SPATIO-TEMPORAL VULNERABILITY ASSESSMENT IN FRACTURED GROUNDWATER SYSTEMS

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Abstract

Governance reforms are required to demonstrate adaptive and resilient urban water resource management that considers complexity, uncertainty in immediate and long term change. Contamination of groundwater is a complex process and full of uncertainty at local and regional scale. The main objective of this research is the study of vulnerability to pollution in an unconfined karstic aquifer. Mainly it is addressed vulnerability integration, in relation to policy, specifically in risk evaluation and risk–benefit considerations. Development of an integrated vulnerability assessment methodology can be useful to effectively manage and protect this valuable freshwater source. The research insights suggest that the establishment of a pattern of effective governance is mandatory as the future highway, the prison and the airport are overlaying the most vulnerable areas of the aquifer and therefore provide policy makers guidance in overcoming urban water governance challenges.

Keywords: Aquifer Management; Vulnerability; Environmental Risk.

1. INTRODUCTION

Cleaning and restoring contaminated groundwater has been often technically difficult and a considerable financial burden and searching for alternative sources for water supply is not always feasible. Consequently, the most effective and realistic solution is to prevent groundwater from contamination. Vulnerability can be somewhat an ambiguous concept. Several authors provide a good overview of different definitions for vulnerability assessment (e.g. Bachmat & Collin 1987; Singh et al. 2011; Vishnu et al. 2011; Ryan et al. 2012;) that should be used as an indicator for risk assessment. The identification of "cold" and "hot" vulnerable spots, and the subsequent overlapping of impacting activities provides policy makers guidance in overcoming urban water governance challenges. The distinction between intrinsic vulnerability and specific (or extrinsic) vulnerability became a significant issue as anthropogenic activities started to affect considerably the environment in the last decades. Intrinsic vulnerability is a function of hydrogeological factors (Aller et al. 1987), whereas specific vulnerability refers clearly to the potential impacts of land use and contaminant dispersion (Ribeiro et al. 2003).

2. MATERIAL AND METHODS

Many different methods have been developed for assessing groundwater vulnerability. In this approach, two vulnerability methods were used for the sustainability study of the unconfined karstic aquifer of Montes Torozos, Duero river watershed (Fig.1): DRASTIC index and the Susceptibility index (SI). The DRASTIC method is a point count system model (PCSM) method for measuring the intrinsic vulnerability (Aller et al. 1987). It considers seven parameters in the geohydrological environment. The DRASTIC has been well accepted in many studies all around the world (e.g. Shukla et al. 2000, Albuquerque et al. 2013, Fernando et al. 2013). As DRASTIC stands for the watershed intrinsic vulnerability characterization, SI stands for the extrinsic or specific vulnerability. The specific vulnerability assessment method, named Susceptibility Index (SI), is an adaptation of the DRASTIC method (Ribeiro 2000) and was created for evaluating aquifer vulnerability to land use impact (Lobo-

Ferreira & Oliveira 1993; Francés et al. 2002; Ribeiro et al. 2003; Stigter et al. 2006). Recent publications have shown the importance in the vulnerabilities computation (e.g. Shresthaa et al. 2017). The impact of natural and anthropogenic activity assessment is a target issue to a sustainable fractured groundwater systems' governance.

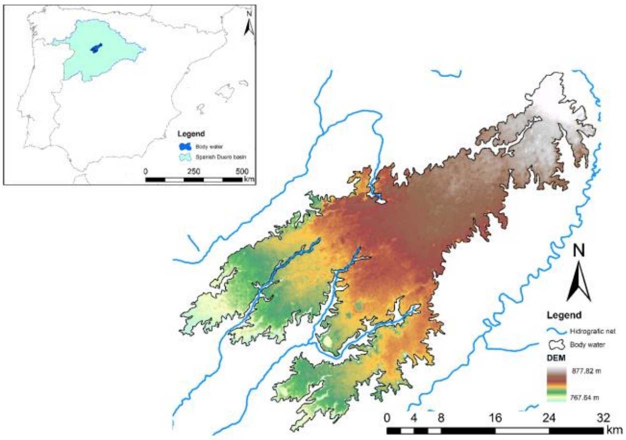


Fig.1. Montes Torozos" localization - Duero watershed

2.1. DRASTIC

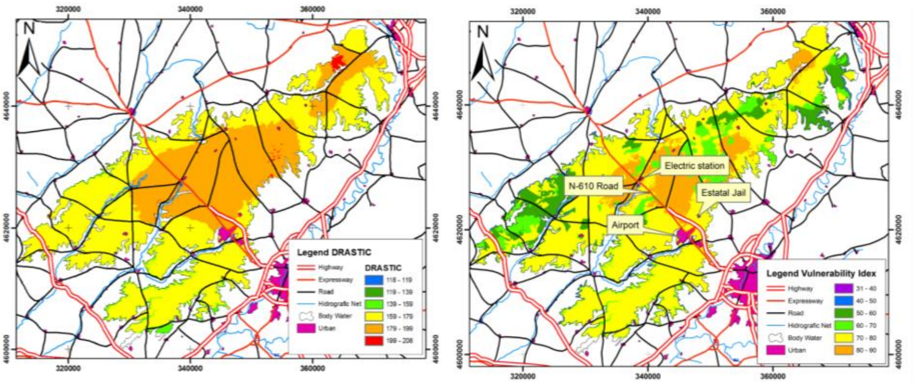
The Depth to Water **(D)** parameter was obtained from piezometric head data recorded during 2010-2011, in 65 wells and 40 springs, homogeneously distributed in the study area and interpolated through a geostatisticals methodology. The aquifer's net recharge parameter **(R)** has been calculated considering the precipitation and temperature serial data (1936-2006) from AEMET. The annual net recharge's values are 178 mm/year (Drastic level = 6. The aquifer media parameter **(A)** was determined considering the lithostratigraphic layers (Instituto Geológico y Minero de España, 1991). The type of soil parameter **(S)** was evaluated using observations collected during the 2012 field campaigns. Since soil is rather superficial or absent throughout the entire study area, this parameter received the DRASTIC value of ten and will contribute significantly to the computation of vulnerability. The surface slope parameter **(T)** was established using the Digital Elevation Model (DEM) (Instituto Geográfico Nacional, Spain, 2009) for the study area, after reclassification into the correspondent DRATIC's classes. There are not high slopes, only on borders could be observed slopes between 6-12 %. The vadose zone impact parameter **(I)** was computed considering the aquifer's lithological information. It is an acceptable assumption as groundwater has shallow characteristics, where the lithological characteristics primarily control water circulation. The hydraulic conductivity parameter (**C**) was assigned the value of 1.00 x10^{-4}m/s based on literature research (CHD, 2009) and corresponding to the DRASTICS's class number ten (Fig. 2 (a)).

2.3. Susceptibility Index (SI)

The SI method (Paralta et al. 2005) is an assessment method of the specific vertical vulnerability to pollution, mainly produced by agricultural activities and defined specifically to nitrates. Specific vulnerability is the term used to define groundwater vulnerability to a contaminant or group of contaminants. The SI method has been calculated with the same parameters of DRASTIC but introducing a new attribute, the anthropogenic activities. DRASTIC kept parameters are: Depth to water, net Recharge, Aquifer media and Topography. The Land use layer was estimated through the CORINE Land Cover 2006 (European Environmental Agency, 2012), considering its evolution in time, aiming a dynamic risk analysis and its spatial-temporal planning as a leverage to a better land use (Fig. 2 (b)).

3. DISCUSSION

The vulnerability maps are a strong tool for inferences and can be used for risk analysis. Considering the shown vulnerability patterns, it is possible to develop a sustainable territory management. In fact, the road network and other infrastructures are overlapping the most vulnerable areas (Martínez-Alegría et al. 2003; Sanz 2010) and the constructed vulnerability maps may help to design and plan some corrective, compensatory or protective measures.



(a) (b)

Fig.2. (a) and (b) Drastic and SI final maps; (b) Hazardous elements distribution

In both used methodologies, DRASTIC and Susceptibility Index (SI), it is possible to discover the existence of higher vulnerability in the central region of the aquifer and being overlaid in the southern part by hazardous infrastructures such as airport, industrial area, and the principal highway. Near the electric plant, there is a gas plant with potential leakage issues and dangerously close to the freshwater spring La Mudarra (Fig. 2).

Some other important issue to strain is the conflict of sensitivity exhibited by both methods. The large spatial variability introduced by the land use attributes in SI computation, shows in this second approach the presence of different vulnerability patches inside the biggest and homogenous DRASTIC's zones, which highlight the importance of the anthropogenic activities in the region.

4. CONCLUSIONS

Vulnerability maps are a powerful tool for hazard analysis and territory's sustainable management. Mostly in the presence of highly dangerous hazards, allowing consistent monitoring and adopting preventive and remediation measures.

Using different vulnerability indexes makes easier future validation and the fitting of more accurate predictive models able to show different scenarios at different stages of uncertainty.

The most vulnerable areas are in the central part of the aquifer, which coincides with the highest phreatic level and the water is closer to the surface. This proximity allows an easy access to groundwater and for that also the most requested for the placement of the hazardous equipment.

Comparing DRASTIC and SI outputs, notable differences can be observed. Land use plays an important role in vulnerability assessment. The hazard equipment is overlaying the high vulnerable areas, which requires monitoring and taking protective and feasibility actions in future, related to urban activities, airport, roads, and electrical plant's location. Urban, industrial and transport infrastructures represent a liability in triggering processes of aquifer contamination and may be regarded as risks associated with pollution episodes due to direct discharges, leaks, or topical accidents in consequence of dangerous goods transportation.

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Topic G: Groundwater protection and aquifer remediation in fractured rock aquifers