Climate change impacts on groundwater recharge in NE Uganda and the potential role of groundwater development in livelihood adaptation and peacebuilding

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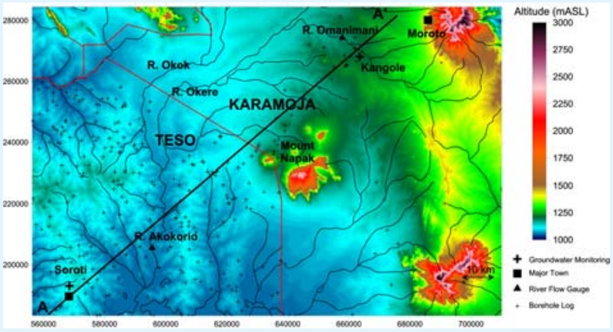
INTRODUCTION

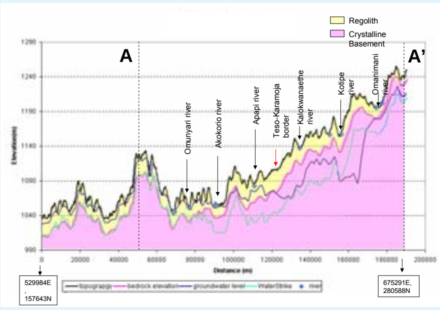
This study draws together the current state of hydrogeological knowledge for the Karamoja-Teso border area of NE Uganda. Numerical models are presented which synthesise available groundwater level data to further our understanding of the processes controlling groundwater recharge. Based on an improved understanding of the processes governing groundwater recharge, inferences are then made as to the impact of possible climate change on groundwater recharge.

BACKGROUND



HYDROGEOLOGY

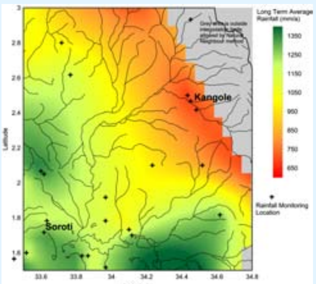
- Fractured and weathered Precambrian bedrock T = 2-58 m^2/d.
- Weathering depths 5 to 40 mbgl.
- Groundwater depth increases from a few metres in the SW (hand-dug wells common), to > 50 m in the NE.
- Optimal drilling depths for fractures yielding 2-4 l/s is 30 to 90 mbgl.
- Fractured bedrock does not behave as a regional aquifer in Karamoja.

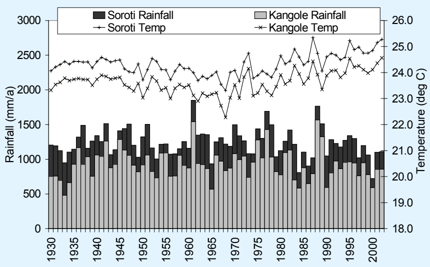


CLIMATE

Rainfall decreases from 1300 mm/a in the SW to less than 650 mm/a in the north and east and has a bimodal distribution with peaks in May and August and very little rain between December and February.

The air temperature record (CRU TS 2.1 gridded monthly dataset) is similar to the global trend with post WW2 cooling giving way to a strong warming trend since the 1960s. No such clear patterns are seen for annual rainfall totals or for changes in the distribution of rainfall throughout the year.



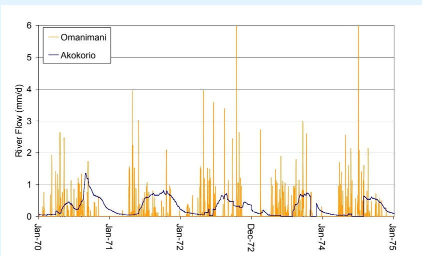


Annual total rainfall and annual average air temperature derived from CRU2.1 data.

HYDROLOGY

Lower river reaches (**Akokorio**) are seasonal and dominated by baseflow. Although flow ceases during times of low groundwater levels, groundwater is retained in the valley areas by underlying low permeability clay rich soils.

Upper reaches (**Omanimani**) show a very 'flashy', run-off dominated response with no indication of any baseflow component, consistent with deeper groundwater below river base levels.

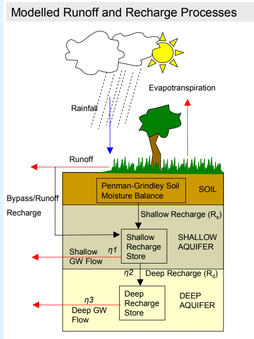


RECHARGE MODELS

A soil-moisture balance model (SMBM) was developed with a daily time-step to estimate direct recharge for the two groundwater monitoring locations at **Soroti** and **Kangole**. The model requires:

- Daily time series of rainfall (RF) (taken from nearby rain gauges) and PEt (derived from CRU2.1 climate data using a modified-Thornthwaite method calibrated against available pan data).
- Root constants (C) and wilting points (D) defined on a monthly basis (default 76 and 127 mm resp).
- Runoff (RO) is given as a fraction of rainfall which can vary with antecedent SMD and RF intensity.
- 'Bypass recharge' factor (proportion of RO-RF) to account for indirect/localised recharge.

The calculated total recharge (direct plus bypass) was then modified using a series of simple stores.



Using the Aquifer Response Function (ARF) to reduce uncertainty in the 'Water Table Fluctuation (WTF)' method for estimating groundwater recharge

Methods for estimating groundwater recharge based on groundwater level fluctuations are prone to large uncertainties due to the uncertainty in values for specific yield (S). However, if simulated recharge is added to a store which drains according to a linear recession constant (η) in order to simulate observed groundwater fluctuations, η can be related to average aquifer parameters using the aquifer response function (for catchments in which the vertical flow gradients are small) by the following equation:

$$\eta = \frac{\pi^2 T}{4SL^2}$$

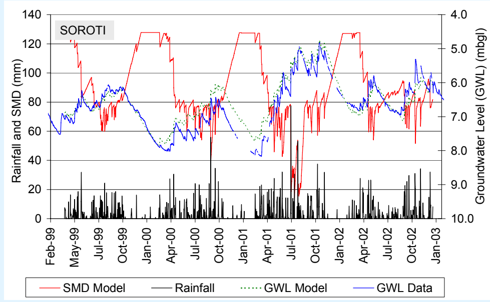
(after Erskine, A. D. & Papaioannou, A. 1997. The use of aquifer re-sponse rate in the assessment of groundwater resources. Journal of Hydrology, vol. 202, 373-391.)

This enables an 'average' catchment groundwater hydrograph response to be modeled using the parameters of S, Transimissivity (T) and a characteristic length parameter (L). For a catchment where flow geometry and aquifer parameters are known within prescribed limits of uncertainty, this can significantly reduce the uncertainty in likely recharge values.

SOROTI

The aquifer was modeled using a single store draining under a linear recession constant (η1) to simulate shallow groundwater flow to the nearby stream. Assume deep recharge, R_d = 0.

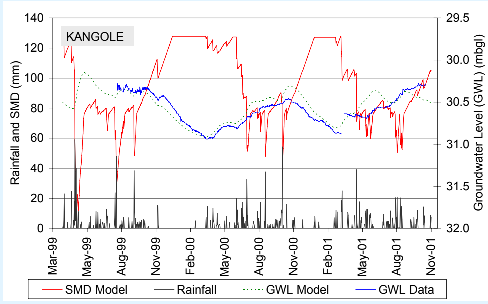
It is clear from the groundwater hydrograph that preferential/ indirect recharge mechanisms must be significant in this area. This is confirmed by the model which showed that without adding a component of bypass recharge, a standard SMBM gave zero recharge for the modeled period.



For L of 400 m and values of T of 5 to 12 m^2/d, 'best fits' using S_y of 1%, 2% and 3% were 70 mm/a, 140 mm/a and 210 mm/a respectively. If S_y was increased much beyond this range, a reasonable model fit could not be made unless T was increased, or L was decreased, out of the expected range. This shows the benefit of using the aquifer response function methodology. For the case of S_y = 2% (clayey overburden) average recharge is 140 mm/a (c.f. RF = 882 mm/a & PEt = 2174 mm/a).

KANGOLE

Situated by the Omanimani 'Sand River'. Shallow recharge (R_s) was added to an upper store representing shallow alluvium which drains according to a linear recession constant (η2) to a deeper groundwater store representing the fractured aquifer. This lower store drains under a linear recession constant (η3) to simulate the abstraction/discharge evident in the hydrograph (Note, η1=0 in this model).



As for Soroti, direct recharge was zero for the modeled period and bypass flow was needed. For Kangole, no attempt was made to relate the groundwater hydrograph recession to aquifer parameters since the fractured aquifer in this location is highly complex and unlikely to fit the underlying assumptions inherent in the analysis which utilizes the aquifer response function.

A best fit simulation gives average recharge of 30 mm/a (c.f. RF = 654 mm/a & PEt = 2072 mm/a). Given that this scenario used a maximum likely value of 1% for the S_y of fractured rock this represents a maximum value of recharge in this location. Since it is likely that the fracture system at this location is fed to some extent by water stored in valley alluvium recharged through focused ephemeral stream flow, average areal recharge to the wider area is likely to be much lower than this.

IMPLICATIONS FOR POSSIBLE CLIMATE CHANGE IMPACTS FOR GROUNDWATER RECHARGE IN NE UGANDA

The latest IPCC report shows a possible median temperature increase of 3 to 4 ºC for East Africa by the end of the century (under the A1B scenario) which may lead to significantly increased PEt. However, rainfall also increases by several percent under this scenario.

If direct recharge is dominant then the possible increase in precipitation may, to a great extent, be countered by an increase in PEt. However, given that the recharge processes actually appear to be dominated by indirect and localised mechanisms, any effects caused by higher temperatures may be more than offset by the predicted increase in future precipitation leading, overall, to an increase in the available groundwater resource.

Acknowledgements: For references please see the paper in the conference proceedings. Data for this study were provided by the Ugandan Directorate for Water Development (DWD) and WaterAid Uganda. Particular thanks go to Callist Tindimugaya (DWD) and Richard Taylor (University College London) for their advice and support.

CONCLUSIONS

- Recharge decreases from around 140 mm/a to <30 mm/a from SW to NE across the study area.
- Localized and indirect recharge appear to be the dominant mechanisms.
- Standard SMBMs are inappropriate for estimating recharge in the region.
- Relating the ARF to linear recession constants can help reduce uncertainty in the WTF method.
- Increases in PEt due to possible future higher temperatures may be more than offset by increases in rainfall in terms of their effect on groundwater recharge.
- If these results are corroborated by further research then increasing groundwater abstraction in the region may be a sustainable option for improving livelihoods in the coming century.