Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/envsci

# Multi Criteria Analysis for the monitoring of aquifer vulnerability: A scientific tool in environmental policy

R.F. Valle Junior [a], S.G.P. Varandas [a], L.F. Sanches Fernandes [a], F.A.L. Pacheco [b,*]

[a] Centre for Research and Technology of Agro-Environment and Biological Sciences, University of Trás-os-Montes and Alto Douro, Vila Real, Portugal

[b] Department of Geology and Chemistry Research Center, University of Trás-os-Montes and Alto Douro, Vila Real, Portugal

ARTICLE INFO

*Keywords:*
Multi Criteria Analysis
DRASTIC
Aquifer vulnerability
Groundwater contamination
Environmental policy
Hydrological sustainability

ABSTRACT

The vulnerability of a fractured aquifer was quantified in the River Sordo basin (northeast Portugal) to check the risk of groundwater contamination in that watershed. Vulnerability was evaluated by Multi Criteria Analysis (MCA) and compared with DRASTIC results. MCA revealed a predominance of electrical conductivity, sulphate and copper as indicators of aquifer vulnerability. DRASTIC showed the highest vulnerabilities in areas covered by alluvium and where granites and metassediments come into contact. A comparison of results by cross tabulation using GIS confirmed that over 96% of the basin is invulnerable or weakly vulnerable to groundwater contamination. The conformity of actual to natural land uses explains the self ability of the basin to control groundwater quality and be in a status of hydrological sustainability. River Sordo ground waters drain to a dam lake which is the source of drinking water to 50,000 people. The lake water is in a very good status, in conformity with the Directive n° 2000/60/EC. The Multi Criteria Analysis is more expeditious in the diagnosis of vulnerability, not considering the hydrogeological, geomorphologic and soil characteristics of the basin required for the application of DRASTIC. The MCA and the DRASTIC were defined as analogue approaches, with the DRASTIC being classified as reference and the MCA as monitoring method. The combined application of DRASTIC and MCA was found crucial for the inclusion of aquifer vulnerability as topic in the framework of groundwater quality protection programmes.



## 1. Introduction

The estimation of aquifer vulnerability is critical for the implementation of ground water quality protection programmes. Over the last decades, a variety of methods for the modelling and mapping of aquifer vulnerability have been developed, with the aim of assisting decision making (e.g. Focazio et al., 2005). Usually, these methods consider similar factors but may use different approaches for data integration, being grouped into four categories: lumped parametric indices (Aller et al., 1987), statistical procedures (Masetti et al., 2009;

* *Corresponding author*. Tel.: +351 259350280.
E-mail address: fpacheco@utad.pt (F.A.L. Pacheco).

http://dx.doi.org/10.1016/j.envsci.2015.01.010
1462-9011/

Sorichetta et al., 2011), process-based algorithms (Neukum and Azzam, 2009), and/or a combination of these methods (Yu et al., 2010). In all cases, the modelling involves integration of hydrogeological (e.g. recharge), geomorphologic (e.g. terrain relief) and soil characteristics, and requires large datasets for execution. For this reason, the assessment of aquifer vulnerability by standard methods is costly and time consuming. Because of its high cost, standard aquifer vulnerability maps tend to be static documents, valid solely for the moment of their elaboration, failing to account for the temporal evolution of specific vulnerability resulting from changes in the land use of the target areas. In the end, these maps may become useless in the outline of groundwater quality management policies. To circumvent this setback, the actuality of conventional aquifer vulnerability maps could be monitored by analogue maps elaborated by expeditious methods based on easily collectable data. A low cost pathway towards aquifer vulnerability monitoring could be the use of specific groundwater quality parameters as vulnerability indicators, for example the concentrations of nitrate and sulphate in areas dominated by agriculture (Huan et al., 2012; Javadi et al., 2011a,b; Neshat et al., 2014; Panagopoulos et al., 2006). In this case, the sole data required for the study of vulnerability would be the chemical analyses of groundwater samples. The tool to process this data could be the Multi Criteria Analysis (MCA) because this technique proved efficient in other studies of groundwater contamination (Rezaei et al., 2013) as well as in studies of solute transport (Dou et al., 1999), environmental assessment (Garfi et al., 2011), or water resources management (Chowdhury and Rahman, 2008). MCA includes the definition and standardization of environmental factors that are relevant to the problem, followed by its weighted linear combination. Standardization is accomplished by fuzzy logic whereby the original factors are converted into scores that are calculated by a probability function (Jiang and Eastman, 2000). Weighted linear combination is a sum of standardized scores, previously multiplied by predefined weights (Eastman, 2012).

A number of studies integrated standard aquifer vulnerability maps with groundwater quality parameters to study the risk of groundwater contamination (e.g. Huan et al., 2012; Wang et al., 2012). But the purpose was never the establishment of a framework where the standard map could be updated at short time intervals by an expeditious analogue map. The objective of this work is to take that step forward, by coupling the estimation of aquifer vulnerability by a standard method with its evaluation by MCA, verifying the reliability of using the two approaches as analogues. As the DRASTIC (Aller et al., 1987) is commonly used for determining aquifer vulnerability, it will be adopted as standard in this study.

## 2. Area of study

The hydrographic basin of River Sordo, which is integrated in the large River Douro basin where the famous Port Wine is produced, is located in the region of Trás-os-Montes and Alto Douro, in northeast Portugal. With an area of approximately 50 km$^2$, the River Sordo basin is a radial shape catchment situated between the northern latitudes of 41°16′05.57″–41°20′12.81″ and western longitudes of 7°55′21.82″–7°45′42.45″, covering a large portion of the Vila Real municipality (Fig. 1).

The River Sordo is a right margin tributary of River Corgo that debouches into River Douro. It is a mountainous river of the Marão cordillera where the altitudes vary between 300 and 1100 m above sea level, the annual precipitation exceeds 1000 mm yr$^{-1}$, and the mean annual temperature approaches 14 °C. The main watercourse is approximately 20 km long and, in combination with its tributaries, forms a dendritic drainage

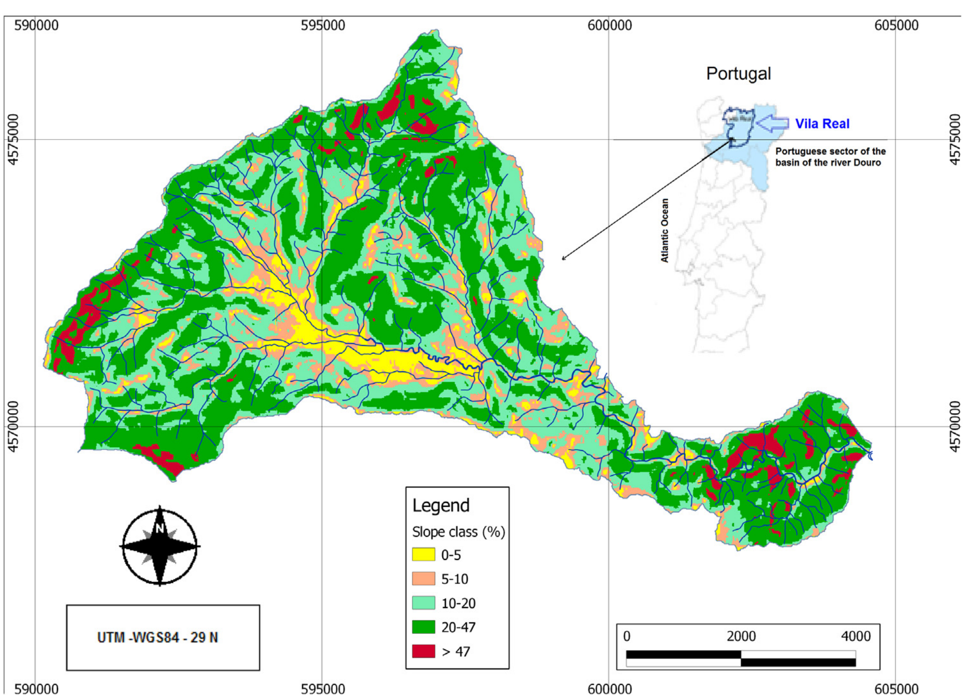


Fig. 1 – Location and slope map of River Sordo hydrographic basin.