

# Groundwater vulnerability assessment in fractured rock hydromineral systems (Caldas da Cavaca, Central Portugal)

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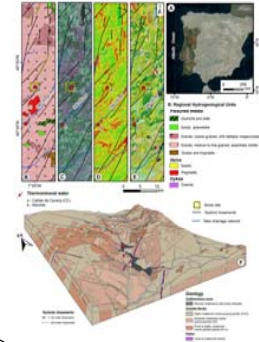
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## Introduction

Assessing groundwater vulnerability is often done through GIS technologies. GIS has become a useful tool to generate vulnerability maps and for simple testing of methods of display. Groundwater protection for human activities with suitable quality makes necessary to determine source protection zones for watersheds in hard-rock hydromineral systems to protect them from several risks of contamination. This study intends to develop a groundwater vulnerability approach in Caldas da Cavaca hydromineral system (Aguiar da Beira, Central Portugal), which has a thermal tradition for almost two centuries, and to contribute to improve the hydrogeological conceptual site model.

## Caldas da Cavaca hydromineral system: regional framework

Caldas da Cavaca is situated in Central Portugal, in the municipality of Aguiar da Beira. The region is located in Beiras Variscan granitic belt — Dão complex granite — of the Iberian Massif, nearby the western border of the Bragança Vilaríça–Manteigas major fault zone, with a general trend of NNE–SSW. The site belongs to the regional morphotectonic unit of the Central Plateau, in the northern part of the wide range of ridges, the so-called ‘Cordilheira Central’ or Central Range. The study area is mainly composed of coarse grained porphyritic granite, alluvial deposits and doleritic dykes (Fig. 1).



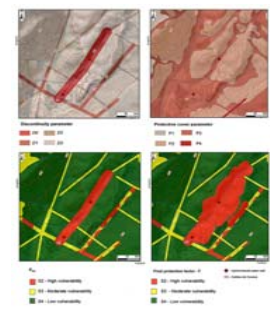
**Figure 1.** Regional framework of the Caldas da Cavaca hydromineral system, Aguiar da Beira: (A) Location of the study site (Central Portugal); (B) shaded relief and regional hydrogeology; (C) Satellite image and tectonic lineaments; (D) Slope; (E) Land cover; (F) Block diagram illustrating the basic geological framework of the study site.

## Materials and Methods

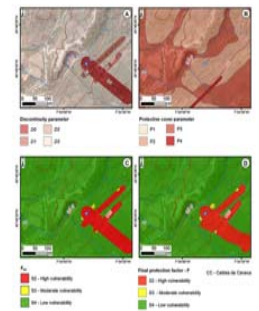
In this work different layers were overlaid, generating several thematic maps to arrive at an integrated framework of several key-sectors in Caldas da Cavaca site. Thus, to accomplish a comprehensive analysis and conceptualization of the site, a multi-technical approach was used, such as, field and laboratory techniques, where several data was collected, like land use, geotectonics, hydrology and hydrogeomorphology, hydrogeology and hydrogeophysics. All these techniques were successfully performed and a groundwater vulnerability to contamination assessment based on DISCO index methodology was delineated.

## Results and Discussion

In this work a groundwater vulnerability assessment was carried out by means of the DISCO index which indicated that the zones surrounding the hydromineral wells fit in a high vulnerability class, while the rest of the area fits in a low vulnerability category (Fig. 2). A similar approach was applied to a spring of normal groundwater located close to Caldas da Cavaca Spa (Fig. 3).



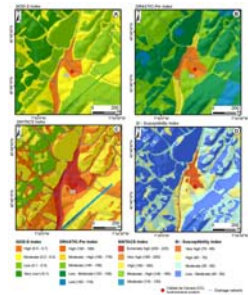
**Figure 2.** DISCO vulnerability index from Caldas da Cavaca aquifer systems (hydromineral water wells): a) discontinuities parameter; b) protective cover parameter; c) intermediate protection factor; d) final protection factor.



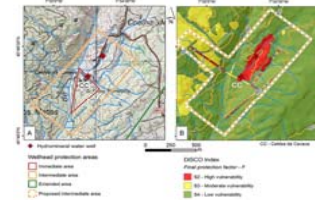
**Figure 3.** DISCO method applied to a spring at Caldas da Cavaca site: a) discontinuities parameter; b) protective cover parameter; c) intermediate protection factor; d) final protection factor.

DISCO index is in general accordance with other vulnerability indexes previously studied in this site, where GOD-S, DRASTIC-Fm, SINTACS and SI indexes indicated that most of the Caldas da Cavaca area fits in a moderate to high vulnerability categories (Fig. 4).

**Figure 4.** Multicriteria intrinsic vulnerability indexes from Caldas da Cavaca groundwater systems and surrounding area: a) GOD-S; b) DRASTIC-Fm; c) SINTACS; d) SI.



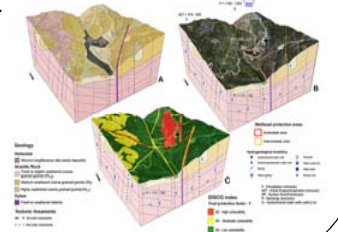
Moreover, most of the high vulnerability groundwater protection zones, defined with DISCO method, include the immediate and intermediate wellhead protection areas previously established in 1996 by the Portuguese legislation for Caldas da Cavaca spa (Fig. 5).



**Figure 5.** Wellhead protection areas for Caldas da Cavaca hydromineral system: A) wellhead protection areas defined in 1996; B) proposed intermediate wellhead protection area.

The results of the application of the DISCO methodology (the final protection factor, F) made it possible to improve the hydrogeological conceptual model and the wellhead protection areas of the water resources of the Caldas da Cavaca.

**Figure 6.** Hydrogeological conceptual model from Caldas da Cavaca hydromineral system: vulnerability DISCO index assessment input. A) general geology and surface rock mass conditions; B) hydrogeological conceptual site model; C) vulnerability DISCO index inputs.



## Concluding remarks

This multi-technical approach highlights the role of groundwater vulnerability mapping in developing the hydrogeological conceptual model of Caldas da Cavaca hydromineral system area and delineating wellhead protection areas, as well as contributing to develop water resources management, environmental sustainability and groundwater protection in the area.

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