

Conference Paper

Contributions for Conceptual Geohydraulic Model of the Underground Hydric Resources of Meda Municipality

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Abstract

This paper presents contributions on underground hydric and geothermal resources of the Meda Municipality land. After a brief introduction about the importance of the theme, the Meda municipality's administrative, geographic, geomorphological and geological frameworks are presented in a synthetic way. The main hydrogeological units of the municipality are presented below and, based on the water surpluses resulting from precipitation, the order of magnitude of the water reserves of those hydrogeological units is advanced. From a vast field survey of groundwater points on the various hydrogeological units, the results obtained from the expeditious physical-chemical parameters are presented, and based on them some waters were selected to carry out complete physical-chemical and some isotopes analyses. Based on all the results, the municipality was organised in three different major hydrogeological domains (Longroiva, Areola, and Graben), for which the conceptual geohydraulic model was developed. From the several results, it is emphasized in particular that in the various domains there are potential to explore special groundwater with characteristics not only for medical spa and aqua-ludic spaces, but also for the production of energy and even not only heat energy, with cascading uses, but also for the production of electricity from groundwater from 70 to 113°C.

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1. Introduction

Water resource management in Portugal is one of the major challenges for the coming years, as water is a basic necessity of great importance in various sectors of activity and can have great impact on the economic and social development of a region. In the Meda Municipality (Fig.1), public supply water came from several groundwater abstractions that were later abandoned in the period that followed the construction of the Ranhados Dam, currently the main supplier of this municipality, with the exception of four localities. The most recent drought episodes have raised some questions about



the need to invest in knowledge concerning the drinking water reserves in this territory. The existing water resources in the geographical area of the municipality of Meda are not, however, restricted for human consumption. Special waters, of economic interest to the development of this territory emerge, some of which were used in the past for medicinal purposes by the population, and the particular case of Longroiva Medical Spa, which nowadays have been adapted and are now a good example of a modern thermal baths.

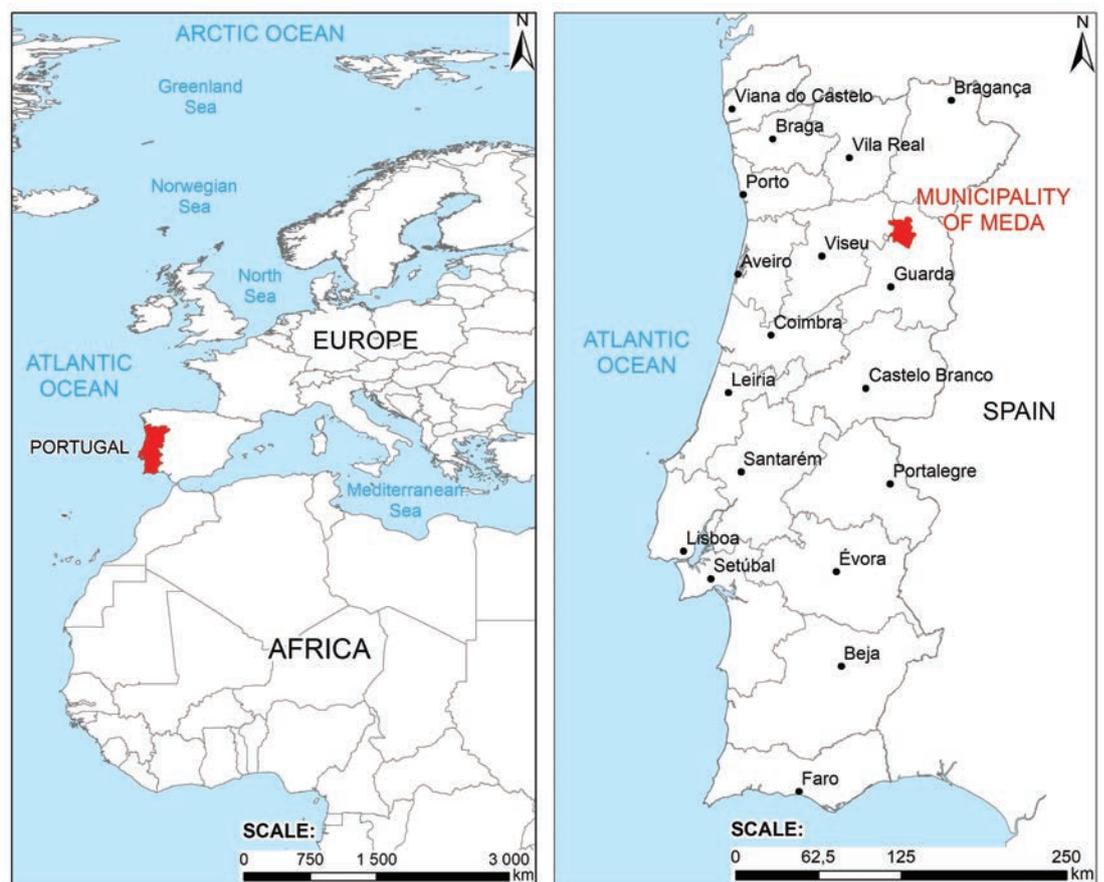


Figure 1: Location of Meda Municipality [1, 2].

The need for an alternative to the existing surface drinking water abstractions in extreme water shortages and the strengthening of the knowledge about the deep circulation of special groundwater in this region in order to improve their protection and management, are the main reasons for this work proposal.

2. Geographical, Geomorphological and Geological Elements

In the extreme west of Europe, located in the northeast part of mainland Portugal, is the Municipality of Meda, one of the thirteen municipalities that are part of the District of Guarda, framed in the Central region, sub-region of Beira Interior North (Fig. 1).

When analysing in particular the geomorphological elements of this region, it is clear that any study that is intended to develop on the groundwater resources existing in the Municipality of Meda cannot be restricted to its administrative limits. Factors such as the boundaries between river basins as well as the orography of the region suggest that it should be considered a larger area. Thus, Fig. 2 shows the area considered for this study within the geomorphology of the region. With regard to the relief, the region is part of a transition zone between the Central Plateaus, where the flattened surfaces dominate, associated with steep slopes and the plateau area of the surface of the Iberian Plateau [3]. This separation is materialized by the tectonic accident of the Vilarica fault (Bragança - Manteigas) [3], which compartmentalizes this area into two large blocks; that fault is characterized by being strike-slip deformation structure, with about 5.5km of horizontal displacement and that triggered a parallel fracturing in a range of 0.5 to 1km wide, which with the unevenness of the extreme blocks and the subsiding of the central block originated the graben of Longroiva. [4]. Locally and with interest for the current work, it is worth mentioning, at the geomorphological level, a mountain range with average altitudes of 750m; that mountain range consists of a granite plateau, about 35km long and 4km wide, which develops from Trancoso (south of Meda), according to the NNE-SSW direction along the largest side, and along the entire study area. In the eastern part of the country there is a vast plain, reaching up to 350m in altitude.

The drainage network that begins along that central mountain range (ridge line) is of the dendritic type and develops to the north-east feeding the Massueime and Centieira streams towards the Côa river, and to the north-west feeding the Teja river, both tributaries of the left bank of the Douro river (Fig. 2).

The area under study is part of the Ancient Massif, which corresponds to the western part of the Iberian Peninsula morphostructural unit called Hercynian basement, with evident episodes of extensive magmatic intrusions [5], more specifically in the Central Iberian Zone, dominated by formations of Pre-Cambrian, Ordovician and Permo-Carbonian age, covered by more recent formations of Tertiary and Quaternary [4].

The oldest formations are the rocks of the Schist-Greywacke Complex (CXG), pre-Ordovician [8] (Fig.3); detached from those rocks, appear the alignments of quartzite

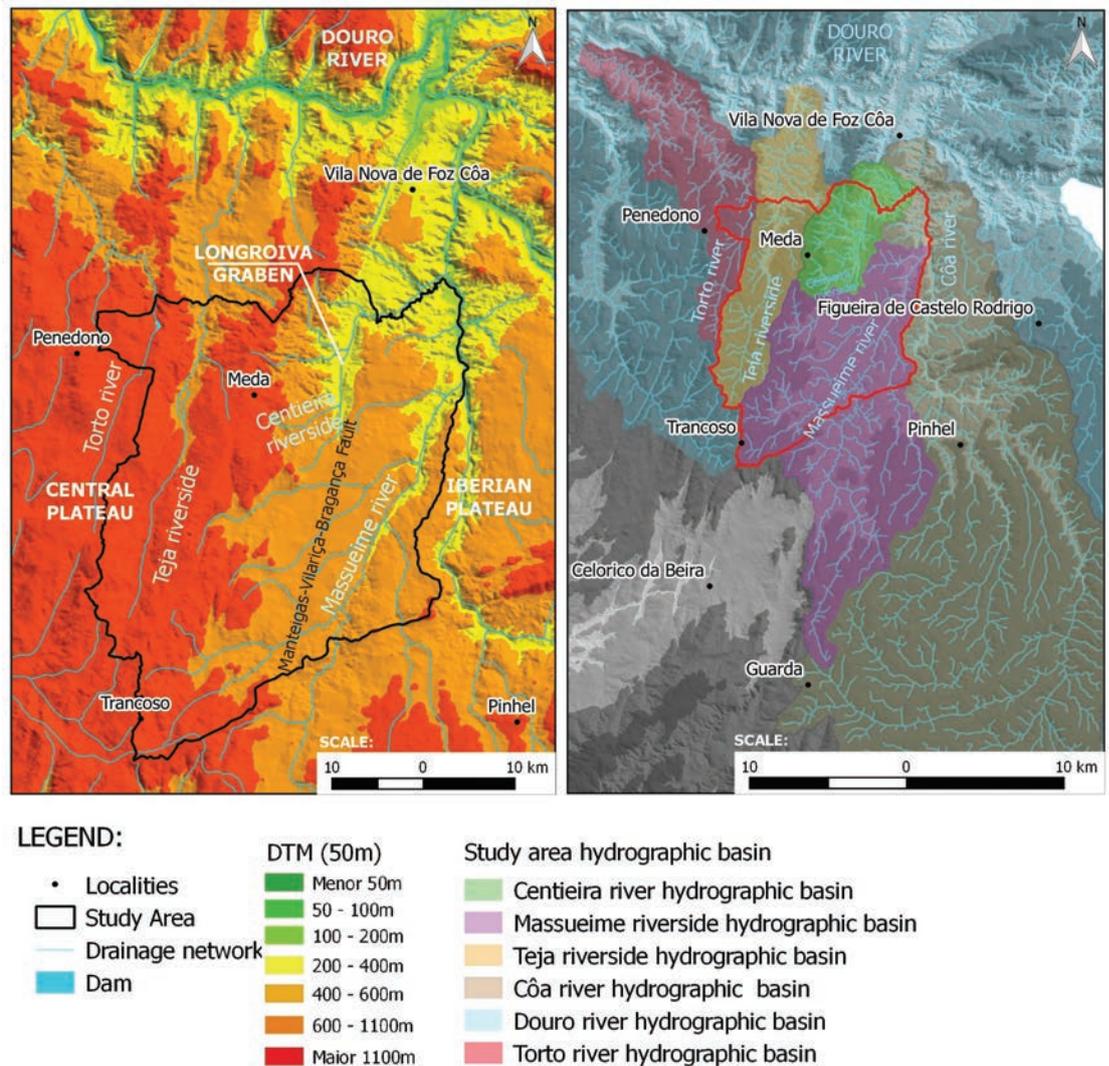


Figure 2: Geomorphological framework: (a) Hypsometry of the region; (b) Hydrographic basin [6, 7].

ridges of the lower Ordovician, residual reliefs of sinclinal folds with E-W direction to ENE-WSW in turn, the granitoids intruded the CXG in the axis of the Lamego-Penedono-Escalhão antiform during the third phase of Hercinic deformation (D3) [4]; are represented in the geological cartography of the region the sin-D3 granites, the leucogranite series and two-mica granites, as well as the series of biotite granites and granodiorites, with an approximate age of 320-310 Ma, and the late-D3 granites, the series of biotite-moscovite granites, as well as the series of biotite granites and associated basic rocks, with about 310-290 Ma, main groups of the Beiras Granitic Batholith [10].

During the late and post-Hercinical period there was the installation of a veins cortege that intruded all that set (CXG and granitoids), through distensive fractures, consisting of veins of granitic/rhyolite porphyre, microgabbro, alkaline basalts, pegmatite or aplite-pegmatite masses and quartz veins [4]. Covering the oldest geological formations, there

are the Cenozoic cover formations, which in the study area are more important the Vilarica arkoses.

3. Hydrogeological Aspects

Throughout the hydrologic cycle, the steps that most contribute to the recharge of aquifers are precipitation and infiltration. However, not all water from precipitation infiltrates to reach aquifer systems, since part of it is immediately returned to the atmosphere through evaporation and transpiration processes, and still another go to the surface runoff. In the current work with the purpose of estimating the recharge values of the aquifer systems of the region, the hydrologic balance was calculated. This generically followed the methodology presented by Thornthwaite and Mather [11]. Of all the results, with interest for the conceptualization of the geohydraulic models under study, emphasize the values of annual precipitation of 824.0 mm, real evapotranspiration of 460.2 mm and annual water superavit (SH) of 364.5 mm. Of those values, the ones that matter most in terms of underground recharge are annual water superavit. These will contribute to the aquifer systems of the region, which are function of several components, namely type of geological formations, their degree of weathering, fracturing, geomorphological aspects, and vegetation cover, among others.

Thus, as a function of the main studies developed, including lithological field surveys, crossing with the data previously presented in geomorphological and geological terms, and also with the survey of water points of the region, and their physical-chemical characterization, the main aquifer systems, in the region under study, are organized as follows:

- Unit 1 - A1: alluvial aquifers, with interstitial porosity, being unconfined aquifers, and associated with the drainage network, especially in the Teja and Concelha rivers; they present maximum thicknesses of 10m, and are essentially of interest for local subsistence agriculture. The water points occurring in this unit are essentially wells of the low depth with diameters generally greater than 2 m.

- Unit 2.1 - G_{sup} : superficial granitic aquifer systems; they are associated with granitic rocks in the approximately 100 m of surface, having essentially fissural porosity, but sometimes also of the interstitial type, in zones with higher degrees of weathering; these aquifer systems are unconfined aquifers, and sometimes constitute interesting groundwater reserves, where several water points are associated, as springs resulting in traditional wells, very small dams, mines, and in the last decades some vertical and

to confined aquifers, and present singular groundwaters with special chemistry and sometimes anomalous temperatures. Its applications are currently few, because the known water points are very few and essentially of the type springs and some holes that are around 200m deep. The use of these waters when properly used is in Medical Spas and in geothermal heaters, and, in places that are not explored in those applications, are used in agriculture.

- Unit 3 - CXG: schistent aquifer systems; they are associated with the rocks of the Schist-Greywacke Complex, being fissured and essentially unconfined aquifers, although punctually, they allow to obtain abstractions by boreholes with drilling by mechanical prospection that lead to artesian abstractions. It should be noted that this unit has very low productivity, however it is the support for some abstractions associated with springs and some boreholes sometimes over 100m deep. The abstractions under these conditions rarely reach operating water flows higher than 0.3L/s, but they are still the necessary support for agricultural activities and even for supporting tourism in rural areas.

The contribution of meteoric water to the recharge of aquifer systems depends, as mentioned above, on the geological type, its degree of weathering, fracturing, geomorphological aspects, vegetation cover, among others, namely the permeability of formations. Thus, $SH = R + G = 364.5$ mm, as the sum of the surface runoff (R) and the underground runoff (G) and considering for the various hydrogeological units the following relationships: Unit 1 - AI: "G/SH" = 60%; Unit 2 - G: "G/SH" = 35%; Unit 3 - X: "G/SH" = 10%, we obtain annual rates of deep recharge, presented in Table 1, which extended to the respective areas result the orders of magnitude of annual reserves according to that presented in the same table.

TABLE 1: Order of magnitude of the annual underground recharge (G) for the hydrogeological units of the Meda Region.

Unit	AI	GSup + GDeth	CXG
Area (km ²)	3	350	152
G (mm)	218,7	127,6	36,5
G (10 ⁹ m ³)	0,66	44,70	5,54

In order to clarify the hydrogeological situation of the region, an inventory of several water points was made, totalling 286 in the whole area (Fig. 4a). The inventory points are made up essentially of natural springs, traditional wells, ponds and boreholes. Initially, their location was recorded with GPS and some physical-chemical parameters were measured with Eutech Instruments' portable multiparametric measurement equipment (model PC650), namely: Temperature (T), Electrical Conductivity (C), Total Dissolved

Solids (TDS), Electrical resistivity (E) and also the water flow in a manual manner. It should be noted that in the first 67 points only pH, electrical conductivity and temperature were measured, due to the limitations of the measuring instruments of the time [15]. Table 2 shows the results obtained for the various aquifer systems in the region. For better geographical visualization, quantity maps were elaborated for pH, C and TDS (Fig. 4).

TABLE 2: Characterization of the aquifer systems through the parameters measured "in situ".

Aquifer System	AI	G_{Sup}	G_{Deth}	CXG
No. samples	16	173	9	57
T (°C)	13 – 20	8,2 - 29,2	15,9 - 45,4	11,2 - 21,2
C (µs/cm)	112 – 1370	18 - 290	407 - 647	38 - 1590
pH	5,56 - 6,69	4,74 - 7,23	7,77 - 8,57	3,67 - 8,56
Eh	-49,5 - 14,9	-67,8 - 57,8	-139,9-16,9	-60,5-136,4
TDS (ppm)	103,6-518,9	16,6 - 266,7	376,4-604,9	34,7 - 518,9
E (kΩ)	0,96 - 4,8	1,87 - 30,11	0,83 - 1,34	0,96 - 4,8

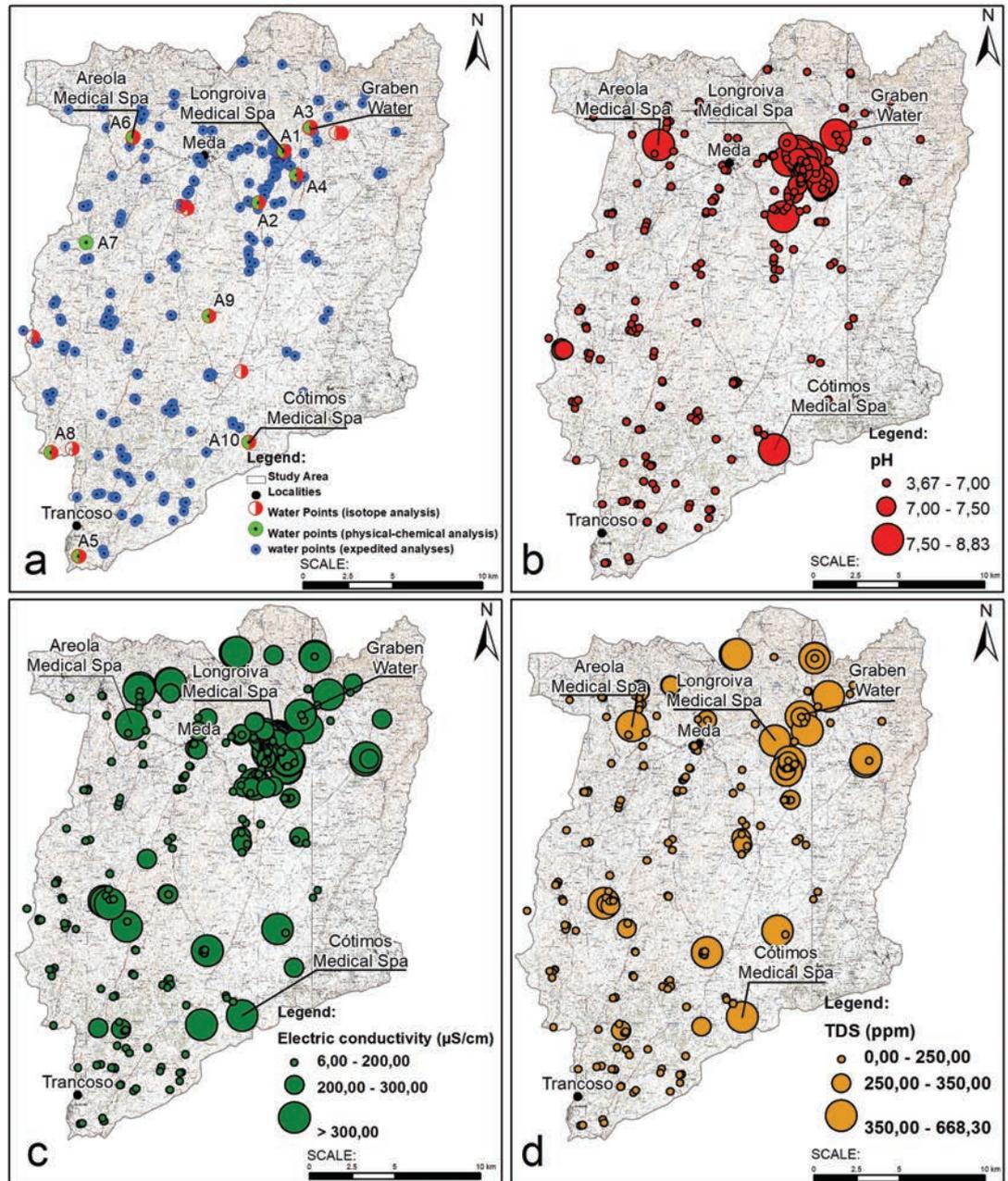
It is emphasized, for example, the case of the pH map, where it is verified that the waters with higher values correspond to the waters of the deep aquifer system, occurring in four preferential areas, Longroiva, Areola, Graben and Cótimos, which maintain the highest values also in the other two parameters.

In order to better understand the characteristics of the various resources, and to contribute to the effective conceptual model of each system, strategic sampling points were selected for groundwater and rainwater, in order to perform laboratory, physical-chemical and isotopic analyses of Tritium, Deuterium and Oxygen-18 (Fig. 4a). Fig. 5 presents graphically the results of the physical-chemical analysis of the samples of the surface and depth granite aquifer systems.

The waters of the AI and CXG aquifer systems were not studied in the present research with the same detail as the granite formations, as they are currently not of strategic and economic interest to the region.

The waters of the deep granitic aquifer system are all bicarbonate-sodium, and are also designated as sulphurous waters due to the particularity of being rich in reduced sulphur species, generally represented by significant values of sulphuration, which according to Fetter [17] corresponds to the total ionic water content of S²⁻ species, including simple and complex sulphur forms. The waters of the granite surface aquifer system range from bicarbonate-sodium to bicarbonate-calcium.

Concerning the groundwater of the deep granitic aquifer system and in order to better understand the geohydraulic model, Coelho Ferreira et al. [18] based on studies on geothermometers based on the chemical composition of water and in particular from



Note: Extract of the Topographic maps n.º 140, 141, 149, 150, 151, 159, 160, 161, 170 and 171, at the scale 1:25000, from CIGeoE (Centro de Informação Geoespacial do Exército).

Figure 4: Water Points Inventory, from Coelho Ferreira [16].

silica and the Na/k ratio, suggest reservoir temperatures of around 113°C for Longroiva; 82°C for Areola and 79°C for Graben. For the depth of the reservoirs, Coelho Ferreira et al. [18] based on studies of the Rybach model [19] obtained the following depths: Longroiva, 2000m; Areola, 2200m and Graben, 2500m.

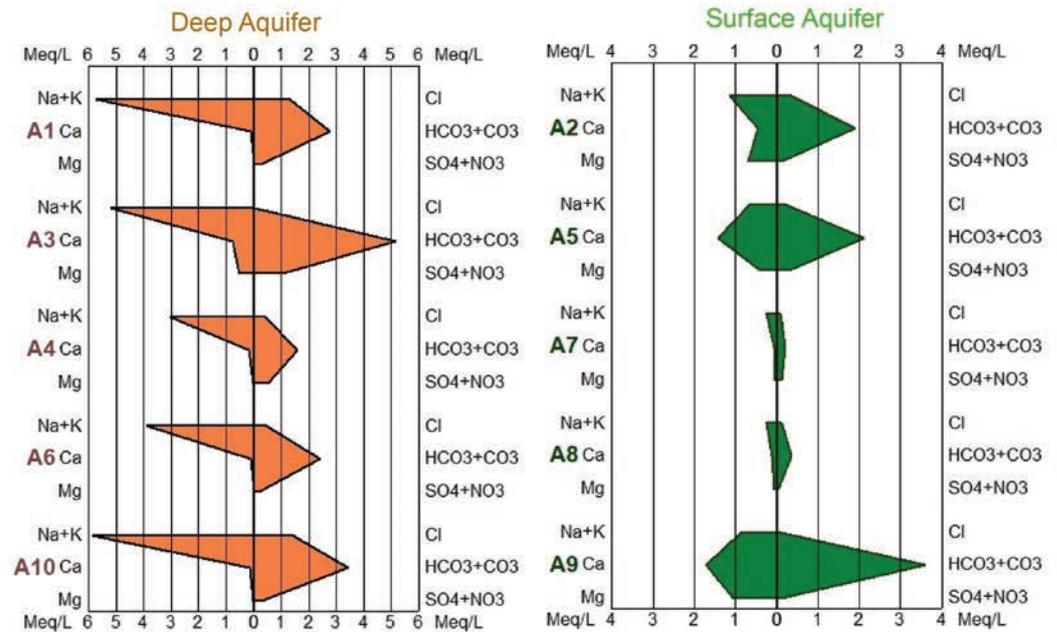
On the studies of the isotopic composition at ^{18}O and D of sulphurous waters, i.e. waters of the deep granitic aquifer system, they suggest recharging altitudes higher than 800m, therefore essentially in areas outside the Meda municipality.

4. Global Aspects of Conceptualization

Considering the studies made, namely the ones concerning discharge zones of the deep aquifer systems, their relation with the systems of the great faults of the region, the geological units, their geomorphological aspects and, in particular, the water chemical properties of the deep aquifer system, its reservoir temperatures along with the recharge zones, we can now organize this territory's aquifer system in three main parts: Longroiva systems; ii) Areola systems; and iii) Graben Systems.

The conceptual model of these systems is shown in Fig. 6, their location in the regional geological map in Fig. 3a. This region's underground water circulation follows, in a general way, what was described by Ferreira Gomes [15] when the Longroiva Medical Spa was legalized. The water resulting from precipitation infiltrates the more superficial hydrogeological units, explicitly in the altered and fractured granite massif. In a first phase, in the less extensive and more superficial circuits, the water percolates in depth towards the thalweg, emerging in some springs.

This is the result of geological traps and occasional aquifers dependent of the alteration and fracturing of the rock mass that, generally, does not exceed one hundred meters deep. Part of this water, of meteoric origin, in its subterranean course, is intercepted by the NNE-SSW-oriented regional faults, which are very difficult to cross and have great extension and depth. Hence, just like circulation corridors, these waters percolate through these faults, from south to north, especially in the first two systems. After going through an extensive and deep underground circuit, where chemical changes occur, resulting from processes of interaction between water-rock-gases and possibly with a microbiological contribution, which made them unique and special characteristics, these waters emerge alongside with the granitoid as formations of the CXG, which acts as a barrier to its percolation. Furthermore, this spring is facilitated by hydraulic loads developed in the aquifer system and by the temperature reached in depth. In the Graben System, east of the main fault system of Vilariça, that is, in its eastern bloc, the underground flows evolve, descending, in depth, from E to W, in order to emerge at the tectonic nodes, between general direction faults W-E, with the Vilariça fault of the NNE-SSW direction.



a Diagramme de Piper

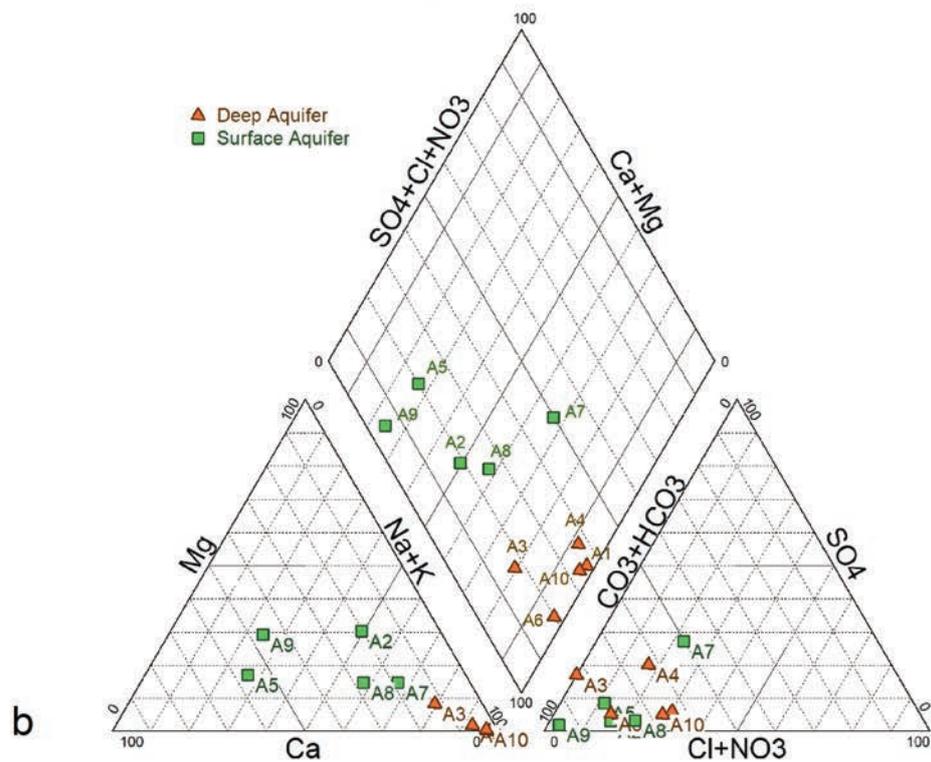


Figure 5: Analytical results of the studied samples of granitic aquifer systems, in diagrams: a) Stiff, b) Piper, to the Meda region.

In any of the three major hydrogeological domains of Meda county, the hydrogeological units referred in item 3 are existent, that is: A_I , G_{Sup} , G_{Depth} , and CXG ; we should stress that, has illustrated in Fig.6, Alluviums (A_I) have little significance, and it is also

emphasized that, the Schist-Greywacke Complex (CXG) has much lower permeability than granites (G_{Sup} , G_{Depth}) and these serve, in global terms, as a barrier to the flows from this unit. It should be mentioned that in the area of the Graben, under the Alluviums, the Arkoses do Vilarica (φ_N) (Fig.3b) occur in a relatively potent manner, having about 50 meters, which, by their characteristics, constitute an aquiclude.

5. Final Notes

In the present study, it is worth emphasizing the occurrence of deep aquifer systems associated with granitoids, and, despite the knowledge about these being very incipient, we state that they must be studied with a great level of detail, because in addition to its potential for health spaces, such as medical spa and other aqua-ludic purposes, they may also be of great value to the municipality and region, as a source of energy. Thus, we highlight the main elements within the three major hydrogeological domains considered for the Meda Municipality: i) Longroiva, with reservoir temperatures (Tr) of 113°C and depth (Pr) of 2000m, ii) Areola, at 82°C and 2200m, for Tr and Pr , respectively; and iii) Graben, with 79°C and 2500m, for Tr and Pr , respectively. It should be noted that having temperatures above 70°C, it is now possible to generate electricity from hot water. This demands, of course, an investment in deep drilling to make groundwater abstractions with natural hot water.

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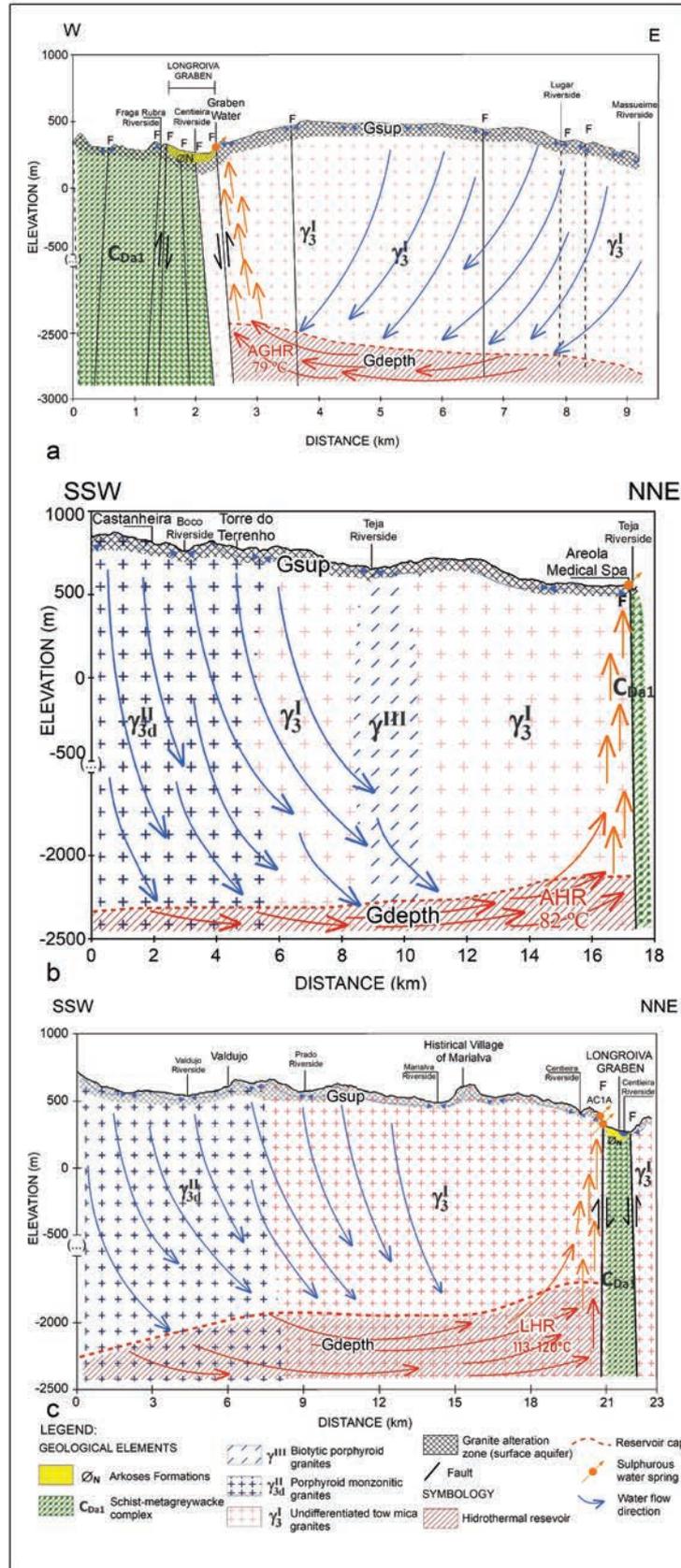


Figure 6: Conceptual Geohydraulic Models: a) Graben System; b) Areola System c) Longroiva System.

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