Saltwater intrusion in the quaternary aquifer of the Dar es Salaam region, Tanzania

Yohana Mtoni\textsuperscript{1,2,*} and Kristine Walraevens\textsuperscript{1}

\textsuperscript{1} Laboratory for Applied Geology and Hydrogeology, Ghent University, Ghent, Belgium.\textsuperscript{2} National Environment Management Council (NEMC), Dar es Salaam, Tanzania

* Email for corresponding author: yohanaenock.mtoni@ugent.be

ABSTRACT

Groundwater is a last-resort source of domestic water supply in Dar es Salaam City because of the scarcity of surface water sources. The Tanzania Government, Non Government Organizations (NGOs), Community Based Organizations (CBOs) and international aid organizations have promoted the drilling of boreholes. From 1997 until the present, boreholes drilling has increased tremendously and the trend is expected to increase even more in the future. Initial assessment of the current state of water quality indicates that the coastal aquifers are vulnerable to saline intrusion. In some areas, overpumping of the groundwater has resulted in encroachment of sea water into the coastal aquifers. Water samples from Mikocheni, Oysterbay, Msasani, Masaki and City Centre areas show elevated chloride, sulphate and sodium concentrations. Using Stuyfzand (1986) water classification method, over 50 percent of the samples showed the type of fresh-brackish to salt and extremely hard. Residents depend on the shallow aquifer at less than 15 m, because at this depth the water is relatively less saline. The saltwater interface is likely to be moving inland on seasonal basis and some boreholes become more saline in late summer. The growing human population in and around the investigated areas has had an adverse impact on the water in the shallow aquifer through, among other factors, indiscriminate abstraction of water without knowledge of the aquifer's capacity. In order to prevent further deterioration of the aquifer, there is a need to establish an inventory of the wells, conduct proper pump tests and geochemical characterization to ascertain the capacity of the shallow aquifer and understand the processes affecting the overall quality of the groundwater.

Keywords: coastal aquifer, salinization, Dar es Salaam, Tanzania, overexploitation

INTRODUCTION

The benefits of groundwater are obvious. In Dar es Salaam City, for example, residents benefited hugely from groundwater during the severe drought in 1997 which affected the surface water supply. Since then groundwater use in the city shows an increasing trend and currently over 50 percent of residents in Dar es Salaam City relies on groundwater supply. However, uncontrolled development of both shallow and deep aquifers, along with climatic circumstances, increases the risk of seawater intrusion. This study makes a preliminarily assessment of water quality in selected areas near the coastline, especially in view of sea water intrusion.

Background

Study Area
The study area extends from Mbezi River and Msasani Bay in the north to the area between Kizinga and Mzinga Rivers in the south (Figure 1). In the east the study area is bounded by the
Indian Ocean and Mzinga Creek. The Msimbazi River originating from Pugu Hills about 35 km west, divides the study area into north and south parts.

**Fig. 1. Area of study, geology and location of groundwater samples.**

**Hydrogeological Setting**
The geology of the study area is characterized by Quaternary sediments which underlie mainly the coastal plain of Dar es Salaam region (Figure 1). The terrace sandstones of the Quaternary System are more extensive in the central and southern parts of Dar es Salaam Region. Neogene sandstone formations interbedded with siltstones and mudstones occupy the upland area south and west of the City Centre.

In the Quaternary formation, the groundwater has been developed very actively, and a large number of boreholes and open wells are installed in both the upper unconfined sand aquifer and the lower semi-confined sand aquifer, that are both separated by a clay aquitard (Mjemah, 2007). Near to the coastline there is a limestone aquifer comprising the reef limestone of Pleistocene to Recent age. Although locally each of the above aquifers is significant, both sandy aquifers are most important for groundwater supply in Dar es Salaam, compared to the limestone aquifer. Most boreholes are drilled at depths ranging between 20 to 80 meters. However, in areas close to the ocean such as Msasani, Oysterbay and City Centre, drilling beyond 15 to 20 meters is likely to encounter saltwater.

**General Climate**
Dar es Salaam Region has a tropical climate with four distinct seasons (Msindai, 1988). Groundwater recharge occurs during short rains (September to December) and long rains (March to May). During the short rains the rainfall and evapotranspiration vary from 600 mm to
1200 mm and 1500 mm to 1750 mm respectively. Similarly, during long rains the rainfall and evapotranspiration vary from 200 mm to 2200 mm and 1200 mm to 1500 mm respectively (Temple, 1970). It is only in April that the amount of monthly rainfall exceeds monthly evapotranspiration (Msindai, 1988). The dry season begins in June until October, and is characterized by little rainfall. Temperatures are high in November through February during which the temperature can rise up to 35°C. It is relatively cool between May and August with average temperature about 22°C.

METHODS OF DATA GENERATION

A first field campaign was conducted in August 2009 and several boreholes were visited in two pilot areas (locality I and locality II). The first series of groundwater samples (Figure 1) were analysed at the Southern and Eastern African Mineral Centre (Dar es Salaam, Tanzania) and at the Laboratory of Applied Geology and Hydrogeology (Ghent University, Belgium) respectively for locality I (16 samples) and locality II (40 samples) (Figure 1). More data (18 boreholes) associated with locality I were collected from well drilling reports from Drilling and Dam Construction Agency (DDCA).

RESULTS

From the Piper plot in Figure 2 (locality I), it was deduced that the majority of samples are Sodium-Chloride type and Sodium-Chloride-Bicarbonate type. Other samples showed diverse chemical compositions. Using Stuyfzand classification (1986) method, the following classes exist: fresh water (15%), fresh-brackish (9%), brackish (38%), brackish-salt (29%) and salt (9%). The majority (56%) of the samples showed the type of extremely hard whereas 23% and 21% respectively are very hard and hard. Groundwater was classified into five categories by subtype, i.e., Sodium-Chloride, Sodium-Bicarbonate, Calcium-Bicarbonate, Magnesium-Bicarbonate and Sodium-Mix.

![Figure 2. Piper plots with representation of major ions in groundwater in the study area.](image-url)
Based on the Piper diagram (locality II), groundwater types are mostly Sodium-Chloride, Sodium-Calcium-Chloride-Bicarbonate, Sodium-Calcium-Bicarbonate-Chloride, Sodium-Calcium-Chloride, Sodium-Chloride-Bicarbonate, and Calcium-Sodium-Chloride-Bicarbonate. The dominant cation is Na⁺ which is found in both aquifers. In the lower aquifer it is present as NaCl water type while in the upper aquifer as NaMix. Ca²⁺ and Mg²⁺ are found in the upper aquifer with HCO₃⁻ or with Mixed anions. In the lower aquifer, locally the CaCl and MgCl water types are found. As regards to the subdivision into main water types according to the Stuyfzand (1986) classification, the following classes exist: fresh water (65%), fresh-brackish (12.5%), brackish (20%) and brackish-salt (2.5%). The major water subtypes are represented by Sodium-Chloride, Sodium-Bicarbonate, Calcium-Bicarbonate, Sodium-Mix and Calcium-Mix.

DISCUSSION AND CONCLUSIONS

Preliminary evaluation of salt water pollution in aquifers in two pilot areas (localities I & II) has shown that there exists sea water intrusion in sites close to the coastline. The coastal aquifers are characterized by the interactions between continental and marine conditions (Mjemah, 2007). In the close proximity to the coastline, this situation has resulted in salinization, and in some localities freshening of saline aquifers. Water samples from boreholes at the City Centre and along the cliffed coastline from Oysterbay to Msasani and Masaki areas, show elevated chloride, sulphate and sodium concentrations. This has been induced by the presence of connate seawater and/or overexploitation of aquifers.

Cation exchange due to freshening is stronger in the shallower layers of the groundwater reservoir. The Na⁺ of the clay is exchanged with the Ca²⁺ of the water, which renders a NaHCO₃ water type. In areas where freshening has progressed further, the CaHCO₃ type of the infiltrating water is preserved. An example of groundwater quality evolution occurs in Kurasini, Changombe and Temeke areas. In these localities, zones of different water type occur, that trend in the direction of groundwater flow, from west to east. Groundwater types are from the inland toward the coast: CaMix, NaMix, and NaCl, showing increasing influence of salinity.

REFERENCES


