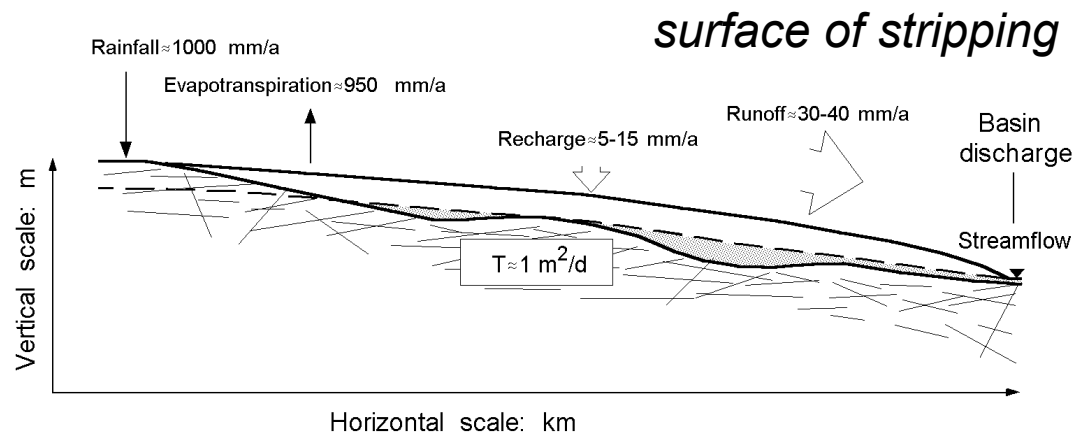
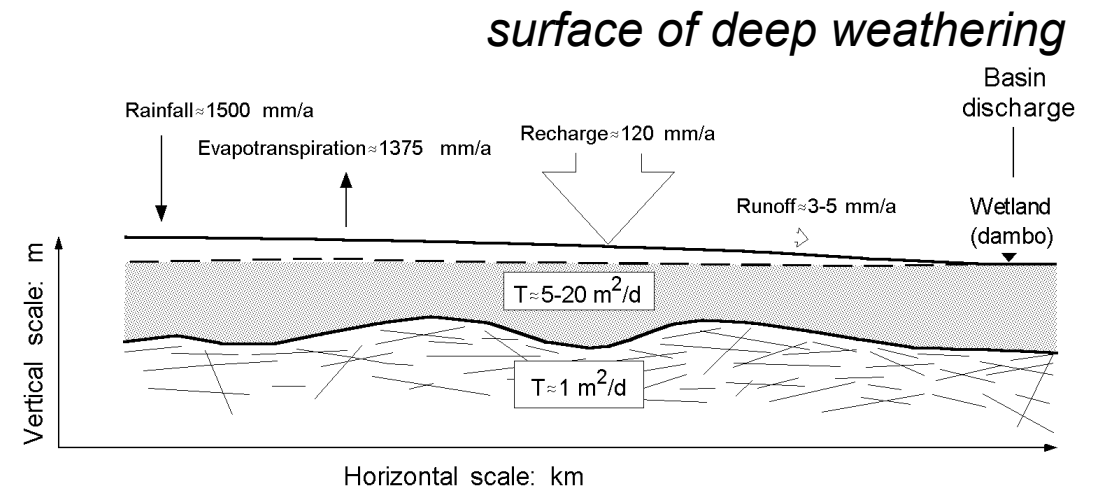


shallow wells versus “boreholes”

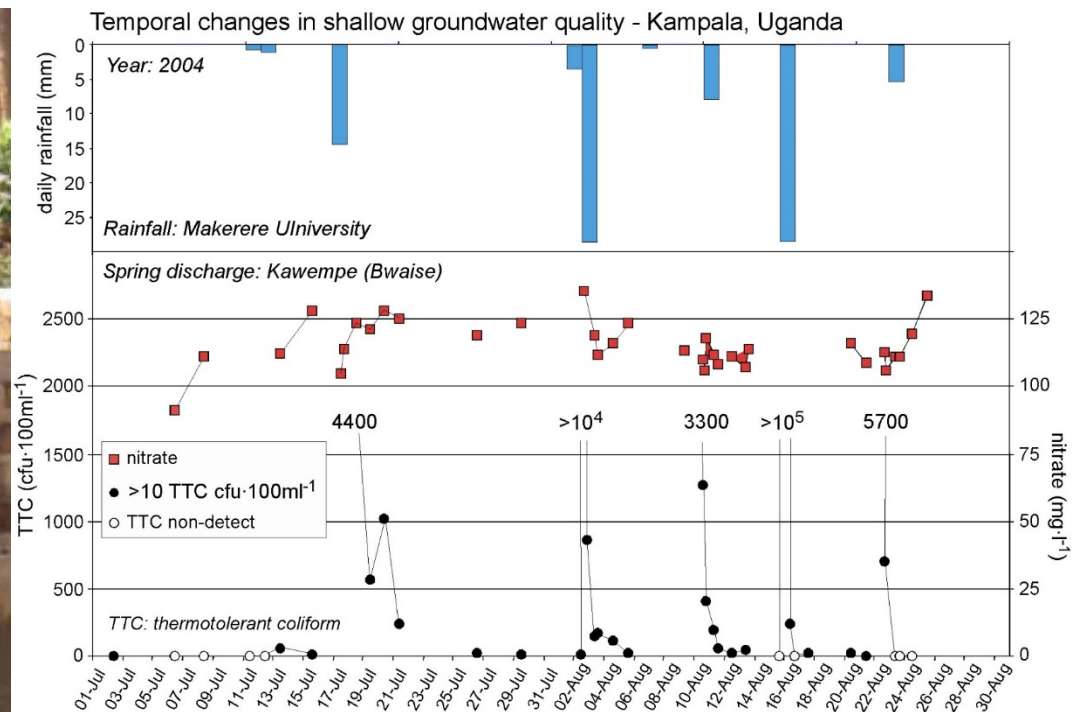
- Omorinbola (Nigeria), Chilton (UK), Sekar (India)



-  Unsaturated zone
-  Water table/Potentiometric surface
-  Weathered-mantle aquifer
-  Fractured-bedrock aquifer

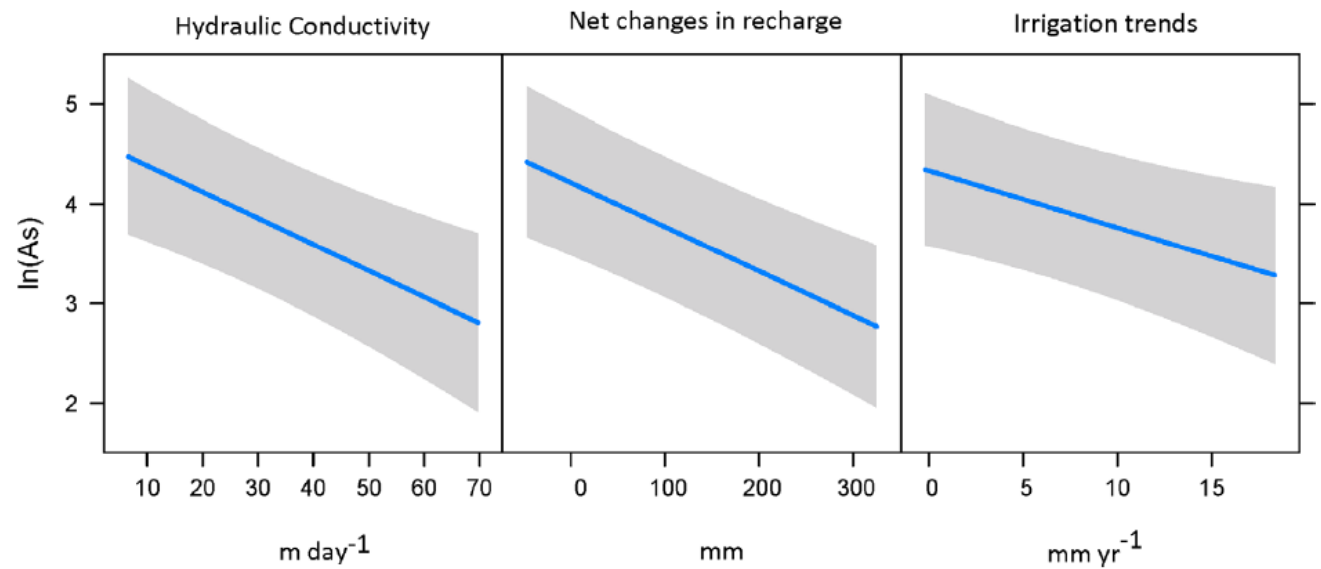
Taylor and Howard (2000) *Hydrogeology Journal* 8: 279-294.

- Kulabako (Uganda)
- Van Foppen (Netherlands)



Taylor et al. 2009. IAHS Publication No. 334, pp. 15-19.

Kampala, Uganda

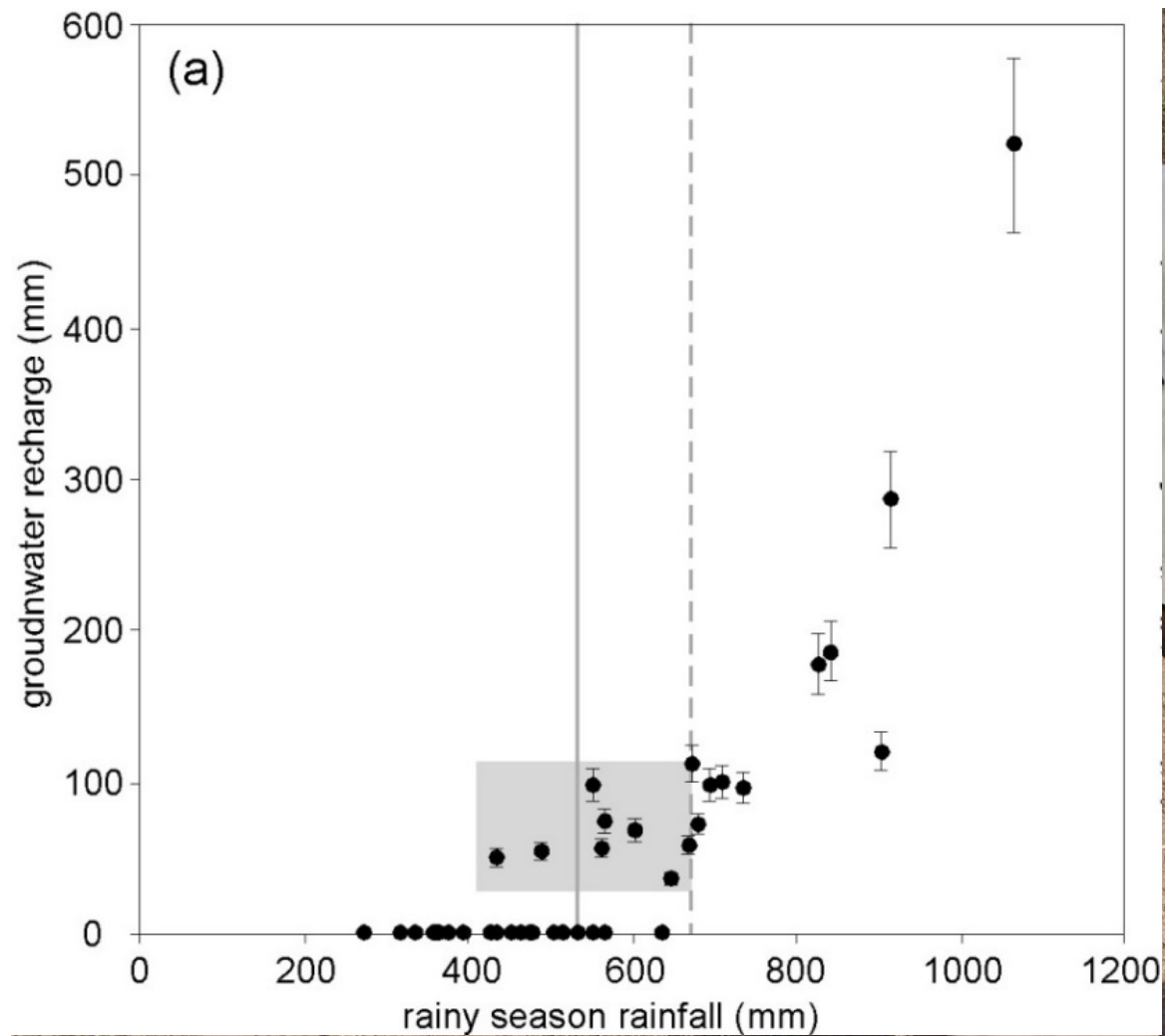


Shamsudduha et al. 2015. Water Resources Research 51: 685-703.

- Shamsudduha (Bangladesh/UK)
- McArthur (UK)



groundwater-fed irrigation of Boro rice (Bangladesh)



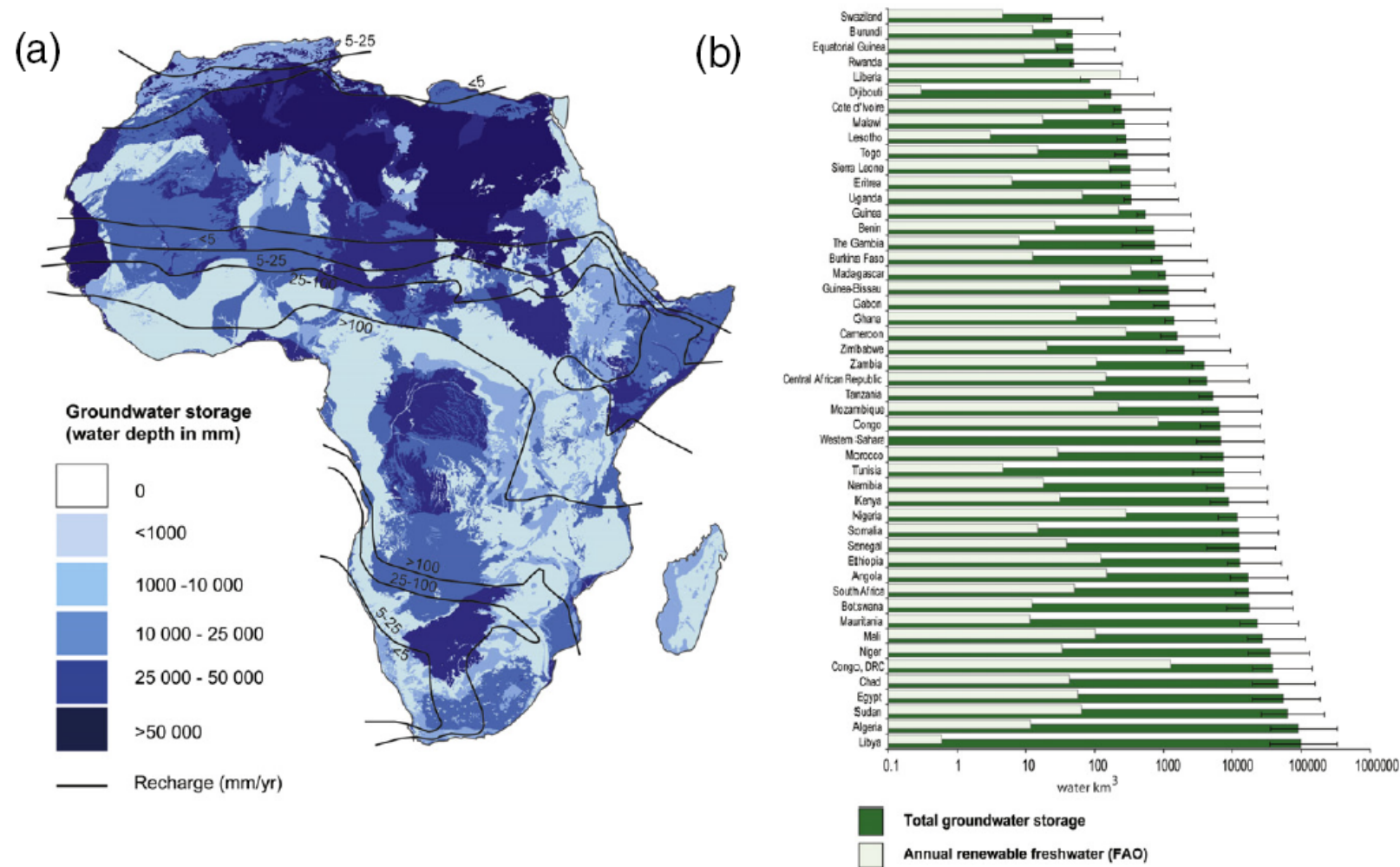
Taylor et al. (2013) Nature Climate Change 3: 374-378.

- Owor (Uganda)



groundwater storage in Africa

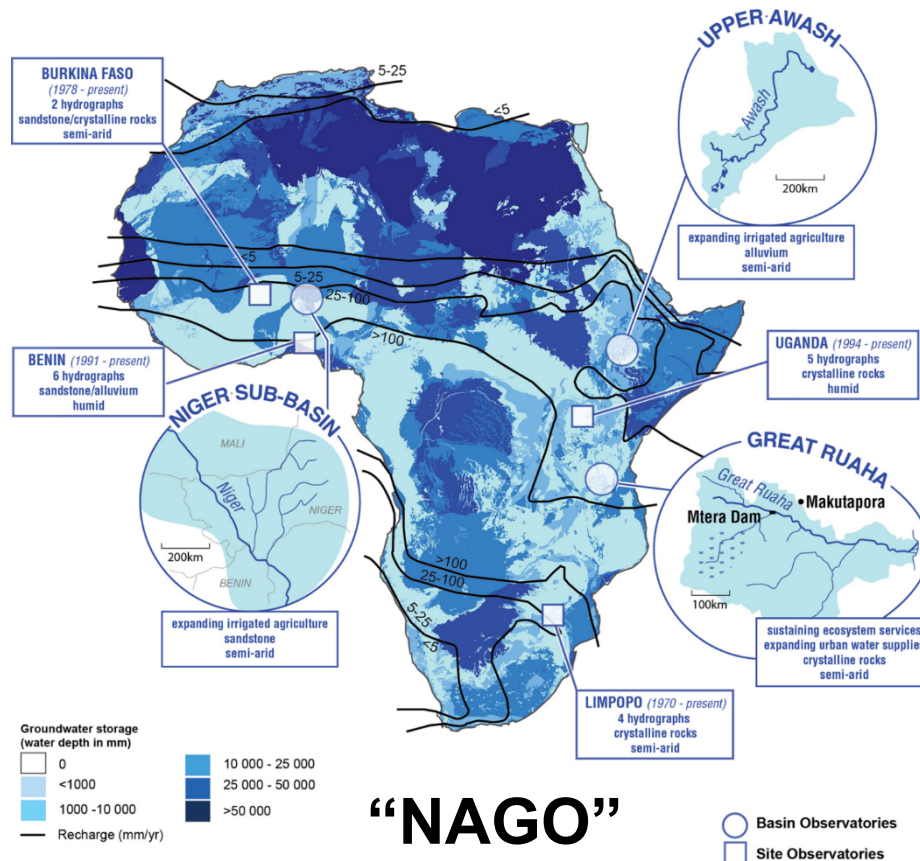
- distributed groundwater storage - 10 to 100 times mean annual river flow



MacDonald et al. (2012) Environmental Research Letters 7: 024009.

GroFutures project

- volume and renewability of groundwater storage under changing climates and land uses – *sustainability of groundwater futures*
- inclusive, participatory framework for groundwater governance in which views of poor women and men and trade-offs are considered



- **Multi-lingual outputs and dissemination events**
- **Learning Platforms:** multi-stakeholder forums across NAGO where ideas on GW development pathways can be embedded in basin planning
- **Project website:** www.grofutures.org – access to all knowledge products, links to partners
- **UPGro Knowledge Broker:** www.upgro.org

High-impact science



Evidence of the dependence of groundwater resources on extreme rainfall in East Africa

Richard G. Taylor^{a,*}, Martin C. Todd^a, Lister Kongola^a, Louise Maurice^a, Emmanuel Nahozya^b, Moses Sanga^a and Alan M. MacDonald^a

Groundwater recharge sustains the groundwater resources on which there is global dependence for drinking water and irrigated agriculture¹. For many communities, groundwater is the only perennial source of water. Here, we present a newly compiled 55-year record of groundwater-level observations in an aquifer of central Tanzania that reveals the highly episodic occurrence of recharge resulting from anomalously intense seasonal rainfall. Episodic recharge interrupts multiannual recurrences in groundwater levels, maintaining the water security of the groundwater-dependent communities in this region. This long-term record of groundwater storage changes in the central-east tropics demonstrates a nonlinear relationship between rainfall and recharge whereas intense seasonal rainfall associated with the El Niño Southern Oscillation and the Indian Ocean Dipole mode of climate variability^{2,3} contributes disproportionately to recharge. Analysis of the intergovernmental Panel on Climate Change AR4 and AR5 multi-model ensembles for the twenty-first century indicates that projected increases in extreme monthly rainfall responsible for observed recharge, are of much greater magnitude than changes to mean rainfall. Increased use of groundwater may therefore prove a potentially viable adaptation to enhanced variability in surface-water resources and of moisture resulting from climate change^{4,5}. Uncertainty in the projected behaviour of the El Niño Southern Oscillation and associated teleconnections remains, however, high^{6,7}.

Groundwater is the world's largest accessible store of fresh water and supplies 50% of the world's drinking water and ~40% of the water used for irrigation¹. Groundwater is the only reliable source of fresh water in many semi-arid and arid regions where surface water is seasonally or perennially absent⁸. The long-term viability of groundwater resources as well as the ecosystems and livelihoods that they sustain, depends on replenishment of groundwater by recharge. Over the past 50 years, groundwater depletion has been estimated and observed in several aquifers throughout the tropics and sub-tropics^{9–11}. Such depletion not only threatens ecosystem function and the livelihoods of groundwater-dependent communities in some of the world's poorest regions but is also estimated to contribute to sea-level rise^{12,13}. A conceptual understanding of the relationship between rainfall and recharge is fundamental to the development of robust estimates and projections of not only groundwater recharge and depletion but of all components of the terrestrial water balance under changing climate and increasing freshwater demand.

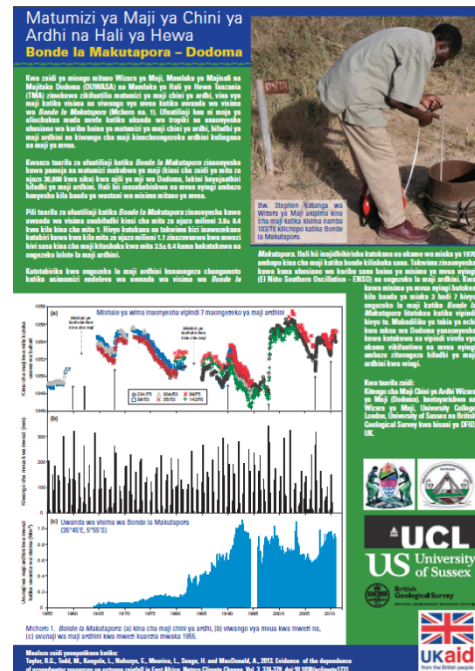
Recharge results from effective precipitation (that is, precipitation minus losses from evapotranspiration) infiltrating the

subsurface where hydraulic gradients are downward. Diffuse groundwater recharge occurs directly through the soil matrix to saturated soils and through soil macropores and fractures that bypass the soil matrix. Focused groundwater recharge takes place indirectly by way of leakage from runoff and surface-water sources including ephemeral streams and is often a critical source of recharge in semi-arid environments^{14–16}. The magnitude of effective precipitation is highly sensitive to changes in precipitation and evapotranspiration, particularly in semi-arid environments where differences between these fluxes are small^{17,18}. Soil moisture-balance modelling studies in the tropics^{19–21} suggest a nonlinear relationship between rainfall and recharge in which recharge is limited to heavy rainfall events (>10 mm d⁻¹) that temporarily exceed high rates of prevailing evapotranspiration. A key uncertainty is whether soil infiltration capacities are able to transmit, in practice, modified increases in recharge generated by heavy rainfall. Indeed, the relationship between precipitation and groundwater recharge remains poorly resolved in many regions owing to a lack of long-term observational data.

Here we present empirical evidence of the relationship between rainfall and groundwater recharge in semi-arid and tropical East Africa from a recently compiled near-continuous, 55-year (1955–2010) record of coincidental, in situ groundwater-level observations (variable time-lag with annual and monthly rainfall (Fig. 1a,b)). Observations derive from the Makutapora Wellfield (3°–4°S, 35°–36°E) in central Tanzania where groundwater is abstracted from an aquifer comprising deeply weathered granite overlain by alluvium. This unique time series, the longest observed record yet published for any location in the tropics, reveals the highly episodic nature of recharge events indicated by positive deflections in groundwater levels that result from anomalously intense rainfall during the austral summer monsoon (November–April). These recharge events interrupt multiannual recurrences in groundwater levels. Rates of groundwater-level decline have increased substantially from ~0.5 m yr⁻¹ (1955–1990) to ~1.7 m yr⁻¹ since 1990. This change is a response to pronounced increases in monthly groundwater abstraction from 0.1 to 0.9 million m³ to supply potable water to the national capital, Dodoma (Fig. 1c). Increased groundwater abstraction is limited by natural, inter-annual groundwater storage that is replenished by rainfall, inter-annual groundwater storage that is replenished on a decadal timescale by episodic recharge.

The observed relationship between seasonal rainfall and groundwater recharge in the tropics (Fig. 2a) as recharge is largely restricted to anomalously intense seasonal rainfall. The cumulative recharge distribution (Fig. 2b) shows that the top 7 (11) seasons of rainfall account for 60% (70%) of the total recharge observed over 55 years from 1955 to 2010; remaining recharge is confined to seasons that

Policy briefs



Radio



Video



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