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Enhanced vulnerability assessment in karst areas by combining mapping with modeling approaches

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ABSTRACT

The objective of this work is to facilitate a sustainable regional planning of water resources in karst areas by providing a conceptual framework for an integrative vulnerability assessment. A combined mapping and modeling approach is proposed, taking into account both spatial and temporal aspects of karst groundwater vulnerability. The conceptual framework comprises the delineation of recharge areas, vulnerability mapping, numerical flow and transport modeling and the integration of information into a combined vulnerability map and time series. The approach is illustrated at a field site in northwest Switzerland (Gempen plateau). The results show that the combination of vulnerability mapping and numerical modeling allows the vulnerability distribution, both in the recharge and discharge areas, to be identified, and at the same time, the time dependence of karst groundwater vulnerability to be assessed. The combined vulnerability map and time series provide a quantitative basis for drinking water management and for regional planning.

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1. Introduction

Water is one of the most valuable natural resources of all, crucial to human and most other kinds of life. Karst groundwater is among the most important water resources. Karst waters supply about 25% of the global population (Ford and Williams, 2007). In Europe, a significant portion of the drinking water supply is abstracted from karst aquifers and in many regions it is the only available source of fresh water (Zwahlen, 2004). Karst water is also an indispensable resource for very specific ecosystems. Apart from its role for natural spring habitats, karst groundwater has an important ecological function as feeder of rivers and lakes. Increasing impact on groundwater systems due to intensified land use by a growing population, industry and agriculture increases the pressure on water resources. At the same time, public authorities, and also more and more citizens, accept only irreproachable drinking water.

In view of this situation, diverse strategies have been developed for the protection of groundwater and spring water, with methods for groundwater vulnerability mapping as the most important (National Research Council, 1993). Karst aquifers have complex and distinct characteristics, which make them very different from other aquifers (Bakalowicz, 2005). They are extremely heterogeneous and anisotropic and therefore particularly vulnerable to contamination (e.g., Daly et al., 2002). In view of these special characteristics, some of the methods used for vulnerability assessment are specifically designed for karst environments (Doerfliger et al., 1999; Goldscheider, 2005; Vías et al., 2006).

In practice, however, there are still major problems with the protection of karst springs, and important points remain unresolved. First, mapping approaches hardly consider the time dependences of vulnerability. Many studies clearly show that spring water quality is a function of time (e.g., Ryan and Meiman, 1996; Auckenthaler et al., 2002). This time dependence cannot be shown on static vulnerability maps. Secondly, the various indices used to generate vulnerability maps are largely conceptual, and thus subjective (Connell and van

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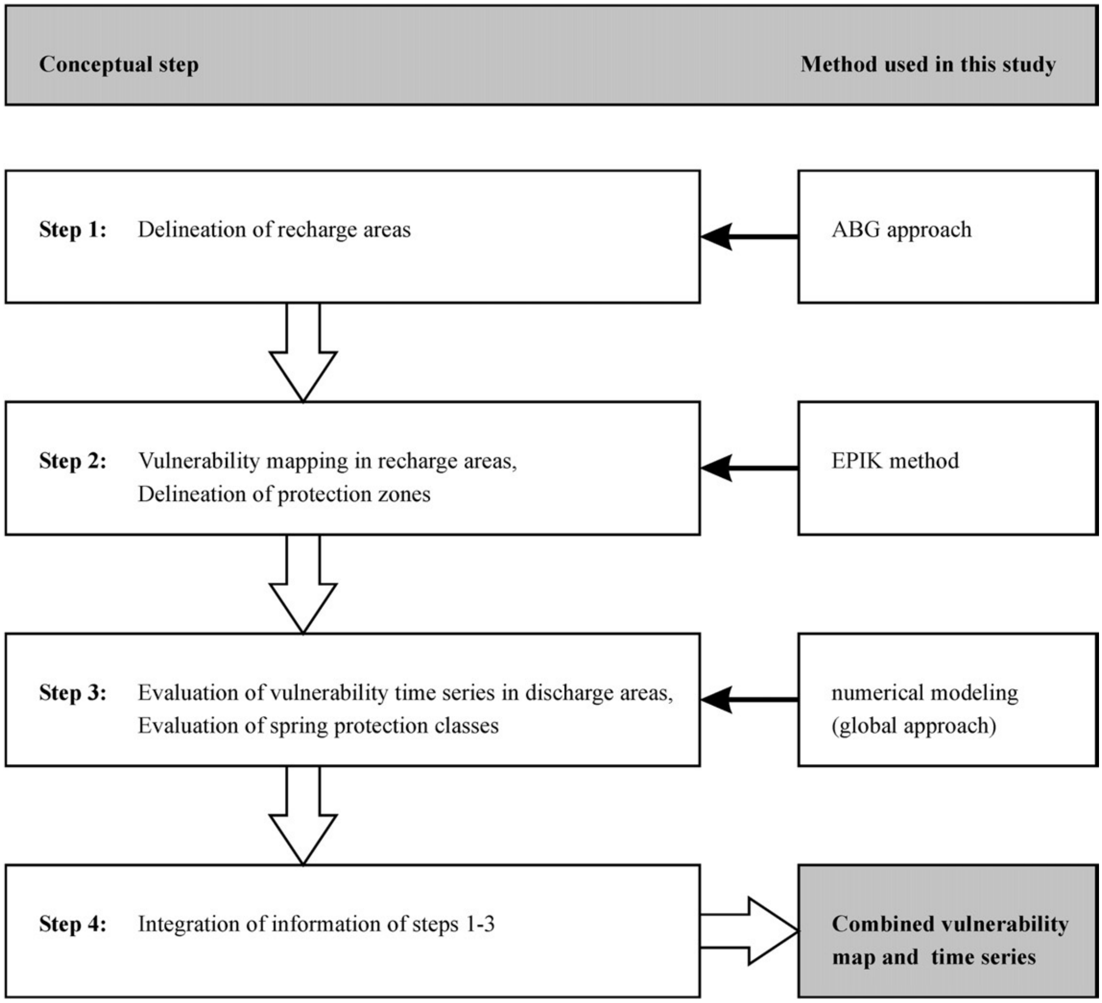

Fig. 1 – Conceptual four-step approach proposed for integrative vulnerability assessment in karst areas. The approach concludes with a combined vulnerability map and time series providing quantitative spatial and temporal information.

den Daele, 2003). There is a need to examine the vulnerability concepts from a quantitative point of view, and for clearly identified reference criteria for quantification, comparison and validation purposes, to be established (Brouyère, 2004). Thirdly, though vulnerability maps take important characteristics of karst terrains into account, they are not adequate to explain the actual processes taking place. And last, the existing mapping techniques indicate the evaluated groundwater vulnerability solely in the recharge areas. However, an indication of groundwater vulnerability at individual springs as well would provide a major aid to drinking water suppliers and regional planners.

In the literature it is often stated that the limitations of vulnerability maps, such as those cited above, could be overcome by mathematical modeling. Goldscheider (2002) remarked that, despite the large number of mathematical flow and transport models, these have rarely been used for vulnerability mapping. Gogu and Dassargues (2000) pointed out that new challenges for hydrogeologists will be posed by the integration of results from process-based numerical models into vulnerability mapping techniques. Zwahlen (2004) suggested the use of calibrated numerical simulations for the validation of vulnerability maps.

This study aims to provide a sustainable regional planning concept for the use and protection of karst water resources. The main objective of this study is to offer quantitative answers to practical questions about the "Where?" and "When?" of karst groundwater vulnerability. To this end, mapping methods were combined with modeling methods. This approach allows both spatial and temporal aspects of karst groundwater vulnerability to be addressed. Numerical flow and transport modeling was conducted, which contributed to vulnerability assessment based on modeled proportions of spring discharge from different flow systems and contaminant loads in spring water as the result of different recharge and flow conditions. The numerical modeling was complemented by 3D geological modeling to provide the structural framework for the hydrology of the study area and for the conducted vulnerability mapping.

This paper is set up as follows: first, a general approach for integrative vulnerability assessment is proposed, followed by a description of the methods used in this study, which are specific to mature, unconfined, shallow karst systems. The methods are then applied to a field site and illustration is given of how the results can be integrated into a combined vulnerability map and time series. The paper concludes with the discussion of our findings.

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