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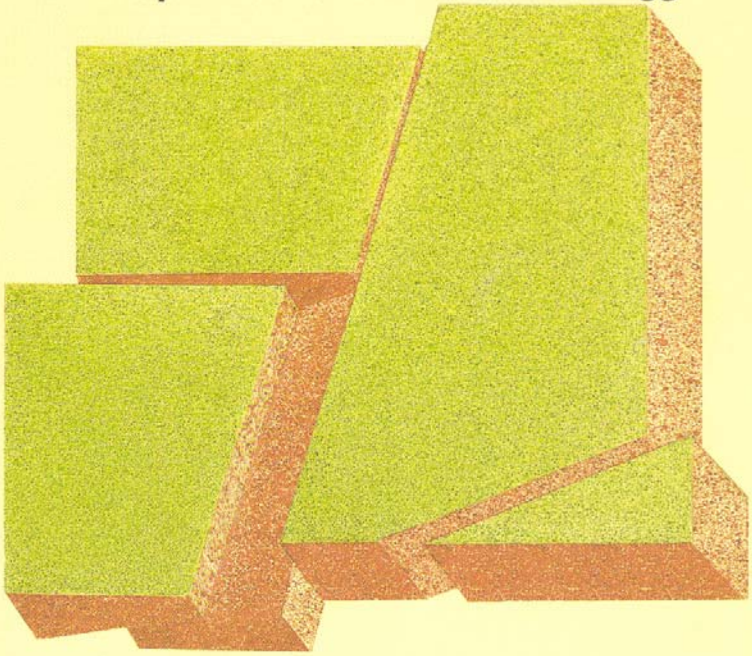

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Protection areas of the São Pedro do Sul Spa, Portugal

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Abstract

This paper presents a case study of the protection areas of one of the Portugal's most important spas. According to its chemical composition this thermal mineral water is rich in bicarbonate, sodium, carbonate, fluor and sulfate. The therapeutic indications are mainly illnesses related to rheumatism and respiratory system. As a complement the thermal mineral water is also used for geothermal purposes, as in the heating of greenhouses for the production of Bananas and Ananas. The study presents geological and hydrogeological characterization of the area and its vulnerability to pollution and the physical and chemical characterization of the thermal mineral water. Finally, in accordance with the Portuguese legislation, the protection areas are defined: for immediate, intermediate and distant zones. The criteria and other aspects that led to their definition are also presented. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Protection area; Thermal mineral water; Greenhouses

1. Introduction

Spas have a long tradition in Portugal, owing mainly to the great diversity in the chemistry of its natural mineral waters, which is a consequence of the geological conditions of the territory. The spa in this case study is located in the village of S. Pedro do Sul, district of Viseu, central Portugal.

The economic importance of the spa for the region can be inferred from the following numbers: in 1998 the number of spa visitors amounted to 20 012, with a direct revenue of 2 952 625 Euro and an indirect revenue of 15 009 000 Euro, considering that each visitor stays 15 days a year at the spa, spending an average of 50 Euro a day on food, lodging and other necessities. Consequently protection areas are of vital importance so as to guarantee the quality of the mineral water and prevent contamination problems which otherwise would lead to the closing of the spa; this would be catastrophic since the spa provides for the living of many people of one of the most wonderful places in Portugal's inland.

The area of the study has two mineral water producing sectors at a distance of around 1.2 km from one another. The *Spa Sector* includes a bathhouse for medicinal treatments and a geothermal central (under construction) for the heating of non-mineral waters for domestic use (heating and water supply); it also includes a well (AC1) with a depth of 500 m and an ancient spring (Traditional Spring, since the Roman empire) which together produce, by artesianism, about 18 l/s at a temperature of approximately 67.5°C. The *Vau Sector* has a small mineral spring and two wells, the SDV1 with a depth of 216 m and

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SDV2, 151 m deep; the water flow from each well (by pumping) is 10 l/s at a temperature of 67°C. At present this sector is being used only to heat greenhouses for the production of Bananas and Ananas.

2. Physical and chemical characteristics of the mineral thermal water

The natural mineral thermal water of S. Pedro do Sul belongs to a group known as sulfurous waters; the results of complete studies are presented in Table 1 and the results indicate a high stability of the chemical composition. The most significant elements in the composition are: bicarbonate (HCO_3^-), Sodium (Na^+), Fluoride (F^-) and Chloride (Cl^-).

3. Geological and hydrogeological aspects

The geological conditions of the S. Pedro do Sul area have been studied by several researchers, but special attention is to be given to the works by Pereira and Ferreira (1985). It must be pointed out that the Spa and Vau sectors (Fig. 1) are part of extensive granitoid massifs. On a regional scale the occurrence of the springs is favored by the great active fault of Verin (Spain)-Régua-Penacova, which in the area of the study prolongs into the Ribamá fault (0°N–10°E) and can conduct flows from great distances and depths (Pereira and Ferreira, 1985). On a local scale tectonic knots between N45°E (Spa fault) and N70°W condition the thermal springs.

From the older to the more recent one, the case study of the region reveals the following characteristics:

Unit 1 — Precambrian/Cambrian
Constituted by schistous rocks, mainly schists and metagraywackes.

Unit 2 — Granitoids (Hercynian)
2.1. Vouzela granite: monzonitic granite medium to coarse grained, formed mainly by quartz, albite-oligoclase, potassium feldspar, biotite and moscovite.
2.2. S. Pedro do Sul granite: granite fine to medium grained, composed mainly by microcline, plagioclase, quartz, moscovite and biotite. Presents considerable radioactivity that may be related to the existence of uranium and thorium. This granite intrudes the Vouzela granite.
2.3. Fataunços granite: granite close to granodiorite, fine to medium grained, with two micas. This granite intrudes the Vouzela granite.

Unit 3 — Quaternary
3.1. Pleistocene: fluvial terraces, mainly with gravel.
3.2. Holocene: alluvia, mainly with sand and gravel.

The schistous rocks and the granites present a fissural permeability, the former being practically impermeable. The mineral water discharge zones are located in the S. Pedro do Sul granites. According to A. CAVACO (1995) in these discharge zones the hydromineral aquifer functions as a confined aquifer; the computed hydraulic parameters are: transmissivity (T) $\approx$ 109 m^2/day, storage coefficient (S) $\approx 4.3 \times 10^{-5}$, hydraulic conductivity (k) $\approx$ 0.5 m/day. The values correspond to the conditions occurring at the tectonic knots found along the spa fault and were determined on the basis of pumping tests using a continuous model with a 200 m saturated thickness after applying the Theis model.

The Quaternary deposits which reveal interstitial permeability do not directly condition the hydromineral circuit, whereby $k = 370$ m/day and $T = 1850$ m^2/day were the values determined for the Vouga river alluvia.

The hydrological data is based on charts between 1933 and 1960 at the S. Pedro do Sul rain measurement station: the annual rainfall average was of 1103 mm and the average annual air temperature was 13°C; considering the results of the monthly sequential hydrologic balance one obtains an annual hydric surplus of 675 mm.

4. Vulnerability and pollution risks

In order to evaluate vulnerability, the DRASTIC index (Aller et al., 1987) has been used. Table 2 shows the obtained values and some qualitative aspects for the main hydrogeological units of the spa zone. Note that the minimum and maximum vulnerability values of the DRASTIC index are 65 and 223, respectively.

With regards to pollution risks, the most significant

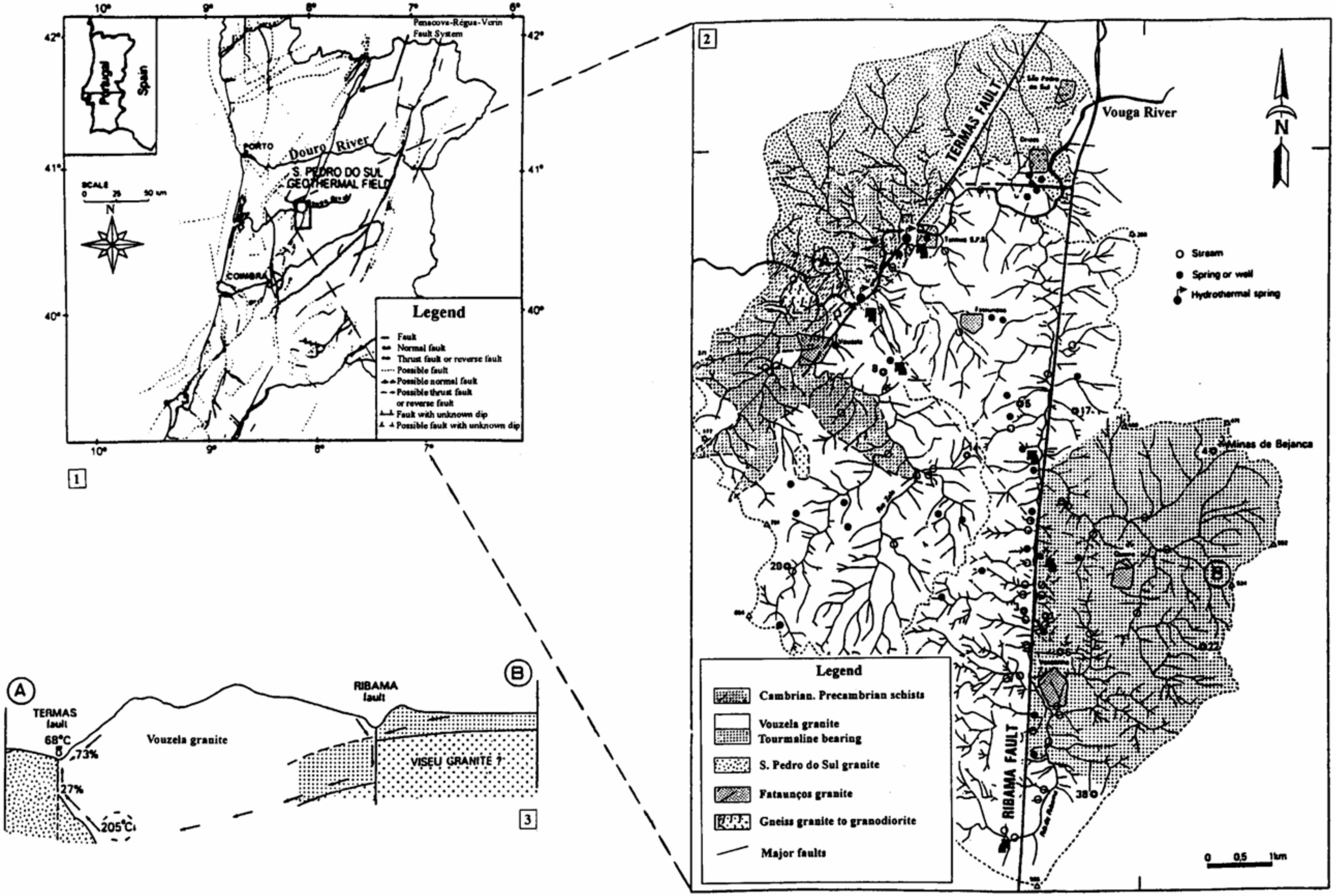

Fig. 1. Hydrogeological setting of the hydromineral and geothermal field of S. Pedro do Sul: (1) Northern Portugal neotectonic map (modified from Cabral and Ribeiro, 1989); (2) and (3) Hydrogeological outline (modified from Haven et al., 1985).

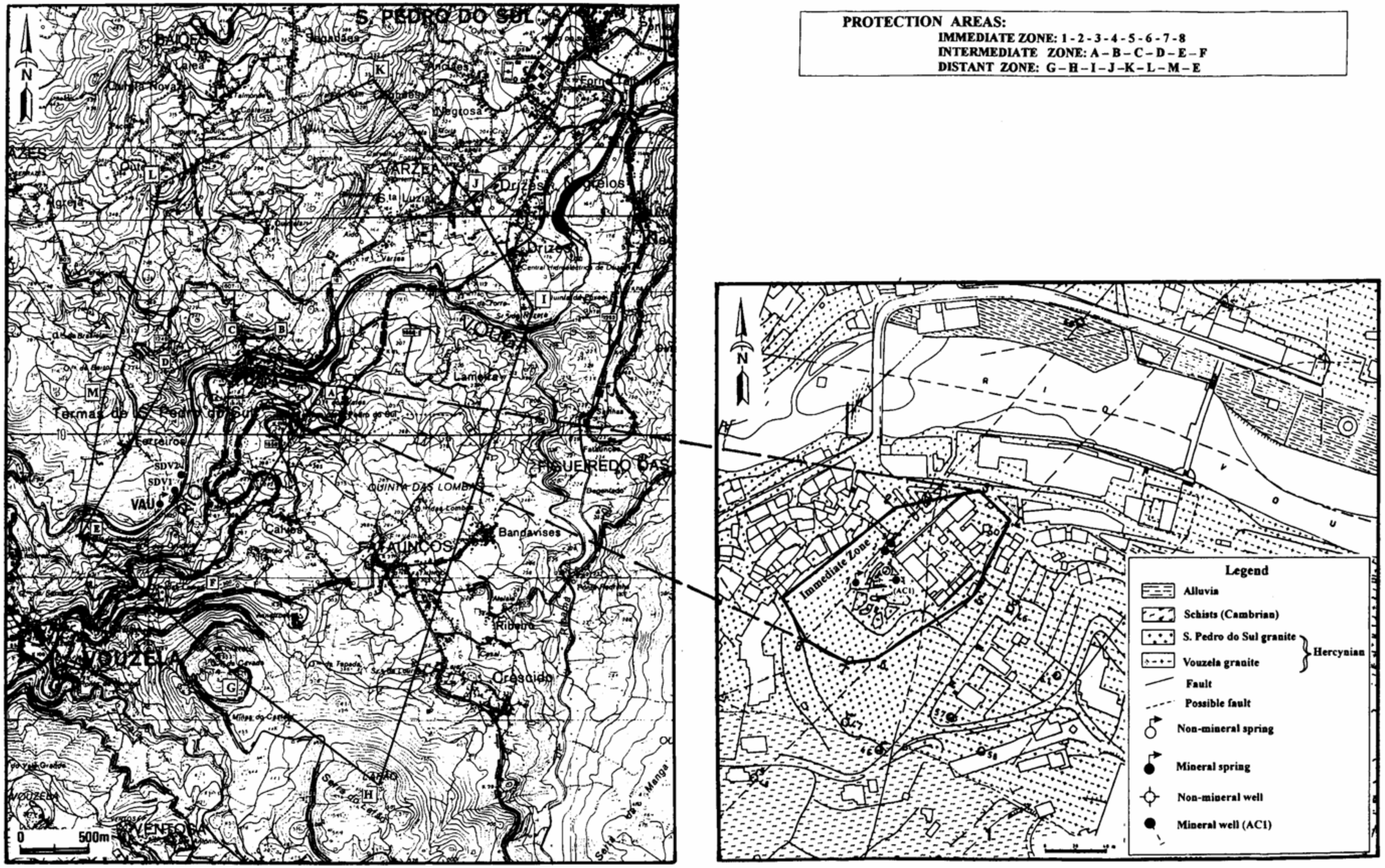

Fig. 2. Outline of protection areas of the hydromineral and geothermal field of S. Pedro do Sul, Portugal.

Table 1
Physical and chemical results of the analysis of the natural mineral thermal water of the hydromineral and geothermal field of S. Pedro do Sul, Portugal

Parameter	Traditional mineral spring						AC1	SDV1	Ave rage	Stand. dev.
	1903[a]	1928[a]	1985[b]	1989[b]	1994[b]	1998[b]	1998[b]	1998[b]		
Temperature (°C)	68.7	67.5	67.5	67.0	66.5	67.3	67.3	67.4	67.4	0.58
pH	–	–	8.33	8.93	8.92	8.91	8.93	8.85	8.81	0.22
Total CO_2 (mol/l)	–	–	2.08	1.98	1.97	1.95	1.98	2.00	1.99	0.04
Conductivity (μS /cm)	–	–	396	450	452	460	466	463	448	24
Alkalinity (HCl 0.1 N) (ml/l)	–	–	24.4	23.7	23.3	23.5	23.1	23.6	22.6	0.41
Total sulfuration (I_2 0.01 N) (ml/l)	36.8	23.1	15.5	23.1	26.4	17.1	18.1	24.6	23.1	6.3
Total silica (mg/l)	66.8	70.4	75.9	70.4	72.9	75.8	75.5	78.8	73.3	3.7
Total solids (mg/l)	–	–	363.3	341.1	352.1	363.2	359.9	368.3	358.0	9.0
Cations (mg/l)										
Na^+	89.5	90.5	88.6	87.0	89.7	89.9	90.5	92.3	89.8	1.4
Ca^{2+}	–	–	2.4	3.2	2.8	2.9	3.0	3.0	2.9	0.25
K^+	–	–	3.59	3.5	3.3	3.5	3.4	3.4	3.4	0.09
Mg^{2+}	–	–	0.73	0.02	0.03	< 0.2	< 0.1	< 0.1	< 0.2	–
Li^+	–	–	0.64	0.55	0.56	0.58	0.58	0.59	0.58	0.03
NH_4^+	0.53	0.02	0.36	0.25	0.34	0.30	0.31	0.31	0.30	0.13
Anions (mg/l)										
HCO_3^-	–	–	120.2	103.7	114.7	112.9	114.7	115.9	113.7	5.0
Cl^-	29.7	27.7	29.8	28.8	27.3	28.4	28.0	29.1	28.6	0.85
SO_4^{2-}	17.7	25.0	8.9	8.6	9.0	9.3	9.3	9.8	12.1	5.28
F^-	–	–	17.1	17.1	17.2	17.4	17.7	17.8	17.4	0.28
CO_3^{2-}	–	–	6.4	8.6	5.7	5.7	6.3	6.0	6.5	1.0
NO_3^-	–	–	< 0.07	< 0.07	< 0.10	0.82	0.97	1.1	< 0.5	–
NO_2^-	–	–	< 0.002	< 0.002	< 0.002	< 0.02	< 0.02	< 0.02	< 0.01	–
HS^-	–	–	1.8	3.0	4.4	1.7	2.8	3.8	2.9	0.98
$H_3SiO_4^-$	–	–	–	–	11.4	14.3	15.2	13.3	13.6	1.4
Secondary constituents ($\times 10^{-3}$ mg/l)										
$H_2PO_4^-$	–	–	18	19	< 40	–	–	–	–	–
Al_3^+	–	–	337	640	52	18	38	20	–	–
Mn^{2+}	–	–	6	2	4	2.1	1.1	2.6	–	–
Br^{2-}	–	–	260	135	130	–	–	–	–	–
B_3O_3	–	–	311	405	400	415	410	412	–	–
Be	–	–	0.5	0.6	0.7	0.7	0.7	0.7	–	–
Pb	–	–	4.7	11	6	–	–	–	–	–
Cd	–	–	< 0.3	2.1	< 0.3	< 1	< 1	< 1	–	–
Nb	–	–	< 0.4	< 1	< 0.5	–	–	–	–	–
V	–	–	< 0.5	< 1	< 3	< 1	< 1	< 1	–	–
Y	–	–	< 0.3	< 1	< 0.1	< 1	< 1	< 1	–	–
Sn	–	–	< 0.7	< 1	< 3	< 5	< 5	< 5	–	–
Cr	–	–	< 0.1	8	< 2	< 4	< 4	< 4	–	–
Fe^{2+}	–	–	26	60	< 25	< 7	< 7	22	–	–
Ba^{2+}	–	–	< 2	< 5	< 2	4	3	4	–	–
I^-	–	–	1	2	< 1	–	–	–	–	–
As_2O_3	–	–	5	< 5	10	3	4	< 3	–	–
W	–	–	54	37	75	80	75	78	–	–
Cu	–	–	0.4	< 1	< 1	< 2	< 2	< 2	–	–
Zn	–	–	4.5	8	11	2	< 1	5	–	–
Sb	–	–	< 0.5	< 5	7	< 3	< 3	< 3	–	–
Ni	–	–	< 0.6	< 1	< 3	< 5	< 5	< 5	–	–
Co	–	–	< 0.5	< 1	< 1	< 3	< 3	< 3	–	–
Mo	–	–	< 1	< 5	6	< 5	< 5	< 5	–	–

[a] Results obtained by Lepierre (Machado, 1999).
[b] Results obtained by IGM Laboratory.

Table 2
DRASTIC Index values of vulnerability for the main hydrogeological units of the S. Pedro do Sul Spa zone

Unit	Parameters[a]	Range	Rating	Weight	Partial index	DRASTIC total	Vulnerability
	1	1.5–4.6	9	5	45	187	Generally high; the pollution can easily spread over great distances
	2	101.6–177.8	6	4	24		
Alluvial	3	Sand and gravel	8	3	24		
	4	No soil	10	2	20		
	5	3%	10	1	10		
	6	Sand and gravel	8	5	40		
	7	40–82	8	3	24		
Granite	1	4.6–9.2	7	5	35	114	Generally medium; in some fractures and rock alteration zones can sometimes be high
	2	50.8–101.6	3	4	12		
	3	Granites	3	3	9		
	4	No soil	10	2	20		
	5	22%	5	1	5		
	6	Igneous	6	5	30		
	7	< 4	1	3	3		
Schists	1	4.6–9.2	7	5	35	96	Generally low; in zones with great rock alteration rates can locally present higher vulnerability
	2	0–50.8	1	4	4		
	3	Schists	3	3	9		
	4	No soil	10	2	20		
	5	6–12%	5	1	5		
	6	Metamorphic	4	5	20		
	7	< 4	1	3	3		

[a] Parameters: 1 — depth of the water table (m); 2 — net recharge (mm); 3 — aquifer material; 4 — soil type; 5 — topography-slope; 6 — unsaturated zone; 7 — hydraulic conductivity of the aquifer (m/day).

ones are: (i) *in the urban area* — pollution derived from human action such as septic tanks, outdated sewerage, Várzea cemetery, filling stations and small industrial activity; and (ii) *in the rural area* — the use of fertilizers and pesticides in small agriculture (although the forest is predominant), the greenhouses in the Vau sector as they must be considered a *contra natura* agriculture and, as such, as an additional risk.

5. Protection areas

The protection areas are intended to reduce the risks of polluting the mineral water of the hydromineral and geothermal field of S. Pedro do Sul, or, in case of an accident, to prevent the pollution in reaching health endangering concentrations at the supply well or mineral spring. A. CAVACO (1995) made a study of the protection areas as they stand and its main criteria are presented herein. Note that a possible use of the Vau sector for medicinal purposes in the future has not been considered and at present only the greenhouses exist there. But if it were to be used for that purpose, the protection areas would have to be redefined.

For the definition of the protection areas two situations were considered:

1. *interference influences:* which result from the usage of mineral or non-mineral water, in other places, and which might interfere with the hydromineral circuit;

2. *qualitative influences:* which are linked to pollution and contamination problems of the hydrogeological systems.

The following boundaries were established: immediate zone, 1 day; intermediate zone, 50–365 days; distant zone, 25 years and/or limits of supply to the hydrographical basin. The evaluation of the interference influences was made on the basis of the classic equations of underground water flow for the collector wells in a continuous model. With regards to the qualitative influences, in which complex phenomena of transport are linked to processes such as advection, dispersion, diffusion and others, an analysis of propagation time in a saturated zone was made. Additionally, the local estimation of vulnerability to pollution according to the DRASTIC index was taken into consideration.

Concerning eventual interference, calculations lead to believe that these can occur in fractured zones of the aquifer at 160, 1200 and 3000 m after 1, 50 and 365 days, respectively. For the estimation of propagation time in a saturated zone the method used was the US EPA (1987); note, for instance, that in granitic rocks and for transit times of 1, 50 and 365 days, distances need not be greater than 25, 200 and 500 m, respectively.

So, taking into account all previously stated aspects, the boundaries of the protection areas (Fig. 2) were set as follows:

Immediate zone — The most vulnerable protection area. Protects the discharge zone of the natural mineral water for medicinal purposes; covers 1.0 ha.

Intermediate zone — Includes all areas surrounding the previously mentioned discharge zones in order to protect the mineral aquifer and even other non-mineral aquifers which might interfere with the mineral water circuit; covers a total area of 157 ha.

Distant zone — The area intended to protect the recharge zones so that any eventual contamination does not reach the hydromineral circuit in dangerous concentrations; covers a total area of 979 ha.

For the different protection areas, Portuguese legislation sets the following restraints:

Immediate zone

1. The following are forbidden: (a) erect any kind of building; (b) perform drillings and underground works; (c) make embankments, excavations or any kind of ground-levelling; (d) use chemical or organic fertilizers, insecticides, pesticides or any other kinds of chemical product; (e) dump any kind of waste products and create garbage dumps; and (f) perform works for the conveying, treatment or collection of sewage.
2. Any of the ensuing acts must be previously authorized: the cutting of trees or shrubs; destruction of plantations; and the demolition of buildings of any kind.
3. The works referred in 1 (a), (b), (c) and (f) may be authorized by the competent authority of the Administration whenever necessary or advisable for the conservation and exploration of the natural mineral water.

Intermediate zone

1. Activities referred in (1) and (2) of the immediate zone are forbidden, except when duly authorized by the competent authority of the Administration and if proven by them that there is no interference in the natural mineral water.

Distant zone

1. The activities mentioned in (1) and (2) of the immediate zone can be prohibited by order of the Minister of Industry and Energy when representing risks of interference or contamination of the natural mineral water.

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