International Workshop

TOWARDS SCENARIOS FOR URBAN ADAPTATION PLANNING
Assessing seawater intrusion under climate and land cover changes in Dar es Salaam, Tanzania

Assessing Seawater Intrusion in the south Pontina Plain
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Overview

**Target:**
To analyze the spatial variation of groundwater salinization in the shallower aquifers by different investigation methods in a coastal area characterized by:

- hydrogeological framework complexity
- economical, environmental and political issues (e.g. high water demand until overexploitation of groundwater, unauthorized withdrawal)

**Methods:**
- Vertical electrical soundings
- Hydrogeochemical and Temperature characterization

**Conclusions:**
- ✓ Seawater intrusion is multistratum as inflows at two different levels of the aquifers
- ✓ Two areas registered values result alarming
Geographical location

The plain hydrogeological system is influenced by:

- The LEPINI mountains along the north-eastern side (lowered by a net of faults).
- The ACQUE ALTE irrigation canal along the north-western side, that represents a drainage axis of the two shallow groundwater systems.
- The AUSONI mountains along the south-eastern side (separated with the Amaseno stream discontinuity).
- The CIRCEO carbonatic block.

The test site is located in the southern area of the Latium region. It’s a coastal area included in the Pontina Plain.

It is extended for 80 km² and it represents a band which extends for 18 km along the coast and for 4 - 5 km inland.

The elevation of the plain ranges from 0 m to 30 m above mean sea level, and the yearly average precipitation is of 800-900 mm/y.
The area, malarious and depopulated until the thirties, is nowadays crossed by a net of irrigation canals.

In this humid region, today a rich agricultural zone, the periodic occurrence of droughts of different intensity is one of the most important factors in the variability of crop yield. Because complementary irrigation is an highly efficient resource to increase such yields, an understanding of groundwater resources is important.

Moreover a large part of the area is occupied by the Circeo National Park, the geo-environmental importance of which is remarkable.

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The non domestic withdrawal is rather $8 \times 10^6$ mc/y

The 74% of domestic withdrawal is localized in the area investigated by the vertical electrical soundings.
The Pontina Plain is an ancient tectonic hollow, over 800 meters deep, and covered by recent Quaternary deposits, made of sands, silts and clays. More ancient outcroppings are located along the south-west coast and are represented by organogetic limestones or Pliocene and Pleistocene clay.

Geological pattern

sand complex
ancient dune soils
black lands
Sandy peat
urbanization
Sandstone
Sandy conoids
Pebbles gravel and sand with scarce matrix
Ancient
Micrite limestone
Red lands
recent alluvial deposit
terraced alluvial
Pebbles and gravel with silty matrix
Conglomerates and breccias
Travertine
Pyroclastic rocks
loose tuffs

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The study area has a surface of approximately 260 km², which extends along a 40 km stretch of coastline to the north of the City centre and is bordered to the east by the Indian Ocean. The western boundary is the Dar es Salaam Plateau, which rises west of the Ocean along the entire study area up to the Pugu Hills.
Hydrogeological pattern

In the area under study they are distinguished three different aquifers: two shallow aquifers (40 – 80 meters b.s.l.) made by sands, the first, and by eluvial deposits the latter.

The Sisto stream represents a drainage axis for these two Quaternary formation aquifers. The first of which, the dune aquifer, in fact, floats on the sea and it is drained by the lakes, the sea and partially by Sisto stream, that delimits the Pontina depression at south-west.

A deeper carbonatic one (more than 100 meters b.s.l.) is separated from them by a clay layer.

The second one, corresponding to the inner band of the coast, is constituted by fluvial marsh outcrops, and is characterized by a lower permeability ($10^{-6}$ m/s).
Geostructural complexity

The composition of these strata is really variable, and as a consequence of it, the different hydraulic conductivity of them makes the aquifer a multistrata one. Nevertheless the groundwater circulation can be considered unique, thanks to water exchange between the different strata, the thickness of which is not defined, because of its geological complexity which makes it very variable from point to point inside the area.
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Seawater inflow

Comparing two previous geophysical investigation campaigns, carried out:

- in the same location
- utilizing the Schlumberger electrode array.

✓ 1952
✓ 1967
✓ 91 VES

Sequence stratigraphy analysis by a series of calibration drillings

✓ 2003
✓ 82 VES.

A first idea about the salt water intrusion evolution in the last 30 years.
The maximum current electrode (AB) separation of these VES has been 800 – 1000 m, depending on the accessibility of soil for expanding electrodes, an avoiding crossing of power lines or sewerage/water net pipelines when expanding the profile lines and for enabling a better description of the features of the aquifers.

The relative investigation depth ranges from 120 to 200 m below the ground surface.
The field geo-electric data, in the form of AB/2 (semidistance between current electrodes) and apparent electric resistivity values were plotted on log – log paper in the field, to confirm their reliability for the subsequent processing and interpretation procedures. The analysis of these curves gives a rough representation of some important experimental results. Moreover, interpreted data from all soundings are utilised for the preparation of mean resistivity contour maps at AB = 60 m, AB = 100 m (each of them for both of periods: 1967 and 2003)
Two main groups

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An apparent resistivity map built considering AB = 60 m (1967) shows two different conditions: in the area situated between the Circeo area and Terracina, the resistivity values decrease eastward passing by a range of 50 – 70 ohm.m to north of S. Felice Circeo, until 5 ohm.m between Borgo Ernada (close to Terracina) and the sea; while in the area to north of Circeo the resistivity values decrease by the coast inward, and on the recent it is higher than 50 ohm.m.

The same map, built with the values of the 2003, points out as the conductivity area at north of Terracina appears dilated: resistivity value inferior to 40 ohm.m occupies the whole eastern area of S. Felice Circeo.
This map reports the percentage difference of the resistivity distribution in the last thirty years, for a shallow range of depth, inside 10 and 30 m. A widespread resistivity decrease, with tops of 80% in some VES, is shown in it. The lowest values have been registered on Sabaudia shoreline and on the western area of Terracina. In particular it is important to outline the situation pointed out by the sounding data at VES 48. From this investigation a decrease by 750 to 35 ohm.m has been registered and it is indicative of the elevation of the transition zone.
The apparent resistivity map with AB = 1000 m (1967) is relative of a survey depth around 200 m. The lowest resistivity values are located along the northern coast of Circeo block, while the highest in correspondence of VES 34 and 30.

The correspondig map, obtained with the up-to-date sounding data (2003) as a whole follows a similar situation, with very low values at north and along the coast between S.Felice Circeo and Terracina.
Looking at the percentage differences is evident a decrease in the resistivity value of 20-60 % along the band between Lago Caprolace and the north of Circeo block. The highest resistivity values with top of 60-80% are registered in correspondence of the VES 30 - 31 included in the area B and VES 6-7-10-12 inside of the area A. In fact they are located in a very anthropic zones which are more rich of turistic infrastructures.
Water sampling results

From 45 wells the depth of whom ranges to 40 – 100 m groundwater samples were collected:

- Latitude
- Longitude
- Quote (m a.s.l.)
- Potenziometric head
- Conductivity (µS/cm)
- Temperature (°C)
- TDS (ppm)
For each of them, a temperature log profile (meter by meter) and a conductivity and TDS ones have been measured.

Cross sections

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Planar sections of conducibility
Planar sections of temperature
The comparison between the reports of the VES investigation driver in 1967 and the 2003 ones shows with evidence that seawater intrusion grew up as in the vertical direction as in the horizontal one.

In the thickness of the aquifer the nowadays VES reports show the seawater comes in at two different levels. The first level is located at about 15 – 40 b.s.l. in the more recent sands as the second one starts at about 80 – 100 b.s.l. at the deepness where the more ancient are found. These two levels are divided by a thick level of Plio-pleistocene silts and clays.

The deeper of the them contains relatively brackish groundwater, whereas the other one has a relatively high TDS content. The seawater intrusion involves the aquifers and the aquitards below the fresh water down to a depth of 10 meters for the first aquifer, and for 40 meters for the second one. In the horizontal direction seawater intrusion incomes for more than 500 m on the west coast and more than 2 km in the east part.
The high values of temperature and conductivity coincide with the elevated TDS concentration measured in some critic zone. Moreover the Schlumberger sounding resistivity method proves to be a powerful tool for investigating the seawater/freshwater interface in the geological setting of the southern shore of Latium region.

In fact it led to distinguish areas where high temperature values and medium conductivity ones were not due to a sea water intrusion increase but to local phenomenas, from areas where the sea water intrusion is a real emergency.

On the whole, the results of the field investigation witnesses a sensible increase in seawater intrusion, which may have been caused by overexploitation of groundwater. Infact the groundwater exploitation in the investigated area is more the 74% of the average net recharge of the whole Pontina Plan.