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Expert based DRASTIC Adaptation to Mineralized Aquifer Vulnerability Assessment – Penamacor, Portugal

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Abstract. Hydrotherapy and bottling mineral water exploitation requires a detailed placement of the catchment and the aquifer's vulnerability assessment for protection perimeter design. The DRASTIC methodology was the starting point used for the herein introduced "specific DRASTIC". It is possible to say that the hydrogeology of the area suggests a predominant low vulnerability. However, hydrogeological and structural characteristics (e.g., granitic fracturation), indicate an extremely high vulnerability to the Termas de Fonte Santa catchment. The "specific DRASTIC" index is held by local parameters in order to downscale the properties for local vulnerability mapping and potential contamination of the aquifer. The Termas de Fonte Santa is classified as very high to extremely high vulnerable and in need of protection and conservation.

Keywords: Vulnerability, DRASTIC, "specific DRASTIC", mineralized aquifer.

1. Introduction

The Termas de Fonte Santa is a thermal medical spa (spa mineral water), located in Central Portugal (Penamacor). The area is a small village with a local development potential and, consequently, requires a mineral water stable quality to be used by human community and contribute to the national economy.

Actually, the thermal mineral water from Termas de Fonte Santa is obtained in a well (reference AM4) with 328 m depth and a water exploitation of about 3.6 m^3/h. The thermal mineral is sulphurous and bicarbonate-sodium water type.

The potential contamination of mineral water from Termas de Fonte Santa will be minimized with the delimitation of a protective perimeter for the catchment AM4.

Vulnerability assessment and groundwater contamination have been studied by many researchers [1], [2], resulting several proposed classifications, such is DRASTIC index [3] and DRASTIC with adaptations [4], [5]. The vulnerability DRASTIC index will be applied to Termas de Fonte Santa area with some adjustments identified and designated.

2. Study Area

2.1. Geomorphology and Geology

The Fonte Santa thermal area presents an elliptical shape (19kmx9km), with a NW-SE major axis, and relatively flattened with an elevation of 400 m [6].

The area is situated in the granitic rocks from Penamacor-Monsanto pluton (area 140 km^2), which are more permeable than the intruded schist-graywacke complex. This complex is dominated by impermeable schists, leading an aquifer groundwater recharge essentially by surface water and water infiltration from the

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granitic rocks. However, it should also be noted an infiltration from outside to inside drainage recharging groundwater reserves.

There is a dominant N40 °E, vertical system of geological fractures, mostly very open, smooth and stretch over an extended region. These fractures represent recent faults that traverse the granite and country rocks. The granitic rocks where resurfaces mineral water is apparently limited and located between two faults, N40 °E, vertical (Fig. 1).

2.2. Geohydrology

Almost Penamacor-Monsanto pluton area records an annual average daily temperature between 13.5 and 15.5 °C, approximately. The lowest values occurred in the NW of the pluton, while the highest ones in the SE. The mean annual rainfall registered value between 750 and 850 mm. The estimated water balance to the Fonte Santa area indicates the occurrence of a dry season and a wet period [7].

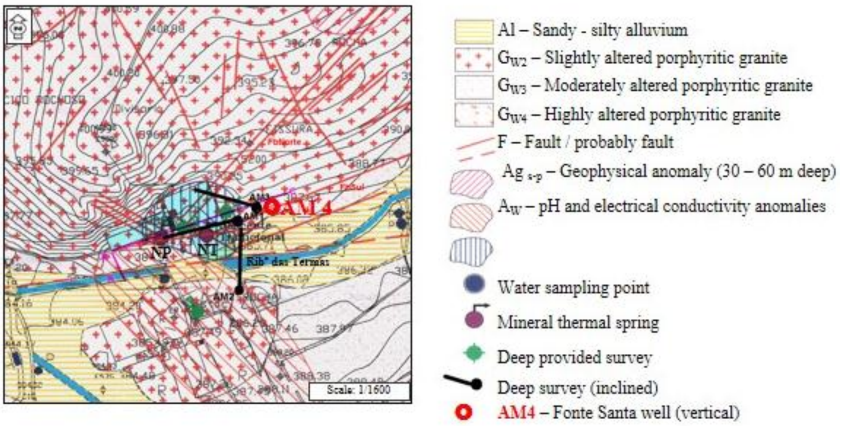

Fig. 1: AM4 well location in the local geology map [7]

The dry period occurs between May and October, with water deficits (DH), achieving its maximum during July. Differently, the wet period, evidenced by water surplus (SH), occurs between November and April of the following year, with a maximum excess of water in January. During the wet period, SH receives two contributions: runoff (R) and groundwater flow (G) according to:

$$SH = R + G = 327.3 \text{ L/m}^2$$

The Penamacor-Monsanto granitic pluton has modest slopes (<10%), sometimes with very fractured and altered areas covered with a thick flora, which enables the occurrence of orientated infiltration processes and, therefore, the aquifer recharge. According to the background experience, a "G / SH" ratio of 35% was considered [8]. This ratio leads an infiltration to the aquifer recharge of 115 L/m^2 per year, which allows a global annual recharge of 16x10^6 m^3 for a total pluton area.

In the vicinity of Fonte Santa (AM4 well) occurs mainly granites, locally covered by thin alluvium located in the stream of Ribeira das Termas (Fig. 1). Nevertheless, there is a complex arrangement of fractures associated with semi-horizontal veins, promoting the occurrence of mineral water in restricted zones.

The mineralized aquifer area comprises slightly altered granitic rocks (Gw2), mainly fractured, which constitutes a confined to semi-confined fissured aquifer. The aquifer deep water layer is around 3 m and effectively develops below 20 m deep, with a vein structure system at the height of the aquifer.

The hydraulic parameters of the mineralized aquifer were obtained [8]:

$k = 0.28$ m/day - permeability coefficient and $S = 26.6 \times 10^{-4}$ - storage coefficient.

These parameters should be taken as a magnitude order value because represent an average of the test flow obtained by two different methods, in a confined aquifer. The applied model is continuous and representing a porous medium, in a productive zone located between 20 and 120 m. In a second phase, were considered modest flow rates, such are 0.25, 0.5 and 1.0 L/s, in a permanent and stationary model, using

Thiem equation. The Fonte Santa thermal area contains sulphurous water and could be sorted out as a low permeability aquifer, according to Lambe and Whitman classification [9]. The granitic rocks associated with the mineralized aquifer from Fonte Santa are represented by slightly altered granites (Gw2), corresponding to an unconfined aquifer in the first 60 m deep, generally with a lower to medium permeability increasing with the fractured system. Another group, with moderate to highly altered granites (Gw3-w4-5), corresponds to a normal aquifer, in the first 60 m deep, fissured and locally interstitial type in highest altered zones. The area is an unconfined aquifer with variable permeability, ranging from low to medium permeability, increasing locally with fracturation. In the study area, there is also an unconfined aquifer associated to the highest permeability of alluvium from the Ribeira das Termas stream, but not extended more than 3 m.

3. Aquifer Vulnerability to Mineral Waters

The presented proposal includes, in a first phase, the application of the DRASTIC method [3] to define vulnerability zones at the Fonte Santa area. After that, the DRASTIC index will be presented with some adjustments related to mineralized water from crystalline rocks, such are the granitic rocks from Penamacor-Monsanto pluton. The adapted DRASTIC methodology – "specific DRASTIC" - will be applied to the mineralized aquifer from Fonte Santa such a study case.

2.3. DRASTIC Index

The acronym DRASTIC stands for the parameter included in the method: Depth to water (D), net Recharge (R), Aquifer media (A), Soil media (S), Topography (T), Impact of vadose zone (I) and hydraulic Conductivity (C) of the aquifer. The calculated DRASTIC indices are roughly analogous to the likelihood that contaminants released in a region will reach groundwater, higher score translates into a higher likelihood of contamination [3].

The DRASTIC method includes a numerical index computed as a weighted sum of the seven parameters. The significant media types or classes of each parameter range between 1 (lower vulnerability) and 10 (higher vulnerability) based on their relative effect on the aquifer. The seven parameters are then assigned weights between 1 and 5 reflecting their relative importance [3]. The DRASTIC index values range between 23 and 226, corresponding to a minimum and maximum vulnerability, respectively, and assigned by different color classes (Table 1).

Table 1: Drastic index and corresponding vulnerability color classes

DRASTIC index	Class colors
<80	violet
80-99	anil
100-119	blue
120-139	dark green
140-159	light green
160-179	yellow
180-199	orange
>199	red

2.4. Expert Issues and DRASTIC's Adaptation

The obtained DRASTIC index for Fonte Santa area – "specific DRASTIC"- indicate an intermediate vulnerability class mainly related to the geological formations and associated structural characteristics. In the study area, the geological and structural aquifer catchment characteristics should be detailed weighted in order to reassess its vulnerability depending on potential contamination of the exploited resource (mineral water). To increase the sensibility of this process and facilitated visual result interpretations were assigned a qualitative vulnerability to DRASTIC indexes (Table 2).

The vulnerability mapping areas from mineralized aquifers intends to adopt the following methodology: i) in a first stage, identification and classification of different rocks according to DRASTIC index and the corresponding qualitative vulnerability class (Table 2); ii) in a second phase, the different rock is reclassified, according to mineral water catchment spatial location factors. For the spatial location is considered: a) singular or topic geological occurrences with a potential connection to the mineralized aquifer (e.g., lithological contacts, faults, veins or other diaclases) and b) spatial location of the hydrogeological formation.

This detailed reclassification leads to a reduction or increase in the classification stage, according to the follow specific characteristics, and the final result will be called as "specific DRASTIC" to Fonte Santa mineralized aquifer.

Table 2: Drastic index and associated vulnerabilities in a mineralized aquifer

DRASTIC index [3]	Potential vulnerability (%)	Degree	Qualitative vulnerability
<80	<30	1	Nonexistent
80-99	30-39	2	Very very low
100-119	40-49	3	Very low
120-139	50-59	4	low
140-159	60-69	5	Intermediate
160-179	70-79	6	High
180-199	80-89	7	Very high
>199	>90	8	Extremely high

The singular geological occurrences is considered if: i) there is no discontinuity with actual or potential binding to mineralized aquifer and the vulnerability class must be the same as DRASTIC; ii) there are local discontinuities or mineral waters upwelling sites, indicating discontinuities with the mineralized aquifer, and must be classified as high to extremely high vulnerability class (degree 6 to 8; Table 2); iii) there are discontinuities or potential mineral waters and must be classified as intermediate to high vulnerability class (degree 5 or 6; Table 2).

Otherwise, the spatial hydrogeological formation position should consider if: i) the litological unity is located upstream of real or potential discharge areas from natural mineral water and the qualitative vulnerability degree class must be the same as the DRASTIC index; ii) the litological unity is located downstream of real or potential discharge areas from natural mineral water; the qualitative vulnerability degree class must be lower than the original DRASTIC index. This reclassification will depend on a detailed analysis of the survey region and its local utilization and exploitation without decrease water quality and quantity resources.

4. Results

The mineralized aquifer from the study area allows to explore sulphurous natural mineral water to be used as medical spa water - Termas de Fonte Santa.

The DRASTIC indexes and respectively vulnerability classification of the different litological units are presented in Table 3. According to singular or topic geological occurrences, the obtained results indicate an extremely low vulnerability associated with the mineralized aquifer (Gw2; Table 3). However, this classification could be not realistic because the granite contains different fractures allowing water infiltration. This outside fluids could have dissolved contaminants that will extend to the mineralized aquifer, promoting a possible pollution source. According this, the surrounding AM4 catchment must be classified as an extremely high vulnerability area and calculated "specific DRASTIC" index will increase from degree 2 to 8.

Table 3: Drastic index and vulnerability of hydrogeological units

Hydrogeological unity	Parameter (*1)	Classes	Degree	weight	Partial index	DRASTIC index	Vulnerability
Al – Alluvium	1 2 3 4 5 6 7	< 1.5 m 102 – 178 mm/year sand and gravel silty 2 - 6 % sand and gravel (fine) 41 - 82 m/day	10 6 8 4 9 6 8	5 4 3 2 1 5 3	50 24 24 8 9 30 24	169	High

G_{W3-W4} Moderately to highly altered granite Unconfined aquifer	1 2 3 4 5 6 7	1.5 - 4.6 m 102 - 178 mm/year Altered igneous rock silty 12 - 18 % igneous rock < 4.1 m/day	9 6 4 4 3 4 1	5 4 3 2 1 5 3	40 24 12 8 3 20 3	110	Very low
G_{W2} Slightly altered granite (Termas de Fonte Santa) Unconfined aquifer	1 2 3 4 5 6 7	15.2 - 22.9 m 102 - 178 mm/year igneous rock thin or absent 12 - 18 % igneous rock < 4.1 m/day	3 6 3 10 3 6 1	5 4 3 2 1 5 3	15 24 9 20 3 30 3	104	Very low
G_{W2} Slightly altered granite (Termas de Fonte Santa) Unconfined aquifer Confined and semi-confined aquifer	1 2 3 4 5 6 7	15.2 – 22.9 m 102 – 178 mm/year igneous rock confining layer 12 - 18 % igneous rock < 4.1m/day	3 6 3 1 3 6 1	5 4 3 2 1 5 3	15 24 9 2 3 30 3	86	Extremely low

(*1) Parameters: 1 – Deep to water; 2 - net Recharge; 3 - Aquifer media; 4 - Soil media; 5 – slopes; 6 – unsaturated zone; 7 - Conductivity of the aquifer.

Another hydrogeological particularly is associated with the alluvium, with a high vulnerability DRASTIC index (degree class 6; Table 3). However, the alluvium is located in a large distance downstream the mineralized aquifer and would be considered as lower vulnerability than similar upstream materials. So, alluvium must bear a different classification according to its spatial location and distance relative to the AM4 Fonte Santa catchment (degree class 6 – upstream; degree class 5 or 4 – downstream).

Attending to the local study area, there is no exceeding preservation areas without relevant particularities that could be used as support infrastructure to the spa area from Fonte Santa, such as parking, residential or recreative areas.

The final results include a comparation of DRASTIC indexes and "specific DRASTIC" proposed to Fonte Santa mineralized aquifer (Table 4) and a detailed map of the study area with associated vulnerability classification (Fig. 2).

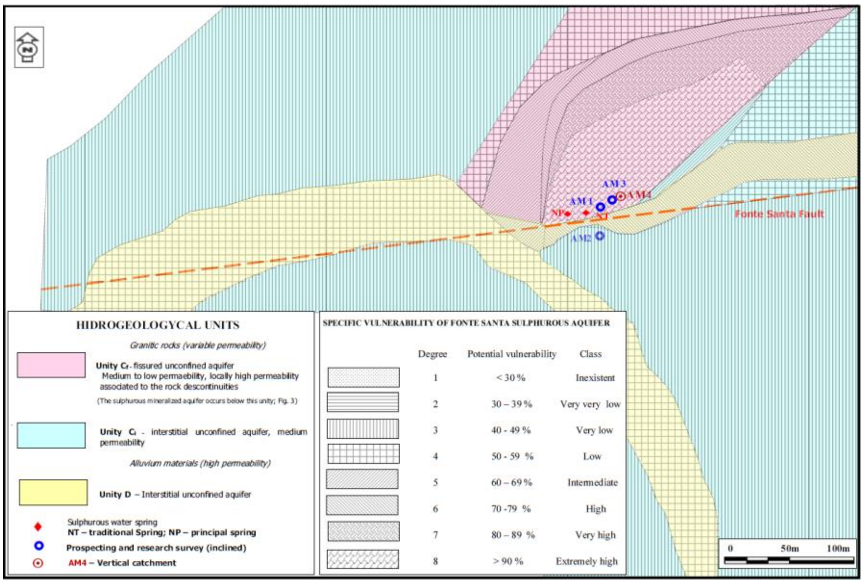

Fig. 2: "Specific DRASTIC" vulnerability map for Termas de Fonte Santa

Table 4: Drastic index and “specific drastic” of the hydrogeological units

Hydrogeological units	DRASTIC index	“Specific DRASTIC” (*)
Al – Alluvium	High	High, intermediate, low
G_{W3-W4} - Unconfined aquifer	Very low	Very low, low, intermediate
G_{W2} - Unconfined aquifer	Very low	Low, intermediate, high, very high, extremely high
G_{W2} - Confined and semi-confined aquifer	Extremely low	Extremely high

5. Conclusions

The DRASTIC index [3] is an excellent method to identify and classify vulnerability areas and potential aquifer contamination. This assessment vulnerability methodology is supported by detailed and specific parameters associated to the study area.

The DRASTIC index is interpreted as a general vulnerability of an area and is not specific to a local hydrogeological unity. So, this methodology is not accurate and precise to be applied in the local mineralized aquifer from Fonte Santa (Penamacor, Portugal). According this, the presented study has applied the DRASTIC index to the mineralized aquifer – “specific DRASTIC” – with the inclusion of two relevant factors: i) the occurrence of pontual or local geological units and ii) the spatial location of the hydrogeological formation relative to discharge areas of the mineralized aquifer. The inclusion of these two field features will leave a more accurate and precise vulnerability classification. The application of this particular methodology has been sorted out as “specific DRASTIC” to be applied in mineralized aquifers, such is Termas de Fonte Santa (Penamacor, Portugal).

The vulnerability map obtained with “specific DRASTIC” will promote the optimization of groundwater protection perimeters, including the definition of immediate and extended protection zones. The mineralized aquifer catchment is situated in the immediate protection zone and will be classified as very high to extremely high vulnerability zone allowing groundwater protection and preservation.

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