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Evaluation Report of findings from Activity 2.2 "Development of methodologies for exploring CC vulnerability scenarios", Project ACC DAR

Subject of evaluation:

A) Kassenga G. R., Gervas J., Ruhinda E. & Ligate F. (Ardhi University, Dar es Salaam, Tanzania, School of Environmental Science and Technology), *Monitoring seawater intrusion in the coastal aquifer of Dar Es Salaam*
B) Coviello M.T.[1], Faldi G.[2], Rossi M.[1], Sappa G.[1], Vitale S.[1] (1 – DICEA, Sapienza University of Rome, 2 – DIAEE, Sapienza University of Rome), *Analysis of the sensitivity to seawater intrusion of Dar es Salaam's coastal aquifer with regard to climate change* – Working Paper, April 2013

1. Introduction

The two Reports subject to evaluation deal with some results of the Activity 2.2 (Exploring Climate Change vulnerability scenarios to seawater intrusion) of the ACC Dar project "Adapting to Climate Change in Coastal Dar es Salaam, Ref. EC Grant Contract No2010/254-773).

The Activity 2.2 has been developed within the framework of the WP2: Develop Methodologies for Designing Adaptation Initiatives.
The WP2 aims at developing methodologies for supporting Dar's municipalities in integrating adaptation initiatives in its Urban Development and Environment Management plans and strategies.

The Activity 2.2 is further described as in the following:
Methodology development will capitalize on existing tools, technologies and established expertise in Dar municipalities, focusing on the CC issues of major concern for the target population. In addition, given the current gaps in climate information and the consequent uncertainties associated with CC impacts at the local level, the project will apply the principle that adapting to short-term climate variability and extreme events can serve as the basis for reducing vulnerability to longer-term climate change. A thematic team will investigate and model specific environmental phenomena (e.g. coastal erosion, sea water intrusion, flooding, etc.) that are already contributing – and will increasingly contribute as CC progresses – to the degradation of those natural resources on which a large part of peri-urban livelihoods depend.

The first research team involved in the Activity 2.2 belongs to the Ardhi University, Dar es Salaam, Tanzania, while the second team belongs to the University Sapienza of Rome (DICEA and DIAEE Departments)

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The former team did not prepared any Working paper: thus, the present evaluation report is only based on the presentation made during the Session 2 of the Workshop of ACC Dar Project held in Rome the 20th of April 2013: for the sake of the evaluation the presentation will be termed in the following as Report A.
The latter team prepared a Working Paper, which will be referred to as Report B.

2. Evaluation Methodology

To the aims of the Activity 2.2 the Report A deals with the following main topics:

- Borehole monitoring methods
- Reconnaissance survey of Monitoring boreholes
- Long-term monitoring campaign
- Short-term monitoring campaign
- Data Compilation, Communication and Analysis
- Benefits of groundwater monitoring
- Conclusion and Recommendations

The Report B presents the results according to a few main chapters:

1. Introduction, Scope and Motivation
2. Approach and Methods
3. Findings
4. Conclusions
5. Limitations
6. Recommendations

I chose to not discuss the two reports separately, given that most of the results presented in the Report B are strictly connected to the type of data collected according to the methods illustrated in the Report A. The reader has to be aware, when examining the two reports, that Report B depends on some extent on the methodological assumptions on which the survey campaigns have been set (Report A).

3. Findings and discussion of findings

3.1 Achievement of objectives

The overall objective of Report A was to describe the activities related to the design of a borehole monitoring network, the geo-referentiation of the boreholes and the execution of field measurements.

The overall objective of the Report B was "*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. More specifically, the study aims to assess the local*

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hydrogeological and geochemical dynamics determining the phenomenon, as well as the anthropogenic and climatic factors that have influenced its present condition".

Even with the problems and limitations, which will be discussed in the following paragraphs, the targets of the two activities have been reached. Therefore, the reports show descriptions of field activities and elaborations in line with the objectives of the Project and the specific Activity to which they refer.

3.2 Efficiency of the methodological approach in the projection of the monitoring net

The situation of Dar es Salaam is not very different from that of many regions of Europe, where, in spite of application of the Directive 2000/60, there are still many difficulties in putting in practice even simple correct monitoring protocols. In many countries monitoring activities still rely on nets, which are not purposely projected.
It is obvious that, without an important financial investment for setting up a monitoring net that should be designed ad hoc, one can only work with what is available. Thus, generally, private wells with pumps or abandoned wells are firstly used.

In the case of Dar es Salaam, being economically unfeasible (without taking also into account the necessary period of time for select correct location and type of wells to be drilled and opportunely cased) to drill new wells or make their requisition from privates or public bodies to the aims of monitoring, the only available wells are those used by people: these wells normally have a number of problems. Commonly, one of these problems is that they are not authorized, or, if they are, the characteristics of the wells are mainly unknown.

Consequently, the first problem for both Reports arises from the type of wells chosen for realizing the monitoring net and to carry out the sampling in the two surveys.

To make the situation more difficult there is the fact that the monitoring net is aimed at controlling a coastal aquifer. Really, groundwater salinization is a long-term phenomenon, which effects, to be clearly understood, have to be examined on large time and spatial scales: moreover, the phenomenon needs the adoption of complex monitoring plan projected on the base of a reliable knowledge of the aquifer/s.

Measures to be implemented for the study (and management) of salinized groundwater require high capital and time investments and can be afforded only by involvement of regional authorities. The problem cannot be solved in a little span of time: restoration of pristine water quality requires a long-term effort of management with feedback on monitoring by using optimization of pumping areas allocation and equilibration of water demand. Monitoring of a coastal aquifer is an only apparently easy task: however, it does cannot rely on clearly outlined protocols, and definition of management practices, at international level, remains an open question.

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With this in mind I have to say that the team of Dar has realized a very difficult job: everything about the adversities encountered in the search and selection of measurement points and in the maintenance of the monitoring net, built with great difficulties, was to be expected and will reoccur in the future.

Despite these efforts, which have been produced with a methodological approach sufficiently correct, at least with reference to the availability of only one type of wells, it should, however, be aware that the network has big limitations regarding the data that it can provide.

As a consequence, the gaps in the interpretation and the weaknesses that I can deduce reading the Report B depend mainly on the fact that the data used are mostly unreliable to the object of the assessment of groundwater salinization condition.

Correctly in the Report B the Sapienza University team says:
……..monitoring campaign was mainly based on private wells with unknown technical features (pump depth, number and depth of screens, etc.)
……and not available for measurements along the aquifer depth (wells equipped with pumps and pipes)…..

3.2.1. Recommendations for the 2nd level net

Everything considered, the network prepared by the team of Dar es Salaam (Report A) can be considered as a network of 2nd Level.

This type of network can be of utility if we consider that it refers to the quality of water in use. Ground waters obtained by pumping are those that people actually use and that determine their quality of life: however, this information is very different from that obtained by a network of 1st level, where wells are not equipped with pumps and are accessible to a wide variety of investigations.
The 1st level network needs for hydrogeological studies and for the purposes of management, targets that the a 2nd level network cannot reach.
In any case, I suggest to maintain this net for future surveys: the information gained up to now by this type of net constitutes a reference point for evaluating future evolution of groundwater quality: however, is very important to try to repeat measures in the same wells and confiscate those eventually and gradually abandoned because of salinization.

The Report B says:
….as regards the seawater intrusion analysis, the study was able to identify the areas where groundwater salinization can (I would have said could) be linked to seawater intrusion;
and gives an useful suggestion:
…. these areas should become priority areas for vulnerability assessment and adaptation action implementation…..

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If we abandon this net in favor of another net consisting of different wells located elsewhere, all the efforts made will lose their value. Proof of this is the part of the Report B in which the team of Sapienza tried to use historical data *(……a lack of systematic historical data for the definition of a background condition…):* those data, obtained from wells located in different networks with irregular grid, in different locations, at different times and on parameters that appear randomly chosen, were mined to the maximum. However, the reliability of the information obtained remains questionable.

Thus, it is suggested, while keeping the measure points already selected, to increase the net only as to the number of wells, creating a denser grid.

In order to improve the effectiveness of information obtained from chemical analyses of the ground waters sampled by pumping wells, it would be appropriate to try to obtain information on the elevation of the pumps. This way, on the basis of existing hydrogeological information, you could probably get a distinction between wells draining the superficial aquifer and those draining the deeper aquifer.

The Report B includes the difficulties concerned with the doubts, which rise interpreting the chemical analyses:
……probably most of times the analyses concerned mixed ground waters coming from both the aquifer layers…

3.3 Seawater intrusion and its control

The existing net cannot allow the control of seawater intrusion, but only, as already said, give an indication of the quality of water used by people. As matter of fact, the wells included in the network reach one or the other of the aquifers existing or they short-circuit the two aquifers: this way, the information on the extent of seawater intrusion is unreliable.

To obtain this information, the team should realize a monitoring net of 1st level. A network of 1st level would be formed by monitoring wells completely windowed on only one of the aquifers; wells should be free from pumping equipment, thus allowing the descent of measuring devices (multi-probes) capable of recording in continuous or on discrete elevations the variations of the Electrical Conductivity and Temperature. Some very common probes can also record pH, dissolved oxygen and redox potential.

Moreover, these wells would be appropriate for locating transducers for measuring in continuous hydraulic heads in the fresh water horizon: this is the only way to obtain reliable piezometric maps in coastal aquifers. If wells intercept brackish thicknesses or even salt waters you can only measure environmental heads. which are not comparable among them.
One or two monitoring wells should be drilled purposely up to reach salt water beneath fresh water and transition zone; they should be extended for many meters into salt waters: they should

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be totally windowed along each aquifer thickness in order to reproduce the real distribution of groundwater in each aquifer.
Electrical Conductivity (EC) logs are at the base of the quantitative control of freshwater-saltwater equilibrium. Moreover, the quantitative control of seawater intrusion requires reliable measure of seawater level and its oscillations: this means that it is necessary to set a mareograph with annexed barograph. Obviously these measures are of paramount importance if the monitoring has also the target to control sea level rise due to climate change.

Such a topic is very difficult to synthetize in a few words and the same is true for possible protocols of monitoring and interpretation of data. You can find pieces of information on the final Report of EC COST Action 621, Groundwater management in karstic coastal aquifers:
http://bookshop.europa.eu/en/groundwater-management-of-coastal-karstic-aquifers-pbQSNA21366/?CatalogCategoryID=r2AKABstX7kAAAEjppEY4e5L

3.3.1. Seawater intrusion or salinization?

In the above mentioned book you can find a chapter dedicated to the problem of identification of the different possible sources of groundwater salinization:

…..Besides present seawater, groundwater salinization can derive from other natural salt sources or from human activities.
…………other sources, besides present seawater intrusion, contribute to salinization, the most common of which are:
- *old salt waters of marine origin;*
- *formation waters;*
- *natural salts (evaporate deposits);*
- *cycling wetting and drying;*
- *highly mineralized waters coming from geothermal fields;*
- *agricultural practices (use of fertilizers and irrigation with treated wastewater).*

From the graphs proposed in the Report B I forthwith realized that the chemical analysis of seawater sampled on the coast of Dar es Salaam and used as saline reference (end-member of mixing) was very peculiar.

In table I you can find the chemical analysis (average values of two samples)) of Dar es Salaam seawater (personal communication, Prof. G. Sappa) and of the typical present seawater. The mean Dar es Salaam seawater has been normalized to TDS of typical seawater to compare the concentration of main ions to those of the latter.

Note that Calculated TDS of (mean) Dar es Salaam seawater is different from that reported on the original analysis. Probably the TDS has not been measured by evaporation or it has been calculated by EC. In any case, giving that I do not have the total chemical analysis dataset, I

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suggest verifying the analytical correctness of all chemical analyses (error of analysis). Correctness of interpretation depends clearly from the correctness of laboratory analyses.

It is easy to recognize that the concentration of Calcium in the Dar es Salaam seawater (normalized to TDS of typical seawater) is more than three times the value in typical seawater, while the concentrations of Magnesium, Sodium and Potassium are lower.
The Na/Cl ratio is significantly lower than typical one (0.85) and Chlorides are in excess.
This seawater has not the chemical composition of typical seawater, rather resembling to seawater that has undergone a profound diagenesis. Since the analysis has been repeated two times, unless significant laboratory errors, we should rely on the values.

How to explain this mismatch?
This could mean that the sampling took place during a phase of extrusion of diagenized salt water coming from the (deeper?) aquifer (during a low tide?). In my experience this is more frequent than expected.
However, this poses a serious question as to the geochemical interpretation of data aimed at interpreting the salinization phenomena.

If the sampled seawater represents the salt water actually present into the aquifer, this means that the source of salinization for freshwater could not be, in many cases, the lateral intrusion of present seawater, but the old salt water upconing. This old salt water could be of marine origin and might have been intruded into the aquifer(s) in the past: thus it could be the remnant of an old transgression phase, during which seawater have remained trapped into the (deeper?) aquifer.

Table I – Chemical analyses of seawater

Parameter	pH	E C	TDS (g/L)	TDS (calc.)	Sodium	Potassium	Magnesium	Calcium	Sulphates	Bicarbonates	Chlorides	
Units		mS/cm	g/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
Mean Seawater Dar es Salaam	8,28	53,55	34,05	27728	7370	153	1051	1150	2575	155	17850	
Typical seawater				31718	10556	380	1262	400	2649	140	18980	
Parameter	pH	E C	TDS	TDS (calc)	Sodium	Potassium	Magnesium	Calcium	Sulphates	Bicarbonates	Chlorides	Na/Cl (meq ratio)
Units			g/L	mg/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	
Mean Seawater Dar es Salaam	8,28	53,55	34,05	27728,3	320,6	3,9	86,4	57,4	53,6	2,5	503,4	0,64
Typical seawater				31718,0	459,2	9,7	103,8	20,0	55,2	2,3	535,3	0,86
Dar es Salaam mean seawater (normalized to TDS of typical seawater)					366,7	4,5	98,8	65,6	61,4	2,9	575,9	0,64

I did not find any trace of these hypotheses in the literature concerning the hydrogeology of Dar es Salaam area; moreover, there is no information about other analyses of local seawater.

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The recognition of the actual source of salinization is not trivial if you think that this information is crucial to the prevention of the phenomenon of seawater intrusion. If, in fact, salinization comes from old salt waters, it means that the hydraulic connection with the sea is partially impeded; this way, high exploitation of groundwater, rather than lateral intrusion, causes mobilization of salt waters (present at the bottom of fresh groundwater) that probably, before the uncontrolled exploitation, were silent.

It is also evident that the behavior of the two aquifers can be different as to the salinization process/source: the superficial one could be more linked to present seawater intrusion, while the deeper one could be affected by presence of old salt waters: however, this is only an hypothesis, which has to be supported by facts.

In case of multiple salt sources, groundwater management is different from that configurable in case of recognition of simple present (lateral) seawater intrusion.

Ultimately, I ascribe great importance to the recognition of the source of salinization as an important element in the reconstruction of the conceptual model of the phenomenon of salinization of groundwater, and the definition of the most appropriate actions to be put in place to prevent the progress of the same phenomenon.

As matter of fact, the CC is only one of the factors that contribute to the complex scenery of Dar es Salaam coastal aquifers.

What to do in the case of continuation of the monitoring activities?

- First of all I suggest the Dar es Salaam team to re-sample seawater in different hours of the day (high and low tide); moreover, I think that it could be interesting to go offshore to get another seawater sample for comparison.
- It is evident that the most important information can be obtained only by direct sampling of salt waters beneath fresh waters in the aquifer(s) in static conditions: I think it could be feasible in some abandoned wells.
- In the Report B the geochemical discussion correctly uses the available sampled seawater as reference of mixing (salt water end-member). However, for the future elaboration I suggest considering that the sampled seawater seems different from typical seawater. The possible existence of a two-way mixing, with present seawater and/or old seawater should be the next step in the elucidation of salinization process.
- I think that the Dari spring is not the right freshwater end-member. Apart from its TDS, which is not low, it probably mixes with old seawater and in my opinion it does not represent a good fresh water reference. In each area very fresh ground waters have been sampled that could be selected more correctly as freshwater end-members.

4. Piezometry, water demand evolution and active recharge

Notwithstanding difficulties and quality of original data, Report B tries to reconstruct historical evolution of piezometry in the area.

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For the static level too, as for the chemical data, there are a lot of questions, which rise about quality of data, measures referred to different nets and different periods.
This way, correctly the Report B states;

…there are very few boreholes where the measurements of static water level have been repeated at least once in the last ten years…
……as the boreholes are of very different and sometimes unknown depths, in many cases the measured static water level of the aquifer was unclear.

Anyway, the team reached a few qualitative conclusions after a careful selection of data repeated on some wells:

As a matter of fact, the comparison between the piezometric levels, plotted for 2003 and 2012 reveals a decrease in groundwater resources over the last decade…..

I welcome this effort and I think that it was the only possible way for obtaining a reference scenario.

However, once again I must say that <u>the measurements of static levels are not significant in a coastal aquifer if you're not sure that the wells intercept only fresh water</u>: if the wells are fully windowed and intercept waters of the transition zone or even salt waters, the measured level is the <u>"environmental" head</u> and refers to a column of water at variable density. To get the real hydraulic heads of fresh water, using wells that intercept water with salinity variable along the vertical thickness of the aquifer, transducers should be positioned strictly a few tens of cm in freshwater (moreover, tapping one only aquifer!). Only with this type of measurements you can get a real piezometric map.
The control the equilibrium between fresh water and salt water requires a monitoring well designed ad hoc, where it is feasible to verify the saline stratification and calculate the true dominance of the groundwater with respect to sea water.

About water demand and resource future availability Report B says:

… unplanned and uncontrolled groundwater exploitation leading to general increase of the aquifer sensitivity to seawater intrusion phenomenon….
…….there are clear evidences of resource availability decrease ………
…….the resource availability decrease on the one hand and the increase in the estimated groundwater withdrawal on the other, 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.

I can say that in this case the available data were used to the fullest.

However, even for the evaluation of active recharge more reliable data regarding all parameters should have been more numerous and more dense to get more reliable results.

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5. Conclusions

The situation of Dar es Salaam, as well as that of other cities and mega-cities that grow along the coast, is certainly very fragile.

The two Reports have the merit of having collected and interpreted at best and in a reasoned way historical data and have started a process of verification of the state of groundwater in those places, even if with low means.

However, many elements are missing to allow making a reliable judgment on the situation. This is only the first step of a long way towards the setting of correct monitoring net.

For this reason I suggest that the Reports, both for the purposes of the project, but mainly because they could be effective in the presentation for a critical discussion with the local authorities, should be implemented, where necessary, with an synthetic appendix concerning not only all the difficulties encountered, but also with suggestions on how to proceed in the future, maybe incorporating some of the suggestions about the features of a purposed monitoring net.

To this aim, it should be worthy to transpose in a written form the presentation by Ardhi Team also.

Acknowledgements

I'm grateful to Prof. S. Macchi and Prof. G. Kassenga for having involved me in the Workshop of ACCDar Project of April 2013.
As discussant, I had the opportunity to meet interesting people and listen to reports on issues which I'm very interested in as a researcher.

Bari, 19th May 2013

Ass. Prof. M. Dolores Fidelibus