Cape Verde Santiago's island salt water origin?

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ABSTRACT

Since its discovery and occupation in the XV century, Cape Verde volcanic archipelago always had freshwater quantity and quality problems. These are directly related with the prevailing semi-arid climatic condition, under direct Sahara desert influence and also by the islands topography. Precipitation regime is irregular, leading frequently to extended drought periods. At Santiago, the biggest of Cape Verde islands, the water origin for field's irrigation and human consumption had always been the natural springs and boreholes. The first's wells for water extraction were done in the 70's of last century. With this new source and a growing population, the demand and pressure over the groundwater resources is reaching the limit by excess of drainage for irrigation. Several episodes of saltwater contamination have occurred near the cost, especially at terminal parts of the creeks, where high permeability geological materials predominate. To extend the knowledge from wells and boreholes geochemical data, several geophysical surveys were conducted through the most significant creeks and agricultural places of Santiago. The employed technique was TDEM (Transient), suited over semi-arid environments and high conductivities layers. Survey's results effectively show deeper conductive layers along several creeks, but they do not seem to have a direct relation to any actual seawater intrusion. That is only detected at the end parts of the creeks.

INTRODUCTION

Like most of the coastal regions of the world, Cape Verde archipelago is seriously affected by saltwater intrusion. The wide-spread cause is always water exploitation associated to population growth and theirs basic needs. This problem is intensified at Cape Verde islands, were climatic and topographic conditions play a crucial role, with natural water recharge being scarce and also irregular over the years. Only the knowledge of water quality and quantity can prevent and further help exploitation under sustainable and safe conditions. The exact source of salinity and its extent is essential to water management. To this purpose, geochemical and isotopic groundwater data were collected from 130 points at Santiago, the biggest and densely populated island of the archipelago (300 hab./km^2). To further extend the study, as this data is only sampled at natural springs, wells and boreholes, geophysical surveys were conducted. The applied method was the time-domain (transient) electromagnetic (TDEM), specially suited to use over dry soil and very sensitive to conductive layers, like saline waters. More then 200 TDEM soundings were carried out at Santiago's most significant creek valleys and agricultural areas.

Santiago settings

Cape Verde geographic location dictates its semi-arid condition, with major climatic influence coming from the Sahara desert (figure 1). The rainy season only last from July-August to October-November, and is mostly orographic dependent at Santiago. The precipitation mean annual value is 323 mm. Over its 1000 km^2 surface area, the precipitation ranges varies from above 650 mm, at central mountains (highest picks have 1392 and 1063 m), to just 150-200 mm at shore sea level. High slope landscapes prevail at those higher elevations, consequence of island volcanic origin and formation. Very intense rain episodes, together with topography, lead to floods at most existing creeks (Mannaerts and Gabriels 2000). Water balance indicates that runoff is 18% of the precipitation and it is directly discharged to the sea, with just 13% infiltration to the soil. The remaining water is lost to evapotranspiration effect, which attains a mean annual value of 1500 mm (M. Gomes 2008).

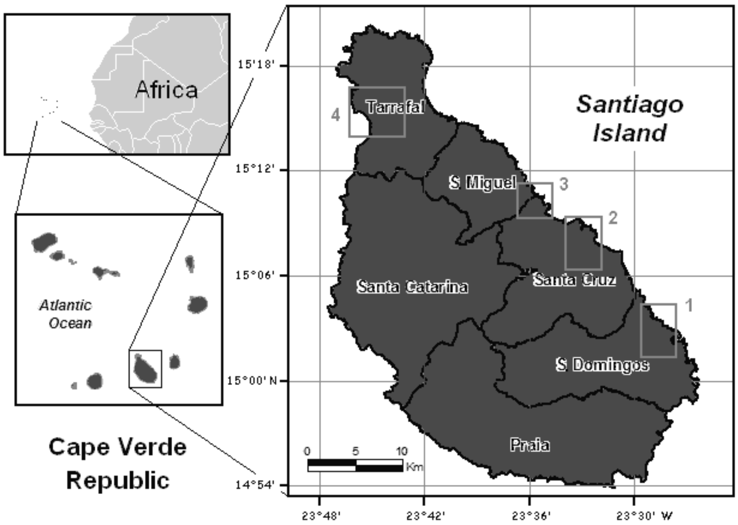

Figure 1. Cape Verde and Santiago island location. Location of TDEM surveyed areas.

Three main hydrogeological units have been identified at Santiago, linked to the island geological eruptive formation (Serralheiro 1976). *Base unit*, the oldest one, is a Palaeogene and inferior-mid Miocene complex, with compact low permeability formations. Transmissivity is small, from 0,2 to 5×10^{-5} m^2/s and maximum extraction of 5 to 7 m^3/h. *Mead unit*, the most extended and thick eruptive formation, with a higher permeability being the principal aquifer. This unit is mainly of basaltic, pillow lavas and pyroclastic, with transmissivity ranging from 10^{-1} to 2×10^{-2} m^2/s (pillow lavas) and mean extraction of 35-40 m^3/h. *Recent unit*, with some piroclactic cones and high permeability. This water's formation is rapidly leaked to the *mead unit* one. Alluvium sediments come from this period (Pliocene-Pleistocene) till modern age. Sediments that fill most of the creeks valleys, especially at terminal part have transmissivity of 10^{-1} to 2×10^{-2} m^2/s, and mean extractions of 40 m^3/h (M. Gomes 2008). Intensive agriculture practices take place at these fertile soil valleys.

TDEM SURVEY

The geochemical data is spatially linked to collecting points and limited; to the surface at springs, to near surface at wells, and to deep of boreholes. Half this data are from inland, and near the coast existing boreholes reach at most only 40-50 m bellow msl. The application of geophysical methods, like TDEM soundings, can to some degree, collect data over a hider area with a greater investigation's depth.

TDEM soundings were done at four study areas (figure 1 and 2). The measures were taken from 2005 to 2006, with annual repetitions at some points, until 2009. The survey equipment was the TEM-FAST 48 HPC (AEMR), with a square single turn loop of 25 and/or 50 m size length. Maximum signal current was 4 A, with 24 V input. Most of the soundings were acquired along profiles, longitudinally throughout axes valleys, going inland from near sea. 1D modelling of individual soundings was done with native software from AEMR. The horizontal layers electric resistivity – thickness model is a good approximation to this sedimentary geological scenario. The data's noise is small and quality of soundings curves is in general good, only limited by the equipment own power. A pseudo-2D geoelectric section was assembled at each creek valley.

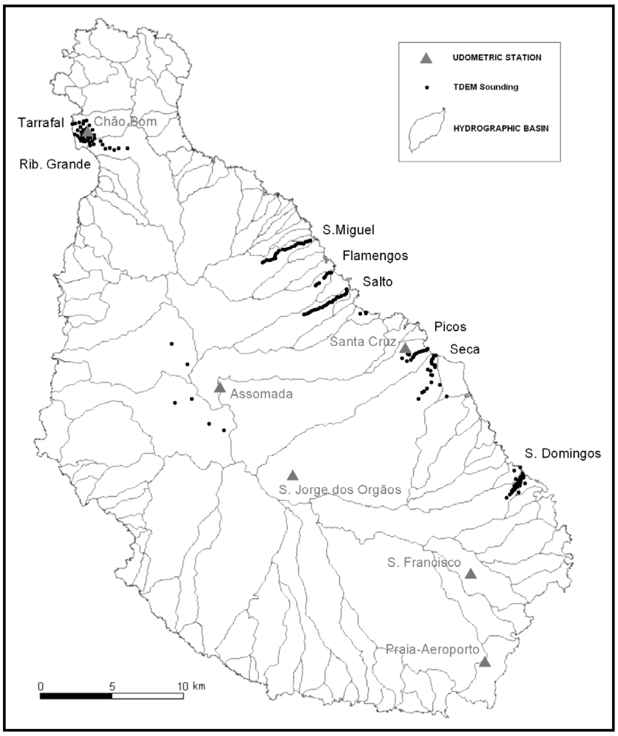

Figure 2. TDEM soundings location at valleys.

RESULTS

The water chemical analyses show a significant variation between geologic formations and their locations. Inland at highlander's *mead unit*, the groundwater composition is of Na-HCO_3-Cl type, with moderate electric conductivity (EC) less then 1000 µS/cm, with some indication of marine aerosol influence. At lower regions near the coast, the *recent unit* sedimentary creek valleys have a Cl-Na or Cl-Mg type composition, with mean EC values of 1800 µS/cm, reflecting clearly a salty water intrusion problem (figure 3), (M. Gomes 2008), (A. Pina *et al*. 2005).

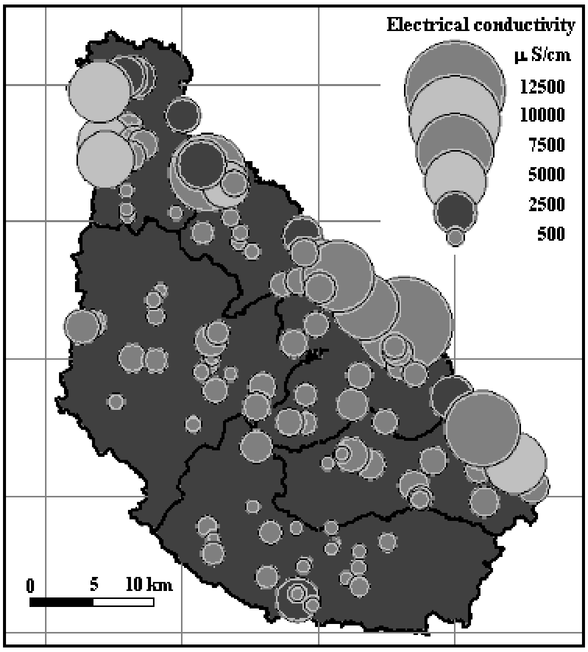

Figure 3. Groundwater electric conductivity.

The TDEM profiles analyses show a common pattern all over the surveyed areas, a superficial and shallow resistive layer followed by less resistive ones. Areas 1 and 2, at southeast and east (figure 1), exhibit a deepest layer (starting at -50 m msl) with resistivity of 0,2- 0,3 ohm-m. That is not seen at the several creek valleys at the northeast surveyed area 3. At northwest area 4 this conductive layers is also detected.

DISCUSSION AND CONCLUSIONS

The features and resistivity values of 2D geolectric pseudo-sections, are correlated and in good agreement with the lithological information from boreholes and wells at surveyed valley. This can be seen at surveyed area 1, S. Domingos creek valley (figure 4). Inland 50-100 ohm-m initial resistivity is due to dry soil. Underneath we have the water table with 10-20 ohm-m. Resistivity value drops to 5 ohm-m at 800 m position to the sea. These two shallow formations correspond to alluvium and fractured basalt. The seawater intrusion is detected till 800 m position. From this position inland, and at roughly -50 m msl, a equally conductive layer is detected. The exact nature and origin of this is not certain, as any borehole or drill was done to this depth. The explanation could be the existence of some bentonite clay layers (detected at these southeast regions) or other salty layers from ancient sea transgressions (Serralheiro 1976).

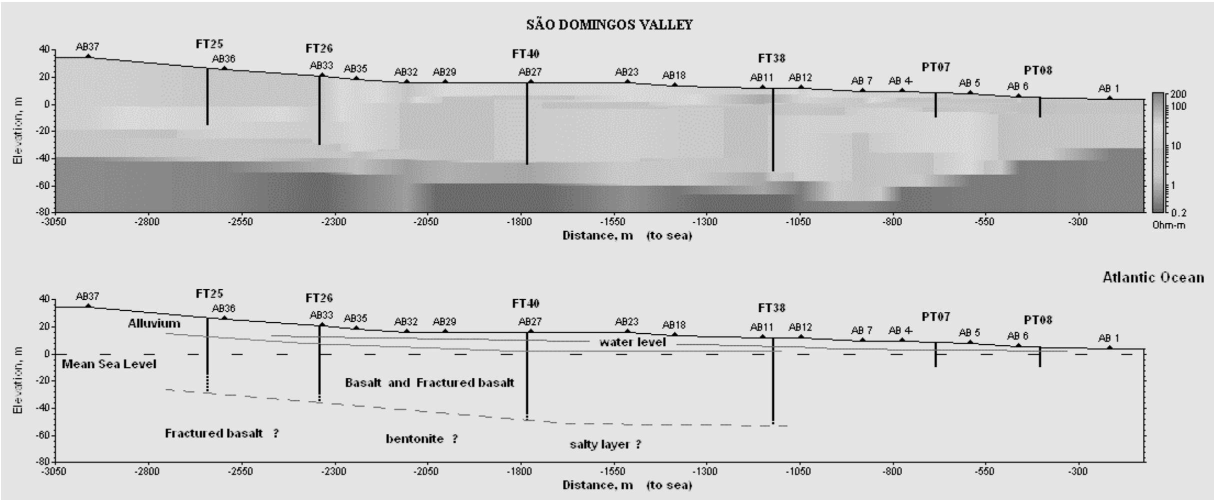

Figure 4. Geolectric pseudo-section at S. Domingos creek valley (June 2005), with TDEM soundings and boreholes location. Lithology is drawn from boreholes information.

Work developed under the scope of the project HYDROARID (PPCDT/CTE/GEX/55399/2004)

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