ACC DAR Adapting to Climate Change in Coastal Dar es Salaam

Seawater intrusion monitoring

Dar Es Salam, 09/19/2013

Giuseppe Sappa (*),

(*) Department of Civil Building and Environmental Engineering
Faculty of Engineering
Sapienza University of Rome
Giuseppe.sappa@uniroma1.it
w3.uniroma1.it/giuseppe.sappa

Last experience in Africa (Tunisia, 2008)

- **SAHARA SUD PROGRAMME: Projet of rehabilitation and creation of datters palms in Rjim Maâtoug**

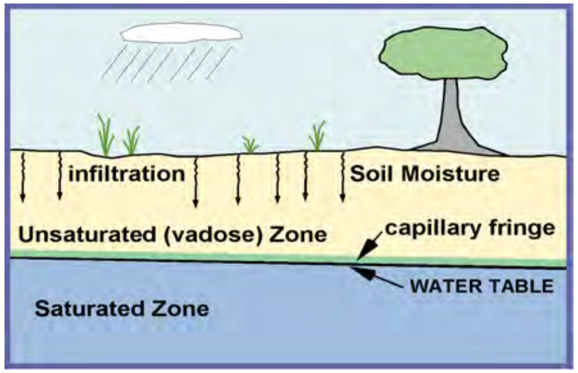
- **Hydraulic Commission for the evaluation and prevision of artesianism lasting**

Last experience in Africa (Cote d'Hivoire, 2009)

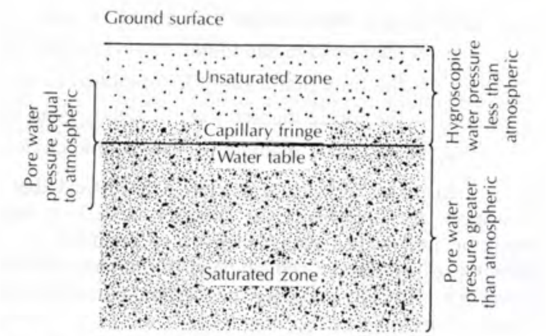
- The new waste solid landfill in Abdjan
- Preliminary design

- The nowadays one

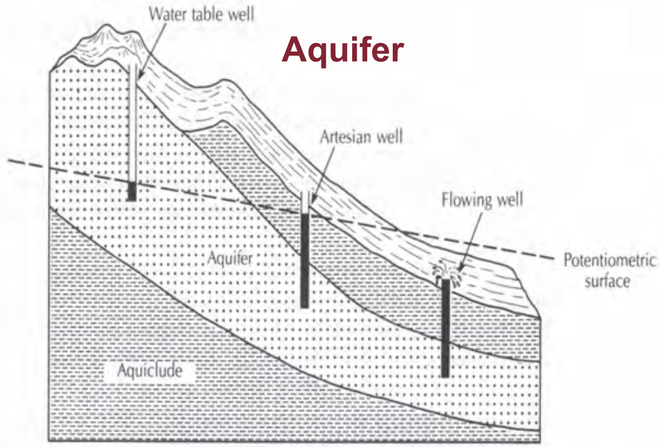
Groundwater



Groundwater



Aquifer



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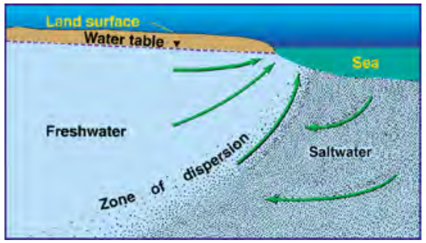
Seawater intrusion involves coastal aquifers

Coastal aquifers are aquifers supported and/or bordered by the sea



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Main properties of coastal aquifers

- High hydraulic conductivity of rocks forming aquifer along the coastline;
- The bottom of fresh groundwater flow is at the same elevation of the average sea level;
- Fresh groundwater flow outcrops by coastal springs, including brackish water;
- At the bottom fresh groundwater is supported by seawater;

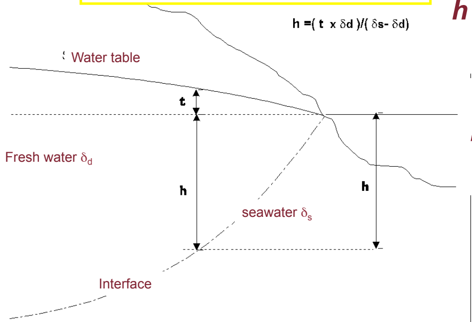
Ghyben (1889) & Herzberg (1901) model

- Hypothesis:
  - Freshwater and seawater are not miscible
  - Seawater is still
  - Freshwater circulation is horizontal

	Seawater				Freshwater
Ions (μg/l)	STUMM e MORGAN (1981)	LLOYD e HEATHCOTE (1985)	CUSTODIO (1987)	DREVER (1988)	WEBBER E THURMAN (1991)
Cl^-	19354	19000	18000-21000	19350	78
HCO_3^-	142	142	70-150	142	58
SO_4^{2-}	2712	2700	2500-2900	2710	12
Na^+	10770	10500	10000-11800	10760	6,3
K^+	399	380	350-400	399	2,3
Ca^{2+}	412	400	380-440	411	15
Mg^{2+}	1290	1350	1100-1400	1290	4

Ghyben (1889) & Herzberg (1901) model

$P_A = \rho_s \ \gamma \ h = \rho_d \ \gamma \ (t + h)$



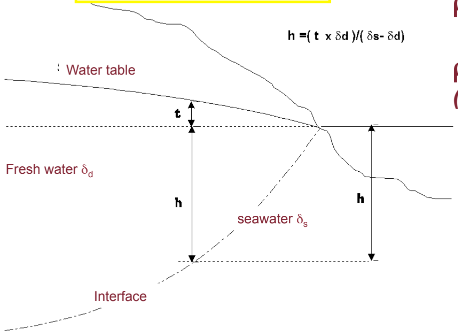
$$h = \frac{\rho_d}{\rho_s - \rho_d} t$$

$$K_s = \frac{\rho_d}{\rho_s - \rho_d}$$

$$33 < K_s < 50$$

Ghyben (1889) & Herzberg (1901) model

$P_A = \rho_s \ \gamma \ h = \rho_d \ \gamma \ (t + h)$



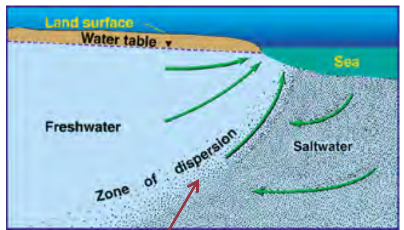
ρ_d = 1000 g/l

ρ_s = 1027 g/l (TDS=42 g/l)

$33 < K_s < 50$

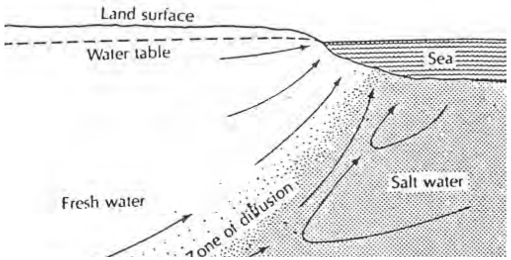
Zone of dispersion or transition zone

- **Freshwater and seawater are miscible**
- **Freshwater flow has sometimes a sensitive vertical component**
- **Seawater is not still**



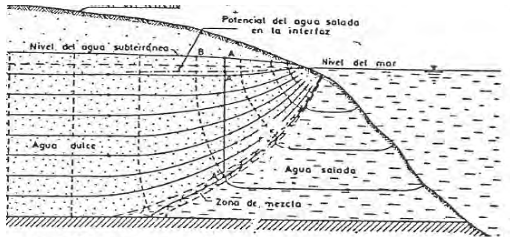
Transition zone

Hubbert correction and the cycling flow of seawater



Hubbert observerd that from coastal springs comes out brackish water. As a consequence of this process, there is a replacing incoming flow of seawater with loss of hydraulic charge. On the other hand the freshwater hydraulic charge in the same point is higher than it would be in static condition.

Hubbert correction and the cycling flow of seawater



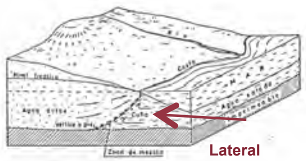
$$(t_d' + h)\,\delta_d = (h + t_s)\,\delta_s$$

$$h = \frac{\delta_d}{\delta_s - \delta_d}\,t_d' - \frac{\delta_s}{\delta_s - \delta_d}\,t_s$$

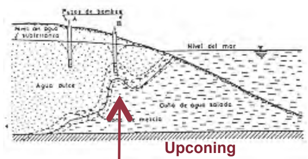
Usually t_s<0, so the *h* given by Hubbert correction is minor than the *h* given by Gyben-Herzberg model and this is the reason of the nowadays application of Gyben-Herzberg model, as it is conservative

Seawater intrusion

- It's the permanent or temporary incoming flow of seawater in a freshwater aquifer, and it's due to the decreasing of fresh groundwater flow towards the sea, caused by:
  - Overexploitation of groundwater
  - Groundwater quality degradation

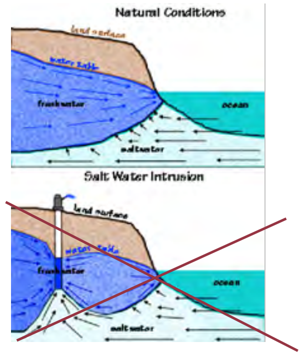


Lateral



Upconing

Seawater intrusion



- It isn't seawater which rise up, but they are dispersion and diffusion processes which increase groundwater salinization

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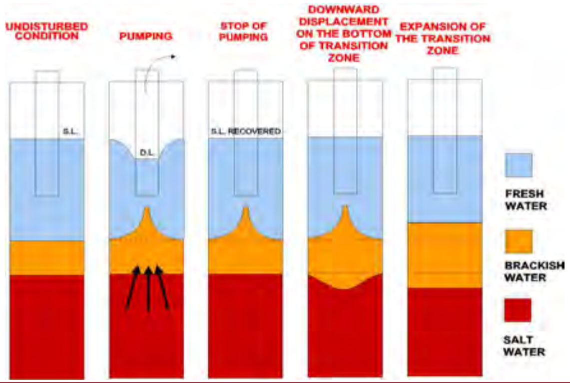
What happens: brackish water zone increases



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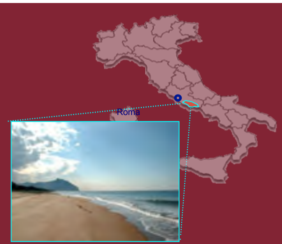
Which tools to monitoring this evolution?

- There are different methods:
  - Areal monitoring (geophysical investigation technologies)
  - Point monitoring (Logs, sampling, on site and laboratory analysis)

Any method needs to be elaborated, verified and interpreted to give a spatial representetion of the phenomenon.

Sometimes they are used together as a multisystem approach to check information coming each one method.

A case history of multisystem approach



SAPIENZA

Assessing Seawater Intrusion in the south Pontina Plain

Overwiew

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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)

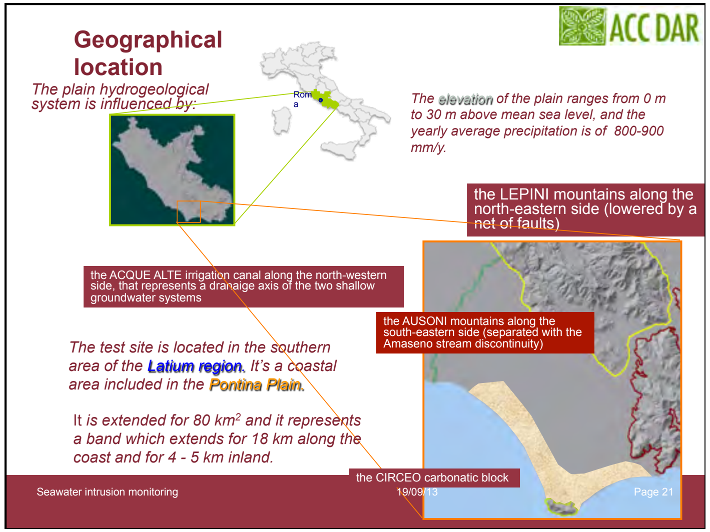
Methods:

- **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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Geographical location
The plain hydrogeological system is influenced by:
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 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 dranaige axis of the two shallow groundwater systems
the AUSONI mountains along the south-eastern side (separated with the Amaseno stream discontinuity)
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 CIRCEO carbonatic block
Seawater intrusion monitoring
19/09/13
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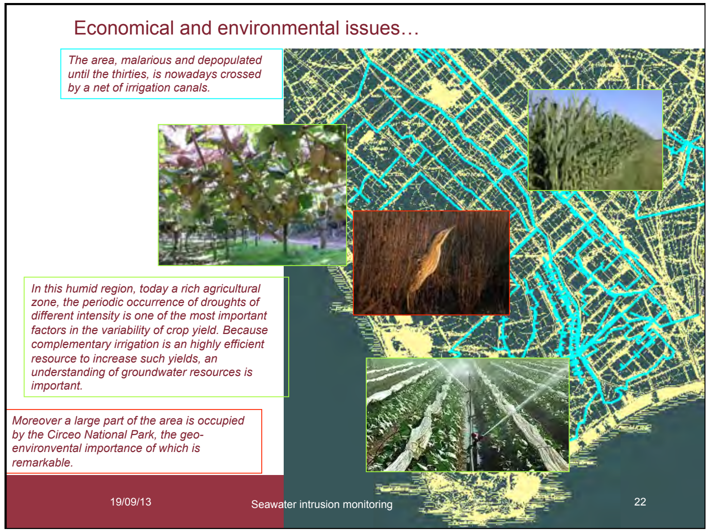
Economical and environmental issues…
The area, malarious and depopulated until the thirties, is nowadays crossed by a net of irrigation canals.
In this humid region, today a rich agricultural zone, the periodic occurrence of droughts of different intensity is one of the most important factors in the 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-environvental importance of which is remarkable.
19/09/13
Seawater intrusion monitoring
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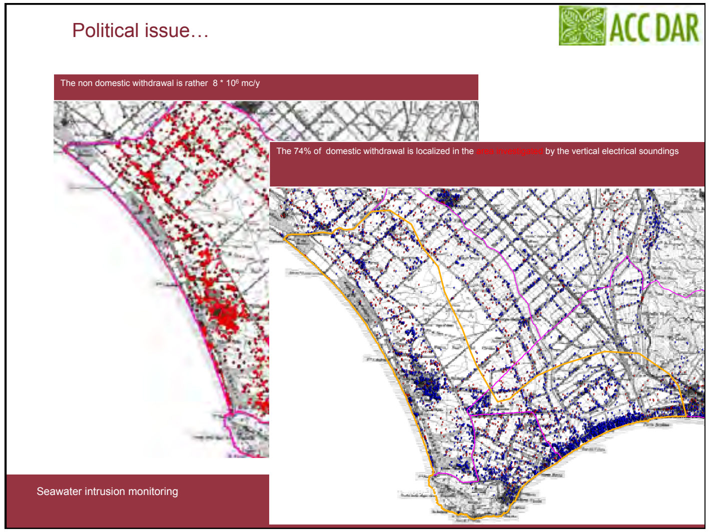
Political issue…
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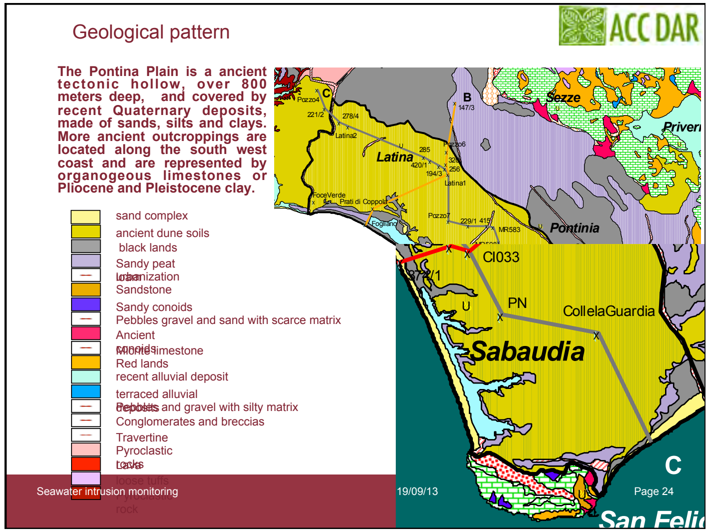
The non domestic withdrawal is rather 8 * 10⁶ mc/y
The 74% of domestic withdrawal is localized in the by the vertical electrical soundings
Seawater intrusion monitoring


Geological pattern
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The Pontina Plain is a 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 organogeous limestones or Pliocene and Pleistocene clay.
sand complex
ancient dune soils
black lands
Sandy peat
urbanization
Sandstone
Sandy conoids
Pebbles gravel and sand with scarce matrix
Ancient
Marly limestone
Red lands
recent alluvial deposit
terraced alluvial
Pebbles and gravel with silty matrix
Conglomerates and breccias
Travertine
Pyroclastic
Lavas
Sezze
Priverno
Latina
Pontinia
CI033
PN
CollelaGuardia
Sabaudia
San Felice
B
C
U
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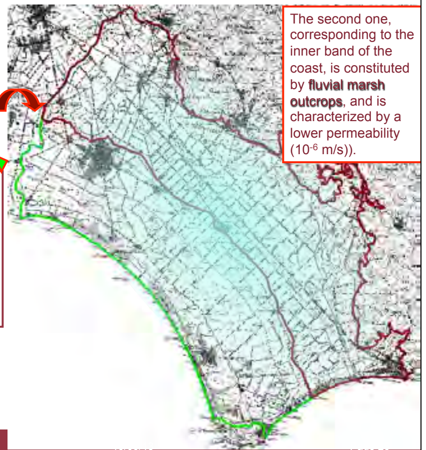
Hydrogeological pattern

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.

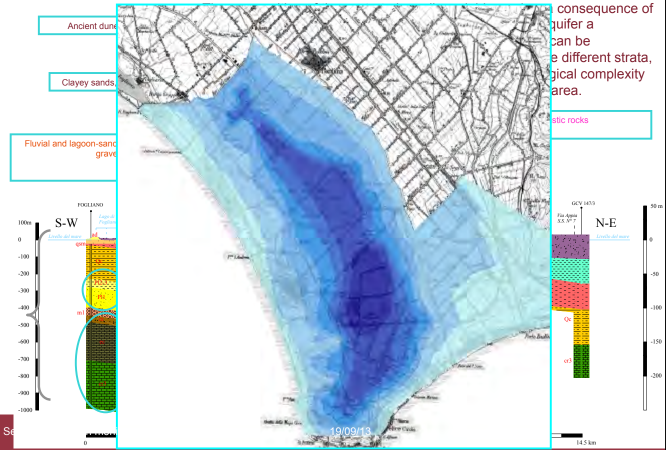


The second one, corresponding to the inner band of the coast, is constituted by **fluvial marsh outcrops**, and is characterized by a lower permeability (10^{-6} m/s)).

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.

Geostructural complexity



consequence of
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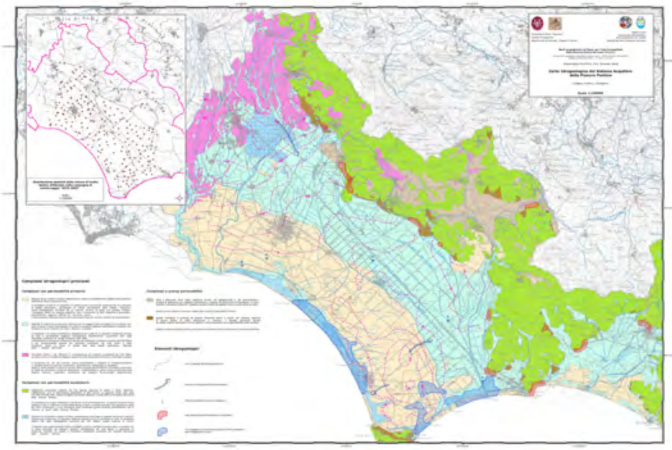
can be
e different strata,
gical complexity
area.



Seawater inflow

Comparing two previous geophysical investigation campaigns, carried out:
- in the same location
- utilizing the Schlumberger electrode array.

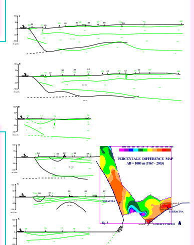
✓ 1952
✓ 1967

✓ 91 VES

Sequence stratigraphy analysis by a series of calibration drillings

✓ 2003

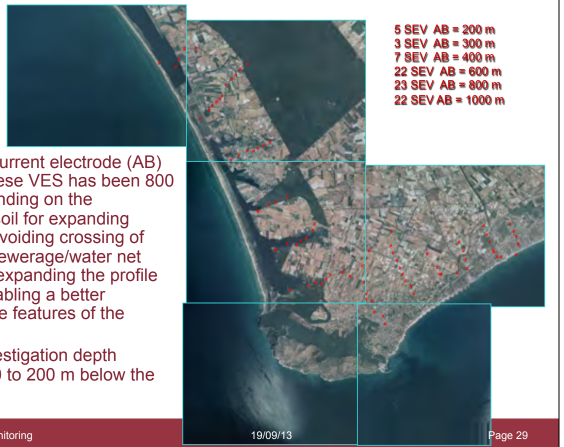
✓ 82 VES.



A first idea about the salt water intrusion evolution in the last 30 years

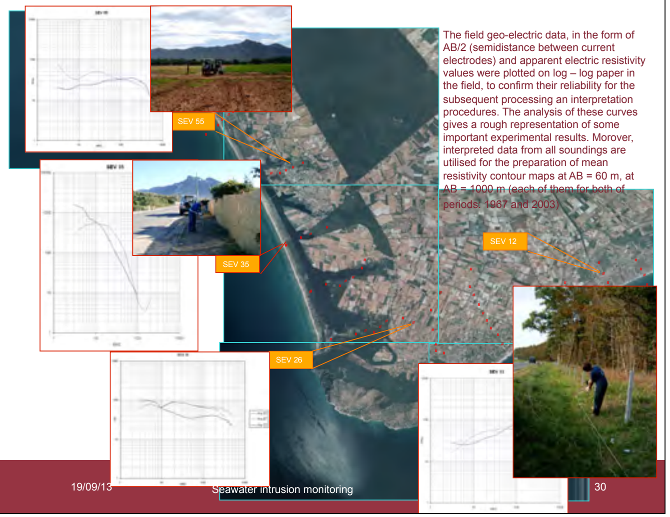
VES 2003

5 SEV AB = 200 m
3 SEV AB = 300 m
7 SEV AB = 400 m
22 SEV AB = 600 m
23 SEV AB = 800 m
22 SEV AB = 1000 m



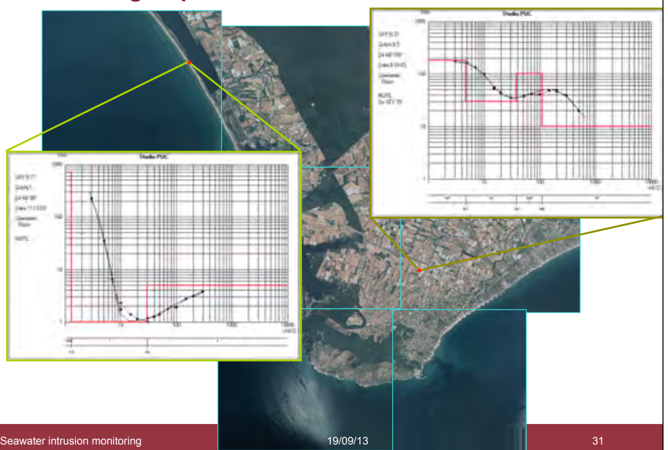
The maximum current electrode (AB) separation of these VES has been 800 – 1000 m, depending on the accessibility of soil for expanding electrodes, an avoiding crossing of power lines or sewerage/water net pipelines when expanding the profile lines and for enabling a better description of the features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

The relative investigation depth ranges from 120 to 200 m below the ground surface.



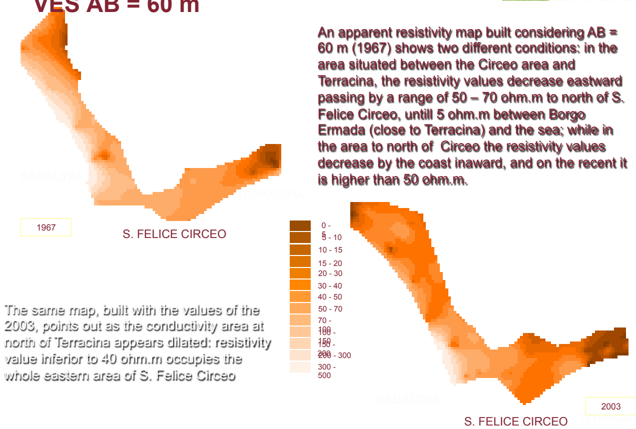
The field geo-electric data, in the form of AB/2 (semidistance between current electrodes) and apparent electric resistivity values were plotted on log – log paper in the field, to confirm their reliability for the subsequent processing an interpretation procedures. The analysis of these curves gives a rough representation of some important experimental results. Morover, interpreted data from all soundings are utilised for the preparation of mean resistivity contour maps at AB = 60 m, at AB = 1000 m (each of them for both of periods: 1967 and 2003)

Two main groups



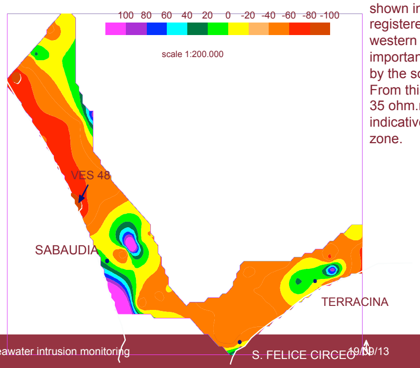
VES AB = 60 m

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, untill 5 ohm.m between Borgo Ermada (close to Terracina) and the sea; while in the area to north of Circeo the resistivity values decrease by the coast inaward, and on the recent it is higher than 50 ohm.m.



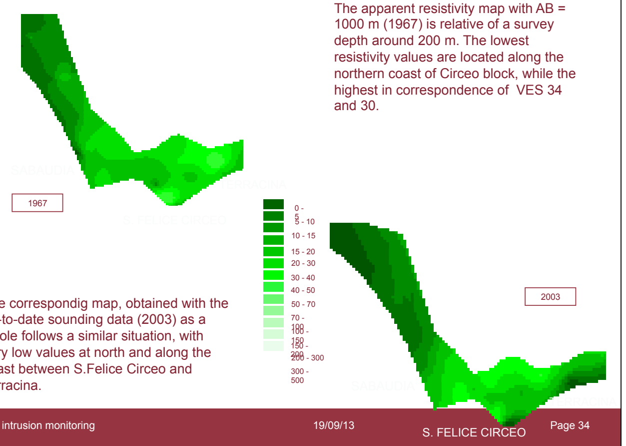
The same map, built with the values of the 2003, points out as the conductivity area at north of Terracina appears dilated: resistivity value inferior to 40 ohm.m occupies the whole eastern area of S. Felice Circeo

Percentage difference map
AB = 60 m (1967 - 2003)



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.

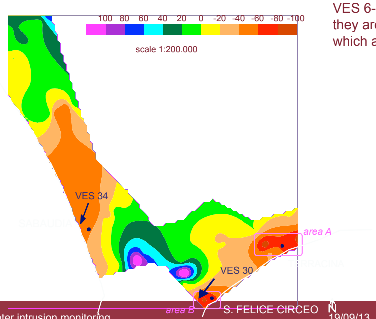
VES AB = 1000 m



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.

Percentage difference map
AB = 1000 m (1967 - 2003)



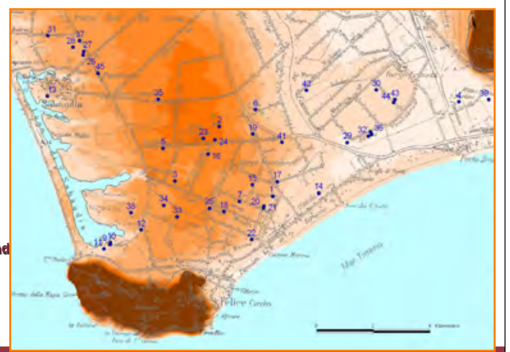
Looking at the percentage differences is evident a decrease in the resistivity value of 20-60 % along the band between Lago Caprolace and the north of Circeo block. The highest resistivity values with top of 60-80% are registered in correspondence of the VES 30 - 31 included in the area B and VES 6-7-10-12 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

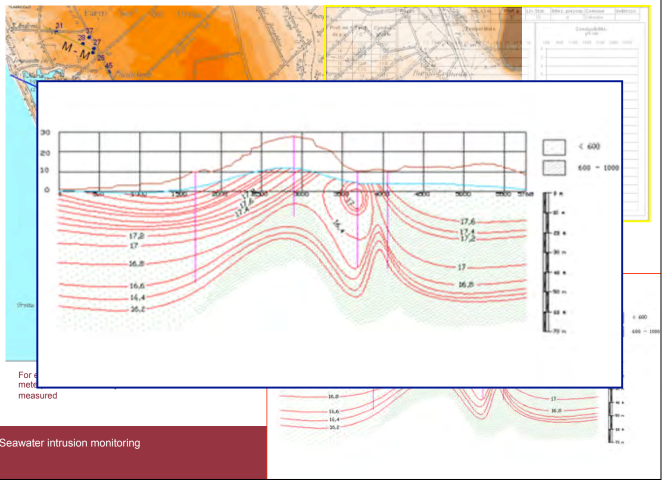
From **45 wells** the depth of whom ranges to 40 – 100 m groundwater samples were collected:

ProfiLine LF197

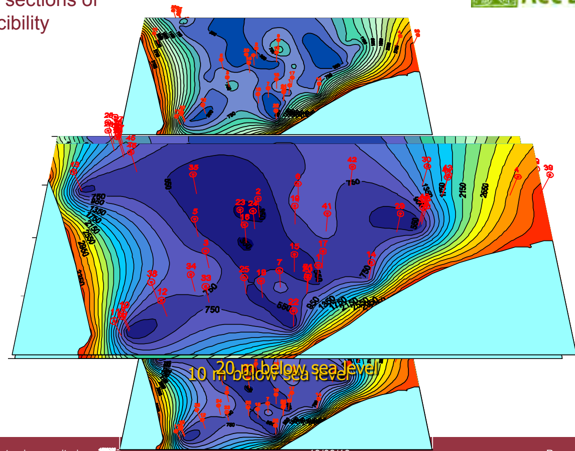
- **Latitude**
- **Longitude**
- **Quote (m a.s.l)**
- **Potenziometric head**
- **Conductivity (µS/cm)**
- **Temperature (°C)**
- **TDS (ppm)**



Cross sections

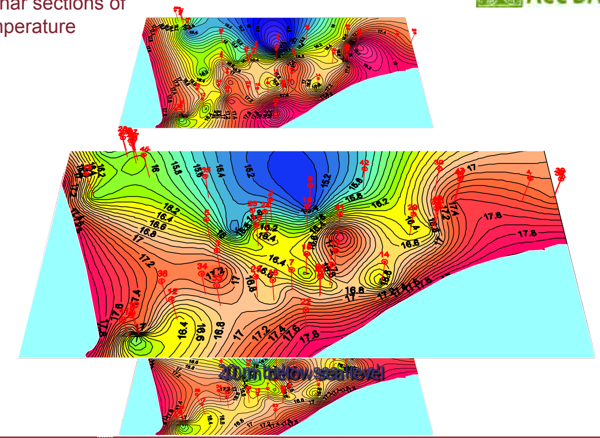


Planar sections of conducibility



20 m below sea level

Planar sections of temperature



Conclusions

- The comparison between the reports of the VES investigation driver in 1967 and the 2003 ones shows with evidence that seawatwer 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 clayes.
- 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.

Conclusions

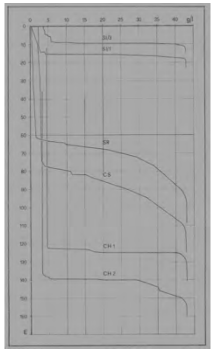
The high values of temperature and conductivity coincide with the elevated TDS concentration measured in some critic zone. Moreover the Schlumberger sounding resistivity method proves to be a powerful tool for investigating the seawater/freshwater interface in the geological setting of the southern shore 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.

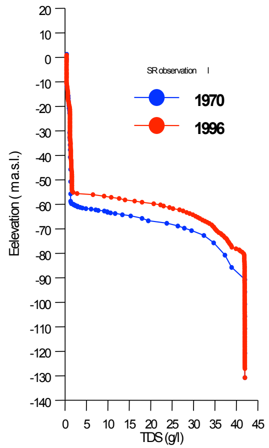
Point monitoring methods

- Multiparameter logs:
  - Multiparameter meter with
    - salinity
    - TDS
    - Temperature
    - pH
    - Electrical conductuvity measurements

Point monitoring methods



- Multiparameter logs:
  - Multiparameter meter with salinity measurement
  - Boreholes:
    - with no pump;
    - with screen along the whole saturated zone



Seawater intrusion evolution between 1970 and 1996 in Apulia region (Italy)

Monitoring borehole SR

Transition zone upper border uplift of 5 mt, but its thickness increases very much

Dar Es Salam case history in the framework of ACC-DAR project

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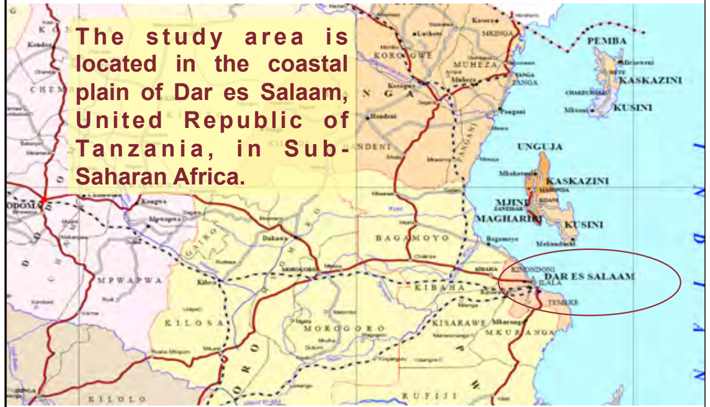
Description of the study area= The site

The study area is located in the coastal plain of Dar es Salaam, United Republic of Tanzania, in Sub-Saharan Africa.



Description of the study area

- The study area has a surface of approximately 260 km^2, which extends along a 40 km stretch of coastline to the north of the City center 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.

Goals and scope

- The overall objective of this study is to explore the current degree of seawater intrusion into Dar es Salaam's coastal aquifer, and its relationships with climatic conditions and urbanization processes, in order to identify the areas of the city with the highest priority for adaptation action implementation.
- Identification of the relationships with environmental parameters, related to climate variability, and anthropogenic factors, related to changes in land cover and the population's water demand, is expected to provide the knowledge base with which to develop future scenarios of the aquifer's Sensitivity to the phenomenon, in terms of the future evolution of both seawater intrusion and groundwater availability for municipal water supply.

Motivation

- Groundwater is the largest reserve of freshwater available worldwide, and thus plays a crucial role in the adaptability of the world population to the effects of climate change on rainfall, soil moisture content, and surface water (Margat, 2006).

- Recent IPCC assessment reports have concluded that very little is known about the relationship between groundwater and CC (IPCC, 2001; IPCC, 2007; IPCC, 2008); however it is recognized that CC usually acts as an effects multiplier in already altered hydrogeological systems, with obvious consequences for dependant ecosystems and communities (Appleton, 2003).

Overall Approach

- According to this approach, vulnerability is defined as *"the degree to which a system is susceptible to, or unable to cope with, the adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity"* (IPCC, 2007).

Vulnerability = f (Exposure, Sensitivity, Adaptive Capacity)

- *Exposure*: the nature and degree to which a system is exposed to significant climatic variations.
- *Sensitivity*: the degree to which a system is affected, either adversely or beneficially, by climaterelated stimuli. The effect may be direct or indirect.
- *Adaptive capacity* (in relation to CC impacts): the ability of a natural or human system to adjust to climatechange (including climate variability and extremes) to moderate potential damages, to takeadvantage of opportunities, or to cope with the consequences. (Fussel, 2006)
-

Approach and Method

The methodology for assessing the aquifer's sensitivity to seawater intrusion consists of the following analytical steps:

- Bibliographic data collection and analysis to assess the geological and hydrogeological sketch of the Dar es Salaam coastal plain;
- Seawater intrusion assessment by hydrochemical methods, through physical and chemical testing of monitored network of representative boreholes from 2001 to 2012;
- Anlysis of climatic and anthropogenic influences on hydrogeological dynamics through investigations on piezometric surface and Active Recharge temporal evolutions;
- Conclusions and recommendations

The geological setting (framework) of the site

The geology of the Dar es Salaam City area is characterized by quaternary sediments, which mainly underlie the coastal plain. The quaternary terrace sandstone, also including coral reef limestone, nearer the coast. The quaternary deposits Neogene sandstone formations, interbedded with siltstones and mudstones, occupy the upland zone south and west of the city centre. Within the Neogene formations, several distinct varieties are recognizable.

Sandstones occupy over three quarters of the region and comprise a variety of main types. The massive terrace sandstone is the bedrock that limits the extent of terraces (Msindai K., 2002). The Pugu sandstones comprise massive, kaolinitic, and cross-bedded sandstones. Calcareous sandstones also occur on back reef areas of the uplands

The hydrogeological setting

- The groundwater reservoir is located within the coastal plain in the quaternary sediments, as the quaternary deposits have higher hydraulic conductivity than the underlying and surrounding Miocene sequence, which includes clay intercalations (Mjema, 2007)

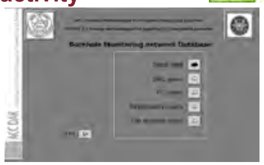
AQUIFER	PERIOD	EPOCH	LITHOLOGY
Unconfined	Quaternary	Pleistocene to recent	Fine sand to medium sand with silts and clay, coral reef limestone and calcareous, alluvial clay, silts and gravels
Aquitard	Quaternary	Pleistocene to recent	Clay, sandy clay (clay)
Semiconfined Aquifer	Quaternary	Pleistocene to recent	Medium to Coarse sand and gravels with clay
Aquitard	Neogene	Mio-pliocene	Clay-bound sands

Numbers and kinds of investigation and analysis results

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	June 2012	Nov 2012
G (mas)	32	6	52	15	8	6	5	4	1	54	0
depth	32	6	51	15	8	6	5	4	1	33	0
SW m	32	6	51	15	8	6	5	4	1	79	0
T C°	0	0	0	0	0	0	2	1	0	79	0
pH	32	6	52	15	8	6	5	4	1	79	0
EC uS/cm	32	6	52	15	8	6	5	4	1	79	0
Total Fitrate Residue mg/l	1	0	12	6	7	4	4	0	0	0	0
TDS mg/l	0	0	0	0	0	0	2	2	1	0	0
Carbonate Hardness mg CaCO3/	7	6	12	6	7	4	3	2	1	0	0
Non Carbonate Hardness mg CaCO3/	30	5	39	10	4	5	3	3	1	0	0
Ca mg/l	32	6	52	15	8	6	5	4	1	79	71
Mg mg/l	32	6	52	15	8	6	5	4	1	79	70
Na mg/l	32	6	52	15	8	6	5	4	1	79	70
K mg/l	32	6	52	15	8	6	5	4	1	79	70
Fe mg/l	26	5	47	15	8	4	5	3	1	0	0
Mn mg/l	25	5	21	10	7	2	4	2	0	0	0
NO3 mg/l	26	4	45	12	8	6	5	4	1	79	71
Cl mg/l	32	6	52	15	8	6	5	4	1	79	71
SO4 mg/l	32	6	52	15	8	6	5	4	1	79	71
PO4 mg/l	30	4	30	15	8	3	5	0	0	0	0
F	0	0	20	0	0	2	2	2	0	0	0
HCO3 mg/l	0	0	0	0	0	0	0	0	0	79	71
CO3 (mg/l)	0	0	0	0	0	0	0	0	0	0	23
P	0	0	0	0	0	0	0	0	0	0	71
ZN	0	0	0	0	0	0	0	0	0	0	0
I	0	0	0	0	0	0	0	0	0	0	0
NH4	0	0	0	0	0	0	0	0	0	0	71
MN	0	0	0	0	0	0	0	0	0	0	0

Groundwater monitoring activity

ACC-Dar Borehole Monitoring Database



Monitoring campaigns	Frequency	Data collected
Long-term monitoring activity involving the entire borehole network (79 boreholes)	Twice in 6 months: -June 2012 (after the *"long rainy season")* -November 2012 (before the "*short rainy season*")	SWL measure (using contact meters) Physical parameters in situ measure (using multiparametric probes): T, pH, EC, TDS Chemical parameters lab measure (laboratory analysis of collected water sample): Ca++, Mg++, Na+, K+, HCO3-, SO4--, Cl-, NO3--, F-, NH4+
Monthly monitoring activity involving a sub-group of the borehole network (33 boreholes, mainly located in the area close to the coastline)	Monthly: -September 2012 -October 2012	SWL measure (using contact meters) Physical parameters in situ measure (using multiparametric probes): T, pH, EC, TDS

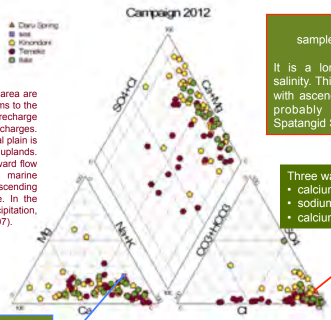
Hydrochemical Framework

Data Analysis methods

- In the aim of evaluating the seawater intrusion and its evolution in the last ten years, the study has proceeded according to the following steps:
  - Elaboration of distribution maps for various parameters (TDS, Cl, SO4, and EC);
  - Graphical representation in the form of a Piper diagram, in order to distinguish water types and identify the most significant groups;
  - Data analysis using Cl—Y diagrams (cross plots) related to the theoretical freshwater-seawater dilution line;
  - Hydrochemical facies analysis by Stuyfzand (1986, 1993) classification.

Piper classification

These watertypes found in the study area are influenced by the recharge mechanisms to the coastal plain. There are two main recharge mechanisms: regional and local recharges. Regional recharge water to the coastal plain is probably contributed by faults in the uplands. These faults cause an ascending upward flow of groundwater from the Miocene marine shale beds. The composition of this ascending groundwater is thought to be saline. In the studied aquifers, it is diluted by precipitation, infiltrating in the uplands (Mjemah,2007).



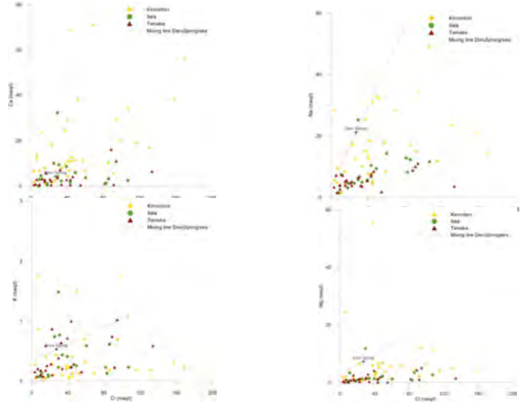
First end member:
sample of the Daru Spring (2005).

It is a long residence water, with high salinity. This NaCl water type is contributed with ascending saline water through faults probably from deep marine Miocene Spatangid Shales (Mjemah, 2007).

Three water types:
- calcium chloride-sulphate type;
- sodium-chloride one;
- calcium –bicarbonate type .

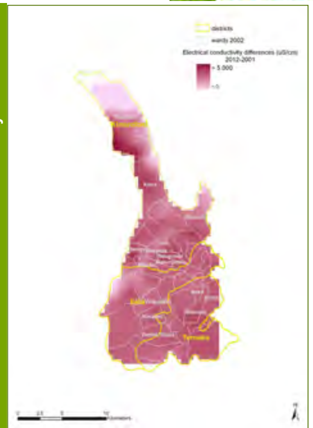
Second end member:
sample of the Indian Ocean (june 2012)

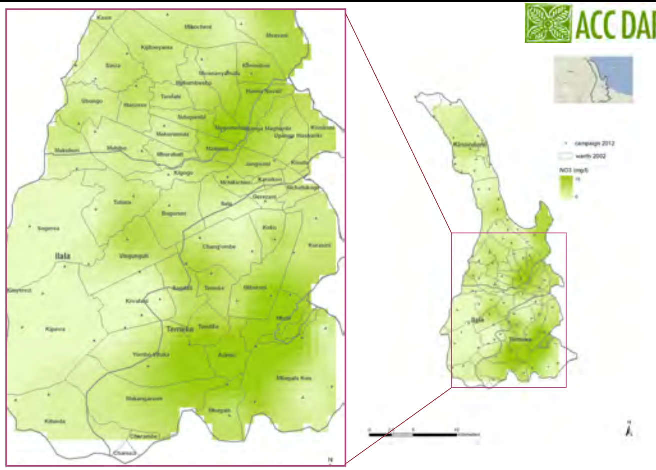
Cross plot Cl-Y



Chloride differences

Electrical conductivity differences

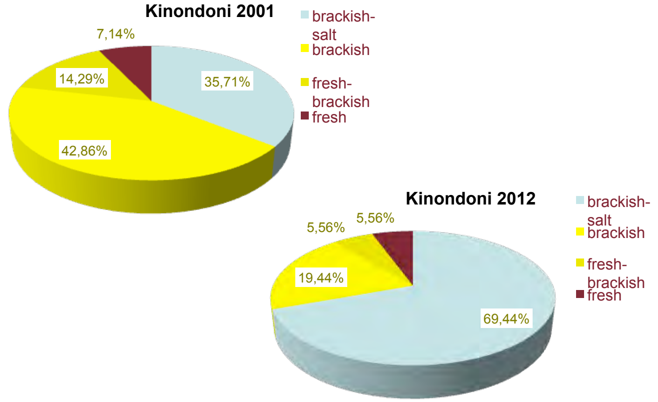




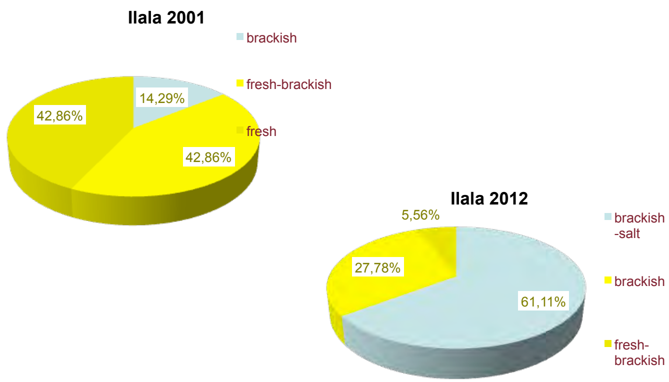
Stuyfzand Classification (1993)

Main type	Stuyf. code	Cl^- (mg/l)
very oligohaline	G	< 5
oligohaline	g	5 - 30
fresh	F	30 - 150
fresh-brackish	f	150 - 300
brackish	B	300 - 1000
brackish-salt	b	1000 - 10000
salt	S	10000 - 20000
hyperhaline	H	> 20000

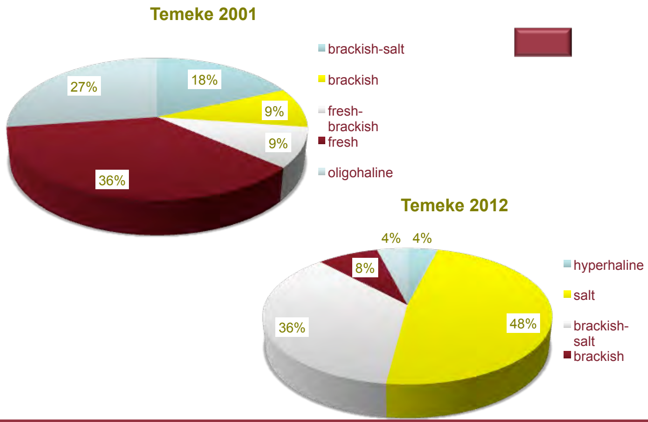
Stuyzand classification evolution



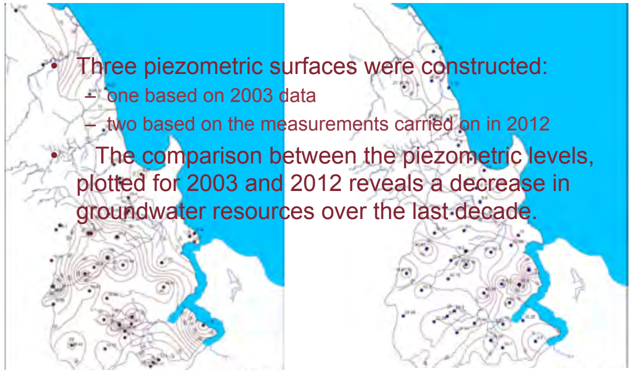
Stuyzand classification evolution



Stuyzand classification evolution



Hystorical evolution of groundwater table



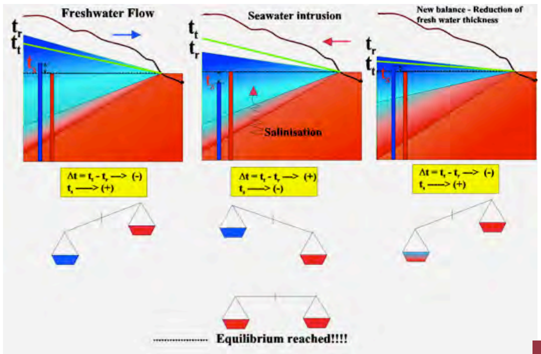
- Three piezometric surfaces were constructed:
  - one based on 2003 data
  - two based on the measurements carried on in 2012
- The comparison between the piezometric levels, plotted for 2003 and 2012 reveals a decrease in groundwater resources over the last decade.

Hystorical evolution of groundwater table
Remarks and comments

- Deepness of boreholes (-12÷98 m): so we are not sure which aquifer level the data is referred to;
- The borehole the measurement is referred to wasn't functioning, but the others nearby it, were switched on;
- Groundwater level is affected by
  - Exploitation
  - Active recharge
  - Seawater intrusion

Borehole	D (m)	Years	D(m) june-november 2012
KIN006	2	2004-2012	0.5
KIN039	8	2001-2012	0.6
ILA020	11.3	2001-2012	2

Effect of seawater intrusion on groundwater level



(From Tulipano L. 2008)

Groundwater Active Recharge

Hydrogeological Inverse Budget (Civita M., 1999)

- Elaboration of precipitation measurements referred to 50 years;
- In the aim of analyzing the climate change impact on groundwater active recharge in the area under study, we considered on the first the average precipitation data referred to the all 50 years of measurements
- On the second, the data have been divided in set of 5 years measurements and it was calculated the average annual precipitation referred to each of the 5-years cycles of data considered.
- The evolution of precipitation during the last 50 outlines a decreasing trend in annual precipitation in the last ten years and a decrease in average annual precipitation as compared with the 50-year average value.

Data reconstruction and estimation

- **BetweenStation**

This method is used to estimate missing rain data values, recorded at neighboring stations (Optimal interpolation assigns weights based on relative distances)

- **WMO Method**

This method is based on this important result " The difference d or ratio q between values of a given elements observed at the station A and B can be established from corresponding sums or mean values (or from simultaneous observation)"

- **Within/Station**

This method use the rain data recorded on the previous and following days to estimate a missing observation.

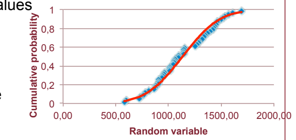
For each missing data first the Between Station, second WMO Method and lastly the within Station estimations was used.

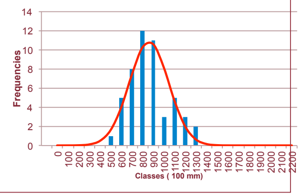
Adaption to probability distributions (Gaussian)

- Adaption of 50 years of annual average values
- Calculation of empirical frequencies
- The distribution parameters are obtained by comparing the moment of the sample to the theoretical moment of the distributions.
- Calcute average value and standard deviation

JNIA = 1132,39 mm SQM = 278,20
OCEAN ROAD = 1025,56mm SQM = 224,36
WAZOHILL = 909,87mm SQM =182,04

✓ PearsonTest verified
✓ Kolmogorov-Smirnov verified





Rainfall Spatial Analysis (IDW)

- Inverse Distance Weighting (IDW) is a type of deterministic method for multivariate interpolation with a known scattered set of points

$$z(x,y)=\sum_{i=1}^{n}\lambda_i z(x_i,y_i)$$

- n = number of points
- x_i e y_i = coordinates stations
- λ_i = point weight

$$\sum_{i=1}^{n}\lambda_i=1$$

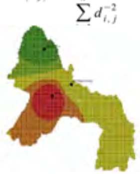
- The most used weight is the inverse of the distance squared

$$z(x_j)=\frac{\sum_{i=1}^{n} z(x_i)d_{i,j}^{-2}}{\sum_{i}^{n} d_{i,j}^{-2}}$$

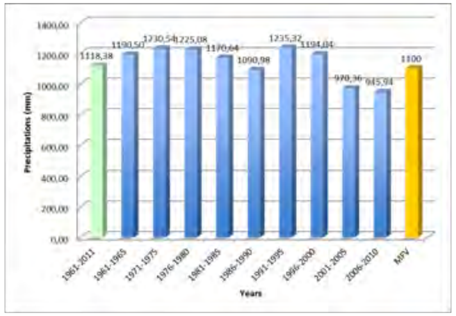
From values to the three stations

- JNIA = 1132,39 mm
- WAZOHILL = 909,87 mm
- OCEAN ROAD = 1025,56 mm

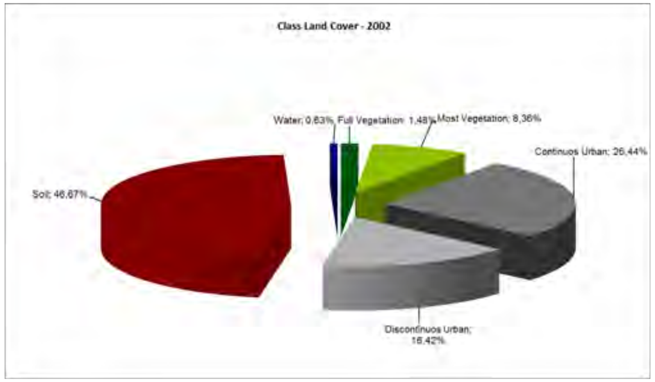
To spatial data for all points



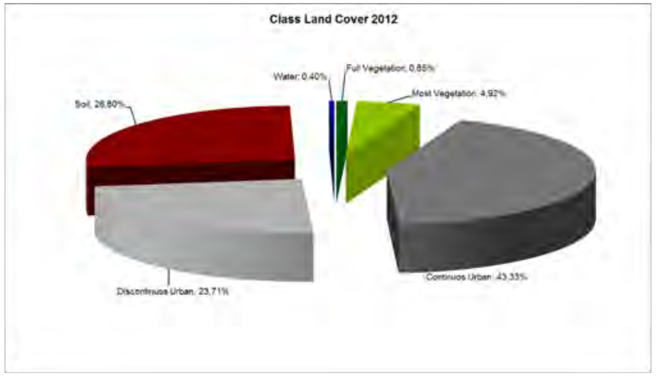
Evolution of precipitations in the 1961-2010 period



Land cover distribution in 2002



Land cover distribution in 2012

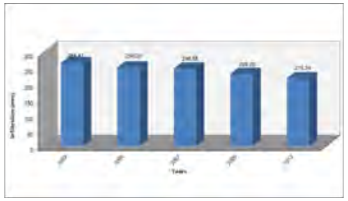


Potential Infiltration Factor values, given to the different land cover class

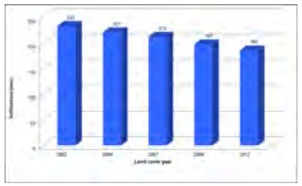
Land Cover Class	Potential Infiltration Factor
Full Vegetation	0,3
Most Vegetation	0,4
Continuos Urban	0,1
Discontinuos Urban	0,2
Soil	0,3
Water	0,6

Infiltration evolution depending on:

- different land covering using the MFV of precipitations

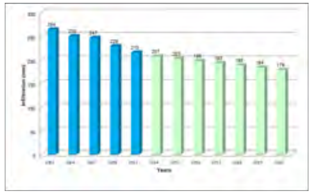


- different land cover distributions referred to the APAV



Infiltration trend for the future with the MFPV and the land cover distribution trend of the last ten years

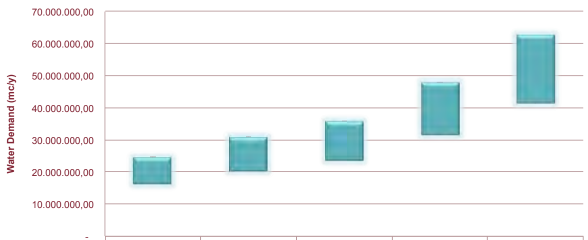
Infiltration trend until 2020 applying the evolution of the last ten years



Groundwater Active Recharge evolution following the trend of the last ten years applying the MFPV

Groundwater Active Recharge evolution until following the trend of the last ten years

Water Demand Evolution



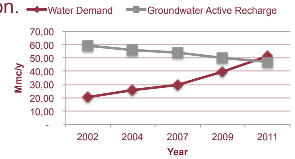
	2002	2004	2007	2009	2011
Scenario A WDPC02	16.413.024,37	20.518.252,57	23.696.317,94	31.604.401,91	41.226.906,04
Scenario A WDPC02	18.579.417,81	23.255.769,54	26.914.257,95	35.954.251,09	46.920.778,47
Scenario B WDPC01	21.884.032,49	27.357.670,09	31.595.090,58	42.139.202,55	54.969.208,05
Scenario B WDPC02	24.772.557,08	31.007.692,72	35.885.677,26	47.939.001,45	62.561.037,96

Conclusions and reccomendations

- The areas where seawater intrusion may become priorities for vulnerability assessment and adaptation action implementation, and they are:
  - Kunduchi and Kawe wards, in the north;
  - Ubungo, Mabibo,Manzese,Tandale,Ndugumbi and Makurumula in the centre;
  - Msasani on the eastern coast;
  - Keko and Miburaniin the south.
  - Yombo Vituka e Kurasini, in the south
- The comparison between historical piezometric data and those from the 2012 surveys showed an important lowering widespread throughout the study area and locally related to the effect of seawater intrusion, because of the enlarging of the transition zone in the coastal areas.

Conclusions and reccomendations

- The evolution of Active Groundwater Recharge, the temporal analysis of climatic and land cover data for the last ten years allowed to define a decreasing trend in the groundwater availability;
- The increase in the estimated groundwater withdrawal point out that unplanned and uncontrolled groundwater exploitation is a significant factor of hydrogeological imbalance, which can be related to a general increase of the aquifer sensitivity to seawater intrusion phenomenon.



Conclusions and reccomendations

- For a detailed understanding of the seawater intrusion dynamics and a more accurate correlation with environmental and anthropogenic causes, it would be desirable a rigorous monitoring activity of all the levels constituting the multilayer coastal aquifer, through the use of well-made boreholes with known technical features and available for deep measurements.
- it could be useful for the local institutions to take in account the arrangement of some monitoring points for the zones identified as the highest sensitive ones, consisting of well executed wells with separate screens on each aquifer levels. This would enable to register in continuous the logs of some of the most important parameters characterizing the groundwater evolution, like SWL, EC, T, TDS, pH, Cl.