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GROUNDWATER IN SEMI-ARID MEDITERRANEAN AREAS: DESERTIFICATION, SOIL SALINIZATION AND ECOSYSTEMS

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ABSTRACT
An investigation concerning groundwater quality and its relation with the soil salinization, desertification and associated ecosystems is being developed in Alentejo, a region of South Portugal affected by a semi-arid climate. The precipitation occurs mainly during the cold season, between October and March/April, and the hot season has a heavy deficit of water.
The geology is based on sedimentary and volcano-sedimentary rocks affected by the Hercynian orogeny.
The plants and trees are adapted to this environment, where specific species resist to these conditions, as the *Quercus suber*, the cork oak.
Some saline waters are present in certain areas, mainly on the flat ones, and the natural vegetation is controlled by the groundwater composition. Ecosystems with plants like *Juncus acutus, Juncus subulatus, Hordeum geniculatum* and *Parapholis incurva* are present and the human settlements tend to avoid those areas, where also the agriculture is difficult to implement.
The presence of this type of waters is justified by deep faults that can transmit highly mineralized waters from deepness and by the concentration of salts at surface caused by the high values of evapotranspiration.

Key-words: Ecosystems, semi-arid area, mineralized waters

INTRODUCTION

The climate in South Portugal is semi-arid, with high evapotranspiration levels in summer. In the area of Mértola, Alentejo region, in South Portugal, some groundwater with high levels of mineralization occur. The investigation of these kind of waters and the particular ecosystems that are present, similar to the ones that form some near shore areas, are the beginning of a study that will be continued in the future, in order to identify all the plants that are present on these particular areas.

CLIMATE, GEOMORPHOLOGY AND GEOLOGY

Alentejo region (figure 1), in South Portugal, is affected by a semi-arid climate, where the precipitation goes from 400 to 800 mm per year (with an exception in a 1,200 m high mountain in the northern part of Alentejo, where it can reach more than 1,000 mm). In this area the potential evapotranspiration values that can go to more than 1,000 mm per year.
The precipitation occurs mainly during the cold season, between October and March/April, letting the hot season with a heavy deficit of water, when the temperatures can reach more than 45 ºC, during some days.

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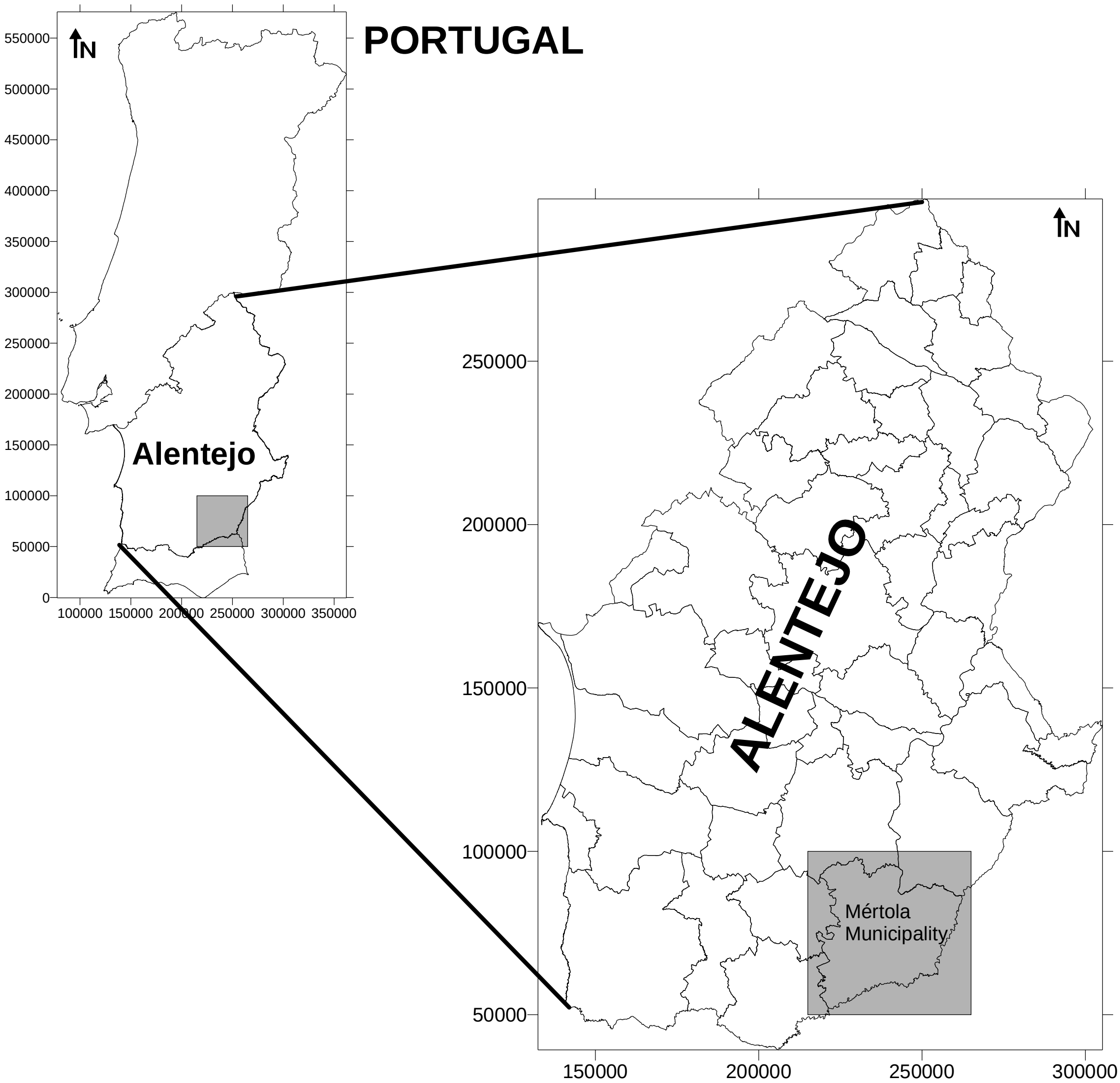

Figure 1 – Position of Mértola municipality and Alentejo region in Portugal.

The geomorphology of Alentejo region is characterised by an extensive flat area with some residual relief. An exception is the S. Mamede mountain (1,200 m), which lies in NE of Alentejo. The W and NW zone consists of the littoral and river depressions, which are influenced by two main rivers, the Tejo and Sado sedimentary basins. In this area the sediments cover the Iberian Shield.

The South of Alentejo, where these high EC waters occur, is a flat area, with exception of the vicinity of the major rivers, which, due to the variations of sea level, cut deeply the landscape. This is the case of Guadiana River and its tributaries near the working area.

The geology of Alentejo is composed by three main geostructural domains of the Iberian Peninsula Precambrian and Palaeozoic Shield (Chacón et al. 1983): the Central Iberian Zone (CIZ), the Ossa Morena Zone (OMZ) and the South Portuguese Zone (SPZ) and by some sedimentary rocks on the NW and west parts. These kind of waters occur in the last one of the crystalline domain (figure 2), the South Portuguese Zone, where the geology is represented by metamorphic rocks like shales, schists, phylits, greywackes, quartzites, acid and basic metavolcanic rocks, between others.

The SPZ geology is the result of a collision between two continents, with the closure of a palaeo-ocean during the hercynian orogeny. The SPZ seems to be an accrecionary prism that has evolved to an imbricate overthrust complex, with fault-strips of the oceanic sediments through the Precambrian substrate (Silva 1989). The associated submarine volcanism gives rise to sulphide concentrations, represented by the Pyrite Belt, an area that correspond to the main pyrite mines both in Portugal and in Spain (Chambel et al. 1998).

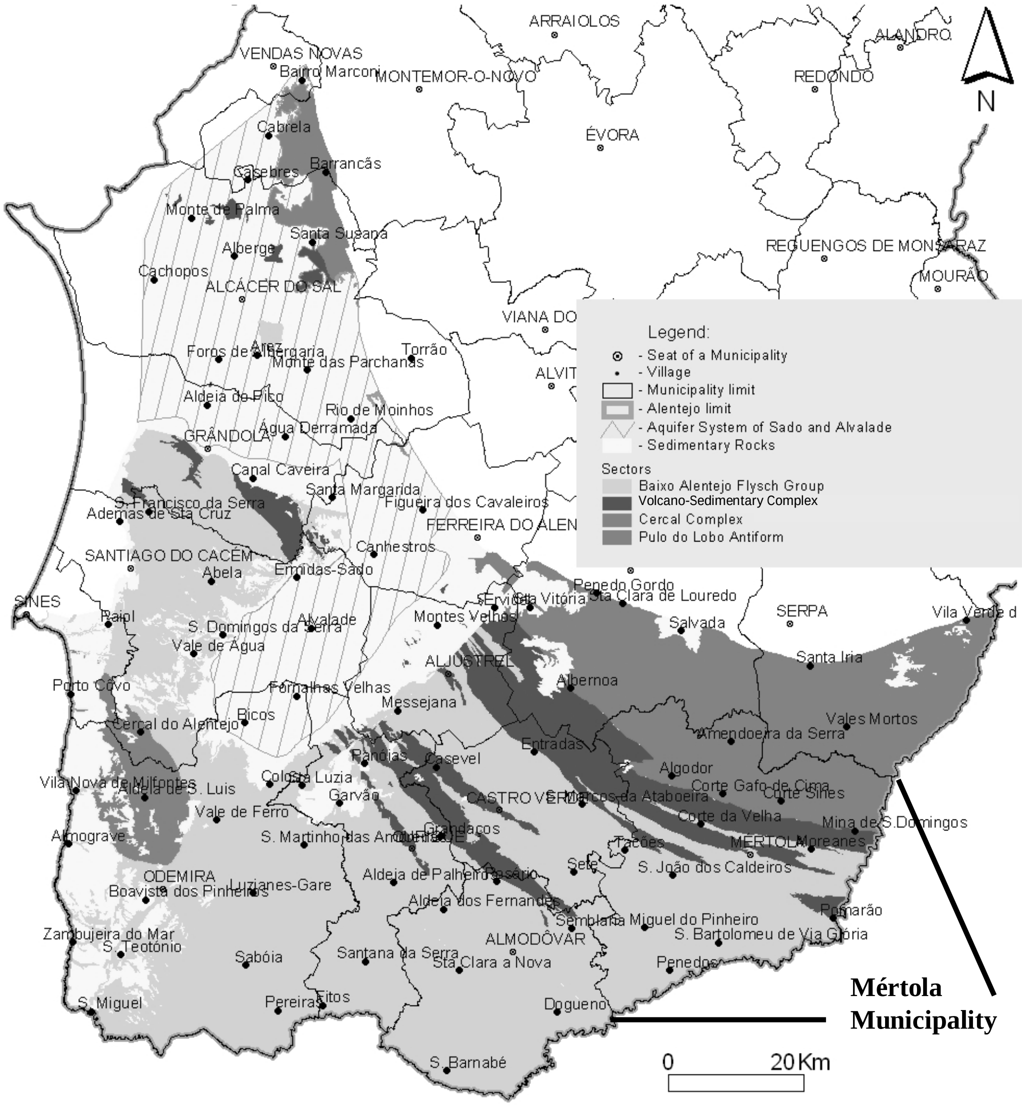

Figure 2 – Geological setting of the South Portuguese Zone (SZP), in South Portugal. The legend is only representative of the area east and south of the line linking Vendas Novas to Vila Verde (de Ficalho).

As seen in figure 2, the SPZ is divided in three main domains:
- the Pulo do Lobo Sub-Zone, in the northern part
- the Volcano-Sedimentary Complex
- the Baixo Alentejo Flysch Group, in the southern part

The northernmost domain is Pulo do Lobo Sub-Zone, an anticlinorium that is the oldest of all the units, consisting of phylites, quartzites and some layers of acid and basic volcanic rocks.

The Volcano-Sedimentary Complex consists of original sedimentary and volcanic rocks containing massive sulphides. It is composed of alternating decimetric to metric layers of metamorphised acid and basic volcanic rocks, shales, graywackes, quartzowackes, siltstones, pellites, quartzites, sandstones, rare conglomerates and limestones and other types of rocks (Chambel & Almeida 2000).

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South of the Volcano-Sedimentary Complex are the most recent sediments of the SPZ, a turbiditic sequence corresponding to the Baixo Alentejo Flysch Group. The northernmost sub-division of this last Group is the Mértola Formation, practically the only one present in Mértola Municipality, followed by the Mira and Brejeira formations, more to SW (Oliveira 1988, Silva 1989).
The Pyrite Belt corresponds to a large region that comprehends all the outcrops of the Volcano-Sedimentary Complex and the rocks that are in between, even if they are part of other domains. This is the area of the pyrite mines and also the area where the actual mineral prospection takes place.

HYDROGEOLOGY

Hydrogeologically the SPZ consists of hard rock aquifers. The low permeability rocks such as schists, phylits, greywackes, metavolcanic rocks, among others, associated with thin alteration layers are responsible for the low aquifer yields, usually less than 1 L/s. But there are some exceptions, especially in an optimal structural context, where some high fracturing is associated with more competent rocks, namely quartzites and greywackes. In such cases, yields can reach more than 5 L/s. Behind quantity, quality is also a problem in SPZ. Here the main issue is the high groundwater mineralization. The electric conductivity (EC) is very high in some wells on special SPZ geo-structures, reaching values of more than 10000 μS/cm in some places.
In general, the samples collected in deep wells show concentrations 1.5 times higher then those collected in large wells and springs, exception for the chloride in the Volcano-Sedimentary Complex waters, where large wells and springs have a median value of 396 mg/L and the deep wells 292 mg/L (Chambel et al. 1999). This is probably due to great evapotranspiration ratios, which promote the concentration of salts resulting from leaching of rocks that have high contents in salts retained during underwater rock formation (Chambel & Almeida 1998; Chambel 1999).
The water samples of the Volcano-Sedimentary Complex and part of the Pulo do Lobo Anticlinorium are more mineralised than those from the other geological formations as can be seen in figures 3 and 4, by the EC water values. The explanation must be in the high degree of fracturation observed in both of them, which results from the occurrence of more competent rocks, when compared with the more ductile rocks of the Baixo Alentejo Flysch Group (Chambel & Almeida 1998; Chambel 1999). This would permit the ascension of deep mineralized water, with chloride and sodium contents as the main ions. This is confirmed by researches in the pyrite mine of Neves-Corvo, some kilometres west of Mértola Municipality (Fernández-Rubio et al. 1988; Fernández-Rubio & Carvalho 1993; Fernández-Rubio et al. 1994), where the works go today at a deep near 700 m and where it was possible to detect the increase of mineralization with deepness, which corresponds to about 475 μS/cm in EC by each 100 m deep, 150 mg/l of chloride and 140 mg/l of sodium by the same 100 m deep.
For the three groups of the SPZ on the area of Mértola, the waters of Pulo do Lobo Anticlinorium are clearly sodium or magnesium chloride type. Some of the salty waters occur inside this group, normally near the Volcano-Sedimentary Complex.
The waters of the Volcano-Sedimentary Complex are basically sodium chloride type, but some of them present some bicarbonate tendency.
On the south part, on the *Flysch* Formation of Mértola of the Baixo Alentejo Flysch Group the waters are more sodium and magnesium bicarbonate type, but the sodium chloride waters continue to be present with some regularity. Rare are the calcium bicarbonate waters. Even so, these are the less mineralized waters of all the three groups.

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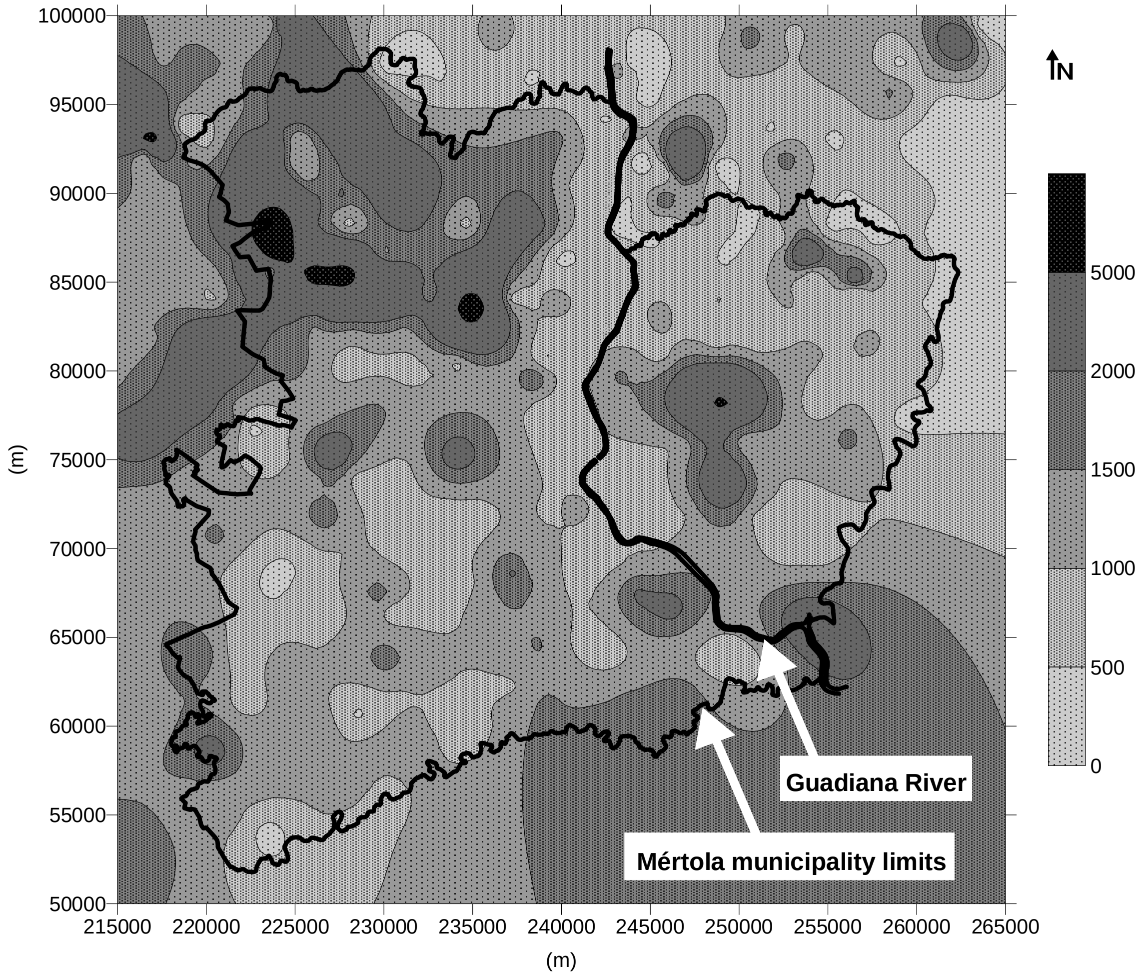

Figure 3 – EC values for the groundwater of Mértola Municipality, in μS/cm.

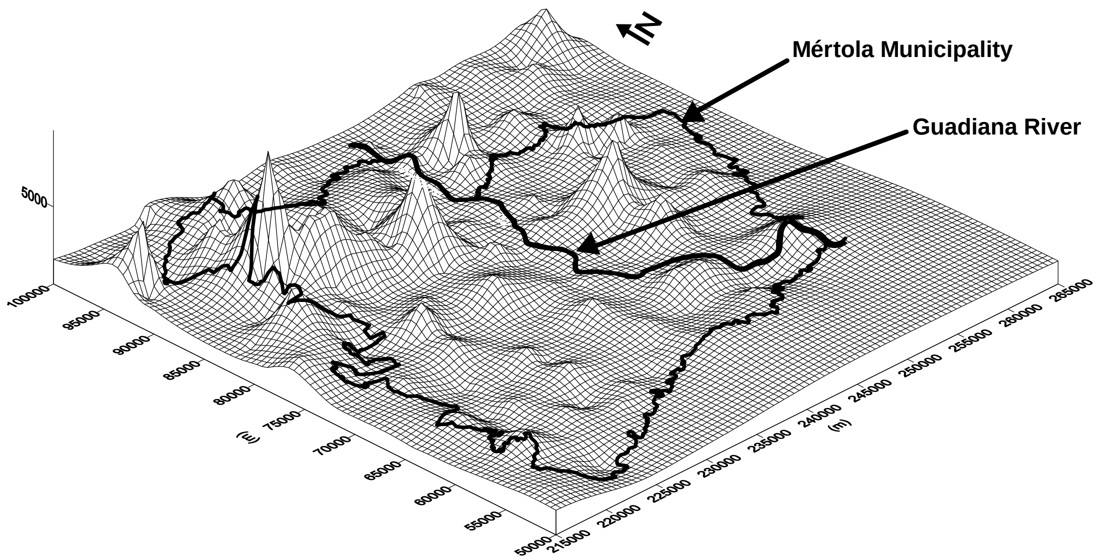

Figure 4 – Three-dimensional representation of the groundwater EC values of Mértola Municipality, in μS/cm.

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The sodium and chloride tendency is clearer on the more mineralized waters, namely on the NW part of the municipality.

The groundwater mineralization near the Guadiana River, on the places where the river crosses the Volcano-Sedimentary Complex, is much lower than in the flat areas, what is probably due to the higher hydraulic gradient on the vicinity of the river. Here, the quicker flow will drain the groundwater more rapidly and the evapotranspiration processes are not so effective to sustain an increase on the mineralization.

ECOSYSTEM ASSOCIATION

The existing plants and trees are adapted to this semi-arid environment, where specific species resist to these conditions, as the *Quercus suber*, the cork oak and the *Quercus ilex* trees.

Investigation is now directed to the determination of specific flora associated with this very special kind of hydrologic environments. In fact, these mineralized waters are only present in certain areas and they seem to control the presence of salts in the soils, the natural vegetation and the behaviour of both animals and humans. The local of study was the NW part of Mértola Municipality, a place where the water mineralization is higher, as can be observed in the figure 3 and 4. The figure 5 shows the studied area.

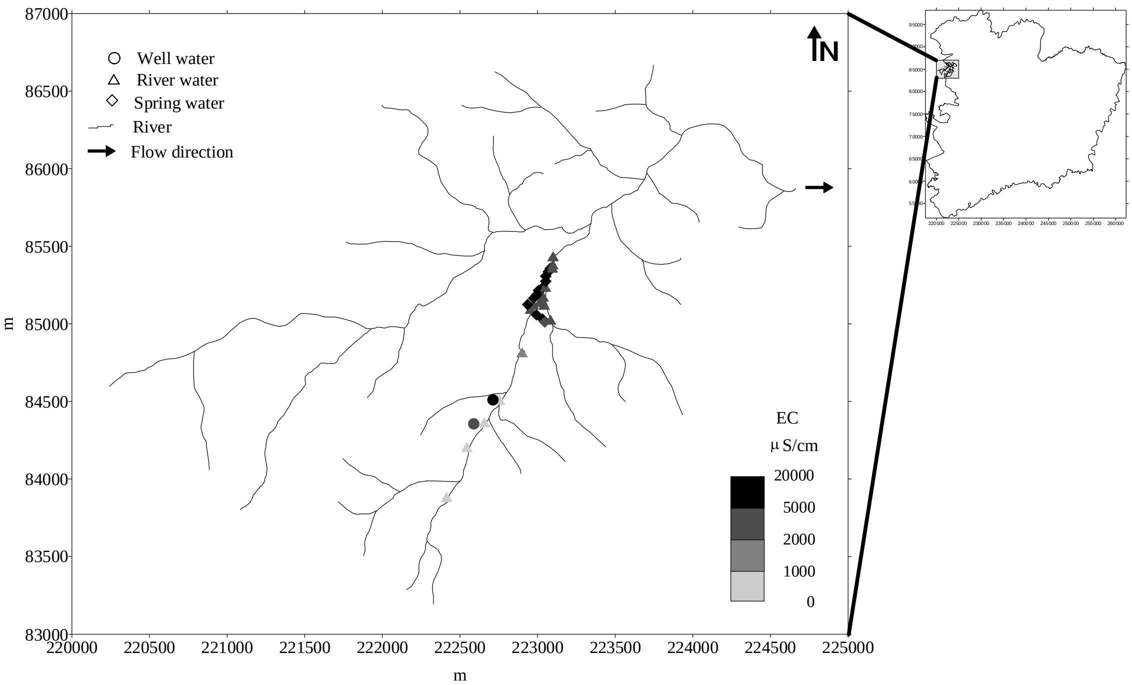

Figure 5 – Selected area for the study of the ecosystems, showing EC interval values measured on the river, wells and spring waters, on 27 and 28 February 1995, after about 15 days without rain, showing a heavy component of the groundwater discharge to the river.

Other of the consequences for the environment is the lost of soil capacity induced by humans when they use these kind of waters to irrigate. Due to the high ratio of evapotranspiration, the soils became highly salines and, after some years, they can't continue to produce, inducing desertification. With the desertification phenomena, the loose of soil is higher, and great part of South Alentejo are loosing soil till 1 cm each year, due to farming practices and soil depletion by concentrate rains, as shown in studies by Rosa (1980), Galvão (1982) and Brum Ferreira *et al.* (1993). In soils with less than half a metre in many places, some of these areas are now practically depleted of productive soils.

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Comparing with the local flora, some special kind of plants occurs only in these special places where mineralized groundwater is present. This is the case of the *Juncus acutus* and *Juncus subulatus* (figure 6), *Hordeum geniculatum* (figure 7), and *Parapholis incurva* (figure 8), that were identified by fieldwork in plain or depressed areas where the groundwaters have EC values upper than 3,000-4,000 μS/cm. The waters are basically Na-Cl type, as the previous investigation had detected. These waters can go up more that 10,000 or even 15,000 μS/cm, and the superficial waters in the areas near the springs rarely have less then 2,000 μS/cm, as it can be seen by the measurements on the area of investigation (figure 5), where the photos 6, 7 and 8 where taken.

Also the behaviour of both humans and animals seems to be controlled by the water quality. The human settlements tend to avoid those areas, but the few people that live there, namely the shepherds, know exactly where the sheeps go to drink (they like the water with EC between 2,000 and 4,000 μS/cm). The shepard himself only drinks water from the rare wells with less than 2,000 μS/cm, and, for waters with more than 4,000 μS/cm, nor the shepherds nor the sheeps drink it. Attending this kind of behaviour, probably all the fauna is also controlled by the water quality.

No agriculture is possible in these areas and even the cork trees are not present.

For the moment only this first species where identified, because the work was only done during summer of 2005, when the dry season don't permit to observe most part of the plants. The springtime will bring new light to the ecosystem association in the area and the investigation will be completed.

CONCLUSIONS

Some species of plants are clearly related with the groundwater quality. In the south part of Portugal, on a geologic special environment called the Pyrite Belt, a strip on the Portuguese geology known for the presence of pyrite mines in a volcano-sedimentary complex, an association of plants normally found near shore is present. In effect, the groundwater in this area has some mineralization, namely sodium and chloride, responsible by the presence of these plants.

In these places the quality of the waters induces high contents of salts in the soils. Together with the use of mineralized water in agriculture, this induces increasing desertification processes, which results on soil depletion by erosion.

For the moment only some species where identified, because the work was only done during summer of 2005, when the dry season don't permit to observe most part of the plants. The springtime will bring new light to the ecosystem association in the area.

The special plants that were identified for the moment are the *Juncus acutus*, *Juncus subulatus*, *Hordeum geniculatum* and *Parapholis incurva* and are related with plain or depressed areas where the waters have EC values upper than 3,000-4,000 μS/cm, basically Na-Cl type. These waters can go up to more that 10,000 or even 15,000 μS/cm, and the superficial waters in the near areas rarely have less then 2,000 μS/cm.

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Figure 6 – *Juncus acutus* and *Juncus subulatus*, plants that are present on this kind of environments.

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Figure 7 – *Hordeum geniculatum*, plant present on these ecosystems.

Figure 8 – *Parapholis incurve*, other plant present on these ecosystems.

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