ACUÍFEROS COSTEROS EN PORTUGAL. ESTADO ACTUAL DE CONOCIMIENTOS

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ABSTRACT

Most of the aquifer systems in Portugal rest on Meso-Cenozoic deposits and the Tertiary basin of the Tajo-Sado rivers. This article reviews the essential aspects and the current knowledge of the aquifer systems, grouped by the regions of Aveiro, Sines and Algarve. In the Aveiro region, some areas of the surface aquifer present saline intrusion, while the Cretaceous aquifer, despite overexploitation, presents no evidence of salinisation due to structural reasons. In the Sines region, the water resources of the aquifer system greatly exceed the volume of extraction and no problems of marine intrusion have been recorded. In the Algarve region, the coastal aquifer systems present quality problems, being affected by localised phenomena of marine intrusion and by other salinisation mecha - nisms, especially the leaching of evaporites, water-rock interactions and the effects of human activities.

INTRODUCTION

In Portugal, groundwater is of exceptional importance in satisfying the demand for fresh water. Figure 1a shows that 60% of the consumption of fresh water, by all sectors, relies on groundwater supplies. Moreover, analysis of the contribution of groundwater to different sectors (fig. 1b) reveals that these waters usually represent the largest contribution.

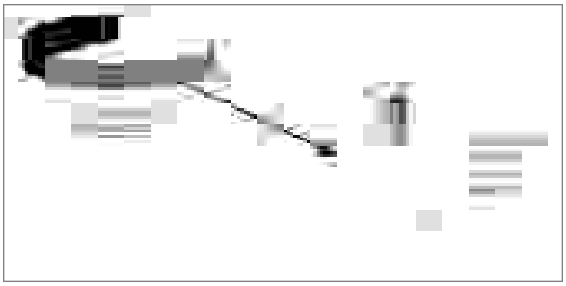

Figure 1 – Percentage of water exploited by origin and by uses.

In Portugal almost 60% of the population (six million people) live in coastal areas which on many occasions also comprise the site of industrial estates, such as Aveiro and Sines. The tourist industry is also of crucial importance, particularly in the Algarve, where it has been estimated that the summer population increases by nearly two million people. Similarly, and because of its favourable climate, this area is the site of important agricultural activity, especially the cultivation of citric fruits and greenhouse crops.

Until a few years ago, groundwater constituted practically the only source of water for various types of consumption in the above regions. The coastal aquifers, therefore, were subjected to intense, and sometimes uncontrolled, levels of extraction, which endangered the equilibrium of this type of aquifer. On occasion, an advance of the fresh water/salt water interface has occurred, although this was in localised cases and did not constitute a generalised advance, as will be seen below.

GEOLOGIC SETTING

The recent publishing of the Hydrographic Basin Plans (1999-2001) and the National Water Plan (INAG, 2001) required, for the first time, a systematic mapping and characterisation of aquifer systems to be carried out (Almeida et al. 2001). Taking geologic characteristics into account, four hydrogeologic units were considered (fig. 2a).

The map of the aquifer systems reveals that Meso-Cenozoic deposits and the Tajo-Sado Tertiary basin comprise the support for the majority of aquifer systems in Portugal. In this context, we shall consider the essential aspects and the current state of knowledge of the aquifer systems, grouped by the regions of Aveiro, Sines and Algarve (fig. 2b).

Figure 2a – Hydrogeologic units.

Figure 2b – Aquifer systems in Portugal.

CASE STUDIES

Aveiro region

Figure 3 shows that in this region there are two aquifer systems, the Quaternary and the Cretaceous (Peíxinho de Cristo, 1985 and 1992).

The Quaternary aquifer system is fundamentally comprised of detritic formations. Detailed studies (Marques da Silva, 1990) have proposed that an aquifer subsystem should be considered at the base of the Quaternary. This subsystem is comprised of coarse sands, sometimes with clays, separated from an upper aquifer subsystem by a level of organic silts. The upper subsystem is constituted of more or less coarse

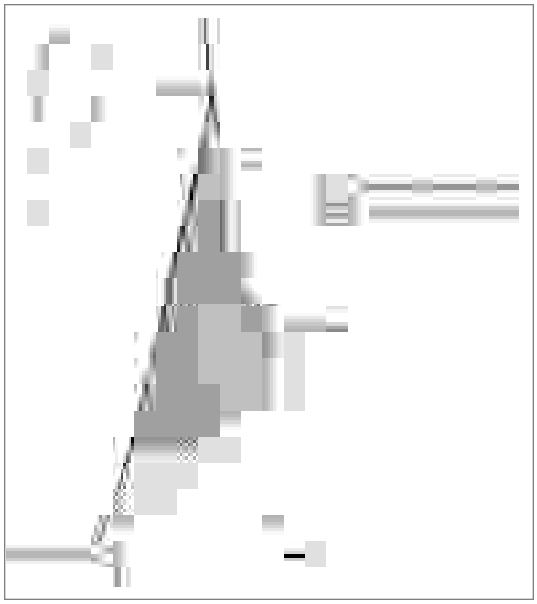

Figure 3 – Aquifer systems in the Aveiro region.

sands from ancient beaches and alluvions, frequently covered by dune sands.

The Cretaceous multi-aquifer subsystem is formed by sandstones and clays, coarse sandstones, fine and very fine sandstones, a carbonate formation and lower coarse sandstones (fig. 4).

With regard to the conceptual function model, the surface aquifer subsystem is considered to comprise an unconfined aquifer in hydraulic connection with sea water, both at the coast and within the *Ría* of Aveiro. The other Quaternary aquifer subsystem functions as a confined or semiconfined aquifer. The Cretaceous aquifer behaves as a confined system.

The hydrogeologic and hydrochemical characteristics of this aquifer system have been studied by various authors (Marques da Silva, 1990, Carreira Paquete, 1998 and Melo, 2002), using different geophysical, hydrogeochemical, isotopic and mathematical modelling techniques, and also taking into account its regional socio-economic importance. Intensive exploitation has led to the existence of piezometric levels (fig. 5) revealing evident overexploitation, with an enormous imbalance between estimated recharge (7.3 hm^3/year) and extractions (21.2 hm^3/year) (Melo, 2002).

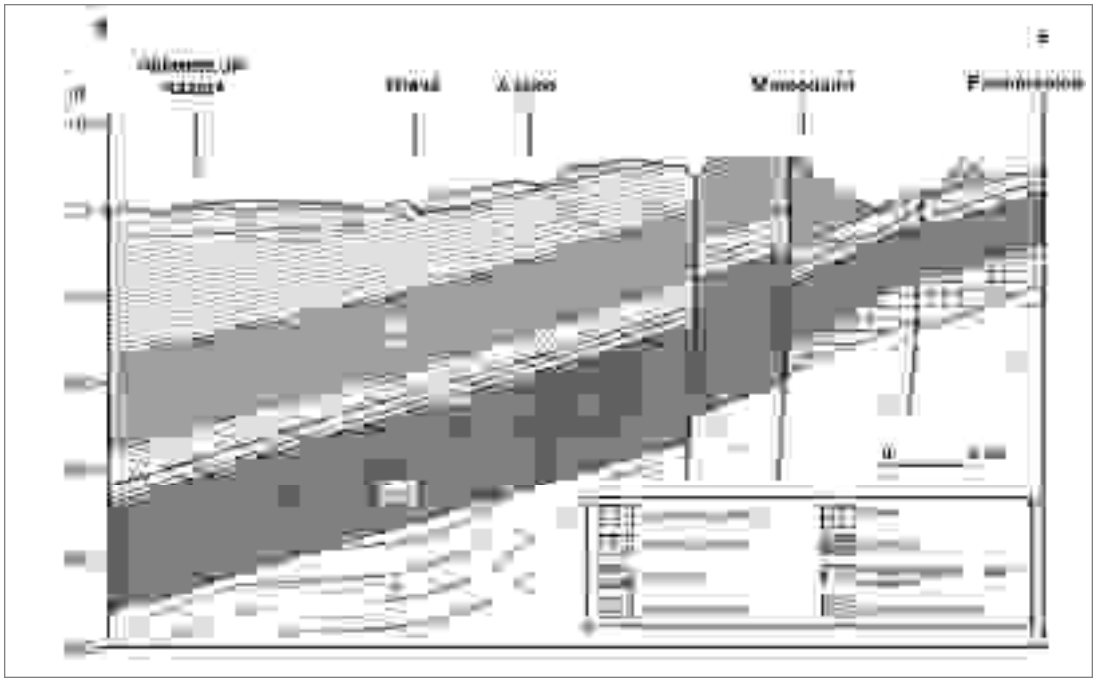

Figure 4 – Cross-section of the Aveiro region.

Using hydrochemical techniques (fig. 6) it has been shown that the dominant facies are sodium chloride for the Quaternary aquifer and sodium-calcium chloride and bicarbonate for the Cretaceous aquifer. Interpretation of the ion ratios and the isotopic analyses reveals that existing mineralisation characteristics, which are generally low (conductivity values of 300-500 µS), cannot be attributed to saline intrusion. The application of a mathematical model enables us to confirm that ancient waters are being exploited and that variations in water types are fundamentally due to hydrogeochemical processes and to the mineral composition of the sediments making up the aquifer system.

Sines region

In this region (fig. 7a), the geologic structure and the nature of the geologic deposits lead us to consider two aquifer systems: a surface one corresponding to Mio-Pliocene detritic formations, and a deep aquifer associated with Jurassic carbonate formations (fig. 7b).

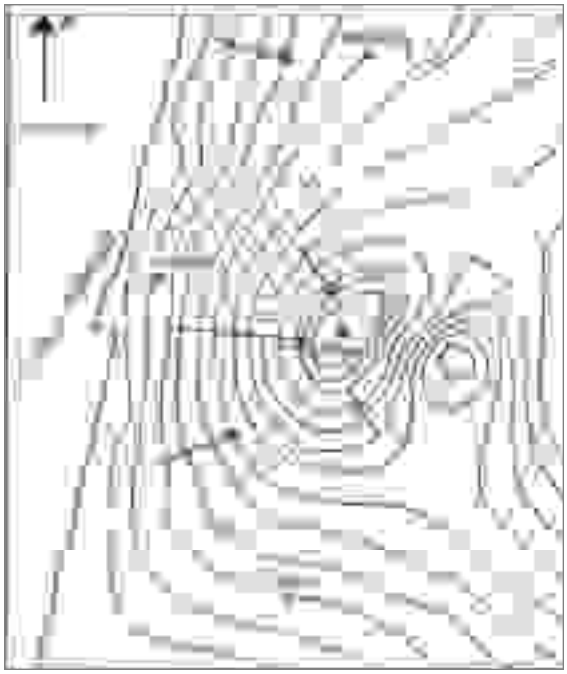

Figure 5 – Map of piezometric isolines for the Aveiro region.

Figure 6 – Piper diagram of the Aveiro aquifer systems.

The porous surface aquifer can present the characteristics of an unconfined or of a confined aquifer, due to its lithologic heterogeneity. The deeper aquifer, of carbonate and dolomitic nature, functions as a karstic, confined aquifer, with strong artesian characteristics.

The hydrogeologic function model reveals that the surface aquifer receives recharge from precipitations and presents a hydraulic connection with effluent water lines. In the karstic aquifer, recharge mainly takes place in the outcropping areas and by indirect drainage through the surface aquifer.

Concerning the water balance, total input has been estimated at nearly 40 hm^3/year, while extractions do not exceed 7 hm^3/year. Thus the system is completely in water surplus. Nevertheless, the piezometric map (fig. 8) shows that saline intrusion has occurred in one sector. This was the result of a situation that has since been corrected in which two wells extracted significant volumes of water (over 150 m^3/h) and produced a

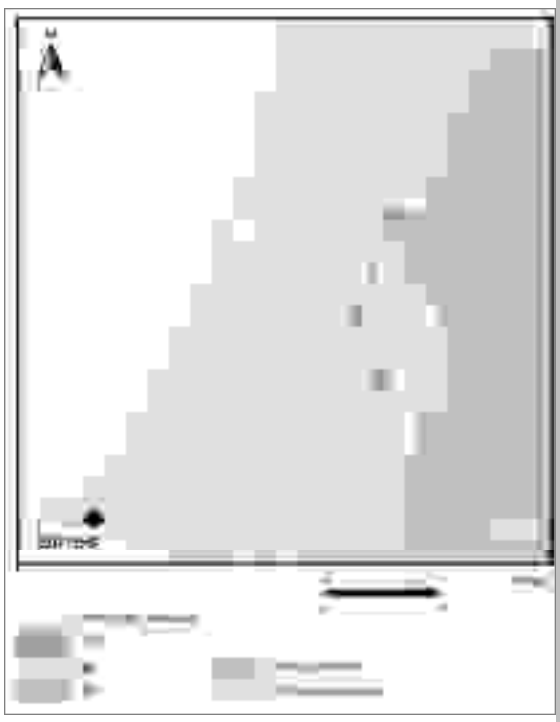

Figure 7a –Sines aquifer system.

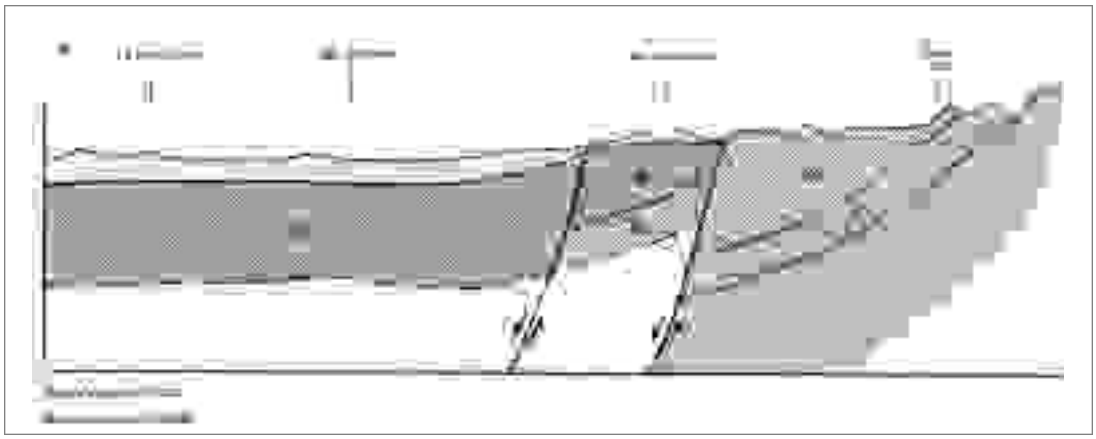

Figure 7b – Geologic cross-section of the Sines aquifer systems.

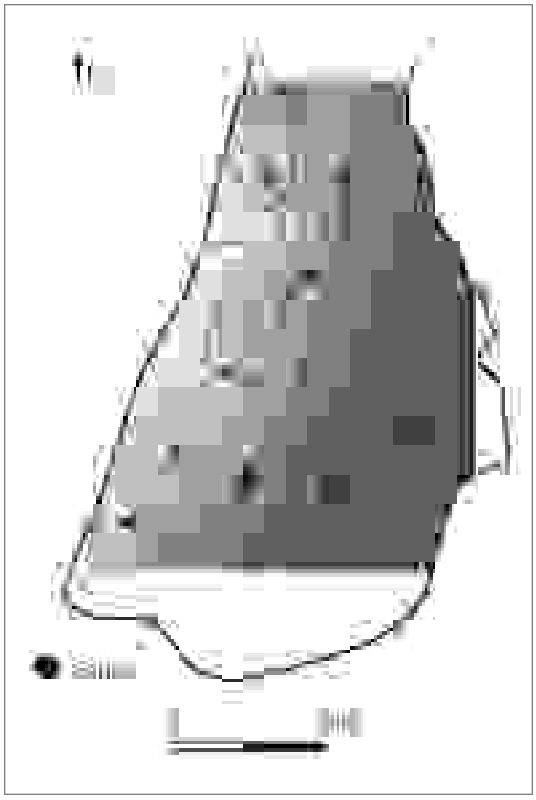

Figure 8.- Piezometric isoline map of the Sines region.

marked fall in groundwater levels and a subsequent local advance of the salt water/fresh water interface. The simple reduction of pumping rates and a reduced lowering of groundwater levels enabled natural flow direction dynamics, towards the sea, to be restored.

With regard to groundwater quality (fig. 9), there is a predominance of calcium and calcium-magnesium bicarbonate facies in the deep aquifer, reflecting the water-rock interaction in the limestones and dolostones.

The surface aquifer presents facies that are mixed or even sodium chloride, due fundamentally to the increased levels of chlorides, arising from the proximity to the coast.

Algarve region

In southern Portugal (Almeida, 1985; ERHSA, 1999; Silva, 1984 and 1988), the predominant lithologies and the regional geologic structure led us to adapt the structure of the Campina de Faro aquifer system as a type model for the inventoried and characterised aquifer systems (fig. 10).

The hydrogeologic cross-section (fig. 11) confirms that the coastal aquifer systems are associated with Miocene carbonate and detritic formations, comprising karstic or porous surface systems. In some cases, these formations are covered by Plio-Quaternary detritic deposits that may behave as aquifers or as aquitards, depending on the clay matrix and on the dimensions of the clastic particles.

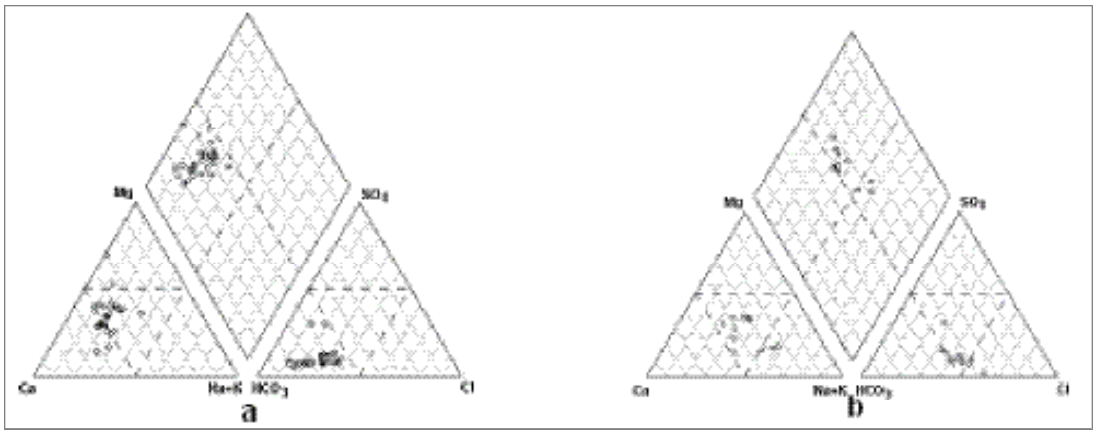

Figure 9 – Piper diagram for the Sines region: a) deep aquifer; b) surface aquifer.

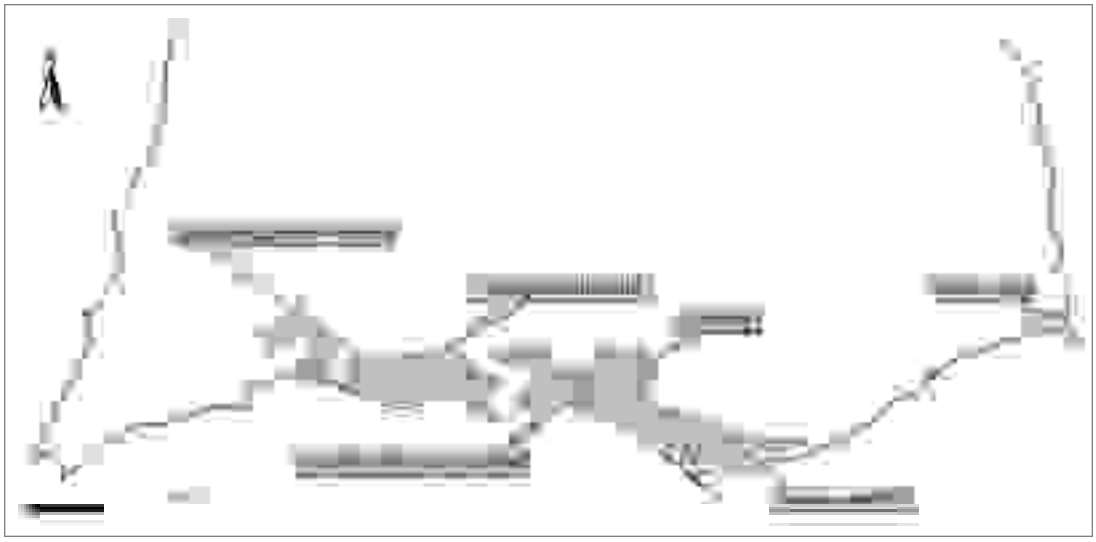

Figure 10 – Coastal aquifer systems in the Algarve region.

At a lower level, the coastal aquifer systems rest on Cretaceous or Jurassic deposits, normally associated with karstic aquifers in multilayer aquifer systems. With respect to their hydrogeologic functioning, recharge is effected by the direct infiltration of precipitations and sometimes by influent water flow lines (as is the case of Ribeira de Quarteira and Río Seco).

Available chemical and piezometric data suggest a deep-level recharge occurs via underly-

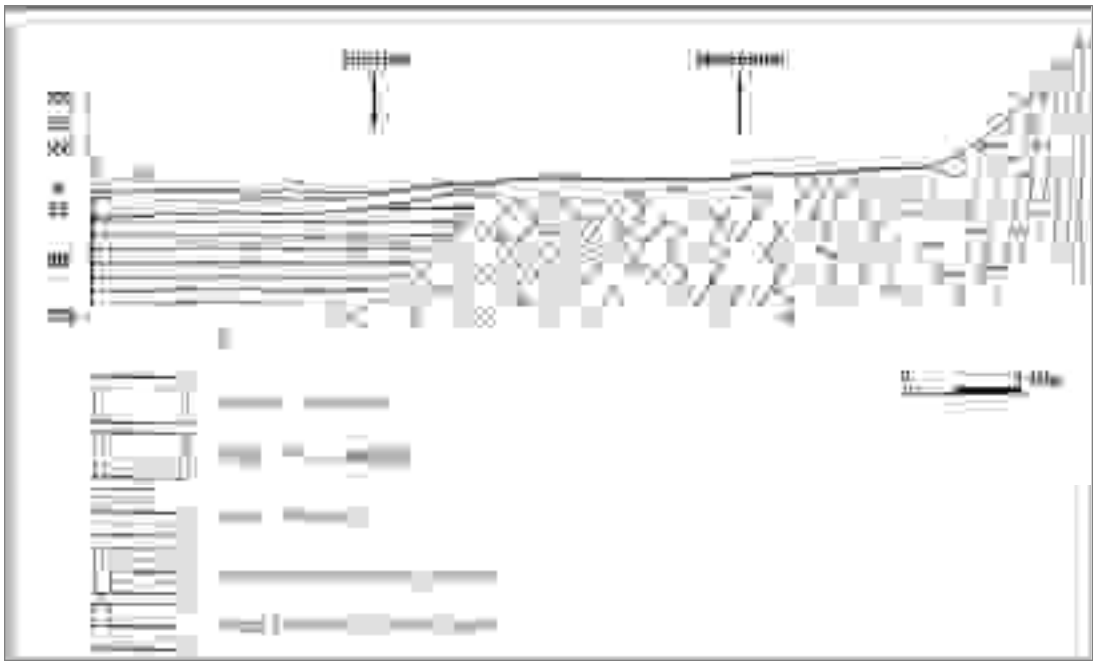

Figure 11 – Geologic cross-section of the Campina de Faro aquifer system.

ing aquifer systems such as the Campina de Faro aquifer and the Quarteira aquifer system. An exceptional case is that of the Monte Gordo aquifer system, which comprises dune and estuary sands beside the river Guadiana, and where there exists one interface to the south and another to the north, in a tributary of the Guadiana.

With regard to groundwater quality (fig. 12), the hydrochemical facies varies from calcium bicarbonate to sodium chloride. This variability is due to multiple factors, including saline intrusion, human activities, water-rock interactions and, sometimes, the leaching of evaporites at shallow depths.

Another important factor is related to the intrinsic characteristics of the aquifers themselves. The fact that they have a small storage coefficient makes them very sensitive to the effects of drought and subsequent reduced levels of recharge.

CONCLUSIONS

From the results obtained and from the observations made by quality and quantity control monitoring networks, the following conclusions can be drawn regarding coastal aquifers in Portugal:

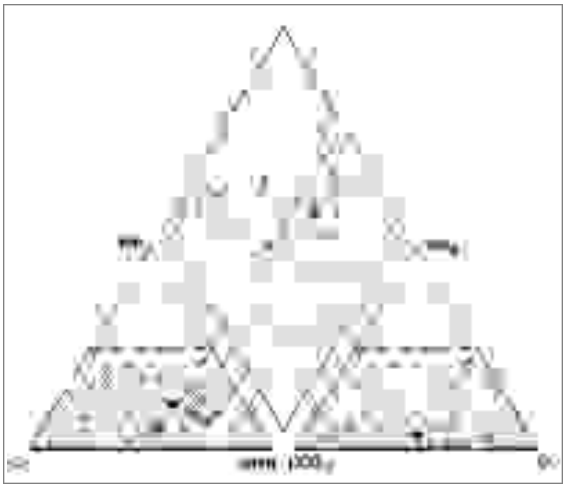

Figure 12 – Piper diagram. Campina de Faro aquifer system.

A. Aveiro region: Some areas of the surface aquifer present saline intrusion. The Cretaceous aquifer, despite being subjected to overexploitation for many years, which created a severe pumping depression, does not present any salinisation caused by structural factors. The piezometric situation has tended to recover due to the availability of new sources of water for human consumption and for industry.

B. Sines region: The aquifer system possesses resources greatly exceeding present extraction rates and does not present any problems of marine intrusion. The only exception occurred when an excessive rate of exploitation was applied in one system, producing slight marine intrusion. This situation has since been corrected.

C. Algarve region: The coastal aquifer systems present groundwater quality problems. Phenomena of marine intrusion have been identified in certain sectors, as have other mechanisms of salinisation, especially the leaching of evaporites, water-rock interactions and human activities. The recent inauguration of a system of drinking water and irrigation supply from the Odeleite dam, constructed over Palaeozoic deposits, will doubtless contribute to improving the quality of groundwater in this region.

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