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A New Graphic for the Determination of the Vulnerability and Risk of Groundwater Pollution

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Abstract: Through the world, methods of vulnerability estimation and risk of groundwater pollution are very numerous. They use the parametric systems with numerical quotation, the cartographic superposition or the analytical methods which are based on the equations. The analysis of the vulnerability and the risk of groundwater pollution presented in this paper were carried out based on the combination of two criteria: the index of self-purification and the index of contamination. It is summarized with a new graphic method, in the form of abacus, simple and rapid of use. It is an abacus made up of two diagrams of triangular form connected to a third of rectangular form identifying the degree of vulnerability and the risk of underground pollution waters. On one of the triangles are represented the index of self-purification of the soil and the thickness of the unsaturated zone and on the other triangle are represented the indices of organic and mineral contamination of groundwater.

Key words: Groundwater • Vulnerability • Pollution • Contamination • Self-purification

INTRODUCTION

The estimation methods of groundwater vulnerability to pollution are very numerous, each one working out its method according to its needs. The methods can be divided into three groups [1]: the cartographic methods which are based on the superposition of maps, methods of the parametric systems which use a numerical system of quotation and, the analytical methods.

According to Vrba and Zaporozec [2], from a qualitative point of view, it is possible to indicate the correlation between three factors, according to the type of method (the density of the points, the quality of information and the denominator of scale). Thus the complex analytical methods are used on a small scale and require an important density of points. For an average density of points, a method with numerical quotation will be preferably used. Lastly, in the zones where the quantity of information is less, it is a cartographic method on a large scale which will be recommended [1]. The number of parameters varies also from one method to another: it often ranges between 3 and 4, but it is seldom higher than 7. A method using a significant number of parameters does not require inevitably more information than another while using less.

From one author to another, a parameter is not given in same manner, with the same processes and properties.

Methodology: The method suggested is given in the form of abacus and is articulated around the purifying capacity of the soil (Index of self-purification) and of the index of contamination. The components of the soil arise under three essential phases: constituent minerals and organics a solid phase, a liquid phase (water) and a gas phase (air, gas …).

The recognition of a soil is based on a good description of the geological profile [3, 4] such as: thickness, porosity, permeability and; mineral and organic composition of the soil. These parameters are important to appreciate the dispersive and purifying capacities soil, with respect to an effluent.

Other physic-chemical factors implicated, act on the transport of solid particles and on the displacement of bacteria and viruses. Geochemical phenomena interfere on the transfer of solutes by adsorption/desorption, precipitation/dissolution. It follows then a degradation of organic compounds in a complex middle with the presence of organic matter, colloids, oxides...

If the purifying capacity of the soil, then that of the unsaturated zone is efficient, the concentration of a pollutant can be considerably reduced before reaching the aquifer.

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Before describing the methodology of the study, it appears important to point out some definitions [5, 6]:

- The notion of vulnerability is based on the idea which the physical middle in touch with the aquifer, gives a more or less high degree of protection with respect to pollutions, according to the characteristics of this middle.
- If vulnerability exists, the risk of pollution results then from the crossing of one or several dangers and from one or several stakes.

To establish the abacus for determining areas of vulnerability and risk of pollution, one bases essentially on the index of contamination [1, 5, 7, 8] and on the index of self-purification [3].

RESULTS AND DISCUSSION

Index of self-purification: The index of self-purification is taken of the method of Rehse; it needs:

- The purifying capacity of the section of soil surmounting the aquifer.
- The thickness of the unsaturated zone.

The principle of calculation of the method of Rehse is simple: we consider that the purification varies according to crossed mediums and proportional to covered distance. This precondition is expressed by the relation:
According to Rehse [9]:

$$E = h_1 i_1 + h_2 i_2 + h_3 i_3 + \ldots h_n i_n$$

E : Total purification during the transfer.
h : thickness not wet of the different soils encountered.
I : characteristic index linked to each type of ground.

If E is superior than 1 [9], we consider that the purification is complete. In the contrary case, it is enough to define the complementary horizontal distance to optimize purification. It is obvious that the not very permeable soils (marly or clay) will have a higher power purification than the very permeable soils. It should therefore be interpreted according to the characteristics of potential pollutants and hydrodynamic conditions of the middle.

Contamination Index: The abundance of the organic and inorganic chemical elements could be related to the human activity (factory, breeding, spreading of fertilizers…). By admitting class-intervals in mg/l, for each element and by adding them, one can locate the indices of contamination [1, 5, 8]. More the index is higher; more the water point is contaminated, consequently vulnerable and presents a risk of pollution.

In the abacus proposed, one considers two indices of contamination: an organic index of contamination (ICO) and an index of mineral contamination (ICM). The organic index of pollution is based on some parameters resulting from organic pollution: nitrates (NO^{-}_3), ammonia (NH_4^+), nitrites (NO_2^-), orthophosphates (PO_4^{---}) and the DBO_5.

The index of mineral contamination is based on the parameters resulting from mineral pollution: lead (Pb^{++}), chromium (Cr6+)…. For each one of these parameters, 3 classes of contents are distinguished having an ecological significance according to limits of WHO. The indices (ICO and ICM) are the average of the numbers of class for each parameter and the values obtained are divided into 6 levels of pollution. These levels are much more important if one takes more than 4 parameters. Thus these indices make it possible to give an account (of manner synthetic) of organic and mineral pollution existing at the intake points.

In order to facilitate the use of the abacus, an application to two organic pollutants and the two inorganic pollutants (mineral pollution) most significant from the contents point of view are required. Taking account of this precondition one will present a demonstration to identify the contamination. At first approximation one will define 03 classes according to the contents:

Contents of the pollutant (mg/l)	Traces •	Natural •	Limit WHO •
Classes	1	2	3

These three classes are defined according to some contents (in mg/l) thresholds (Traces, Natural, Limit WHO) [10-16]. To define the threshold of the natural contents, we takes account of the importance of the concentrations in each types of aquifer (shallow or deep: the nitrates for example tend to decrease in-depth) or by the natural presence of concentrations. Also certain thresholds resulting from library searches or will be calculated by interpolation.

The classes thus defined, depend on the indices of organic and mineral contamination.

Combinations of the ICO or the ICM: Considering these classes (1, 2, 3) one can have the combinations of the following indices of contamination (Table 1).

Table 1: Index of contamination classes according to the combinations of ICO alone or in the ICM only

Classes ICO1 or ICM1	1	1	1	2	2	2	3	3	3
Classes ICO2 or ICM2	1	2	3	1	2	3	1	2	3
Indice of contamination	2	3	4	3	4	5	4	5	6

Table 2: Total index of contamination (ICT) based on the sum of classes combinations of the ICO and ICM

Classes ICO	2	2	2	2	2	3	3	3	3	3	4	4	4	4	4	5	5	5	5	5	6	6	6	6	6
ClassesICM	2	3	4	5	6	2	3	4	5	6	2	3	4	5	6	2	3	4	5	6	2	3	4	5	6
ICT*	4	5	6	7	8	5	6	7	8	9	6	7	8	9	10	7	8	9	10	11	8	9	10	11	12

N.B. (*) ICT: Indice of Total Contamination

For Example: NO_3^- identifies ICO1; Pb^{++} identifies ICM1; DBO_5 identifies ICO2; Cr^{6+} identifies ICM2.

According to table1, some is the made combinations of classes ICO1 or ICM1 and of ICO2 or ICM2, one can have only the following indices of contaminations:

2(*) : this value indicates that the water point is not contaminated.
3 : with this value the contamination is felt: low grade.
4 : this value indicates a contamination: moderated grade.
5 : this value indicates a contamination: moderated grade.
6(*) : this value indicates: high grade.

N.B.(*) These values will be more important with several parameters (polluting) used.

Combinations of the sum of the Index (ICO and ICM): Based on table 1 we can establish the various combinations of the sum of the indices of contaminations of the ICO and ICM (Table 2).

According to table 2 the sum of the indices of contaminations (ICO and ICM) can be only of:

Sense of increasing contamination

4(*) : This value indicates that the point of water is not contaminated.
5 : with this value contamination arises (low grade).
6 : this value indicates a contamination.
7 : this value indicates a contamination.
8 : this value indicates a contamination.
9 : this value indicates a contamination.
10 : this value indicates a contamination.
11 : this value indicates a contamination.
12 : This value indicates contamination (high grade).

N.B. (*) This value will be more important with several parameters (pollutants) (it will be equal to the number of parameters used).

Having information necessary on the indices of contaminations (organics and mineral) and on the index of self-purification of the unsaturated zonem, it is possible to represent these data on the abacus proposed (Figure.1). The state of vulnerability and risk of pollution of the water point studied is defined by the Cartesian coordinates of the point of its total index of contamination and of the point of its total index of self-purification, defined on the two triangular diagrams (Figure 1).

The triangle A which indicates the total index of self-purification: equal to the product hickness by the index of self-purification. The triangle B represents the total index of contamination: equal to the sum of the indices of organic contamination (ICO) and mineral (ICM).

From the abacus, 4 zones of vulnerability and risk of pollution will be then defined:

Zone I: Zone protected nonvulnerable to pollution without risk from pollution.

Zone II: Vulnerable zone with weak risk of pollution (Absence of vertical self-purification (self-purification in the nonsatisfactory unsaturated zone), vulnerable zone far from all human activities.

Zone III: Protected zone surfaces some (satisfactory vertical Self-purification), possibility of underground risk of pollution.

Zone IV: Vulnerable zone with risk of pollution (absence of vertical self-purification).

Two cases of application are represented for better illustrating the method of determination of the vulnerability and risk to the water pollution:

- First case: unsaturated zone made up with only one geological facies
- Second cases: unsaturated zone made up with several geological facies

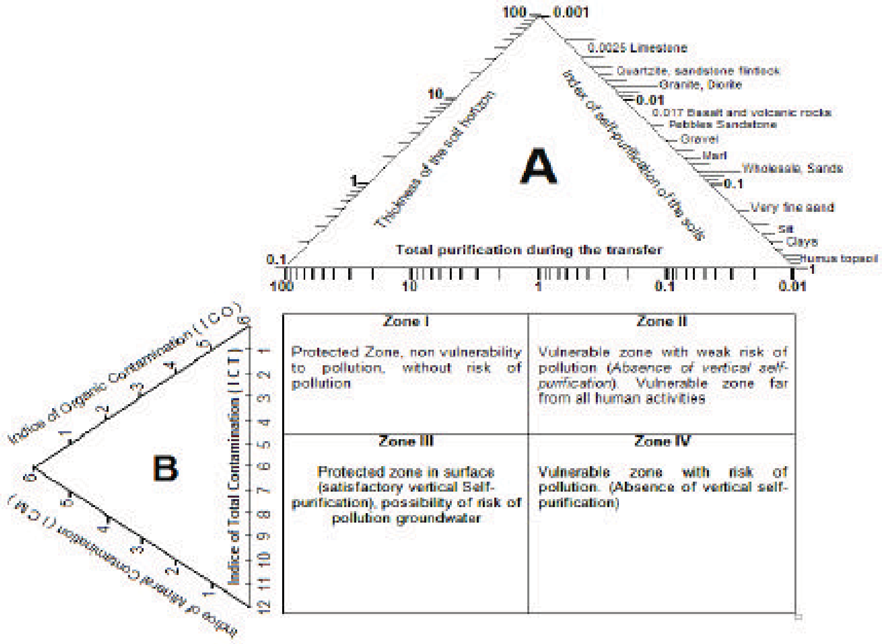

Fig. 1: Determination of vulnerability and risk of waters pollution zones (N. KHERICI)

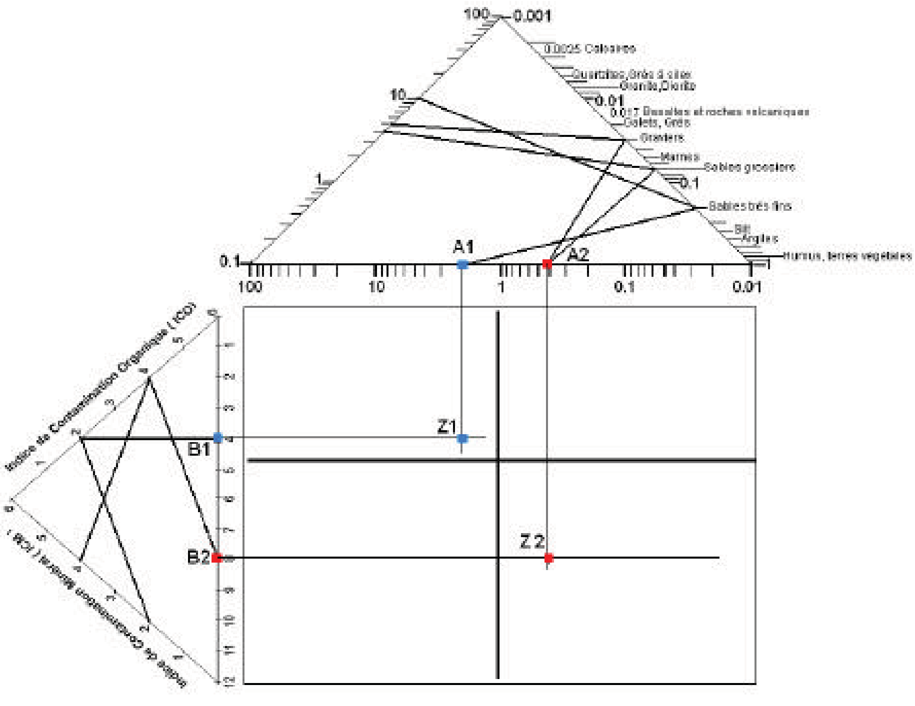

Fig. 2: Example of determination of vulnerability and risk of waters pollution zones (N.KHERICI)

Example 1: The unsaturated zone with a water point consists of 10 meters of sands.

NO_3^- = 3 mg/l; DBO5 = 1 mg/l
Pb^{++} = Traces; Cr^{6+} = trace

Example 2: The unsaturated zone with a water point consists of 4 meters of coarse sands and 5 meters gravels.

NO_3^- = 56 mg/l; DBO_5 = 2 mg/l
Pb^{++} = Traces; Cr^{6+} = 0.1 mg/l

•For NO_3^- (ICO1) the classes will be the following ones:

Polluant organique1 (NO_3^-) (mg/l)	Traces	00-10	Natural	10-50	Limit WHO	>50
Classes		1		2		3
Example 1		1				
Example 2						3

•For DBO_5 (ICO2) the classes will be the following ones:

Polluant organique 2 (DBO_5) (mg/l)	Traces	00 - 01	Natural	01 - 05	Limit WHO	>05
Classes		1		2		3
Example 1		1				
Example 2				2		

•For Pb^{++} (ICM1) the classes will be the following ones:

Pollutant minéral 1(Pb) (mg/l)	Traces	00-0.0	Natural	0.0-0.1	Limit WHO	>0.5
Classes		1		2		3
Example 1		1				
Example 2		1				

•For Cr^{6+} (ICM2) the classes will be the following ones:

Contents of the organic pollutant(mg/l)°	Traces	00-0.0	Natural	0.0-0.0011	Limit WHO	>0.05
Classes		1		2		3
Example 1		1				
Example 2						3

-In example 1 the index where:

ICO (ICO1+ICO2) = 1 + 1 = 2 (class 1 for NO_3^- et class 1 for DBO_5)
ICM (ICM1+ICM2) = 1 + 1 = 2 (class 1 for Pb^{++} et class 1 for Cr^{6+})

-In example 2 the index where:

ICO (ICO1+ICO2) = 2 + 2 = 4 (class 2 for NO_3^- et class 2 for DBO_5)
ICM (ICM1+ICM2) = 1 + 3 = 4 (class 1 for Pb^{++} et class 3 for Cr^{6+})

The representation of these two examples is illustrated in Figure 2. The two examples illustrated in this article are enough to show the potential of the application to support the exploration and the simple and fast analysis of the vulnerability and the risk of groundwater's pollution.

Z1 [A 1 = 2; B1 = 4] : Protected Zone, non vulnerability to pollution, without risk of pollution

Z2 [A2 = 0.43; B2 = 8]: Vulnerable zone with risk of pollution. (Absence of vertical self-purification)

CONCLUSION

To show the state of vulnerability of the aquifers and the risk of pollution; sometimes the data call upon treatment rather complex and heavy of use. The recourse to various diagrams and graphs is thus rather frequent. Some diagrams are suitable to study very specific risks, others only determines the vulnerability of middle. For this purpose a new method was developed. It uses, simultaneously, the qualitative data of water and the physical data of soil. The new diagram proposed, is formed by two triangles, one representing the natural agents (thickness of the unsaturated zone, geologic facies, degree of self-purification) and the other anthropogenic agents (organic and inorganic pollutants). The diagnosis is then rapidly. This method can be generalized to several parameters (pollutants) by multiplying combinations of classes, which requires a simple reorganization of the diagram indices of contamination.

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