GROUNDWATER VULNERABILITY IN DIFFERENT CLIMATIC ZONES

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Summary

The environmental control of all potential groundwater contaminant activities is economically not logical, and its implementation is almost impossible to perform because of serious administrative, social, and technical restrictions. In a similar way to the human activities that can generate contaminant loads of variable hazard to groundwater, different aquifers will respond differently to the same contamination event, because of their hydraulic and physico-chemical characteristics.

Aquifer vulnerability maps can aid in the differentiation of areas that need more environmental attention, including detailed studies and application of groundwater monitoring programs. In the same way, the knowledge of the contaminant degradation capacity by the unsaturated zone can reduce costs and environmental requirements during the installation of a new activity.

The term “vulnerability” is defined as an intrinsic property of a groundwater system that depends on the sensitivity of the material in permitting the degradation of the saturated zone by pollutant substances originating from human activities. Although the concept of vulnerability is simple in itself, its application presents peculiarities that, if not correctly identified, may limit its application in programs of groundwater resources protection.

Although the influence of climatic aspects on vulnerability is yet not well understood, it is well known that the climate can influence both basic parameters that manage the aquifer vulnerability: a) the water availability controls the level of hydraulic accessibility of the saturated zone to the penetration of contaminants; and b) the soil thickness, presence of clay minerals and organic material, and biological activity influence the contaminant attenuation capacity of the strata overlying the saturated zone. In semi-arid regions, the small thickness of the soil and little biological activity increase the vulnerability of aquifers. However this is counterbalanced by the deeper level of the water table, poor water circulation in the unsaturated zone, and presence of clay minerals (such as montmorillonite), that present high adsorption capacity of inorganic contaminants. On the other hand, in tropical and humid regions, the greater thickness and biological activity of the soils reduce the aquifer vulnerability. However the bioturbation creates a large amount of macroporosities that work as preferential pathways of water circulation. Furthermore, the retention capacity of the soils for inorganic contaminants is lower due to its typical clay mineralogy.

The determination of the vulnerability in any region must be based on the balance of the two basic parameters mentioned above.

1. Introduction

Since the early 1980s, concerns regarding aquifer contamination have increased exponentially worldwide. The major dependence on groundwater for potable water supply and many other economic activities has forced governments to establish effective programs in order to safeguard groundwater quality or even to remediate existing contaminated sites.

At the same time, the aquifer and soil remediation procedures present many problems, such as high costs of implementation, slow results, and in many cases, serious technological limitations. In addition, there is a limited availability of technical personnel in poor and developing countries.

Any urban or rural area is complex and presents many potential groundwater contaminant activities. A groundwater protection program that tries to apply universal controls over all activities or land uses is economically inconsistent, and its implementation presents serious administrative and social restrictions. Thus, the best strategies for groundwater quality protection are:

- To identify areas or activities that present higher hazard to groundwater quality, making it possible to establish priorities for environmental control,
- To constrain land occupation in areas that present more sensitivity and are thus more likely to be contaminated, and
- To protect important water sources that has been or will be used for public supply.

Groundwater pollution vulnerability mapping is an important tool to identify areas that are more sensitive to contamination.

There are two basic parameters that must be analyzed in the definition of the vulnerability of a specific region: that is, the hydraulic accessibility and the attenuation capacity of contaminants in the unsaturated zone and/or aquitard. The climate influences both, since it controls the availability of water for recharge, the depth of the water table, and soil thickness and other characteristics, such as mineralogy and biological activity, which control the attenuation and retention of contaminants.

2. Concept of Groundwater Pollution Vulnerability

The concept of aquifer pollution vulnerability, as understood today (2002), was preliminarily introduced during the 1960s and more widely used in the 1980s. Aquifer vulnerability is based on the idea that the strata overlying the saturated zone may provide some degree of protection to groundwater against an imposed anthropogenic contaminant load. The term vulnerability would then be defined as an intrinsic property of a groundwater system that depends on the sensitivity of the material in permitting the degradation of the saturated zone by pollutant substances originated from human activities.

Although the concept of vulnerability is simple, its characterization involves difficulties related to the geological aquifer complexities. Normally, each contaminant or group of contaminants has a specific fate and transport characteristics in the groundwater system, and there is no scientifically consistent single method that could cover them all.

For this reason, many authors have preferred to develop vulnerability methods for a specific contaminant, class of contaminants (pathogens, microorganics, heavy metals, nutrients, and so on), or type of activities. This vulnerability is called "specific" or "integrated" as opposed to "intrinsic" vulnerability, which depends on the characteristics of the aquifer only.

The procedure to elaborate specific vulnerability maps has many limitations, and adequate data and/or sufficient resources are still lacking to achieve this aim. On the other hand, an atlas for each specific contaminant or activity could be generated, although this procedure can present difficulties for implementation in a groundwater protection program.

VULNERABILITY CLASS	**DEFINITION**
Extreme	Vulnerable to most water pollutants with relatively rapid impact in many pollution scenarios
High	Vulnerable to many pollutants, except those strongly absorbed or readily transformed, in many pollution scenarios
Moderate	Vulnerable to some pollutants but only when continuously discharged or leached
Low	Only vulnerable to conservative pollutants in the long term when continuously and widely discharged or leached
Negligible	Confining beds present with no significant groundwater flow

Table 1. Absolute index for groundwater pollution vulnerability

In the future, because of the rapid development of computer techniques such as geographical information systems (GIS), it will be possible to manage many different maps, attributing different numerical values for each layer and, finally, allowing the easier operation of an aquifer vulnerability atlas.

A map that identifies areas with different attenuation capacities for a contaminant or a group of contaminants is generally the final product of the application of a vulnerability method. The majority of the techniques present relative vulnerability indexes rather than an absolute indicator of integrated pollution vulnerability. For practical reasons, an absolute index is much more useful and allows the comparison of geographically different areas. Table 1 presents a practical definition of aquifer pollution vulnerability classes.

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Biographical Sketches

Ricardo Hirata is an Assistant Professor and Researcher at the University of São Paulo and former Chief Hydrogeologist for the Geological Institute of the State of São Paulo (Brazil). He also worked for CEPIS/PAHO-WHO (Pan American/World Health Organization) in Peru, and the Water and Electric Energy Department in Brazil. His primary interests include groundwater contamination, water resource management, and groundwater protection policy. Dr. Hirata has participated in many missions in Latin America, as a temporary adviser for CEPIS/PAHO and the International Atomic Energy Agency (IAEA). He was also a Visiting Professor at the University of Costa Rica and finished his Post-Doctoral Fellowship at the University of Waterloo (Canada), and his Master's and Doctorate at the University of São Paulo (Brazil). Since 1983, he has worked intensively with groundwater, and teaching short courses in Brazil and 15 countries in Latin America and the Caribbean region. He has published 91 technical and scientific papers on a wide range of groundwater topics with increasing emphasis on groundwater contamination, and aquifer protection and management, including technical reference manuals for WHO/PAHO, World Bank and UNESCO.

Reginaldo Bertolo has his Master's and Doctorate in hydrogeology from the University of São Paulo (Brazil), and worked at the Geological Institute of the State of São Paulo and as senior consultant for several environmental consultancy companies. His areas of interest are soil and groundwater contamination, site investigation and remediation, regional hydrogeologic resources evaluation, wellhead protection area evaluation, and hydrodynamics and hydrogeochemistry of the unsaturated zone. He is presently working at ERM-Brazil, a consulting company.