ACC DAR Adapting to Climate Change in Coastal Dar es Salaam

International Workshop

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

ANALYSIS OF DAR ES SALAAM COASTAL AQUIFER SENSITIVITY TO SEAWATER INTRUSION WITH REGARD TO CLIMATE CHANGE (first results)

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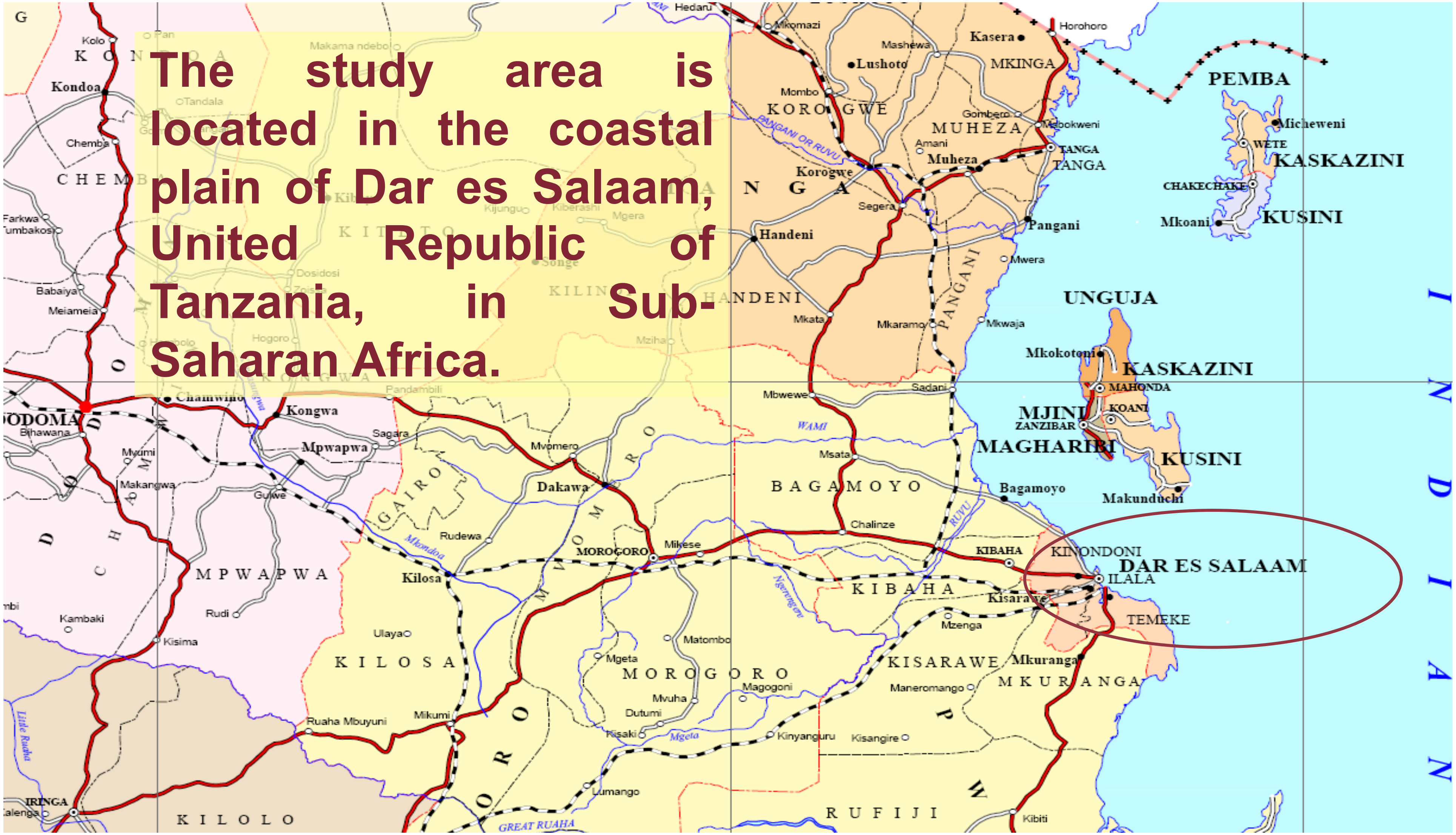
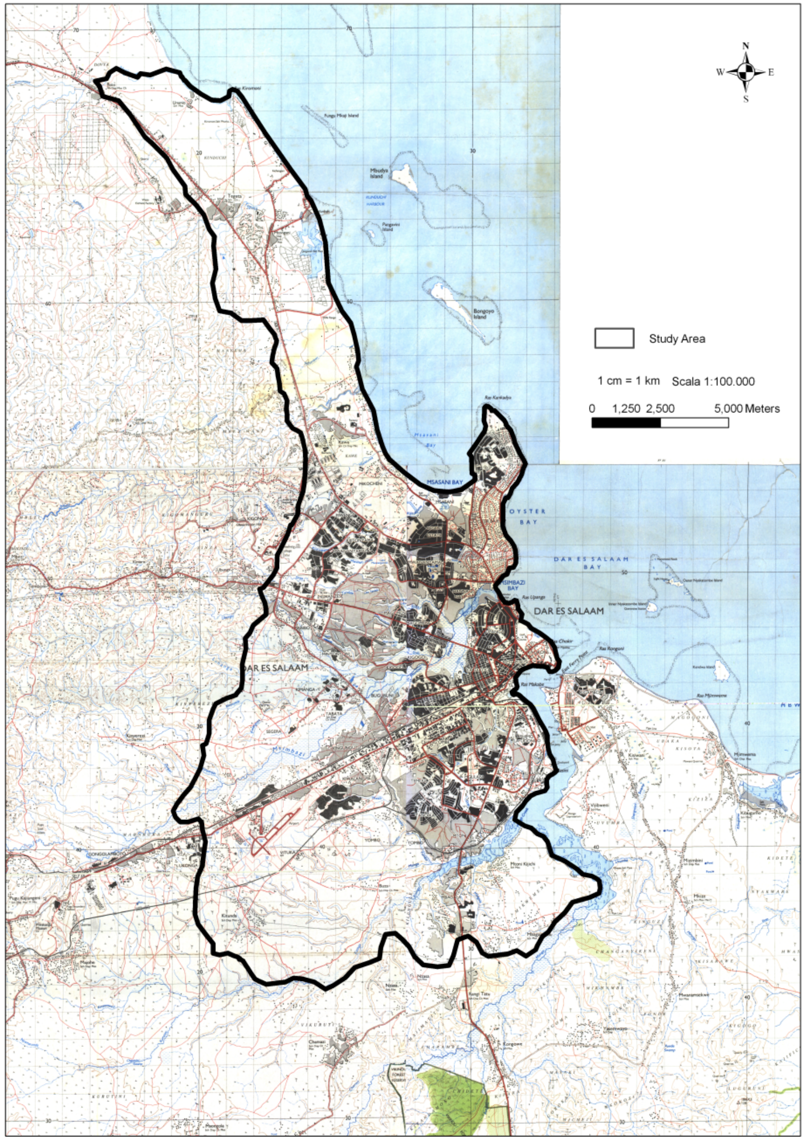
Description of the study area= The site

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).

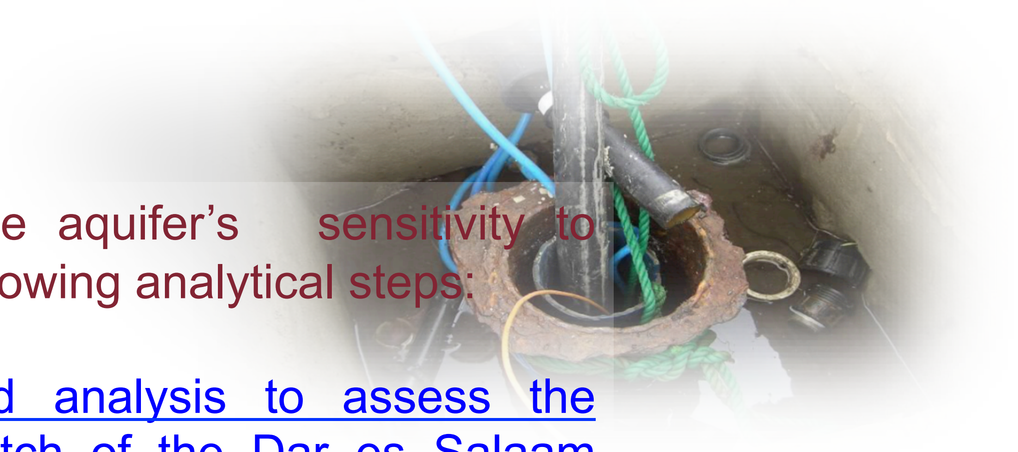
Overall Approach

- 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



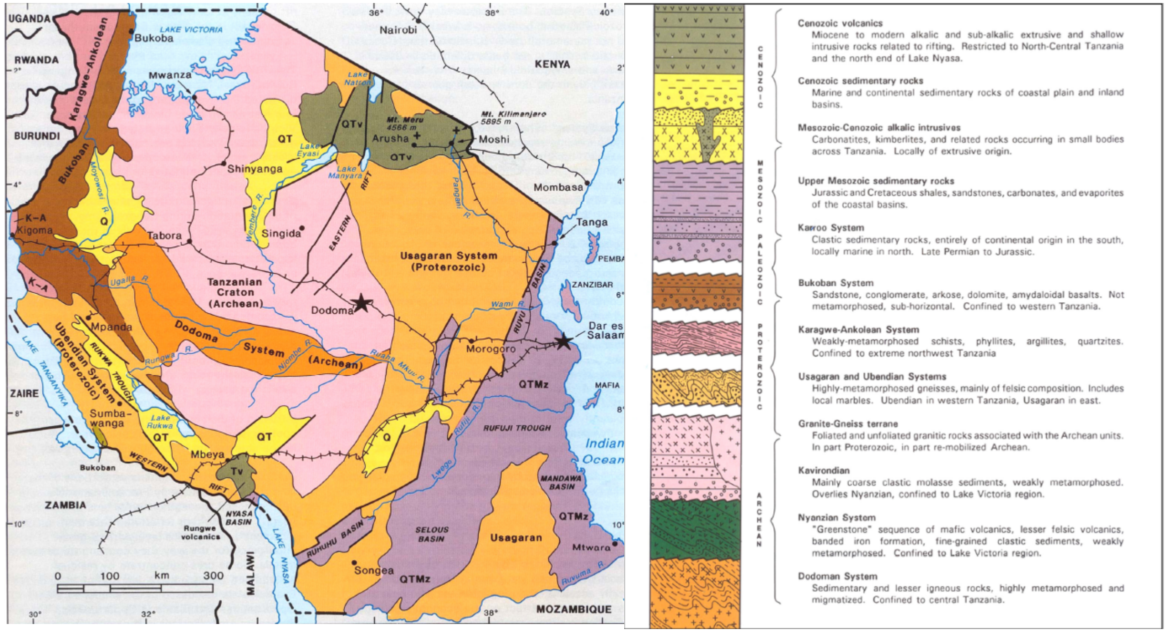
The methodology for assessing the aquifer's sensitivity to seawater intrusion consists of the following analytical steps:

- 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 hudrogeological 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)

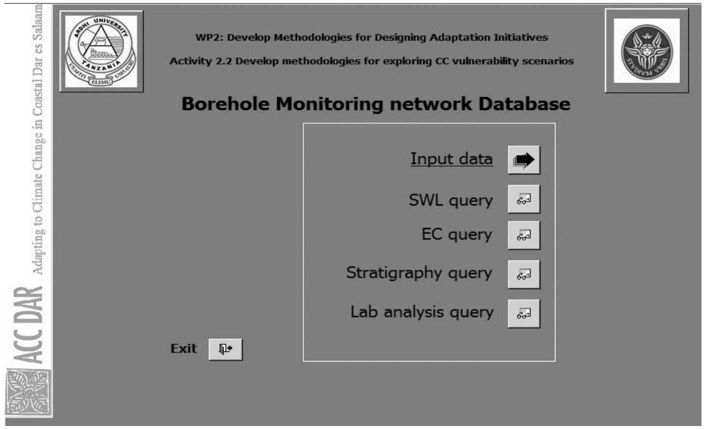
AQUIFER	PERIOD	EPOCH	LITHOLOGY
Unconfined	Quaternary	Pleistocene to recent	Fine sand to medium sand with silts and clay, coral reef limestone and calcareous, alluvial clay, silts and gravels
Aquitard	Quaternary	Pleistocene to recent	Clay, sandy clay (clay)
Semiconfined Aquifer	Quaternary	Pleistocene 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

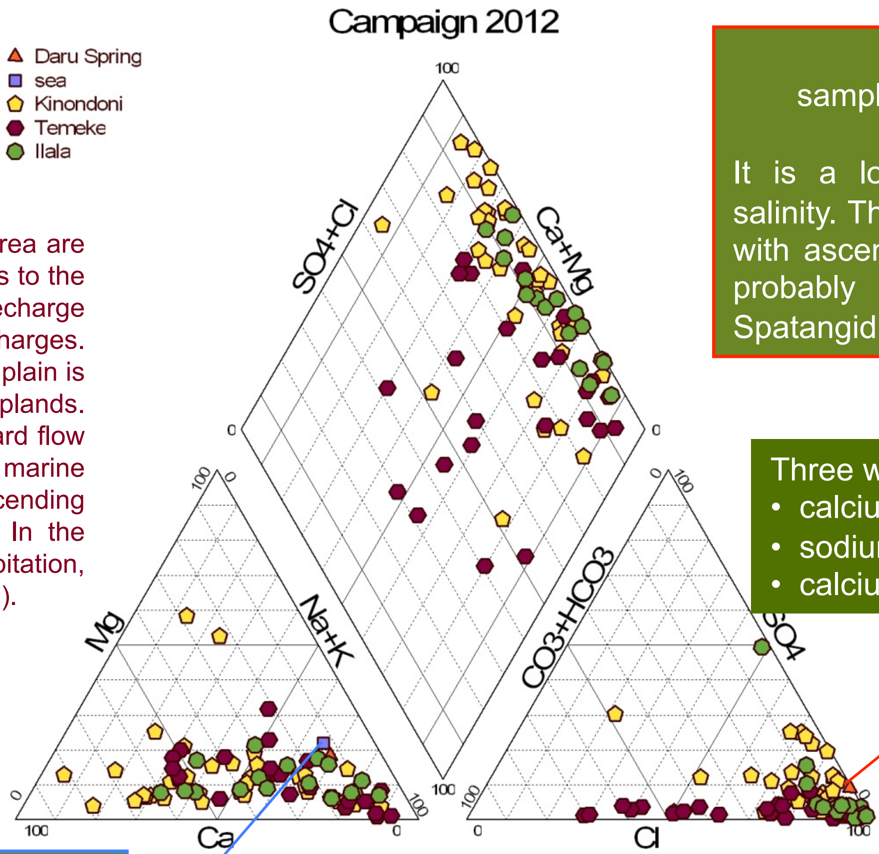
Hydrochemical Framework

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).

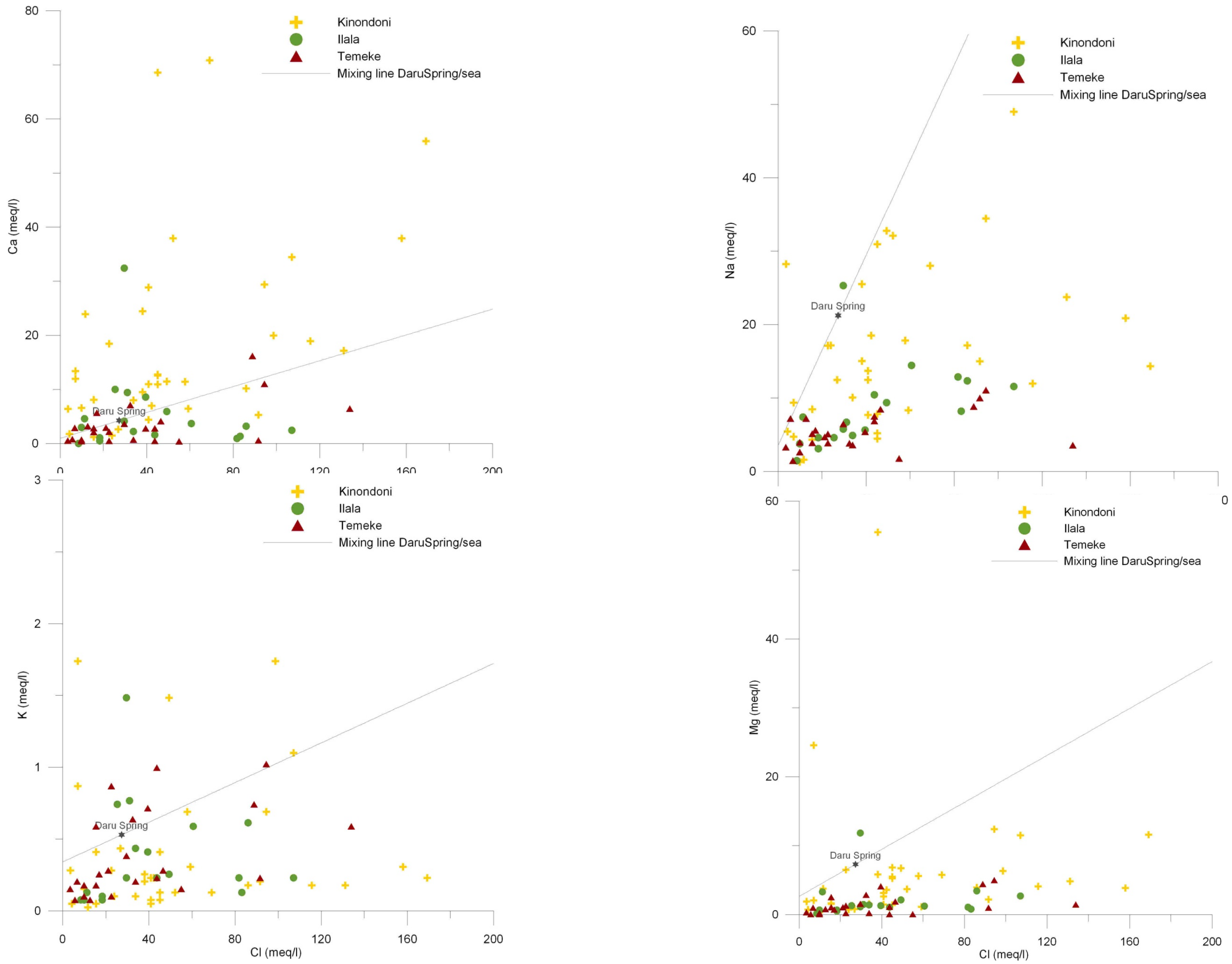
Three water types:

- calcium chloride-sulphate type;
- sodium-chloride one;
- calcium –bicarbonate type .

Second end member:

sample of the Indian Ocean (june 2012)

Cross plot Cl-Y



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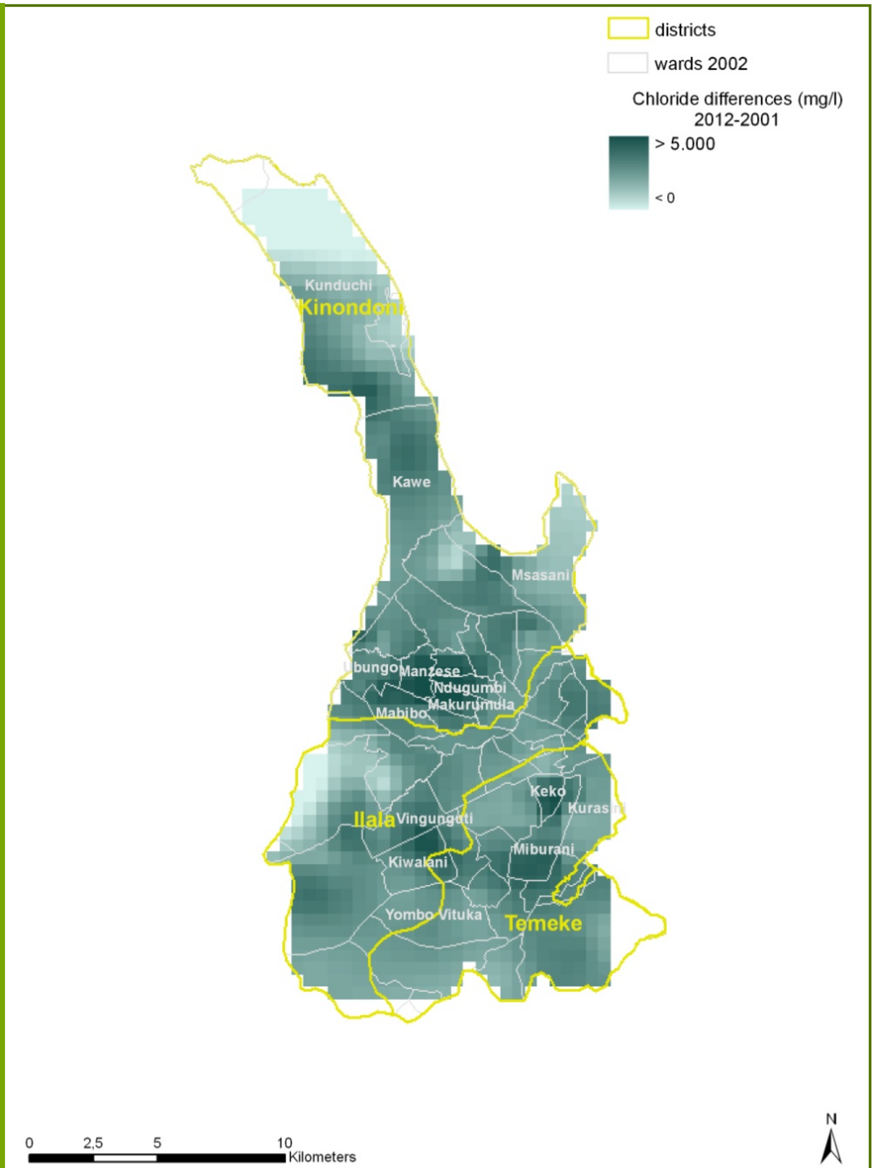
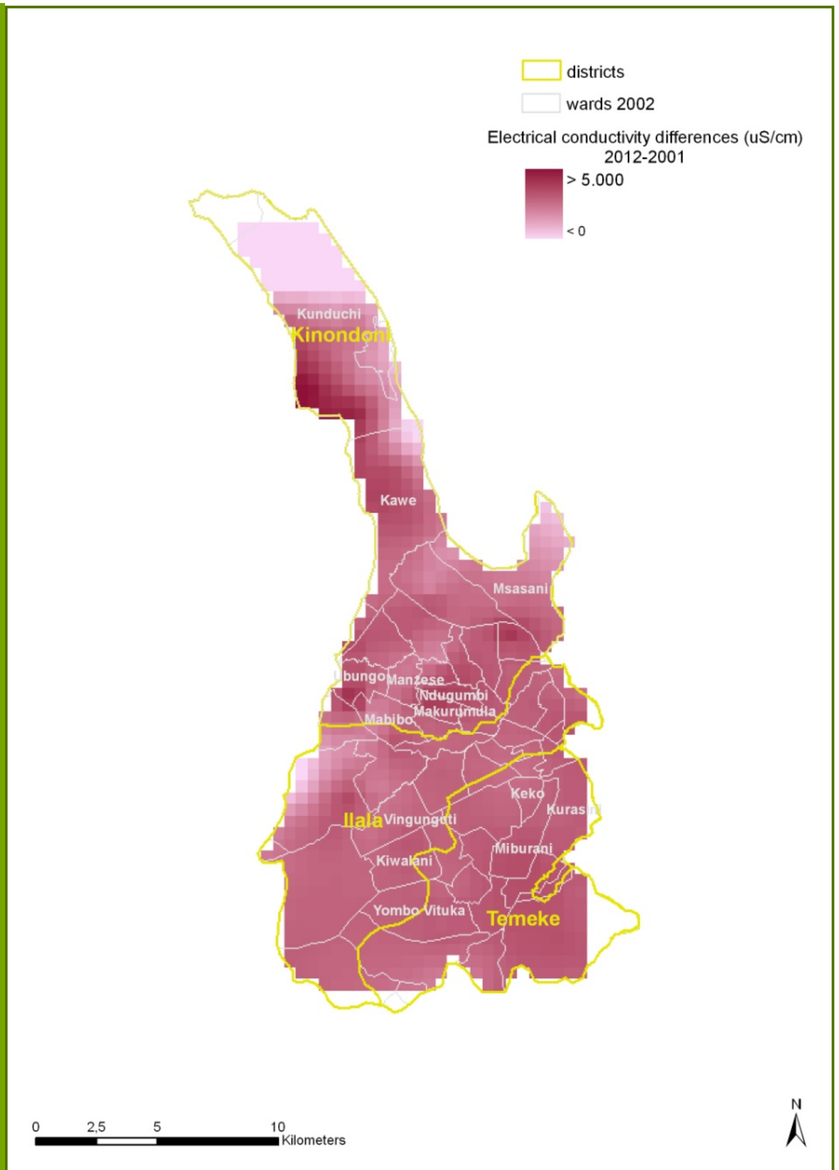
Chloride differences



Electrical conductivity differences



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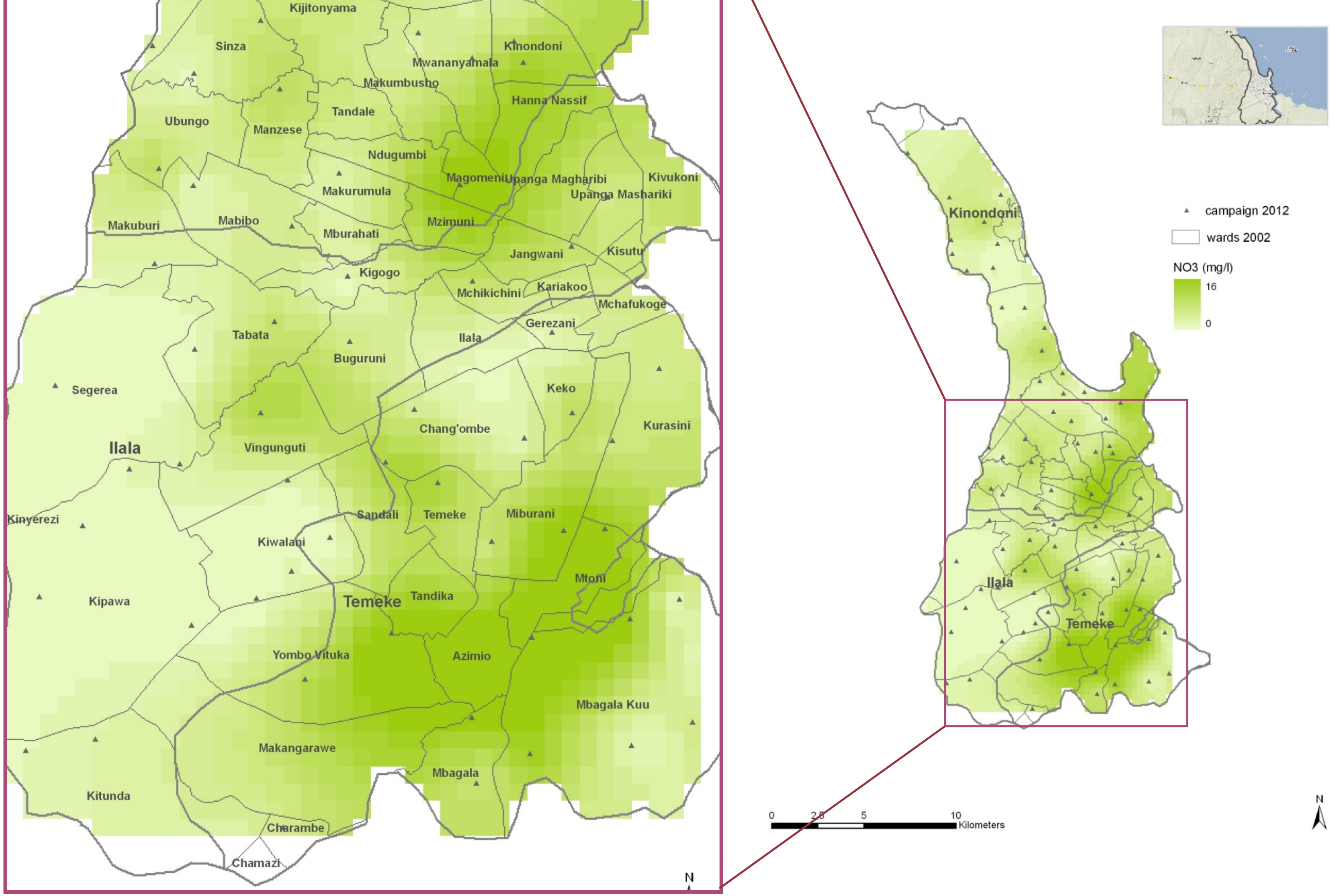
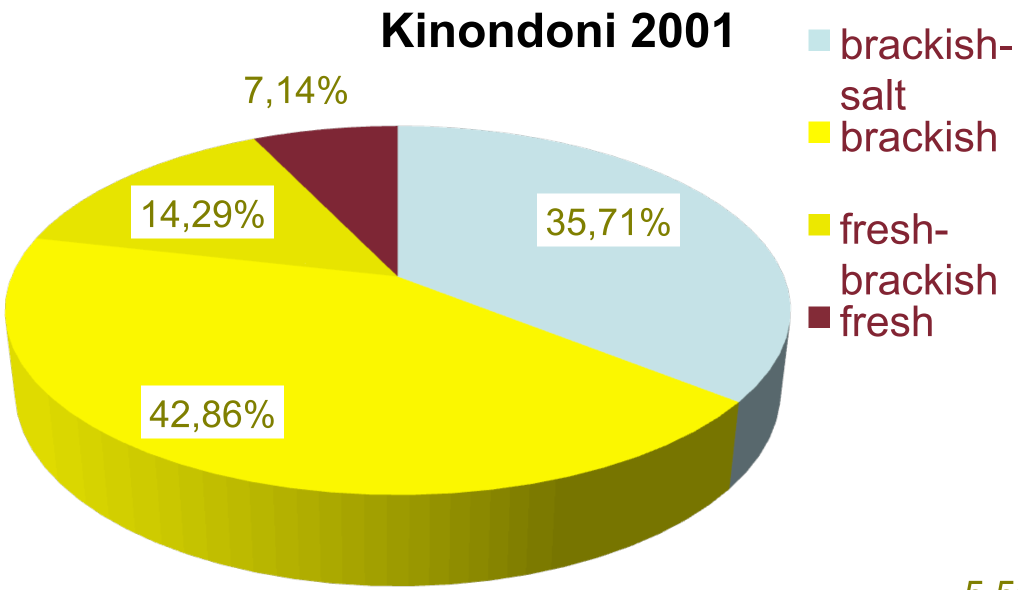


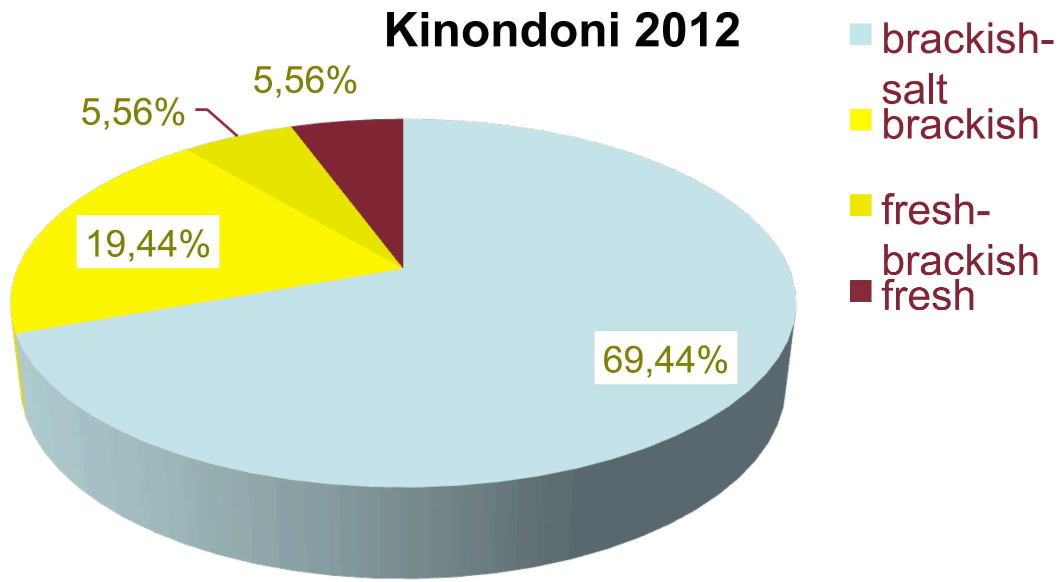
Kawe
Mikocheni
Msasani
Kijitonyama
Sinza
Kinondoni
Mwananyamala
Makumbusho
Hanna Nassif
Tandale
Ubungo
Manzese
Ndugumbi
Magomeni
Upanga Magharibi
Kivukoni
Upanga Mashariki
Makurumula
Makuburi
Mabibo
Mzimuni
Mburahati
Jangwani
Kisutu
Kigogo
Mchikichini
Kariakoo
Mchafukoge
Gerezani
Tabata
Ilala
Buguruni
Segerea
Keko
Chang'ombe
Kurasini
Ilala
Vingunguti
Kinyerezi
Sandali
Temeke
Miburani
Kiwalani
Mtoni
Kipawa
Temeke
Tandika
Yombo Vituka
Azimio
Mbagala Kuu
Makangarawe
Mbagala
Kitunda
Charambe
Chamazi
N
Kinondoni
Ilala
Temeke
campaign 2012
wards 2002
NO3 (mg/l)
16
0
0 2.5 5 10 Kilometers
N

Stuyfzand Classification (1993)

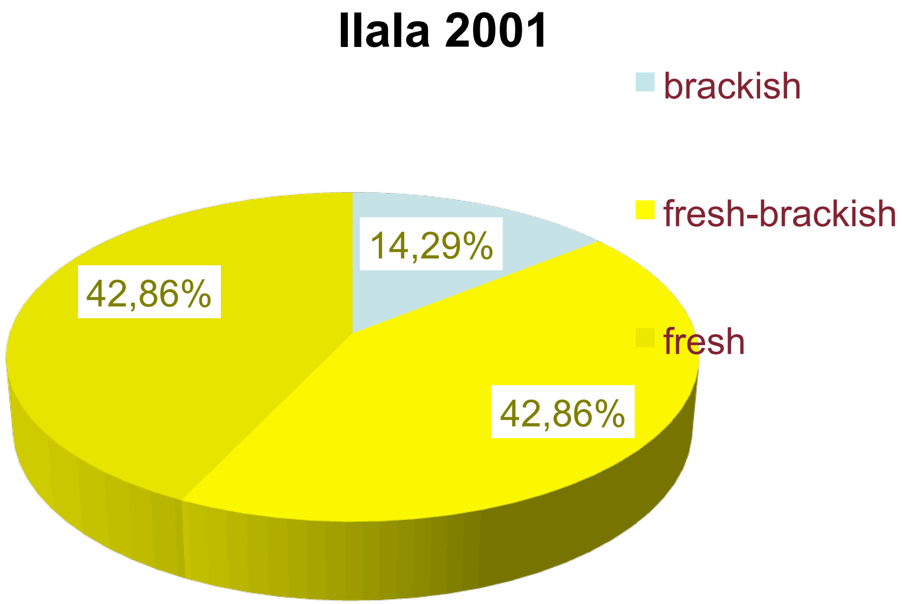
Main type	Stuyf. code	Cl^- (mg/l)
very oligohaline	G	< 5
oligohaline	g	5 - 30
fresh	F	30 - 150
fresh-brackish	f	150 - 300
brackish	B	300 - 1000
brackish-salt	b	1000 - 10000
salt	S	10000 - 20000
hyperhaline	H	> 20000

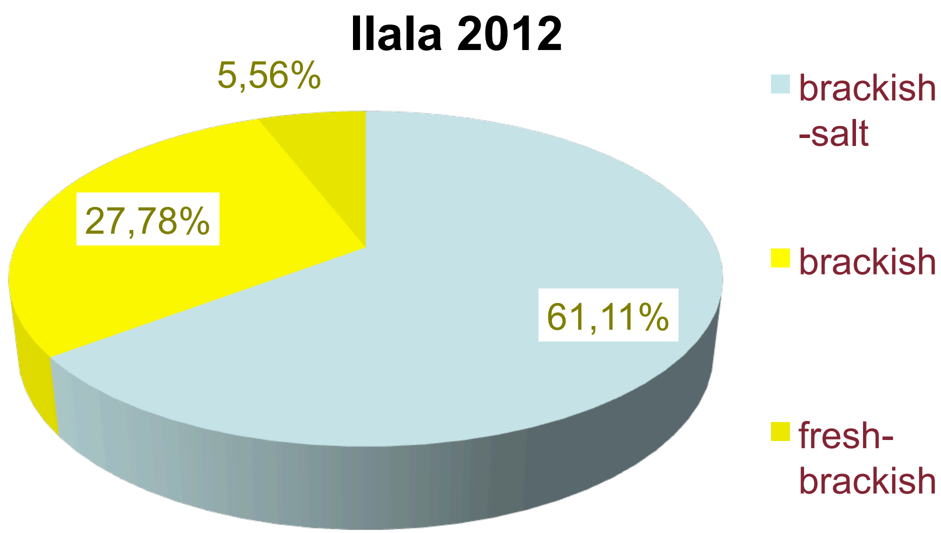
Stuyzand classification evolution



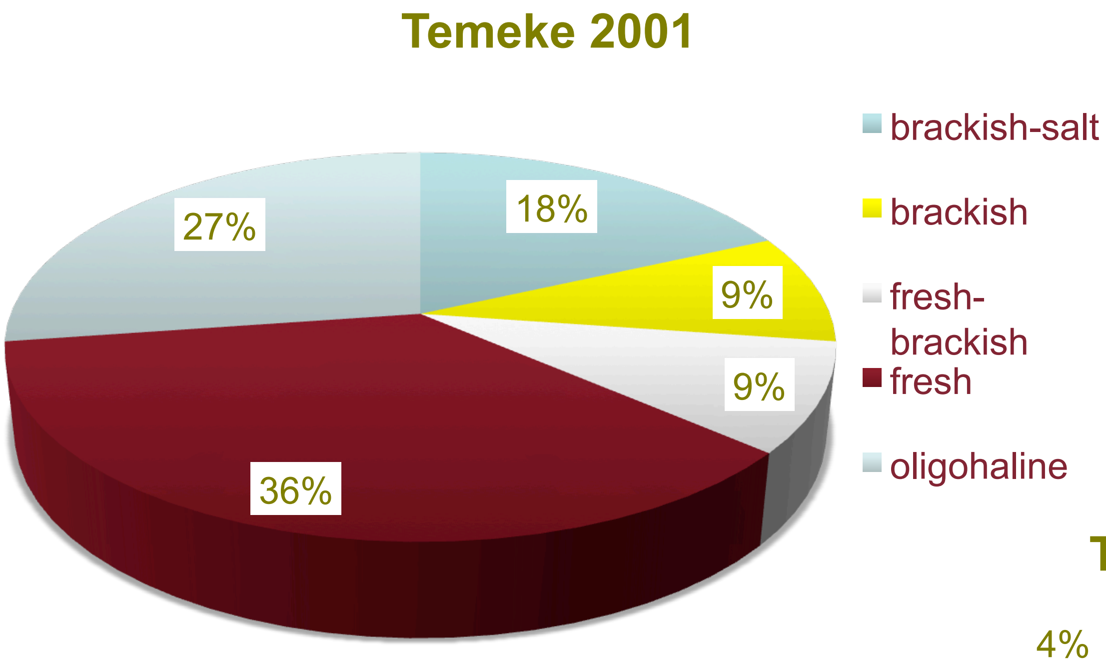


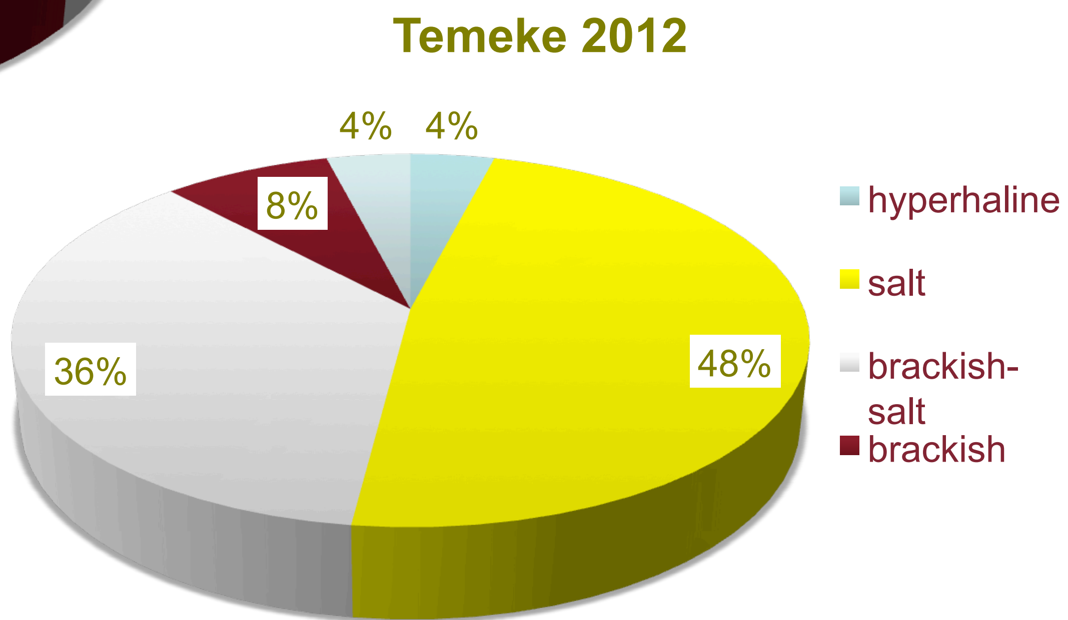
Stuyzand classification evolution



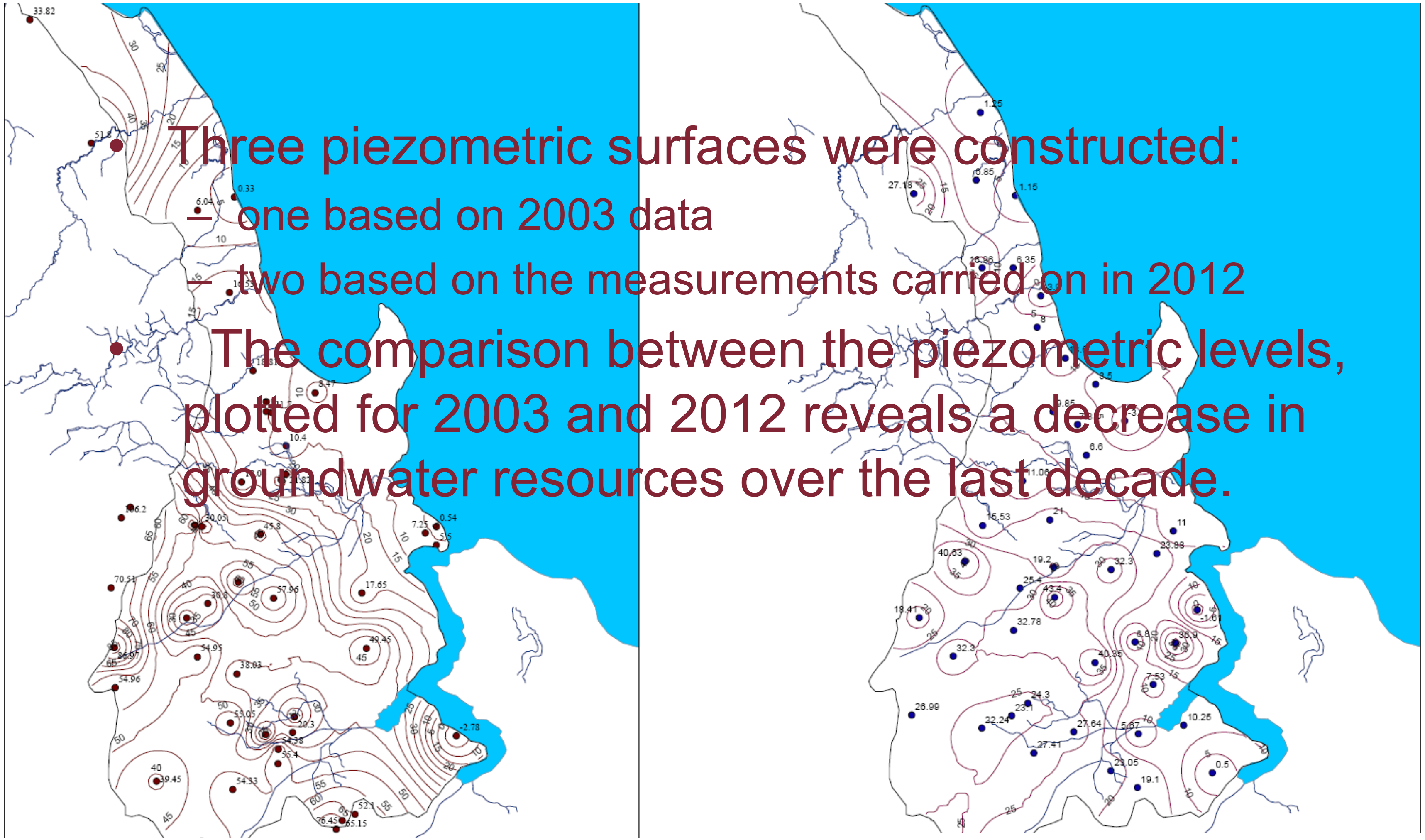


Stuyzand classification evolution





Hystorical evolution of groundwater table



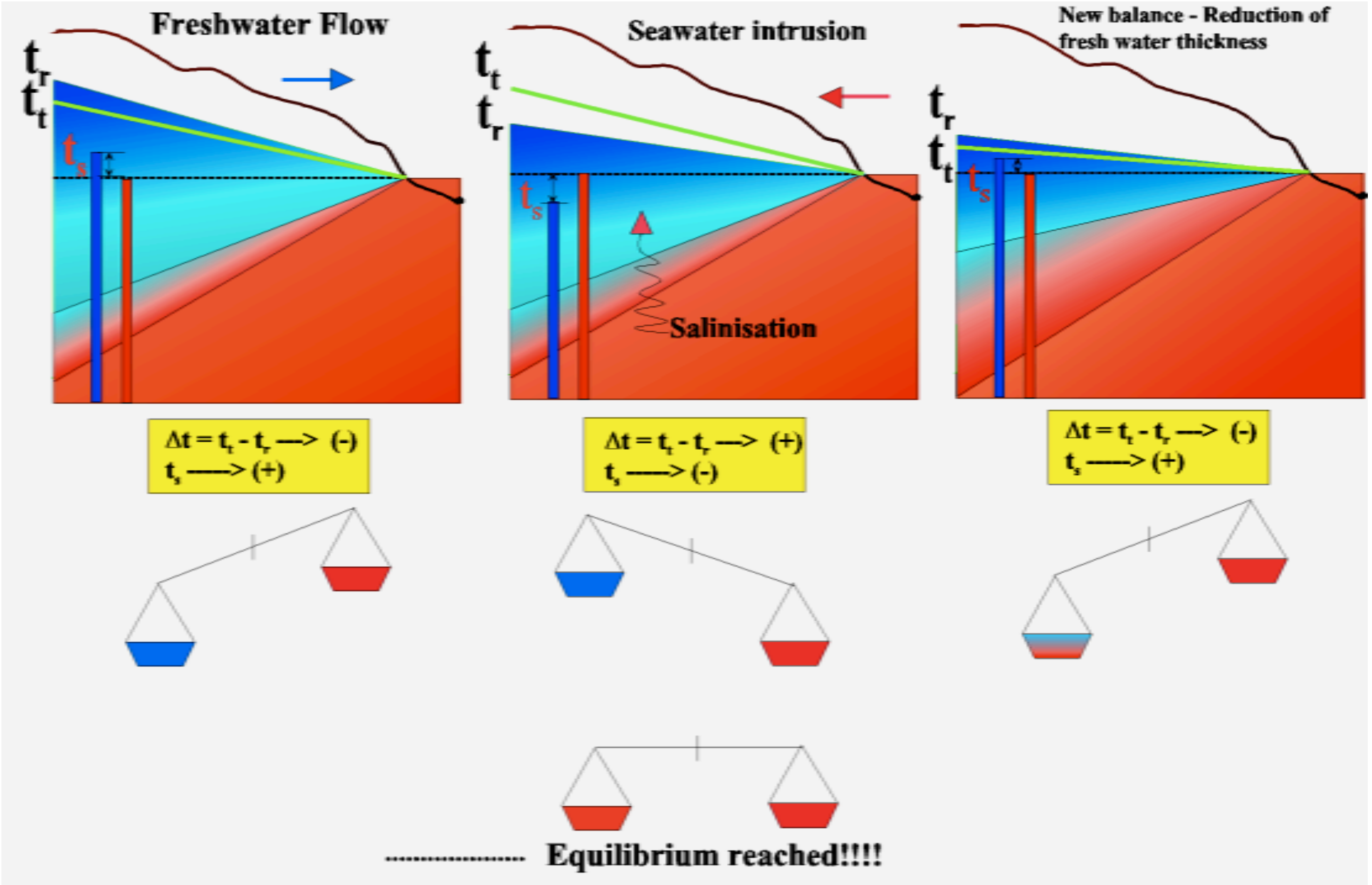
- Three piezometric surfaces were constructed:
  - one based on 2003 data
  - two based on the measurements carried on in 2012
- The comparison between the piezometric levels, plotted for 2003 and 2012 reveals a decrease in groundwater resources over the last decade.

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.

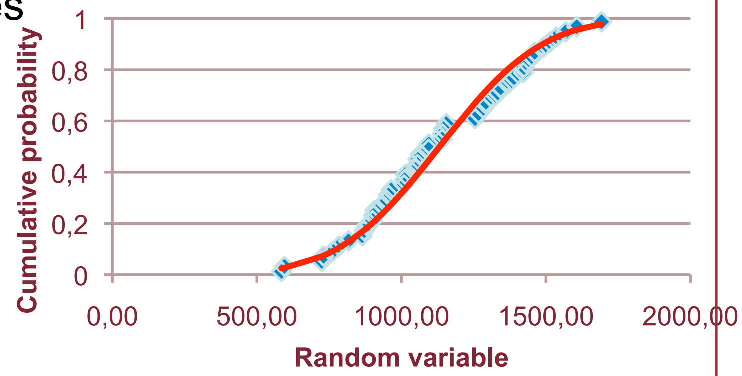
- Calcute average value and standard

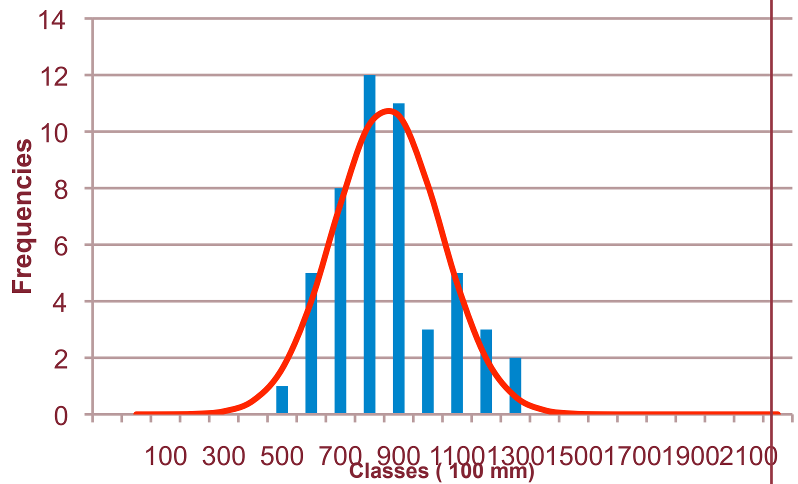
deviation

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

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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

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

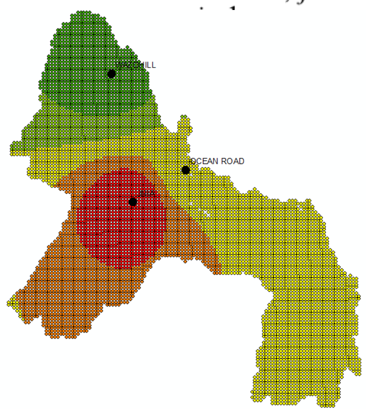
- The most used weight is the inverse of the distance squared

$$z(\underline{x}_j)=\frac{\sum_{i=1}^{n} z(\underline{x}_i)\,d_{i,j}^{-2}}{\sum_{i=1}^{n} d_{i,j}^{-2}}$$

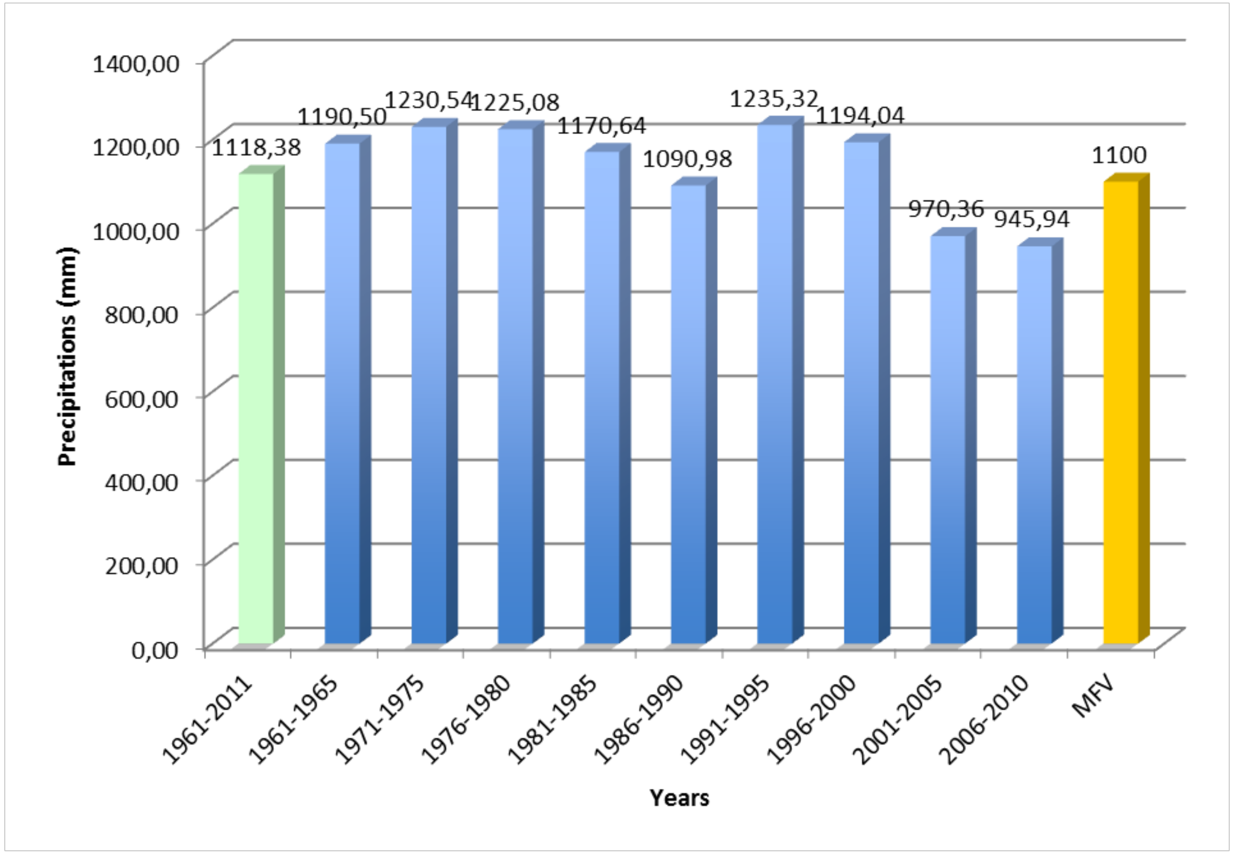
From values to the three stations

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

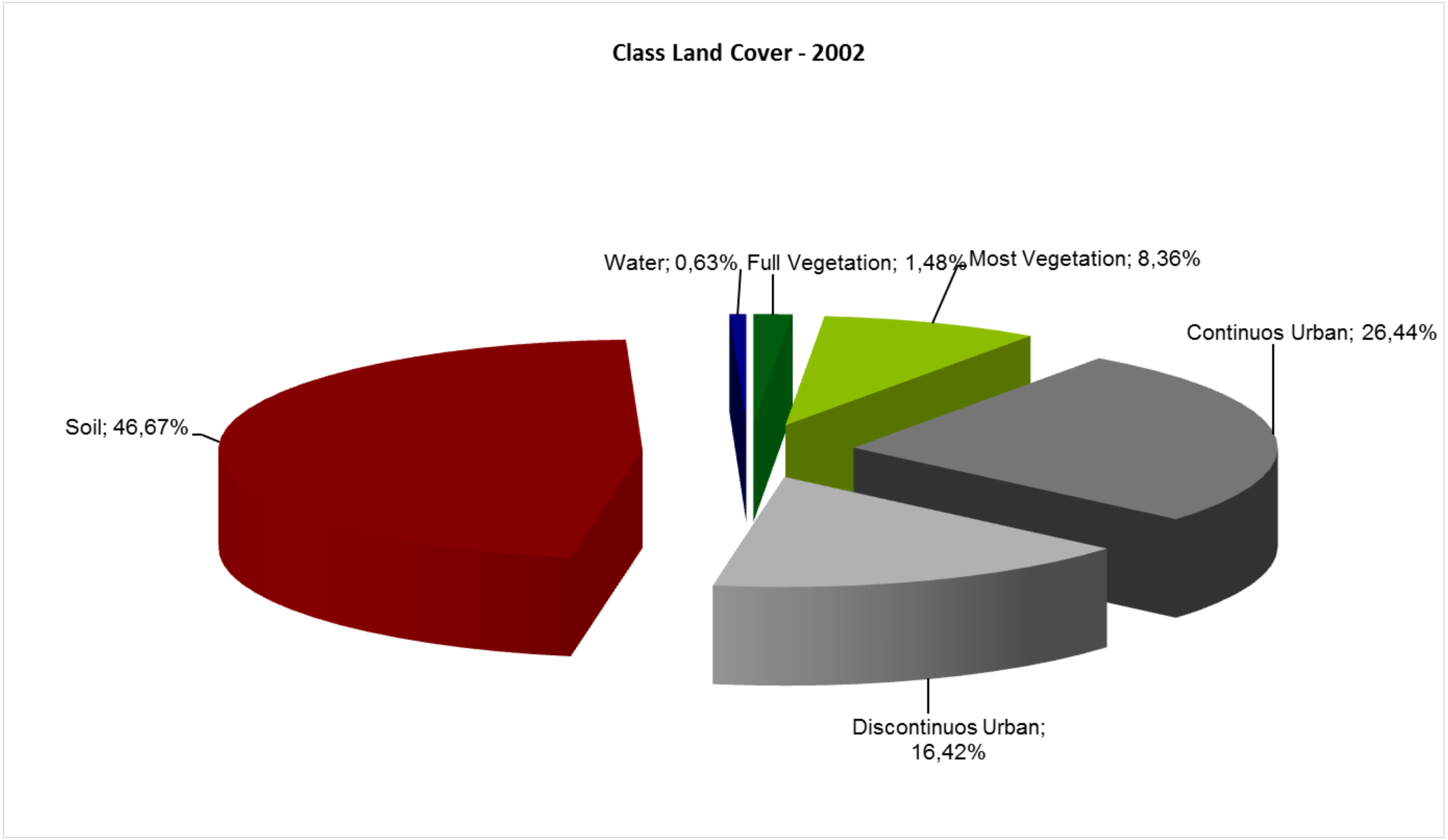
To spatial data for all points



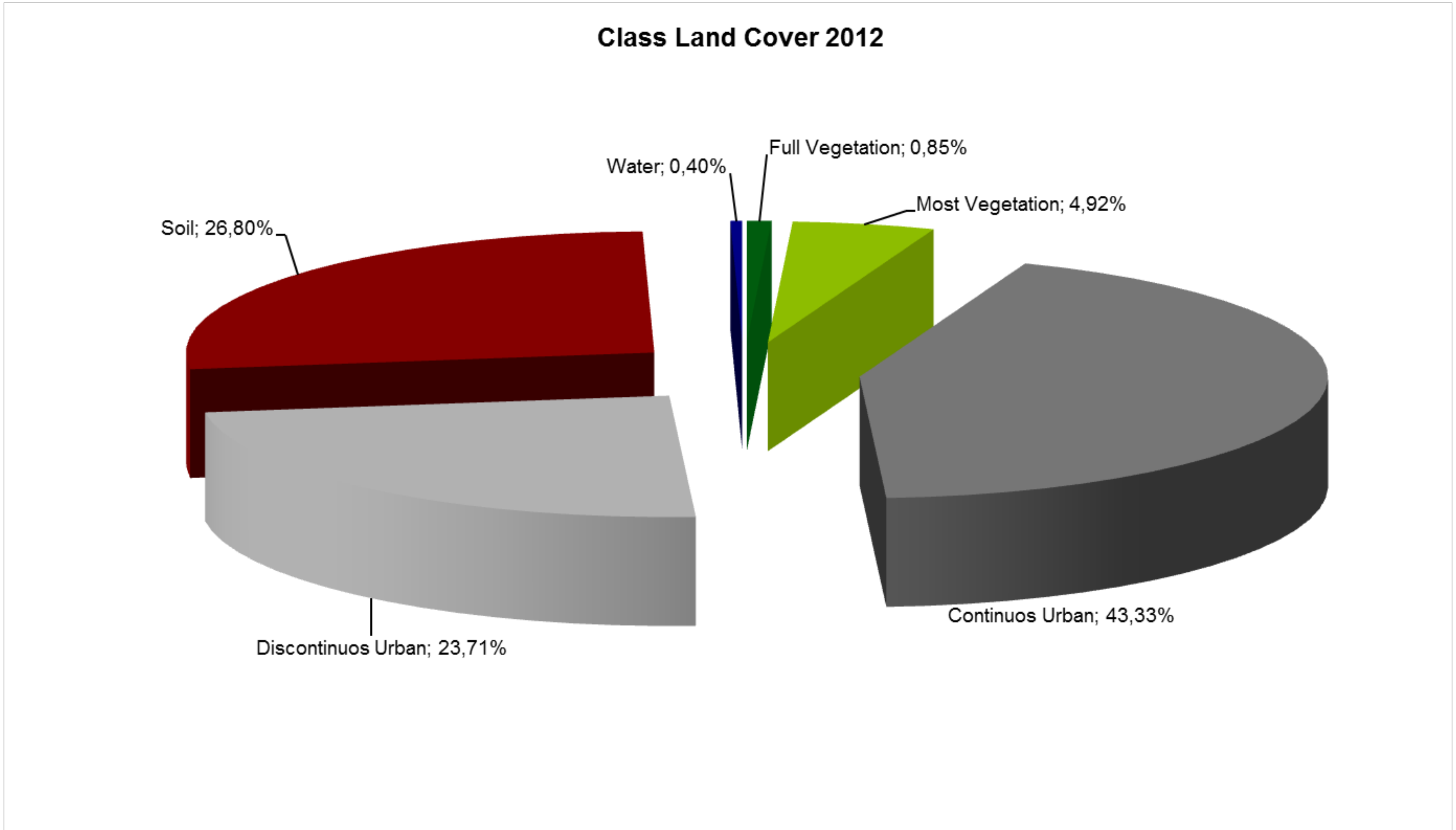
Evolution of precipitations in the 1961-2010 period



Land cover distribution in 2002



Land cover distribution in 2012

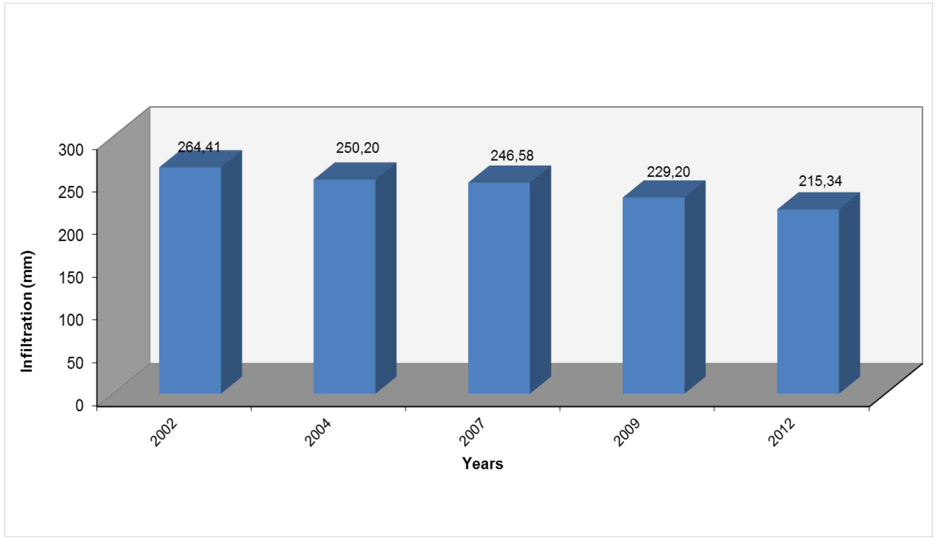


Potential Infiltration Factor values, given to the different land cover class

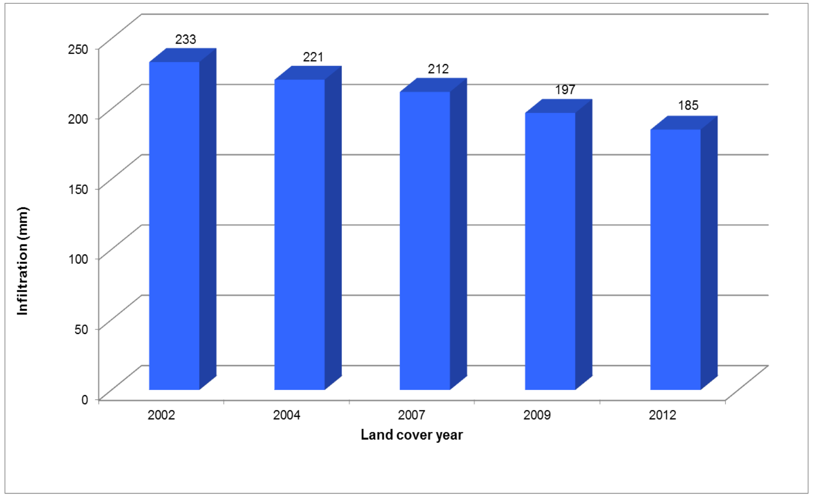
Land Cover Class	Potential Infiltration Factor
Full Vegetation	0,3
Most Vegetation	0,4
Continuos Urban	0,1
Discontinuos Urban	0,2
Soil	0,3
Water	0,6

Infiltration evolution depending on:

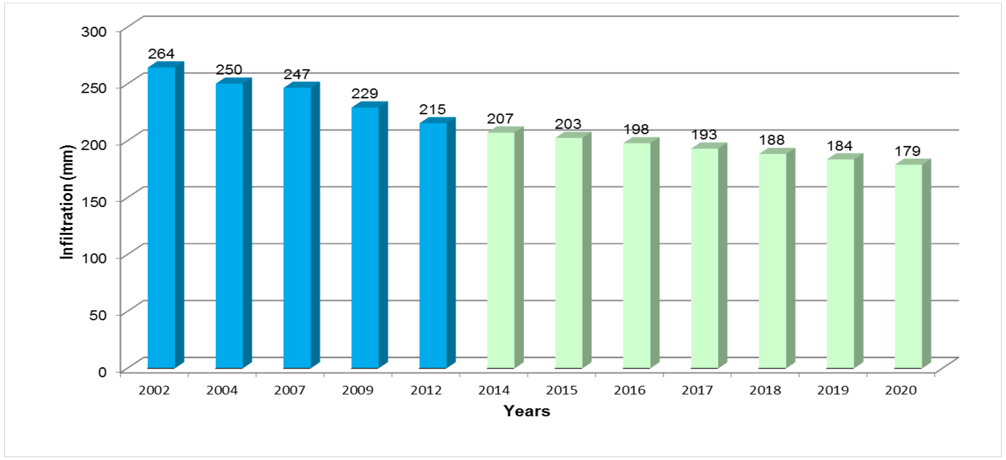
- different land covering using the MFV of precipitations



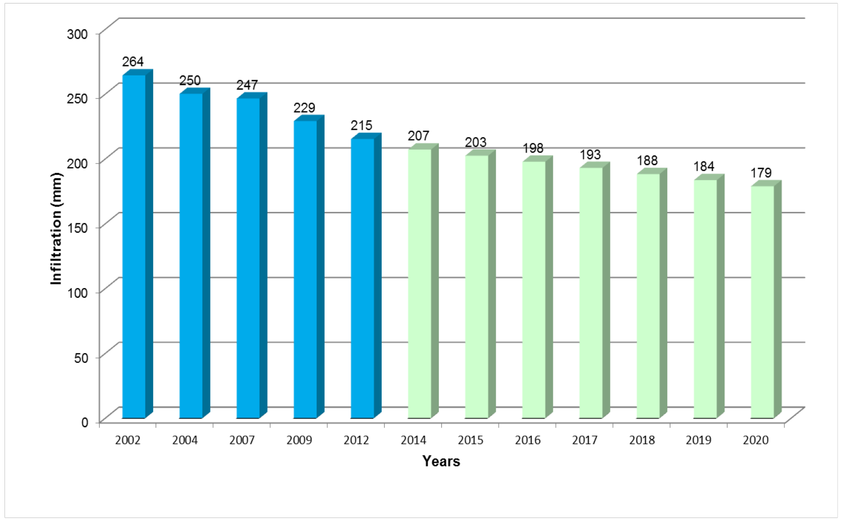
- different land cover distributions referred to the APAV



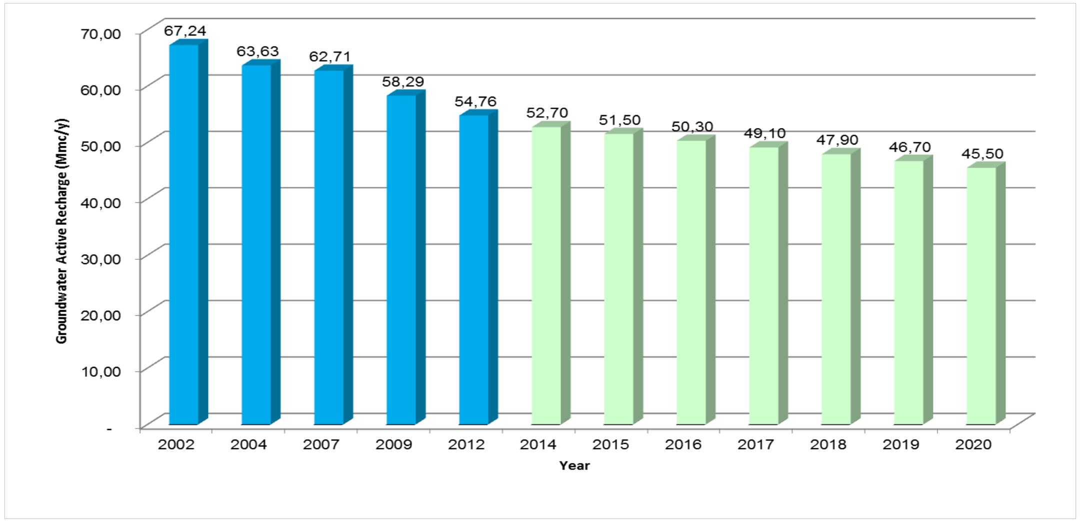
Infiltration trend for the future with the MFPV and the land cover distribution trend of the last ten years



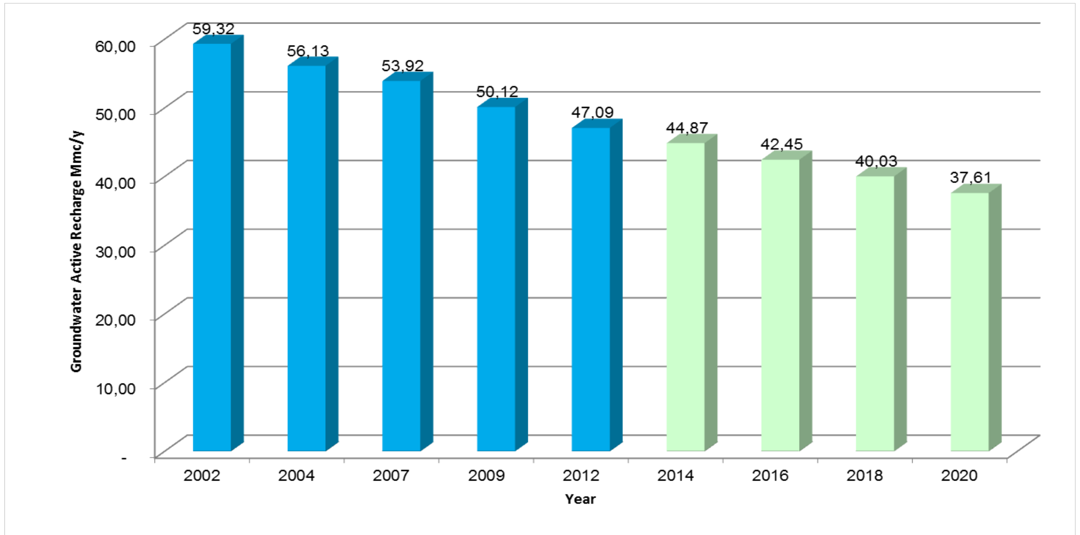
Infiltration trend until 2020 applying the evolution of the last ten years



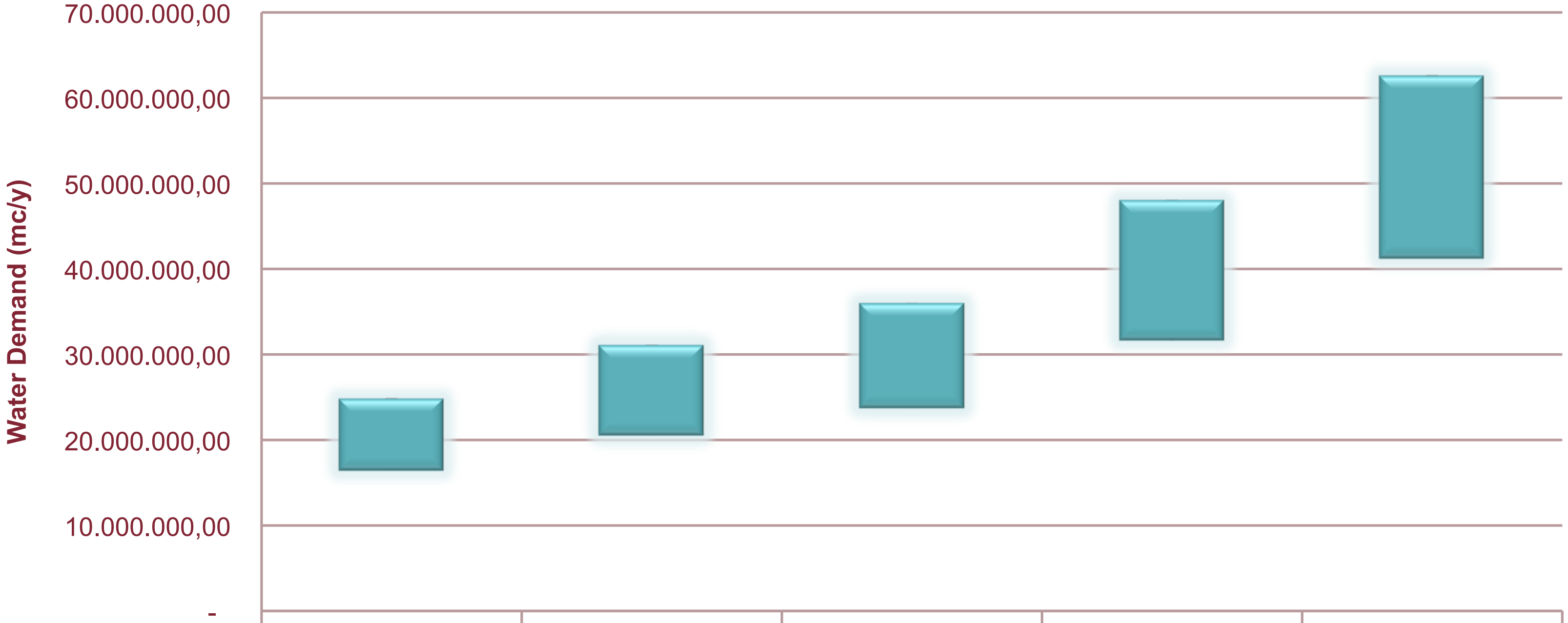
Groundwater Active Recharge evolution following the trend of the last ten years applying the MFPV



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



Water Demand Evolution



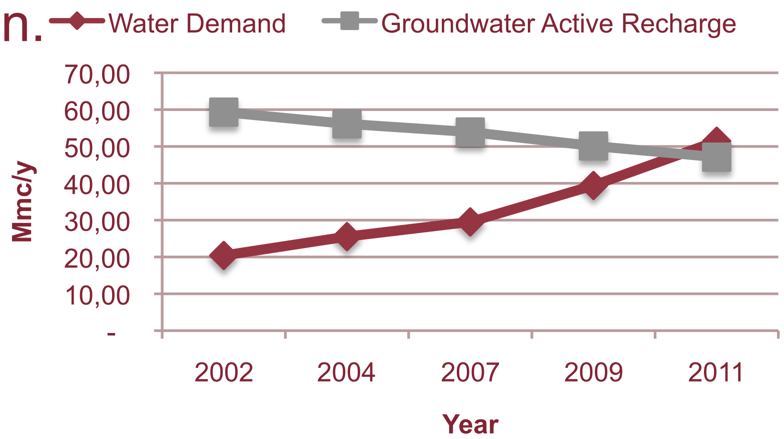
	2002	2004	2007	2009	2011
Scenario A WDPC02	16.413.024,37	20.518.252,57	23.696.317,94	31.604.401,91	41.226.906,04
Scenario A WDPC02	18.579.417,81	23.255.769,54	26.914.257,95	35.954.251,09	46.920.778,47
Scenario B WDPC01	21.884.032,49	27.357.670,09	31.595.090,58	42.139.202,55	54.969.208,05
Scenario B WDPC02	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 also 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.