QUANTIFYING THE RECHARGE OF CRYSTALLINE AQUIFERS IN A SEMI-ARID SAHELIAN CONTEXT: A MODELLING EXERCISE IN THE TOUGOU CATCHMENT, BURKINA FASO.

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1. Introduction

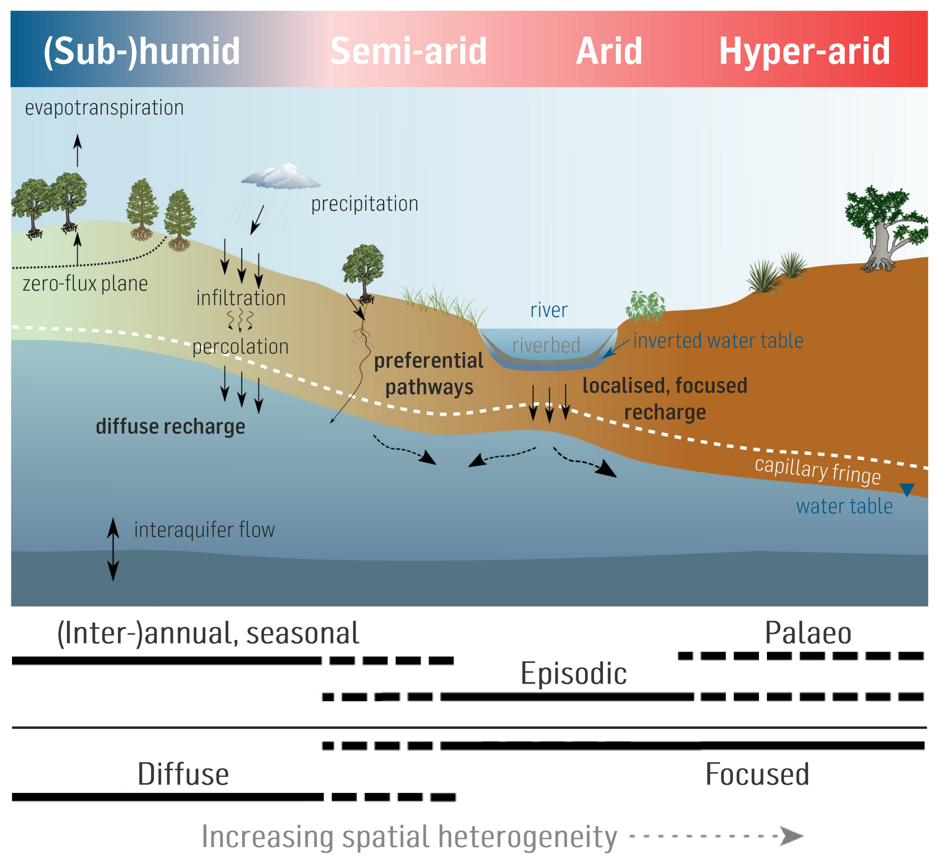
Quantifying groundwater recharge is fundamental to assessing current and future water security in the face of increasing abstraction and climate change, and to ensuring sustainable management of groundwater resources (MacDonald et al. 2021). However, estimating recharge has traditionally been complex due to its episodic nature and high inter-annual variability, particularly in arid and semi-arid regions (Cuthbert et al. 2019), the lack of widely applicable methods that can directly and accurately quantify it, and even the lack of a consistent definition of what recharge is (Gong et al. 2023).

We present the hydrological observatory of the Tougou catchment and the efforts we have made to characterise recharge mechanisms and its quantification on the basis of data collected along a representative kilometer transect across the intermittent river.

2. Groundwater recharge pathways to weathered-rock aquifer systems in dryland catchments

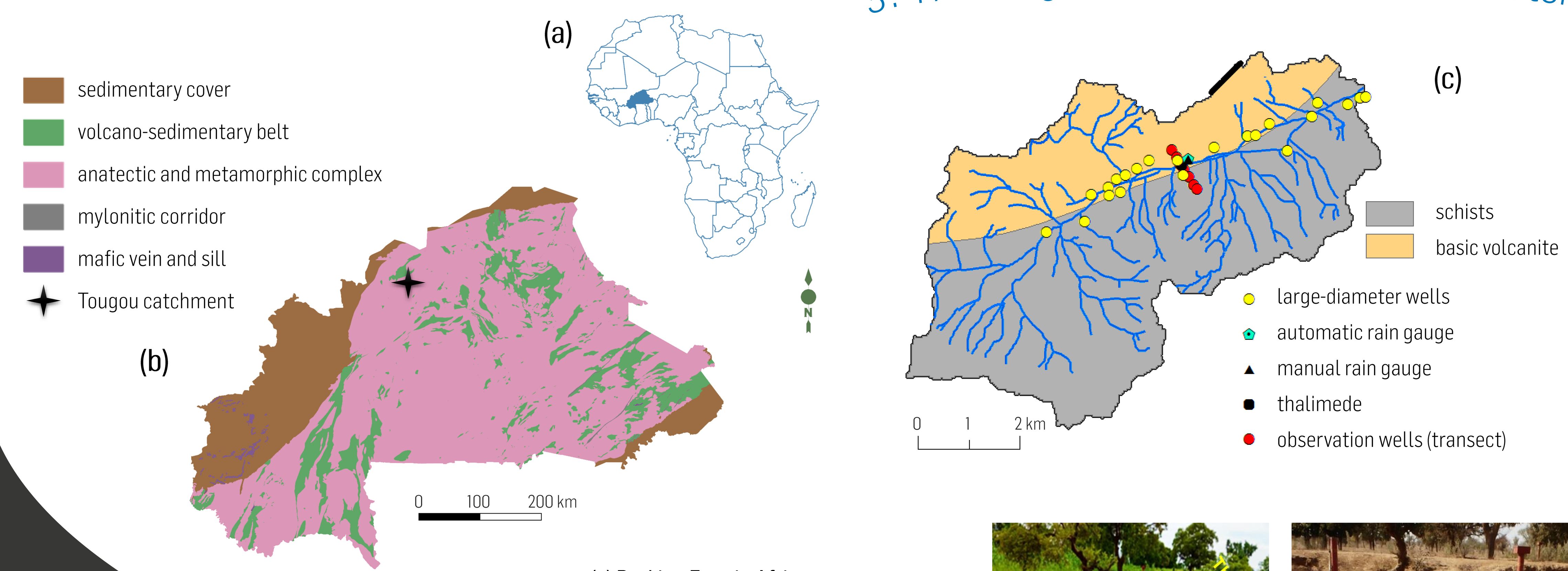
Located in the Sahelian zone of West Africa, the Tougou catchment is an ideal place to study recharge, in semi-arid conditions where both diffuse and focused recharge coexist, and where the crystalline context is conducive to the development of preferential recharge pathways.

In such areas, in particular in Africa, data on recharge is limited (Xu & Beekman 2019), although better quantification of recharge and understanding of the pathways by which it occurs are particularly crucial (Zarate et al. 2021).



Temporal and spatial variations and processes of recharge in sub-Saharan Africa (from Healy 2010, Xu & Beekman 2019 and Cuthbert et al. 2019)

3. The Tougou critical zone local observatory



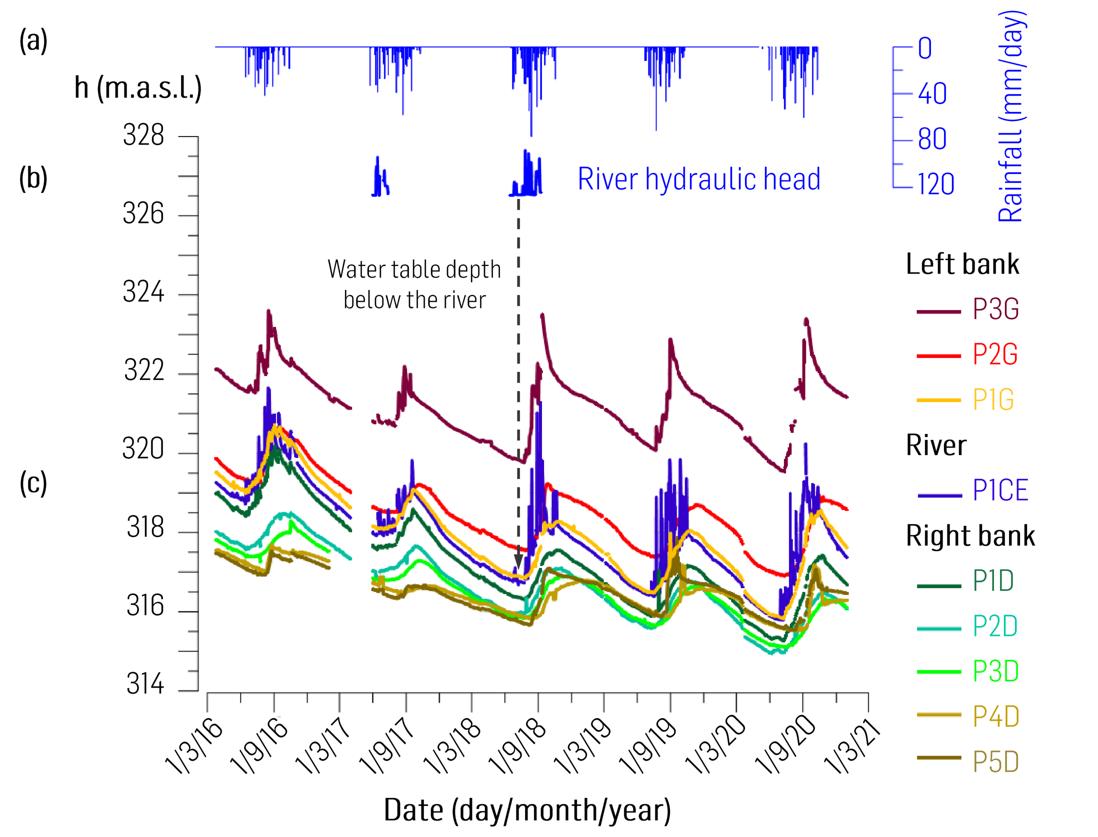
(a) Burkina Faso in Africa
(b) Simplified geology of Burkina Faso
(c) Tougou catchment with the location of the transect in red on a geological background and a view of the installations in the river in the centre of the transect (Rusagara et al. 2022)

Covering an area of 37 km² and shaped by metamorphic rocks, the Tougou catchment has long been a local observatory of the critical zone, instrumented and monitored by 2iE. Previous analysis of the hydrogeological data available in the catchment revealed a classic weathered rock aquifer system consisting of a superficial saprolite aquifer overlain by residual soils and laterite and underlain by an altered shale aquifer (Rusagara et al. 2022). A kilometre-long transect has been equipped with observation wells for daily monitoring of groundwater levels between 2016 and 2020, coupled with measurements of the river level during the wet season.

4. An overview of the recharge mechanisms of the Tougou catchment

Observations

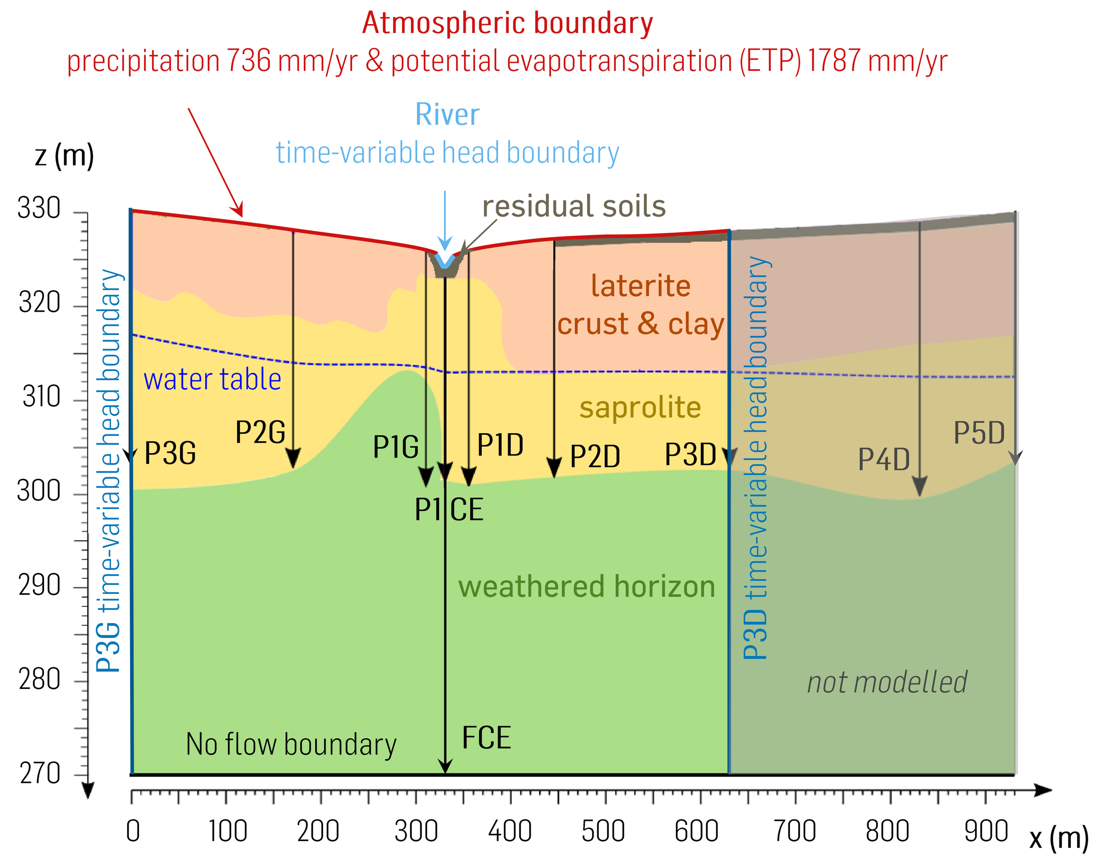
Time series recorded along the transect: (a) rainfall (b) river water level (partially in 2017 and fully in 2018) (c) groundwater level



The mean depth to the water table in the unconfined saprolite aquifer is around 9 m. Hydraulic heads generally decrease from left to right bank, as does the amplitude of their variations, while the phase shift of the groundwater signal with respect to the meteorological forcing increases, a sign of a less diffusive medium or the result of pressure transfer. The aquifer system has two characteristic response times: the faster one indicates a highly reactive medium to the most intense rainfall events, particularly under the river, which favours aquifer recharge, probably by preferential pathways.

Modelling design

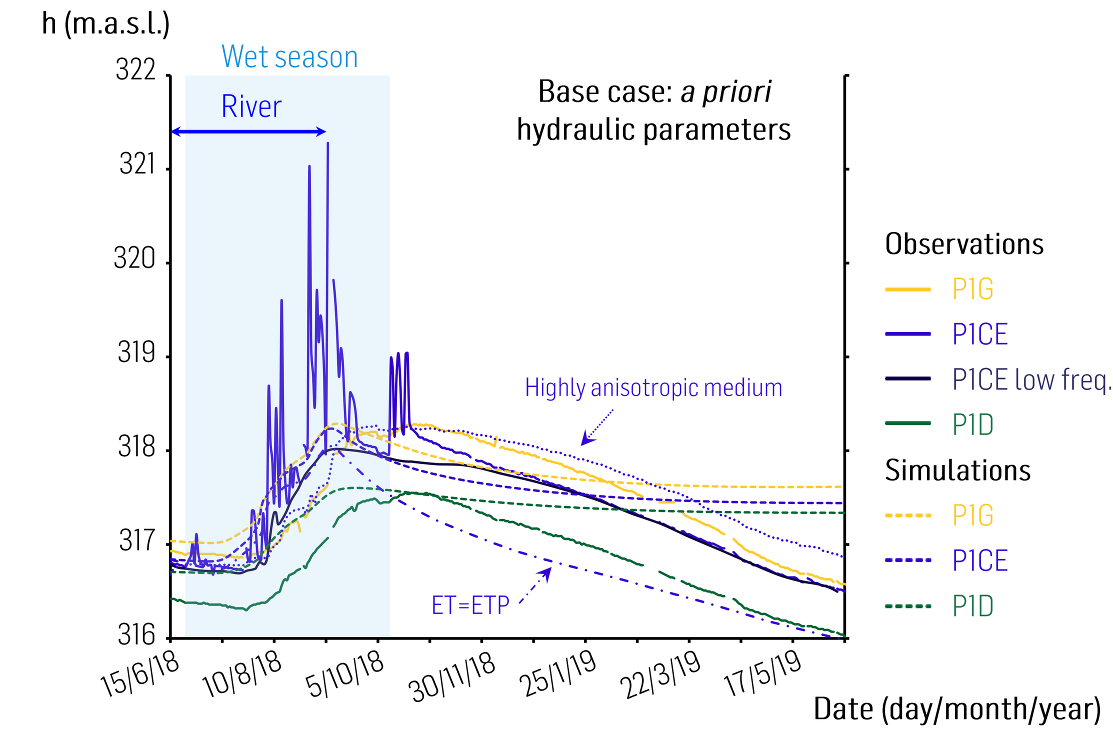
We use the variably saturated finite element model HYDRUS-2D (Šimůnek et al. 2008) to simulate part of the transect during the 2018-2019 hydrological year, from the rainy season onwards, using the hydraulic parameters from Phogat et al. (2017) in a similar crystalline modelling context as *a priori* values and a range of hydraulic conductivities for the clayey saprolite aquifer from 5×10^{-6} to 7×10^{-5} m/s as indicated by pumping tests.



The 630 m long 2D modelled profile with the 4 formations considered, the boundary conditions and the location of the observation wells

Quantifying recharge

Given the diversity of responses from one well to another, revealing a highly heterogeneous medium, we focus here on what happens under the river (P1CE, P1G and P1D).



We get the low frequency groundwater rise but not its recession due to the lack of lateral drainage in this 2D model configuration. Increasing evapotranspiration to its potential or horizontal relative to vertical hydraulic conductivities allows to the recession to be simulated but is unrealistic.

In the base case, river infiltration is 55 mm/yr. Our previous estimates of recharge from analysis of groundwater level fluctuations were around 15 mm/yr and up to 50 mm/yr for P3G on the north bank and 150 mm/yr below the river in 2018 (Rusagara et al. 2022).

References

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5. Work in progress & Perspectives

We are still carrying out model sensitivity analyses to refine our description of recharge along the transect. Further analysis is required to identify the dominant factors causing water level fluctuations under the intermittent river:

(a) Work is needed to better represent and account for the influence of initial conditions, for example by extending the simulation over time, which will require the simulation of unrecorded river levels. Unfortunately, the observatory has not been monitored since 2021 and is now closed for security reasons.

(b) The simulation of high frequency hydraulic head variations remains challenging and may require the use of a dual porosity or permeability model.

(c) In the future, we will also be using a model such as Hydrus-3D, which allows us to couple unsaturated and saturated zones.

We could then usefully attempt to extrapolate local recharge estimates to the whole Tougou catchment scale.

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