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A regional flux-based risk assessment approach of contaminated sites on groundwater bodies

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Abstract In the context of the Water Framework Directive, management plans have to be set up about water quality issues in surface and ground water bodies in the EU. In heavily industrialised and urbanised areas, the cumulative effect of multiple contaminant sources is likely to present a risk which has to be evaluated. In order to propose adequate measures, the calculated risk should be based on criteria reflecting the risk of water quality deterioration, in a cumulative way and at the scale of the whole surface water or groundwater body. An integrated GIS- and flux-based risk assessment approach for groundwater and surface water bodies is described with a regional scale indicator for the evaluation of the quality status of the groundwater body. It is based on the SEQ-ESO currently used in the Walloon Region of Belgium which defines, for different water uses and for a detailed list of groundwater contaminants, a set of threshold values reflecting the levels of water quality and degradation with respect to each contaminant. The methodology is illustrated with a first real scale application on a groundwater body corresponding to a contaminated alluvial aquifer which has been classified at risk of not reaching a good quality status by 2015.

Key words regional risk assessment, groundwater body, industrial contaminants, Water Framework Directive, megasite

INTRODUCTION

The EU Water Framework Directive requires management plans about quality of surface and groundwater bodies. These plans can not be defined without considering contaminated industrial sites potentially harmful for water resources. Each single site does not necessary constitute a threat for the whole aquifer or the groundwater body. However, in heavily industrialised and urbanised areas, because of the spatial extent of groundwater bodies, many contaminant sources are likely to be considered with complex groundwater vectors for contaminant dispersion. In such a context, a meaningful regional risk assessment approach has to be developed (e.g. Critto & Sutter 2009), considering the cumulative effect of multiple contaminant sources. At the same time, all the spatially distributed data require GIS databases and decision tools.

METHODOLOGY FOR REGIONAL RISK ASSESSMENT

The regional risk assessment tool is structured as follows. A geodatabase, organised according to the Source-Pathway-Receptor schema, has been developed under MS Access environment to store and manage all the spatially distributed information required for regional risk assessment. An activity-matrix tool has also been incorporated to provide a list of pollutants potentially released by given industrial activities and inversely. 75 relevant contaminants are included with their physical and chemical properties (solubility, Koc,...). Within the groundwater body, the various potential sources of pollution are identified and geo-referenced into the geospatial database (Fig. 1a). For each of the selected contaminant sources, a leaching-dispersion model is applied in order to calculate the dispersion of contaminants in the aquifer, using a numerical groundwater flow and transport model developed for the groundwater body (Fig. 1b). Repeating the same procedure for all identified sources of contaminants provides a map of contaminants plumes in the studied groundwater body (Fig. 1c). At each time step, the generated plumes are classified in terms of groundwater quality classes using the SEQ-ESO evaluation system used in the Walloon Region (Rentier et al, 2006) giving a global picture of the quality status of the groundwater body (Fig. 1d). The index is a dimensionless number ranging from 100 (for high quality) to 0 (degraded) aggregating the different contaminants and their respective threshold values. Finally, a global quality index (I_{global}) is calculated for the groundwater body at each time step, using a weighting-average procedure (Fig. 1e).

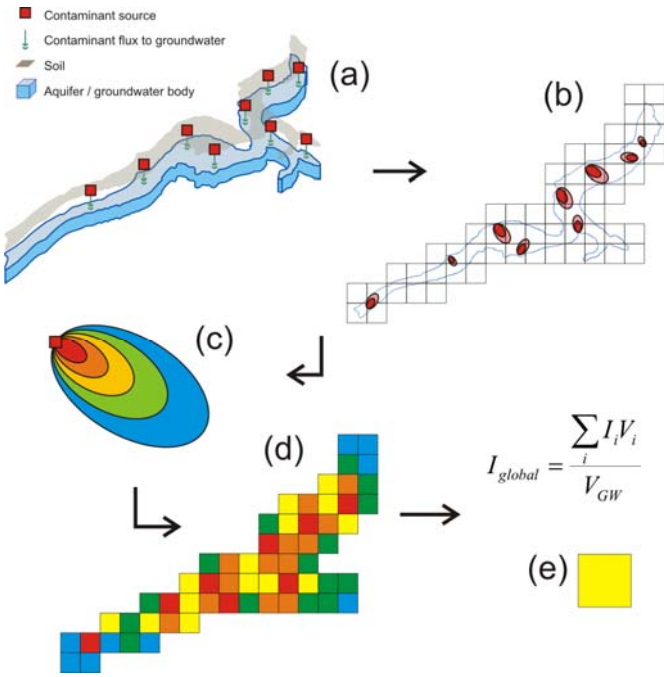

Fig. 1 Regional risk assessment methodology for groundwater bodies. I_{global}: global quality index for the whole groundwater body at time t [-], V_{GW}: volume of groundwater comprised in the zone where the risk is assessed [V], V_i: volume of water into the cell *i* [V], I_i: quality index for the cell i[-].

The proposed methodology offers several advantages. First of all, it is compliant with the ongoing legislation in the Walloon region, based on the SEQ-ESO and it fits very well with the guidelines of the EU Water Directive which promotes the use of aggregated indicators able to reflect trends in groundwater quality. Second, the methodology is able to aggregate different types of contaminants into a single ranking system, considering various water uses and their respective threshold values. Third, the indicator can be used for risk assessment by comparing the global spatially aggregated indicator and the corresponding threshold values. Finally, the indicators can be used as a referential for the socioeconomic analysis.

ILLUSTRATION AND CASE STUDY

As a first example, synthetic groundwater flow and transport models have been developed representing an aquifer with lateral no-flow boundaries conditions except a draining river boundary condition to the East to model the pollution of an alluvial aquifer by industrial contaminants (benzene, benzo(a)pyrene and TCE) with contrasted physico-chemical properties. Fig. 2 shows maps of SEQ-ESO indicators for the 3 pollutants after one and ten years and the evolution with time of the groundwater global quality index which diminishes as the pollutants spread through the aquifer.

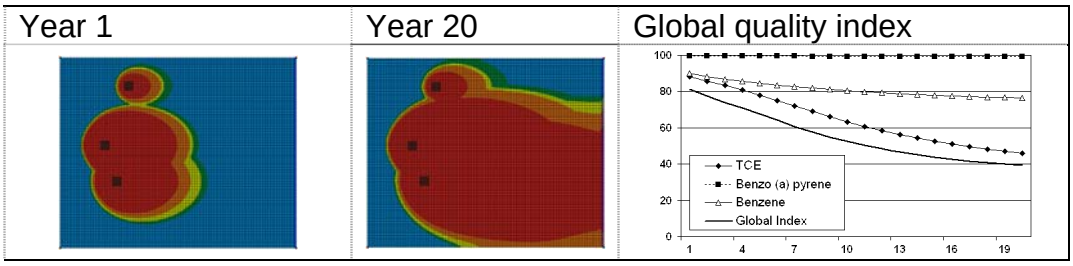

Fig. 2 Evolution of the global quality index using SEQ-ESO with spatial integration.

A first application has been developed for Groundwater Body RWM073, corresponding to the alluvial deposits of the Meuse river in the region of Liège (Fig.3a), which presents a risk of not reaching a good chemical status required by the EU Water Framework Directive for 2015 because of the numerous contaminated sites resulting from the heavy industrial past in this area. For this example, industrial plants lying within the category “mining”, “gas station” and “metallurgy”, with a spatial extent larger than 100 m² are considered and benzene is considered only. Groundwater flow and transport simulations are performed using Modflow and MT3D over a 20 years period. The groundwater flow model is calibrated using piezometric head measurements available in the area (Fig.3b). Transport parameters are defined based on experiments in the Meuse alluvial aquifer (Batlle-Aguilar et al. 2009). A worst case scenario is modelled assuming that all potential sources of benzene are active and benzene does not degrade in the alluvial aquifer. Fig. 3c shows the resulting map of benzene concentrations in the alluvial aquifer after 20 years. Fig. 3d shows the evolution of global groundwater quality index of the groundwater body as affected by benzene dispersion alone.

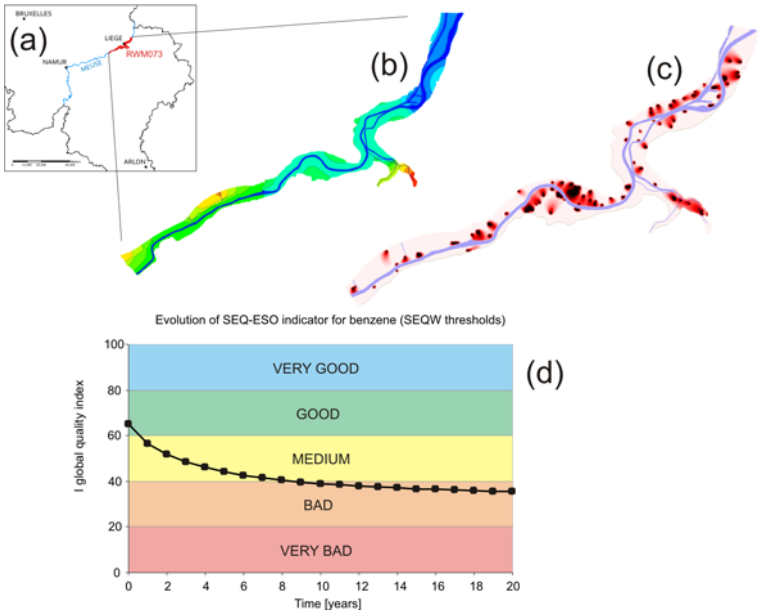

Fig. 3 First results of the RRA on RWM073 considering industrial activities releasing benzene in groundwater. The resulting SEQ-ESO indicator leads to a bad quality status of the groundwater body.

CONCLUSIONS AND PERSPECTIVES

The regional scale risk assessment for groundwater bodies presented here is a flexible approach for evaluating the pressure of various sources of contamination on a regional groundwater body as it aggregates into a single, easy to use and to report indicator, various cumulative sources of contaminants of different chemical natures, properties and toxicities. The indicator allows also to identify and to report trends in groundwater quality in the complex problem of urbanized and industrialized catchments. A key element will be to incorporate a statistical approach for handling all the uncertainties that remain at regional scale, on contaminant sources, properties, hydrogeological conditions etc. This analysis now serves as basis for a socio-economic approach that is intended to provide indications on costs and benefits generated by total or partial remediation of the contaminated groundwater body according to different management scenarios.

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