1**, **2**, **3**, **4***)* according to (*Kherici, 2010*).

3.1. The organic contamination index (ICO):

To calculate the ICO, without the DBO5 measure over a long period we have taken into consideration the organic parameters represented by nitrates and nitrites.

And thus the engendered tables allow us to classify the region aquifer data.

Exp: ICO = the class of the nitrates + the class of the nitrites. NO3=42mg/l, NO2=0.3mg/l, Exp: 2 + 3 = 5

3.1.1. Classification of the Organic elements

Nitrate (NO_3):

Table 1. ***Identification of classes in the nitrate samples.***

Classification Element	Traces	Class 1	Natural	Class 2	Limit WHO	Class 3
NO_3 (mg/l)	0-10	1	10-50	2	>50	3
Shallow aquifer		14		9		17
Deep aquifer		24		16		14
The aquifer of the massive dune of Bouteldja		25		9		10
Unconfined aquifer of El-Chatt		0		14		1

The classification of the nitrates according to theWHO, allows to see that the amounts of nitrate in the studied waters are relatively high (over than 50 mg/l) and are identified according to table 1, in the 3rd class. They are found in the majority of the aquifers close to the agglomerations (Righia, Berrihane and Sebaa) and in the water of the Wadis Seybouse and Méboudja.

According to **Table 1** all aquifers are affected by nitrates pollution. It should be noted that the low levels represented by the class 1 (**Table 1**) issued from the water of shallow aquifers and from the free aquifer of the dunaire massive of Bouteldja, identify areas that are far from all human and agricultural activities. The waters in Class 2 and Class 3 (contents exceeding the WHO norms) reveal areas of high activity or in the presence of agglomerations. Also the deep aquifer of Annaba presents 14 values over the norms, despite the protected structure of this aquifer (confined).

Consequently, it is clear that the water points situated close to (Wadi Seybouse and Meboudja), agricultural sites (unconfined aquifers) and to the agglomerations are the most affected by nitrates.

Nitrite (NO_2):

As shown in **Table 2** the contents in nititrite are high in the superficial aquifer and the unconfined aquifer of El-Chatt and largely out passes the norms. This state is in perfect correlation with the domestic throw-away society, the agricultural and industrial (presence of ammonium in the industrial waste but in the deep aquifer the waters of some samples are ranked in the third class (> 0.1mg/l) explaining the relation caused by drainance between the superficial and the deep aquifer.

Table 2. *Identification of classes in the nitrite samples.*

Classification Element	Traces	Class 1	Natural	Class 2	Limit WHO	Class 3
NO_2 (mg/l)	0-0.05	1	0.05-0.1	2	>0.1	3
Shallow aquifer		0		4		37
Deep aquifer		22		14		8
The aquifer of the massive dune of Bouteldja		23		8		0
Unconfined aquifer of El-Chatt		0		0		15

3.2. Mineral contamination index (MCI)

It represents the sum of the classes of the two elements with the most significant concentration that is issued from mineral pollution of a same sample. In the studied region we have chosen lead and manganese.

From the projection of the two indexes (organics and mineral) we obtain the total contamination index (ICT).

3.2.1. Classification of mineral elements

Lead (Pb^{++}):

Being a heavy and a dangerous metal, it presents a risk of pollution of the waters in the superficial and deep aquifers.

Table 3. *Classification of lead according to the WHO.*

Classification Element	Traces	Class 1	Natural	Class 2	Limit WHO	Class 3
Leead (mg/l)	0-0.05	1	0.05-0.1	2	>0.1	3
Shallow aquifer		13		14		6
Deep aquifer		05		5		3
The aquifer of the massive dune of Bouteldja		14		3		2

Table 3 shows that the concentrations of lead in the samples are largely over the norms and are localized either besides a pollution source (polluted wadis by urban and industrial wastes affecting the deep and the superficial aquifers) or next to domestic waste (sewerage net) near the agglomerations of Berrihane and Rghia (**Fig. 1**). At that place we have to note that the high concentrations in lead are caused by the heavy traffic in the region (*Hamzaoui, 2007*).

Manganese (Mn^{++}):

According to the results, in **Table 4** we note that the superficial aquifer is the most contaminated by the manganese where 16 are found in class 3. The taking points are situated along the Meboudja wadis and Seybouse and are charged with wastewater especially of industrial origins (El-Hadjar steel plant, Debièche, 2002) in addition to the domestic waste directly pored in this wadis. Compared to those of the deep aquifer, the samples are less affected. In some places the waters of the deep aquifer present a high concentration resulting from the infiltration of the waters of the superficial aquifer by drainance.

Table 4. ***Classification of manganese according to the WHO.***

Classification Element	Traces	Class 1	Natural	Class 2	Limit WHO	Class 3
Manganese (mg/l)	0-0.05	1	0.05-0.1	2	>0.1	3
Shallow aquifer		22		2		16
Deep aquifer		2		5		6
The aquifer of the massive dune of Bouteldja		19		0		0
Unconfined aquifer of El-Chatt		15		0		0

3.3. The total contamination index (ICT)

It is the sum of the two preceding indexes ICO5 Organic contamination A) and ICM (mineral contamination index)

ICT = ICO + ICM

For the previous example/

ICT = 5 + 4 = 9 (**Fig. 3**)

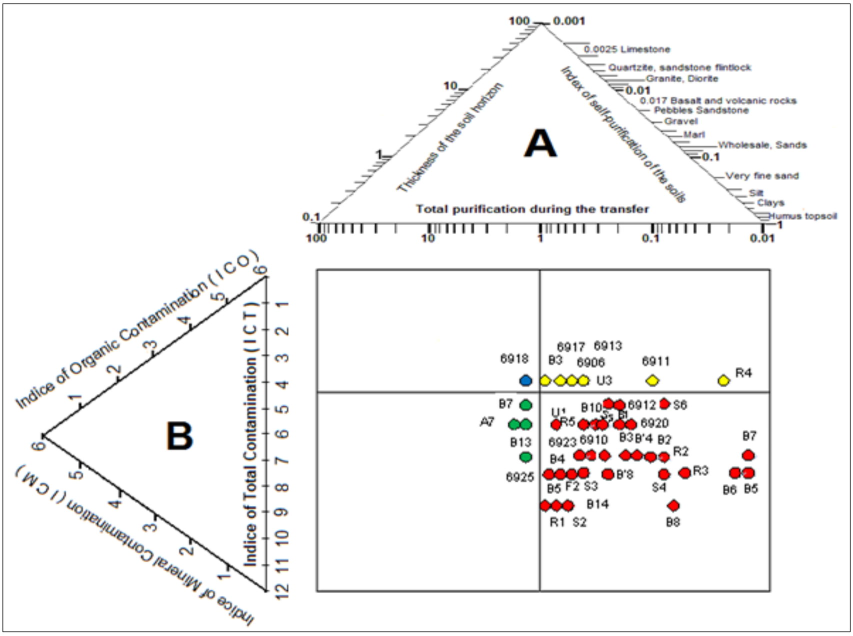

Fig. 4 Determination of vulnerability and pollution risk of water pollution zones (The aquifer of the massive dune of Bouteldja)

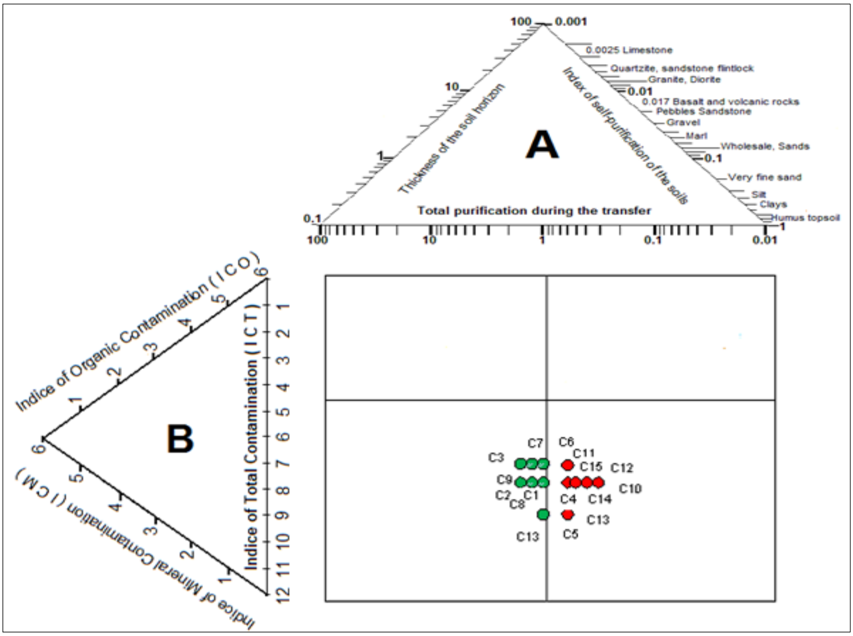

Fig. 5 Determination of vulnerability and pollution risk of water pollution zones (unconfined aquifer of El-Chatt)

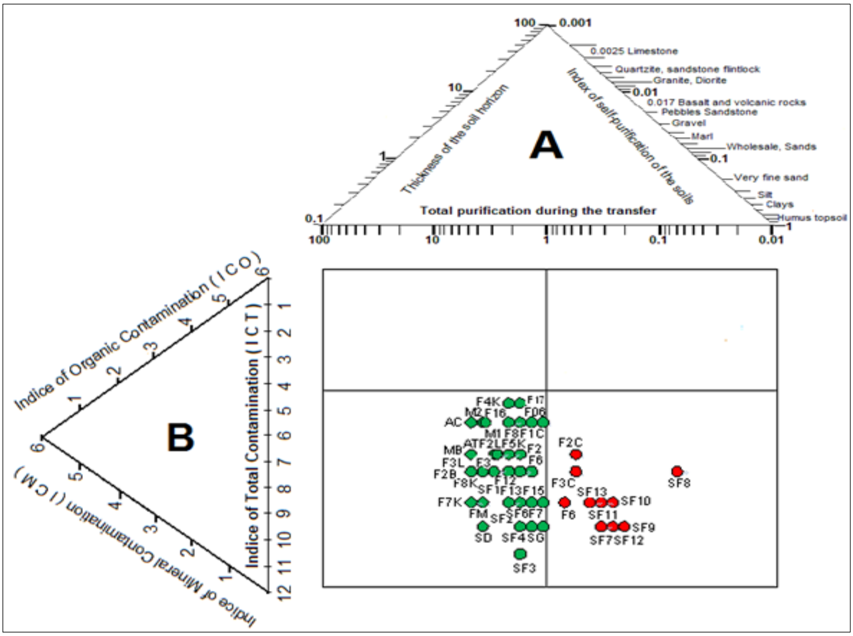

Fig. 6 Determination of vulnerability and pollution risk of water pollution zones (Deep aquifer) in Annaba-Bouteldja region.

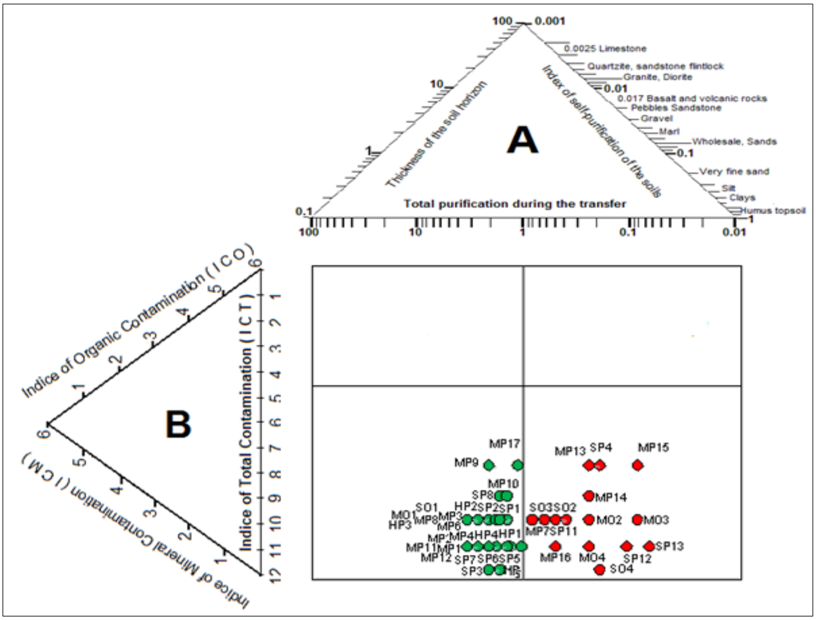

Fig. 7 Determination of vulnerability and pollution risk of water pollution zones (superficial aquifer) in the Annaba plain region.

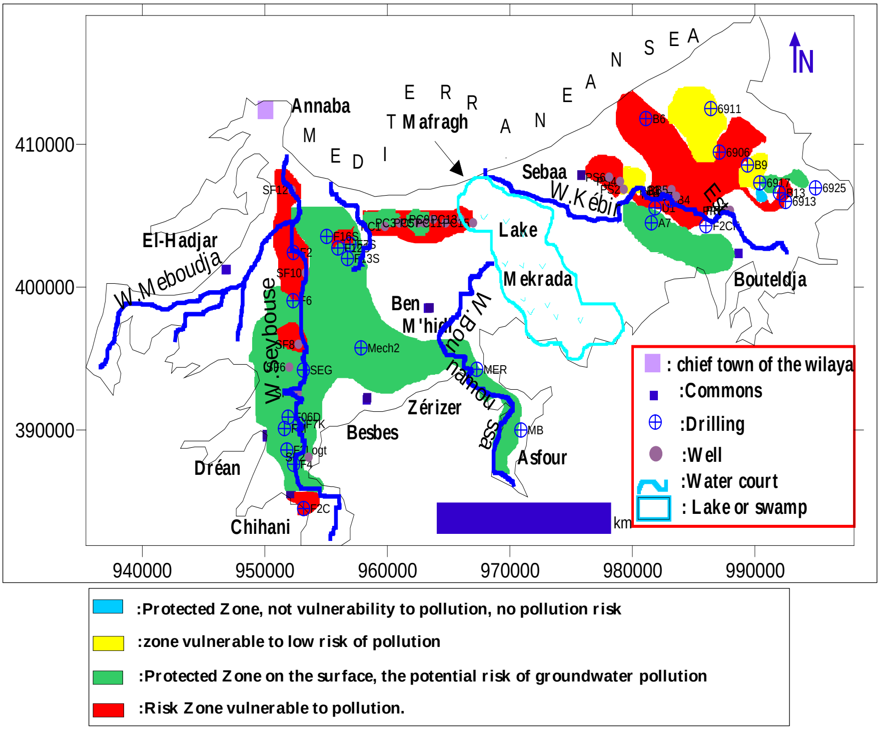

Fig. 8 Map of vulnerability and pollution risk of the different aquifers in Annaba Bouteldja region.

3.4. Results and discussion

The projection of the entire data analyses of water in the *Kherici 2010* (**Fig. 3**) suggested diagram allows us to classify the state of vulnerability and the pollution risk in each studied aquifer. For a better comprehension of the situation of the actual estate of the aquifers, we have supported the diagram results (**Fig. 4**, **5**, **6**, **7**) by additional maps which have been done by the serfer. The realization of these maps allows us to show the pollution sources (rivers, and agglomerations) and the localization of these sources according to water points.

3.4.1. The dunaire massive

According to data processing (maps and diagrams), the dunaire massive presents 4 states of vulnerability and risk to pollution:

The vulnerability and the risk of pollution occupies the center of the dunair massive, and the reason remains in the presence of the terrain composed of permeable formations essentially find to average to fine sands, and sands with gravel, in the drilling sites (6920, 6923, 6912) where the purifying capacity on the vertical way Md is less than 1; so the self-purification is not complete. The contamination if it exists, must continue in the aquifer (saturated zone).

At this place the mineral index of contamination (ICM) is high in some drillings of about 5, in the same way the organic index of contamination (ICO) is high up to 6 in the wells of the surrounding agglomerations .This zone is the most accessible to pollution with a high contamination risk:

- The vulnerability of the terrain with a weak risk of pollution is situated in the north part and at the west of Bouteldja where the lithology presents fine to coarse sands and sands with gravels and where the purification capacity of the soil over the vertical way Md is inferor to 1due to the pizometric level which is very near the surface of the soil and which gives an insufficient self-purification and incomplete. Thus, it should be continued in the aquifer layer (the saturated zone).
- The surface protected terrain but presenting a risk of pollution of groundwater by (underneath contamination) is localized in the Northeast and at the West of Bouteldja). The lithology of this terrain is composed of fine sands and clay sands or clay where we note a high purification capacity of the soil over the vertical path Md is Superior to 1, associated with a relatively important thickness of the unsaturated zone (piezometric level compared to soil more than 5m).
- The protected zone with a weak risk of pollution occupies a very limited surface in the dunaire massif of Bouteldja. At that place the purification capacity of the soil over the vertical path Md is Superior to 1 because of the importance of the piezometric level compared with the surface of the soil.

3.4.2. The free aquifer of El-Chatt

The interpretation of the El-Chatt aquifer analyses allows as to distinguish between two different types of vulnerability and risk to pollution (**Fig. 1**):

- The vulnerable terrain with risk of pollution occupies the majority of El-Chatt community. The lithology of this terrain is formed by wind white sands. The wells present a purification capacity of the soil over the vertical path Md inferior to 1 (The piezometric level of these wells are very near the surface of the soil almost 1.5m) and the organic contamination ICO is high and reaches 5.

- The protected zone presenting a risk of pollution occupies the center of El-Chatt area. The lithology is the same and the purification capacity of the soil over the vertical path Md is superior to 1 with a piezometric level far from the soil surface (8m). However we note that the organic contamination index values (ICO) are also high.

3.4.3. The deep aquifers

In the deep aquifers we can distinguish two different states of vulnerability and risk to pollution.The red color shows the vulnerable estate and the green one the protected a state .

- The red is less present, it occupies the surfaces that are very limited in Annaba plain along the Seybouse Wadis and which indicates a vulnerable area that presents a risk of pollution. The lithology of the unsaturated zone is clay marly and where the purification capacity of the soil over the vertical path Md is superior to 1 in the majority of the drillings .The vulnerability is rather related to the organic ICO and mineral contamination indexes ICM and which are respectively high and respectively up to 6 (Saline drillings) and up to 5 (Pont Bouchet drillings).
- The green almost occupies all the part of the deep aquifer of El-Hadjar towards Ben M'hidi; El-Asfour with a good protection of the aquifer .The majority of the drillings and the wells have a soil purification capacity over the vertical path Md superior to 1 up to 5. At this place the clay layer is very thick. It is 10 to 15 m with a mineral contamination index ICM that sometimes exceeds 6.

3.4.4. The superficial aquifer

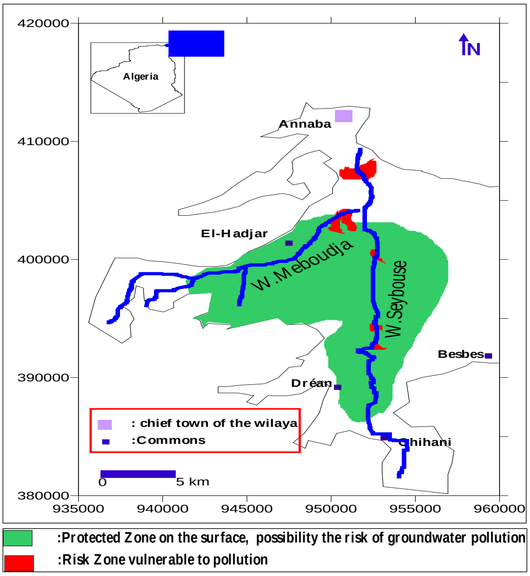

Fig. 9 Map of vulnerability and pollution risk of the superficial aquifer in Annaba region.

There are two types of states of vulnerability and risk to pollution in this aquifer (**Fig. 9**):

- The vulnerable terrain with risk of pollution occupies the red colored area. The lithology of this terrain is essentially formed of sandy-clay layer with a soil purification capacity over the vertical path Md inferior to 1 linked above all to the piezometric level near the surface of the soil (inferior to 1 m). The mineral contamination index is very high up to 6.
- The green which almost occupies all El-Hadjar plain indicates a surface protected terrain with a possible underneath contamination risk. The lithology is nearly the same where the soil purification capacity over the vertical path Md is superior to 1 but the organic ICO and mineral contamination index ICM are high.

In this aquifer, there are two types of states of vulnerability (**Fig. 9**) and risk of pollution.

4. CONCLUSION

The realized diagrams over the studied region have made it possible to make a distinction between the different degrees of pollution with a neat classification of the different studied aquifers resulting in the following conclusions;

The most vulnerable aquifers with a high risk of pollution are situated all along the Mediterranean Sea: the unconfined aquifer of El chat and the aquifer of the massive dunaire of Bouteldja because of the thickness of the unsaturated zone and of the good permeability of its geological formations. However these aquifers remain the major source of drinking water (good quality) and the diverse agricultural and industrial uses in Annaba region.

The relatively better protected aquifers are the superficial and the gravel deep aquifer (confined aquifer). Despite the intensive agricultural and industrial activity in the region, these aquifers are vulnerable when in contact with the Seybouse and Meboudja wadis.

Because it has been proved that these vital, big groundwater reservoirs are vulnerable and present a risk of pollution, the following protection measures must be taken:

- Protection perimeters supported by a general evacuation plan of used water must be installed.
- Purification stations of used water in the urbanized localities must be constructed.

REFERENCES

Antonakos A.K., Lambrakis N.J., (2007), *Development and testing of three hybrid methods of the assessment of aquifer vulnerability to nitrates based on the drastic model, an example from NE Korinthia. Greece*, Journal of Hydrology, volume333, Issues2-4, 15, 288-304.

Attoui B., (2010), *Etat de la vulnérabilité à la pollution des eaux des grands réservoirs d'eau souterraines de la région d'Annaba-El-Tarf et identification des sites d'enfouissement de déchets. Mémoire de magister*, Université d'Annaba, 1-64.

Baghvand A., Nasrabadi T., Nabibidhendi G., Vosoogh A., Karbassi A., Mehradadi N., (2010), *Groundwater quality degradation of an aquifer in Iran central desert*, Desalination, vol. 260, Issues1-3, 30 September 2010, 264-275.

Boufekane A., Saighi O., (2010), *Utilisation des Sig pour la caractérisation de la vulnérabilité à la pollution-Application a la nappe Alluviale de l'Oued Nil (Jijel,N.E Algérien)*, Journal International Network Environmental Management conflicts Santa Catrina-Brazil, 1(1), 267-274.

Bousnoubra H., Kherrici N., Deradji E.F., (2005), *Vulnérabilité de la nappe dunaire de Bouteldja (Nord-Est algérien) à la pollution et à l'aménagement*, Earth and Life, vol. 1, N3, 15-22.

Bousnoubra H., (2002), *Ressources en eaux des région de Skikda, Annaba, El-Tarf, Geulma, Souk Ahras, évaluation, gestion et perspective vulnérabilité et protection. Doctorat d'Etat*. Université d'Annaba, 150p.

Chaffai H.L., Djabri L.S., Lamrous S., (2005), *Réserves hydriques de la Wilaya d'Annaba. Inventaire, evaluation et besoins futurs en ressources en eau*. Hydrogéologie n 4, 31-35.

Debiechet H., (2002), *Evolution de la qualité des eaux (salinité, azote et métaux lourds) sous l'effet de la pollution saline, agricole et industrielle. Application à la basse plaine de la Seybouse Nord-Est algérien. These Doctorat*, Univ. de Franche-Comté, 199 p.

Derradji F., (2004), *Identification quantitative et qualitative des ressources en eau dans la région d'Annaba – El Tarf (Nord-Est de l'Algérie) . Thèse de doctorat d'état.* Université d'Annaba, 124 -200.

Detay M., (1997), *La gestion active des aquifères Masson*, 145p.

Ettiene Dongo K., Boyssoro H., Dibi B., Mahaman B., Biemi J., *Contribution des Méthodes de Vulnérabilité Intrinsèque DRASTIC et GOD à l'Etude de la Pollution par les Nitrates dans la*

Région de Bonoua (Sud-Est de la Côte d'Ivoire), European Journal of Scientific Research, ISSN 1450-216X, Vol. 31, No.1, 157-171.

Hamzaoui W., (2007), *Caractérisation de la pollution des eaux en milieux industriels et urbain cas de la plaine d'El-Hadjar .Mémoire de magister*. Université d'Annaba, 21-25.

Hani A.D., (2003), *Analyse méthodologique de la structure et des processus anthropiques: Application aux ressources en eau d'un bassin côtier méditerranéen, These Doctorat*. Es-Sciences, Univ. Annaba, 214p, 18-33.

Kherici N., (1993), *Vulnérabilité à la pollution chimiques des eaux souterraines d'un systèmes de nappes superposées en milieu industriel et agricole Annaba –la Mafragh Nord –Est Algérien. Doctorat d'Etat,* Univ de Annaba, 28-34.

Kherici N., Bousnoubra,H., Derradji E.F, Rouabhia A.K., Fehdi C., (2010), *A new graphic for the determination of the vulnerability and risk of groundwater pollution,* Geographia Technica. No.1, 1-24.

Lake, L.R., Lovett. A., Hiscock K.M, Beston M., Foley A., Sunnenberg G., Evers S., Fletcher S., (2003), *Evaluating factors influencing groundwater vulnerability to nitrate pollution: developing the potential of Gis*, Journal of Environmental Management, vol. 68, Issue 3, 315-28.

Mohamed H.H, Ayed A., Alain F., Ramiro R., (2007), *Validité de l'application des méthodes de vulnérabilités DRASTIC,SINTACS et SI à l'étude la pollution par les nitrates dans la nappe phréatique de Metline –Rasjbel-Raf Raf (Nord-Est Tunisien),* compte rendus Géosciences, vol. 339, Issue 7, 493-505.

Saadali B., (2007), *Concentration des éléments chimiques des sources dans le massif dunaire de Bouteldja, Mémoire de magister*, Université d'Annaba, 17.

Saidi S.,Bouri S., Bendhia H., Anselme B., (2009), *A Gis-based susceptibility indexing method for irrigation and drinking water management planning: Application to Chebba-Mellouleche.Aquifer, Tunisia.* Agricultural water Management, vol. 96, Issue 12, December 2009, 1683-1690.

Schijven J.F, Hassnizadeh S.M, Husman, A.M (2010), *Vulnerability of unconfined aquifers to virus contamination water research*, vol. 44, Issue 4, February 2010, 1170-1181.

Sedrati N., (2006), *Vulnérabilité et impact des agglomérations sur la qualité des eaux .du massif dunaires de Bouteldja Mémoire de magister*, Géologie, Université d'Annaba, 43.

Rouabhia K., (2004), *Vulnérabilité et risque de pollution des eaux souterraines de la nappe des sables miocènes de la plaine d'El Ma El Abiod (Algérie),* Sécheresse, vol. 15, N 4, 347-352.

Worrali F., Kolpin D.W., (2004), *Aquifer vulnerability to pesticide pollution-combining soil, land-use and aquifer properties with molecular decriptors*, Journal of Hydrology, vol. 293, Issues 1-4, June 2004, 191-204.