ACC DAR Adapting to Climate Change in Coastal Dar es Salaam

SAPIENZA UNIVERSITÀ DI ROMA

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International Workshop

Mainstreaming climate change adaptation into urban development and environmental management plans and programs

# GROUNDWATER MANAGEMENT IN DAR ES SALAAM COASTAL AQUIFER UNDER CLIMATE CHANGE PRESSURE

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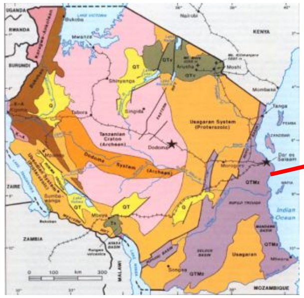
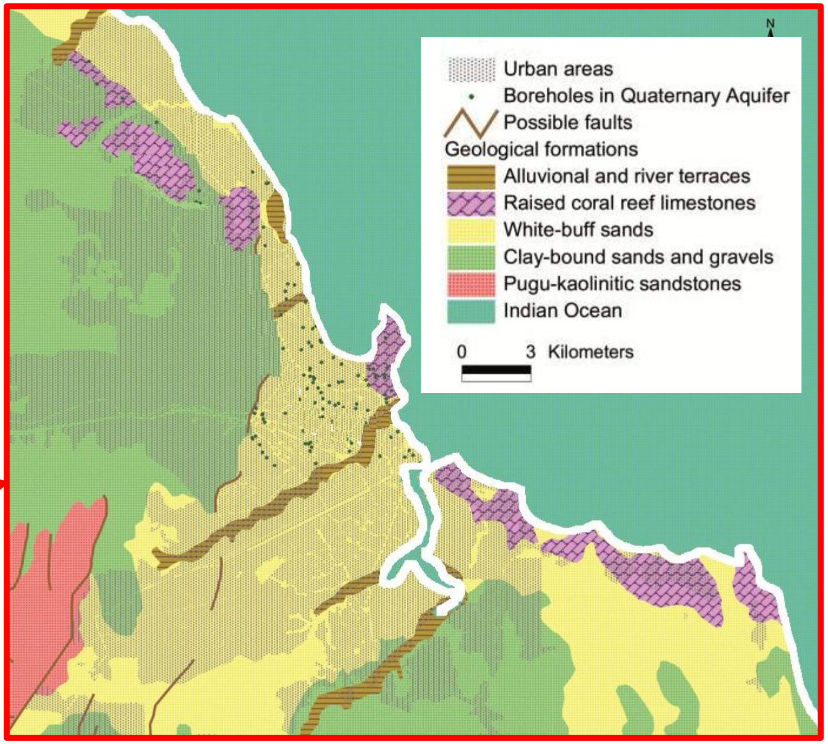
# Geological framework

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 include coral reef limestone, nearer the coast.



Geology of Tanzania

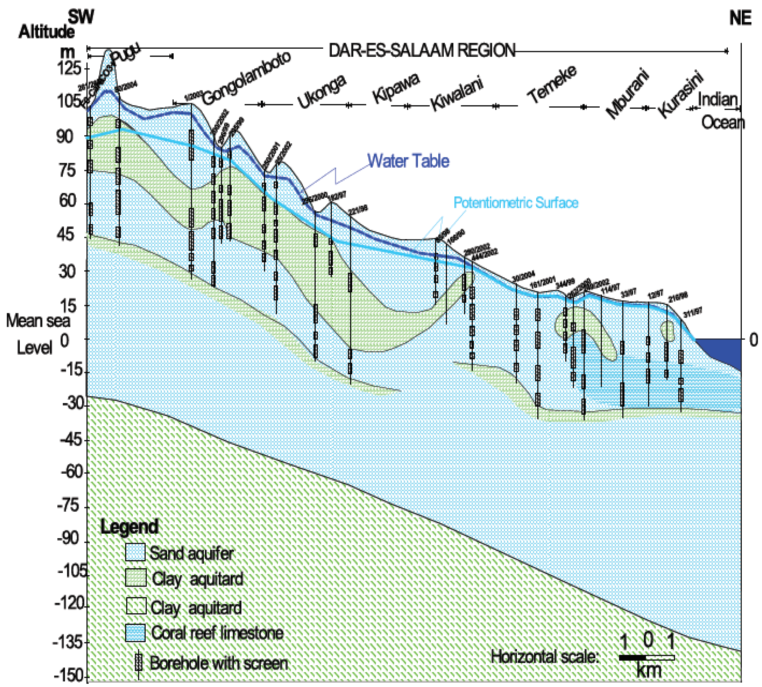


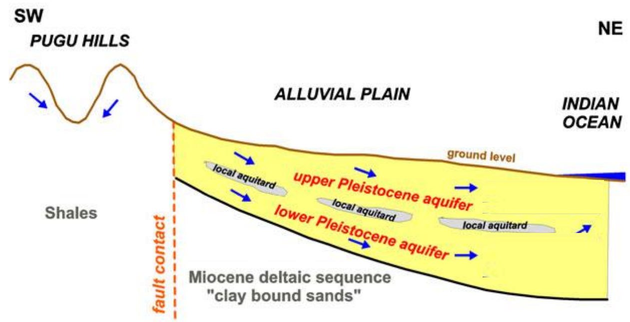

Geology of Dar Es Salaam

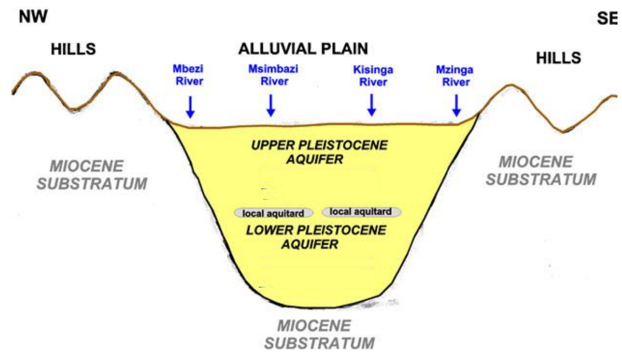
Formations outcropping in the study area:

- White buff sands and gravel
- Alluvional and river terraces
- Raised coral reef limestones
- Clay-bound sands and gravels

# Hydrogeological framework



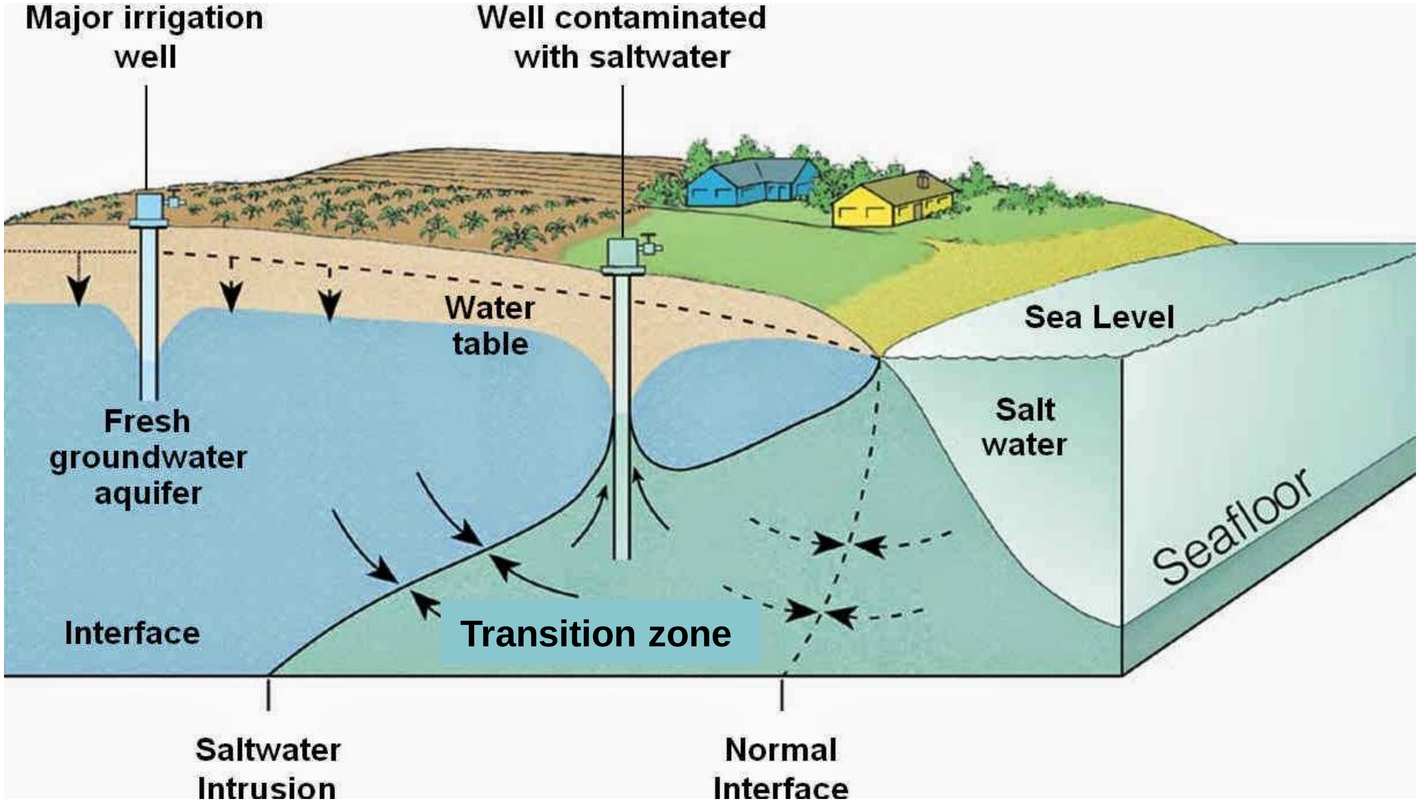




The groundwater reservoir is located within the coastal plain **in the quaternary sediments.**
**It is made of two main aquifers,** an upper unconfined sand aquifer and a lower semi-confined sand aquifer, separated by a clay aquitard.
**The sediment type for both aquifers is almost the same.**
In the area closest to the ocean where the clay layers are particularly fragmented the two aquifers are most interconnected.

| MULTI-LAYERED AQUIFER | PERIOD, EPOCH | LITHOLOGY | THICKNESS |
|---|---|---|---|
| **Unconfined** | Quaternary, Pleistocene to recent | Fine to medium sand with silts and clay, coral reef limestone and calcareous, alluvial clay, silts and gravels | 5 – 50 m |
| **Aquitard** | Quaternary, Pleistocene to recent | Clay, sandy clay | 10 – 50 m |
| **Semiconfined** | Quaternary, Pleistocene to recent | Medium to Coarse sand and gravels with clay | 100 m |
| **Aquitard** | Neogene, Mio-pliocene | Clay-bound sands | ≈ 1000 m |

# Coastal aquifers

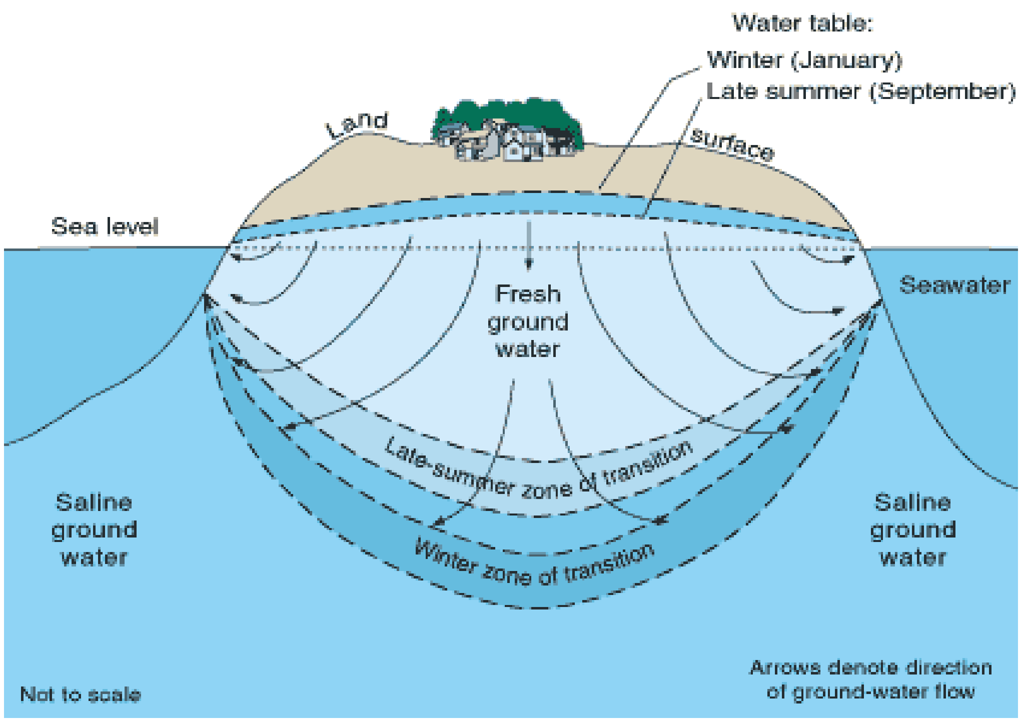
- Stable density stratification (freshwater overlying saltwater) is the most common salinity configuration in coastal aquifers.
- Dispersion of the two water types occurs, due to both mechanical mixing and chemical diffusion, and a **transition zone** develops between fresh and salt groundwater.
- The present fresh/salt water distribution in a coastal aquifer is very often determined by the long-term hydrogeological and physiographical history of the region.

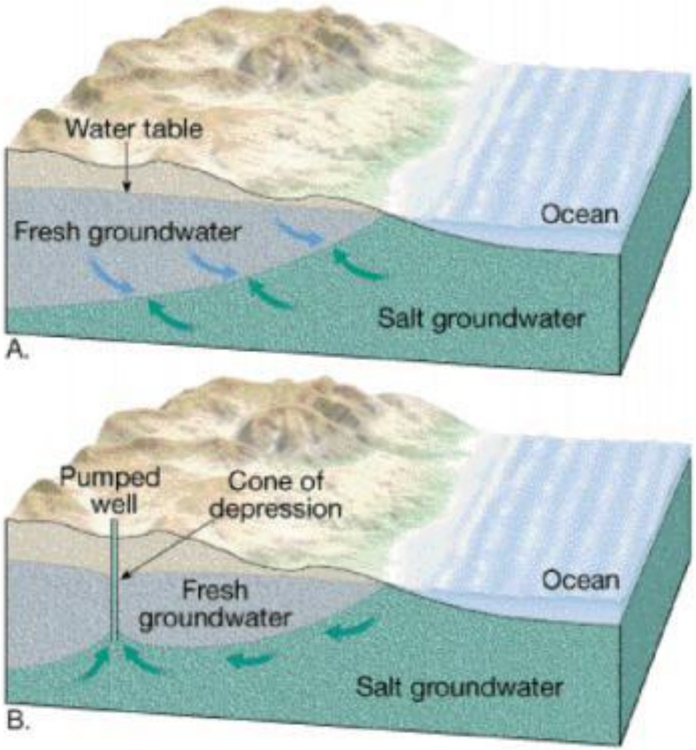


# Displacements of the transition zone

The dispersion zone undergoes cyclic displacements related to

- Tidal effects
- Surface hydrology effects (e.g.seasonal variations of freshwater head, recharge variability and surface–subsurface interactions)
- Anthropogenic influences: overexploitation and CC



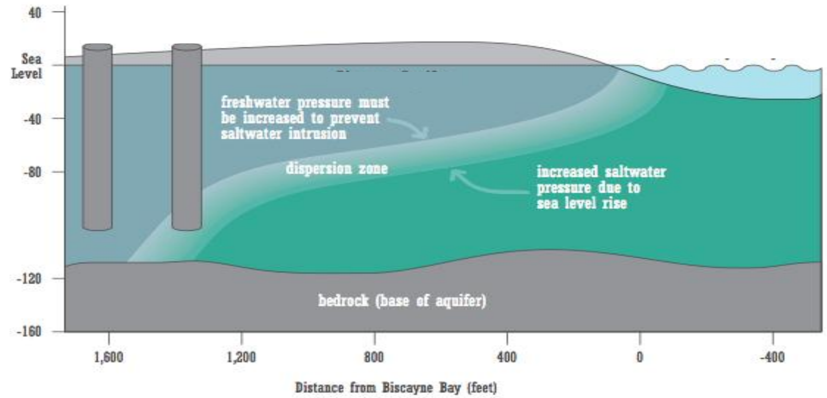
# Types of seawater intrusion

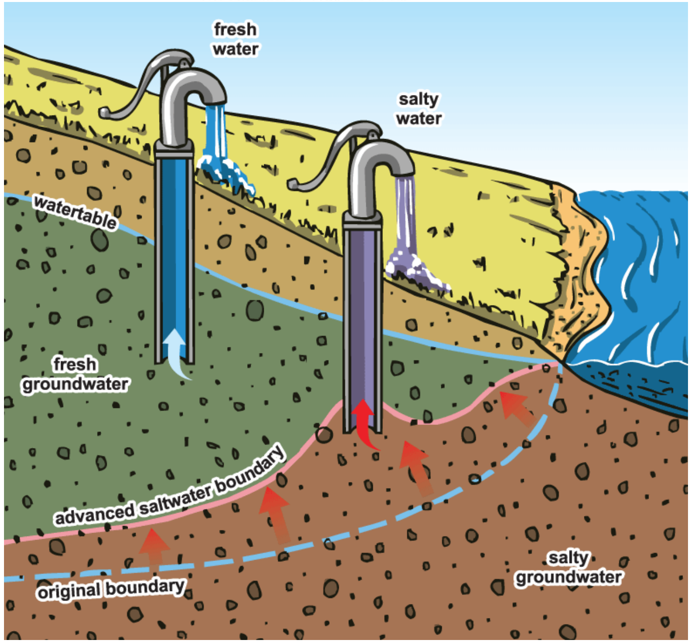
- **LATERAL**

Due to tidal effects and overexploitation. Landward penetration of seawater increases with increasing aquifer permeability and with decreasing freshwater flow.

- **UPCONING**

Saltwater upconing may occur when a pumping well is installed in a coastal freshwater reservoir. When overexploitation of the freshwater aquifer occurs, locally, due to pumping, the saltwater will be flowing upwards towards the wells in a cone shape. The mixing zone expands, and saline water ascend into the aquifer.



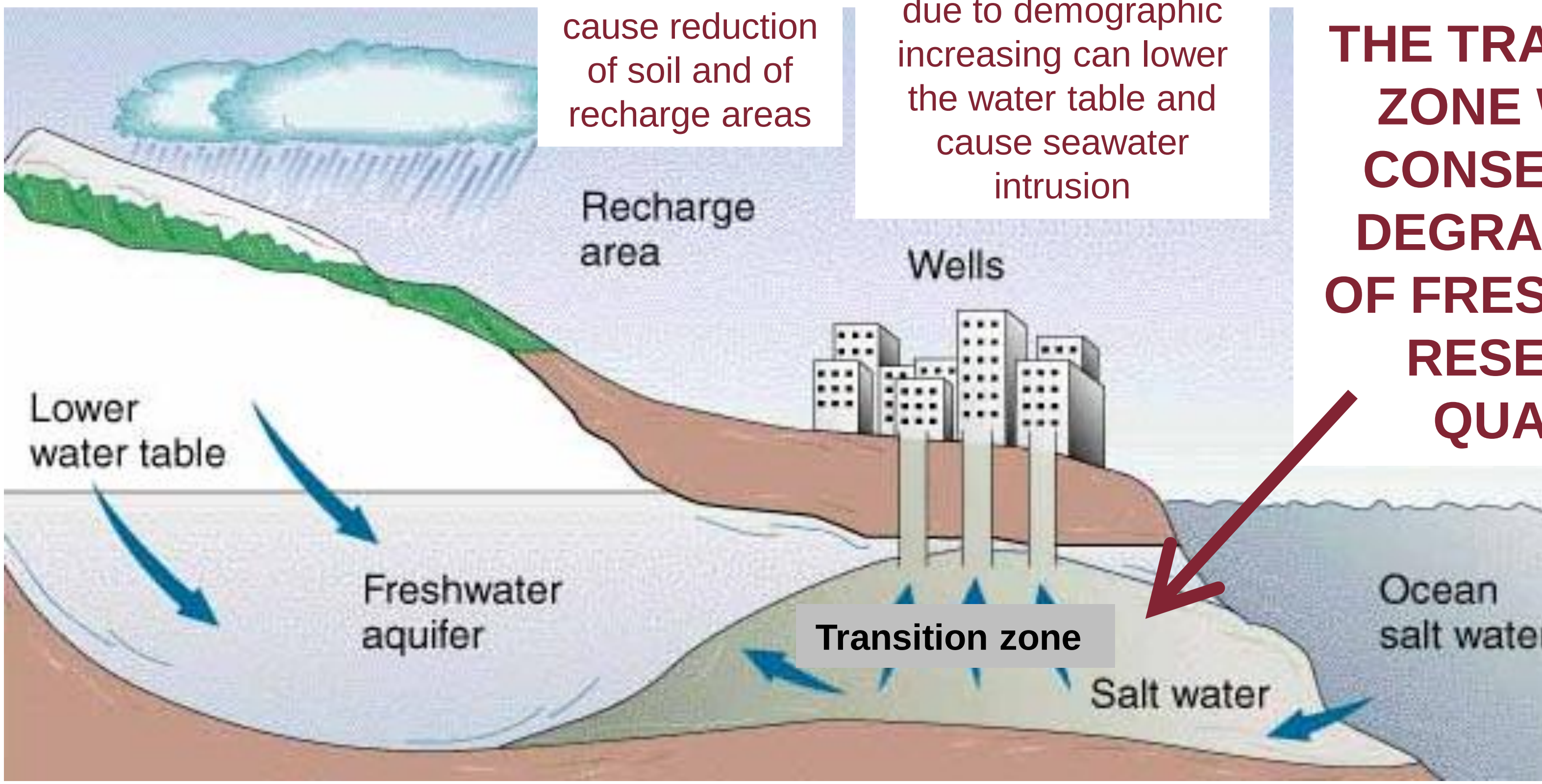
# Anthropogenic and CC influences on seawater intrusion

Changes in meteorological parameters resulting from CC affect the hydrological cycle, and the amount of annual precipitation that reach the ground.

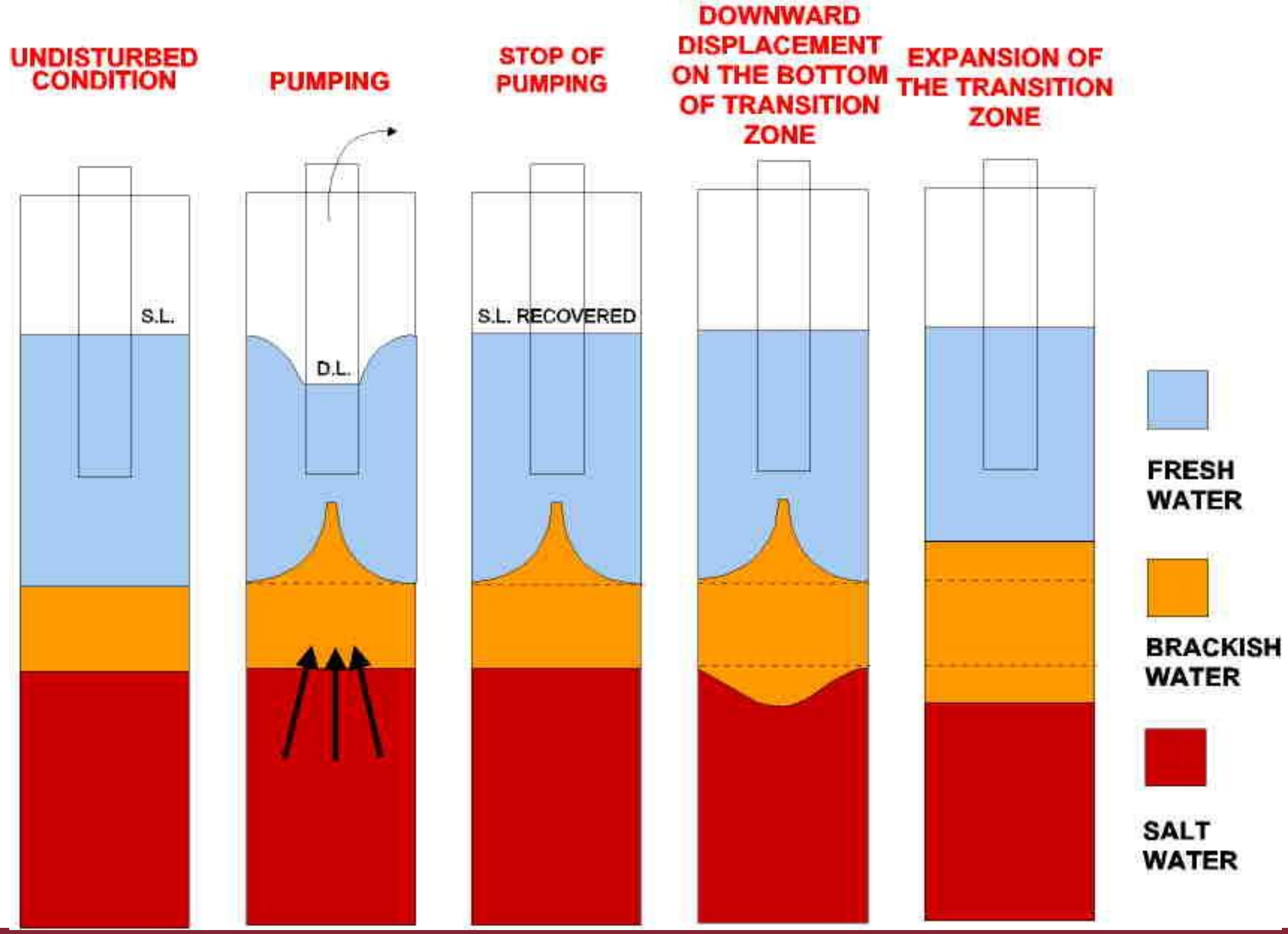
Increasing of urbanized land cause reduction of soil and of recharge areas

Eccessive withdrawals due to demographic increasing can lower the water table and cause seawater intrusion

**THE FINAL EFFECT IS THE EXPANSION OF THE TRANSITION ZONE WITH A CONSEQUENT DEGRADATION OF FRESHWATER RESERVES QUALITY**



# Anthropogenic and CC influences on seawater intrusion



## Assessment of the effects of CC on groundwater availability

According to the goals and scope of the project, analysis of climatic and anthropogenic influences on hydrogeological dynamics have been conducted through investigations on temporal evolutions of Groundwater Active Recharge (AGR) and Seawater Intrusion (SI) in the period 2001-2012.

The analysis provided the knowledge base with which have been developed 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.

# Approach and methodology

The methodology for assessing the aquifers sensitivity to CC and 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;
- Collection of available historical data, execution of a monitoring campaign and organization of the results of the investigation in a specific relational database;
- Analysis of climatic temporal evolutions (in the last 50 years) of meteorological parameters, precipitation and temperature;
- Analysis of climatic and anthropogenic influences on hydrogeological dynamics through investigations on Groundwater Active Recharge temporal evolutions;
- Seawater Intrusion assessment by hydrochemical methods, through physical and chemical testing of monitored network of representative boreholes from 2001 to 2012.

# Collection of available historical data

- Meteorological data

  50 years of observations from 3 meteorological stations
  (Jnia, Wazo Hill, Ocean Road)
  parameters:
  - Precipitation
  - Temperature

- Hydrogeological data

  Collection of existing data from 400 boreholes for the period from 2001 to 2010.
  principal parameters:
  - static water level
  - physical parameters
  - chemical composition

  Collection of land cover distribution data for the period from 2001 to 2012, through the analysis of satellitar images.

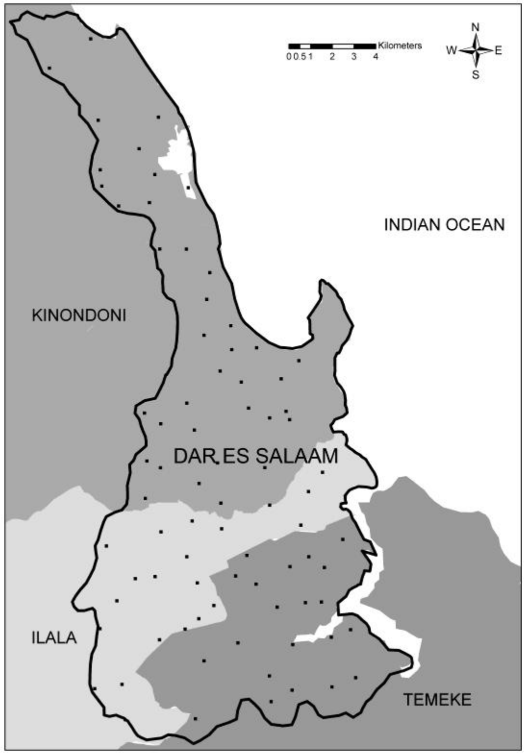
# Groundwater monitoring activity

The monitoring procedures consisted in a variety of survey activities depending on temporal scale (long-term and monthly surveys) and the type of data to be collected (in situ and laboratory measures).

**Scheme of the monitoring campaign**

| Monitoring campaigns | Frequency | Data collected |
|---|---|---|
| Long-term monitoring activity involving the entire borehole network (79 boreholes) | Twice in 6 months:<br>-June 2012 (after the *"long rainy season")*<br>-November 2012 (before the "*short rainy season*") | SWL measure (using contact meters)<br><br>Physical parameters in situ measure (using multiparametric probes): T, pH, EC, TDS<br>Chemical parameters lab measure (laboratory analysis of collected water sample): $Ca^{++}$, $Mg^{++}$, $Na^{+}$, $K^{+}$, $HCO_3^-$, $SO_4^{--}$, $Cl^-$, $NO_3^{--}$, $F^-$, $NH_4^+$ |
| Monthly monitoring activity involving a sub-group of the borehole network (33 boreholes, mainly located in the area close to the coastline) | Monthly:<br>-September 2012<br>-October 2012 | SWL measure (using contact meters)<br>Physical parameters in situ measure (using multiparametric probes): T, pH, EC, TDS |

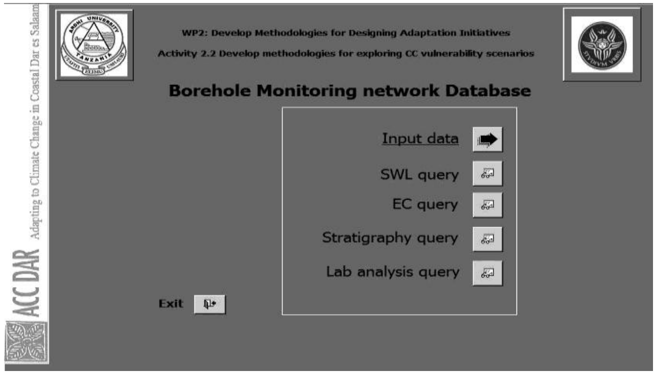
**The borehole monitoring network**



# Realization of the ACC-DAR Borehole Monitoring Database

The ACC-Dar BMD is a relational database built in the framework of Activity 2.2 in order to store and manage all the hydrogeological data gathered concerning seawater intrusion into the Dar es Salaam coastal aquifer.
Considering its notoriety and user-friendly accessibility, Microsoft Access was deemed the most appropriate relational DBMS to develop the ACC-Dar BMD.

Through the BMD, technical (depth, year of construction, coordinates, etc.) and historical chemical-physical data on the boreholes can be accessed and updated according to the information gathered during present and future survey activities.




The monitoring network is currently made up of 79 boreholes, the details of which are stored in the BMD

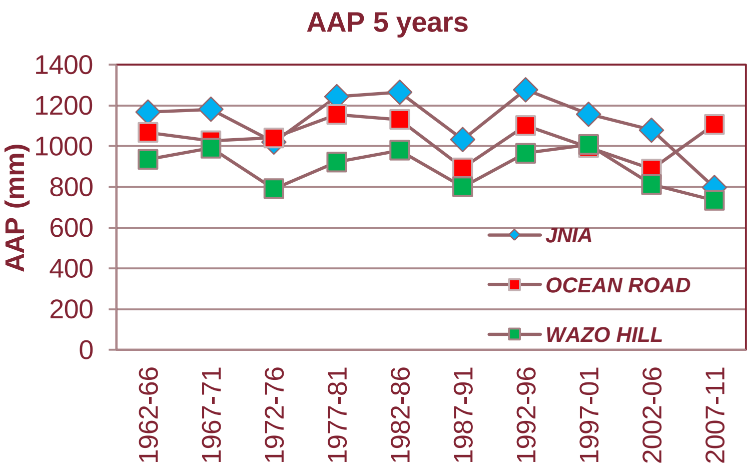
As with all relational databases, data in the ACC-Dar BMD are arranged in tables, related to each other through a system of primary keys

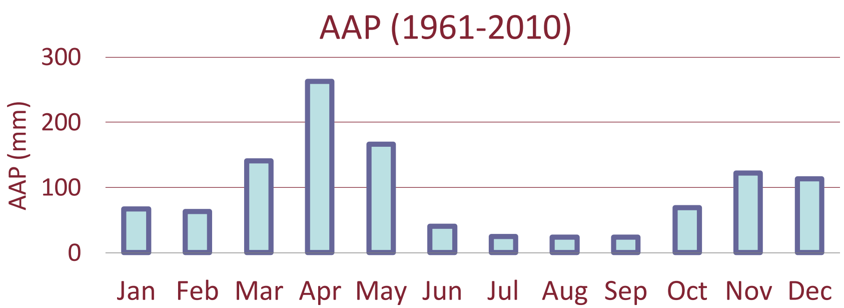
Specific queries have been built to quickly recover the data (stratigraphies, static water levels, chemical analysis, etc.).

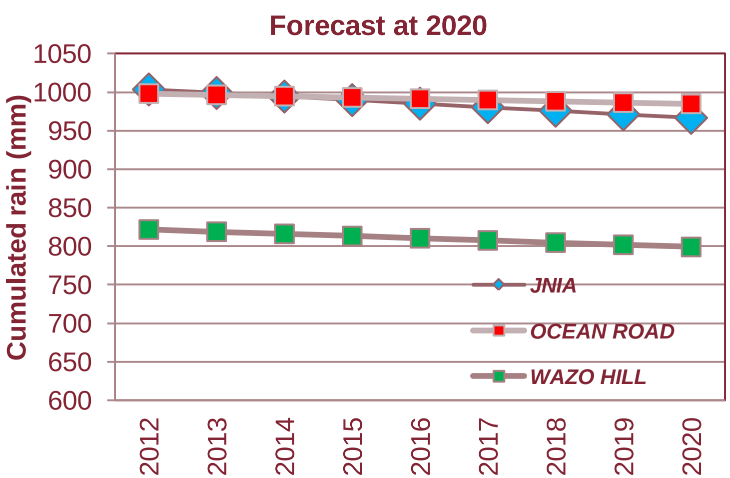
The ACC-Dar BMD is intended as the basic tool for future seawater intrusion survey activities, whose purpose is to serve as a reference point for similar projects in the future.

http://www.planning4adaptation.eu/042_Maps.aspx

# Evolution of rainfall patterns in the period 2001-2012



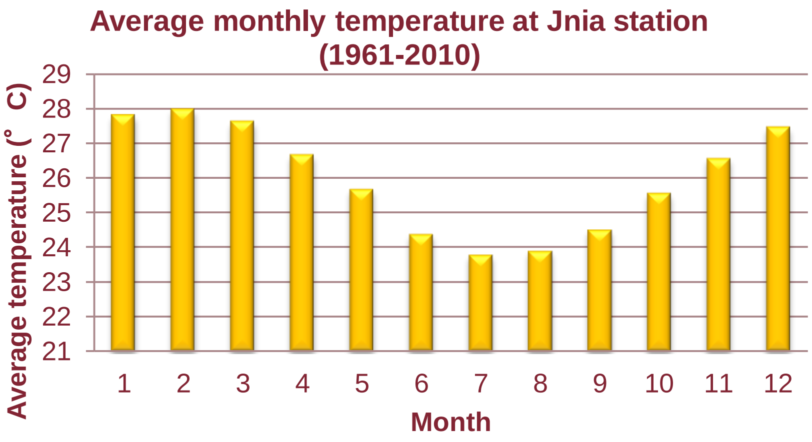



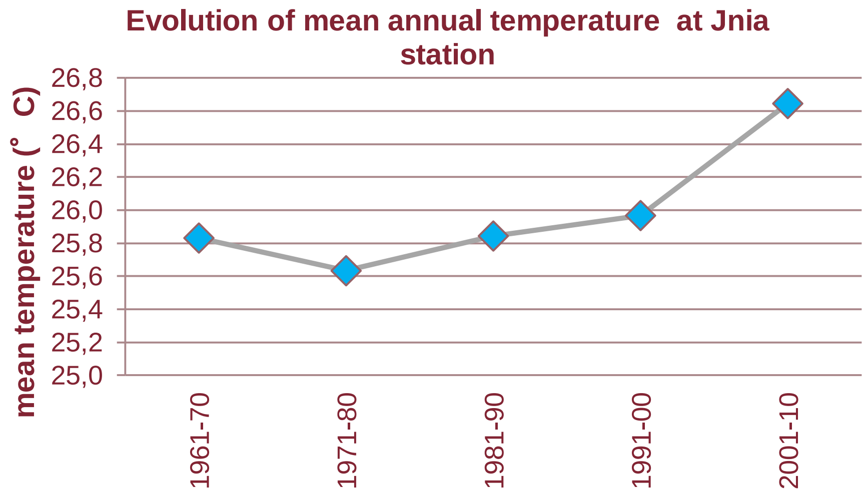




50 years of observations at 3 stations:
*JNIA, Ocean Road, Wazo Hill*
**Average annual precipitation (AAP): 1050÷1100 mm**
Jnia MPAM: 1123,5 mm
Ocean Road MPAM: 1041,6 mm
Wazo Hill MPAM 895,3 mm

**Analysis of time series shows an alternation of 20-years cycles in the evolution trend of total annual precipitation.** Thus, although forecast analysis at 2020 shows a decrease in precipitation, this trend could be reversed in the following years.

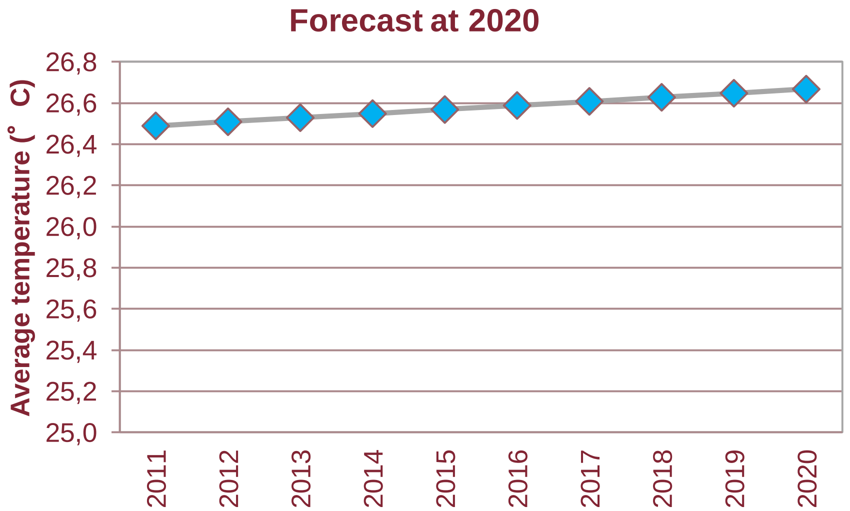
# Evolution of atmospheric temperature from 1961 to 2012



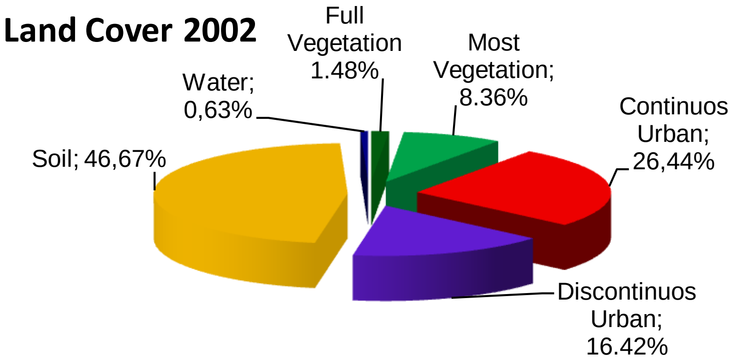

50 years of observations (1961-2010) at Jnia station:
Mean annual temperature: 26° C
Maximum average temperature: 30,8° C
Minimum average temperature: 21,2° C

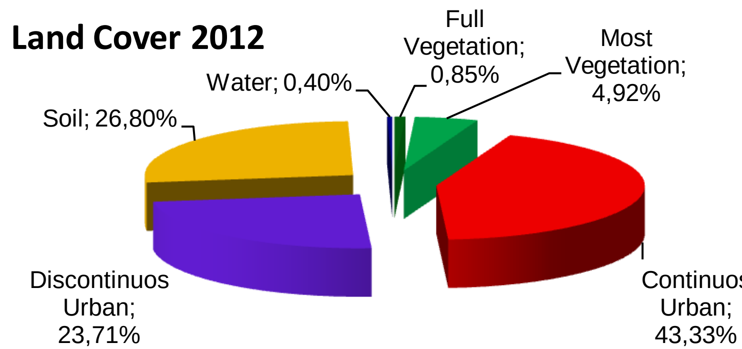
Forecast analysis at 2020 shows a 26,7° C expected mean annual temperature for Dar Es Salaam



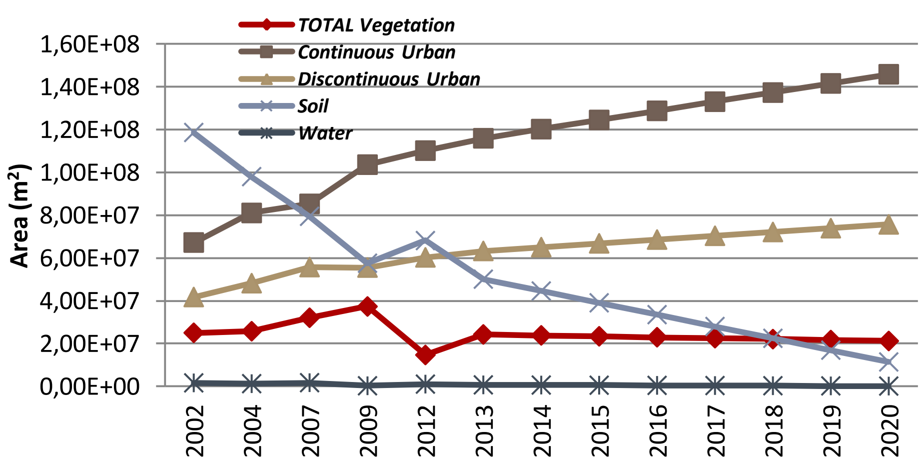
# Evolution of land cover in the period 2002-2012

Analysis of available data has revealed an expansion of the urban area as both continuous urban (+ 64%) and discontinuous urban land (+44%) to the detriment of soil (-42,6%) and vegetation (-42,8), with consequent loss of recharge area for the aquifer. the change of land use should be considered a consequence of climate change.
Evolutionary forecast was carried on using linear regressions. It has been estimated an increase of urban land of about 60%.

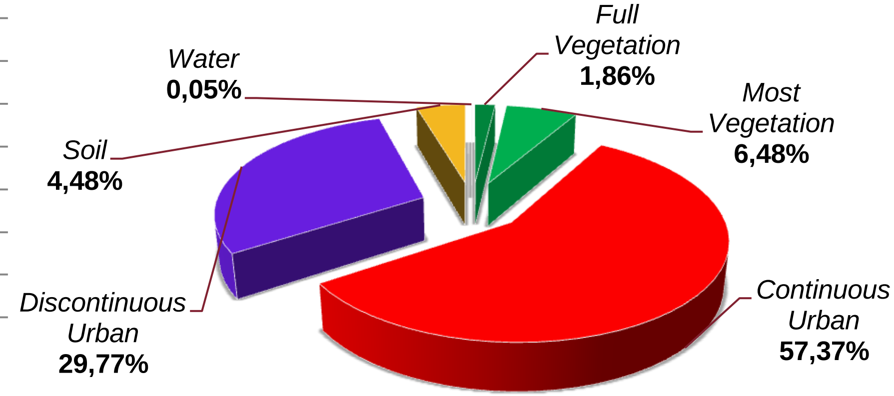



## Evolution of land cover with forecast at 2020




## Land cover: forecast at 2020

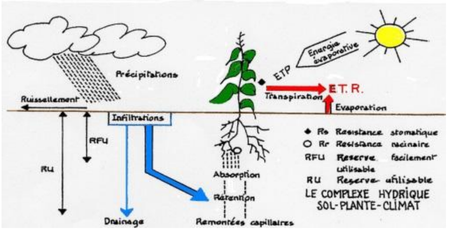


# Groundwater Active Recharge

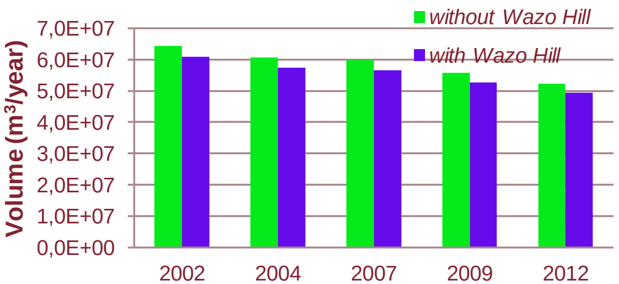
Groundwater Active Recharge was evaluated using two different methodologies:

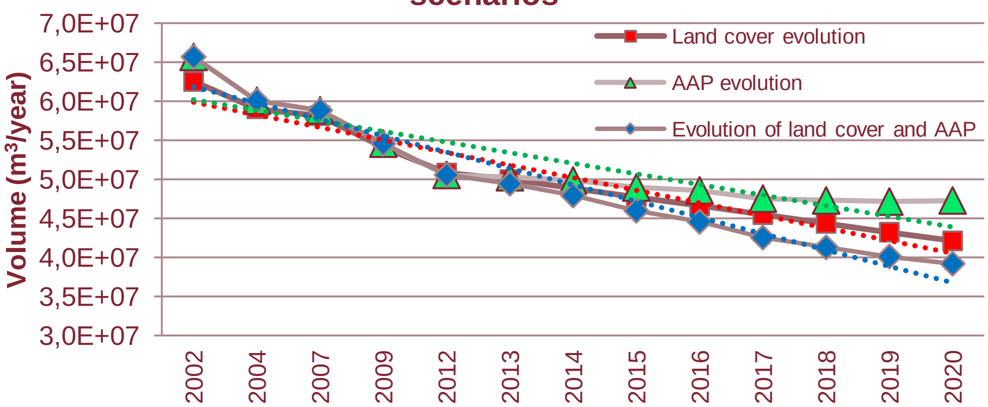
**Inverse Hydrogeological Budget**

The Inverse Hydrogeological Budget (Civita M. & De Maio M., 2001) was applied to determine quantitatively the active recharge relating to the basin of interest. The methodology was applied in a modified version adapted for the study case: GAR was calculated directly as the result of the sum of the products of a value of average annual precipitation (AAP was assumed equal for the whole study area, it was calculated as the average value of the three stations) multiplied by the extension of each land cover type and by a specific coefficient of infiltration $\chi_p$ for each land cover type (the territory was subdivided in six classes of land-use).



| Land cover | $\chi_p$ |
|---|---|
| Continuous Urban | 0.1 |
| Discontinuous Urban | 0.2 |
| Soil | 0.3 |
| Full Vegetation | 0.3 |
| Most Vegetation | 0.4 |
| Water | 0.55 |



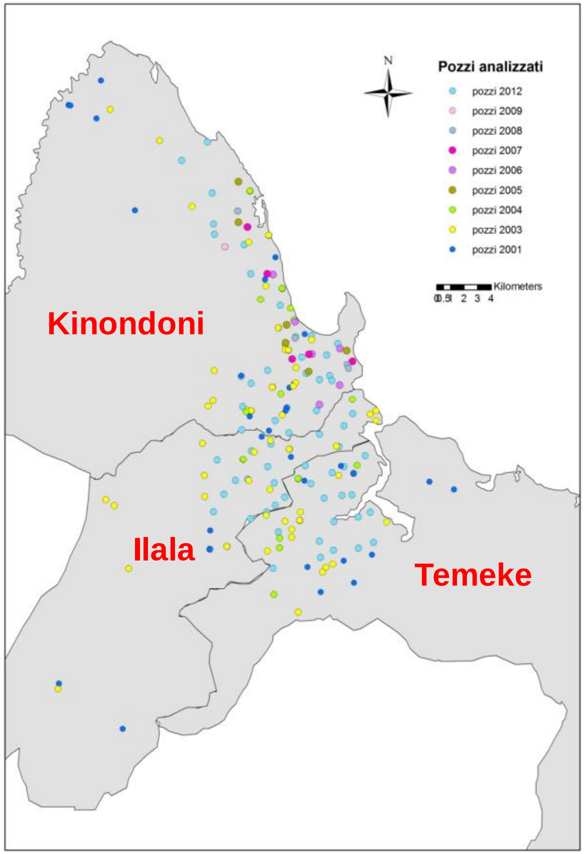




**GAR estimated at 2012 is 49,4x10$^6$– 52,2x10$^6$ m$^3$/y (-20% respect to 2002)**
**GAR estimated at 2020 is 38x10$^6$ - 43,3x10$^6$ m$^3$/y (-22% respect to 2012)**
**Values obtained agree with those of other studies conducted on the same area.**

# Seawater intrusion assessment

## Numbers and kinds of investigation available from 2001 to 2012

| Parameters | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | Jun-12 | Nov-12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of boreholes | 32 | 6 | 52 | 15 | 8 | 6 | 5 | 4 | 1 | 79 | 71 |
| G (mas) | 32 | 6 | 52 | 15 | 8 | 6 | 5 | 4 | 1 | 54 | 54 |
| depth | 32 | 6 | 51 | 15 | 8 | 6 | 5 | 4 | 1 | 33 | 33 |
| 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 Filtrabe 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 $CaCO_3$ | 7 | 6 | 12 | 6 | 7 | 4 | 3 | 2 | 1 | 0 | 0 |
| Non Carbonate Hard. mg $CaCO_3$ | 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 |
| $NO_3$ (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 |
| $SO_4$ (mg/l) | 32 | 6 | 52 | 15 | 8 | 6 | 5 | 4 | 1 | 79 | 71 |
| $PO_4$ (mg/l) | 30 | 4 | 30 | 15 | 8 | 3 | 5 | 0 | 0 | 0 | 0 |
| F (mg/l) | 0 | 0 | 20 | 0 | 0 | 2 | 2 | 2 | 0 | 0 | 0 |
| $HCO_3$ (mg/l) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 79 | 71 |
| $CO_3$ (mg/l) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 23 |
| P (mg/l) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 71 |
| ZN (mg/l) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| I (mg/l) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $NH_4$ (mg/l) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 71 |
| MN (mg/l) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

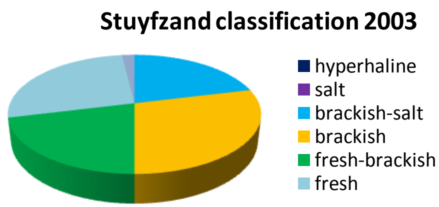


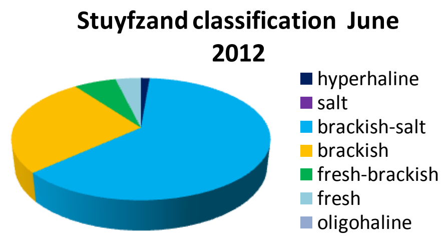
# Seawater intrusion assessment

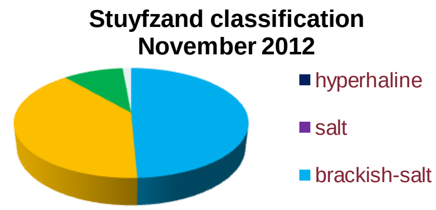
## Data Analysis methods

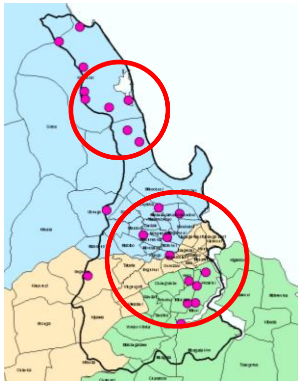
Stuyfzand classification (1986,1993) allows to determine hydrochemical facies and the presence of seawater intrusion.

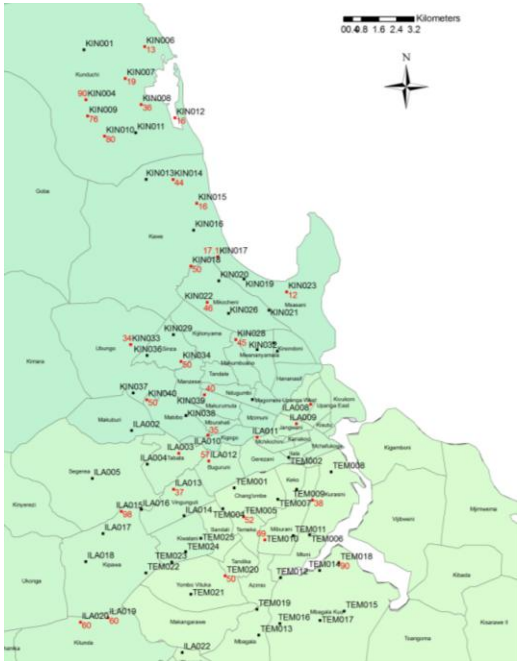
Monitoring campaign 2012: distribution map of boreholes with signs of seawater contamination.





Analysis that have been carried out allowed to identify some regions of the study area, where seawater intrusion influences groundwater's composition. **It has been possible to recognize an enlargement of areas affected by salinization, in respect to those of ten years ago, and it has been possible to identify some aspects, which are possible indicators of the hydrogeochemical processes underway in the area, which combine to determine groundwater quality.**

The areas where seawater intrusion may become priorities for vulnerability assessment and adaptation action implementation, which add up to the ones highlighted in the previous report are: Kunduchi, Kawe, Mikocheni, Sinza, Mabibo, Buguruni, Chang'hombe, Miburani, Yombo Vituka and Kitunda

ACC DAR

## Remediation and reccomendations

- Lowering groundwater exploitation
- Rainwater Harvesting
- Monitoring

# Rainwater Harvesting

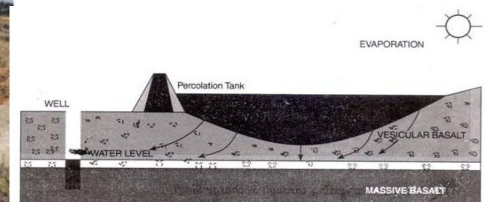
Proper rainwater harvesting techniques can provide enough water for domestic, industrial and irrigation uses. Rainwater harvesting (RH) is one of the best options available to fight drought in semi-arid regions.
RH represents a potential mean to increase human well-being without eroding the ecosystems functions that waterserves in the local territory.

- **Percolation ponds** are artificial ponds that are made to store the rainwater in order to limit the runoff and evapotranspiration and promote the infiltration into the soil, in order to contribute artificially to aquifer recharge. The capacity of these basins can reach 10000-15000 $m^3$, depending on rainfall and surface used.
- **Percolation tanks** and **check dams** are used to contribute to aquifer recharge using excess water coming from the water courses present in the area. It is generally realized in large non-cultivable areas that are surrounded by dikes to permit that rainwater and river flood be collected and infiltrate into the soil.
- Other types of collection and storage of rainwater already in use in Tanzania, which are intermediate between check dams and percolation ponds, include **charco dams, valley dams, hillside dams**.

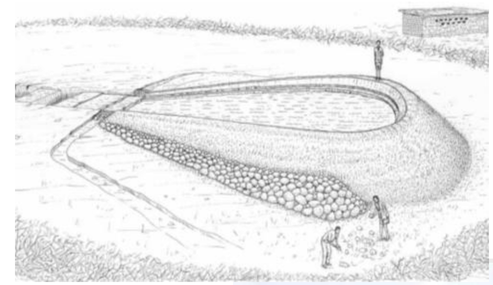
**Percolation pond**

**Check dam**

**Scheme of a percolation tank**

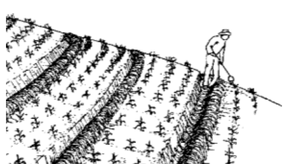


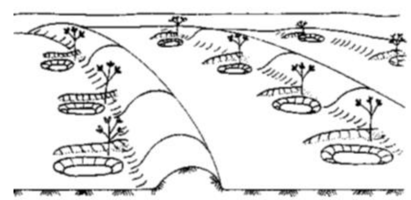

**Charco dams**



**Beside these some traditional methods of tillage allow storage of larger quantities of water and the improvement of the physical properties and fertility of soils.**

**Tillage**



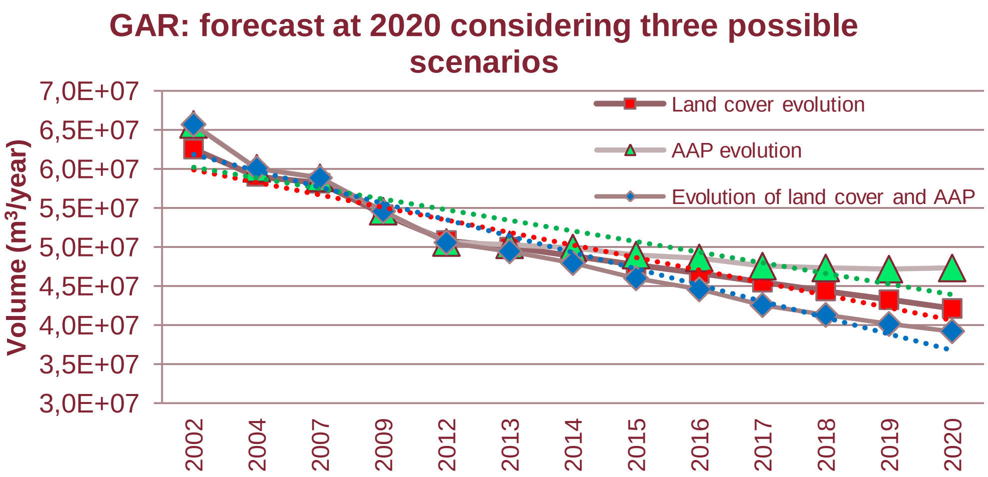


# Aspect that needs to be considered

- The effective management of coastal groundwater resources usually requires that the position and thickness of the mixing zone is reasonably well characterized.
- 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 piezometers and 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.

## Conclusions

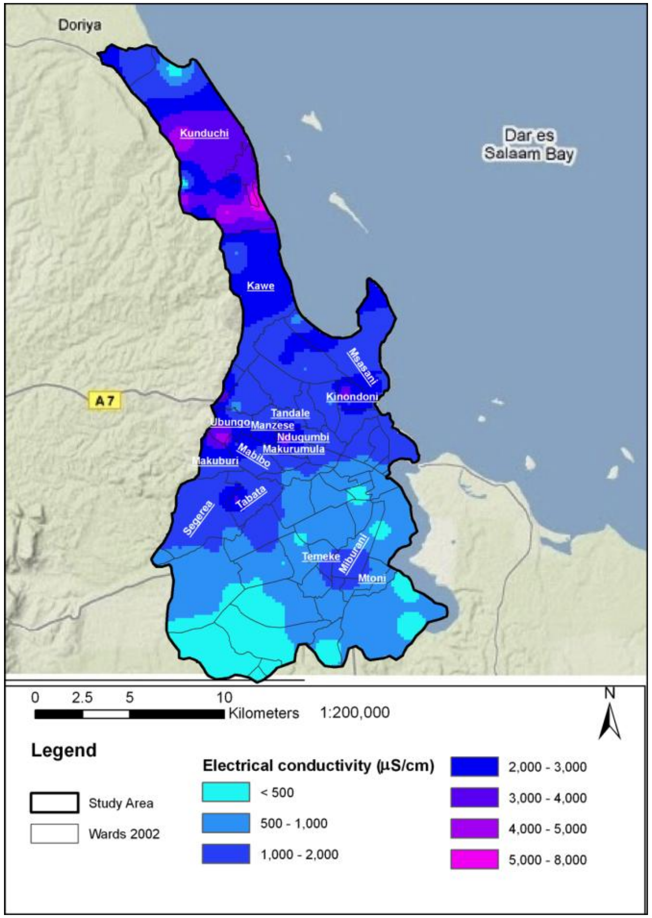
- Groundwater active recharge has decreased over the past decade for the combined effect of CC and anthropogenic causes. The latter ones are due to the growing urbanization of Dar Es Salaam, which involved consumption growth and land cover changes, with loss of recharge areas for the aquifer. CC involves modifications in the rainfall pattern and average annual temperature rise, and have contributed to modify the entity of the parameters in the hydrological budget, leading to the decreasing of GAR.



# Conclusions

- The analysis of historical data and the execution of monitoring campaigns and geochemical analysis provided a clear indication of the enlargement of the areas affected by salinization in the period from 2001 to 2012 with a large contribution from seawater intrusion.

- Increased climate variability brings about uncertainty in terms of rates of replenishment of freshwater reserves, thus groundwater resources management plans must include integrated management of surface and groundwater resources, to meet the needs of different users with water of different salinity, on the basis of their actual needs and for different uses.



# Conclusions

Groundwater management is a widespread environmental problem all over the world.
The website of the IAH Coastal Aquifer Dynamics and Coastal Zone Management (CAD-CZM) Network was conceived to collect and organize data and information on coastal aquifer characteristics from all over the world and let them available to researchers, professionals, and stakeholders.

http://www.iah-cad-czm.net