A Multi-sensor hydrologic modeling framework to assess the impacts of small-scale water storage practices to water resources over Uganda

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Introduction

Efforts by government and development partners to achieve 100% accessibility to water by every Ugandan, have led to an increase in the development of small scale local water harvesting/collection points. The common technologies through which water is accessed include boreholes/hand pumps, wells, dams and rainwater harvesting tanks (fig 1).

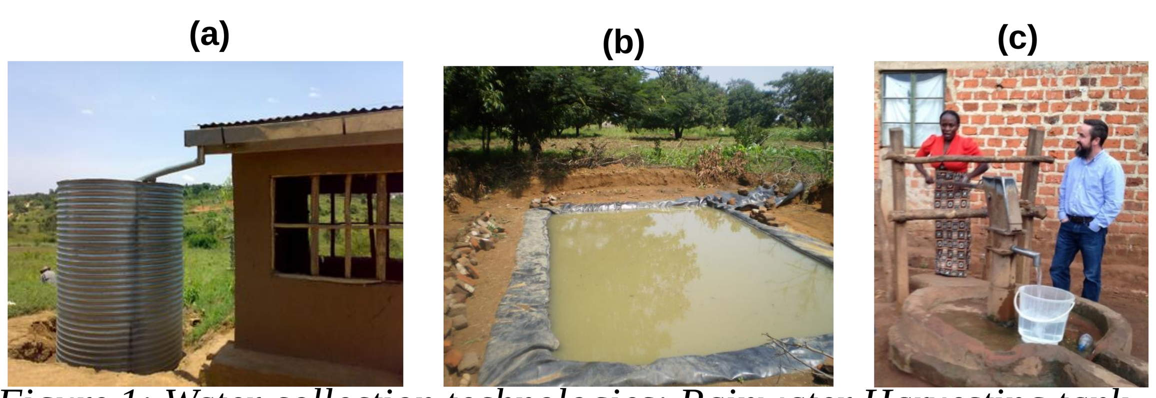


Figure 1: Water collection technologies: Rainwater Harvesting tank (a), Runoff collection Dam (b) and groundwater Hand pump (c).

There are over 70,000 groundwater supply points, 20,000 rainwater harvesting tanks and 300 dams in Uganda.

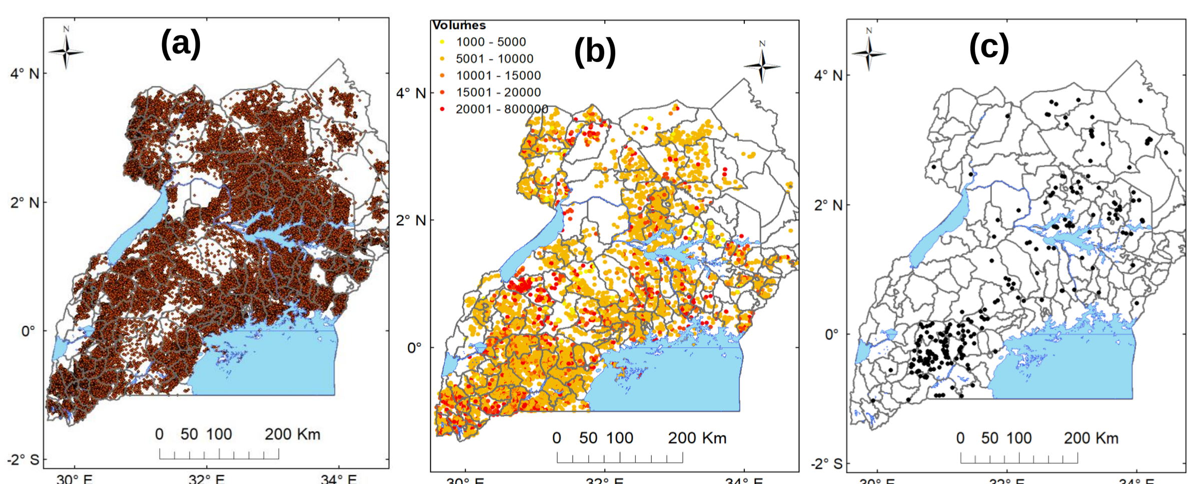


Figure 2: A network of Groundwater supply points (a), Rain harvesting tanks (b) and Dams (c) across Uganda

At a local scale, the growing small scale water harvesting practices (from rainfall, groundwater and surface runoff) in Uganda may be insignificant. However we hypothesize That the combined effect of the different harvesting practices impacts regional hydrologic fluxes and water balances, impacts that are unknown.

For instance, there is anectodal evidence of increasing borehole failure that correlates with the growth of the groundwater network (figure 3). Many of the drilled boreholes have become non-functional within 20 years.

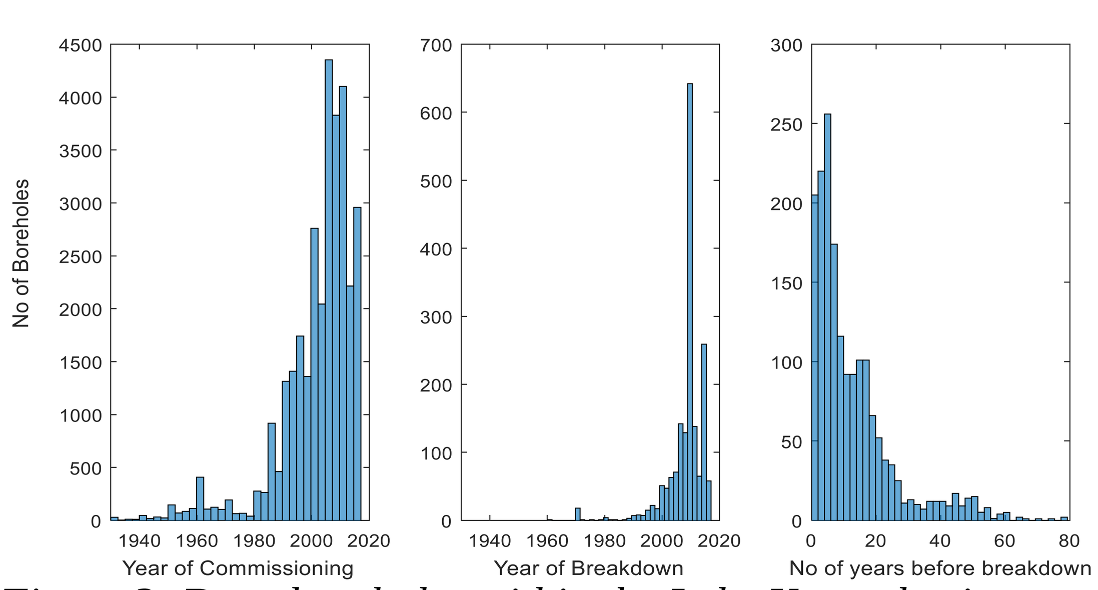


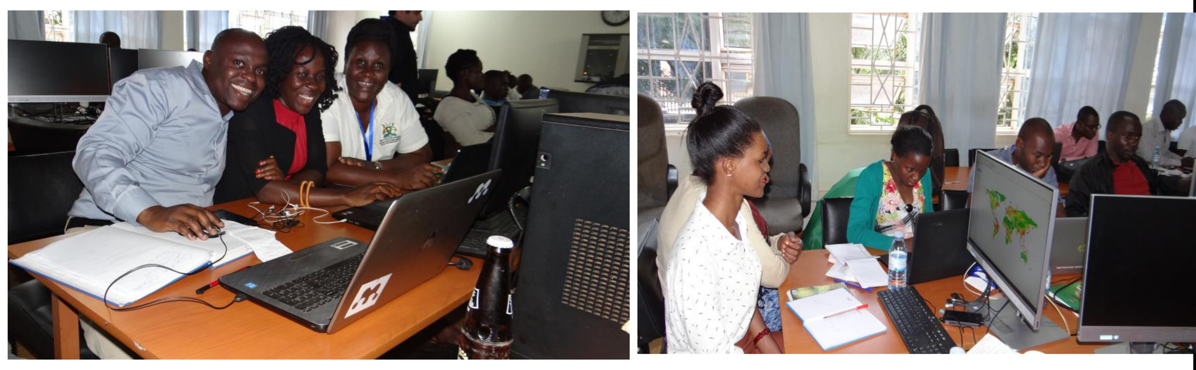
Figure 3: Deep boreholes within the Lake Kyoga basin

This study therefore seeks to address the following objectives

(1) Quantify and characterize water harvesting from groundwater (GWH), surface water (SWH) and rainwater (RWH) in space and time
(2) Characterize recharge, stream flows and groundwater behaviors across temporal and spatial scales
(3) Examine runoff, recharge and groundwater storage alterations that result from water harvesting practices
(4) Identify locations suitable for water harvesting that minimize downstream hydrological impacts

Highlighted project activities

Project Inception meeting in Mbarara, Western Uganda. Participants were mainly water officers, environmental officers and natural resources managers



Participants in the Hydrologic modelling workshop held at Makerere University.

Materials and methods

This study exploits multivariate data from satellites and ground-based hydrologic observations in a land surface model framework to examine the impacts of small scale water harvesting on regional hydrology.

The study is in two phases: 1) collection and analysis of past and present data to characterize recharge, streamflow, water levels and water use and 2) Model simulations and evaluations of water harvesting (WH) impacts on hydrology.

Table 1: Required Datasets

Type	Data	Source
1. Hydro-climatic data	Precipitation, temperature Recharge, groundwater levels and storage changes, streamflow Land use/land cover	TRMM, GPM, DWRM PERSIANN, re-analysis, Field measurements Models, GRACE satellite, Physical recharge approaches. MODIS, LANDSAT
2. Water use/harvesting	Quantities of water harvested, from groundwater , surface water and rainfall	Field surveys, Hypothetical estimates, NGOs, Ministry of Water and Environment (MWE), global datasets (e.g. Wada et al., 2014), models (e.g. WaterGAP)
	Water policies and management practices	MWE and Local district water departments
3. Socio-Economic data	Population distribution and number of people served by water points	UBOS, field surveys, MWE

Estimation of water use

- Rainwater amounts harvested will be estimated by combining optimal RWH storage [Hanson et al., 2014] over climatologically homogeneous zones [Basalirwa, 1995] across Uganda and volumes of tanks. These estimates are limited in that the tank is assumed to capture the same amount of water through time.

- Surface water harvested (SWH) will be taken as the weighted product of average dam capacity and the number of dams within a specified area (MWE, 2010). The weighting approach will assign bigger weights and thus larger SWH amounts over areas with more dams.

- Groundwater (GW) use per capita would be estimated based on estimates of groundwater use per individual household, number of boreholes and total number of people served.

The Community Land Model (CLM)

NCAR's grid-based land surface model (CLM) is employed to experiment the impact of water storages on hydrology. Each model grid can be conceptually visualized as a bucket receiving water from rainfall: if the bucket is full, then the excess water is diverted off as runoff, which is routed to neighboring grid cells at lower elevations (figure 4(a)).

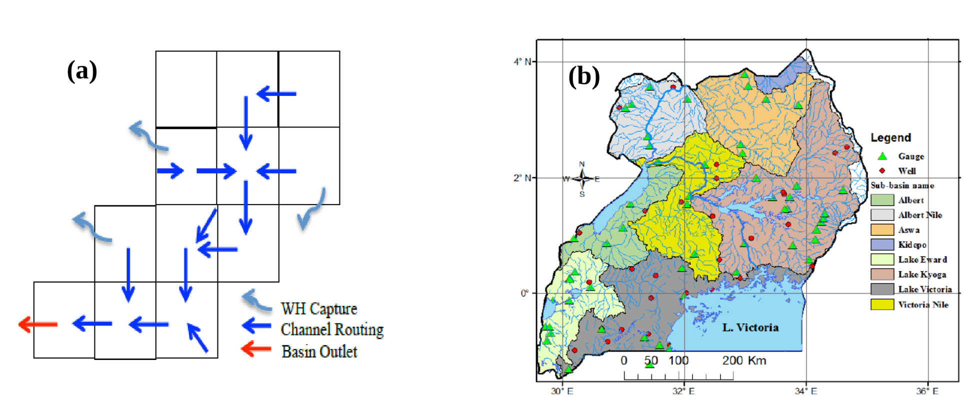


Figure 4: A schematic of the grid-based water harvesting process (a) and Hydrologic sub-basins, Uganda (b)

The method proposed here involves 'withdrawing' a certain amount of runoff from each grid before routing it to neighboring cells (figure 4(a); thus representing the process of SWH. Similarly, precipitation reaching each grid will be limited by the estimated RWH values, while GW use values will be deducted from GW storage within CLM. For each grid, water will only be 'harvested' if the grid-generated runoff/precipitation/groundwater is greater than the estimated WH amount. To maintain mass balance, we assume that water 'withdrawn' is eventually evaporated, thus the evaporation scheme in CLM will be modified to capture these additional fluxes.

Scenarios of water harvesting will be developed (based on land use changes and population growth) at sub-basin scale (figure 4(b)) and evaluated using the CLM model. Results will be used to characterize suitable areas for future water harvesting projects.

Preliminary results

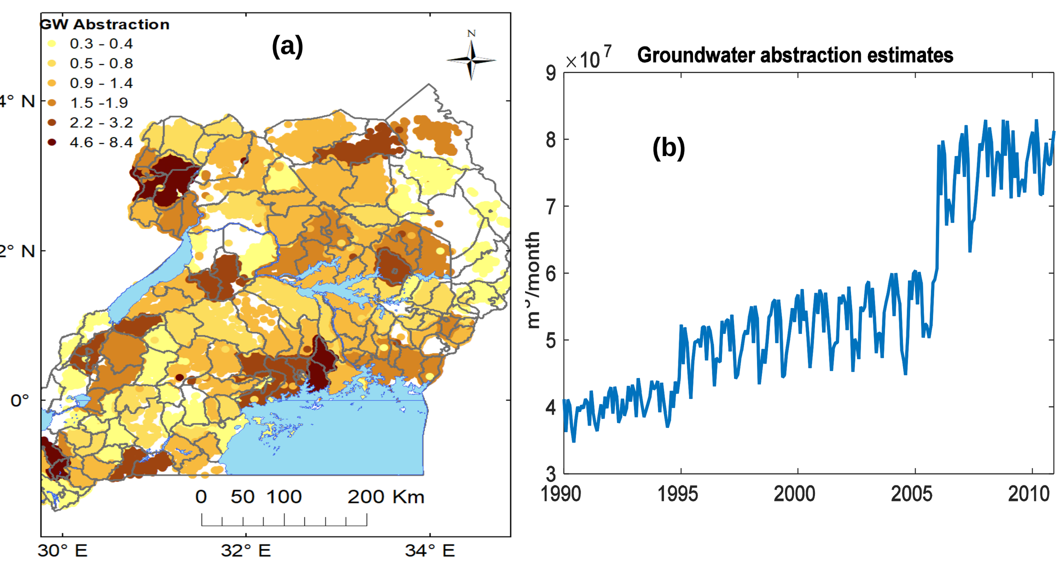


Figure 4: Estimated groundwater harvested per district (10^6 m^3/day) (a) and *Volume* (m^3/month) *of groundwater abstracted over Uganda from WaterGAP model (b)*

- Preliminary estimates of groundwater use show that districts with dense populations use more groundwater (figure 4(a).
- Model-based estimates show that groundwater use has increased through time (figure 4(b)

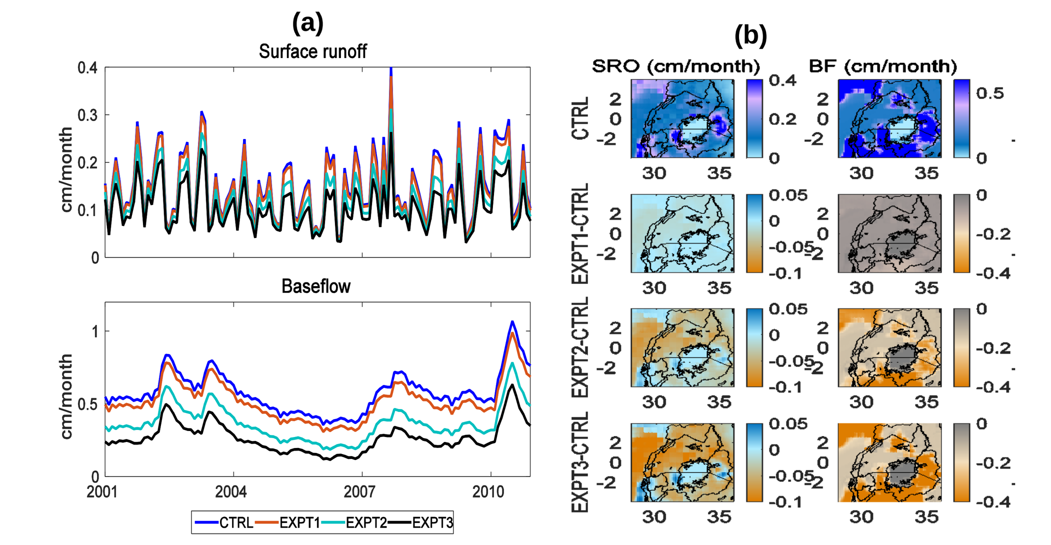


Figure 5: Monthly variations of simulated surface runoff (SRO) and baseflow (BF) for control and experimental runs (a), and Spatial distribution of changes in annual mean surface runoff and baseflow for the different experiments

- Three experiments have been run using the CLM model incorporating groundwater abstraction (GWA) from the WaterGAP model [Döll et al., 2012]., i.e. 1) control (CTRL) experiment with no GWA, 2) EXPT1 with GWA, EXPT2 with 50% increase in GWA and EXPT3 with 100% in GWA.

- Preliminary results show that increases in groundwater harvesting leads to declines in surface runoff, baseflow and groundwater storage (figure 5).

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Next steps

- Analyses of historical behaviors of recharge, groundwater and streamflow
- Estimation of water harvesting from different stores
- Incorporation of water harvesting into CLM model simulations with
- Paper drafts for publication purposes

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