Session: Nature Based Solutions, Ecosystem Services and Groundwater. Links with the SDGs (Abstract 164)

# Nature-based water storage in seasonal rivers in support of resilient livelihoods in semi-arid regions in Africa: Assessing the recharge and storage potential of the Toroka sand river in Kenya


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*"Groundwater: Key to the Sustainable Development Goals"* Conference

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UNESCO IHE DELFT NaBWIG Nature based Water Infrastructures for #GlobalGoals SORBONNE UNIVERSITÉ

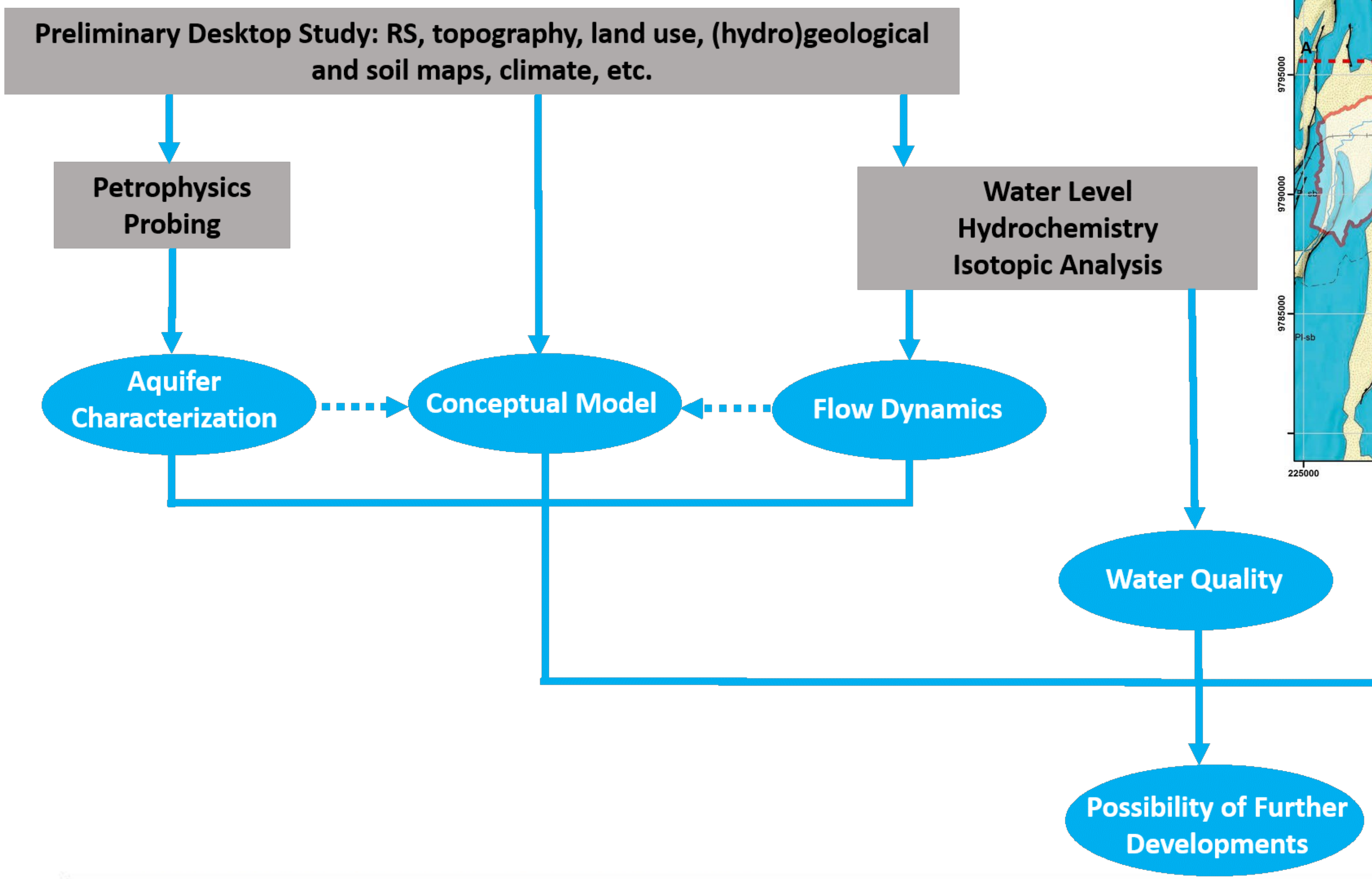
# Problem Statement and Significance

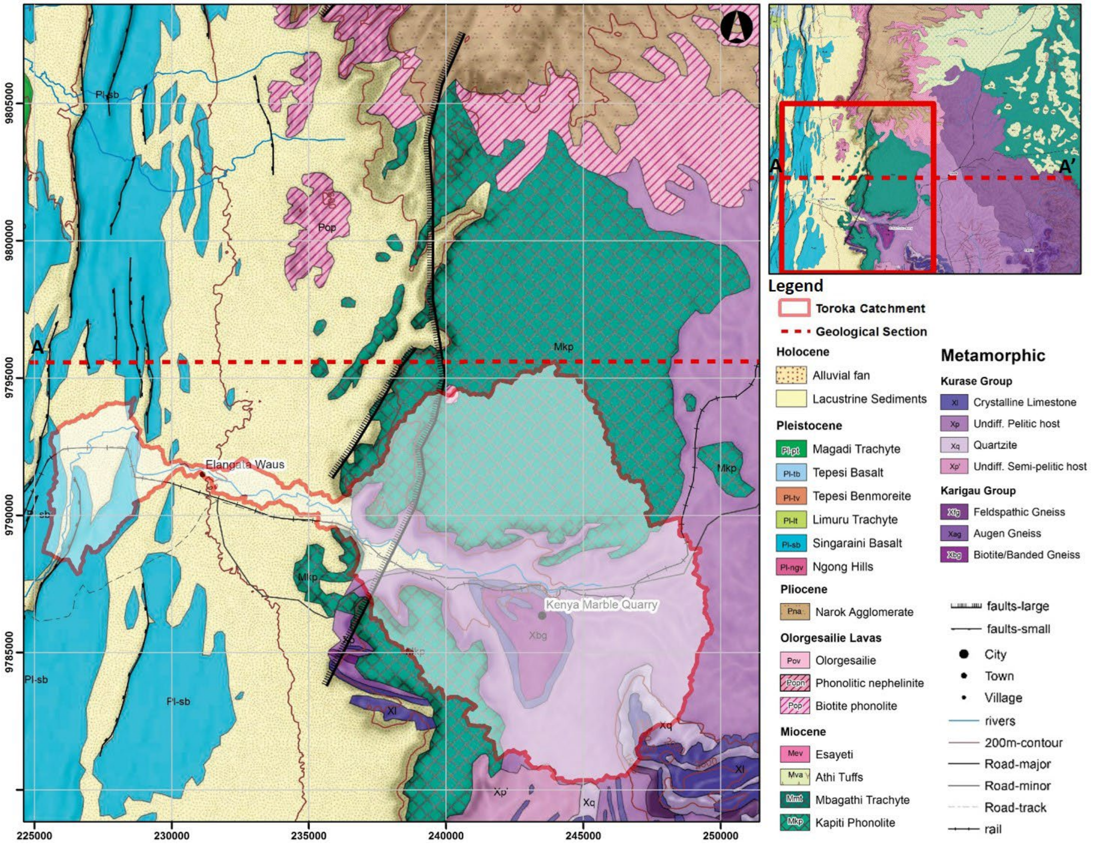
- **NaBWIG**: optimize ecological functions and storage capacities of natural systems.
- Rural communities in (semi)arid regions had historically relied on **sand rivers** (Hussey, 2007; Hamer et al., 2008).
- Important for agriculture (but **underutilized**).
- **Sustainable exploitation** of sand rivers:
  - Improve small scale agricultural productivity (SDG Target 2.3);
  - Sustainable supply of freshwater to address water scarcity (Target 6.4);
  - Adaption to climate hazards (droughts) (Target 13.1).


*Livestock water sources at the alluvial aquifers in Kajiado County (Kiptala et al., 2020)*

# Research Methodology

- Conceptual Framework of the Research Methodology

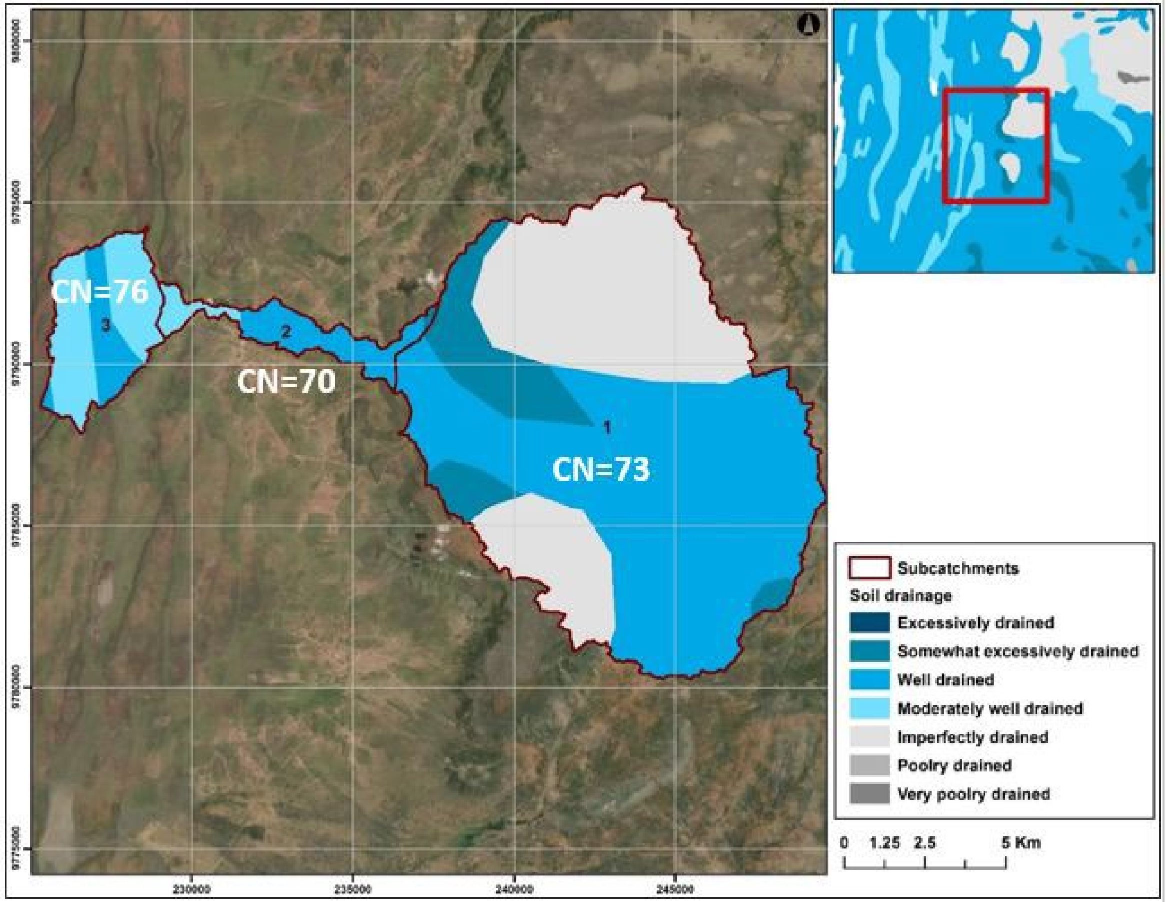


# Rainfall-Runoff Analysis

- Higher CN, higher runoff potential.
- Spatially distributed CN method.
- Compared with surveys and RS results.
- Local knowledge:
  - Flooded river during April (100% of the participants)
  - Dry year: 11 surface runoff days
  - Typical year: 17 days
  - Wet year: 26 days

*Soil drainage (data source: SOTER database for Kenya)*

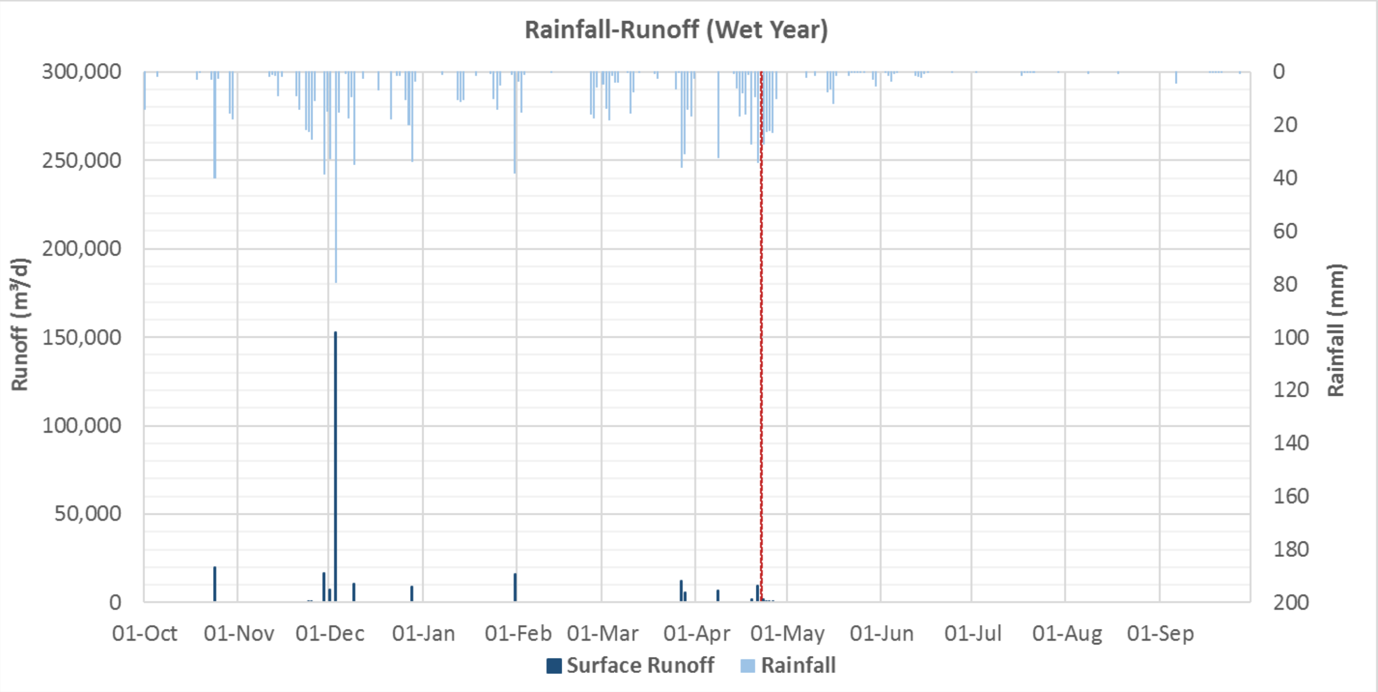


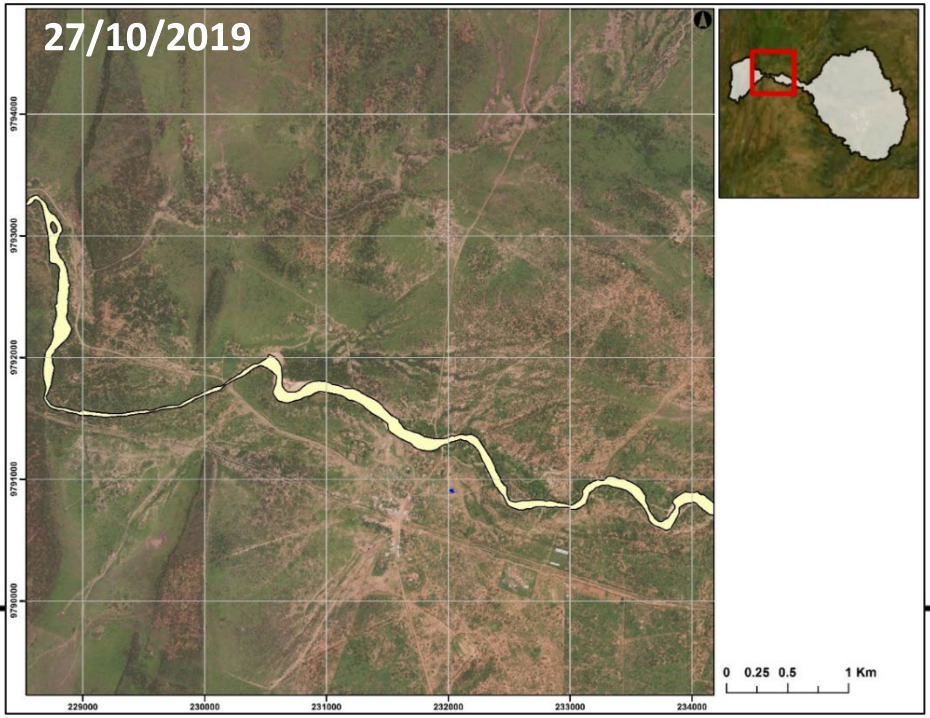

*Summary of the runoff analysis results using **CHIRPS** rainfall data*

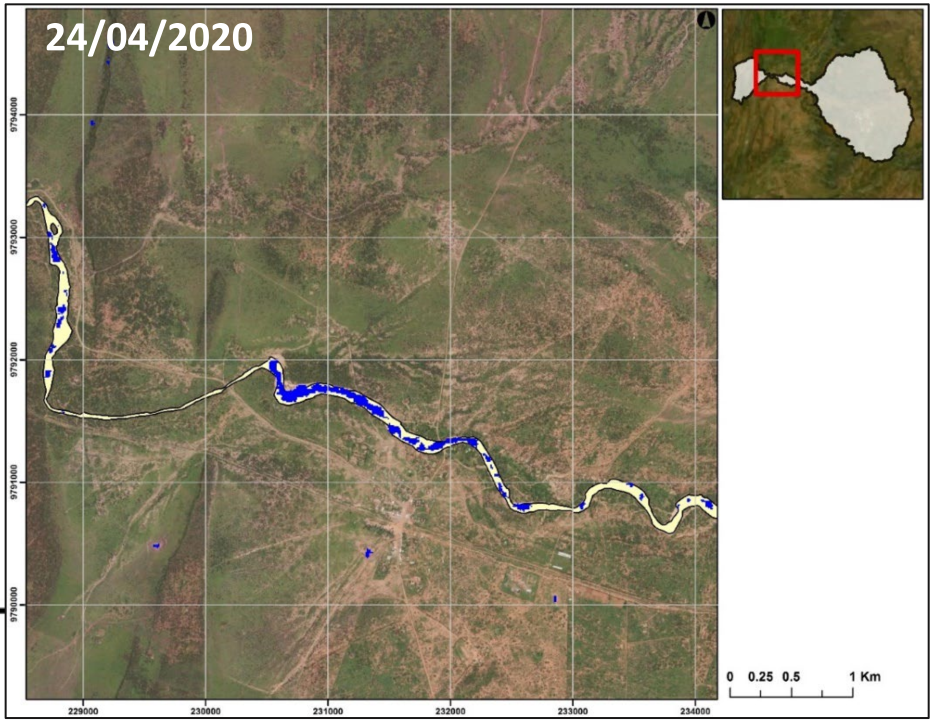
| | Dry Year | | | Average Year | | | Wet Year | | |
|---|---|---|---|---|---|---|---|---|---|
| | CN = 73 | CN = 70 | CN = 76 | CN = 73 | CN = 70 | CN = 76 | CN = 73 | CN = 70 | CN = 76 |
| **Runoff Occurrence (days)** | 4 | 3 | 6 | 8 | 6 | 11 | 20 | 18 | 27 |
| **Minimum runoff (mm/d) *** | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Maximum runoff (mm/d)** | 2.5 | 1.5 | 3.8 | 12.9 | 10.2 | 15.9 | 23.8 | 20.0 | 28.0 |
| **Total runoff (mm/year)** | 4.6 | 2.5 | 7.6 | 26.4 | 19.2 | 35.6 | 50.9 | 35.7 | 71.4 |

# Surface Water Mapping

- Sentinel-1 data products (7 acquisition dates).
- Surface water during April (fully saturated).

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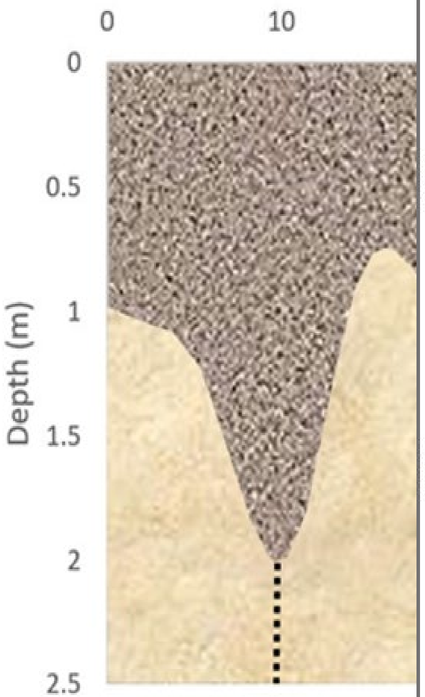
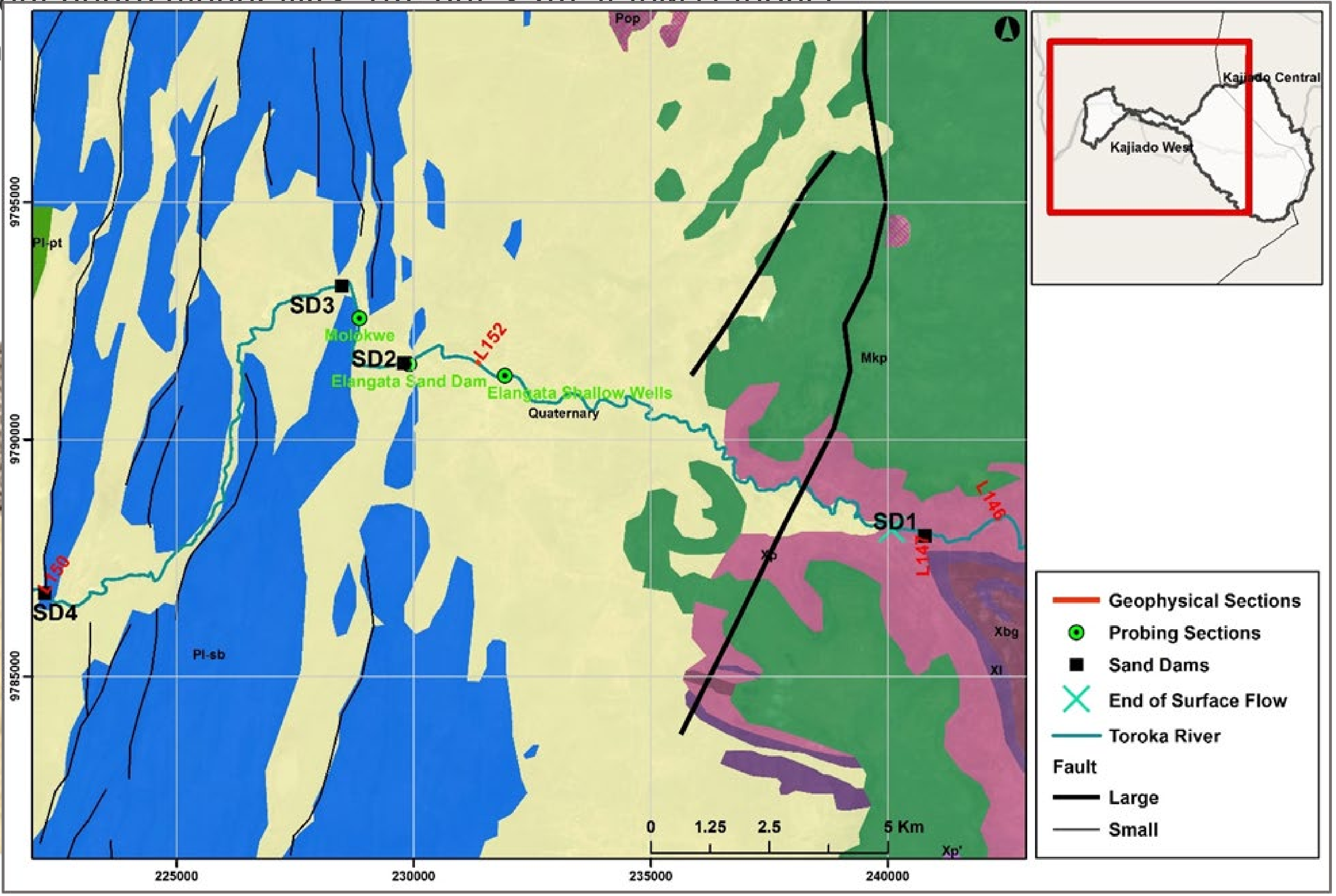
# Subsurface Characterization

- Irregular sediment depth (generally < 1m; but > 2m at few stations)
- Riverbed sedim




Probing section for Elangata Wuas (near the shallow wells). Note: dotted lines indicate locations where more than 2m of sand was found




*Geophysical survey and probing locations*

# Storage Capacity

- Consumption rates (MOWI, 2005):
  - 10 L/capita/day
  - 50 L/livestock unit/day
- Demographic data (KNBS, 2019)
- Livestock per household (surveys)

**Annual Estimated Demand: 0.50 MCM**

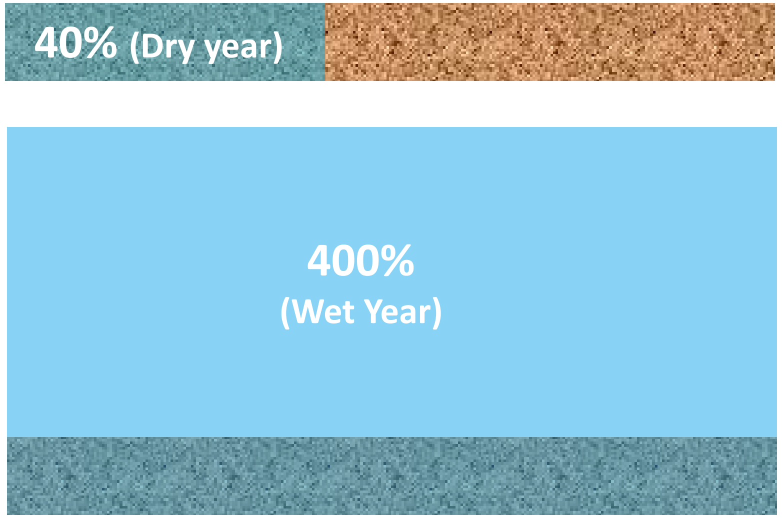
≥

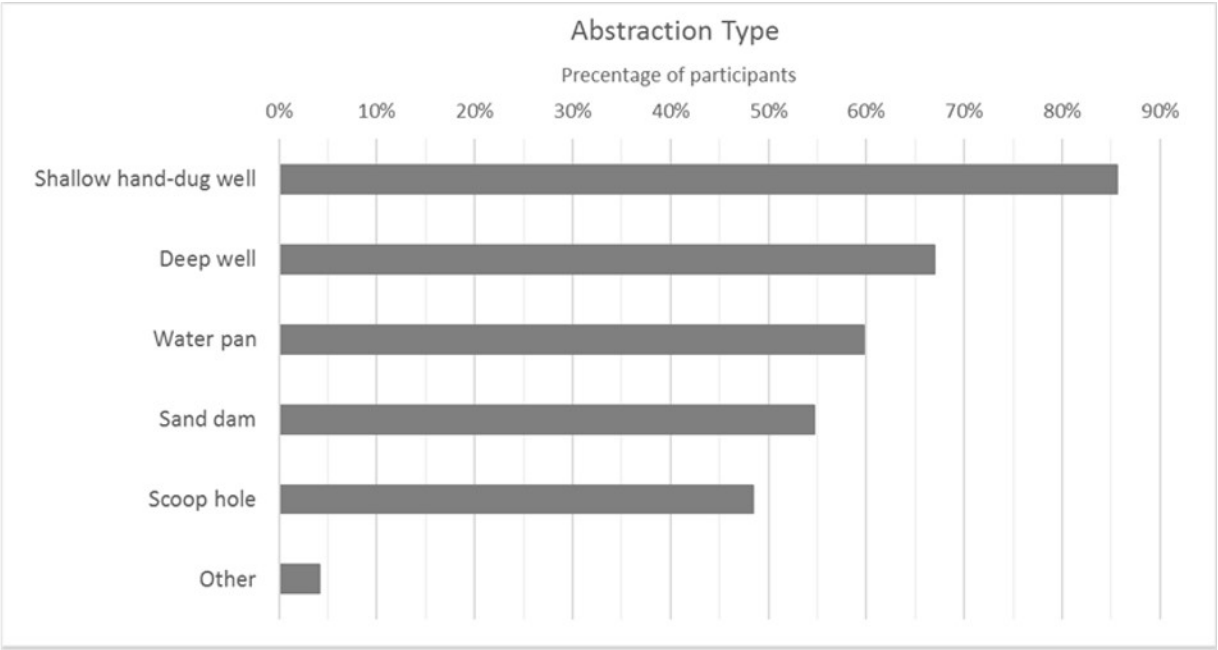
- Sand depth: 1.5 m
- River surface area: 0.84 km$^2$
- Effective porosity: 15% to 40%

**Storage Potential: 0.19 to 0.50 MCM**

Surface runoff (subcatchments 2 and 3)

Average storage capacity

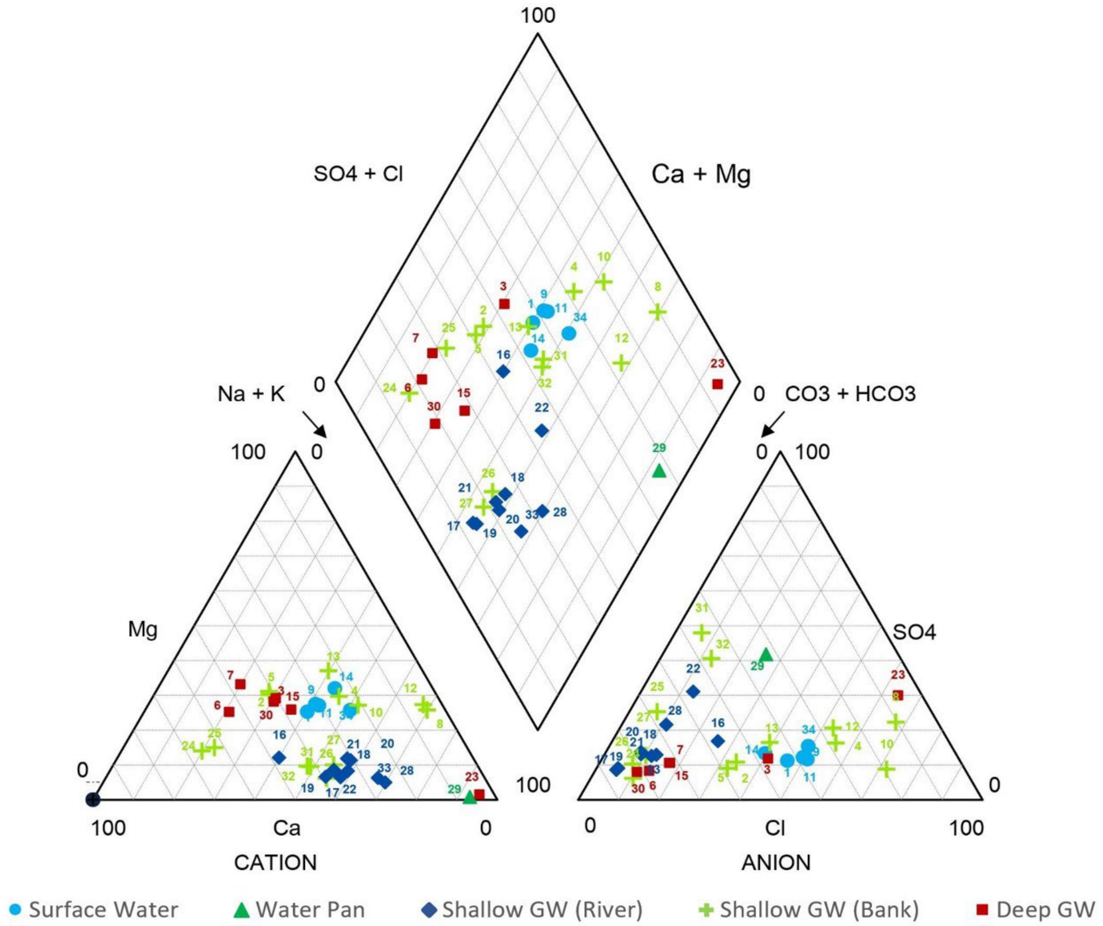



*Currently used water supply infrastructure*

# Schöeller and Piper Plots

- All the **sand river samples** are suitable for drinking.
- Sand river samples: $NaHCO_3$ (possibly silicate weathering).
- Some river bank samples reflect sand river characteristics.
- Others show mixing (locally recharged groundwater and infiltrated runoff).
- **Deep groundwater**: $CaHCO_3$ (dissolution of calcite or originally recharged in a $CO_2$ rich environment).
- **Surface water** mostly affected by hydrogeological processes.

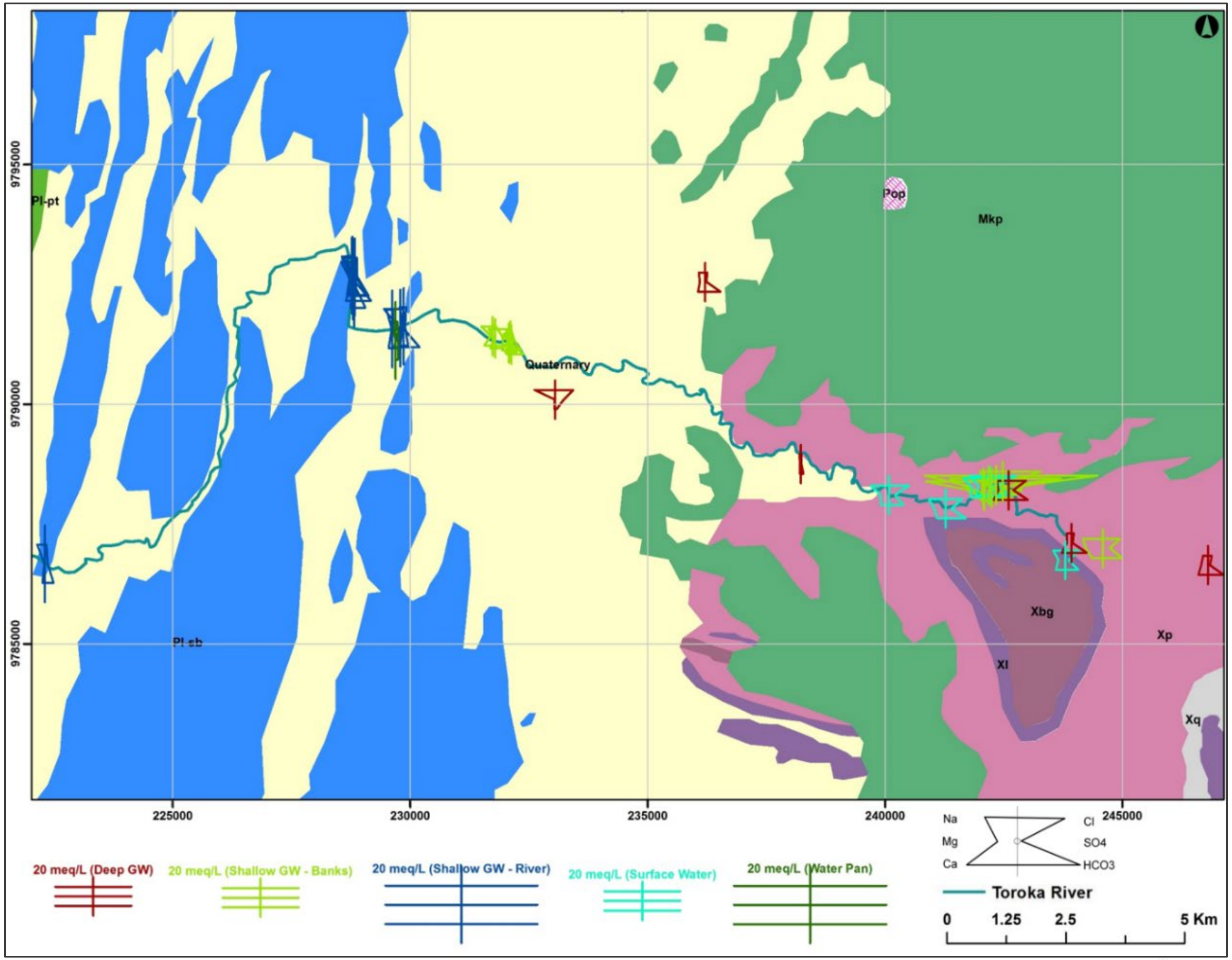



*Piper plot*

*Schöeller diagram of the sand river's shallow groundwater samples*

# Chemical Water Type

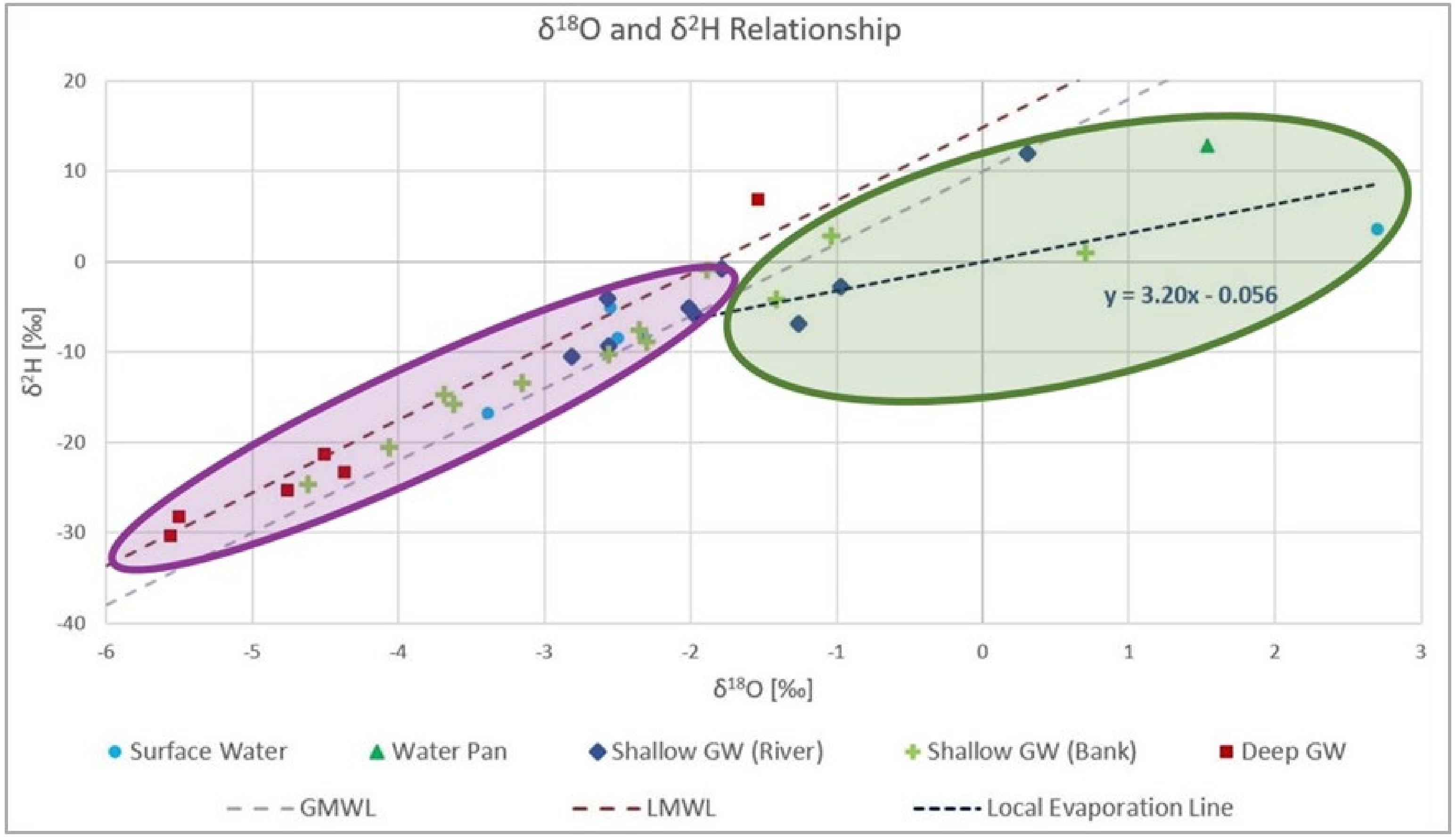
- **River banks:** dominance of $Ca^{2+}$ and $Mg^{2+}$ in the gneiss environment, $Na^{+}$ in the quaternary.
- Higher EC of the banks' groundwater: enhanced evapotranspiration and lower recharge.
- **Upstream** samples mainly brackish, **downstream** samples show lower salinity (younger/recently recharged) → Different flow systems.




*Stiff diagrams*

# Stable Water Isotope Analysis

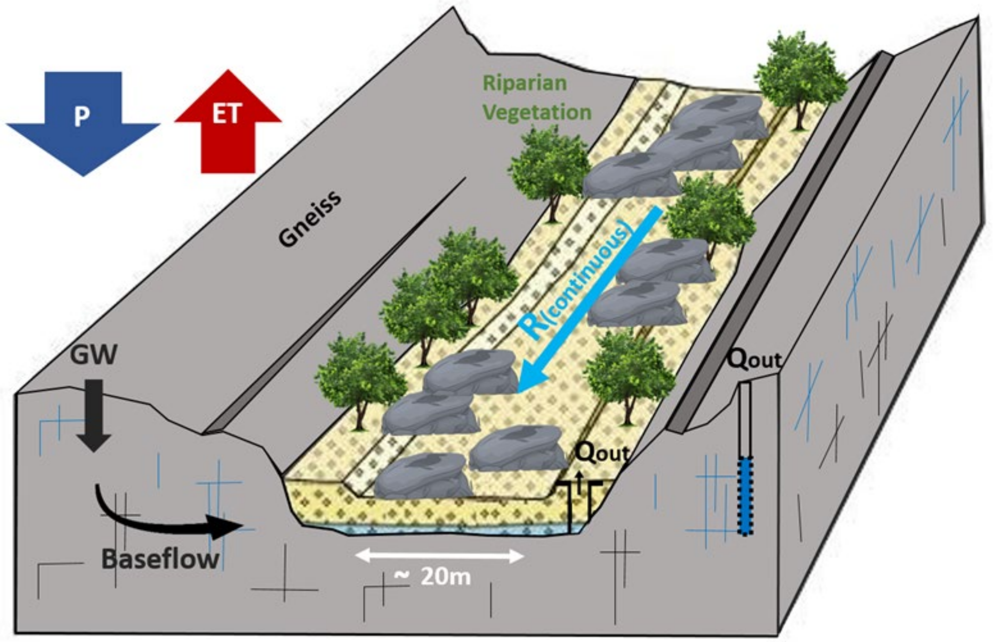
- A **first group** close to the GMWL (mainly recharged by local precipitation).
- A **second group** showing a heavier isotopic composition (due to evaporation).
- Plot of $\delta^{18}O$ versus the $Cl^-$: sand river and surface water samples show enriched isotopic composition (compared to deep groundwater) → higher evaporation effect.
- Two groups of river bank samples.



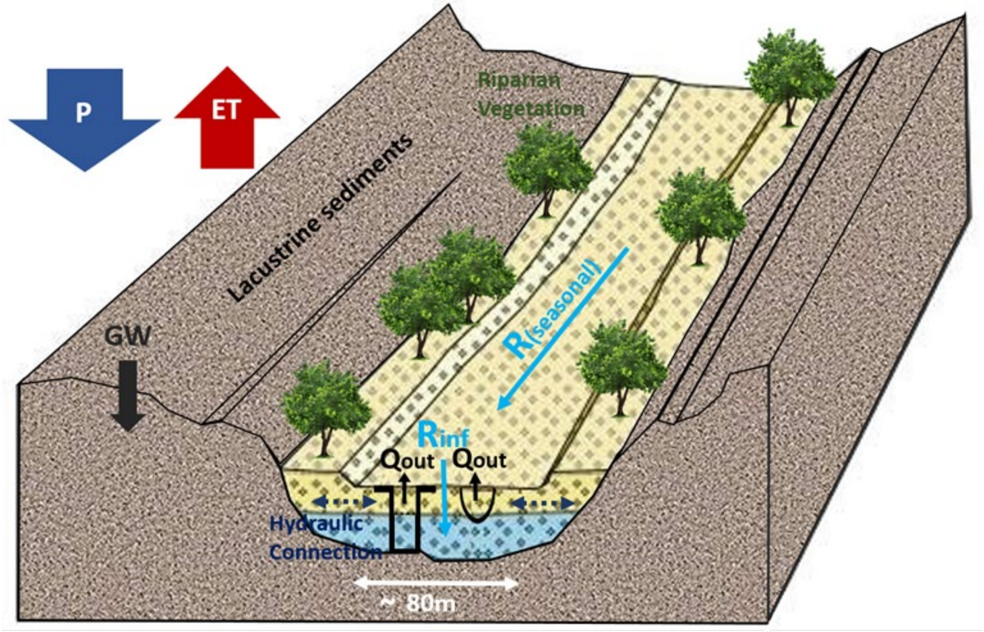

*$\delta^2H$ versus $\delta^{18}O$ (classified scatter points per water source)*

# Sand River's Characteristics and Behavior

- **Wider and thicker** in the downstream.
- **Continuous surface flow** in the gneiss-dominated area (before disappearing).
- Surface water has **baseflow characteristics** (enriched with dissolved ions, chemical composition as groundwater).
- **River banks groundwater** in the gneiss environment different than quaternary (dominance of $Ca^{2+}$ and $Mg^{2+}$).
- River banks groundwater **result of mixing** between locally recharged groundwater and infiltrated surface runoff (especially in the downstream).
- Some river bank samples showed the same water type as the sand river → **interaction/hydraulic connection** between those two systems.




*Conceptual model for the upstream part (gneiss environment)*




*Conceptual model for the downstream part (quaternary environment)*

# Water Availability

- Sand river groundwater **suitable for drinking** (Hussey, 2007).

- **Uncertainty of the storage** capacity (suitable for abstractions).
- Storage potential: **10000-27000 m³/km** (versus **62500** m³/km for the **Shashane** (Moulahoum, 2018) and **13000-17000** m³/km for the **Middle Mara** (Wekesa et al., 2020)).

- Storage accumulated during a **wet year** can **cover the demands for one following dry year** (locals adapt by well deepening and changing the source).

- Water stored within the riverbed sediments is **subject to evaporation** (the top 33 to 60% of the sediment can be affected).
- Storage also threatened by **sand harvesting** (reported in the literature, satellite imageries and during the fieldwork).

- **More consistent use** of the sand river's water (to cover part of the demand).
- Fraction of the recharge for **ecological demands**.

*River section affected by sand harvesting.*

# General Recommendations

- Low storage potential --> **Enhancing the storage** (especially that sand harvesting is occurring).
- Building **sand dams and subsurface dams** (downstream part).
- **Small surface reservoirs** in the upstream (away from the sand deposits, low-permeability hardrock).
- **Losses** through evaporation and leakage through rock fractures.
- **Artificial recharge** of the sand river through managed releases from an upstream dam.
- Abandoned agricultural lands: **capacity building** activities (economic importance of agriculture).




*Field pictures of a broken sand dam (left) and a functional sand dam (right)*

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