Protection Perimeter of a New Mineral Water in an Essentially Urban Environment: The Case of the São Tiago Medical Spa (Portugal)

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Abstract. São Tiago medical spa is an integrated structure in a new Health Tourism Complex, in Penamacor, Portugal, with a recent start of operation, due to the classification of a new natural mineral water in place. That medical spa bases its exploration on the natural mineral water obtained from the Well P1. Thus, to facilitate the preservation of the quality of the resource, natural mineral water, one of the fundamental instruments is the implementation of a Protection Perimeter of Well P1 and its associated aquifer system. In this sense, in this paper, after briefly presenting the basic geoenvironmental aspects that are the base for the elaboration of the Protection Perimeter, the methodology of its elaboration is explained, with the final solution, which constitutes a territory organized by three zones: Immediate Protection Zone, Intermediate Protection Zone and Extended Protection Zone. The official restrictions legally foreseen for those zones are mentioned and the official systematization of the current occupation of the territory is presented, in terms of the Municipal Master Plan (PDM), while emphasizing the potential sources of existing pollution. Finally, some comments are made about the future orientation regarding the occupation of the territory in the interior zones of the Protection Perimeter, so that the new Health Tourism complex, consisting of a medical spa, hotel, and aqualudic spaces, endures in the time, and helps the sustained economic growth of the region.

1. Introduction
São Tiago Medical Spa is a very recent medical spa, which started its activity in 2017. This medical spa resulted from the need to leverage the population of the municipality of Penamacor, which is a region in the interior of Portugal (Fig. 1) and has been losing a lot of population over the last decades. Penamacor was once a very important settlement, having had its first charter in the year 1199, elevating the settlement to a town, after Sancho I (2nd king of Portugal) had conquered Penamacor from the Muslims [1]. At the site groundwater was researched that had the potential to be classified as mineral water and that would lead to the construction of a medical spa. This came to be, and the main results that led to the medical spa were presented by Ferreira Gomes in several works [2,3,4].

In addition to the construction of a medical spa, a 4-star hotel was also built in association, and all the necessary infrastructure for its proper functioning. In Figure 2 some images of the new complex are presented, namely about its framing with the surroundings and some equipment of the same and in particular the image of the abstraction of groundwater, natural mineral water, which is the support of the same.
The licensing of the São Tiago mineral water was only possible because it was based on a set of unprecedented technical and scientific studies, essentially geohydraulic [5]. Subsequently, the Portuguese State imposed other studies to be carried out, namely to establish the Protection Perimeter [6] and the Mineral Water Exploitation Plan [7]. The referred Protection Perimeter (PP), carried out with technical and scientific procedures, was proposed to the Portuguese government on 9/08/2017. Under Portuguese Law [8] it was published in Notice No. 4657/2018, DR 69, Series III, 09-04-2018 for public consultation. At the present date, it has not yet been officially established, understanding that the reason for the delay is “bureaucratic issues”.

As the PP involves 3 zones (Immediate, Intermediate and Extended) with different restrictions and conditionings to the use and fruition of the lands involved, it can create conflicts about actions and potential occupations of them. For that reason, it is important to establish the PP with firm technical-scientific criteria because successively each time there is a pretension in fruition of such spaces, often there will have to be opinions about the harmful potential, or not, in relation to the mineral aquifer system to be provoked by the new pretensions.

Figure 1. Location/geographic framing of São Tiago Medical Spa.
Thus, this paper has as main objective to present the fundamental principles used for the proposal for setting the PP of São Tiago Medical Spa, presenting the final solution obtained, in addition to presenting the restrictions imposed by Portuguese law [8] for each zone, making also a prospective about possible problems, depending on the current urban easements, emphasizing that most of the protection areas are developed on urban areas of the village of Penamacor.

2. Environmental aspects of the territory
Geomorphological, geological, hydrogeological and other elements, in some detail, were presented in an unprecedented report [3] presented to the Portuguese State to propose the legalization of the new natural mineral water. The main aspects on those themes were presented in Ferreira Gomes [2,3,4]. The local geological sketch of the area of greatest interest to the groundwater abstraction area under study is shown in Figure 3, and it should be noted that the units that are preponderant to the present study are: i) Recent fluvial alluviums; ii) Hercinian granites; and iii) Schist-metagreywacke complex, ante-ordovician. The fluvial alluviums are of little thickness, generally with thicknesses of less than 5m, and are essentially sandy, with extensive grain size, predominating the coarser fraction. The granitic rocks preponderant to the aquifer system under study, are medium to coarse grained, with little alteration in the urban zone of Penamacor, i.e., in the higher altitude zones, and very coarse grained, porphyritic, two-mica, generally very altered and sometimes even sandy in the lower zones, including the zone where the mineral water abstraction is installed (P1 Well). The schist-metagreywacke complex, is understood not to have significant importance in the context of this study. Still from a geological point of view, it is worth noting that the granite massif, and especially in the higher zones, urban area, is extremely fractured, in addition to the occurrence of some relatively extensive faults of predominant directions NNE-SSW; these situations favour the recharge of water in depth, in order to supply the groundwater abstraction area.
Figure 3. Geological map of the main area under study (a), and sketch of the conceptual hydrogeological model to supply the abstraction of the São Tiago Medical Spa - Penamacor (b).
The conceptual hydrogeological sketch of the area of interest to the present study is presented in Figure 3b. The distance in the horizontal from the zone of mineral water abstraction, Well P1, to the upstream zone, in the centre of the town of Penamacor, is about 1200m. The highest altitudes are around 483m asl and the lowest in the abstraction area is around 461m asl.

From a hydrogeological point of view, considering the geological setting of the region and in particular the basin where Well P1 is located, the following hydrogeological units are considered, from top to bottom [2]: i) 0 - 2 m depth: free aquifer, consisting of alluvial deposits, of medium global permeability, with normal water; ii) 2 - 65 m depth: free aquifer, geological formation consisting of very altered granite of low global permeability and mixed type (interstitial in the most altered zone and fissural in particular in the less altered zones), of normal water; iii) > 65 m depth: semi-confined type aquifer, where the mineral water is captured, consisting of slightly altered to healthy granite, of very low overall permeability of fissural type, of water with special characteristics, to resurface in the well in fractures that are understood to be relatively extensive.

For the aquifer system of natural mineral water, the following hydraulic parameters have been advanced [2]: Hydraulic conductivity - \( k = 1.45 \times 10^{-7} \text{ m/s} \); Transmissivity - \( T = 1.1 \times 10^{-6} \text{ m}^2/\text{s} \); Storage coefficient - \( S = 3.0 \times 10^{-2} \).

The mineral aquifer system is explored by Well P1, with 324m of depth, and with an admissible flow of exploration, \( Q = 0.7 \text{ L/s} \). In terms of quality, natural mineral water is classified by sodium-calcium-magnesium bicarbonate water [3].

3. Protection Perimeter

3.1 Introduction: criteria and methods

With the Perimeter Protection (PP), the main objective is to reduce the risk of pollution of the aquifer and, if it happens, to prevent it from reaching the abstractions in dangerous concentrations. Generically, the PP corresponds to a set of zones in which the conflict of interest between land uses and mineral water use is to be disciplined.

The PP, according to Decree-Law 86/90 [8] and Law 54/2015 [9], comprises three zones: immediate zone, intermediate zone, and extended zone. The elements necessary to justify the PP proposal for the São Tiago Medical Spa are presented below, taking into account the following global aspects: i) Immediate zone, as the most vulnerable protection zone, and which is intended to protect the mineral water discharge zone, that is, essentially the water in the abstraction; ii) Intermediate zone, as the area necessary to protect the mineral aquifer or even other non-mineral aquifers, eventually interfering with the mineral water circuit; iii) Extended zone, as the area that intends to protect essentially the recharge zones and in particular the main structures (fractures) that serve as a significant recharge to the hydromineral circuit, thus ensuring that very careful consideration can be given to the future installation of any activities that may show evidence of damaging the resource.

At present, there are powerful tools from the point of view of specific software to help optimize the protection perimeters, taking into account the geometry of the aquifer massif, its physical and hydraulic characteristics, its boundaries and also various types of pollutants from microbiological to physical and chemical. However, there are strong limitations in the application of these tools, as it is necessary to know the hydrogeological model rigorously, and in the environments of fissured plutonic rocks, as is the present case, it is a very complicated task, especially because they include very varied heterogeneities, such as very diverse fractures, from faults, joint, cleavages, contacts of different lithologies and others. On the other hand, the large oscillations in the topography make the application of such tools difficult. Thus, in the present work, the method developed in Mendes [10] and presented in other works [11,12] is considered. That method has an application resulting from a combination of
four methods: 1) partial application of the Wyssling method [13]; 2) application of the fixed radius formula, expressed in the Decree-Law nº 382/99 [14]; 3) geological/structural and geomorphological aspects of the groundwater abstraction area; 4) consideration of the vulnerability of the geological formations of the groundwater abstraction area. In the methods that use the transit time of contaminants in the determination of the protection zones; it is usually considered, as in the present work, a transit time of 1, 50 and 3500 days for the immediate, intermediate, and extended protection zones, respectively. Figure 4 presents an outline of the model of the three zones to be obtained by this method [10].

![Diagram of protection zones](image)

**Figure 4.** Scheme on the main elements for the application of the method developed in Mendes [10] to optimize the Protection Perimeter of groundwater abstraction.

### 3.2 Application and Results

In order to optimize the PP, for the present case study, the following parameters were considered:

- the exploration flow (Q) is accepted as a value of 0.7 L/s (60.48 m³/day);
- the value of effective porosity is considered to be 0.2%, which corresponds to an appropriate value for granites foreseen in the annex of the Decree-Law nº 382/99 [14];
- the value of the saturated thickness (H) to be used is 76m, as a consequence of the characteristics of Well P1;
- the value of hydraulic conductivity (k) considered, for the granitic formations present in the productive zone is k= 1.45x10^{-7}m/s (0.013m/day), obtained from the flow test in Well P1
- the value of hydraulic gradient (i) is considered as equivalent to the value of the average slope of the hydrographic basin where the abstraction is located, in this case, the value of 0.12.

The results obtained are presented below:

i) by the Wyssling method, with the appropriate adjustments, for the various protection zones:
   - Immediate zone (t = 1 day) - So = 12m, Su = 11m, B = 510m, B’ = 255m;
   - Intermediate zone (t = 50 days) - Su = 35m;
   - Extended zone (t = 3500 days) - Su = 40m.

ii) by the method of Ray Fixed, are obtained for:
   - Immediate zone (t = 1 day) - r = 60m;
   - Intermediate zone (t = 50 days) - r = 140m;
   - Extended zone (t = 3500 days) - r = 1200m.

#### 3.2.1. Immediate Protection Zone

For the Immediate Protection Zone, in Mendes [10] the results presented previously for the Wyssling method are taken as the basis, however, in this specific case, the values obtained for B and B’ are very unadjusted to reality. On the other hand, the values for So and Su are very consistent and are considered adequate; thus, taking into consideration that the location where
the groundwater abstraction is installed - Well P1, is semi-horizontal, and that the aquifer system is semi-confined, it is understood that a circle with a radius of 12m with centre at P1, will correspond to the adequate Immediate Protection zone for the São Tiago medical spa. Thus, the Immediate Protection Zone results in a circle with a radius of 12 m, with centre in Well P1, with a global area of 0.0452 ha.

3.2.2. Intermediate Protection Zone. For the Intermediate Protection Zone, it should be noted that the Wyssling method, with the necessary adjustments, orientates towards a dangerous situation (Su=35m), as does the fixed radius method, which only orientates towards a circle with a radius of 140m, therefore also dangerous for the present situation. When it is mentioned that those results are dangerous for the mineral aquifer system, because, consequently, they orient to reduced areas, and when analysing the vulnerability map of that territory (presented in [4]), the areas of Very High Vulnerability would not be safeguarded. Thus, it was understood that the proposal for the boundary of the outer zone of the Intermediate Protection Zone should coincide with the boundary of the Concession Area of the natural mineral water, in order to include almost all the area of Very High Vulnerability, resulting in a rectangle in plan, as shown in Figure 5 (rectangle 1-2-3-4), with a global area of 16.9648 ha.

3.2.3. Extended Protection Zone. For the optimization of the Extended Protection Zone, when initiating the process applying the Wyssling method, the result is Su=40m; afterward, when applying the fixed radius method, r= 1200m is obtained. When analysing these results, it is verified that for upstream of the Well P1, it would lead to consider the urban zone almost in its totality, occupying even an area beyond the ridge limit of the basin; thus, the extreme limit is considered approximately in the basin border zone. It was considered to shorten the area further in this urban zone to minimize conflicts in the future, however, because there are many fracture systems, this did not happen as it is clearly a recharge zone of the mineral aquifer system, thus resulting in a trapezoid equivalent to an r =1065m, as shown in Figure 5 (trapezoid 5-6-7-8-9), with an overall area of 142.4880 ha.
4. Restrictions in the Perimeter Protection Zones
Regarding the restrictions that the legislation imposes, they are listed in Law No. 54/2015 [9], however, due to their importance, the following are mentioned:

i) Immediate Protection Zone
   1 - In the immediate zone of the PP, the following are prohibited:
   a) Carrying out urban operations and any interventions therein, even if exempted from prior control;
   b) Drilling and underground work;
   c) The realization of landfills, excavations or other operations that imply or have the effect of changes in the land;
   d) The use of organic or chemical fertilizers, insecticides, pesticides or any other chemical products;
   e) The discharge of wastewater and the abandonment or deposition of waste;
   f) Agriculture, pig farming, intensive grazing and similar activities;
   g) The execution of drainage infrastructures, collection and treatment of wastewater.
   2 - In the immediate zone, the cutting of trees and shrubs, the destruction of plantations and the demolition of construction of any kind, are subject to prior authorization by the competent entities of the Administration.
   3 - The activities and works referred to in paragraphs a), b), c) and g) of point 1, when they take advantage of the conservation and exploitation of mineral water, may be authorized by the competent authorities of the Administration.

ii) Intermediate Protection Zone
   In the intermediate zone of the PP, the activities provided for in the previous point (i), shall be subject to authorization by the competent administrative entities; such authorization shall only be granted when it is proved that those activities will not result in any damage to the conservation or exploitation of the mineral water.

iii) Extended Protection Zone
   In the extended zone, only the activities provided for in paragraphs 1 and 2 of point i) may be prohibited, based on the risks of interference or contamination of mineral water, but only by order of the member of the Government responsible for the sector that supervises mineral waters.

5. Territory Occupation and Potential Pollution Sites
Having the need to analyse the real or potential risks of pollution of the mineral aquifer system where the Well P1 is installed, in order to obtain natural mineral water, it became necessary to organize the zone of influence, in areas with different occupations, based on the designations presented in the Municipal Master Plan (PDM) of the municipality of Penamacor [15]. Thus, from that document for the territory under study there are the following areas (Fig.6): a) Urban Zone (ZU); b) Urban Expansion Zone (ZE); c) National Agricultural Reserve (RAN); and d) National Ecological Reserve (REN) with the following sub-areas: i) Headwaters of water lines; and ii) Flood Beds; iii) Erosion Risk Zones; and iv) Maximum Infiltration Zones. Thus, taking into consideration the various areas in terms of land use planning, and crossing the same areas in the vulnerability map [4], the situations are highlighted:

a) less favourable:
   i) the urban zone is located in an area of medium vulnerability, and although the distances are relatively considerable for Well P1, because it is in an area of hydric recharge, there must be very good sense, so that in that territory there is no infiltration of contaminated fluids; in particular there must be great care with the sewer network in the sense that it functions normally, without infiltration from ruptures or leaks, on a continuous basis;
   ii) ii) the RAN area is located NW of the São Tiago Medical Spa, and being part of this area of high vulnerability, the use of agriculture may lead to contamination outbreaks, like, indeed, already it is happening when checking the water quality of some springs that occur in that area, and for that reason, it is advisable, that in a future alteration of the PDM, this area loses this status, remaining only as a REN area, as this situation is favourable.

b) favourable:
i) around the urban area, namely the NW and SW, there are REN areas classified as Headwaters of water lines, and Erosion Risk Areas; this situation is favourable because these sectors are already limited to urban occupation, and therefore they are favourable situations, as it is in areas of medium vulnerability, and of recharge to the mineral aquifer.

Other situation to mention is the fact that the Medical Spa and surrounding areas do not have any limitations. This fact can be favourable or unfavourable, highlighting that having some "freedom" of occupation, any project for the area, should always be the subject of much attention about the potential contamination of the aquifer system, because most of the area has a very high vulnerability. It is worth mentioning the occurrence of the Wastewater Treatment Plant (WWTP) and a small lake of semi-stagnant waters, which, not being serious emergency situations, will be of great importance that in future interventions the WWTP moves south, least for about 700m downstream of Well P1.

![Figure 6. Map of the Occupation of the Territory of the São Tiago Medical Spa area (from PDM maps of Penamacor municipality [15]).](image)

### 6. Conclusions

The bet on believing, on the part of the local political power, in harmony with the private investment, to implant a Health Tourism Complex, with a new Medical Spa, integrated with a Hotel and aqua-ludic spaces, was achieved. This situation was only possible because the resource, "groundwater", occurs on-site, with characteristics that led to its classification as natural mineral water, suitable for thermalism. Investments have been made and the Health Tourism Complex is in operation. This will have a future, if among others, its resource, natural mineral water, preserve its stability in quality. One of the fundamental instruments for the preservation of the quality of the resource will be the rigorous implementation of the Protection Perimeter. In that sense, it is necessary to enforce the restrictions legally provided for the Protection Perimeter Zones and presented in detail in item 4.
From the point of view of optimization of the Perimeter of Protection, it is emphasized that the final solution of the configuration of the various zones cannot be the application of any blind method, of simple application of math formulas, but rather, the result of the application of these methods simultaneously with the criteria of local geology and vulnerability, that using common-sense, and that, in case of doubt, the notion of security should be implemented, in favour of the preservation of the resource, leading to larger areas for the protection zones of mineral water abstractions.

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