The uncertain sustainability of the Dodoma's safe water supply

Photo 1: Makutapora Groundwater Basin - flooding during the 2015/16 El Niño event

Since 1954, the Makutapora Wellfield has provided a safe and climate-resilient supply of water to the city of Dodoma. Following substantial rises in wellfield pumping in the 1980s and most recently in 2015, sharp declines in groundwater levels have occurred (Figure 1) and raised concerns over the sustainability of groundwater resources supplying safe water to the city of Dodoma. Previously, it has been estimated that the "safe yield" of the Makutapora Wellfield is between 50,000 to 70,000 cubic metres per day if supported by "managed aquifer recharge" yet the basis for these evaluations remains unclear.

Defining a sustainable pumping rate for the Makutapora wellfield is complicated by the variable and episodic nature of groundwater replenishment. For example, groundwater recharge during the 1997/1998 El Niño event accounted for nearly 20% of all of the recharge received over a 56-year period from 1955 to 2010 (Figure 1)[1]. Further, the long-term response of the wellfield to intensive pumping is uncertain due to a lack of knowledge of the groundwater system supplying safe water.

Groundwater withdrawals disrupt natural flows in the subsurface, creating 'cones of depression' around pumping wells. These serve to enhance the 'capture' of groundwater by:

(i) reducing groundwater flows to springs, rivers, lakes, wetlands, and vegetation (or combinations of these) that occurred prior to pumping; and

(ii) increasing groundwater recharge through enhanced subsurface drainage.

In the Makutapora Wellfield, current data and monitoring infrastructure do not permit mapping of groundwater drainage beyond pumping wells (Figure 2). This knowledge gap means that it is uncertain whether declining groundwater levels resulting from increased withdrawals will be slowed or even stopped by enhanced groundwater drainage towards pumping wells or whether groundwater levels will decline even faster if drainage is inhibited or even prevented by a geological feature such as an impermeable fault.

Makutapora Wellfield

Photos 2a, 2b: (a) Makutapora Wellfield - sampling a pumping station; (b) drowned gauging station at Chihanga

Available monitoring records are so far promising. Following a sharp, 50% increase in groundwater pumping from ~1 to ~1.5 million cubic metres per month in May 2015, declining rates in groundwater levels in the wellfield have since slowed substantially (Figure 3), suggesting that drainage to pumping wells in the wellfield is adjusting to accommodate intensified pumping. How the wellfield is meeting this increased demand remains unclear and requires not only continued monitoring but also an urgent expansion in current monitoring infrastructure.

On-going research by Sokoine University of Agriculture (SUA) and University College London (UCL), supported by WamiRuvu Basin Water Board, Cardiff University, University of Sussex, and the British Geological Survey shows that recharge is strongly dependent upon episodically intensive rainfall. This conclusion is evident not only from groundwater-level monitoring records (Figure 1)[1] but also stable isotope ratios of oxygen ($^{18}O/^{16}O$) which show the composition of heavy rainfalls match that of groundwater (Figure 4). Monitoring data also reveal that groundwater recharge is directly related to the duration of streamflow entering the Makutapora wellfield and surrounding depression (Figure 5, Photos 1, 3, 4).

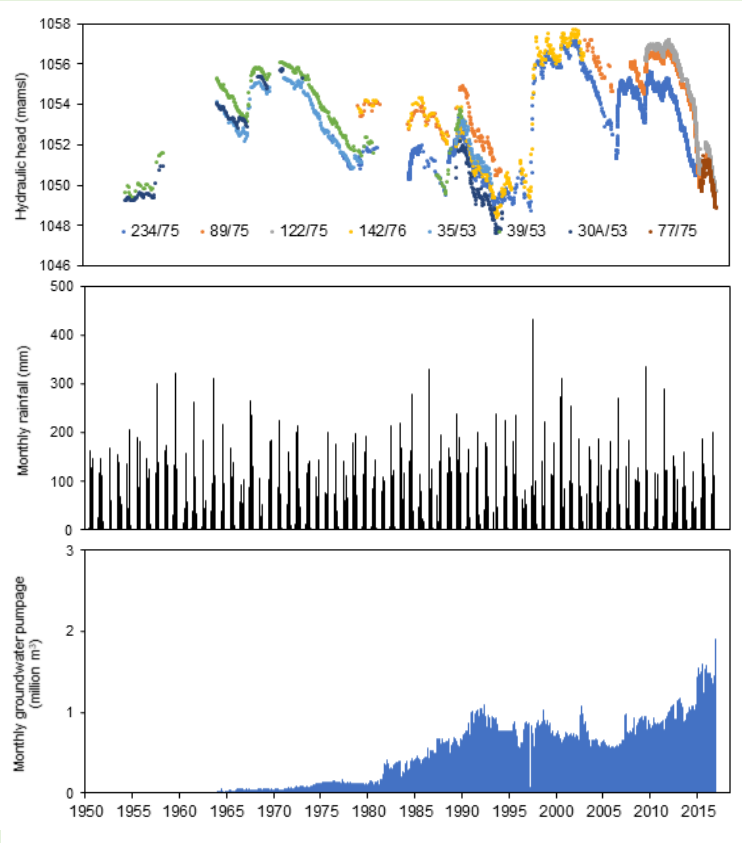

Figure 1. The Makutapora Record of groundwater levels, pumping, and rainfall from 1954 to present

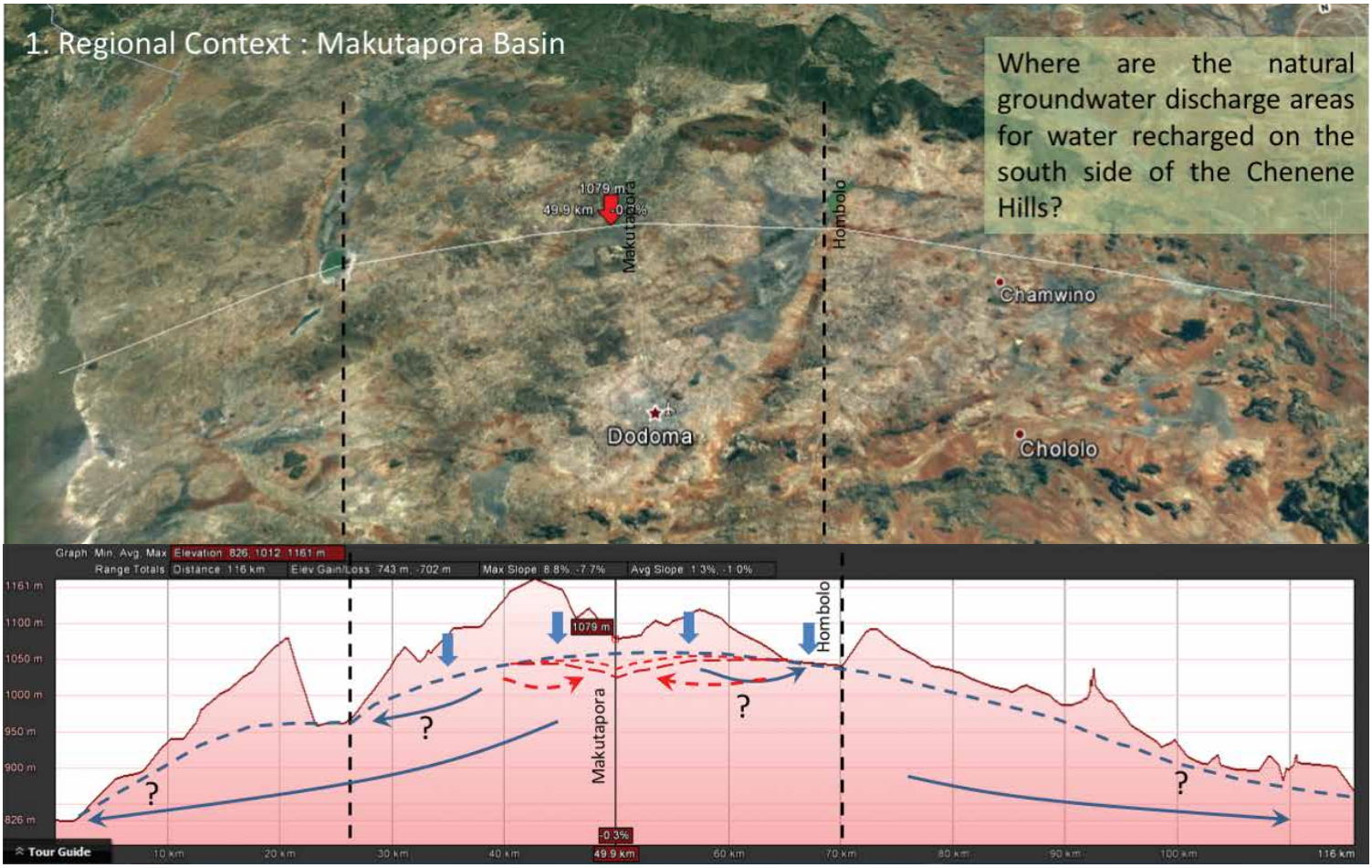

Figure 2. Topographically defined cross-section of the Makutapora Groundwater Basin in central Tanzania derived from GoogleEarth

Strategic improvements in monitoring infrastructure in the Makutapora wellfield have recently been made through this research activity and include both real-time, hourly monitoring of groundwater levels by telemetry. These improvements enhance operational capacity and the ability to investigate wellfield responses to climate variability and pumping. An expansion in the network of monitoring facilities is urgently required to resolve whether:

(i) groundwater drainage including whether groundwater flows to or from Lake Hombolo, a reservoir on the eastern boundary (Figure 2); and

(ii) increased groundwater pumping induces greater recharge through greater 'capture' of surface water by enhanced subsurface drainage in the Makutapora depression.

Resolution of these two uncertainties would uncertainty in the sustainability of intensive groundwater abstraction from the Makutapora wellfield supplying safe water to the city of Dodoma. An expanded monitoring infrastructure would also better inform opportunities for 'managed aquifer recharge', enhancing the frequency and magnitude of groundwater replenishment, and provide a basis for an operational model of the wellfield to manage pumping.

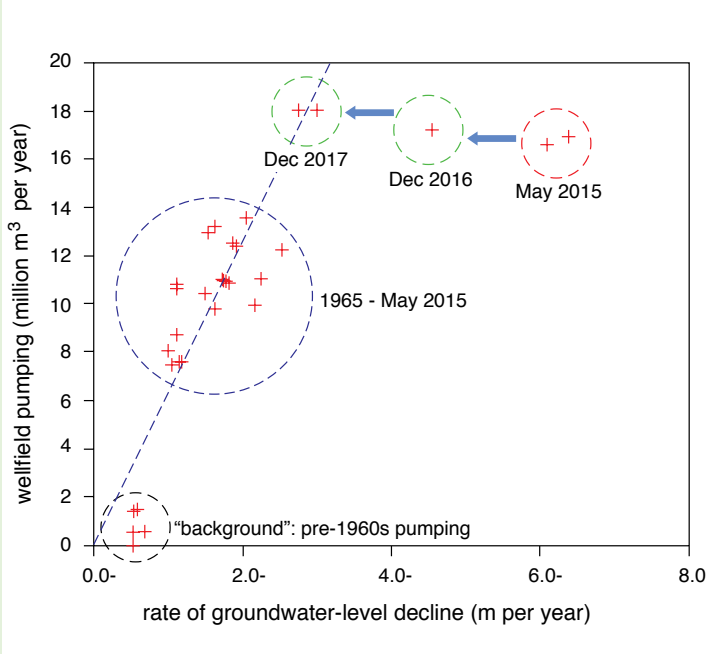

Figure 3. Recent slowing (blue arrows) in the rate of groundwater-level decline observed in the Makutapora Wellfield, suggesting a realignment of wellfield drainage to accommodate intensified pumping

Makutapora Wellfield

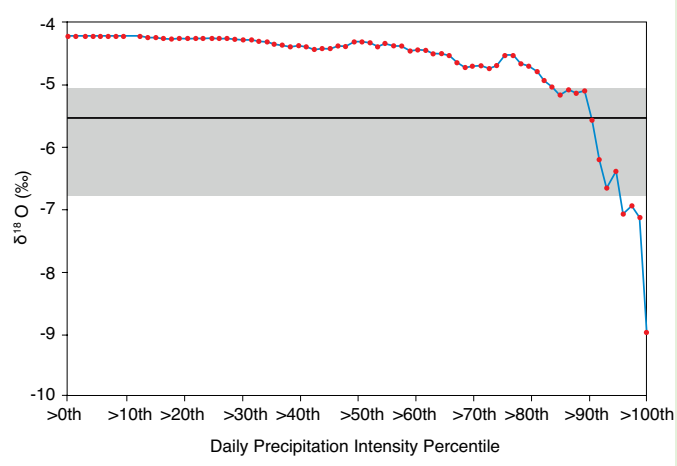

Figure 4. Stable-isotope composition of rainfall as a function of rainfall intensity shows how only the most intense rainfalls (>70th percentile) correspond to the composition of groundwater in the Makutapora Wellfield

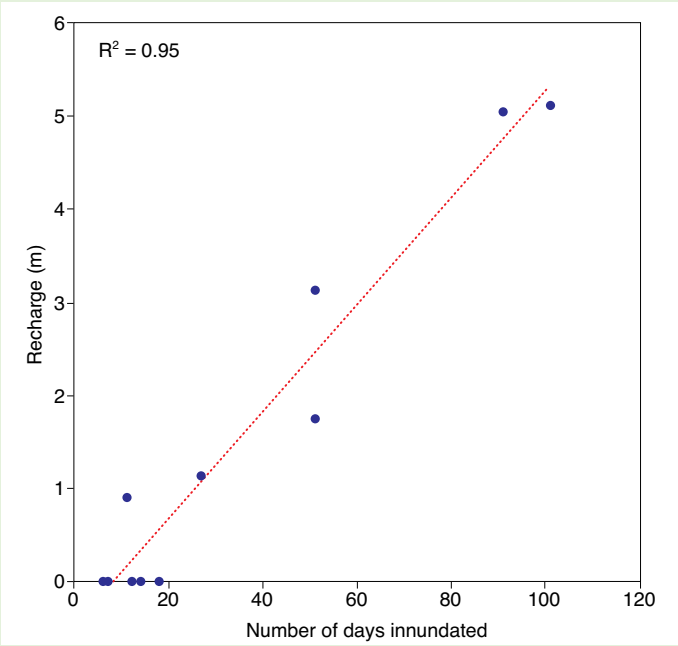

Figure 5. Observed groundwater recharge from monitoring-well records is directly related to the number of days of streamflow observed at the Meya-Meya gauge (photo 4)

Photo 3: Short lived floodwater flow in the Makutapora Wellfield

Photo 4: Meya-Meya gauge in the Makutapora Wellfield

Summary

Recent research in the Makutapora Wellfield shows:

- the sustainability of intensive groundwater pumping depends greatly on episodic, extreme seasonal rainfalls that are commonly associated with El Niño events;
- these extreme rainfall events generate short-lived floodwaters within the Makutapora Basin that are the primary source of replenishment to the wellfield;
- large increases in pumping produce sharp declines in groundwater levels but these lessen over time as pumping wells draw groundwater from a larger area in the wellfield; and
- the continued ability of the wellfield to sustain intensive pumping now, and to meet Dodoma's rapidly growing demand for safe water, is unclear and requires an urgent expansion in monitoring infrastructure.

[1]Policy brief prepared by the UCL, SUA & WRBWO. Research is supported, in part, by the UK government under the EPSRC Banking the Rain (Ref. 172313) and NERC-ESRC-DFID UPGro GroFutures (ref. NE/M008932/1) projects. This policy brief follows an earlier brief, *Groundwater use and climate: The Makutapora Record;* and manuscript: Taylor, R.G., Todd, M., Kongola, L., Nahozya, E., Maurice, L., Sanga, H. and MacDonald, A., 2013. *Evidence of the dependence of groundwater resources on extreme rainfall in East Africa.* Nature Climate Change, Vol. 3, 374-378.

Further details can be found at: **www.grofutures.org**