International Water Resources Association
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Ministry of Equipment and Water

IHE DELFT Institute for Water Education
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TU Delft
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XIX WORLD WATER CONGRESS
International Water Resources Association (IWRA)
Marrakech, Morocco | 1-5 December 2025

# Recharge mechanism and hydrogeological functioning of mountainous springs in East African highland-lowland systems

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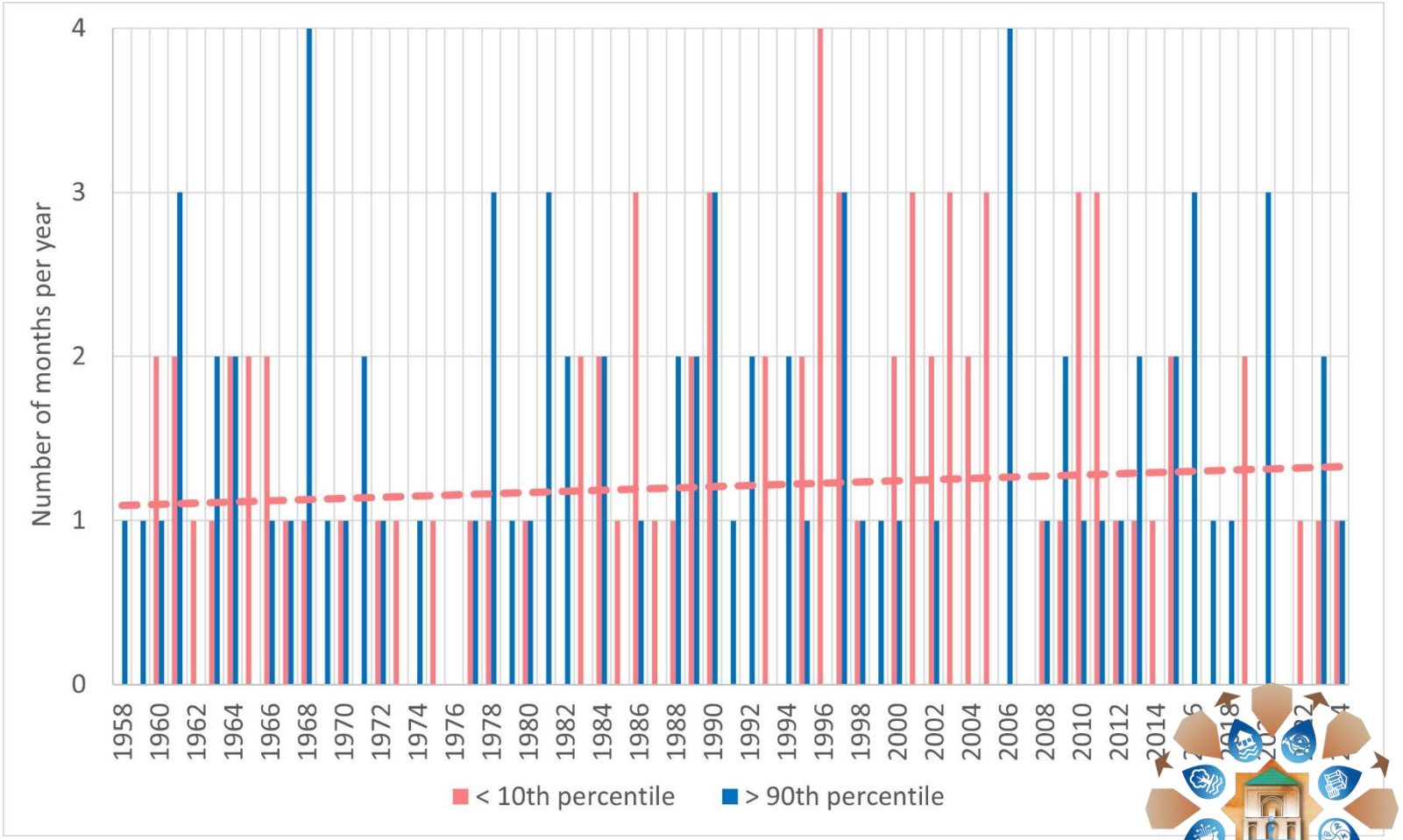
# Contents



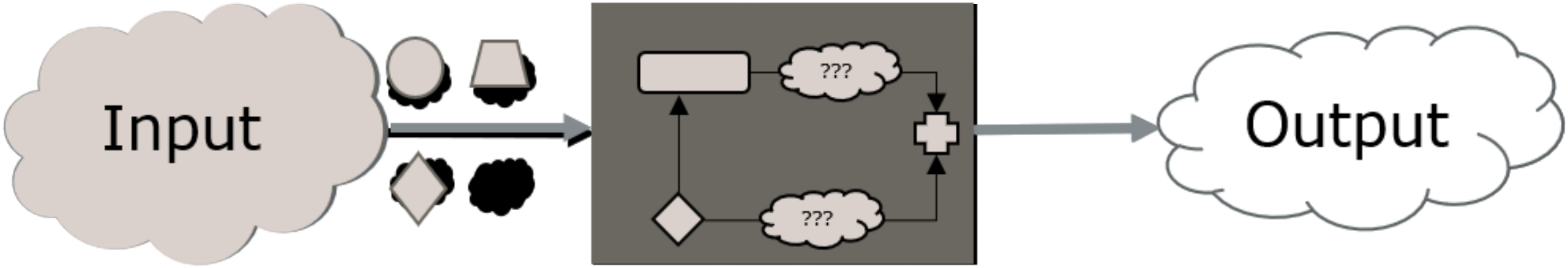
# Introduction

- East African montane forests are commonly known as water towers *(Hohenthal et al., 2015)*.
- Increasing competition over freshwater resources.
- Unpredictability of temperature and rainfall patterns in The Horn of Africa *(UNICEF, 2022)*.
- Gap in understanding the interplays between climate variabilities, alterations in land use, and their impacts on groundwater hydrology *(Jain, 2021; Mengistu et al., 2022)*.



# Objectives

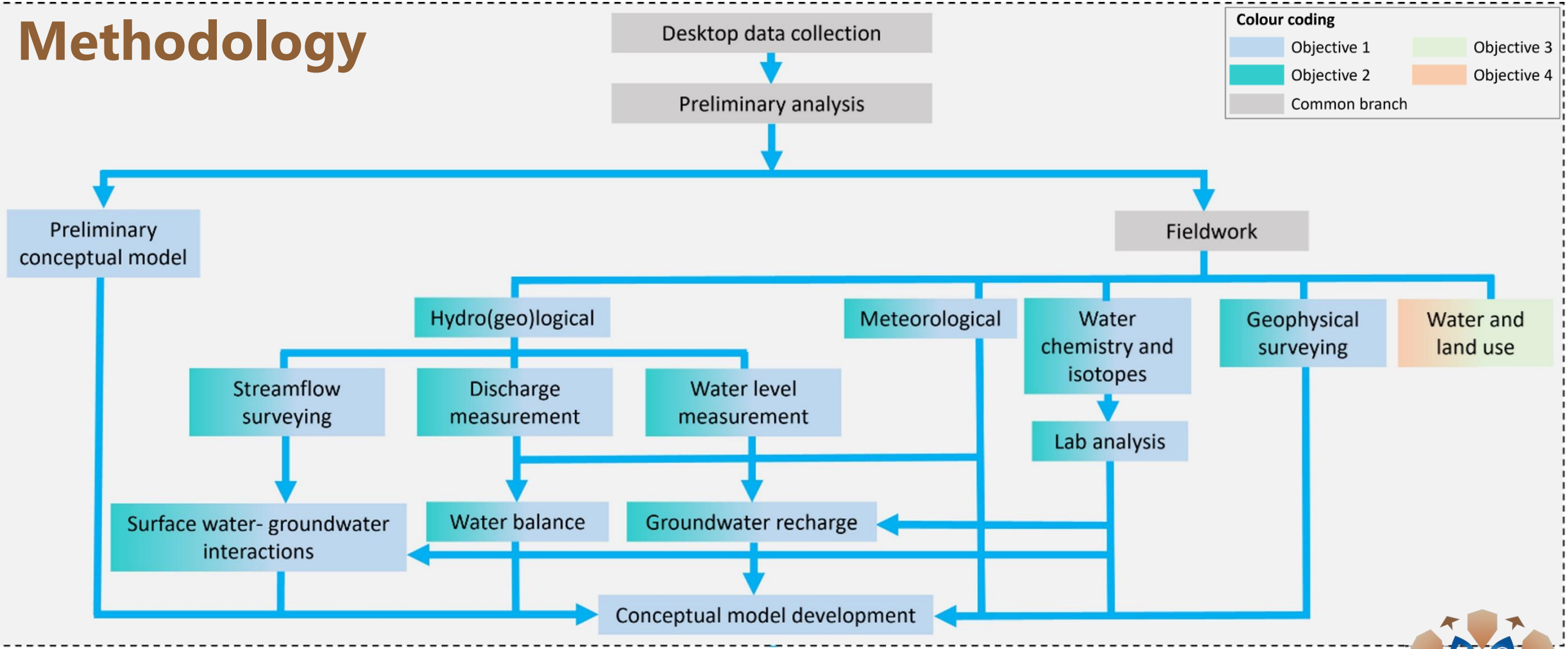
Characterize the hydrogeological setting and develop a **conceptual understanding of highland-lowland hydrological dynamics**, including surface water-groundwater interactions.



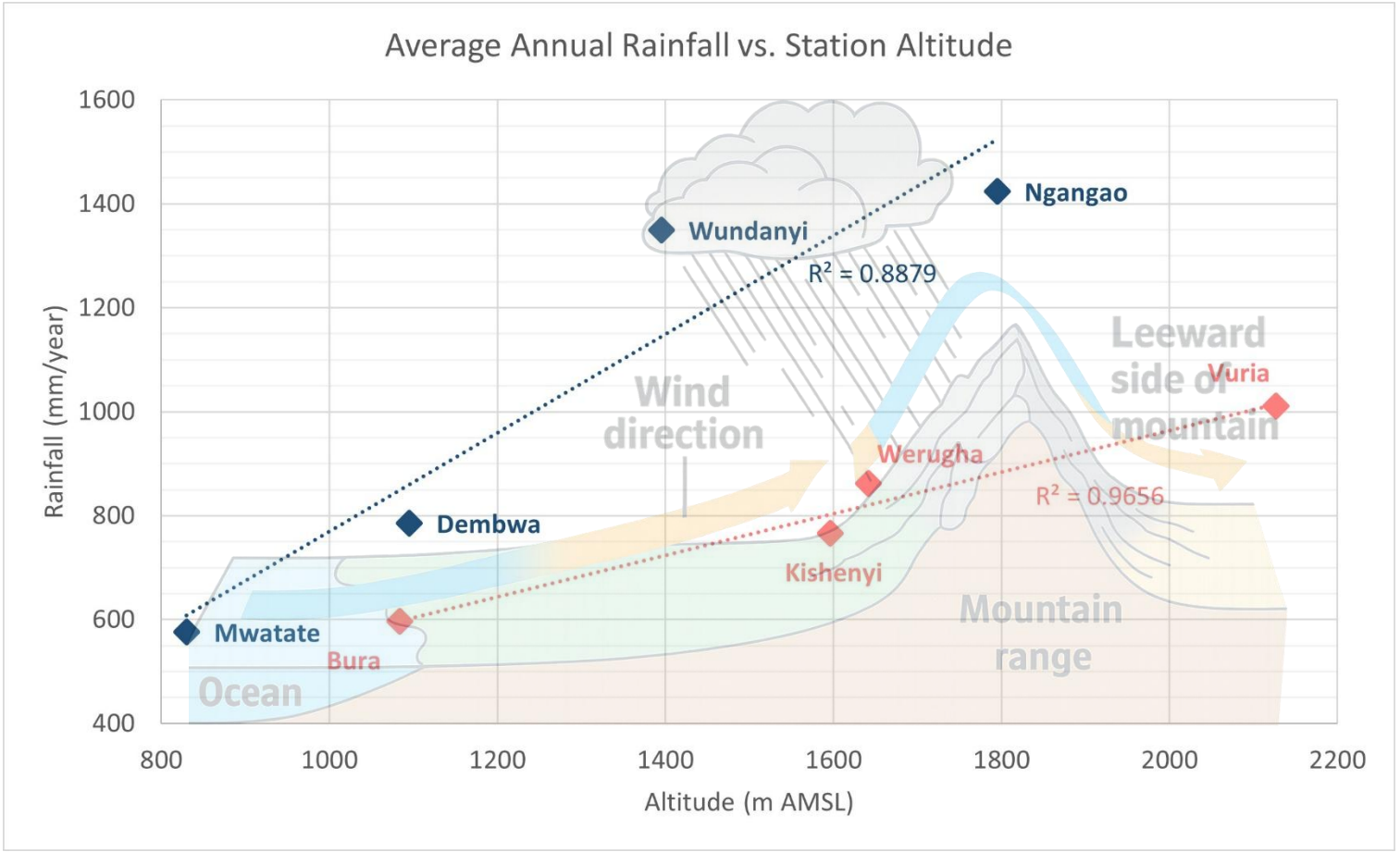

*Mountainous areas are the "blackest of black boxes" in the hydrological cycle (Klemes, 1988)*

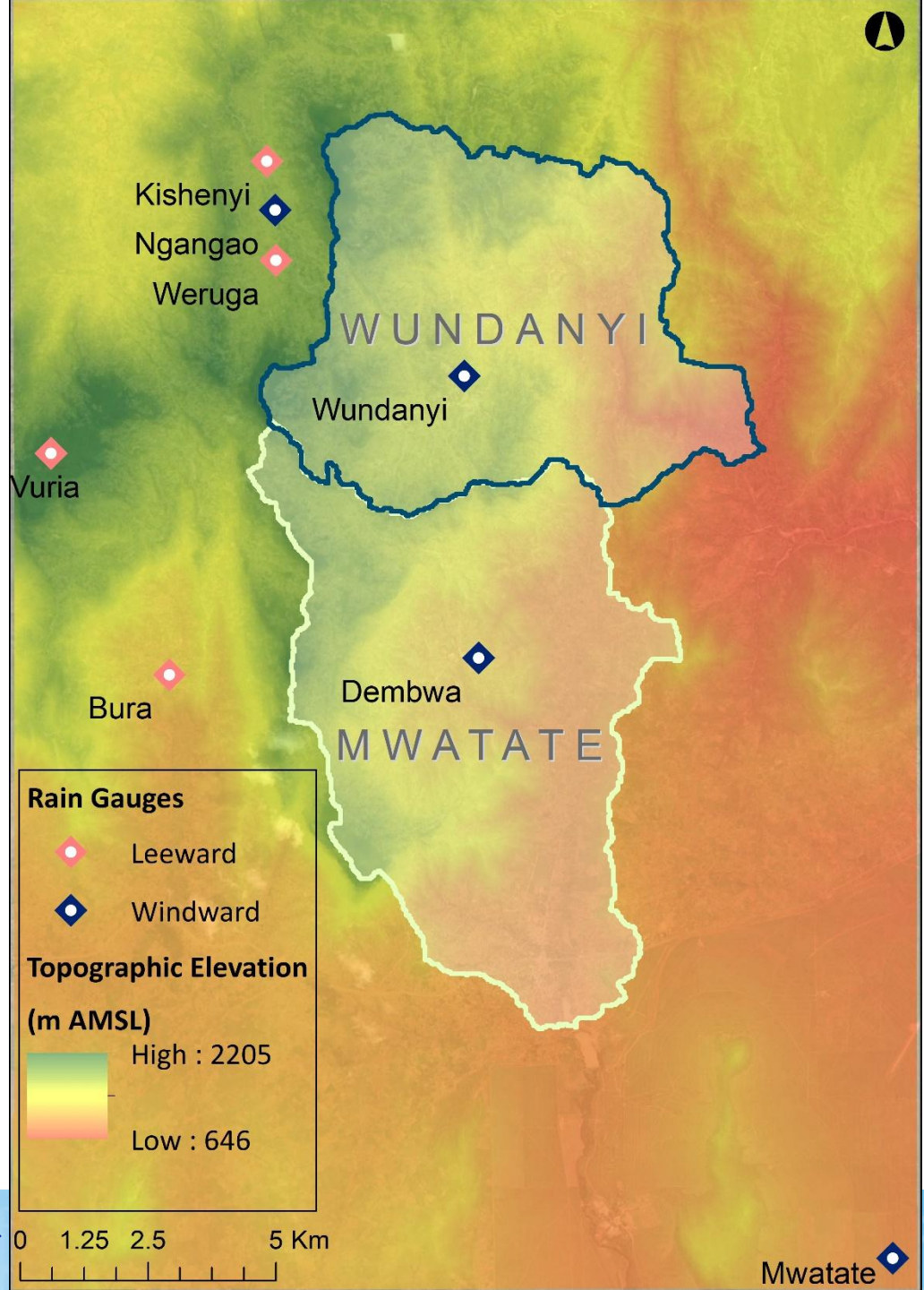
**High level of uncertainty** in understanding and modelling hydrological processes.

# Methodology



# System's Input



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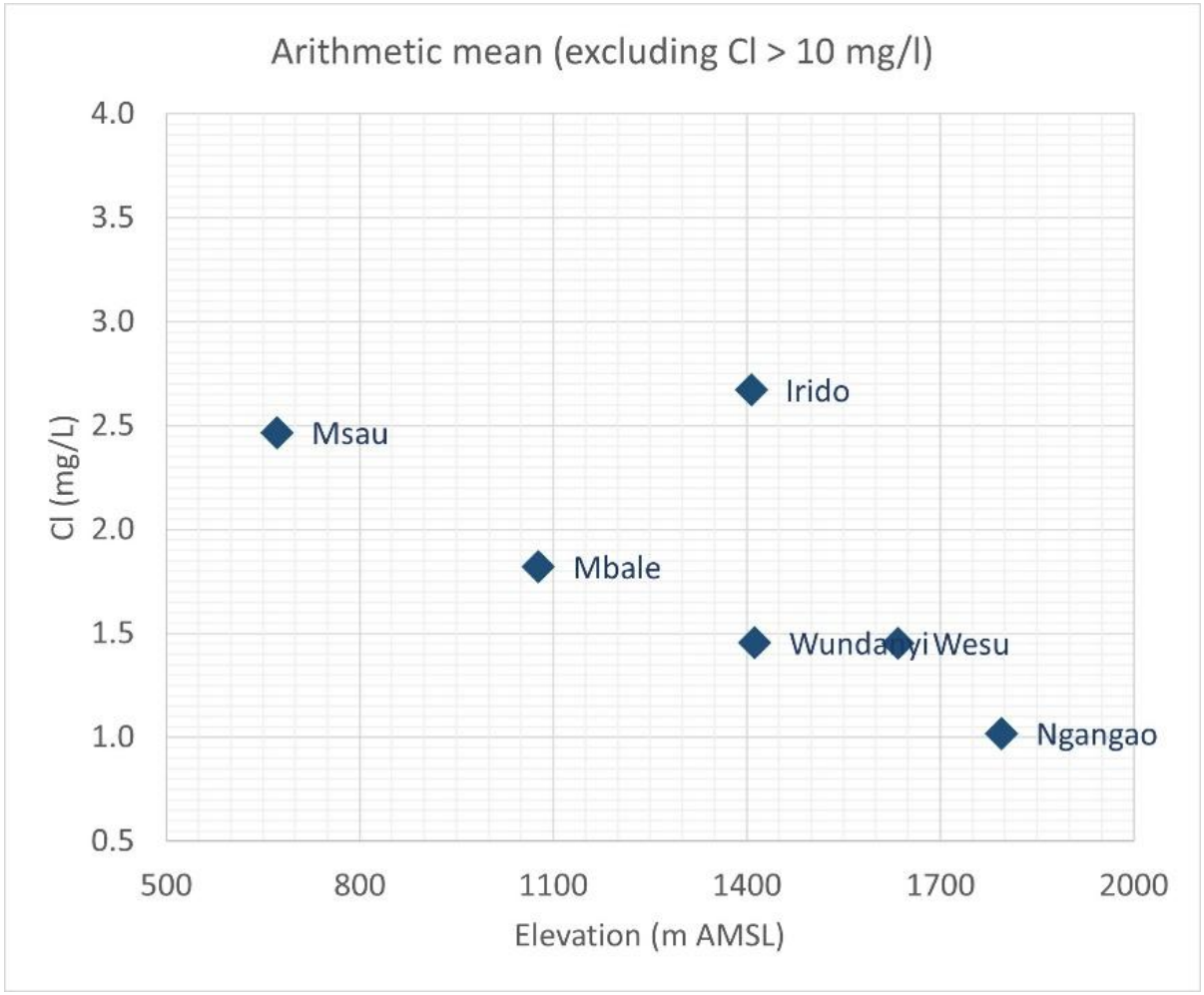
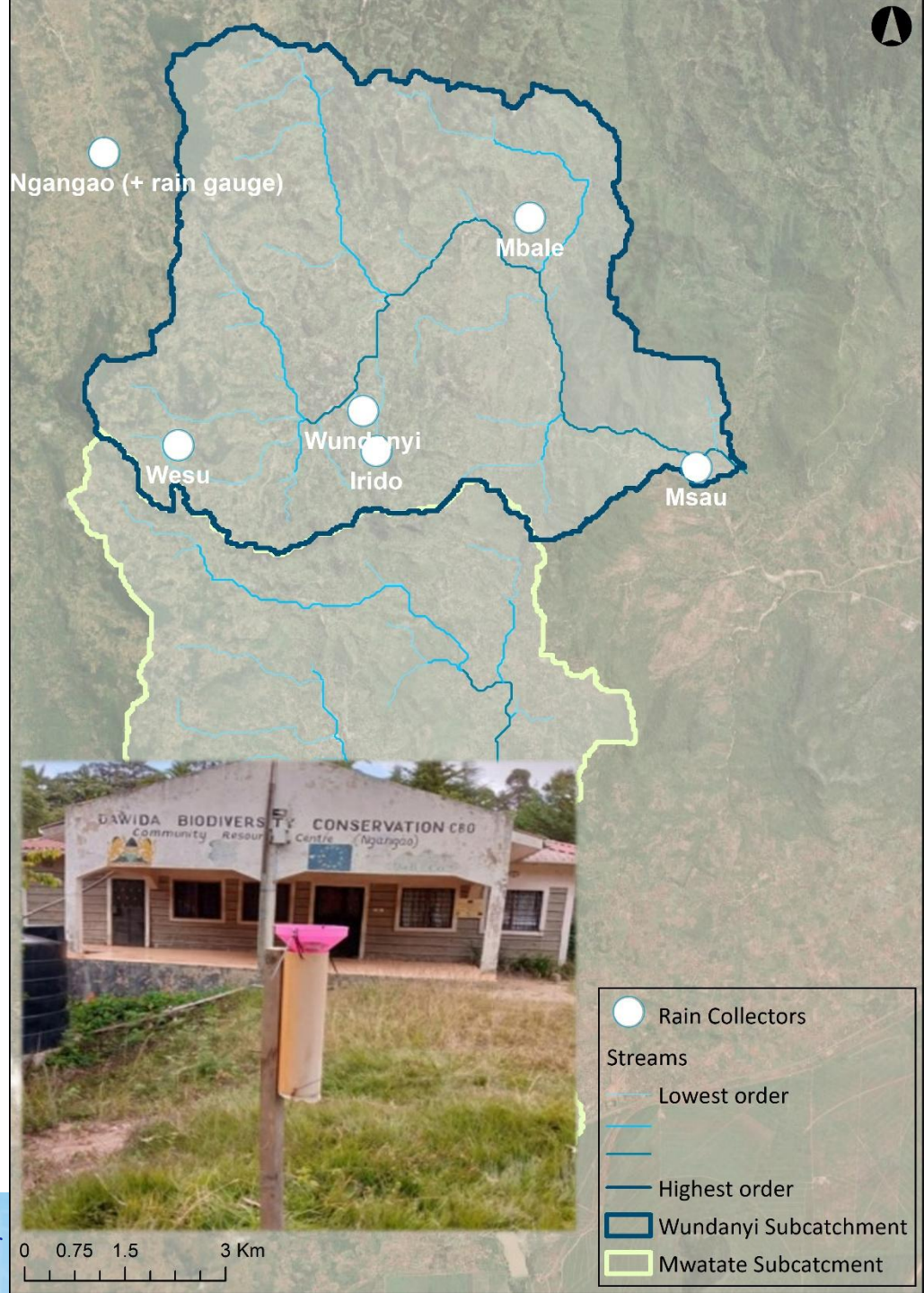
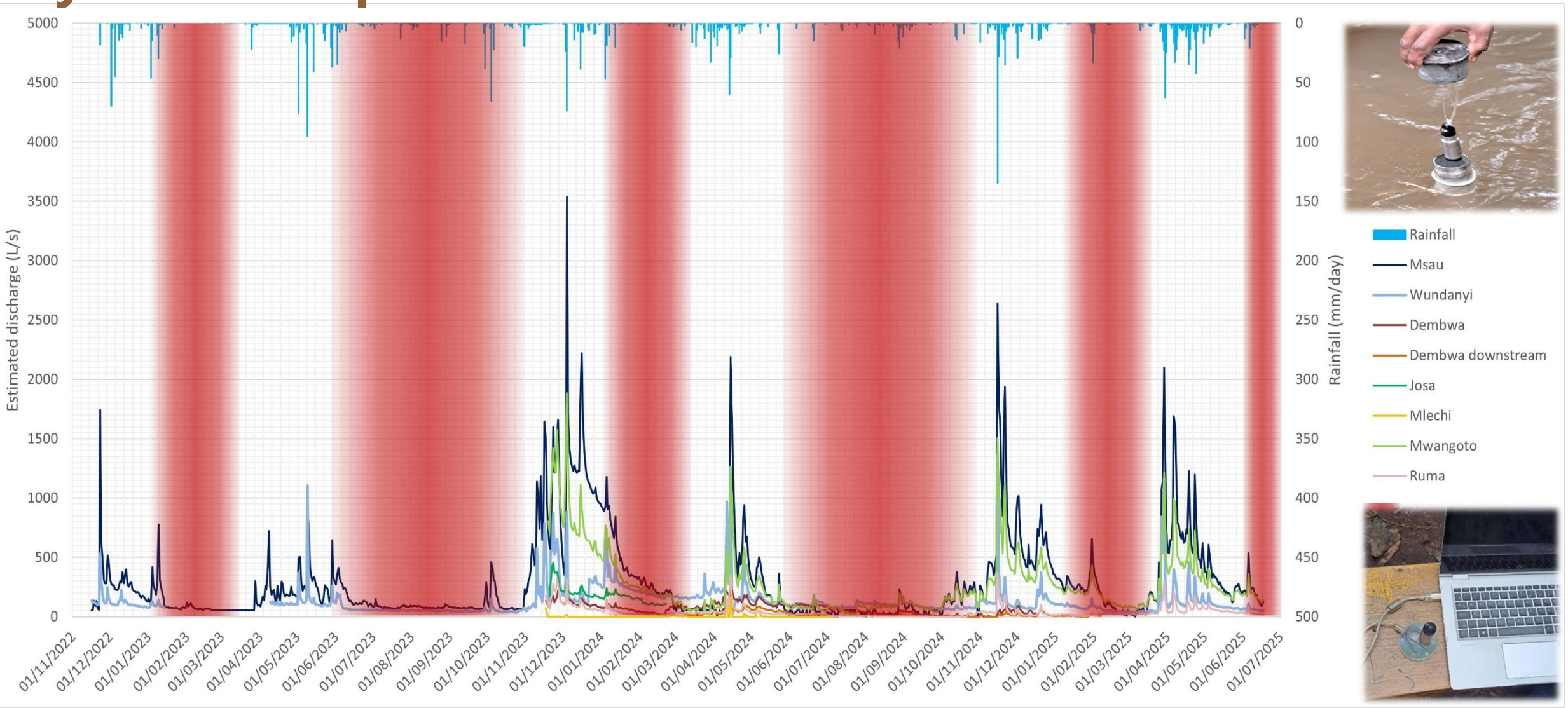


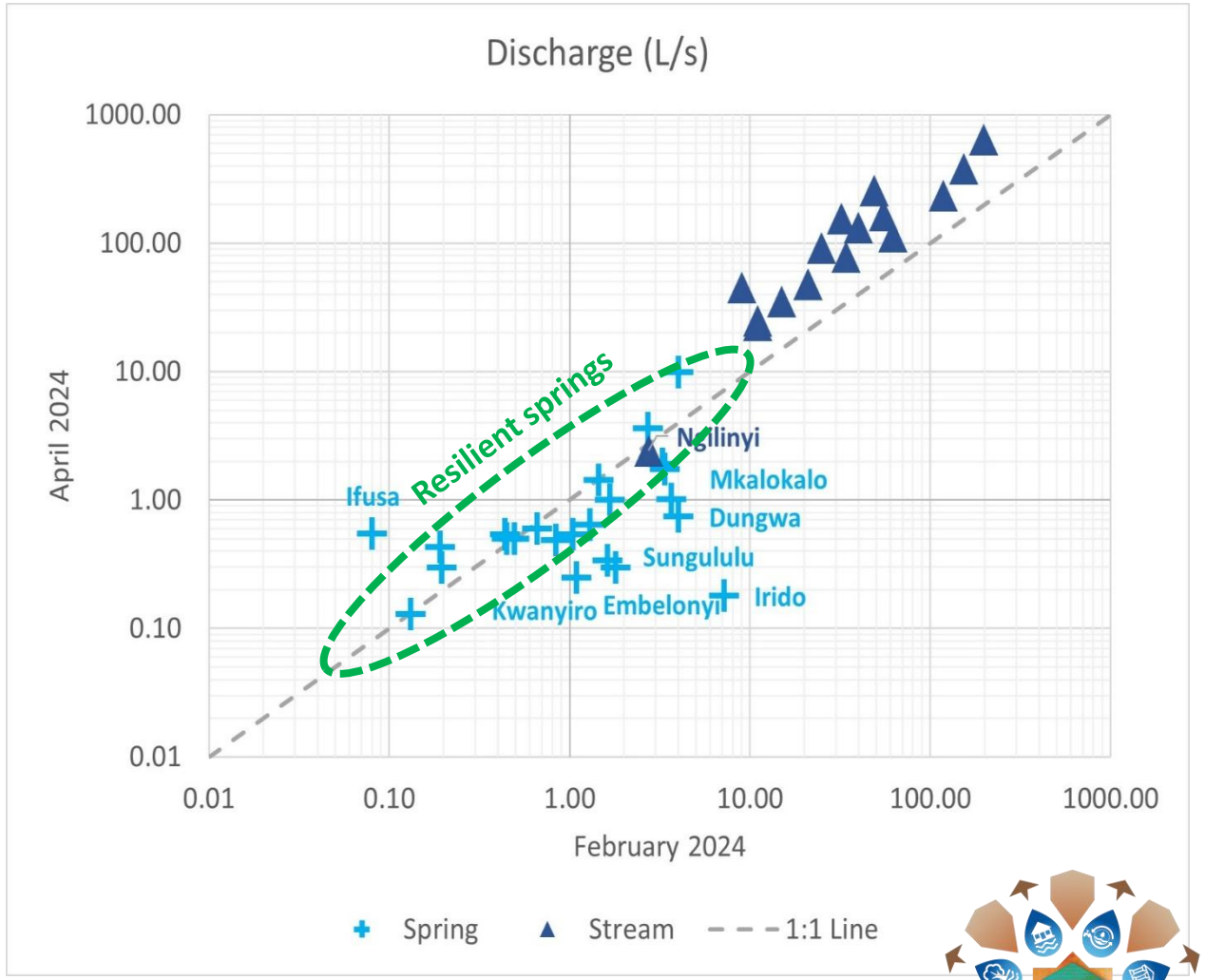



# System's Output

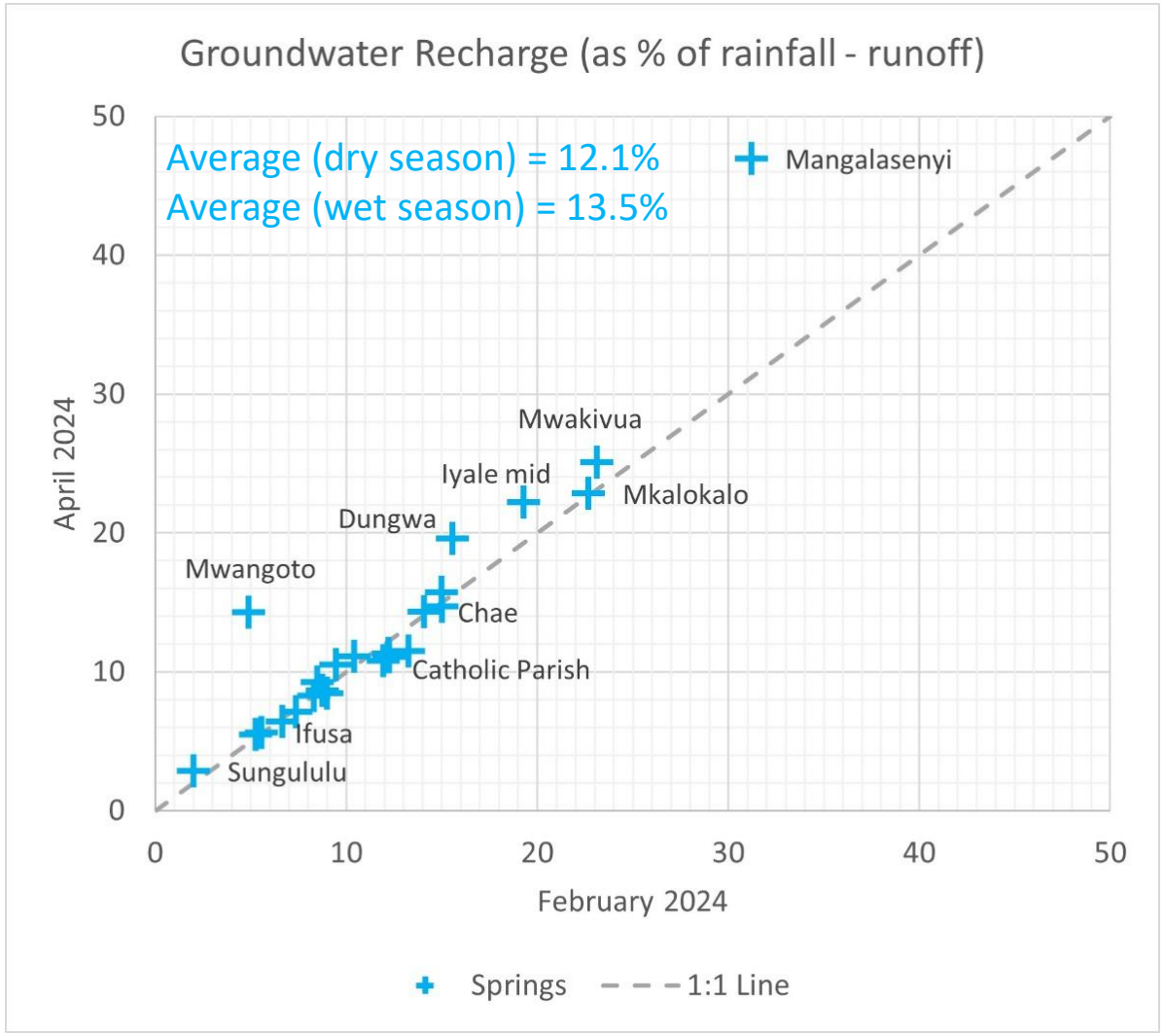


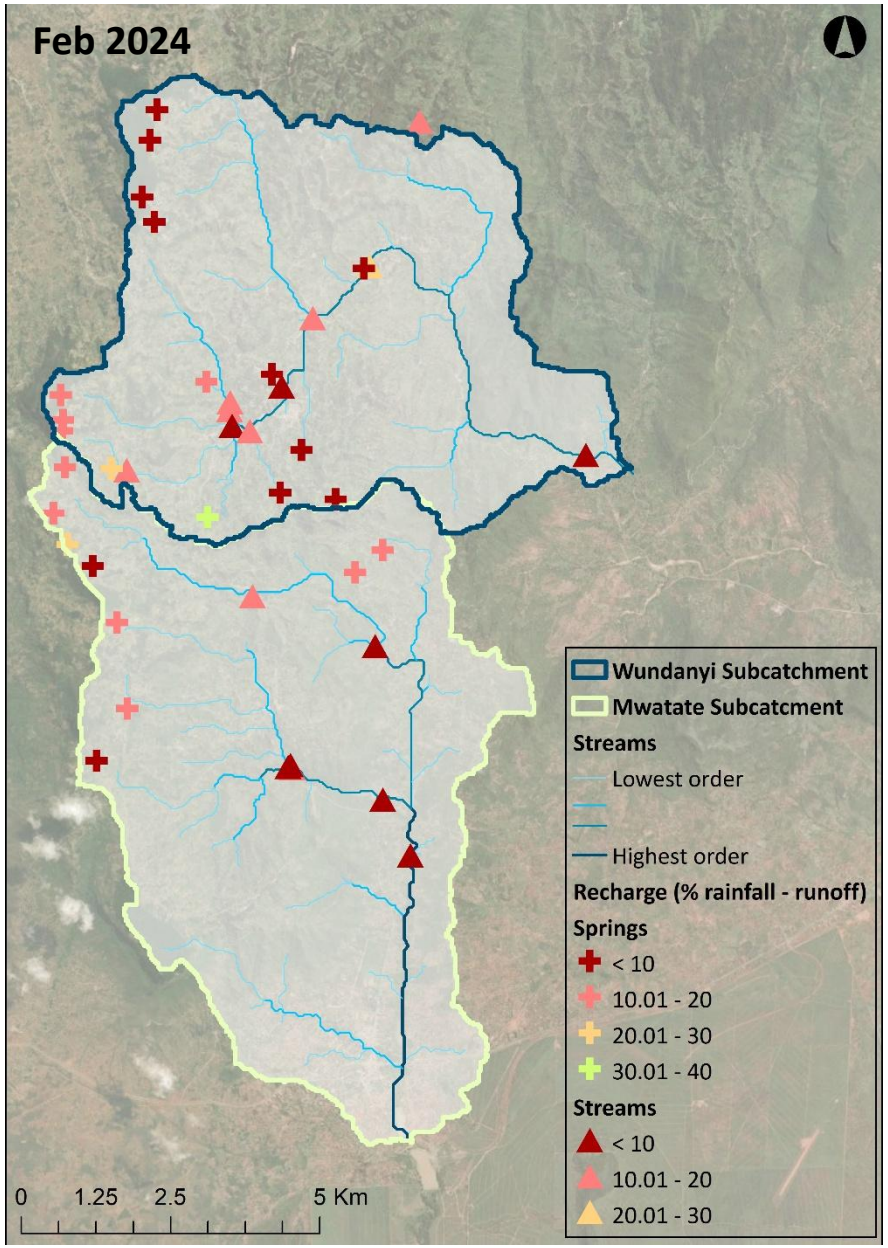
# Processes

- Stream discharge consistently higher in the wet season.
- Spring discharge mostly equal or lower in the wet season with some exceptions → delayed response.



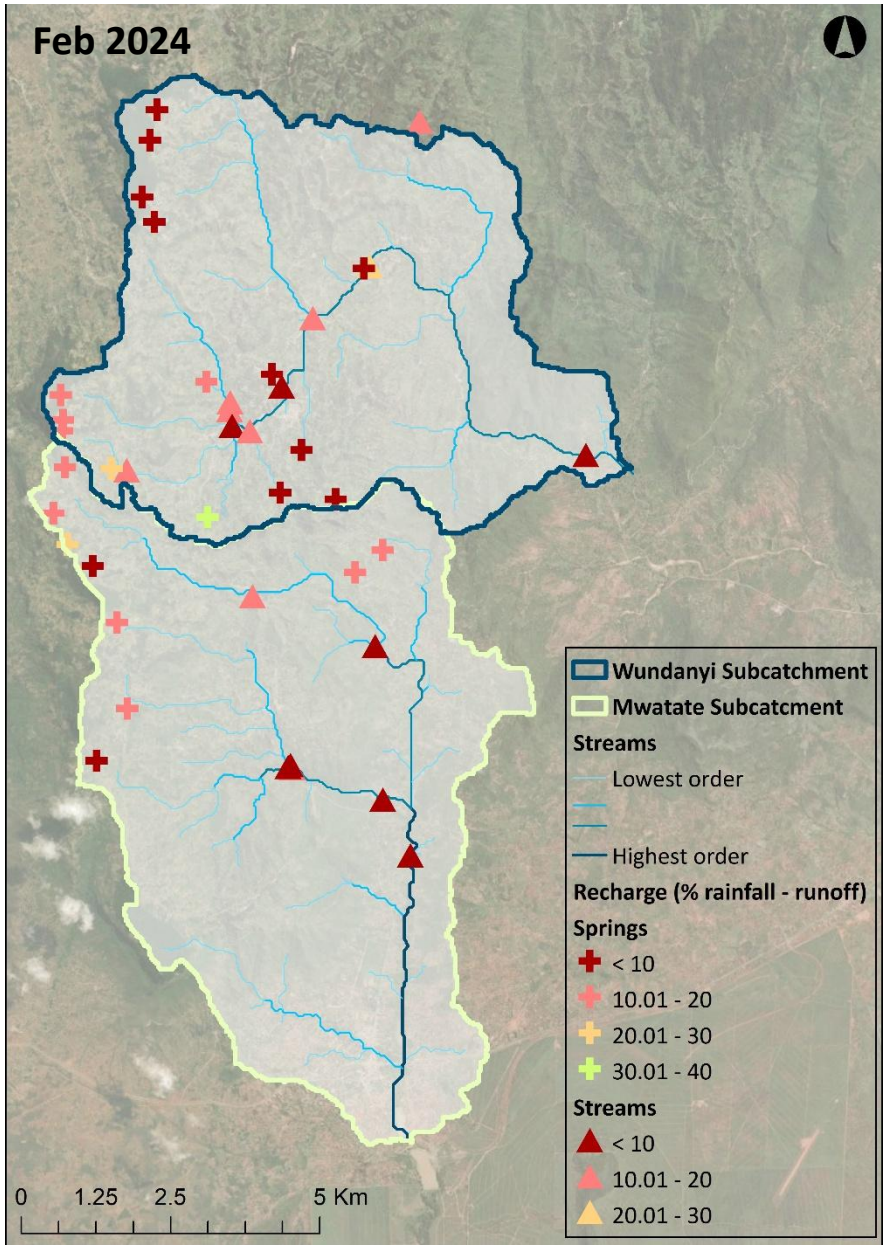
# Processes


Groundwater Recharge (as % of rainfall - runoff)
Average (dry season) = 12.1%
Average (wet season) = 13.5%
Mangalasenyi
Mwakivua
Iyale mid
Mkalokalo
Dungwa
Mwangoto
Chae
Catholic Parish
Ifusa
Sungululu
April 2024
February 2024
0
10
20
30
40
50
Springs
1:1 Line


Feb 2024
Wundanyi Subcatchment
Mwatate Subcatcment
Streams
Lowest order
Highest order
Recharge (% rainfall - runoff)
Springs
< 10
10.01 - 20
20.01 - 30
30.01 - 40
Streams
< 10
10.01 - 20
20.01 - 30
0
1.25
2.5
5 Km

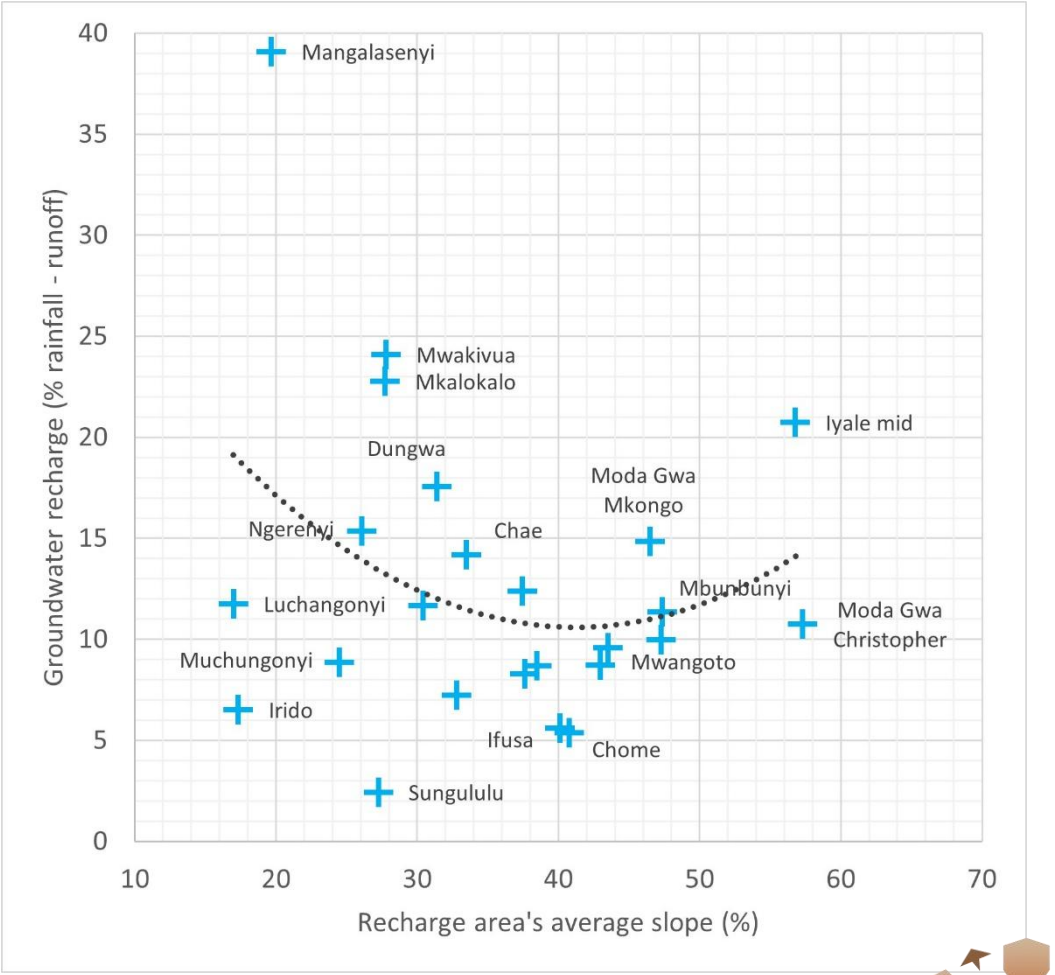
# Processes

| Elevation Zone | Groundwater recharge (% of rainfall - runoff) | | | | |
|---|---|---|---|---|---|
| | Number of samples | Min | Max | Average | Standard Deviation |
| Highland (> 1500 m AMSL) | 17 | 5.3 | 31.2 | 13.5 | 7.1 |
| Transition Zone (1100-1500 m AMSL) | 6 | 2.0 | 15.6 | 8.3 | 4.9 |
| Lowland (< 1100 m AMSL) | 1 | 11.9 | 11.9 | 11.9 | N/A |



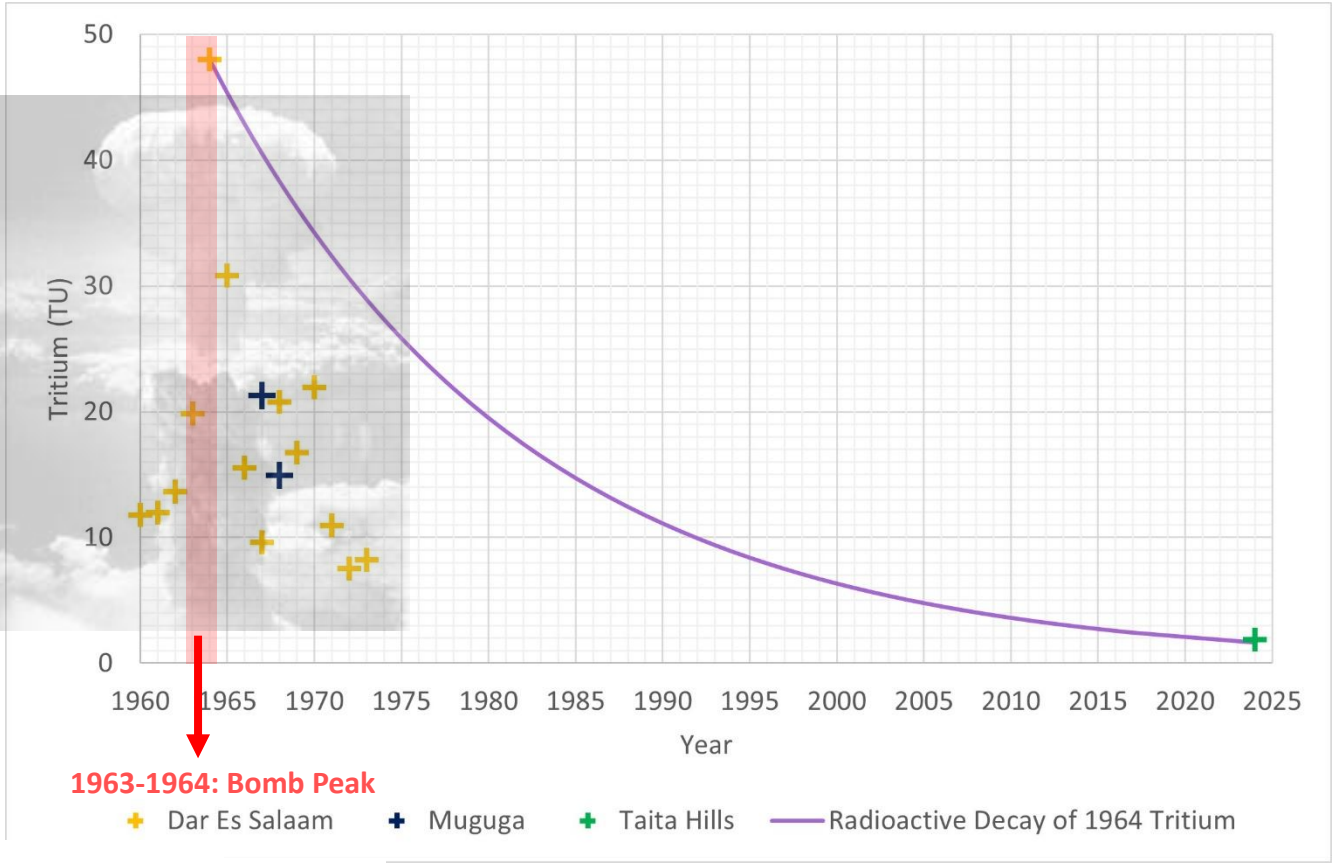
# Processes

| Spring recharge area | Groundwater recharge (% of rainfall - runoff) | | | | |
|---|---|---|---|---|---|
| Landuse | Number of samples | Min | Max | Average | Standard Deviation |
| Agroforestry | 14 | 2.9 | 47.0 | 14.1 | 10.9 |
| Cropland | 1 | 25.1 | 25.1 | 25.1 | N/A |
| Montane forest | 3 | 7.1 | 8.5 | 8.0 | 0.7 |
| Plantation forest | 5 | 5.6 | 22.2 | 12.8 | 6.2 |
| Thicket | 1 | 14.3 | 14.3 | 14.3 | N/A |

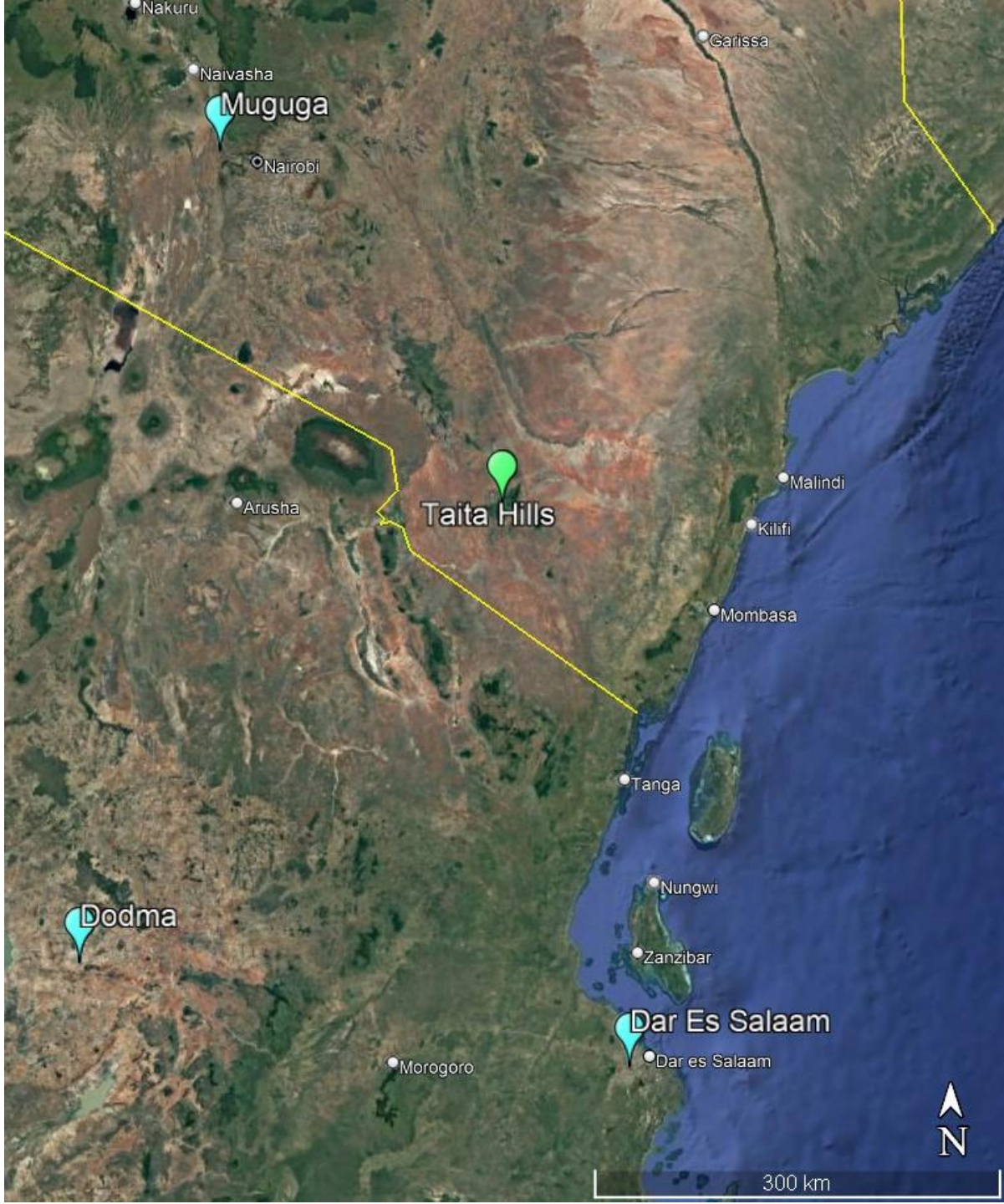


# Processes

- Tritium in Rainwater: Why is 1964 ≈ 2024?

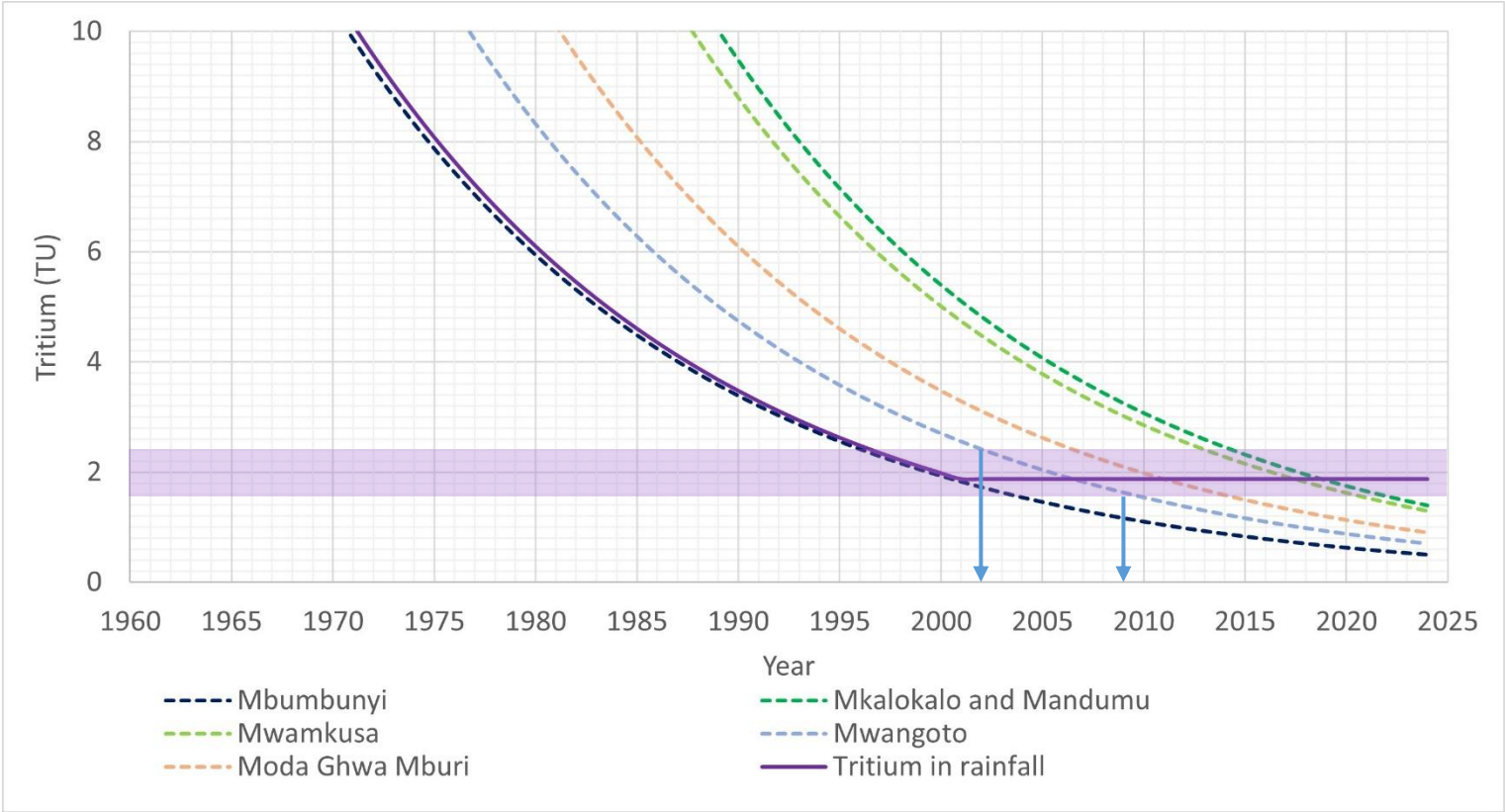



*Scan to know more about Tritium*



# Processes

- Tritium in rainwater has been constant since early 2000s *(Lindsey et al., 2019)*.

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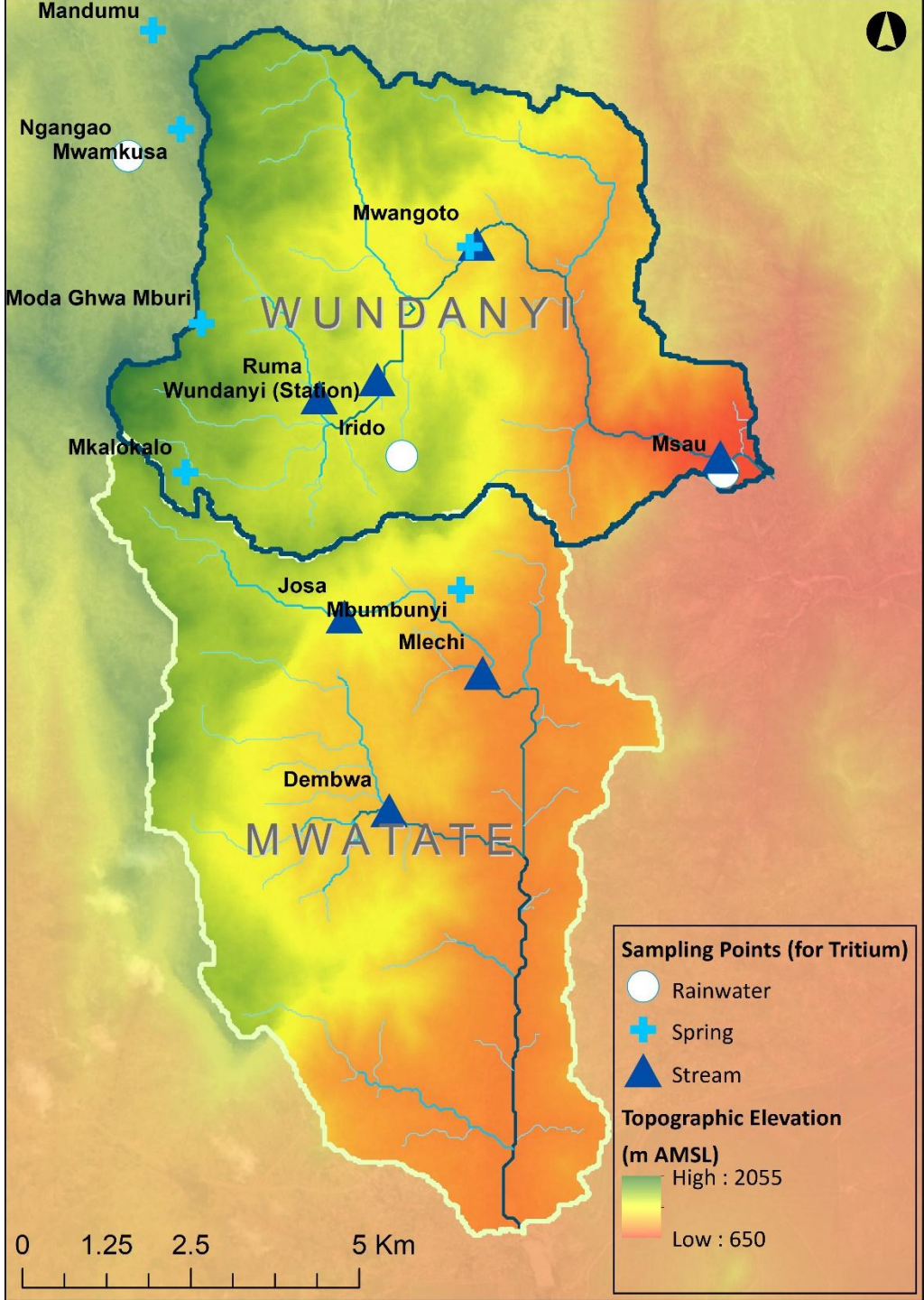
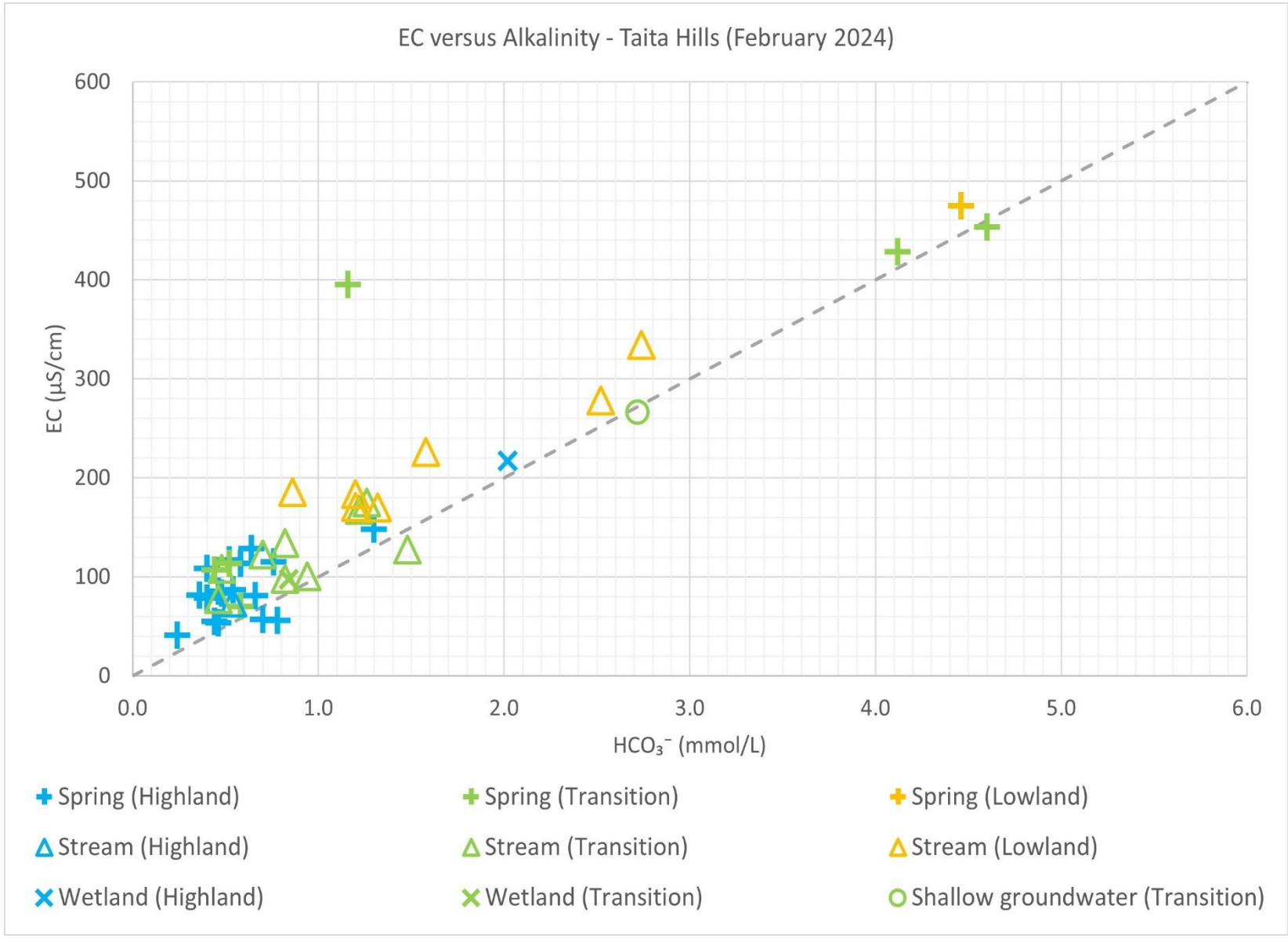


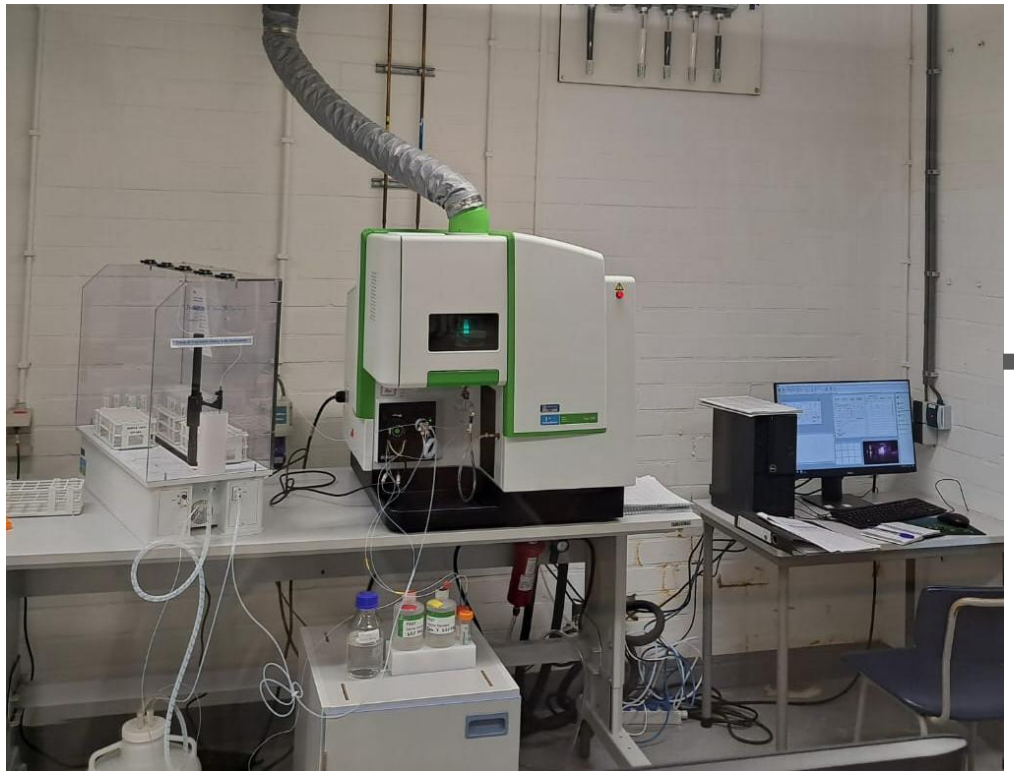
# Processes

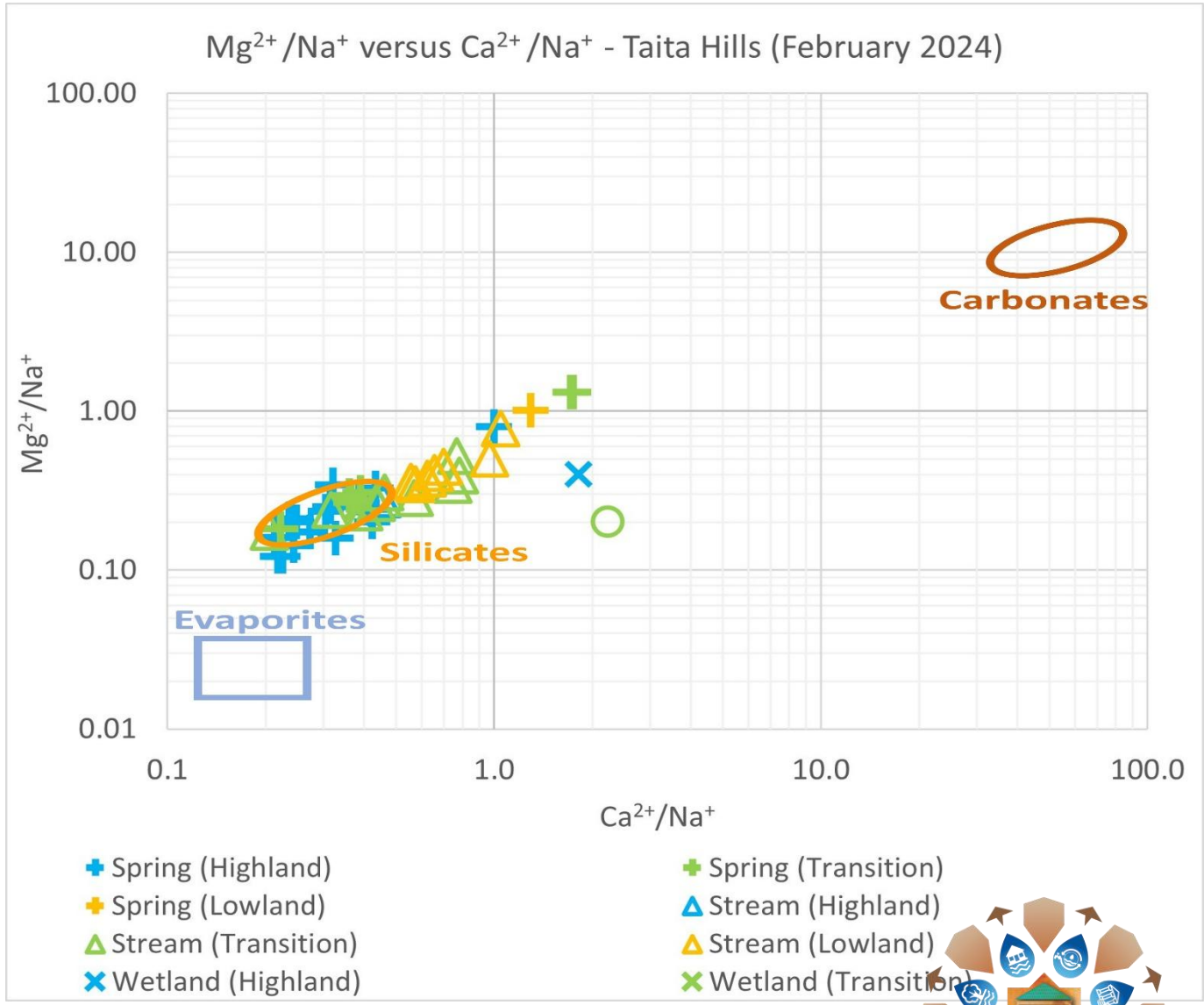
- Groundwater chemistry largely controlled by water-rock interactions.
- Springs: mostly at lower EC and alkalinity (except Mbunbunyi, Mwangoto, Embelonyi which have longer residence times).
- Streams: influenced by both baseflow and surface runoff.



# Processes

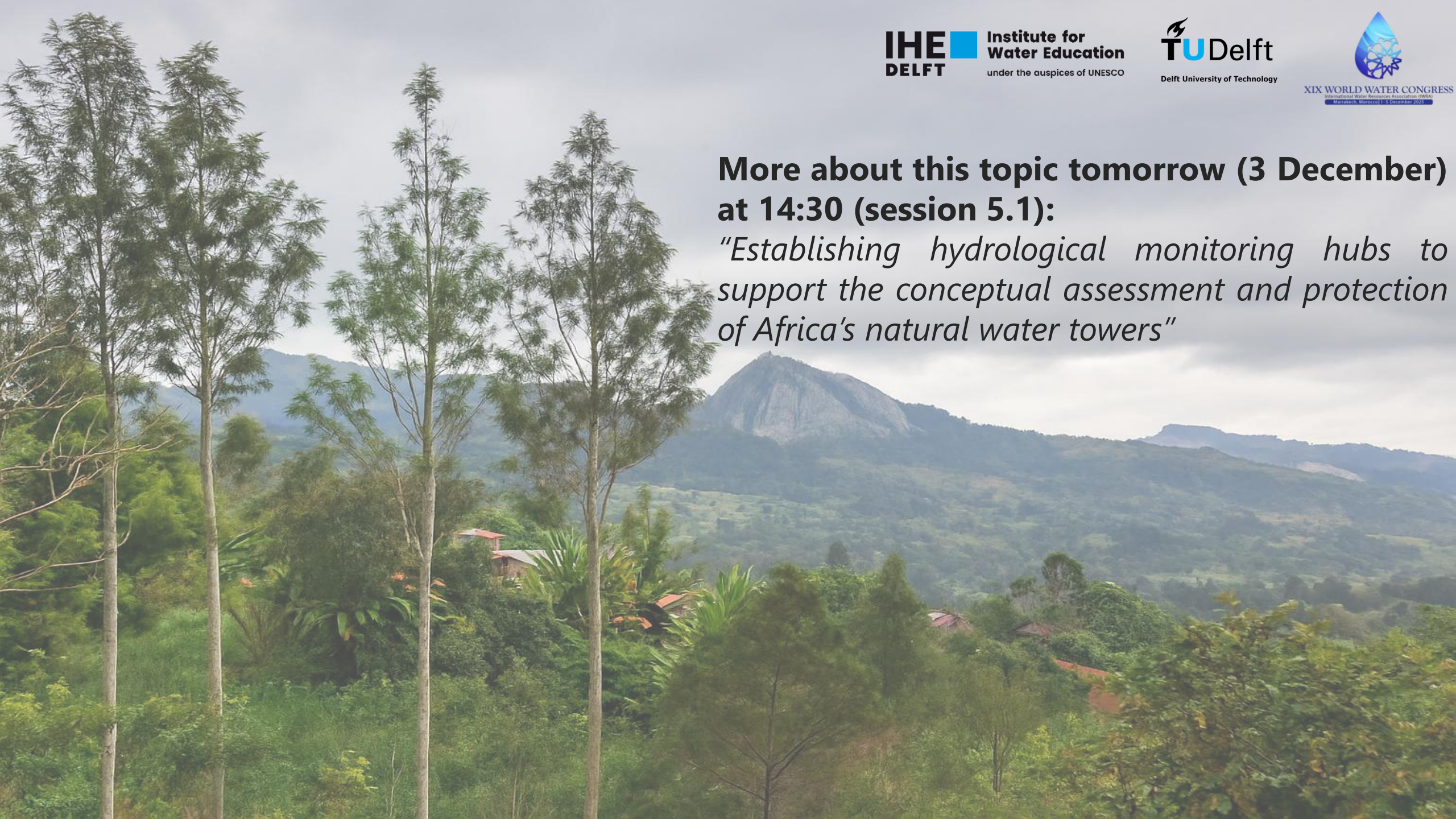
- The chemical composition mainly influenced by the dissolution of silicate minerals.





# Conclusion

| | | |
|---|---|---|
| **Rainfall** | - Stronger gradient (and orographic effect)<br>- Stronger declining trend (yet insignificant)<br>- Higher number of extremely dry months | - Continuity between the wet seasons<br>- Lower number of extremely wet months |
| **Recharge** | | - Higher in Wondo Genet (TBC) |
| **River Discharge** | - Much higher than contributing springs | - Much higher than contributing springs<br>- Higher in Wondo Genet |
| **Dry Season Discharge** | | - Higher (> double) in Wondo Genet |
| **Processes and Flow Systems** | - Local and deeper/more regional flow systems<br>- Impact of structural geology<br>- Silicate weathering | |
| **Highland Contributions** | Highland (also beyond the study area) provides important flow contributions to downstream areas | |
| **Landuse Transitions** | Forest/woodland → Agroforestry → Cropland | Cropland → Forest → Cropland |
| **Anthropogenic Impact** | More/larger infrastructure | More contamination (higher nitrate levels) |



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**More about this topic tomorrow (3 December) at 14:30 (session 5.1):**

*"Establishing hydrological monitoring hubs to support the conceptual assessment and protection of Africa's natural water towers"*

# References


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# Thank you!

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