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# Advances in Geoethics and Groundwater Management: Theory and Practice for a Sustainable Development

Proceedings of the 1st Congress on Geoethics  
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Porto, Portugal 2020

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# Groundwater Vulnerability Assessment in the Naturtejo UNESCO Global Geopark, Portugal

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## Abstract

Nowadays, groundwater vulnerability assessment has become a useful tool for groundwater contamination prevention. Groundwater vulnerability maps provide useful data to protect groundwater resources and work as a tool for the improvement of changes in agricultural patterns and land use applications. The study area of this research survey is the Naturtejo UNESCO Global Geopark, located in central inland Portugal and corresponding to a mainly rural territory where intensive agricultural practices showed a rising tendency in the last decades. The most used method of vulnerability evaluation is the DRASTIC index. In this survey, a modified DRASTIC method, DRASTICAI, is introduced. A new attribute designated as *anthropogenic influence* is introduced. Map algebra in a GIS environment allowed the computation of two maps by overlaying the needed attributes. The Vila Velha de Rodão and Idanha-a-Nova municipalities show moderate to high vulnerability and, therefore, in need of monitoring, since intensive agricultural practices are the main economic activity. The algebraic subtraction of DRASTIC and DRASTICAI maps revealed a considerable increase in the risk of contamination, over the surveyed area, namely in Idanha-a-Nova where it is observed risk increase up to 45 points, changing from

moderately vulnerable to highly vulnerable and, therefore, stressing the importance of anthropogenic activities.

## Keywords

Naturtejo Geopark • Groundwater • DRASTIC • DRASTICAI • GIS

## 1 Introduction

Nowadays, groundwater vulnerability assessment has become a useful tool for groundwater contamination prevention. Groundwater vulnerability maps provide useful data to protect groundwater resources and to work as a tool for water management with changes in agricultural patterns and land use applications (Babiker et al. 2005; Albuquerque et al. 2013; Awawdeh et al. 2014; Singh et al. 2015). Several authors acknowledge two different types of groundwater vulnerability, the intrinsic vulnerability and extrinsic or specific vulnerability (Stiger et al. 2006): the first term as a function of hydrogeological factors and the second one defined through the potential anthropogenic influence. The most widely used method of vulnerability analysis is the DRASTIC index (Aller et al. 1987), as it is easy to compute with the minimum data requirement.

The main aim of this study was the evaluation of the groundwater vulnerability to contamination, in the Naturtejo Geopark (Fig. 1), using a modified DRASTIC method in a GIS environment. The modified DRASTIC index (DRASTICAI) was made by assigning a new attribute designated as anthropogenic influence.

## 2 Materials and Methods

The DRASTIC model is constructed using combined spatial datasets on depth to groundwater ( $D$ ), aquifer recharge ( $R$ ), aquifer media ( $A$ ), soil media ( $S$ ), topography ( $T$ ), impact of

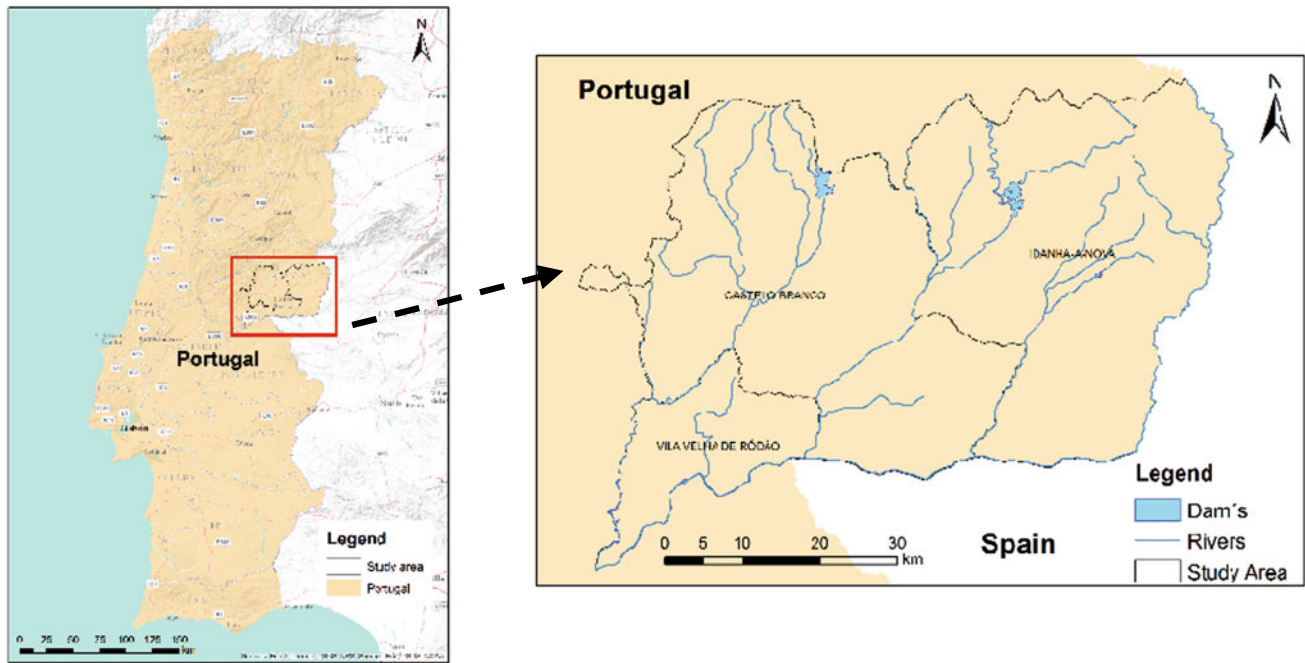
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**Fig. 1** Study area: Vila Velha de Rodão, Castelo Branco and Idanha-a-Nova municipalities integrating the Naturtejo Geopark

the vadose zone ( $I$ ) and hydraulic conductivity ( $C$ ) of the aquifer (Aller et al. 1987). The purpose of the DRASTIC index implies multiplying each factor weight (Table 1) by its category rating (Table 2) as follows:

$$\text{DRASTIC} = D_r * D_w + R_r * R_w + A_r * A_w + S_r * S_w + T_r * T_w + I_r * I_w + C_r * C_w \quad (1)$$

In this study, one extra parameter was added to the DRASTIC model to map the groundwater vulnerability in the study area more accurately, including the *anthropogenic influence*. This new parameter, *anthropogenic influence* (AI), was assigned a weight value equal to 5, and the modified DRASTIC index, DRASTICAI, computed using the following equation:

$$\text{DRASTICAI} = D_r * D_w + R_r * R_w + A_r * A_w + S_r * S_w + T_r * T_w + I_r * I_w + C_r * C_w + AI_r * AI_w \quad (2)$$

where  $D$  is depth to groundwater,  $R$  is recharge rate (net),  $A$  is aquifer media,  $S$  is soil media,  $T$  is topography (slope),  $I$  is impact of the vadose zone,  $C$  is conductivity (hydraulic) of the aquifer, and  $AI$  is anthropogenic influence (Table 1):

ArcGIS 10 was used to process the datasets and to create the eight layers, corresponding to the eight considered attributes, and groundwater vulnerability maps by overlaying the available information (Fig. 2).

**Table 1** Assigned weights for DRASTIC parameters

Parameters	Weight
Depth	5
Recharge	4
Aquifer media	3
Soil media	2
Topography	1
Impact of vadose zone	5
Hydraulic conductivity	3
<b>Anthropogenic influence</b>	<b>5</b>

Source Aller et al. (1987) and DRASTICAI

**Table 2** DRASTIC

DRASTIC/DRASTICAI	Range	Rating
Depth to groundwater	<1.5 m	10
Recharge rate (net)	51–102 mm/year	3
Aquifer media	Metamorphic igneous rock	3
	Stratified arenite and limestone	6
Soil media	Thin or absent	10
Topography (slope)	<2%	10
	2–6%	9
	6–12%	5
	12–18%	3
	>18%	1
Impact of the vadose zone	Shale and clay shale	3
	Stratified arenite and limestone	6
	Metamorphic   Igneous rock	4
Hydraulic conductivity of the aquifer	<4.1 (m/d)	1
Anthropogenic index ( <i>Source</i> Singh et al. 2015)	Built up with high density	9
	Built up with medium density	8
	Built up with low density	7
	Built up with very low density	5
	Agriculture	5
	Forest	2
	Water body	1
	Shrub land	2
	Waste land	1

*Source* Aller et al. (1987) and DRATICAI parameters

### 3 Results

For aquifer vulnerability assessment of the study area, seven and eight thematic maps were prepared for the DRASTIC and the DRASTICAI indices computation, respectively (Fig. 3).

The DRASTIC risk map shows two different levels of vulnerability: low and moderate (Fig. 4a). The northern Idanha-a-Nova and Castelo Branco areas show low vulnerability (105–119) as the remaining territory is moderately vulnerable (120–138). However, when analysing the DRASTICAI map, it is possible to identify considerable changes in the spatial patterns of vulnerability (Fig. 4b). Indeed, five levels of growing vulnerability, from low to high, can be acknowledged. Idanha-a-Nova municipality is

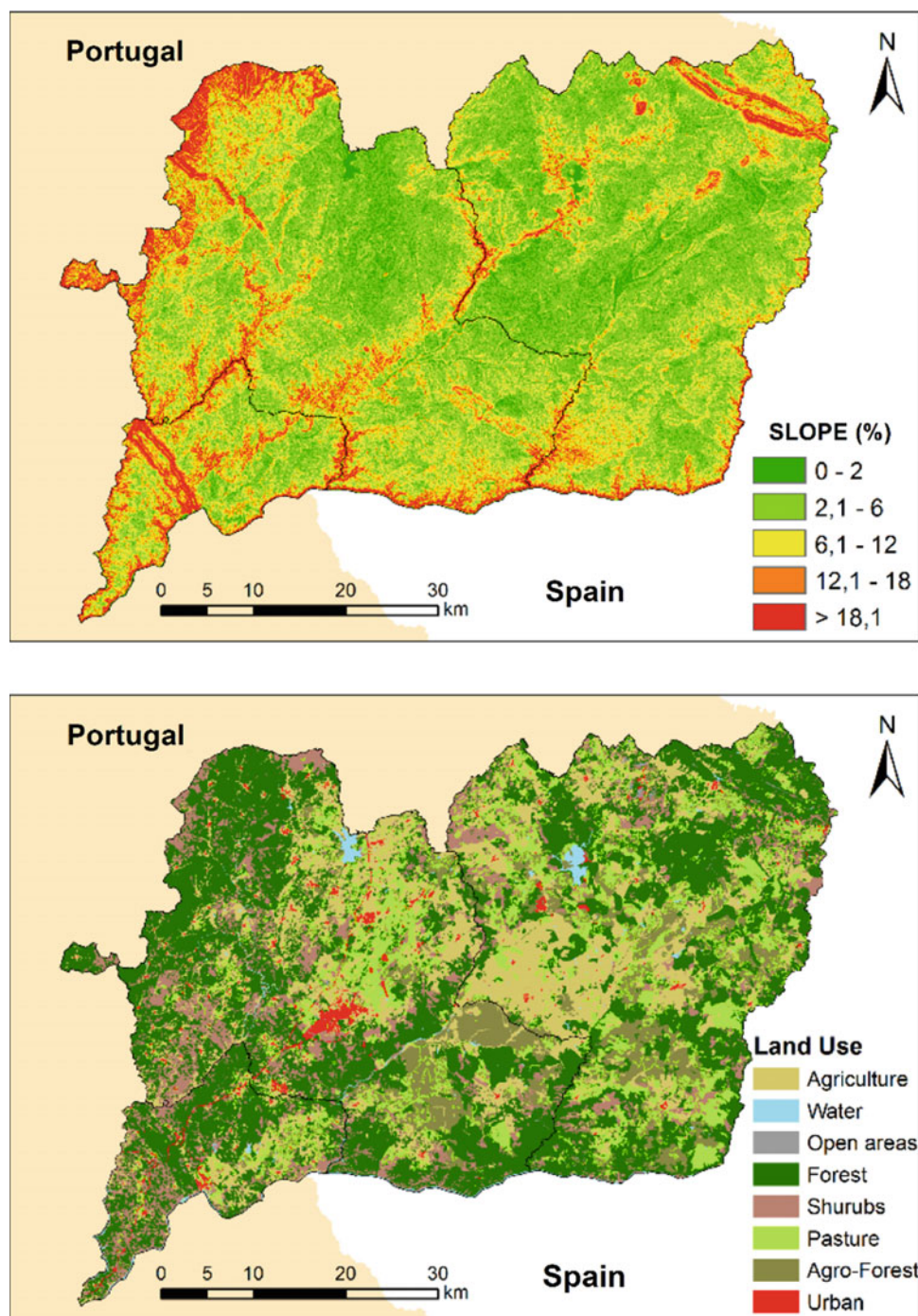
the most affected by the anthropogenic influence due to intensive farming activities.

### 4 Discussion

Land use parameters can significantly affect hydrogeological parameters. The properties of hydrogeological parameters can be changed by the use of pesticides, the addition of urban and industrial wastes, leakages from septic tanks and waste dumping sites. Land use classification of the study area showed that a major portion of the area is used for agriculture (Fig. 3). Groundwater is more vulnerable to nitrate concentration in agricultural fields. In groundwater systems, nitrate distribution principally depends upon the soil dynamics, recharge rate, groundwater movement and



**Fig. 2** Maps corresponding to the topography and anthropogenic influence

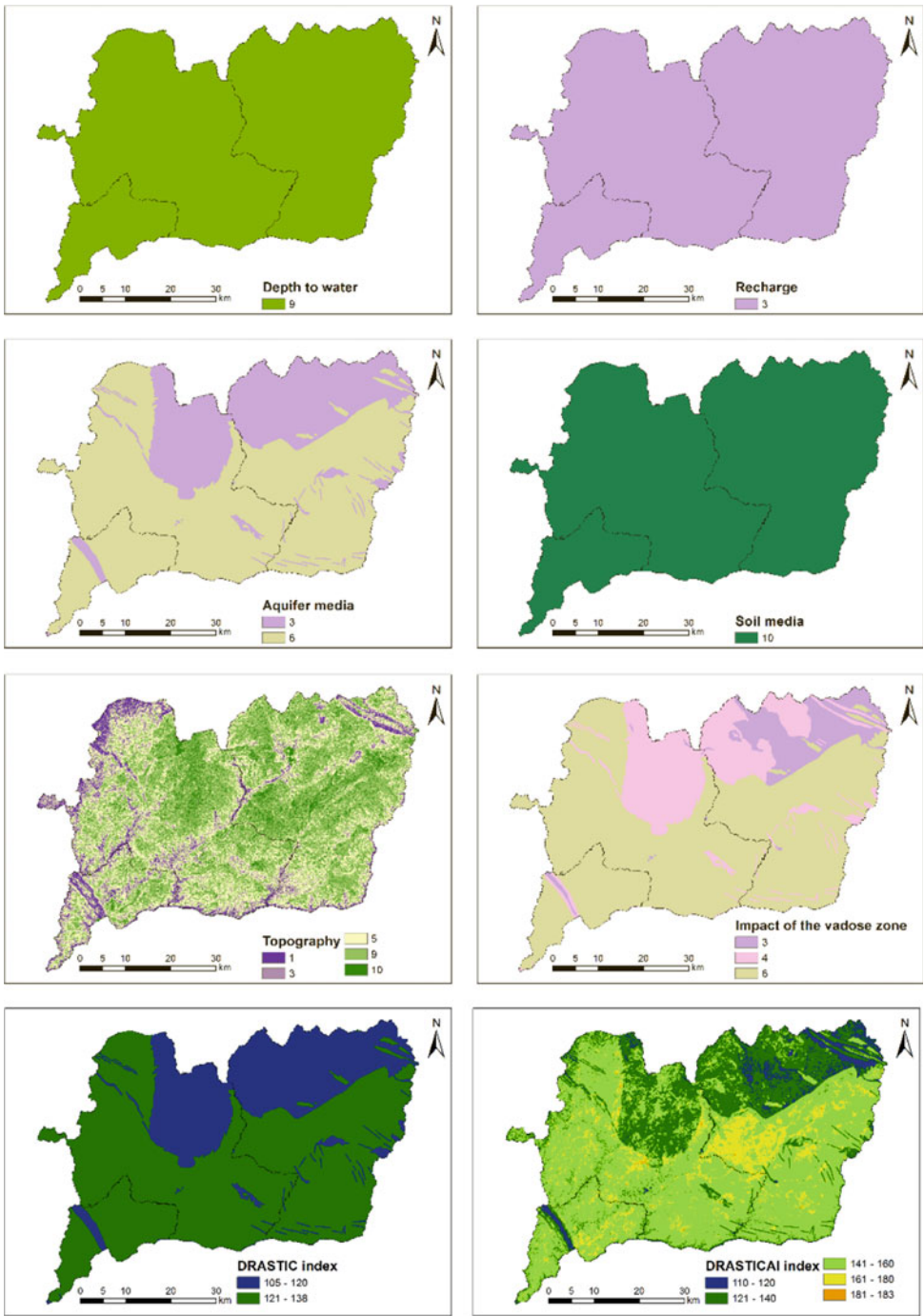


on-ground nitrogen loading (Shirazi et al. 2013). The study area is significantly influenced by agricultural activities.

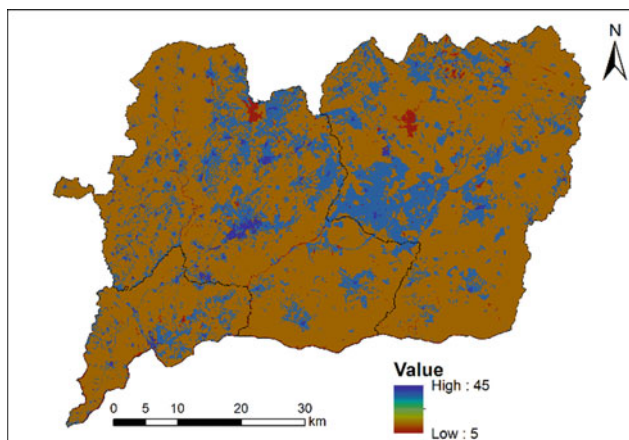
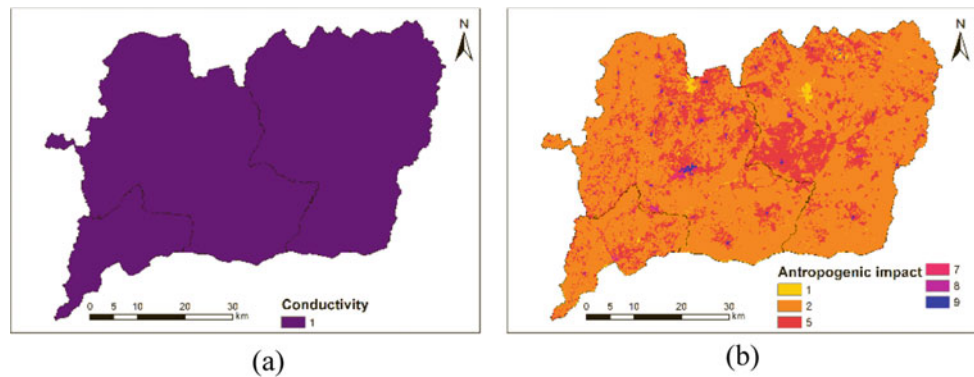
The algebraic subtraction between the DRASTIC and DRASTICAI maps shows an important contribution of the

anthropogenic influence (Fig. 5). It is possible to mention all over the surveyed area, but specifically in Idanha-a-Nova municipality, a rousing effect from low/moderate vulnerability up to highly vulnerable.

**Fig. 3** DRASTIC and DRASTICAI layer attributes



**Fig. 4** DRASTIC (a) and DRASTICAI (b) maps



**Fig. 5** Map representing the algebraic subtraction of DRASTIC and DRASTICAI

## 5 Concluding Remarks

This survey aimed at the evaluation of the groundwater vulnerability to contamination, in the Naturtejo Geopark area, using a modified DRASTIC index, DRASTICAI. This new index was constructed by adding a new attribute designated as *anthropogenic influence*.

The DRASTICAI spatial patterns indicate a clear influence of anthropogenic activities, mainly in the Idanha-a-Nova municipality.

Water is one of the most strategic resources in the world. Portugal has important resources of groundwater that may be

strategic to face the expected dry years to come. Furthermore, regularly monitoring and evaluating groundwater quality is needed for integrated management and policymaking.

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