THE ARTIFICIAL RECHARGE OF THE AQUIFERS BY CONSIDERING THE GROUNDWATER VULNERABILITY TO POLLUTION.

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ABSTRACT

The water resources shortage in arid and semi-arid regions let water managers searching for adequate solutions which can respond to the increasing demand.
Artificial recharge of aquifers by resources drawn from far away is a mobilisation mode adopted especially in arid and semi-arid areas. The cost of this operation is often very high but counterbalanced by the advantages provided by this mean:

- mobilisation of this resource in zones were it's available;
- injection by different means in aquifer zones whose characteristics are known;
- a storage mode which allows to conserve resources from evaporation, as opposed to storage in dams that are also confronted to deposits that reduce considerably their capacity;
- Artificial recharge can also benefit from natural mean of transport when it takes into account the groundwater hydraulic gradient at a time of choosing injection zones.

Artificial recharge on permeable zones constitutes the most used mean but such zones are unfortunately the most vulnerable to pollution.
If the aquifer conductivity and that of the vadose zone is an important factor for pollutant propagation, the groundwater pollution potential is conditioned by a number of factors which control and affect the groundwater flow.
The cartography of the groundwater pollution potential of a given area, combined to the repartition of favourable zones to artificial recharge, constitute a tool to decision making concerning the choice of recharge zones that takes into account environmental aspects.

Keywords: Groundwater, Artificial Recharge, Pollution, Vulnerability

1. INTRODUCTION

The artificial recharge, answers according to cases, to three principal concerns :

- Modification of the water quality;

- Restoration of a disturbed balance;
- Increase the resource volume and the optimization of the mode of exploitation.

This last point is the principal objective needed in the arid and semi-arid areas by considering the water resources shortage.

In the case of aquifers with free tablecloth, witch is the most common case, the devices implemented for the provoked infiltration varies from the simpler to the most complete device: in river beds, in basins of “full land”, in basins with vegetation or with sand…

One can also quote the spreading of risings which is practised in many arid plains in Africa and Asia.

At the upstream of any operation of basin recharge, the pre-treatment by decantation is essential to lower the solid load of water (generally with less 1g/l).

In addition, operations of harrowing, tilling or of installation of a vegetable carpet in the basins contribute to the maintenance and the reduction of the filter layers obstruction; this obstruction being the principal disadvantage which limits the lifespan of the device and lead to the renewal of the ballasting. The duration of activity without maintenance of the ballasting depends on the quality of water injected. The installation of pre-filters (generally of gravels from 5 to 12 mm) as well as an intense ventilation of water by a flow in cascades at the upstream of the recharge basins improves appreciably the output of the device (Bize et al. [1]).

More powerful means of pre-treatment, by improving considerably quality of water, contribute to improve the total output of the device like the sifting or the injection of coagulant and activated carbon.

Another process consists in coupling the recharge operation with the lagunage in the same basin. The lagunage lasts approximately 2 weeks. On its arrival in the basin, water is charged by oxygen while cascading. In addition, the algae and various species of plankton produce large quantities of oxygen (which can exceed triple of the value with saturation).This oxygen allows the bacterial destruction in solution. The chlorophyllian activity of the plankton breaks up CO2, which causes a massive reduction in bicarbonates and a partial softening of the water.

In spite of its beneficial effects, the lagunage leads to a relatively intense obstruction following the precipitation of the carbonated products and the proliferation of algae.

Even in case of pre-treatment, the risk of groundwater pollution remains. It’s consequently useful to determine the vulnerability to pollution of a given area before making any operation of recharge there.

2. PROCESSES WHICH AFFECT THE CONTAMINANTS

The attenuation of a contaminant during its transit through the soil, the vadose zone and in the aquifer is controlled or affected by various natural physical processes and chemical reactions which lead to the change of its state. The extent of these reactions depends on the conditions present such as for example the pH, the potential redox, the size of the grains, the surface of the zone.... The chemical processes in the hydrodynamic systems are complex and depend as well on particular characteristics of the aquifers as on properties of pollutants (Cherry et al. [2]).

The parameters which have a role in the attenuation of a contaminant are mainly: the density, the solubility, the sorption, the biodegradation, the oxidation and reduction, the dilution, the hydrolysis, the dispersion, the viscosity, the mechanical filtration, the ionic exchanges, the volatilization and the neutralization (fig.1) while the degree of attenuation depends on:

- The time of contact between the contaminant and the material through which it circulates;
- The size of the grains and the physical and chemical characteristics of the aquifer media, like those of the vadose zone and the soil;
- The distance covered by the contaminant.

For many materials the degree of attenuation of the contaminant is significant when:

- The time of contact increases;
- The specific surface of the grains increases;
- The distance covered by the contaminant is large;

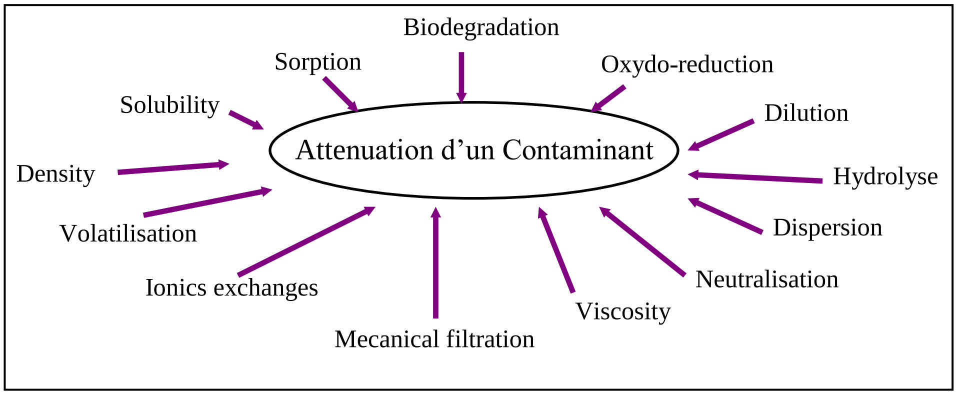

Fig. 1 - Principal parameters having a role in the attenuation of a contaminant

Before reaching the saturated zone, a contaminant crosses the soil and migrates by the vadose zone. The processes of attenuation which proceed there are especially the biodegradation, the neutralization, the mechanical filtration, the volatilization, the dispersion and certain chemical reactions.

The degree of the biodegradation and the volatilization decreases with the depth. The type of the material intervenes in the length of the circuit and thus in the propagation of the contaminant.

Among the mechanical processes of the attenuation of the contaminants, one can quote:

- The dilution;
- The mechanical filtration which retains contaminants which are broader than the pores of the filtering device. The retention of the large particles will decrease the porosity and the permeability of the device which requires a regular maintenance;
- The dispersion which is a process of a no permanent and irreversible mixture through which the contaminant disperses in groundwater according to two components: longitudinal in the direction of the flow and transversal, by repeated divisions. Dispersion in a porous aquifer and under a streamline flow, results in fact from the combination from two processes which are the molecular diffusion and the mechanical dispersion (Todd [3]; Wilson et al. [4]). The dispersion form depends in fact on the way in which contaminant is introduced in the aquifer (continuous or discontinuous). Dispersion depends also on the homogeneity of the aquifer: if the permeability increases, dispersion is more significant than if the permeability is low;
- The viscosity of a contaminant controls partially the rate of migration because it is indirectly proportional to the permeability; moreover it decreases with the increase of the temperature. The reductions of the half of the viscosity will double hydraulic conductivity.

Through various mechanisms, physical or chemical, natural or provoked, the processes of attenuation of the contaminants act all along the transit of the contaminant since the soil surface up to the saturated zone of the aquifer.

Before an operation of artificial recharge by a provoked infiltration, it’s interesting to seek the optimization of the natural processes of attenuation of the contaminants, or rather the research of the zones where the component: soil-vadose zone-materials of the aquifer give an optimized character to the processes of attenuation.

Indeed, in an objective of efficiency of the recharge, the sites usually chosen are those which offer, inter alia parameters, a short time of transit for the injected water, a low depth of the saturated zone (4 to 10 m starting from the bottom of the basins of infiltration), a good permeability of materials of the vadose zone and of the aquifer.

This step is valid when an effective treatment is operated at the upstream of the operation of recharge, this is unfortunately not the case in the areas where the means miss.

Thus, in order to minimize the risk of pollution of an aquifer starting from an operation of recharge, it is necessary to know the spatial distribution of the vulnerability to pollution of the groundwater in the concerned zone. The definition of this parameter will allow a better choice of site.

3. THE GROUNDWATER VULNERABILITY TO POLLUTION

The vulnerability to pollution of the aquifers is the result of a combination of several factors: hydrogeologic, reaction aquifer-contaminant and sources of contamination in a given area.

3.1 Different approaches of the vulnerability to pollution

The assessment of the groundwater vulnerability to pollution was the object of many works in last years:

- Method Legrand [5]: it uses numerical quotations to evaluate the vulnerability to pollution of a given site (hydrogeology of the site, the sensitivity of the aquifer combined with the severity of a contaminant, the natural vulnerability to pollution of the site and the undergone changes by the site). Numerical quotations remain in this case with the appreciation of the engineer, therefore subjective and at ends of comparison between different sites in particular;
- Gibbs et al. [6] established a classification of the wastes sites by taking account of their potential hazard to populations, and this through the contamination of the groundwater. The classification of the site is done via four factors: risk on the health of the site and the mode of waste processing adopted, the concerned population, proximity of the wells or aquifers and susceptibility of the aquifers to the propagation of a contaminant. A variable number between 0 and 100 is used to indicate the potential risk of a given site. This approach is used in particular cases and by a qualified technical staff;
- Another approach was developed by the department of the natural resources of Michigan [7]. Its purpose is to classify a great number of sites in terms of risk of contamination of the environment by assessing five principal parameters: the potential liberty of propagation of a contaminant, exposure of the environment, the potential targets, the chemical risks and existing exposures. The user of this approach obtains a number variable between 0 and 2000 points which evaluates the relative risk of a site compared with others;
- Hutchinson and Hoffman [8] developed a system of classification of the groundwater vulnerability to pollution, used by the geological service of the New Jersey. It’s an evaluation of the geological criteria of the site compared to the vulnerability (eleven factors) as well as the determination of the criteria of the zone (eight criteria).The combination of the factors and criteria gets a number variable between 0 and 100; the higher numbers correspond to high risks;
- The DRASTIC method was developed in 1987 in the United States by the Natural Water Well Association (Aller et al. [9]). It’s a standardized method of evaluation and cartography of the groundwater vulnerability to pollution independently of

the type of pollutant. It takes into account the physical properties which have a role in the migration and the attenuation of a contaminant within the complex soil – vadose zone - aquifer and which control and affect the groundwater flows: Depth to water, the effective recharge, the aquifer media, the type of soil, the topography, the impact of the vadose zone and the conductivity of the aquifer.

These factors are represented by weights and rates which depend respectively on their relative importance and on the local hydrogeologic conditions. The combination of the weights and rates of the various parameters procures a numerical value which is the DRASTIC index. The cartography of the vulnerability index rests on the superposition of 7 indicial maps.

The DRASTIC method rests on four fundamental assumptions:

- The source of the potential contamination is located at the surface of the soil;
- The contaminants are transported from the surface of the soil to the aquifer by infiltration;
- The contaminant has the same mobility as the groundwater;
- The type of contaminant does not intervene in the definition of the vulnerability.

This method considers in fact that the behaviour of the pollutant from the surface of the soil to the saturated zone is the same one as that of a rainfall subjected to infiltration. It thus procures a general indication on the distribution of the groundwater vulnerability to pollution in a given area, which can however include other parameters and information specific to a particular site.

The advantage of this method lies not only in the fact that it proposes a standardized numerical system for the evaluation of the groundwater vulnerability to pollution but also in its cartographic representation which is very important for the plans of occupation of soils.

One will also note that recent methods applied to the specific case of the karstic fields were developed these last years, such as the EPIK method developed by the center of hydrogeology of the university of Neufchâtel (Doerfliger and Zwahlen [10]).

An application of this method to the alluvial aquifer of the El Madher plain which is situated approximately at 15 Km at the North-East of Batna city (North East of Algeria) made it possible to delimit the zones vulnerable to pollution (Menani, [11]). The use of matrices of calculation whose elements represent the discretized field allowed a rigorous cartography of the groundwater vulnerability to pollution (fig. 2).

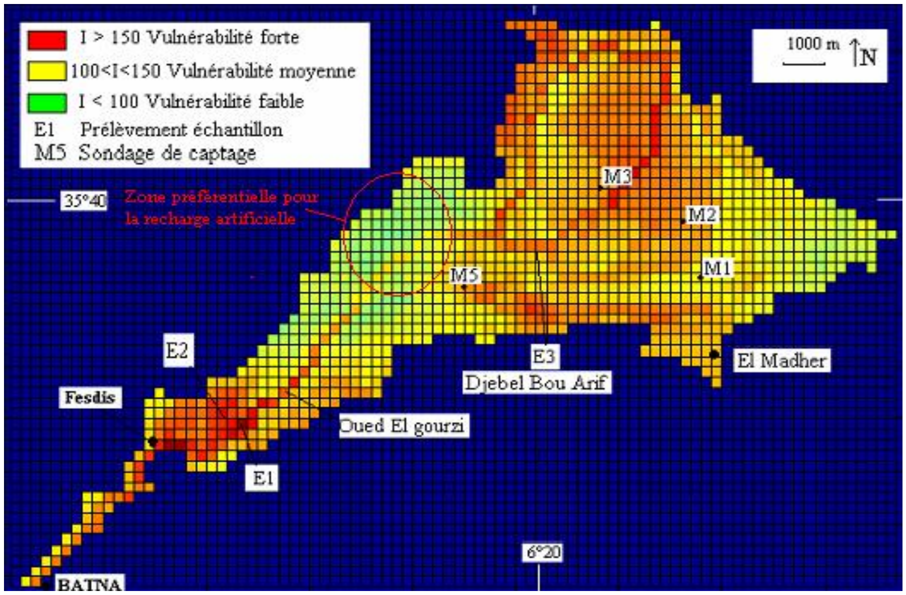

Fig. 2 – The groundwater vulnerability to pollution map of El Madher Plain (North-East of Algeria)

This short summary on the methods which treat the groundwater vulnerability to pollution shows the diversity of the approaches as well as the variety of the parameters taken into account. Some of these methods are applicable to particular cases. On another side, the appreciation of certain criteria, intrinsic or relative, seems subjective.

The territory management suggests an approach which would have the following advantages:

- Applicable in all cases
- Simple and easy to use
- Using informations generally available
- Exploitable at various levels of expertise
- Independent of the type of pollutant

3.2 Validity of the methods

It is difficult to carry out an assessment of the validity of all these methods, in particular those which take account of the nature of the pollutant, which returns to the evaluation of very particular cases.

On the other hand, concerning the methods which do not take account of the nature of the pollutant, like the DRASTIC method, the precision with which this method allows to distinguish between the vulnerable areas from those which are naturally protected, was tested in several areas of the United States (Aller et al., [9]) like in Quebec. In this last case and among others, Flechette [12]; Isabel et al. [13] and Champagne et al. [14] checked the validity of the method on different hydrogeologic units. In all cases, the really contaminated zones correspond to those where the indices of vulnerability are highest. In El Madher plain (Algeria), results of chemical analyses (Saadi [15]; Zouita [16]) also made it possible to check the correspondence of the vulnerable zones with the really polluted zones. These partial data tend to validate the DRASTIC method as an indicator of the groundwater vulnerability to pollution.

4. COMBINATION OF THE APPROACHES

The assessment and the cartography of the groundwater vulnerability to pollution of a given zone allow, on the basis of adapted method, to have a tool of decision-making for the choice of the sites of the artificial recharge.

Concerning the artificial recharge by provoked infiltration which interests us more particularly, it is useful to seek the sites which present the best possible combination of the natural processes of attenuation of the contaminants. The practical conveniences of installation of the basins of recharge as well as the financial incidence also intervene in the choice of sites but will not be treated here.

Besides the natural processes of mitigation of pollutants which take place in the aquifer, those which interest an artificial recharge take place in particular in the complex soil-vadose zone.

The attenuation of the contaminant, by mechanical processes, physical or chemical, is optimized by:

- A long time of contact between the contaminant and the material through which it transits or circulates;
- A complex soil - vadose zone - aquifer characterized by deposits in cycles or better, in rhythms, allowing a better mechanical filtration, a lengthening of the course of the contaminant as well as the facilitation of physicochemical reactions on the level of the fine particles (ionic sorption and exchanges primarily).

These criteria of attenuation are overall taken into account in the evaluation of the groundwater vulnerability to pollution in a given zone. If the zones least vulnerable to pollution constitute sites favourable to the artificial recharge, it cannot be however the only selection criterion. Indeed, these zones have characteristics which limit the speed of the recharge (fine elements, deposits in sequences, weak conductivity…).

In the areas where the means of treatment are missing, the evaluation and the cartography of the vulnerability to pollution of a given zone make it possible to locate the sites potentially favourable to the artificial recharge. More detailed characterizations can make it possible thereafter to refine the choice of the sites offering the optimum solution which takes account of the environmental aspect.

In the case of El Madher plain, zones with weak vulnerability, in particular that located in the Western part of the plain (sector of M5 catchment on figure 1), constitutes the zone most favourable for an artificial recharge of the alluvial aquifer. Conditions mentioned above are less constraining there.

5. CONCLUSIONS

The water resources shortage and their unceasingly worsened pollution, leads to the search for other alternatives of mobilisation, in particular in areas where the qualified personnel as well as the materials are missing.
The search for approaches which take account of this reality guided this article. To carry out an operation of artificial recharge of an aquifer by taking account of the environmental aspect in unfavourable contexts suggests a judicious exploitation of the natural conditions of attenuation of the contaminants.
The maps of the groundwater vulnerability to pollution which rest on various approaches are useful for the choice of the site destined to the artificial recharge.

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