Physical and societal challenges in groundwater security in coastal East Africa: case studies in the Comoros Islands, Kenya and Tanzania

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1. Abstract

African coastal regions are expected to experience the highest rates of population growth in coming decades. Fresh groundwater resources in the coastal zone of East Africa (EA) are highly vulnerable to seawater intrusion and increased water demand is leading to unsustainable and ill-planned well drilling and abstraction. Wells supplying domestic, industrial and agricultural needs are, in many areas, too saline for use. Climate change, including weather changes and sea level rise, is expected to exacerbate this problem. The multiplicity of physical, demographic and socio-economic driving factors makes this a very challenging issue for management. At present the state and probable evolution of coastal aquifers in EA are not well documented. The UPGro project 'Towards groundwater security in coastal East Africa' brings together teams from Kenya, Tanzania, Comoros Islands and Europe to address this knowledge gap. An integrative multidisciplinary approach, combining the expertise of hydrogeologists, hydrologists and social scientists, is investigating selected sites along the coastal zone in each country. Hydrogeologic observatories have been established in different geologic and climatic settings representative of the coastal EA region, where focussed research will identify the current status of groundwater and identify future threats based on projected demographic and climate change scenarios. Researchers are engaging with end users as well as local community and stakeholder groups in each area in order to understanding the issues most affecting the communities and identify sustainable strategies for addressing these.

2. Introduction & Objectives

Groundwater resources in the coastal zone of East Africa are at risk due to:

- Increased demand linked to rapid population growth leading to unsustainable and ill-planned well drilling and abstraction;
- Sea water intrusion;
- Climate change which is likely to cause rising sea levels;
- Low recharge rates due to altered precipitation and temperature.

The general objectives of the UPGro project are:

- To establish the current status of groundwater resources in the coastal zone of the East African;
- To develop coastal groundwater monitoring networks as well as research networks in the region;
- To identify issues with past practices and to work towards more effective and sustainable approaches.
- Provide a sustainable research platform for long-term research in the EA region.

3. Methodology

The emphasis of this 12-month research programme is on establishing pilot sites (groundwater observatories), compiling existing data sets and strengthening research networks in each country. Partners are extending the networks to ensure a balance of expertise (hydrogeologists, hydrologists and socio-environmental researchers) and representatives of stakeholder groups to ensure a throughflow of information between researchers and end-users. The ongoing baseline work enables identification and characterisation of key sites in each country (in terms of socio-environmental and hydrogeological issues) in which long term observatories are being established. This forms the basis of a further funding application to sustain this investment for the long term and build on the initial research capital.

The research is organised in 3 Work Packages (WP):

- **WP 1**: assess the current hydrogeological conditions and the aquifer vulnerability to saline water intrusion, aquifer properties, groundwater flow and quality and recharge and abstraction rates;
- **WP 2**: hydrological monitoring and modelling of the impacts of environmental change (precipitation, evapotranspiration, land use recharge ;
- **WP 3**: assess the socio-cultural-economic and environmental issues affecting ground water resources management.

4. Research locations

Research is taking place in 3 countries in the East African/Western Indian Ocean region: the Comoros Islands, Kenya and Tanzania (Figures 1 and 2). In the Comoros, 3 strategic sites have been instrumented on Grande Comore island (Ngazidja), which is composed of young volcanic rocks: Vouvouni (SW), Hahaya (NW) and Oichili (E). In Kenya, an urban site in Kilifi County, north of Mombasa, largely composed of coral platform rocks was identified and instrumented. In Tanzania, a largely rural site in Kilwa district, composed of recent coral rocks as well as older clastic sediments has been instrumented.

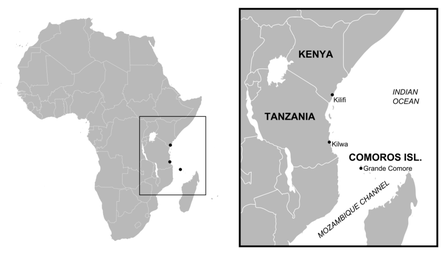

Figure 1: Location of research sites in East Africa: Grande Comore Island in the Comoros Archipelago, Kilifi in Kenya and Kilwa in Tanzania.

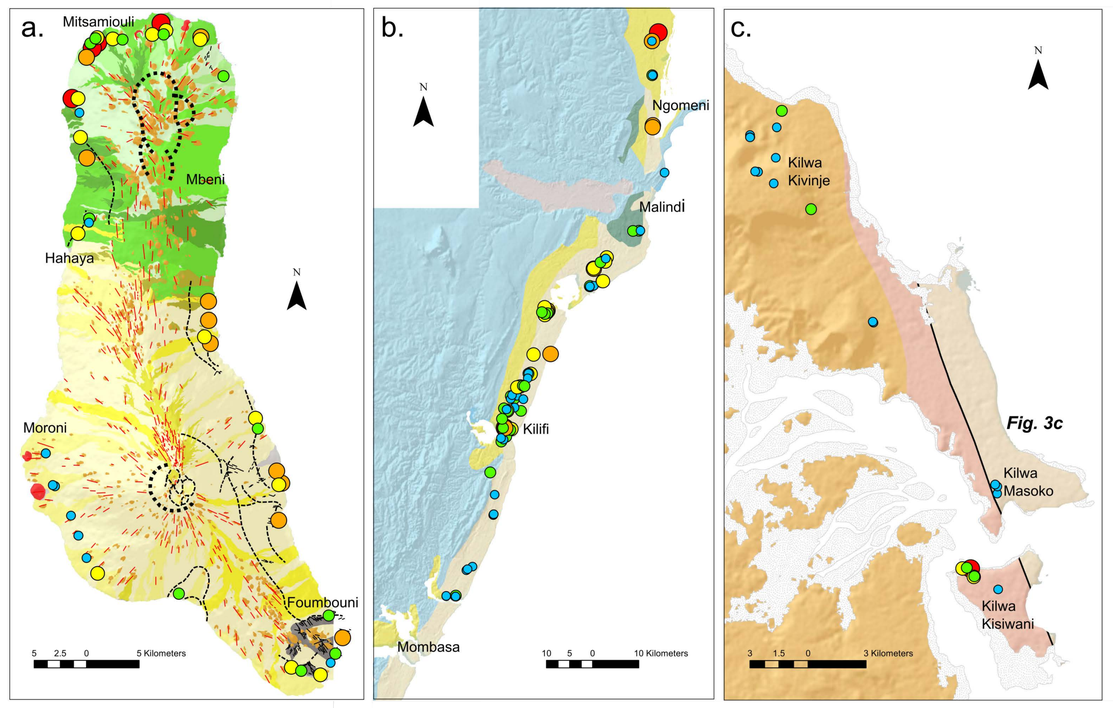

Figure 2: salinity (TDS) measured in boreholes and wells of the study areas; (a) Grande Comore, (b) Kilifi region and (c) Kilwa region.

Figure 3: (a) A well drilled in recent lava flows (Comoros) (b) a modern large diameter well (Kilifi) (c) an ancient well (Kilwa Kisiwani)

5. Initial results

Research activities across WP 1-3 are on-going. Here, the first results from WP1 regarding the current status of groundwater resources in the studied sites in the three countries, are presented.

Borehole surveys have revealed a large number of existing wells, either used for public/community drinking water supply, domestic drinking water or domestic irrigation. Most of them are traditional large diameter wells (figure 3) that penetrate only a few metres below the water table. To date (well inventories are not yet complete), the majority of wells display high levels of salinity, above the recommended drinking guideline of 1000 mg/L (figure 2). Small diameter boreholes that penetrate deeper below the water table often show the highest salinities. Syntheses of aquifer hydrodynamic properties reveal very high transmissivities and hydraulic conductivities, ranging 10^{-3}-10^{-1} m^2/s and 10^{-3}-10^{-2} m/s, respectively. Specific yield is often higher than 10^{-2} indicative of generally unconfined conditions.

Geophysical surveys, including electrical resistivity tomography (ERT), were carried out across the studied area (figure 4). While recent volcanic rocks of Grande Comore show generally higher resistivities due to absence of clays, all sites display widespread saline intrusion, marked by a gently dipping freshwater/saltwater interface (the interface typically occurs at less than 50m below sea level at 1-2km from the coast. Results confirm both the high salinity gradient with depth observed in wells/boreholes and the large spatial variations of measured salinities due to differences in well depths. It also highlights the difficulty in mapping groundwater salinity and the importance of vertical information to enable proper 3D interpretation.

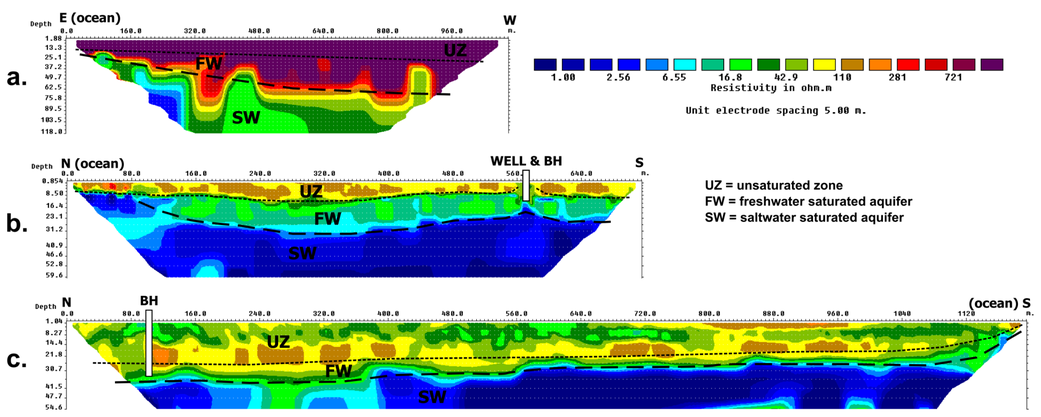

Figure 4: Inverted resistivity distributions for (a) Vouvouni area, Grande Comore, (b) Kilwa Kisiwani island, Tanzania, (c) Pwani University, Kilifi, Kenya.

Time-series (*f*=15 min) of groundwater head, salinity (water electrical conductivity (EC)) and temperature have been recorded since August 2013 in selected wells at each site. Results reveal contrasting hydrogeological behaviour across the regions, particularly regarding aquifer response to external forcings:

- In the basalt lava flows of ***Grande Comore***, heads and EC fluctuations are primarily controlled by the tidal signal, and, to lesser extend by pumping.
- In the coral limestones of ***Kilifi***, heads and EC are primarily controlled by seasonal fluctuations, i.e. the contrast dry/wet season and at a lesser extend the tidal signal for groundwater heads.
- In the clastic sediments of ***Kilwa***, heads and EC fluctuations are primarily controlled by water abstraction, with an observable increase in salinity during pumping, and secondarily by seasonal (wet/dry season) changes.

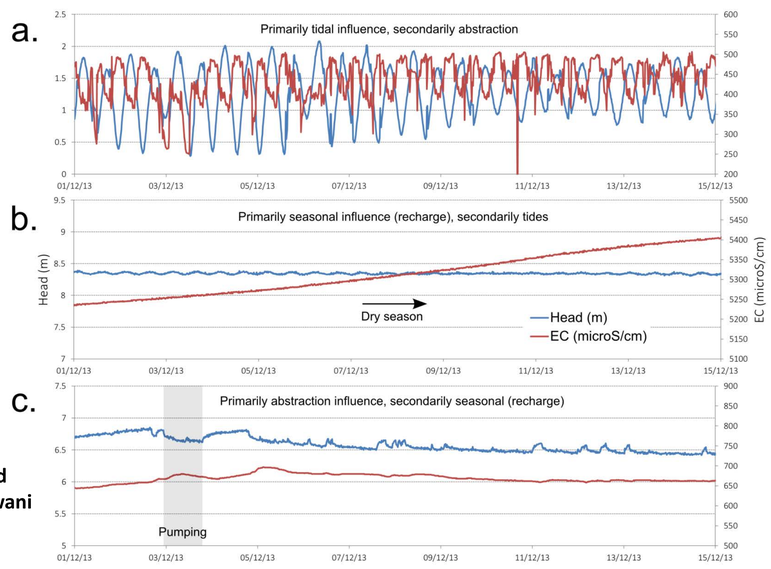

Figure 5: Head and EC fluctuation in instrumented borehole of (a) Vouvouni, Grande Comore; (b) Pwani University, Kilifi, Kenya and (c) Kilwa Masoko, Tanzania

6. Conclusions, further work and funding

Initial results on the hydrogeological functioning of these coastal aquifers suggest that, even though all aquifers across the 3 regions are similarly productive, with broadly similar spatial patterns of seawater intrusion, the temporal dynamics of salt transport is strongly controlled by the geological setting.

It also suggests that the response of fresh groundwater to long-term climate and anthropogenic changes is expected to be significantly different across the region.

Parallel work is investigating in detail the groundwater external drivers including climate and land use as well as the resilience of both water management and communities to expected change.

The current research partnership is being extended to additional countries (eg. Madagascar and Mozambique). Future funding will allow implementation of longer term research encompassing the physical, social and cultural diversity of the coastal fringes of Eastern Africa and the Mozambique Channel .

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