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

Saltwater Intrusion and Nitrate Pollution in the Coastal Aquifer of Dar es Salaam

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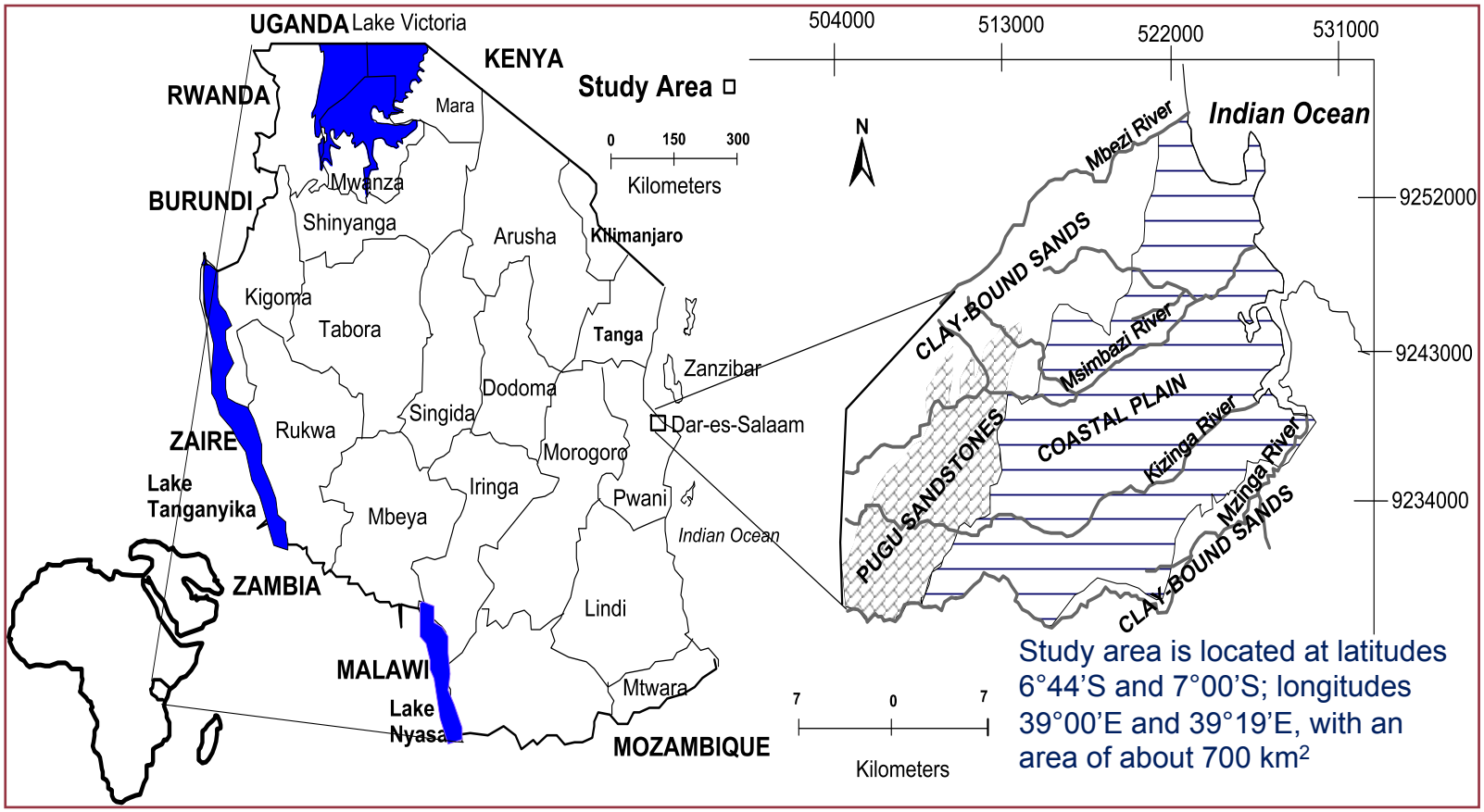
Presentation outline:

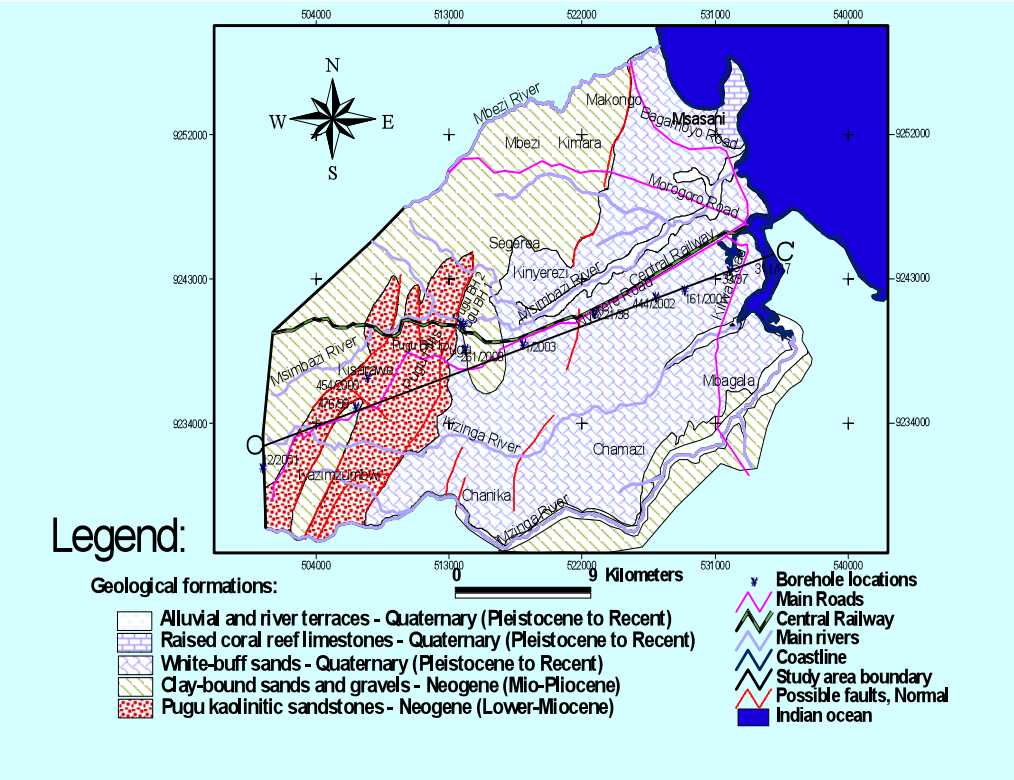
- **Introduction**
  - Description of the study area
  - Geology and hydrogeology
  - Groundwater exploitation
  - Features affecting the coastal aquifers
  - Coastal aquifers: freshening and salinization
- **Saltwater Intrusion investigation**
- **Nitrate Pollution Investigation**
- **Conclusion and recommendations**

Introduction



Geographical and geological situation of the study area

Geology of the study area

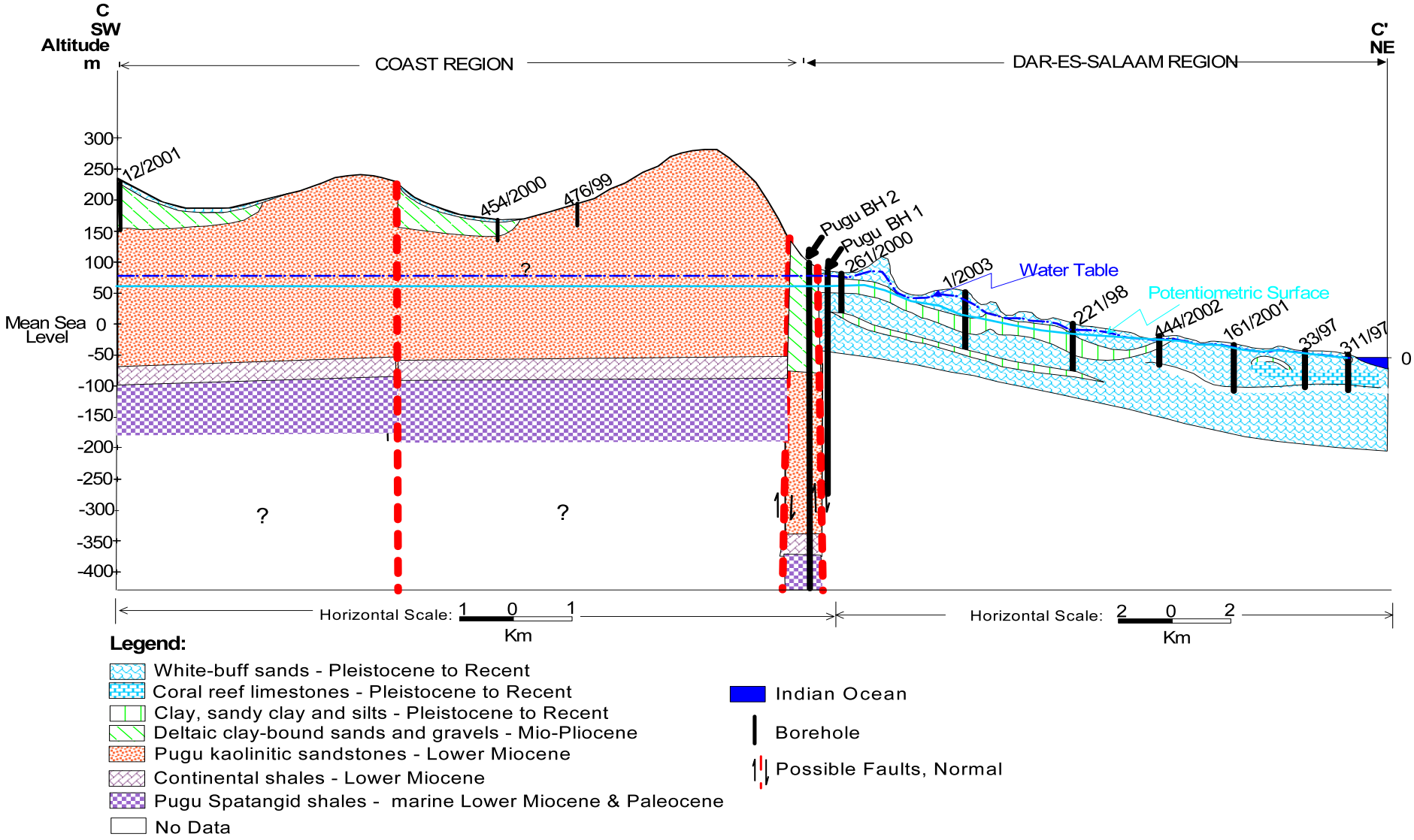


Geologically, the study area comprises three major parts:

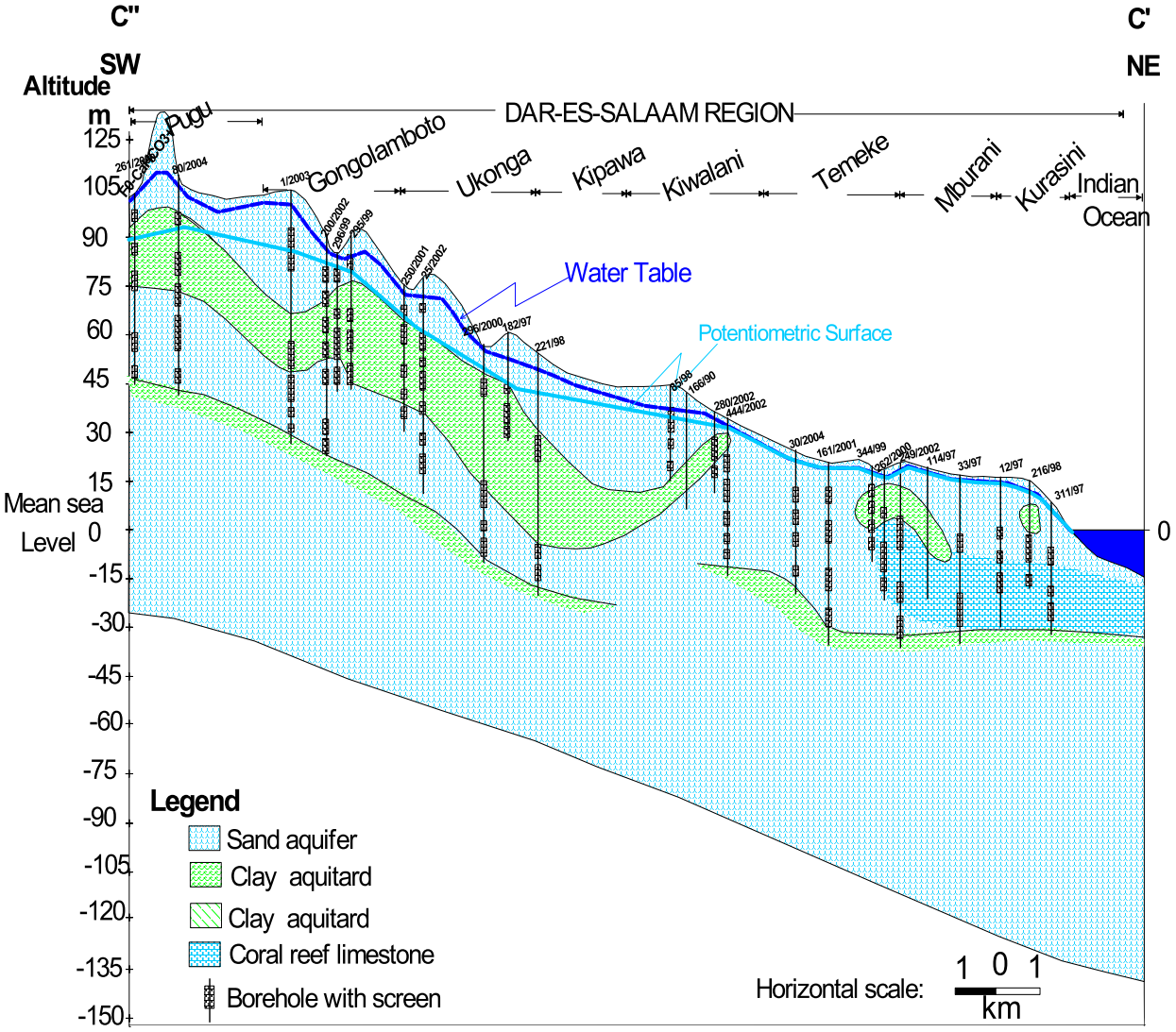
- The central coastal plain with Quaternary fluviatile-deltaic sediments;
- The deltaic Mio-Pliocene clay-bound sands and gravels in the northwest and southeast and
- The Lower Miocene fluviatile sandstones of Pugu Hills in the west of the study area;

- The Quaternary deposits of Pleistocene to Recent periods have total thickness of approximately 150 m within Dar-es-Salaam City area.
- The underlaying deltaic deposits of Mio-Pliocene age have a thickness around 1000 m and are considered as the base of the groundwater reservoir.

Geology of the study area



Hydrogeology of the study area



Unconfined aquifer: The uppermost water-bearing unit in the study area is the unconfined aquifer, which consists primarily of unconsolidated materials. The unconfined aquifer is shallow in the south-western part with an average thickness of 10 m and deep in the eastern part of the study area up to 50 m.

Semi-confined aquifer: The lower aquifer system is under semi-confined conditions in unconsolidated sediments. It is considered as a Pleistocene to Recent deposit and has an average thickness of 100 m. The semi-confined aquifer overlays the base of the groundwater reservoir, formed by an aquitard of thickness about 1000 m in the Mio-Pliocene clay-bound sands.

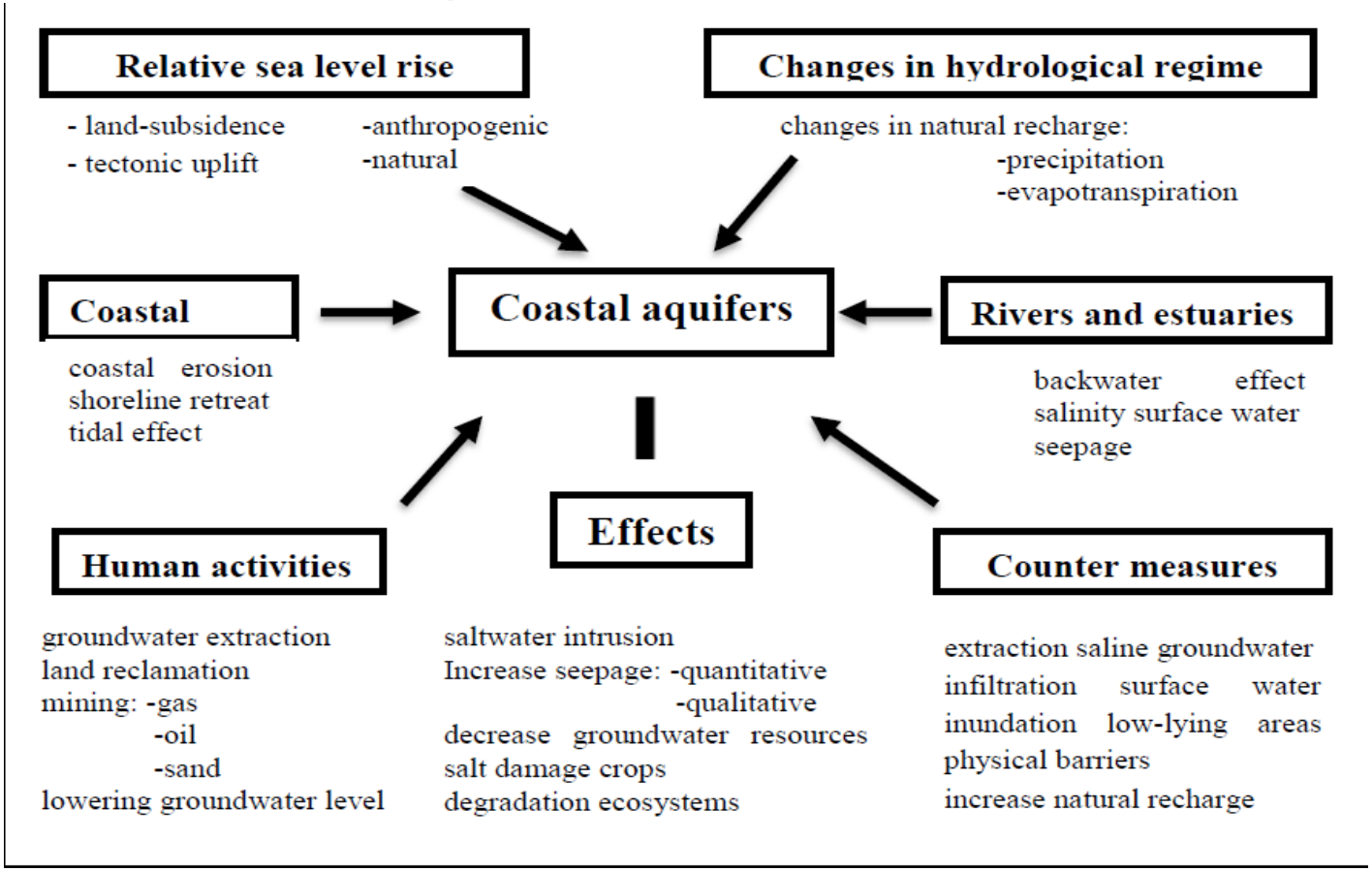
Groundwater exploitation

- The fact that the city receives inadequate surface water supplies, the use of groundwater for domestic purposes, irrigation and industries has become increasingly important. City's water demand is about 424,000m^3/day (Mato and Mujwahuzi, 2010) for the estimated population of the city of about 5 million.

- The groundwater replenishment under natural infiltration is estimated to be 186 mm (72.17 x 10^6 $m^3 year^{-1}$) indicating that only 16.7% of the long term average annual precipitation of 1114 mm ends up as groundwater recharge (Mtoni et al., 2011).

- Estimated total groundwater abstraction is approximately 69.3 x 10^6 $m^3 year^{-1}$. The water balance suggests an average sustainable yield of 28.67 x 10^6 $m^3 year^{-1}$ (calculated as 40% of natural groundwater recharge) (Mtoni et al., 2011; Ponse, 2007). This indicates Dar es Salaam Quaternary Coastal Aquifer is clearly over-exploited.

Features affecting the coastal aquifers



(Source: Kumar, 2006)

Climate change, sea level rise and saltwater intrusion present the future challenges of water resources management in coastal areas.

Salinization and Freshening of the coastal aquifer

2 END MEMBERS:

recharge water: infiltrating rain dissolving calcite **F-$CaHCO_3Ø$**

seawater **S-NaClØ**

SALINIZATION

- *advection* will bring the new saline end member in the aquifer, and both end members will move with groundwater flow
- At the interface, both end members will be mixed by *dispersion*

$$F \rightarrow F_b \rightarrow B \rightarrow B_s \rightarrow S$$

- the main chemical reaction will be *cation exchange*

$\Rightarrow$ deficit of marine cations (-)

$$CaHCO_3Ø \rightarrow CaCl\text{-} \rightarrow NaCl\text{-} \rightarrow NaClØ$$

2 END MEMBERS:

seawater **S-NaClØ**

recharge water: infiltrating rain dissolving calcite **F-$CaHCO_3Ø$**

FRESHENING

- *advection* will bring the new fresh end member in the aquifer, and both end members will move with groundwater flow
- At the interface, both end members will be mixed by *dispersion*

$$S \rightarrow B_s \rightarrow B \rightarrow F_b \rightarrow F$$

- the main chemical reaction will be *cation exchange*

$\Rightarrow$ surplus of marine cations (+)

$$NaClØ \rightarrow NaCl+ \rightarrow NaHCO_3+ \rightarrow MgHCO_3+ \rightarrow CaHCO_3+ \rightarrow CaHCO_3Ø$$

Factors changing groundwater quality as a result of freshening or salinization (Walraevens & Van Camp, 2005)

Saltwater Intrusion Investigation

METHODOLOGY

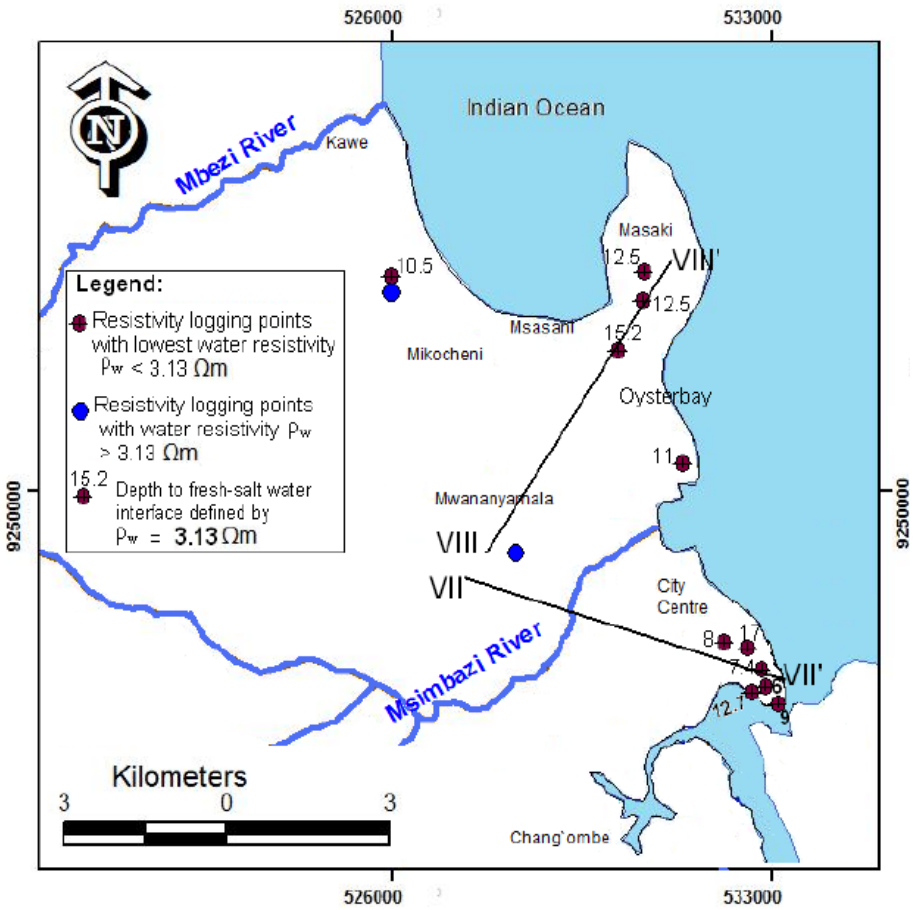
- **Piezometric level measurements – Dipper and divers**
- **Geophysical survey –Identify the freshwater- saltwater interface**
- **Laboratory analysis –Major Cations and Anions**
- **Mapping chemical parameters**

Geophysical Investigation

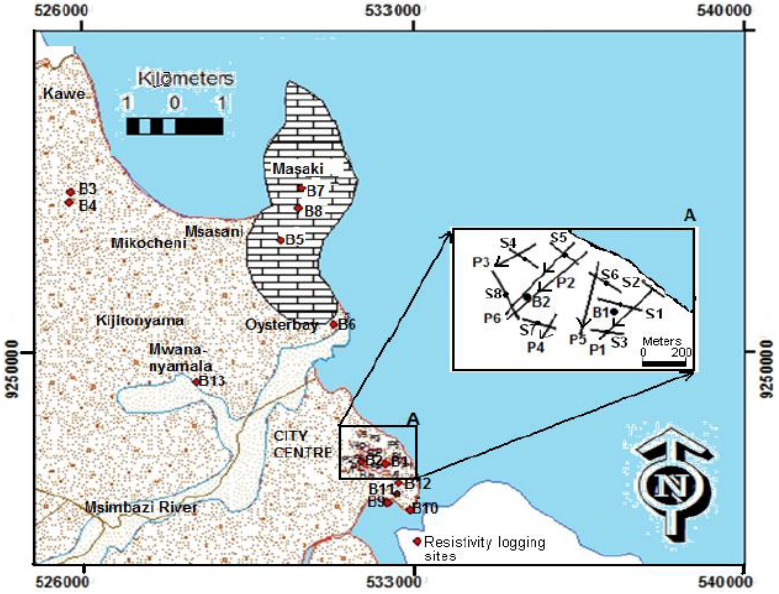
Resistivity logging

Vertical Electrical Sounding

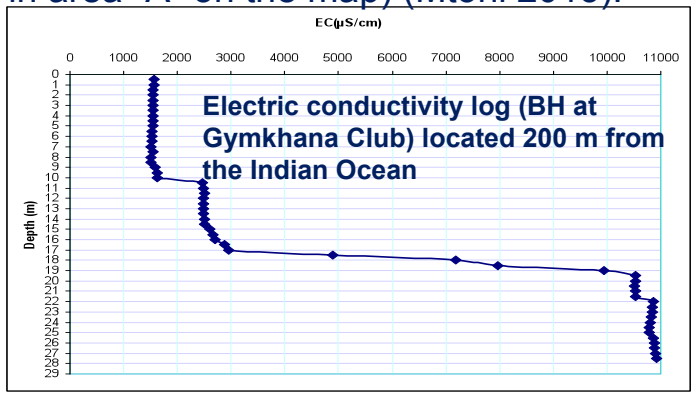
Geophysical Investigation



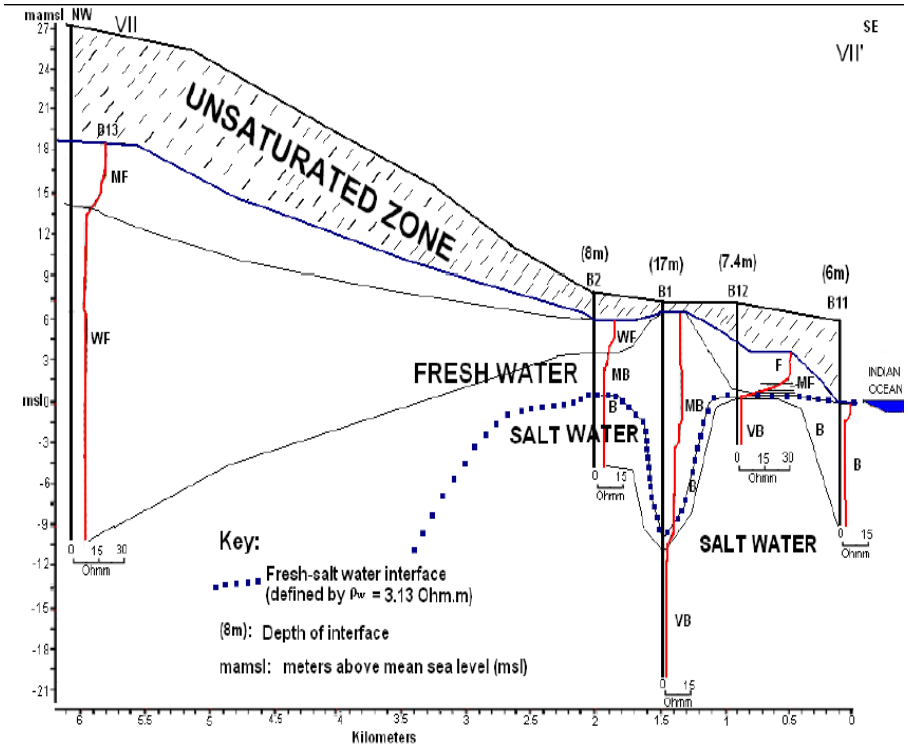
Map showing depth to fresh- salt water interface based on water resistivity logging data (defined by ρ_w =3.13 Ωm). (Mtoni 2013).



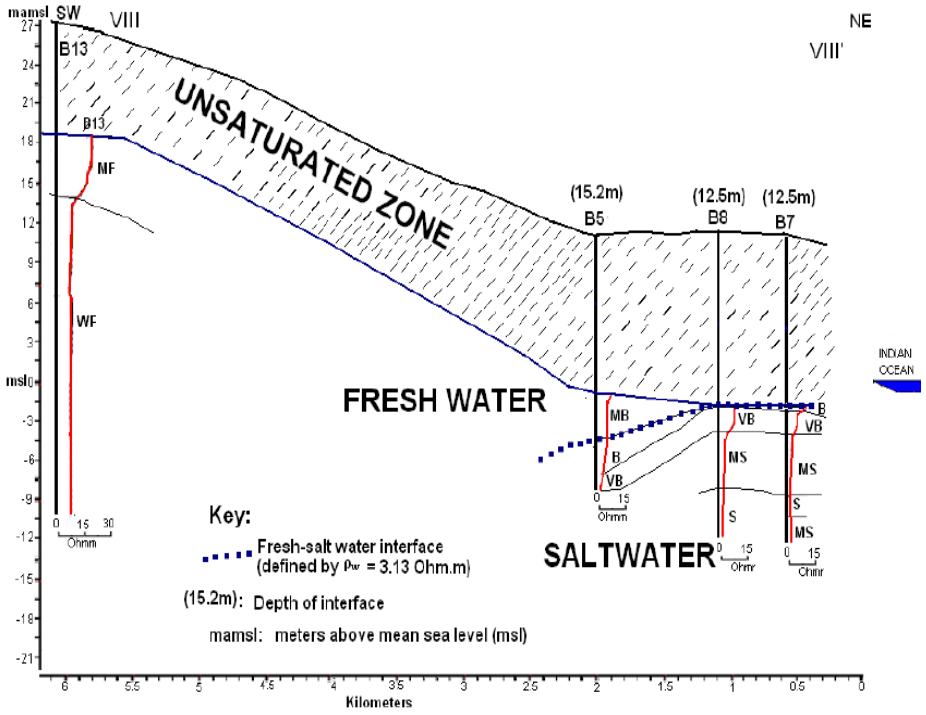
Map showing the locations of the test sites of resistivity logging (B1-B13), resistivity profiles (P1-P6) and vertical electrical soundings (S1-S8) (the latter in area "A" on the map) (Mtoni 2013).



Geophysical investigation

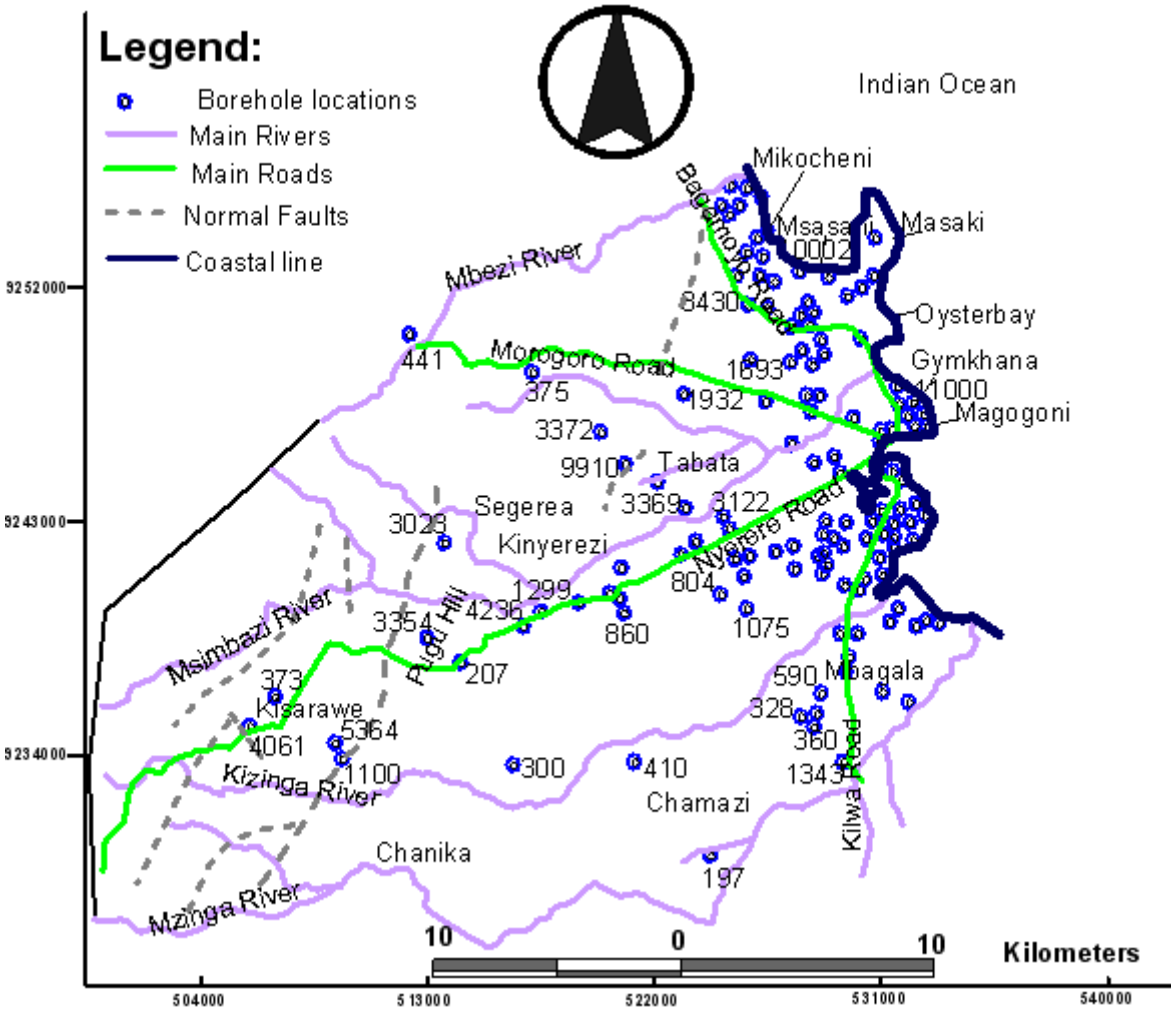


Fresh- salt water interface based on water resistivity logging data (defined by ρw =3.13 Ωm). (Location of resistivity profile VII-VII' (Mtoni, 2013)



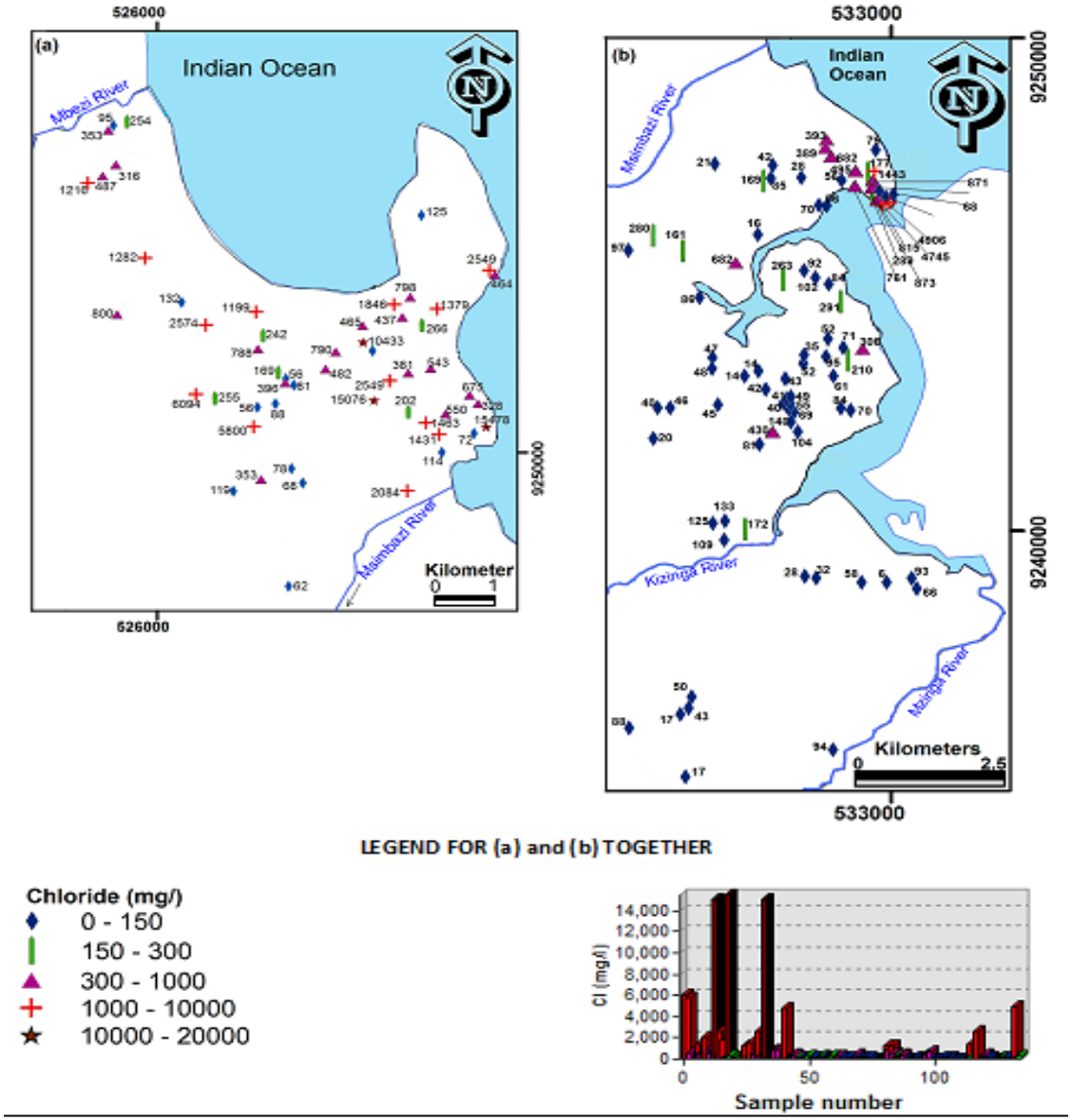
Fresh- salt water interface based on water resistivity logging data (defined by ρw =3.13 Ωm). (Location of resistivity profile VIII-VIII' (Mtoni, 2013)

Laboratory analysis – Major Cations and Anions



A total of 184 duplicate groundwater samples from boreholes and hand dug wells were collected (between 2004 and 2010) from each sampling point for major ions determination in the laboratory.

Chemical analysis – Major Cations and Anions



Chloride distribution in the study area:

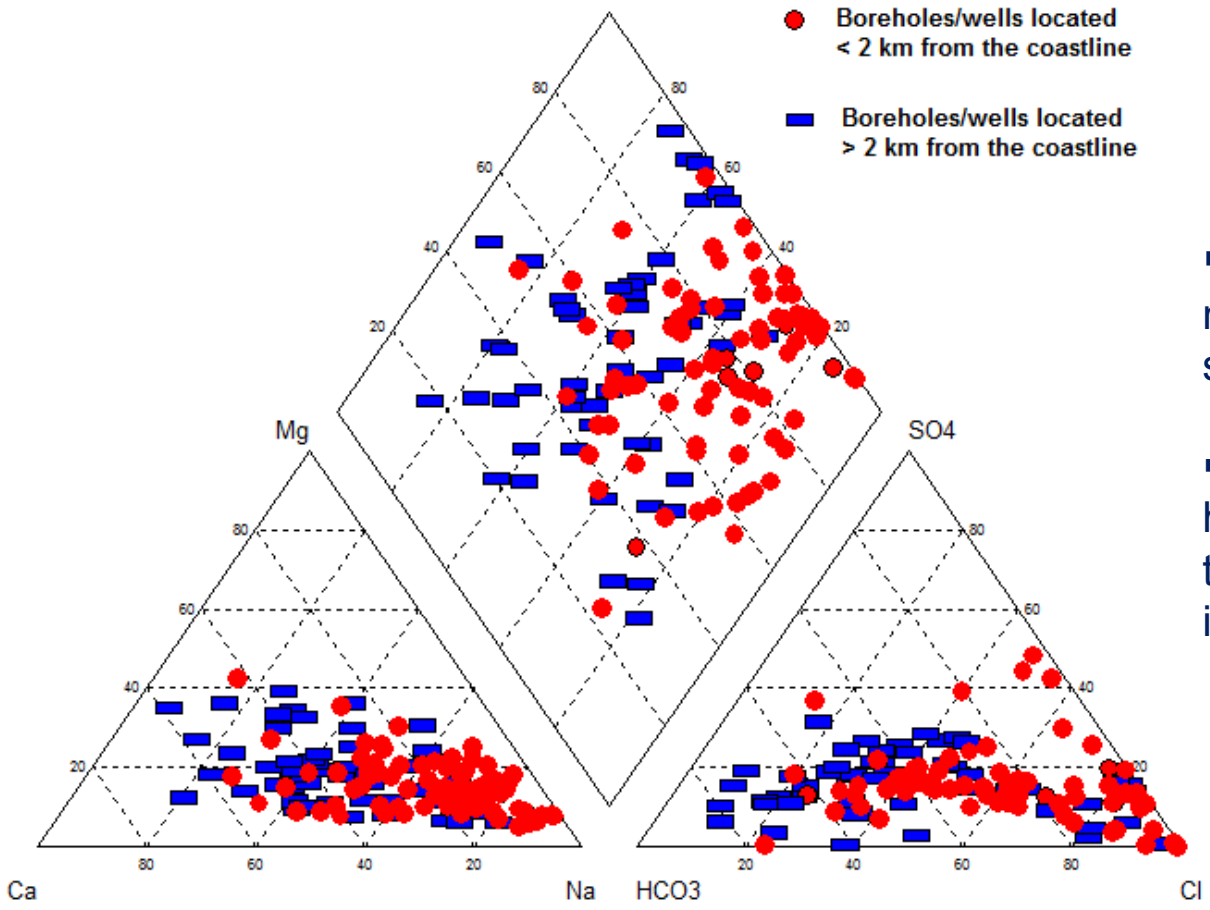
- Chloride concentration shows a general increase down gradient to the east towards the Coastline.

- Cl^- values range from 6.4 to 15,478 mg/l.

- This further indicates that groundwater in close proximity of the coast is influenced by the intrusion of seawater.

Chemical analysis – Major Cations and Anions

Piper diagram showing boreholes/wells located in close proximity to the coastline (< 2 km) and further from coastline (> 2 km)

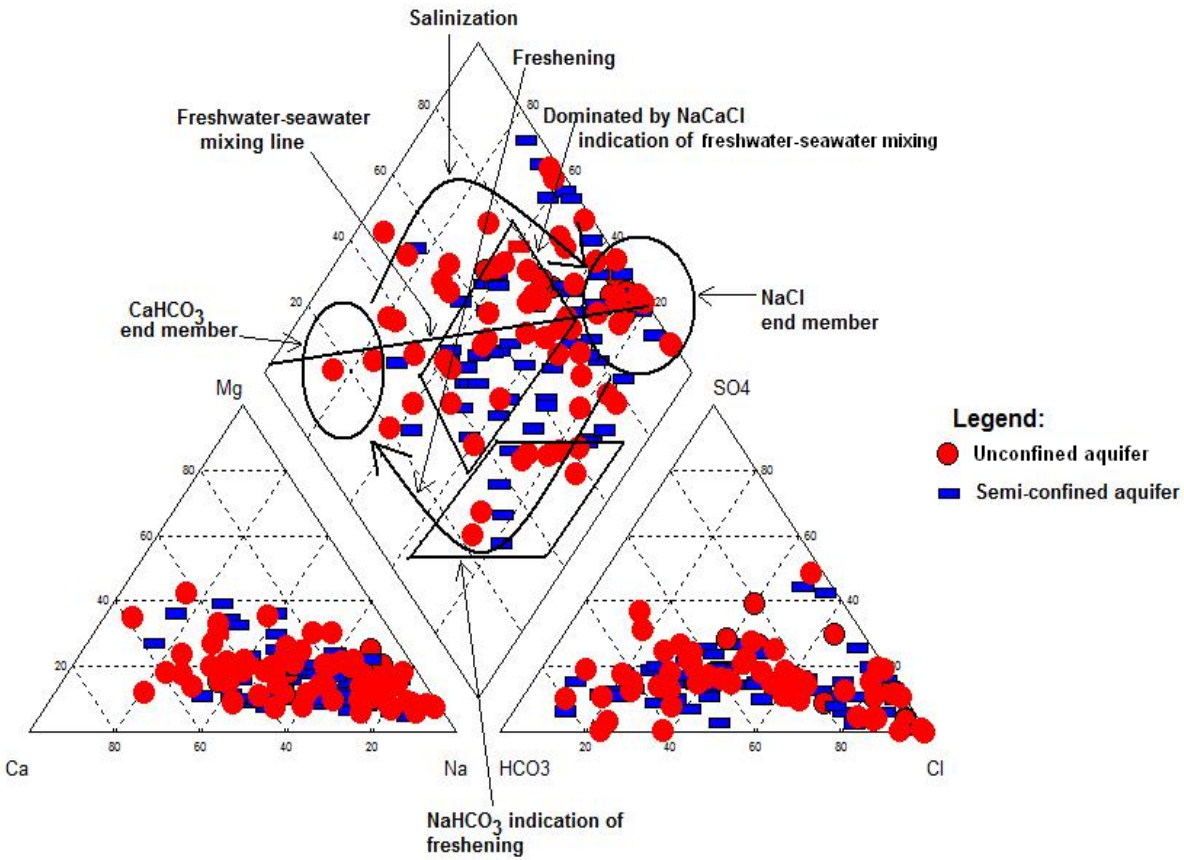


Hydrogeochemical Process

- High enrichment of Na^+ and Cl^- near the coast gives an indication of seawater intrusion into the aquifer.
- The boreholes close to the coast have much higher Na/Cl molar ratios than the boreholes located further inland

Chemical analysis – Major Cations and Anions

Piper diagram with classification of major ions and groundwater types in the study area



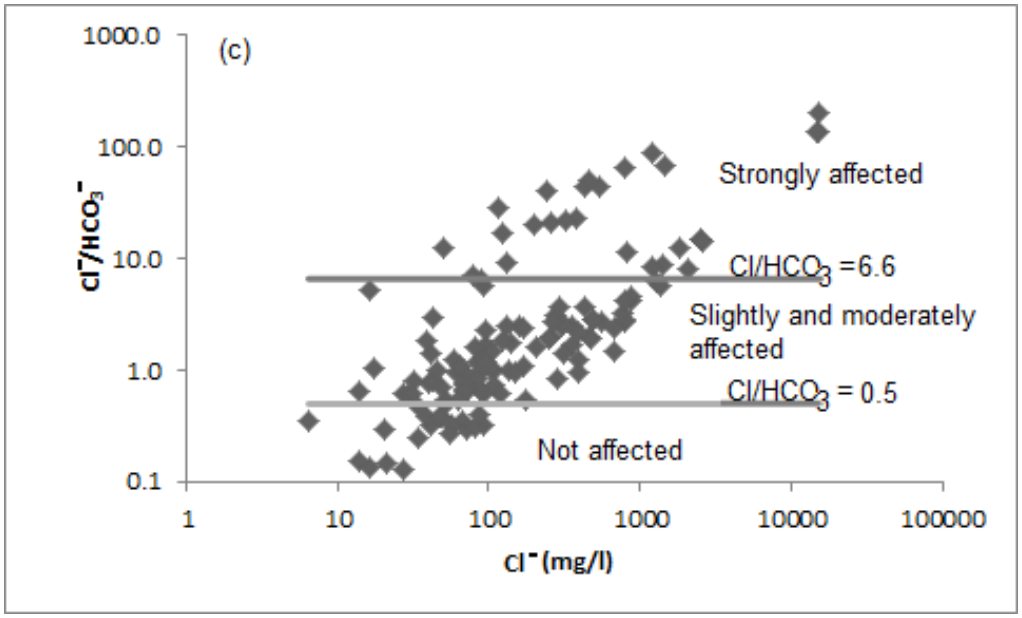
Hydrogeochemical Process

- In general, the concentration of cations decreases in the order Na>Ca>Mg>K and of anions in the order $Cl>HCO_3>SO_4>NO_3$.

- Correlation analysis indicates that most of the ions are positively correlated. The reasonably good correlation among the ions especially Na^+, Cl^-, and Mg^{2+}, indicates that such ions are mainly derived from the same source of saline waters.

- This implies that the salinization of the study area occurring near the coastline is associated with seawater.

Chemical analysis – Major Cations and Anions



Scatter diagram of log Cl^-/HCO_3^- ratio versus Log Cl^- (mg/l) (Mtoni et al., 2012)

- The ratio of Cl/HCO3 ranges between 0.13 and 198.70. The effect of salinization of the groundwater was classified using the Cl-/HCO3- ratio <0.5 for unaffected groundwater, 0.5–6.6 for slightly and moderately affected, and >6.6 for strongly affected groundwater (Revelle, 1941).
- Considering the values of Cl- concentration and the ratio Cl/HCO3, 14 % of groundwater samples are unaffected, 63 % of groundwater samples are slightly or moderately affected and 23 % are strongly affected by the saline water.
- 64 % of unaffected water samples are from boreholes/wells drilled away from the coastline (>2 km) and are characterized as fresh groundwater, whereas 67 % of strongly affected water samples are from the wells drilled towards the coastline (<2 km).

Sources of Nitrate pollution

Unplanned settlement along Msimbazi River

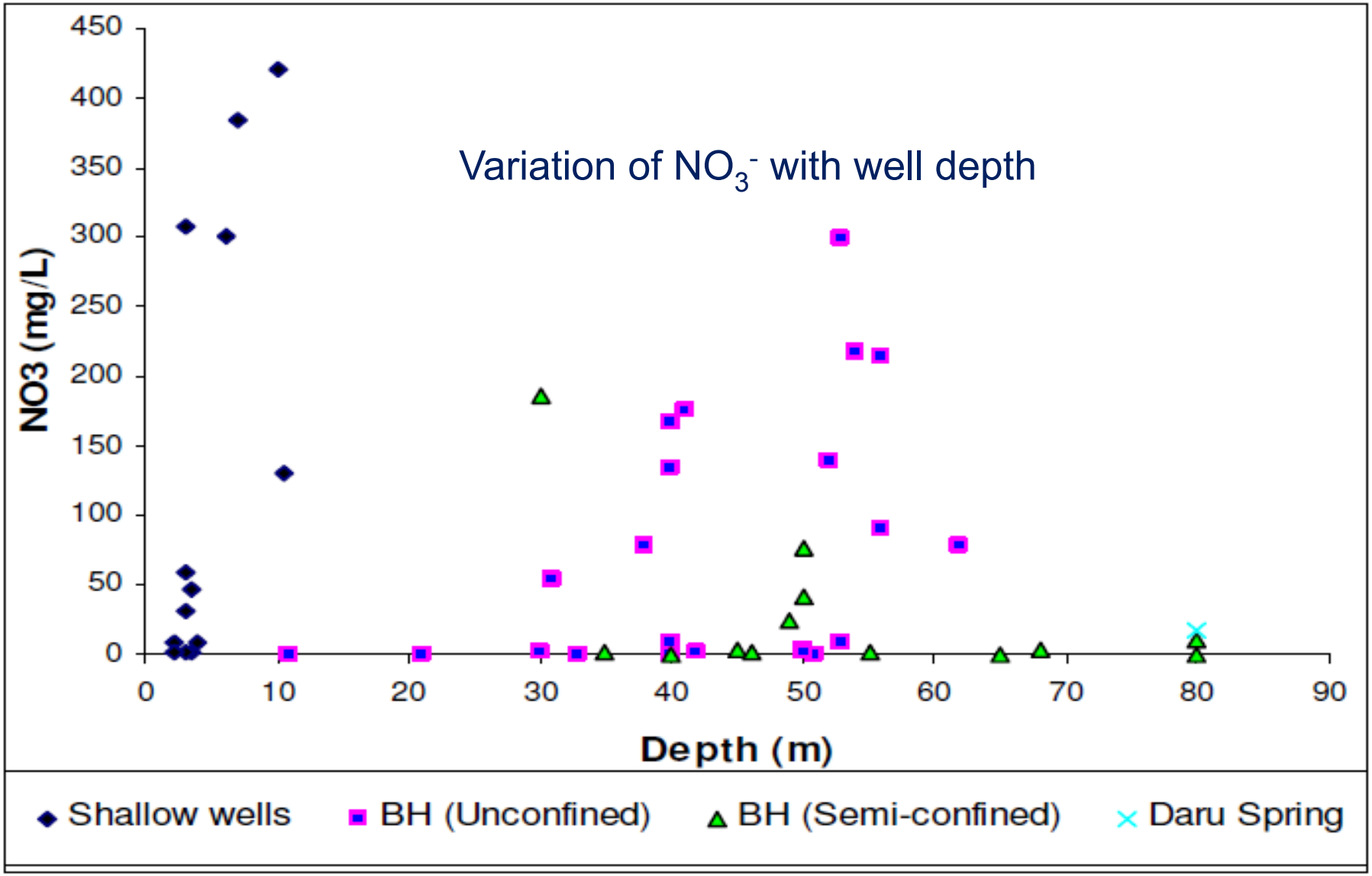
Sources of Nitrate pollution

Vingunguti open dump in Dar-es-Salaam City

Statistical descriptive for physico-chemical parameters of groundwater (in mg/L) in the study area

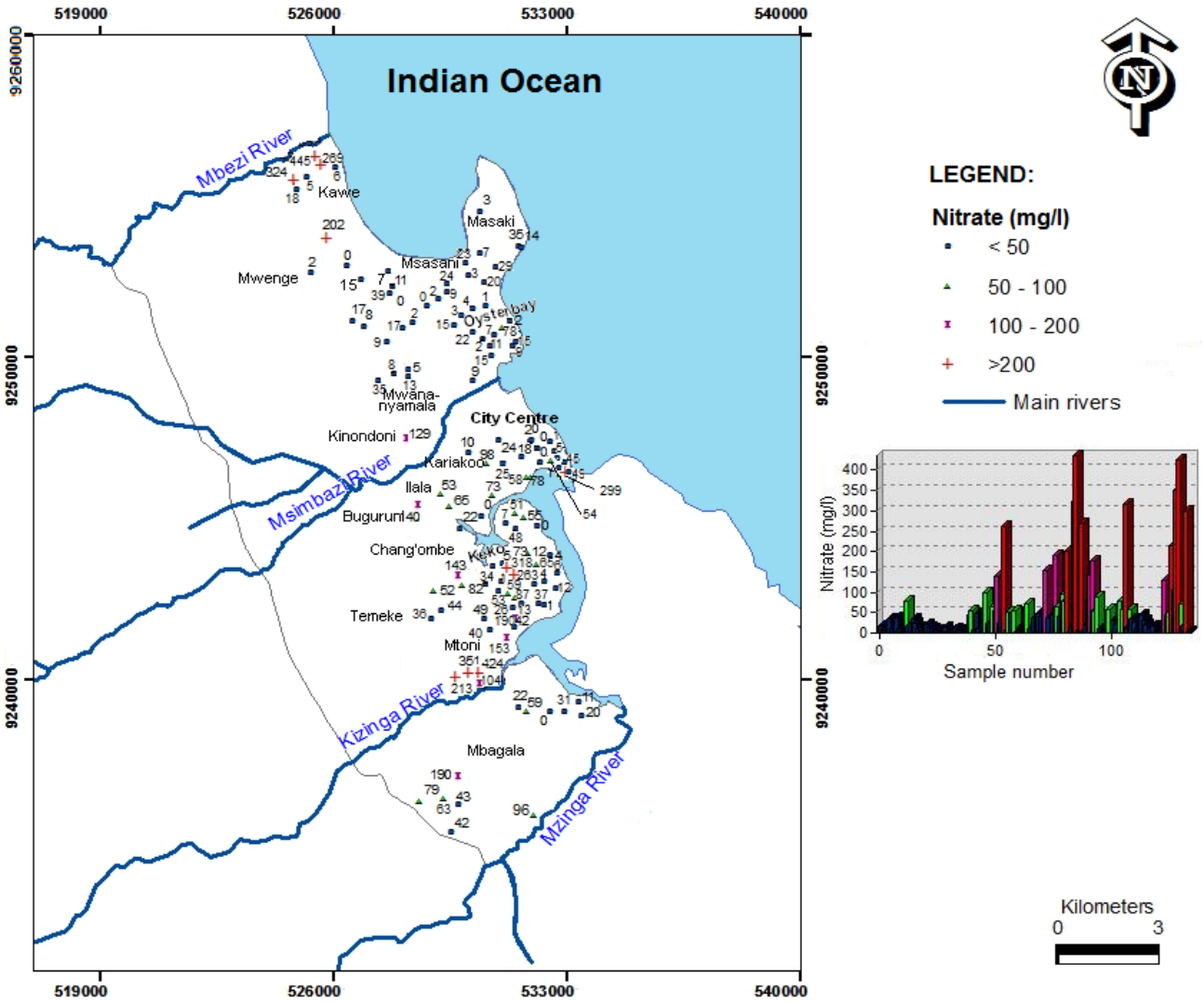
	Min	Max	Mean	Median
Na^+	14	1317	261	145
K^+	2	158	19	11
Ca^{2+}	2	444	67	37
Fe^{2+}	<0.01	15	1.50	0.2
Mn^{2+}	<0.01	3.80	0.55	0.3
Mg^{2+}	2	572	48	19
NH_4^+	<0.01	21.53	0.7	0.1
Cl^-	19	3603	427	240
SO_4^{2-}	2	475	112	57
HCO_3^-	<1	642.94	207	153
NO_3^-	<0.01	**421.20**	81	21
pH	4.80	7.7	6.6	6.7
EC(µS/cm 25°C)	230	11020	1803	1299
T(°C)	24.6	30.4	27.6	27.9
TDS(mg/L)	171	6902	1215	876

Nitrate Pollution in Dar es Salaam Aquifer



Groundwater pumping from shallow well

Nitrate distribution in the study area



- Nitrate levels of 50–100 mg/l within the City Centre can be related to the leaking from the unrehabilitated aging sewerage system.

- Nitrate values of 100–200 and >200 mg/l in dense informal settlements reflect the existence of high to very high density of pit latrines, respectively.

- A study conducted by 5 years later reported a maximum value of nitrate of 421 mg/l in Mbagala area Mjemah (2007).

- The current study has shown values of nitrate ranging from 0 to 435 mg/l, the maximum valueobserved at Kawe (Mtoni et al., 2012).

Conclusion

- Results from the hydrogeochemical investigation in the study area indicate that the Dar es Salaam quaternary coastal aquifer (DQCA) is experiencing contamination primarily by seawater intrusion due to over-exploitation and the use of on-site sewage disposal systems, in particular pit latrines and septic tanks

- In general, the concentration of cations decreases in the order Na>Ca>Mg>K and of anions in the order $Cl>HCO_3>SO_4>NO_3$.

- However, HCO_3^- dominates over Cl^- in some samples. Correlation analysis indicates that most of the ions are positively correlated. The reasonably good correlation among the ions especially Na^+, Cl^-, and Mg^{2+}, indicates that such ions are mainly derived from the same source of saline waters.

- This implies that the salinization of the study area occurring near the coastline is associated with seawater.

Conclusion…

- The upper aquifers are strongly affected by pollution as evidenced by high NO_3^- of over 50 mg/L. The high NO_3^- in the upper aquifer is indicating that domestic sewage and urban agricultural practice seriously affect groundwater. In addition, there are other anthropogenic sources of pollution, such as leakage from crude dump sites.
- Groundwater pollution in Dar es Salaam is due to both point and diffuse sources:

➢ The point sources include

- the on-site sanitation facilities. Where, about 90% of the population in the City of Dar es Salaam use this disposal systems i.e. pit latrines and septic tank systems
- infiltration from waste stabilization ponds, solid waste dumpsites,
- underground fuel storage facilities (such as petrol stations),
- industrial establishments (small and large scale) and other commercial points.

➢ The diffuse sources include activities like;

urban-agriculture (vegetable growing and chicken/pigs husbandry).

Recommendations

- Application of rational groundwater management practices, including the decrease of pumping rates, is crucial in attaining the sustainability of groundwater resources in the study area.

- Establishing a groundwater monitoring program close to the coast is equally important, based on which, measures may be taken to avoid the advancement of seawater intrusion on a large scale.

- However, the study recommends further investigations by use of geochemical isotopes. These are important tools in coastal-aquifer studies because they provide a means to differentiate among alternative sources of saline water.

- Tide gauge records in Dar es Salaam is very useful for assessing the sea level rise. Long records of at least 50 years are needed to give conclusive evidence of sea level rise, because of the influence of natural variability in the climate system

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I would like to recognize the contribution in this research from my colleagues namely:

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[a]National Environment Management Council (NEMC), P.O. Box 63154, Dar es Salaam, Tanzania
[b]Laboratory for Applied Geology and Hydrogeology, Ghent University, Krijgslaan 281 S8, 9000 Ghent, Belgium

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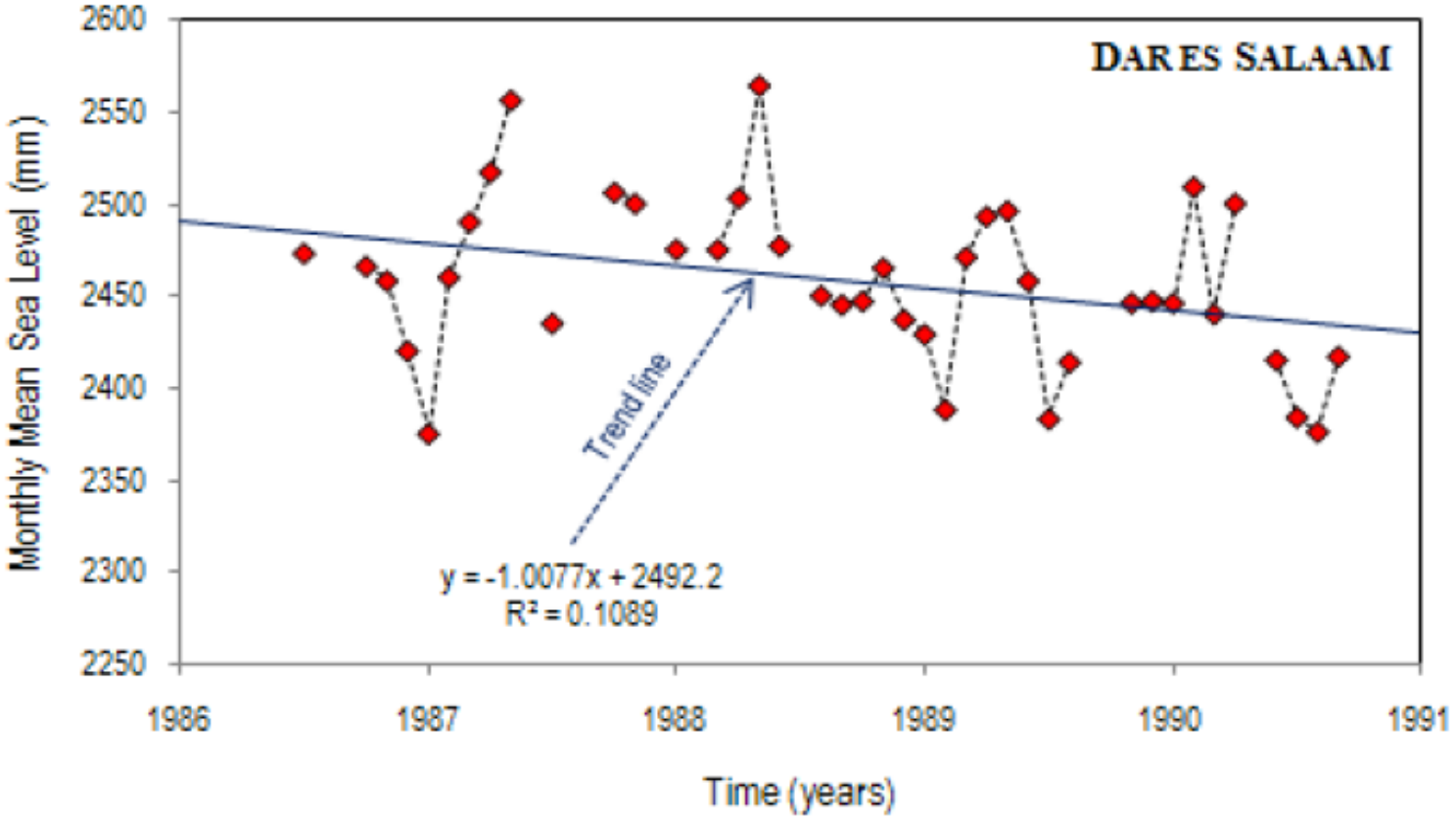
- Walraevens, K., and Van Camp, M., 2005. Advances in understanding natural groundwater quality controls in coastal aquifers, 18 SWIM. Cartagena 2004, Spain, pp. 451-460


THANK YOU

Sea level rise



Four years of monthly mean sea level tide gauge measurements for Dar es Salaam station (06°49.2'S, 39°17.3'E), Tanzania (Source: University of Hawaii Sea Level Center, UHSLC). (Cited in Kebede and Nicholls, 2010)