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**ENSURING AVAILABILITY AND SUSTAINABLE MANAGEMENT
OF WATER AND SANITATION FOR ALL**

**The Merti aquifer (Kenya), a sustainable water resource
for the Dadaab refugee camps and local communities?**

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The Merti aquifer (Kenya) is the only permanent water resource for the supply of the Dadaab refugee camps and local community. Risk of well salinisation and water level depletion has led to the concerns regarding sustainability of groundwater management. A methodology was developed to quantify groundwater recharge, based on hydrogeological data analysis, linking river discharge rates to groundwater recharge by combining remote sensing techniques with surface/groundwater numerical modelling. Also, the risk of salinisation of wells was assessed by means of numerical modelling combined with data provided from a groundwater monitoring network. Groundwater recharge estimates yielded 50 to 100 times higher values than previous studies, suggesting a multi-layered aquifer system. Since abstractions are concentrated within only one aquifer horizon of the system, they were found to be close to recharge rates. Hence, groundwater prospection of deeper horizons could reveal a potential for new groundwater resources in the area.

Introduction

Humanitarian crisis in arid areas, where groundwater is often the only permanent water resource, could lead to water scarcity and therefore to crucial public health, social, economical and securities issues (Bromwich, 2007). As an example, the Merti aquifer, located in Eastern Kenya close to the Somali border, provides water to the Dadaab refugee camps, known as the biggest refugee camps in the world with a population varying between 350'000 and 450'000 persons. Signs of water depletion and salinity increase since the early 1990s led to the concern of the preservation of this groundwater resource in order to ensure its long term availability for the refugees and the local community.

Previous studies estimated groundwater recharge of the Merti aquifer between 2.6 and 33 x 10⁶ m³/y while the abstraction is estimated to be 4.8 x 10⁶ m³/y (GIBB, 2004). Historical water level depletion and salinity increase are not strongly demonstrated because of scarce long term and coherent data.

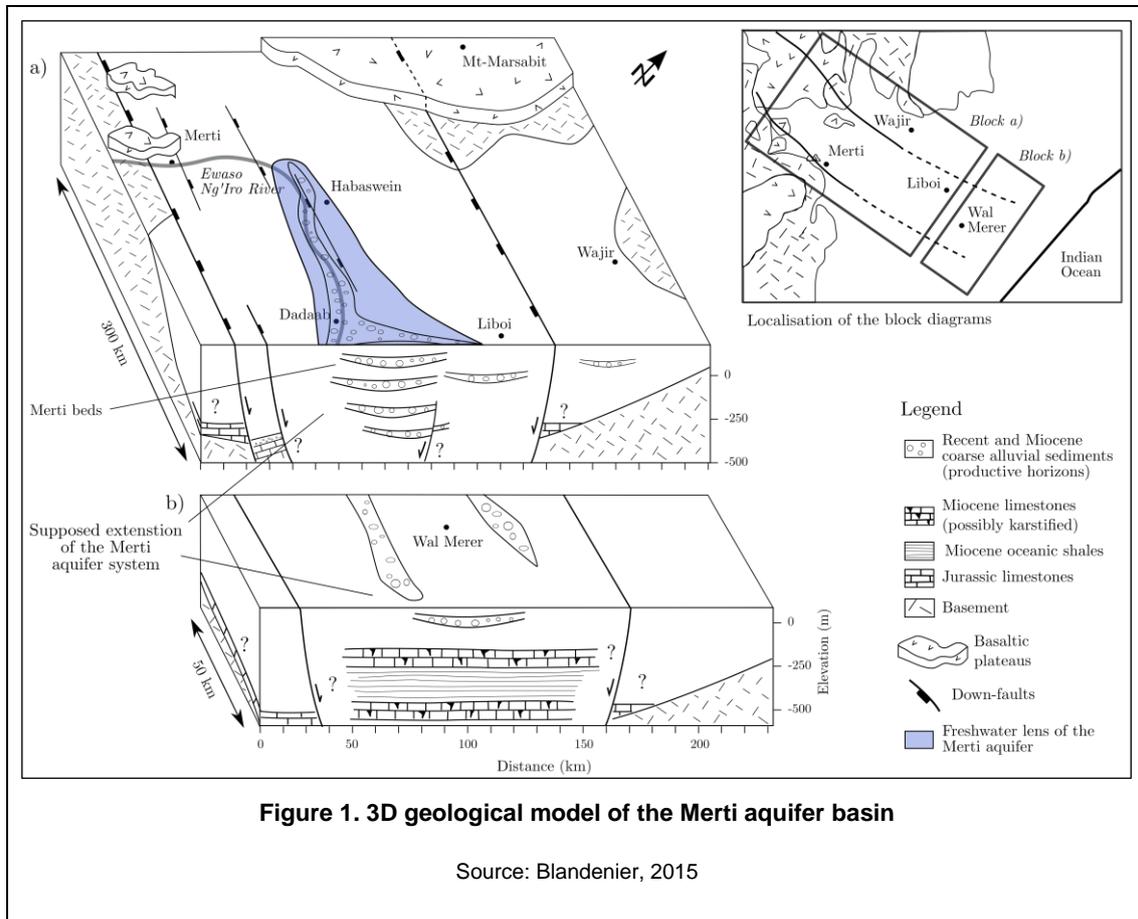
This paper summarises the main findings of a PhD thesis (Blandenier, 2015) which was financed by the the Swiss Agency for Development Cooperation (SDC) and UNHCR with the aim to assess the impact of groundwater abstraction for the Dadaab camps on the Merti aquifer and the sustainability of groundwater resource management.

Particular focus is put on the presentation of the methodology developed for the quantification of groundwater recharge, based on remote sensing techniques and coupled physically-based surface/groundwater numerical modelling, and on data from a monitoring network composed of 20 stations installed over the entire Merti aquifer.

Context

The particular hydrogeological setting of the Merti aquifer is characterised by the combination of the vast aquifer size, the semi-arid to arid conditions and the interplay between fresh water surrounded by brackish-salty groundwater (Figure 1). Moreover, the hydrology of the basin is characterised by major periodic inundations caused by the intermittent Ewaso Ng'iro River. In the past, these inundations led to the formation of a swamp, the so-called Lorian Swamp, located at the end of the permanent path of the Ewaso

Ng'iro River and directly upstream of the freshwater lens. Nowadays, this area is not permanently wet any longer but recurrent inundations are still supposed to play a major role for the groundwater recharge.

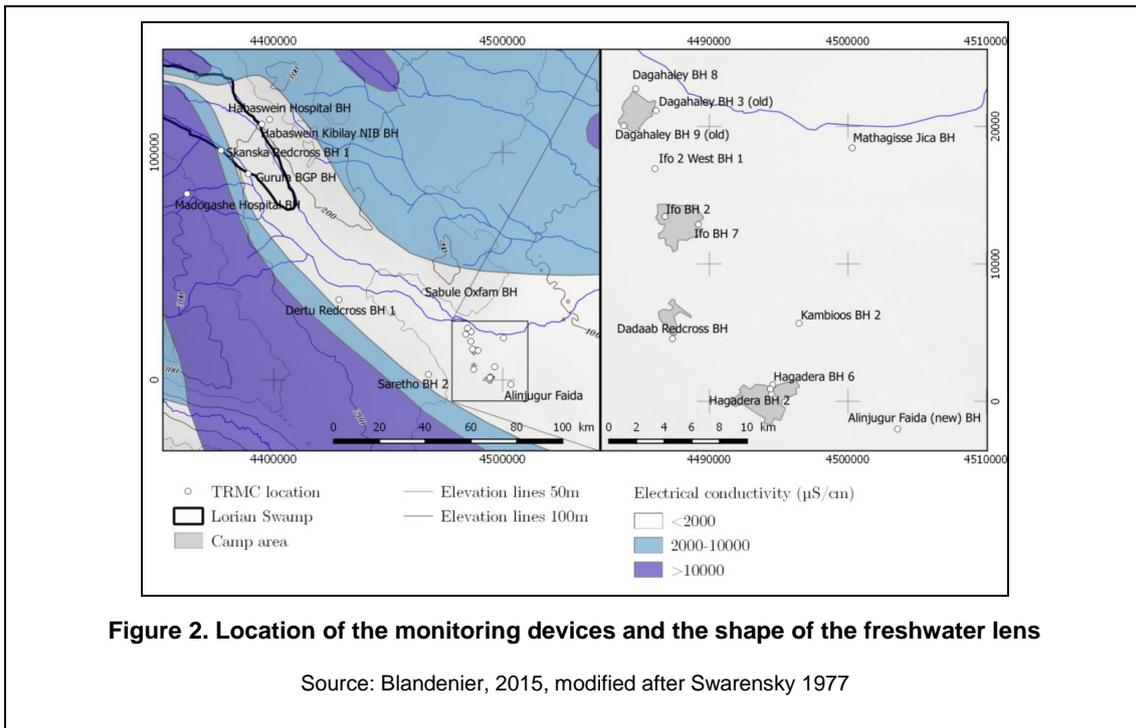


Methodology

The general methodology of this study relies on a combination of classical hydrogeological methods, remote sensing techniques and numerical approaches. First, the compilation of geological and hydrogeological investigations and data allowed characterisation of the geometry of the aquifer and its hydrodynamical parameters. Then, remote sensing techniques were used to assess a series of flood events, which were then reproduced by numerical simulation in order to quantify groundwater recharge. Finally, the risk of salinisation of wells was assessed by investigating the dynamics of the Merti freshwater lens by means of synthetical numerical experiments combined with data provided by the groundwater monitoring network.

Geological and hydrogeological characterisation of the aquifer

The geological and hydrogeological characterisation of the aquifer (Figure 1) was carried out through the analysis and compilation of previous geological (Bosworth & Morley, 1994; Hendrie, Kuszniir, Morley, & Ebinger, 1994; Nyagah, 1995; Rop, 2011; Winn, Steinmetz, & Kerekgyarto, 1993; WRAP (Ministry of Water Development), 1991) and hydrogeological studies (Earth Water Ltd, 2012; GIBB Ltd, 2004; Lane, 1995; Swarzenski & Mundorff, 1977), geological maps, boreholes logs, hydrodynamical data obtained from pumping tests and groundwater levels as well as electrical conductivities from historical data and from a monitoring network of 20 devices (Figure 2) installed within the framework of this project. The analysis of the geology allowed definition of the aquifer geometry. The Merti aquifer is located within a large Miocene sedimentary basin, composed of a succession of coarse and fine layers of sediments (Bosworth and Morley, 1994; Nyagah, 1995 and Winn et al., 1993). The granulometry and the hydraulic conductivity of the sediments diminish towards the border of the basin. The freshwater lens develops in the central zone with high hydraulic conductivities.



Quantification of recharge

In order to assess the sustainability of groundwater management in the Merti aquifer, the main focus of the study was to develop a new methodology to better quantifying concentrated groundwater recharge under the Lorian Swamp. This was done in a two-step procedure: *i*) mapping the short-term evolution of flooded surfaces for a series of flood events using MODIS remote sensing products and then *ii*) reproducing these flood events using a physically-based coupled surface/groundwater numerical model, resulting in a direct relationship between river runoff and groundwater recharge.

The bands 2 and 5 of the MODIS satellite were converted into inundation maps containing wet and dry pixels using the Normalised Difference Water Index (*NDWI*) developed by Gao (1996). Inundation maps were established with a temporal resolution of 8-days and with a spatial resolution of 1km. These maps were then used to calibrate the coupled surface/groundwater numerical simulation of the inundation events, using the topography as model geometry (SRTM digital elevation model, Jarvis et al., 2008). The model input data was the river discharge and precipitation during the inundation events, as well as the potential evapotranspiration. Adjusting a ground conductance parameter of the soil allowed fitting the simulated inundated surfaces to the observed ones for each inundation event. The model was run for 6 inundation events between 2002 and 2010 and allowed to quantify the groundwater recharge for each event and to find a linear relation between the river discharge rate and the groundwater recharge. Applying this relationship to the entire river discharge data series since 1949 yielded an average annual concentrated groundwater recharge below the Lorian Swamp of 195 to $329 \times 10^6 \text{ m}^3/\text{y}$.

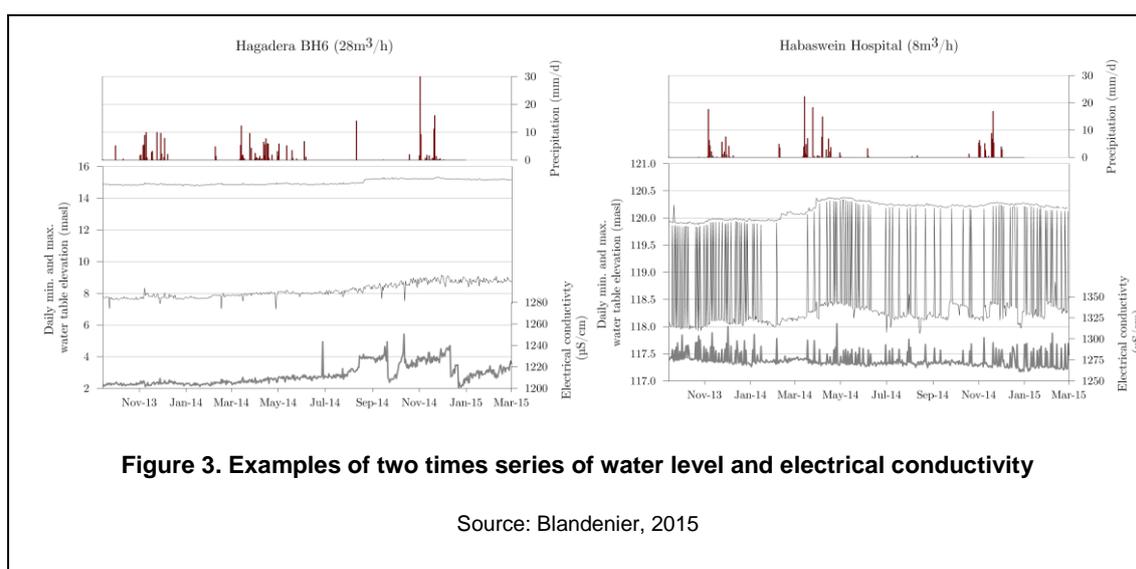
The diffuse recharge, based on satellite data of precipitation and evapotranspiration as well as from values from studies in similar environments (Scanlon et al., 2006), was estimated between 12 and $62 \times 10^6 \text{ m}^3/\text{y}$ (between 1 and $5 \text{ mm}/\text{y}$ in vertical recharge flux), yielding a total recharge ranging between 207 and $391 \times 10^6 \text{ m}^3/\text{y}$.

These results suggest far higher groundwater recharge values than previous studies. However, knowing the regional hydraulic gradient and transmissivities measured by pumping tests revealed that the aquifer system needs to be far thicker than the Merti beds (approximately 40 meters) in order to accommodate the above estimated recharge (about 50 to 100 higher than previous estimations). This observation led to the hypothesis that the Merti aquifer is an multi-layered aquifer system composed of numerous water bearing horizons located within the coarse-sedimentary succession, of which only the first horizon (the so-called Merti beds) is currently exploited. Since only the Merti beds are currently exploited, the previous aquifer recharge estimations are coherent, since the water budgets were only made for a sub-system (the Merti beds).

Freshwater lens dynamics and monitoring

In order to cross-validate these recharge rates, a second approach was adopted, investigating the dynamics of a freshwater lens in response to the estimated recharge rates. This was done with a series of numerical models. These models aimed at analysing the effect of the recharge rates and mechanisms (rainfall, concentrated recharge) on the freshwater lens geometries and to compare these geometries with the observed geometry of the freshwater lens of the Merti aquifer. This approach confirmed that concentrated recharge is the dominant recharge mechanism, contributing with more than 80 % to the total recharge. The numerical modelling revealed a very high inertia of the freshwater lens.

The monitoring network also confirmed a high inertia of the freshwater lens. Indeed, over the 18 months of monitoring the static water levels only showed variation of few centimetres and the electrical conductivities didn't show significant increase in most of the boreholes (Figure 3).



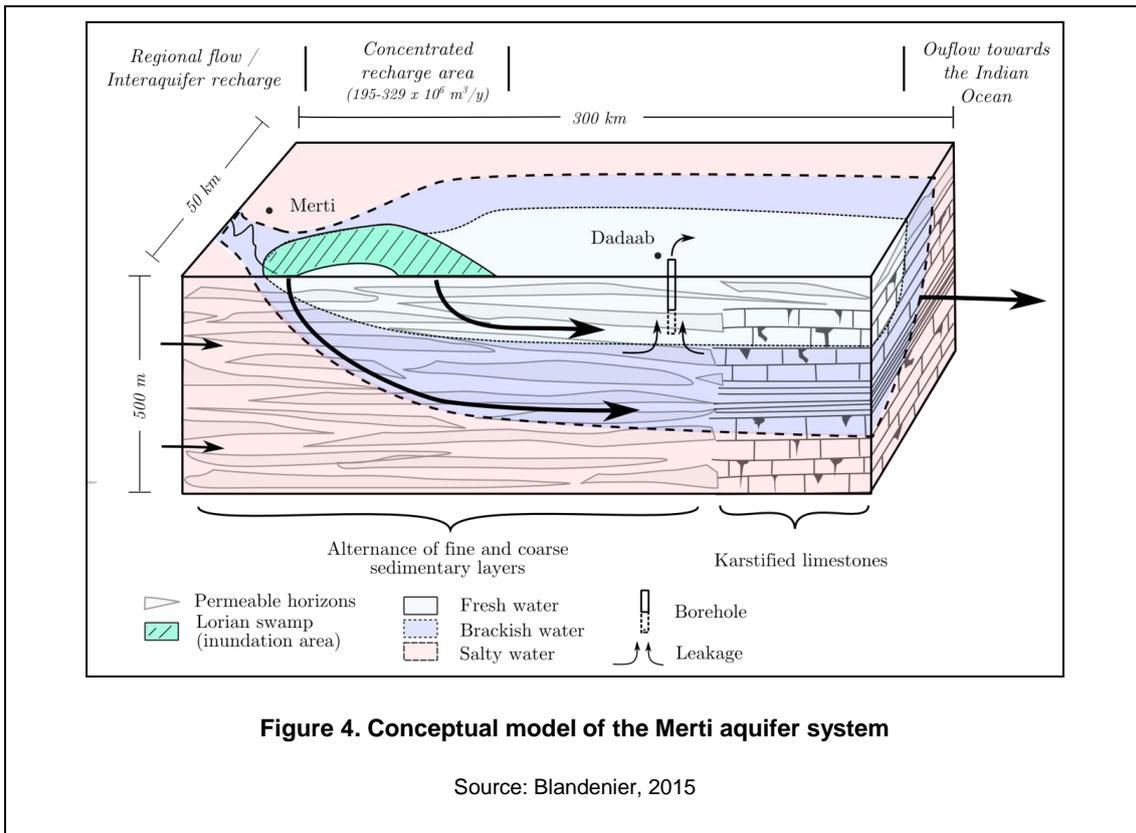
Discussion

The recharge results and the proposed multi-layered aquifer system suggest that deeper aquifer horizons below the Merti beds may contain fresh to brackish groundwater (Figure 4). However, the depth of the transition between the fresh and brackish water remains unknown since no deep water prospection has been done in the area. The very stable water levels and electrical conductivity values measured through the groundwater monitoring network support the hypothesis of deeper freshwater bearing horizons which act as a “buffer” between the exploited horizon (the Merti beds) and possible deeper brackish/saline water. Thus, the possibility of contamination of the wells by upconing of saline water from the underlying layers of the aquifer system is reduced due to the probable presence of the fresh water between the Merti beds and any underlying saline/brackish water. Furthermore, the numerical modelling carried in this study showed that the risk of migration of saline water from the lateral saline zones is low on the regional scale.

However, locally, especially close to the border of the freshwater lens, as in Hagadera (south of Dadaab), signs of salinity increase were observed (up to 100 $\mu\text{S}/\text{cm}$ during a period of few years), which require careful consideration of the salinity evolution. These increases remain low and electrical conductivities of these boreholes remain below the value of 2'000 $\mu\text{S}/\text{cm}$, which is the limit considered for potable water.

Considering the Merti beds only, and not the entire aquifer system, groundwater axial flow is estimated to be 5 to 8 $\times 10^6$ m^3/y . Comparing this to the 4.8 $\times 10^6$ m^3/y of extractions shows that the uppermost limit of exploitation of the Merti beds has been reached and calls for careful monitoring.

Hence, in order to investigate the potential of the underlying freshwater resources, it is recommended to drill deep exploration boreholes (<350 m), in the upstream area, close to the Lorian Swamp, as well as in the area of refugee camp. Such boreholes would allow to better evaluate the available freshwater resource and the risk of contamination of the boreholes by upconing of saline water. Additionally, it would also allow to confirm the estimation of the groundwater recharge by estimating the flow of freshwater through the entire aquifer system and not only through the Merti beds.



Since groundwater salinity along the edges of the freshwater lens is higher, it is recommended to maintain the groundwater monitoring network. This data is essential for the understanding of the groundwater dynamics but also to identify precursory signs of rapid salinity increase and to adapt the groundwater extraction strategy. If the groundwater extraction should be increased in the refugee camps, then it is recommended to increase extraction in the area of the central freshwater lens (Dagahaley and Ifo) and not in Hagadera.

Finally, an extension of the monitoring network over the concentrated recharge area (the Lorian Swamp) may allow to better understand and quantify the recharge mechanism of the aquifer, and thus, its sustainability. Such monitoring networks are also a valuable tool for technicians in charge of the day-to-day exploitation of the wells, for instance for the monitoring of the pumping duration or the identification of well degradation (e.g. clogging).

Conclusions

This study provided evidence that the groundwater abstraction for the refugee operations in Dadaab has not significant impact on the water levels and on water quality on a large scale. However, groundwater abstraction in the Merti beds is at its upper limit. Locally and particularly close to the edge of the freshwater lens (e.g. Hagadera), risk of salinisation remains an issue. For this reason, it is recommended to continue the monitoring in particular in these boreholes.

To assess the groundwater recharge in arid areas and of large scale aquifers, this work has highlighted the potential contribution of remote sensing technologies coupled with numerical modelling approaches, as well as tailor-made monitoring systems. Furthermore, to assess the sustainability of a groundwater resource management it is essential to consider the entire aquifer system and not only the abstraction area.

In relation with the theme of the conference “Ensuring availability and sustainable management of water and sanitation for all”, this work confirmed the necessity to undertake comprehensive studies documented by mid to long-term monitoring data of aquifers in order to assess the sustainability of groundwater resource management schemes. This mid to long-term perspective is often difficult to enforce in humanitarian operations, which deal with emergency situations. However, with humanitarian emergencies often become mid-long-term operations.

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