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Risk-based prioritization methodology for the classification of groundwater pollution sources

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HIGHLIGHTS

- Risk-based ranking methodology to support the definition of GW management strategies
- Methodology to rank pollution sources which threaten the good quality status of GW
- Identification of different receptors' vulnerability levels according to GW uses
- Integration of spatial analysis and Multi Criteria Decision Analysis (MCDA)
- Flexible methodology which can be applied to different GW uses

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ABSTRACT

Water management is one of the EU environmental priorities and it is one of the most serious challenges that today's major cities are facing. The main European regulation for the protection of water resources is represented by the Water Framework Directive (WFD) and the Groundwater Directive (2006/118/EC) which require the identification, risk-based ranking and management of sources of pollution and the identification of those contamination sources that threaten the achievement of groundwater's good quality status. The aim of this paper is to present a new risk-based prioritization methodology to support the determination of a management strategy for the achievement of the good quality status of groundwater. The proposed methodology encompasses the following steps: 1) hazard analysis, 2) pathway analysis, 3) receptor vulnerability analysis and 4) relative risk estimation. Moreover, by integrating GIS functionalities and Multi Criteria Decision Analysis (MCDA) techniques, it allows to: i) deal with several sources and multiple impacted receptors within the area of concern; ii) identify different receptors' vulnerability levels according to specific groundwater uses; iii) assess the risks posed by all contamination sources in the area; and iv) provide a risk-based ranking of the contamination sources that can threaten the achievement of the groundwater good quality status. The application of the proposed framework to a well-known industrialized area located in the surroundings of Milan (Italy) is illustrated in order to demonstrate the effectiveness of the proposed framework in supporting the identification of intervention priorities. Among the 32 sources analyzed in the case study, three sources received the highest relevance score, due to the medium-high relative risks estimated for Chromium (VI) and Perchloroethylene. The case study application showed that the developed methodology is flexible and easy to adapt to different contexts, thanks to the possibility to introduce specific relevant parameters identified according to expert judgment and data availability.

1. Introduction

Water management constitutes a priority for EU environmental policies and it is one of the most serious challenges that major cities are facing today. Over 97% of all freshwaters available on earth (excluding glaciers and ice caps) is represented by groundwater, which constitutes the largest reservoir of freshwater in the world (European Commission, 2008). In the last two decades, the European regulatory framework related to water protection has continuously increased. A key role has been played by the Water Framework Directive (WFD), which was initially issued in 2000 (2000/60/EC) and then amended six years later by the Groundwater Directive (2006/118/EC). The latter introduced additional technical specifications on the protection of groundwater against pollution and deterioration, including assessment of good chemical status, identification and reversal of upward trends in pollution and measures to prevent or limit inputs of pollutants into groundwater. Additional directives including measures and requirements for water assessment and management are the Nitrates Directive, the Urban Wastewater Treatment Directive, the Plant Protection

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Products Directive, the Biocides Directive, the Integrated Pollution Prevention and Control (IPPC) Directive and the new Industrial Emissions Directive (IED), the Landfill Directive, the Waste Framework Directive and the Construction Product Directive. As far as the groundwater protection is specifically concerned, the objective of the whole set of water related directives is to reach the "good environmental status" of groundwater bodies by the end of 2015. The procedure for the verification of the groundwater "good environmental status" laid down by the Groundwater Directive is briefly reported in Fig. 1.

According to Fig. 1, the *design of a monitoring network* is the first step for the verification of groundwater "good environmental status" and is aimed at providing a coherent and comprehensive overview of groundwater chemical status within each groundwater body. On the basis of the results of the monitoring phase, the *verification of not exceeding national threshold values* should be assessed at any monitoring point in that body or group of groundwater bodies. Exceeding values can be accepted in cases where an appropriate investigation confirms that these concentrations do not cause significant environmental risks or the other conditions for good groundwater chemical status are being met or groundwater human uses are still supported. When groundwater quality is impaired, *the sources of potential pollution need to be identified* and monitored in order to assess the impact of existing plumes of pollution (Directive 2006/118/EC). Moreover, it is necessary to carry out additional trend assessments for identified pollutants in order to verify that plumes from contaminated sites do not expand, do not deteriorate the chemical status of the body or group of bodies of groundwater, and do not pose a risk for human health and the environment (Directive 2006/118/EC). Finally, the sources of pollution identified in the previous step need to be prioritized by identifying those contamination sources that threaten the achievement of groundwater's good quality status; accordingly, a risk-based ranking of interventions to reduce the environmental impacts has to be defined by decision-makers.

This paper is aimed at addressing the last issue and presents a new risk-based prioritization methodology able to support the definition of a management strategy for the achievement of the good quality status of groundwater. In this context, where the assessment and management of environmental problems are influenced by the large geographical scale, a regional approach is solicited and can be well-represented by the relative risk model proposed by Landis (2005). In general, risk-based methodologies are used to support local authorities in ranking contamination sources in order to select those to be investigated more thoroughly or in order to prioritize the remediation actions (Long and Fischhoff, 2000; Marcomini et al., 2009; Pizzol et al., 2011). Many relative risk methodologies for contaminated sites prioritization have been developed and applied at regional or local level for ranking (potentially) contaminated sites on the basis of available data. Two notable examples are PRAMS (EEA, 2004) and SYRIADE (Pizzol et al., 2011; Agostini et al., 2012). Moreover, Einarson and Mackay (2001) and Troldborg and colleagues (2008) developed two methodologies specifically addressed to risk assessment and prioritization of contaminated sites which affect groundwater bodies. Other studies focused on approaches to estimate the vulnerability of groundwater resources to contamination (Focazio et al., 2002), on logistic regression analysis (Tesoriero and Voss, 1997; Nolan et al., 2002) and on multiple linear regression (Boy-Roura et al., 2013; Nolan and Hitt, 2006) to evaluate aquifer susceptibility and groundwater vulnerability and to predict the concentration of contaminants in groundwater as well as the probability of chemical concentrations in groundwater to exceed a certain threshold.

However, none of the reviewed studies presents a prioritization methodology suitable to identify and classify the contamination sources which can hamper the achievement of the good quality status of groundwater, as required by the Groundwater Directive. To fill in this methodological gap, the objective of this paper is to present a MCDA methodology aimed at supporting experts and local authorities in the classification of the main sources of pollution that can impact a groundwater body and consequently threaten the achievement of the good quality status of groundwater. While conventional approaches for prioritization have been developed mainly for potentially contaminated sites in order to provide investigation priorities which will demonstrate the real exceeding of thresholds values, the proposed methodology includes evidences of contamination sources and impacts caused by the analyzed contaminants on groundwater quality. Accordingly, only contamination

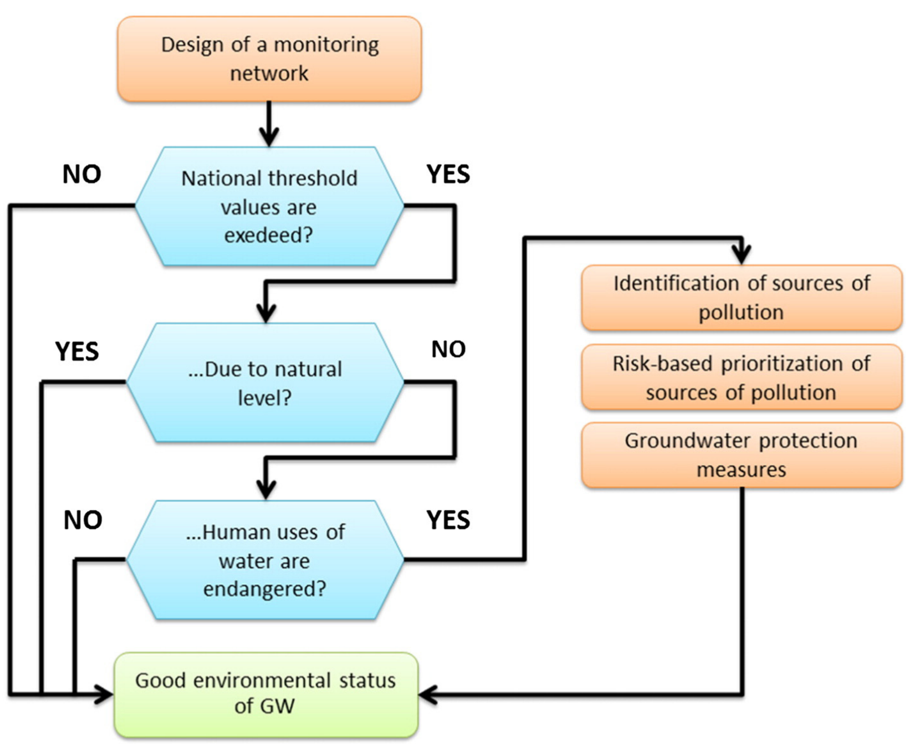

Fig. 1. Procedure for the verification of the groundwater "good environmental status" according to the Groundwater Directive (2006/118/EC).