Groundwater assessment in sand rivers in adaptation to climate variability and water scarcity: opportunities and challenges in semi-arid Africa

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*Poster presentations today 16h
NATURE-BASED WATER STORAGE IN DRY RIVERS IN AFRICA

• Warm semi-arid regions frequently considered of low potential for agricultural development, due to limited/irregular access to water

• UN WWDR (2018): dry rivers can provide water storage for up to 60,000 km² of irrigated land in Africa

• A4Labs project: assess sand river potential, strengthen links water – energy – crop – market for the individual farmer (https://a4labs.un-ihe.org/)

• Requires the study of sand river aquifer characteristics at different scales
SAND RIVER AQUIFER RESEARCH QUESTIONS

- Sand river aquifer: type of alluvial aquifer formed in thick sand beds of wide ephemeral rivers deposited from pronounced upstream catchment weathering and erosion

- Groundwater assessment RQ:
  1. Hydrogeology and connectivity with margins
  2. Recharge/discharge mechanisms
  3. Abstraction location/rates
  4. Hydrochemistry and water quality
  5. Competition with other users

Adapted from Gonzalez-Carballo (2018)
1. Hydrogeology and connectivity with margins
   • Geophysics, auger drilling, sediment analysis
   • Infiltration and pumping/slug tests
   • Remote sensing, drone surveys
   • Groundwater flow modelling

2. Recharge/discharge mechanisms
   • Infiltration tests
   • Rainfall/runoff data, soil water balance
   • Water level measurements in piezometers
   • Groundwater flow modelling

3. Abstraction location/rates
   • Pumping tests
   • Groundwater flow modelling

4. Hydrochemistry and water quality
   • Major ion, Fe, Mn analysis
   • Stable water isotope analysis

5. Competition with other users
   • Water balance

Gonzalez-Carballo (2018)
Hydrogeology and connectivity with margins

Gonzalez-Carballo (2018)

CONCEPTUAL MODEL

Recent alluvial deposits (sand river)
Former alluvial deposits
Sand deposits on higher terraces
Weathered Paleozoic rocks
Paleozoic sedimentary rocks
Neo-Proterozoic basement

K = 12 m/d
K = 0.7 m/d

May Gobo
Ethiopia
Hydrogeology and connectivity with margins

- Riverbed formed of poorly sorted fine to coarse sand, \( K_h = 80 - 120 \text{ m/day} \)
- Thickest part of sand river deposits at the outer bend (> 5m)
- Sand river very irregular and formed out of disconnected reservoirs
- Estimated groundwater flow velocity 0.26 m/d (100 m/a)
- Connectivity with river bank is limited

Hydrogeology and connectivity with margins

- Limpopo main channel: wider and thicker sand deposits
- Sand slightly finer, but still medium coarse, $K_h$ 30-120 m/day, $S_y$ 0.15
- Connectivity with margin limited by fine sediment
- Locally has been proven to exist, linked to the presence of paleochannels

Abi (2018)
Recharge/discharge mechanisms

- Rapid groundwater recharge takes place during “flood” events through lateral and vertical flow in the coarse sand deposits;
- Flood events occur almost every year and cover large part of the river valley;
- In the largest sand river systems a significant fraction of recharge is released again as base flow.
Recharge/discharge mechanisms

Water chemistry in the dry season

Climate
Semi-arid
P 450 mm/yr

Hydrogeology
sand river
confined by clays

Land use
Farming

Largest sand river (downstream)

Groundwater in “river bed dunes”:
• chemical signature of flood water
• isotopic signature indicates no evaporation signal

Abi (2018)

Limpopo
Mozambique
Recharge/dischARGE mechanisms

- Groundwater recharge from infiltration of river runoff
- Sand river re-saturation very fast and limits initial runoff
- Evaporation is the dominant discharge mechanism
- Evaporation effect observed up to a depth of 0.8 - 1.2 m
- Extinction depth limits the storage depletion during the extended dry seasons
Groundwater flow model of May Gobo subcatchment (steady state)

- Sand-dam makes the river influent
- Rate of transfer between sand river and riverbank is very reduced
- Evaporation is the dominant discharge mechanism
- Adequate abstraction system required

Recharge/discharge mechanisms

Simulation of sand dam role and development scenarios

- Smallest sand river (upstream)
  - 12.0 m³/d
  - 1.3 m³/d
  - 0.8 m³/d

Base case: May Gobo dam

- 1.8 m³/d
- 1.2 m³/d

Scenario 1: No Dam

Gonzalez-Carballo (2018)

May Gobo Ethiopia
Abstraction location/rates and implications

- Evaporation is important salinization mechanism
- Lack of isotopic fractionation is linked to limited “residual water” and redissolution of salt
- Quinn et al. (2018) find a correlation between age of the dam and salinity in Kenya
- Evaporation can be reduced by good abstraction practices
**Abstraction location/rates**

**Increase in well density**

Water demand below 450 m³/d entirely met.
Demand below 800 m³/d is satisfied at 95%.

For high abstraction rates, strategies 1-2 are better.

- Optimum well placement is behind rock sill.

**Moulahoum (2018)**

Shashane, Zimbabwe

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**Hussey (2007)**

- Strategy 1: 11 wells
- Strategy 2: 15 wells
- Strategy 3: 21 wells
- Strategy 4: 30 wells
Abstraction location/rates and implications

**Increase in well density**

- **Strategy 1**: 11 wells
- **Strategy 2**: 15 wells
- **Strategy 3**: 21 wells

**Shashane Zimbabwe**

Moulahoum (2018)

**Total abstraction 800 m³/d**

More recharge and less runoff due to abstraction
TAKE HOME MESSAGES

• The dominant mechanism of sand river recharge is runoff infiltration, a very fast process, which guarantees rapid replenishment of depleted storage;
• The dominant mechanism of sand river discharge is evaporation;
• Groundwater flow below the riverbed is slow and further hampered by rock sills, creating independent compartments;
• Good abstraction practices in time (start of dry season) and space (inside river bed) minimizes evaporation losses and the risk of salinization;
• In the largest sand river systems evaporation is less important than lateral discharge towards the river and base flow;
• Connectivity with the margins is often limited by hardrock or very fine sediments, but may locally be relevant (e.g. paleo-channels, requires further study);
• Downward leakage of sand river water can be relevant in fractured bedrock;
• The impact on riparian vegetation and downstream users requires further study, but runoff can be reduced if exploitation of a sand river is intensified.
Thank you! Questions?

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