WATER RESEARCH COMMISSION

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The WRC operates in terms of the Water Research Act (Act 34 of 1971) and its mandate is to support water research and development as well as the building of a sustainable water research capacity in South Africa.

TECHNICAL BRIEF

Groundwater

Aquifer vulnerability to contamination

Improved assessment methods and protocols for vulnerability mapping

Aquifer vulnerability – key research issues

When a formal strategy for groundwater protection research was being developed some years ago, among the key issues to be identified were the need for improved methods to assess the vulnerability of aquifers to contamination and the need for improved protocols for producing vulnerability maps, both taking into consideration available information on soils overlying the aquifers. Research addressing these issues has subsequently been completed and products of the research are now available for application by practitioners and decision-makers.

Definitions

Aquifer vulnerability to contamination comprises two components: **unsaturated zone** vulnerability and **saturated zone** vulnerability. For the unsaturated zone, vulnerability is defined as the ease with which groundwater at the water table may become contaminated by a contaminant source located at the soil surface or within the unsaturated zone.

For the saturated zone, vulnerability is defined both in terms of the length of time from cessation of contamination activities to when a given contaminant can be detected in the groundwater and, also, the volume of the aquifer in which the contaminant exceeds a preset concentration. The decision-maker might need to focus on either unsaturated or saturated zone vulnerability, or a combination of these, depending on the type of decision to be made.

Research products

Unsaturated zone vulnerability

For the unsaturated zone, the AQUISOIL (Aquifer Vulnerability Soil Assessment) approach and a modified DRASTIC approach, called EUZIT (Excel-based Unsaturated Index Tool) have been developed. Both approaches can be used for assessing vulnerability at the water table.

AQUISOIL focuses on the soil zone as the 'first line of defence', but can also be applied to the whole unsaturated zone down to the water table. AQUISOIL comprises three types of vulnerabilities which are rated for each single layer and weighted according to thickness, i.e. chemical, hydraulic and climatic variability.

With regards to chemical vulnerability, a new soil classification was developed, which relates sorption to selected soil properties by means of so-called chemical envelope equations, for more than 170 soil samples representing major diagnostic horizons and classes of materials recognised by the South African soil classification system. These envelopes predict the upper limit of contaminant sorption to be expected at a specified value of each soil property. Chemical vulnerability classes have been defined accordingly for the retention of cationic (metal), anionic and non-polar organic contaminants.

Hydraulic vulnerability is derived from a permeability index, which is based on soil texture and the presence or absence of a cemented layer or horizon. Climatic vulnerability uses a leaching or recharge index, calculated with one of several, optional, classical algorithms that take into account factors such as rainfall, surface runoff, profile storage etc. AQUISOIL has been incorporated in a spreadsheet programme for easy use.

EUZIT is a spreadsheet-based, modified DRASTIC approach that allows for a multilayer unsaturated zone. The vulnerability rating of the unsaturated zone is based on a combination of factors that contribute to the likelihood of contaminants reaching the saturated zone by following the path of aquifer recharge. The factors considered are the unsaturated zone thickness, hydraulic properties (vertical hydraulic connectivity), flow mechanism (preferential and matrix), travel time, recharge (based on well-established methods), slope and contaminant sorption and decay (degradation).

The weightings for each factor are user defined, depending on site-specific conditions.

Saturated zone vulnerability

Two approaches may be used to determine saturated zone vulnerability to contamination: one (numerical) uses geochemical and reactive transport models; the other (generic) generalises contaminant transport using an analytical equation. Research has concentrated on the first approach and has evaluated the aquifer vulnerability to inorganic contamination from landfill leachate, industrial effluent and acid mine drainage for two common aquifer types in South Africa (coastal primary and dual porosity aquifers). Vulnerability of the saturated zone to contamination is expressed in terms of both spatial impact and persistence of the contaminant.

GIS-based vulnerability assessment

A geographic information system (GIS) enables the compilation of vulnerability maps in conjunction with other infrastructural information so that planners and decision makers can easily relate to the results. Two GIS approaches have been developed to map unsaturated zone vulnerability: the one has incorporated EUZIT into a GIS to assess the variation in groundwater vulnerability across an area; the other makes use of a modified UGIf model.

By building the input datasets into a GIS and converting them to grids, the EUZIT algorithms can be applied using the GIS 'map calculator' functions. Within the GIS it is also possible to carry out a sensitivity analysis to optimise the weightings (and ratings) for each vulnerability factor.

Depending on the scale of the application and on spatial variability, a smoothing out of spatial variability is, however, possible owing to the use of relatively broad ranges for the rating classes. With further research, it would be possible to refine the rating classes to enhance spatial resolution with regard to the assessment and mapping of groundwater vulnerability.

The UFIf model, which estimates fluxes of organic pollutants in an urban environment, was modified to include screening level algorithms for vulnerability assessment. These require a combined grid containing attributes that include average recharge rates, soil volumetric water contents, vadose zone depths and retardation factor values. The UGIf model has been made suitable for South African conditions through the incorporation of representative land types.

The use of both the GIS-based EUZIT and UGIf are to be encouraged as they present decision-makers with a spatial representation of the vulnerability of the unsaturated zone.

Case studies

Two study sites were selected to illustrate the use of the newly-developed approaches to the assessment of groundwater vulnerability; the Goedehoop irrigation site near Secunda, in Mpumalanga, and the Coastal Park waste disposal site near Cape Town. It was found that the unsaturated zone vulnerabilities are relatively high for both aquifers.

The smaller travel times and higher leaching potential indices as derived from the AQUISOIL and EUZIT spreadsheet tools and the UGIf model lead to the conclusion that the unsaturated zone vulnerability to dissolved organic contaminants of the primary Cape Flats aquifer at Coastal Park is higher than the corresponding vulnerability of the dual porosity, weathered zone aquifer at the Goedehoop site. This means that contaminants generated at the surface are likely to reach the water table and pollute the aquifer sooner at the Coastal Park waste disposal site.

The unsaturated zone vulnerability, expressed in terms of the spatial impacts of inorganic and organic contamination, is expected to be higher at the Coastal Park waste disposal site, whereas the persistence of contamination is expected to be greater at the Goedehoop site. More detailed modelling that takes account of site-specific physical properties of the Cape Flats aquifer at the Coastal Park waste disposal site is needed to enable a better comparison of the saturated zone vulnerabilities of both aquifers.

Aquifer vulnerability and decision-making

Aquifer vulnerability assessments form an important input into managing the risk of water resource degradation. As part of the research, a framework to support decision-making has been developed to assist groundwater vulnerability assessment practitioners to understand the role of their assessments in groundwater management and to assist them in the selection of more appropriate approaches.

The framework highlights the fact that groundwater vulnerability assessments serve as an input into contaminant risk assessment which, in turn, will contribute to a cost-benefit analysis. It is the outcome of the cost-benefit analysis which will ultimately inform decision-making.

Further reading:
To obtain the report, *Assessment of Aquifer Vulnerability in South Africa* **(Report No: 1432/1/07)**, contact Publications at Tel: (012) 330-0340; Fax: (012) 331-2565; E-mail: orders@wrc.org.za; or Visit: www.wrc.org.za