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Evaluation of the groundwater quality in the Alcochete area using GIS

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Abstract
Most of the water needed for domestic, agricultural, recreational and industrial activities in the Alcochete municipality (Portugal) comes from groundwater sources. However, doubts remain on the state of its quality and attractiveness for the current uses. A monitoring campaign was set in 67 groundwater sources (26 wells and 41 boreholes) for the period of 4 months to evaluate the water quality status. In order to better analyse the large and complex available information it was necessary to setup a Geographic Information Systems (GIS), which allowed georeferencing data, creating relational databases and generating thematic and suitability maps for the use of groundwater. The results show that most of the water wells are chlorinated calcic type and have no minimum quality to be used for production of drinking water, but may be used for agricultural irrigation. Most o the water boreholes are chlorinated sodium type, and approximately 70.7% presents the minimum quality to be used for production of drinking water and all of the sources can be used for agricultural irrigation. Nitrate is the most important contaminant, but chlorides and iron are also of concern. The results of this study will allow establishing relationship between water, geological environment and anthropogenic fluxes, which have been influencing changes in water quality, as well as determining flow directions, recharge and discharge areas. This information, which was aggregated in a database using GIS is very useful for the further establishment of sustainable water management measures.

Keywords: GIS, groundwater, water quality

1. Introduction

The municipality of Alcochete (Portugal) is located at the left bank of the Tejo river, having an area of approximately 128.5 km^2 and is part of the Lisbon Metropolitan Area. Land use is very fragmented, coexisting patches of built-up areas, interspersed with areas of plots of annual or perennial crops and large areas of shrub and tree cover with degrees of human intervention varying widely. Water resources are very important to satisfy uses such as drinking water supply, industrial activities and agricultural irrigation. Therefore, the evaluation of the water quality of the main sources and its suitability for the most important uses is an essential step to define measures for its preservation.

The sedimentary basin of the Tejo and Sado rivers is composed of two distinct aquifer systems. One including lower aquifers occurring in the limestone formations of detrital-Burdigalian and lower Helveciano and complex detrital clay-the middle and upper Miocene-type captive, with specific yields from 3 to 8 l/s, flow-rates ranging from 40 to 100 l/s, transmittance of 10^{-2} m^2/s, and storage coefficients varying between $3x10^{-4}$ and $7x10^{-4}$ [1]. The second aquifer system corresponds to formations of Pliocene and Quaternary (alluvium and river terraces) and is free type. The thickness of this aquifer is variable and sometimes difficult to define, usually not exceeding 120 m. The transmissivity varies between 1.5×10^{-2} to $3x10^{-2}$ m^2/s with storage coefficients ranging from 10^{-2} to 10^{-3} [1].

The alluviums occupy the bottom of shallow valleys called the Rio das Enguias. They are classified as Old Alluvial Quaternary (Al1) and Recent Alluvial Quaternary (Al2). The thickness of these materials is highly variable, reaching up to 60 m as observed through geotechnical and hydrogeological surveys setup for the foundations study of the Vasco da Gama Bridge [2]. The Santa Marta formation belongs to the Pliocene and is the most representative unit of study area. Its composition is variable including fine sand to coarse sand poorly consolidated, often crisscrossed stratification, and also greyish clay beds. The colour varies from white (sands of Coina) to red and yellow (Alcochete). Its thickness is variable, reaching 320 m depth in Pinhal Novo, decreasing then to the north along the coast, where not exceeds 40 m.

According to Simões [3], the orientation of the fractures and deformations seem to indicate the existence of two distinct tectonic episodes. An oldest formation, where the fracture follows a predominantly NW-SE direction, and a newest where the fracture follows a NE-SW direction. The latter coincides with the slope of the current section of the river Tagus and the orientation of the failure of Benavente. Pais *et. al* [2] refer that the main macro-structures present are the so-called failure of the "Gargalo Tejo" and the failure of Pinhal Novo - Alcochete. The latter does not show significant morphological expression, since the local topography has low amplitude, most likely corresponding to surface erosion.

The hydrogeochemistry study allows establishing relations between the water sources and the geological environment, reflecting the influence of the local lithology, as well as soil and water quality. It also allowed determining flow directions, recharge and discharge areas, identifying sources of pollution and establishing measures for the sustainable use of water.

This study aims to assess the groundwater quality in the main sources used by the municipality of Alcochete, in order to evaluate the status of contamination and quality degradation of the aquifers. The results will be used to setup new measures for water quality protection.

2. Experimental Procedure

The first step of the work involved the characterization of the study area and the identification of the main groundwater sources. The following data was used for this purpose: cartographic information (extracts of military maps at 1:25000 scale), land use maps, information on geomorphology, geology, tectonics and hydrogeology ("Geological map of Portugal", leaf 34, in [2], scale 1:50000, and information obtained from geological studies carried out by private companies). These information allowed generating a digital terrain model (scale 1:100000), thematic maps for land use, geological and hydrological characteristics, location of population agglomerates and roads, and a new suitability map for groundwater quality for the study area, all of them generated with ArcGIS software v.9.0.

Simultaneously, information was collected on well and boreholes location (namely flow-rates, physical, chemical and microbiological data) and the main uses. 67 groundwater points were selected (41 boreholes 41 and 26 wells) and the available information was georeferenced (Figure 1). The monitoring campaign involved biweekly collection of water samples for 4 months to determine the following parameters: water level alkalinity, bicarbonates, calcium chlorides, copper, lead, chromium, electrical conductivity, hardness, iron, phosphates, magnesium, mercury, nickel, nitrate, dissolved oxygen (DO), potassium, pH, redox potential (ORP), resistivity, salinity, total dissolved solids (TDS), sodium, silica, sulphates, and temperature. The sampling was carried out after 15 minutes pumping water using the sterilized bottles. All analyses were done according to standard methods [4].

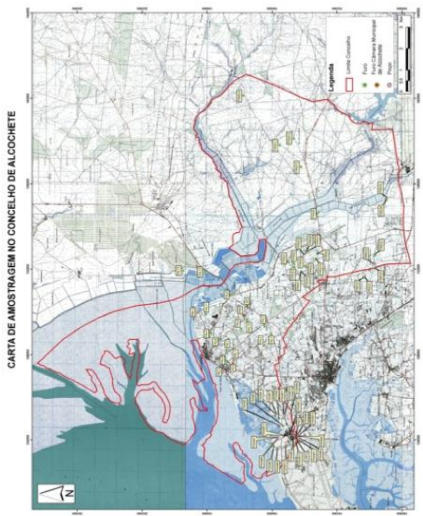

Figure 1. Location of the sampling points

The results were analysed taking in account the range of variation of the parameters, the minimum values allowed for public supply and agricultural irrigation according to the water quality legislation (Decree-Law No. 236/98 of 1 August, on water quality), supported by a statistical analysis and histograms of the distribution. Thematic maps were prepared for the variation of each physical and chemical parameter using the software ArcGIS v.9.0.

3. Results and Discussion

The study area is part of the Hydrogeological Unit of the Tejo Basin - Sado. According to the Aquifer Systems of Portugal [5], there can be considered four aquifer systems in this area: Alluvial Tejo, Right Bank, Alvalade Basin and Left Bank. The aquifer presents various porous layers, generally semi-confined or contained as a result of structural complexity and changes in the lithology. The Pliocene sediments are composed almost entirely of sands with lenticular intercalation of clays. However, the top layer presents recent detrital material with a free aquifer, being the second hydrogeological unit in the zone, reaching a maximum of 60 m.

The results of the sampling campaign (physical and chemical characteristics in the 67 groundwater sources) were analysed taking in account the minimum quality needed for the production of water for human consumption and for use in agricultural irrigation, taking into account the minimum allowable values (VMA) and the minimum recommended values (VMR) presented in Decree-Law No. 236/98. All the monitoring results are presented in Casinhas [6]. The water wells are mainly chlorinated calcic waters, although in some places their hydrochemical characteristics correspond to calcic bicarbonate waters. The water boreholes can be considered mainly sodic chlorinated water, emerging a few points as chlorinated water and calcic waters with sodium bicarbonate.

The results show that only two wells (7.6% of the total sampling points in wells) have a minimum quality to be used for drinking water production, whilst 29 water boreholes (70.7% of the total sampling points in boreholes) can be used for this purpose (*i.e.* only 31 in 67 groundwater samples meet the minimum water quality to be used for production of water for human consumption). The better quality of the water in boreholes is understandable since, as they are more deeply, the respective aquifers are more protected from anthropogenic contamination. However, there are 12 boreholes with a significant contamination with nitrate and iron (Figure 2), which also reflect the vulnerability of deeper aquifers to be contaminated.

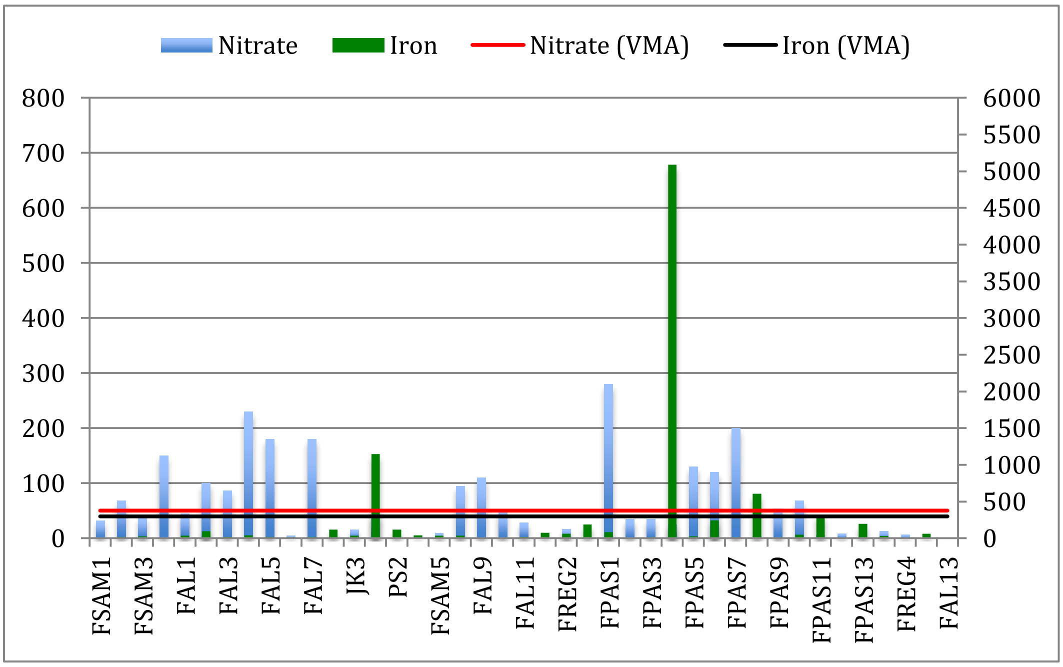

Figure 2 – Results for nitrate and iron in all the boreholes

Regarding the use of water for agricultural irrigation, there is no violation of the limits setup as VMA and, therefore, all the points may be used for irrigation. However, looking at the VMR limits (recommended values), there is only one well and four boreholes that fulfil the limits. The parameters with more concern are the conductivity, chlorides and nitrates in the wells, and the iron and nitrates in the boreholes. These results show the vulnerability of the aquifers to the contamination of nitrates from agricultural land (due to the use of excessive fertilizers), saline intrusion from the Tagus estuary (due to the excess of extraction of groundwater) and some industrial or waste landfill contamination (presence of high concentrations of iron). Thus, the risk of salinity on soils (high values of conductivity and SDT) and toxicity for plants (high values of Na and Cl) may increase in ten wells and four boreholes. The index of sodium adsorption (SAR) was calculated, indicating that 12 wells and the generality of the boreholes present a risk of sodicity to the soil, which may become these sources not suitable for irrigation in the future.

There are high concentrations of silica in deeply water sources (average value of 27 mg/L and a maximum of 48 mg/l in the area of Camarate - Bela Vista). In 23 wells (88.5% of the samples) and 7 boreholes (17% of the samples) the nitrate concentrations are over 50 mg/L (VMA for the production of drinking water and VMR for agricultural irrigation), with a maximum concentration of 760 mg/L and 280 mg/L for the wells and boreholes, respectively. These results show the vulnerability of groundwater to be contaminated with nitrates that come from the fertilization of agricultural land. The concentrations of heavy metals present no risk for water uses, although there was observed concentrations of copper above the VMA for the production of drinking water in 5 wells and 2 boreholes.

Thus, the majority of water wells can only be used for agricultural irrigation and some boreholes show already some vulnerability to nitrate contamination, being urgent the definition of measures to control the pollution focus, including the control of fertilizers in agriculture, overextraction of groundwater and discharge of effluents into water streams and soils.

4. Conclusions

The Alcochete area has a good availability of groundwater sources that could satisfy most of the common uses (agricultural irrigation and water supply for human and industrial activities). However, most of the water from wells does not present a minimal quality for the production of potable water, since they are contaminated with nitrates and chlorides, whilst most of the boreholes present minimum quality for this use. Both sources show minimal quality to be used for agricultural irrigation, however, the majority of the physic-chemical parameters have values above the maximum recommended values (VMR) for this use. Thus, in order to ensure sustainable use of these resources is essential to implement measures for protecting the water sources, especially for free aquifers.

5. References

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