Numerical modelling and analysis of the February 2023 flood event in the Umbeluzi catchment (Mozambique)

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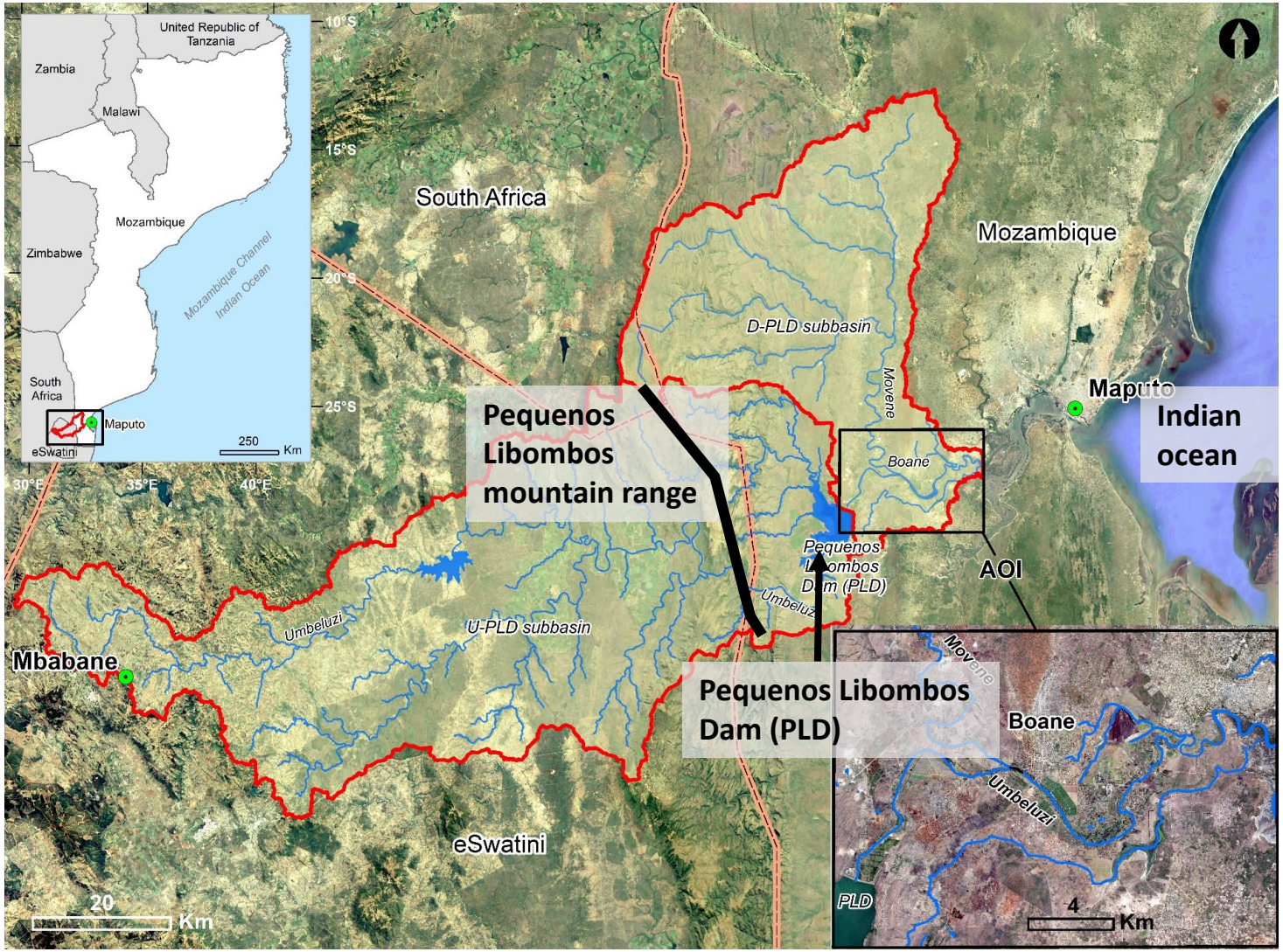
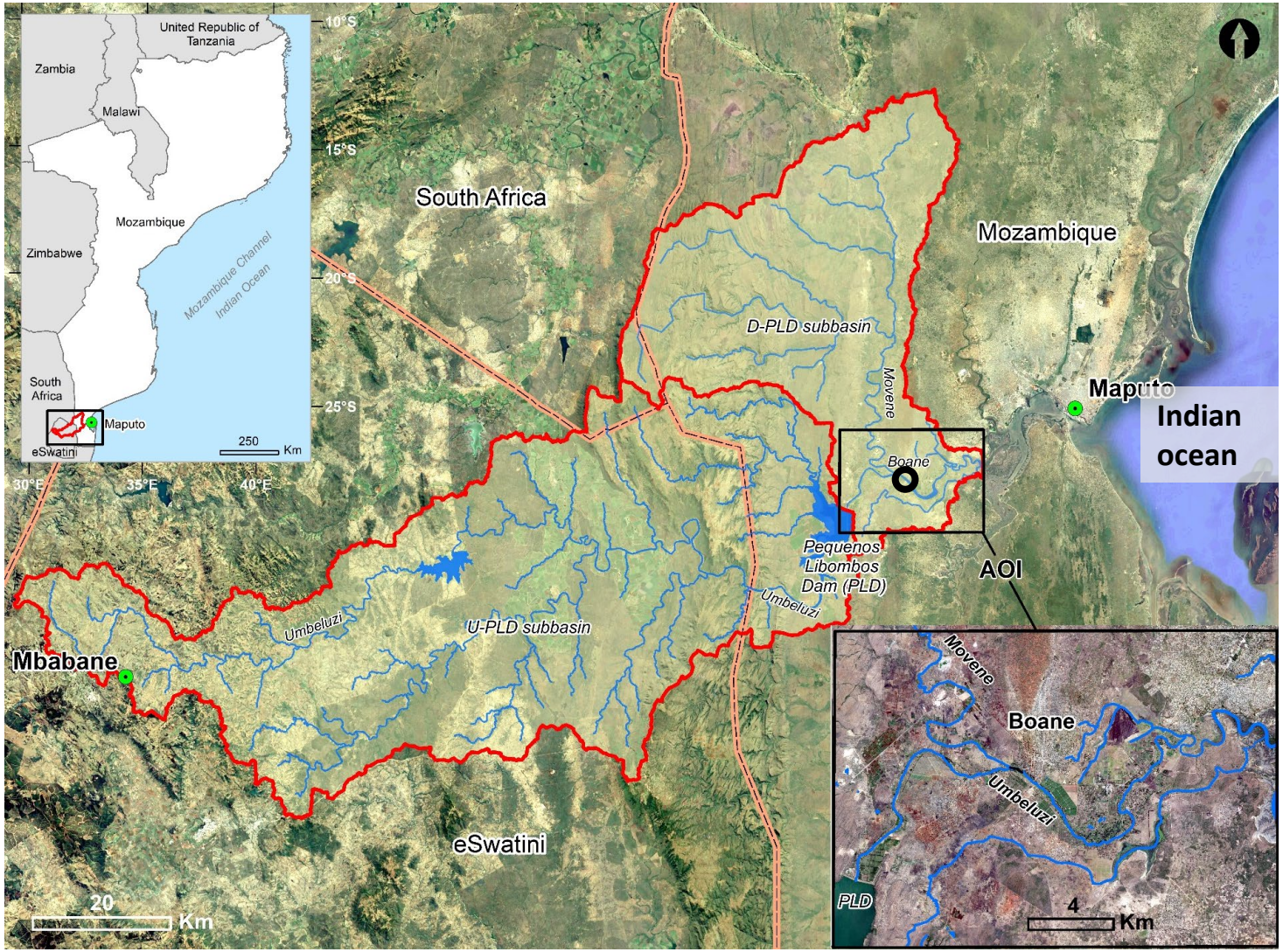
The Umbeluzi catchment



- Area: aprox. 5,500 km^2
- Located within Mozambique (41%), eSwatini (58%) and South Africa (1%)
- Flows into the Indian Ocean in Maputo
- Maximum altitude: 1,828 m (Malolotja Nature Reserve)
- Mean altitude: 346 m
- Pequenos Libombos mountain range along the borderline between Mozambique and eSwatini
- Pequenos Libombos Dam (PLD): 385 hm^3 at NPL
- Average annual precipitation: 744 mm
- Wet period from October to March with 84% of the total annual precipitation

The Umbeluzi catchment



- Downstream-PLD (D-PLD) subbasin with 1,700 km^2
- Upstream-PLD (U-PLD) subbasin with 3,880 km^2
- Area of Interest (AOI) around Boane, with 313 km^2, just downstream of the PLD
- AOI receives the outflow discharge from the PLD + surface runoff from the D-PLD subbasin
- Hydrometric station located in Boane, with discharge data from 1955-1986, until the PLD was built
- Maximum registered discharge: 7,250 m^3/s in 1984
- Several flood events (1966, 1972, 1977, 1984, 2000, 2016, 2020 and 2023) that caused significant damage

The February 2023 flood event

Protection Cluster
Mozambique

Mozambique I PROTECTION NEEDS ASSESSMENT

Boane Accommodation Centers - February 2023

For External Circulation

KEY FIGURES

16,588
displaced persons

3,317
displaced households

6 of 16
accommodation / transition centers assessed

4,764* *including Magude District
displaced persons reached through this assessment

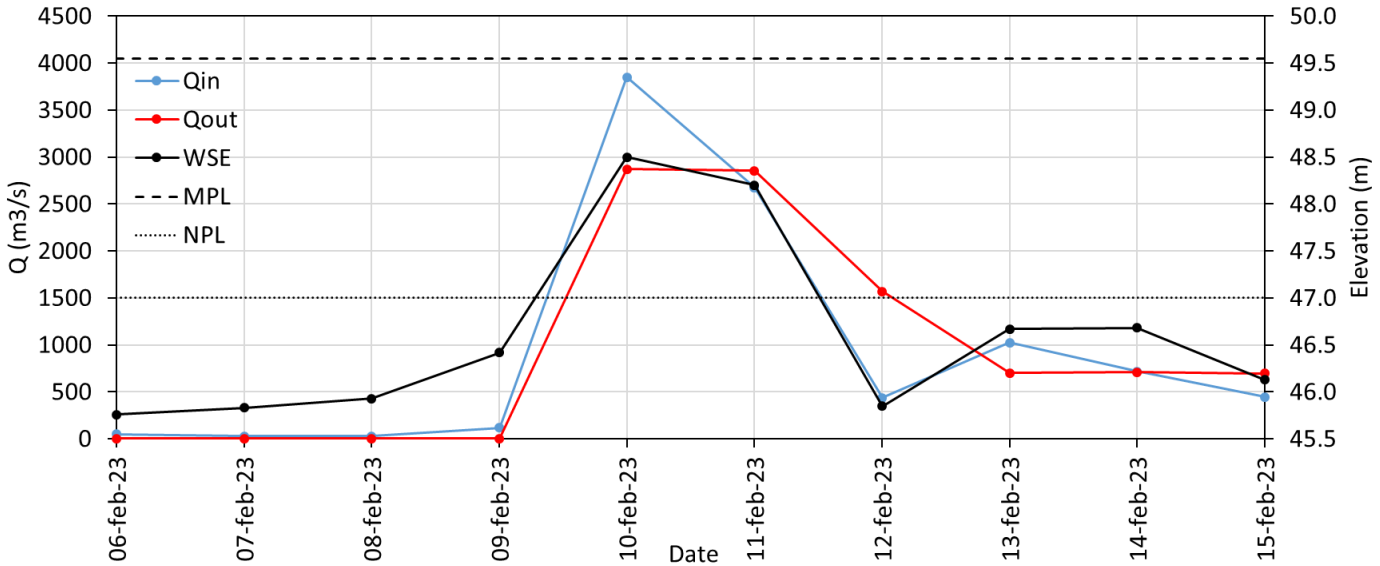
In the first weeks of February 2023, heavy rains caused flooding in Boane, Namaacha, Matola and Magude Districts of Maputo Province and Maputo City. The flooding affected at least 43,426 persons and displaced approximately 16,588 persons (3,317 households) presently accommodated in 16 centers.

Heavy rains hit the southern region of Mozambique between 7 and 11 February, causing widespread flooding and structural damages, particularly in Maputo city and province

LOCATION OF ASSESSED SITES

Boane District, Maputo Province

N



Daily averaged inflow and outflow from the PLD

To guarantee its structural safety, the PLD was forced to release water at its maximum discharge capacity (2,850 m^3/s) during two days

The February 2023 flood event

Data sources

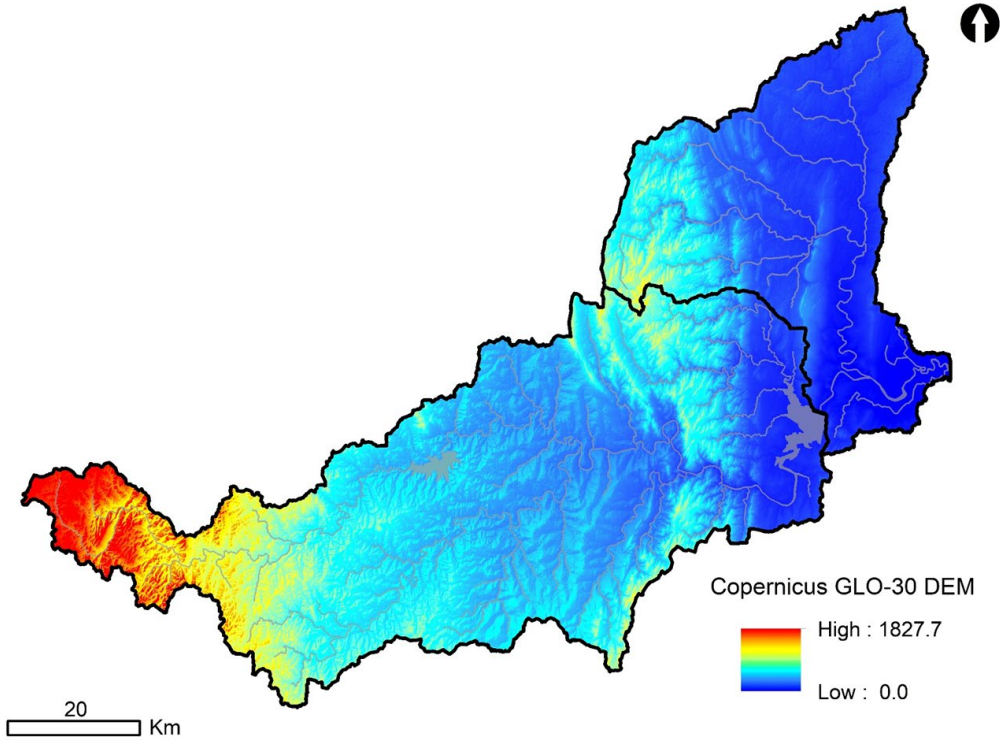
Numerical model

- Freely available global data sets
- Physically-based parameters with no prior calibration

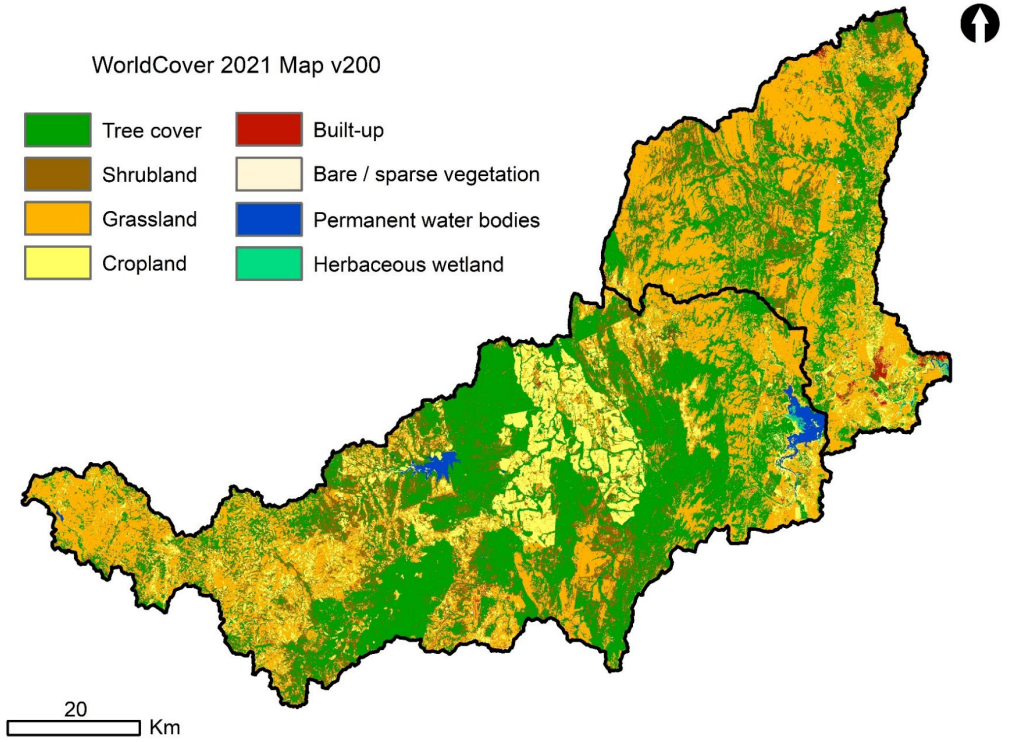
The methodology can be reproduced anywhere for free

Variable	Data set	Resolution	Source
DEM	Copernicus GLO-30	30 m	https://panda.copernicus.eu/web/cds-catalogue
Rainfall	GPM IMERG Final Precipitation L3	10 km, 30 min	https://disc.gsfc.nasa.gov
Land Cover	ESA WorldCover 10m 2021 v200	10 m	http://due.esrin.esa.int/page_globcover.php
Infiltration	GCN250	250 m	https://doi.org/10.6084/m9.figshare.7756202.v1

Data sources: DTM and Land Cover



Copernicus GLO-30 DEM

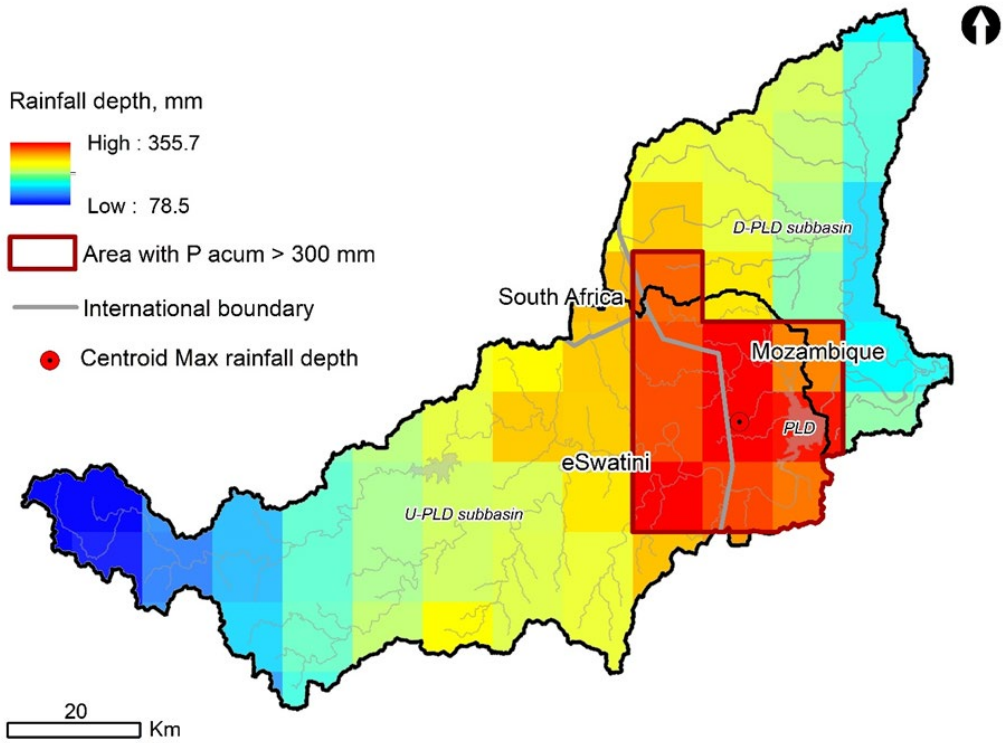


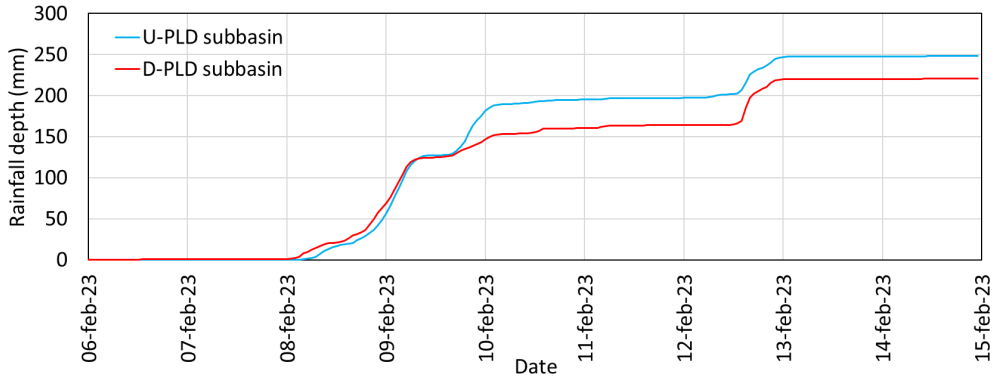
ESA WorldCover 2021 10 m

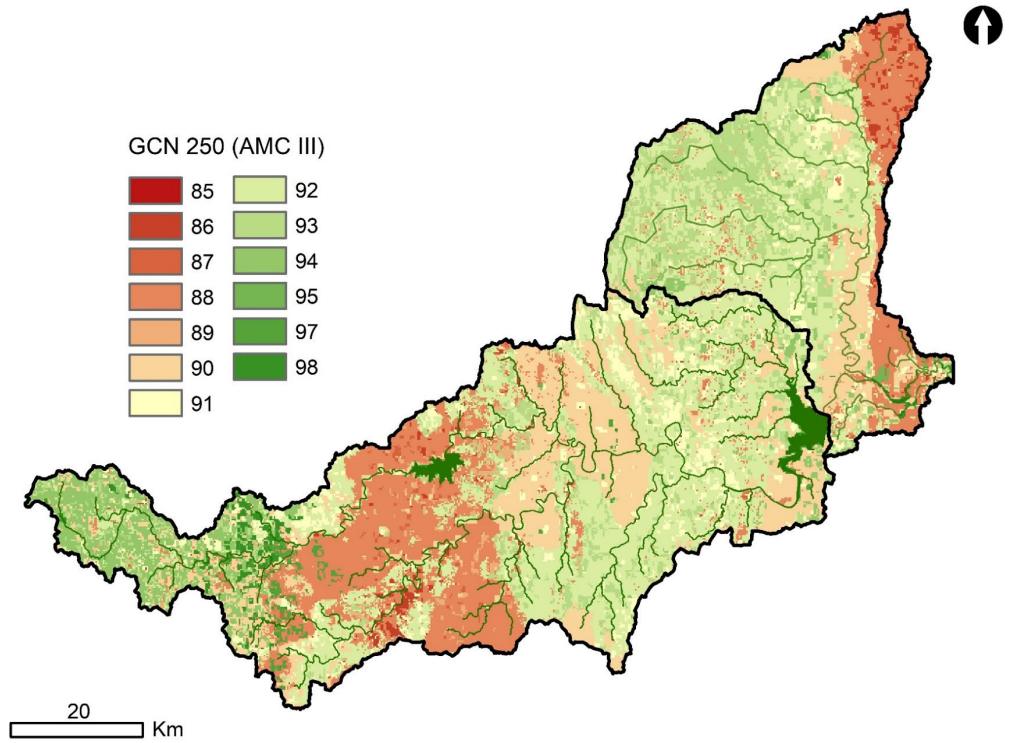
Main land uses in the catchment

- Trees (38%)
- Grassland (38%)
- Cropland (12%)
- Shrubland (10%)

Data sources: Rainfall and infiltration







Considering **wet AMC soil conditions** the CN varies between 85 and 98 in the hillslopes and floodplains, with a basin-averaged value of 91.

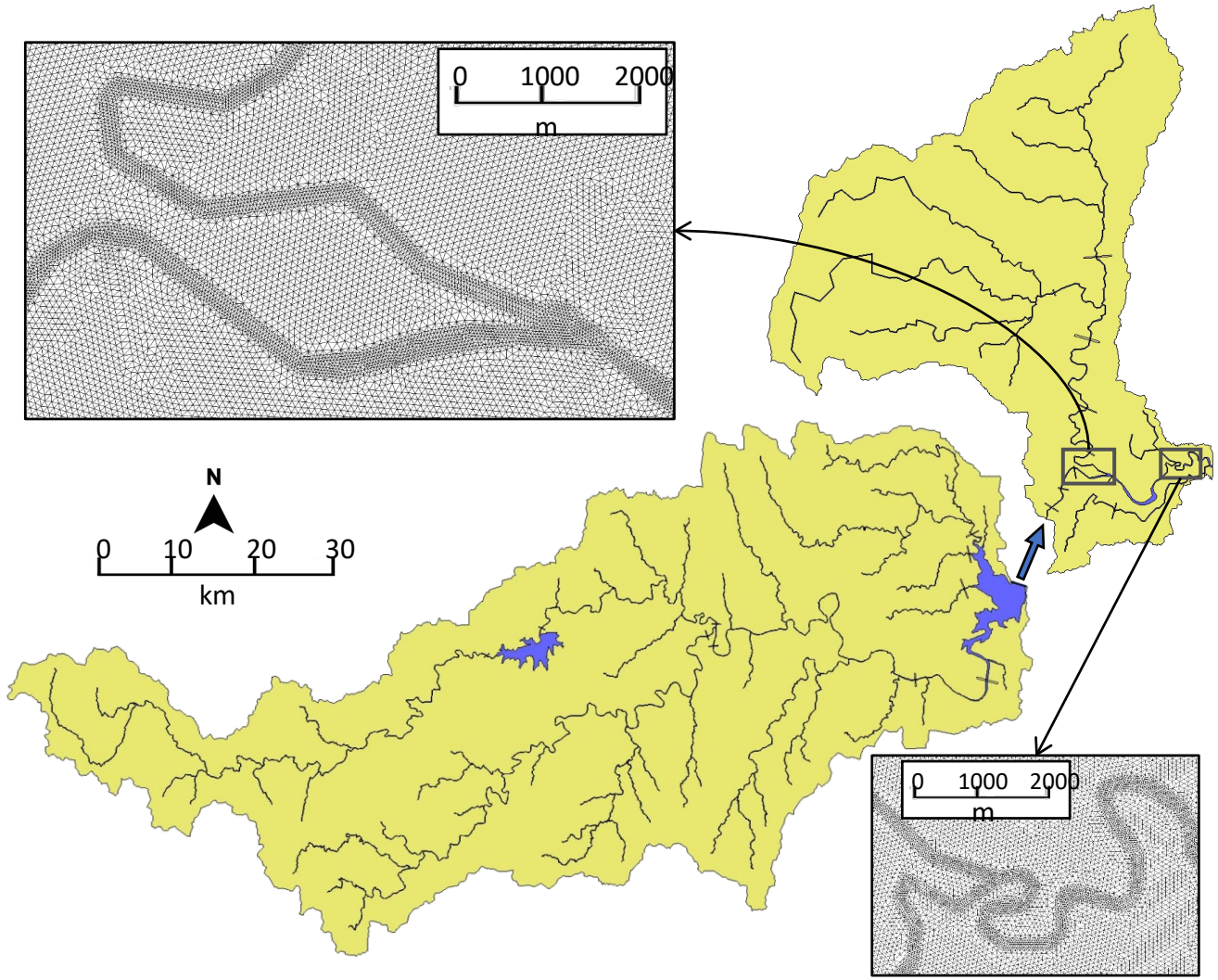
Numerical model (Iber)

Iber

- 2D model based on the Shallow Water Equations
- Hydrodynamic and hydrological capabilities
- Freely available at www.iberaula.com

Modelling approach in the Umbeluzi catchment

- Two models: U-PLD and D-PLD
- Coupled by the outflow from the PLD
- Discretization considering hillslopes, stream network and reservoirs
- Mesh size from 25m (river) to 80m (hillslopes)
- U-PLD: 1.4 M elements
- D-PLD: 1.1 M elements



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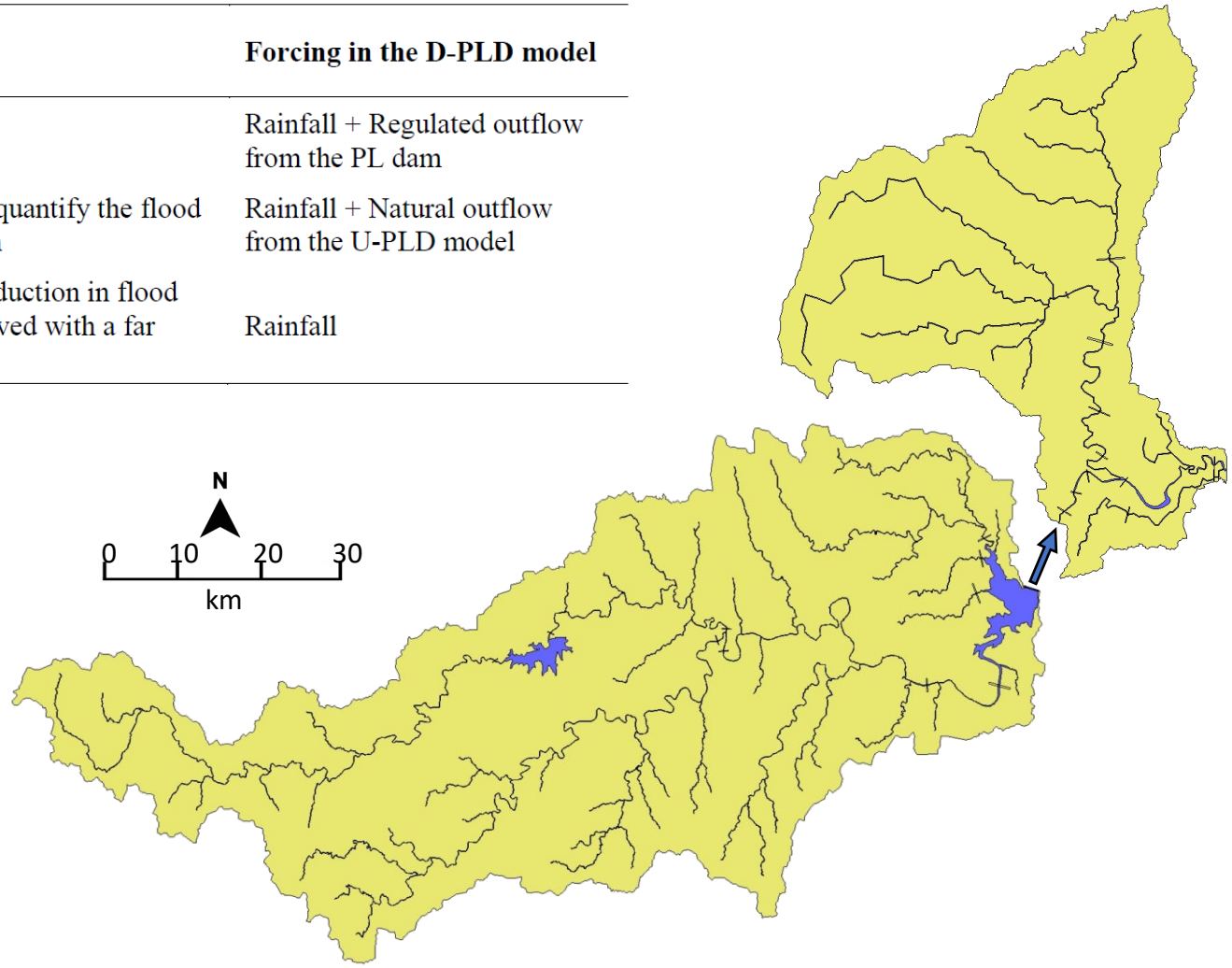
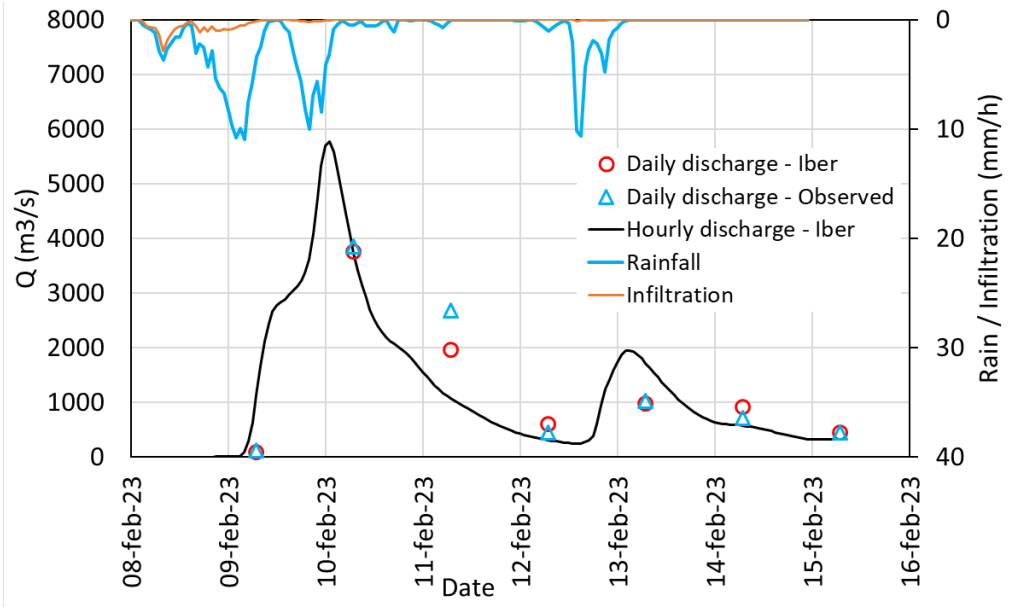
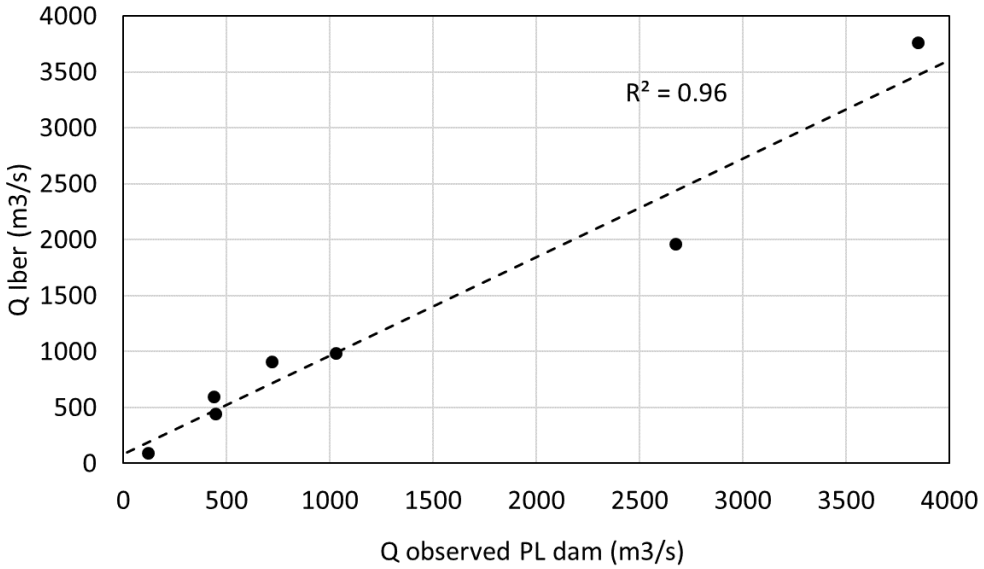
Modelling Scenarios (MS)

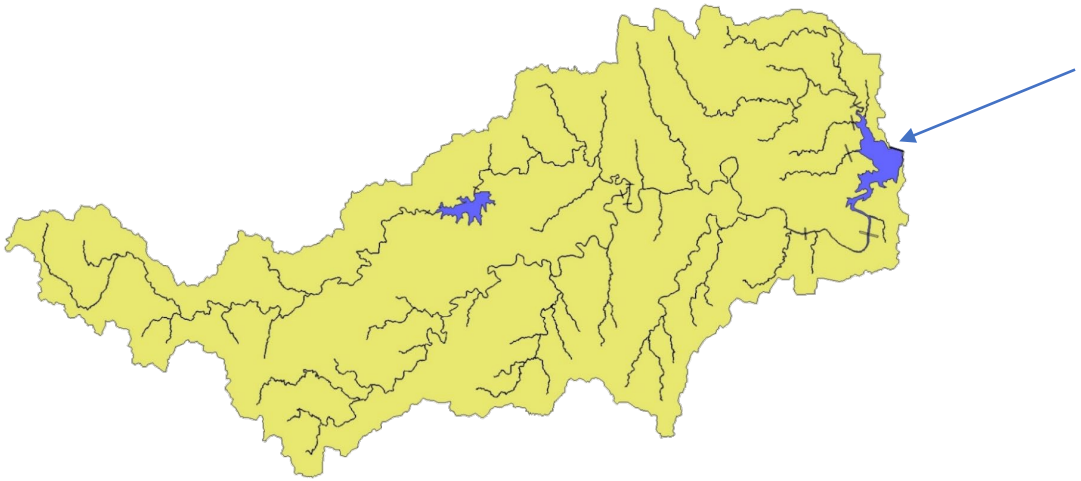
Modelling Scenario	Brief description	Purpose	Forcing in the D-PLD model
MS1	Actual flood event	Validate the model	Rainfall + Regulated outflow from the PL dam
MS2	No PL reservoir	Comparison with MS1 to quantify the flood control exerted by PL dam	Rainfall + Natural outflow from the U-PLD model
MS3	Reservoir with unlimited storage	Quantify the maximum reduction in flood hazard that could be achieved with a far larger reservoir than PL	Rainfall



MS1: Model validation



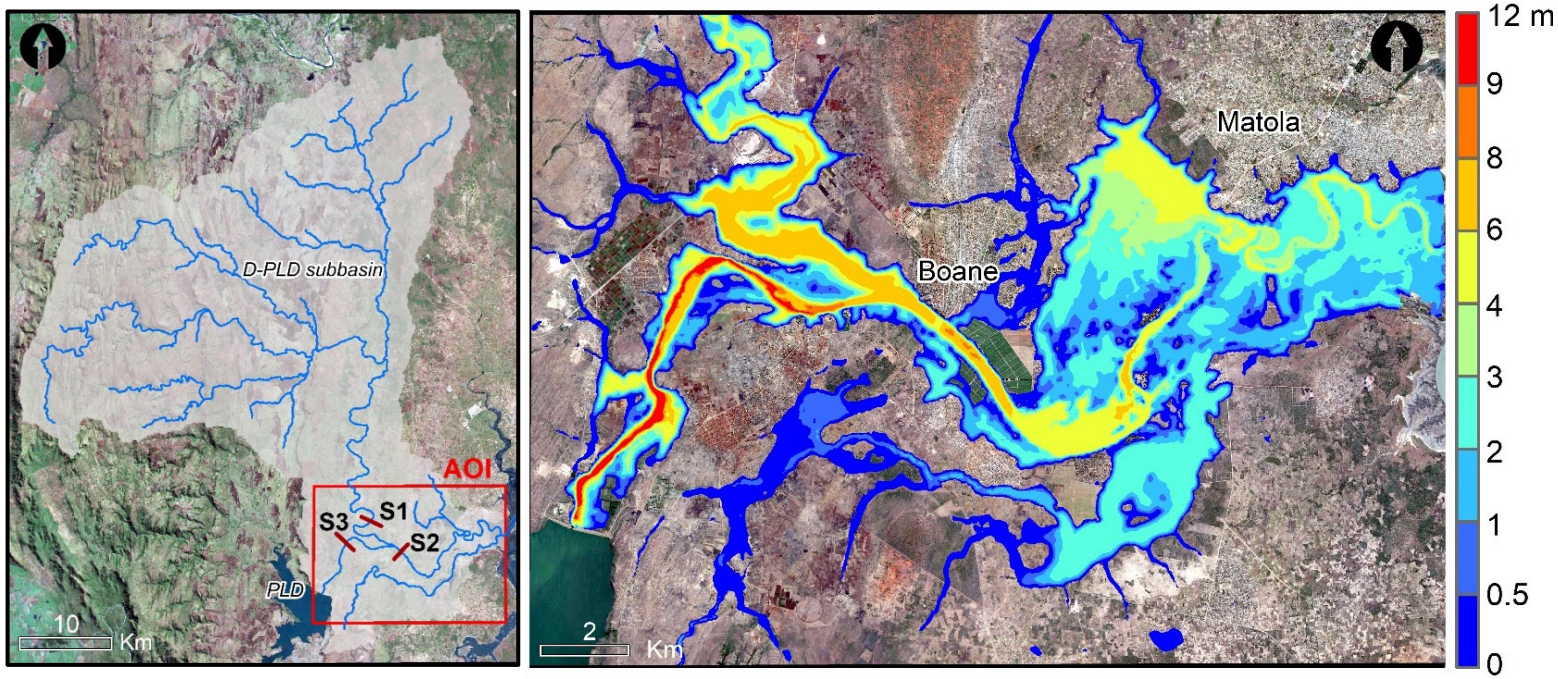


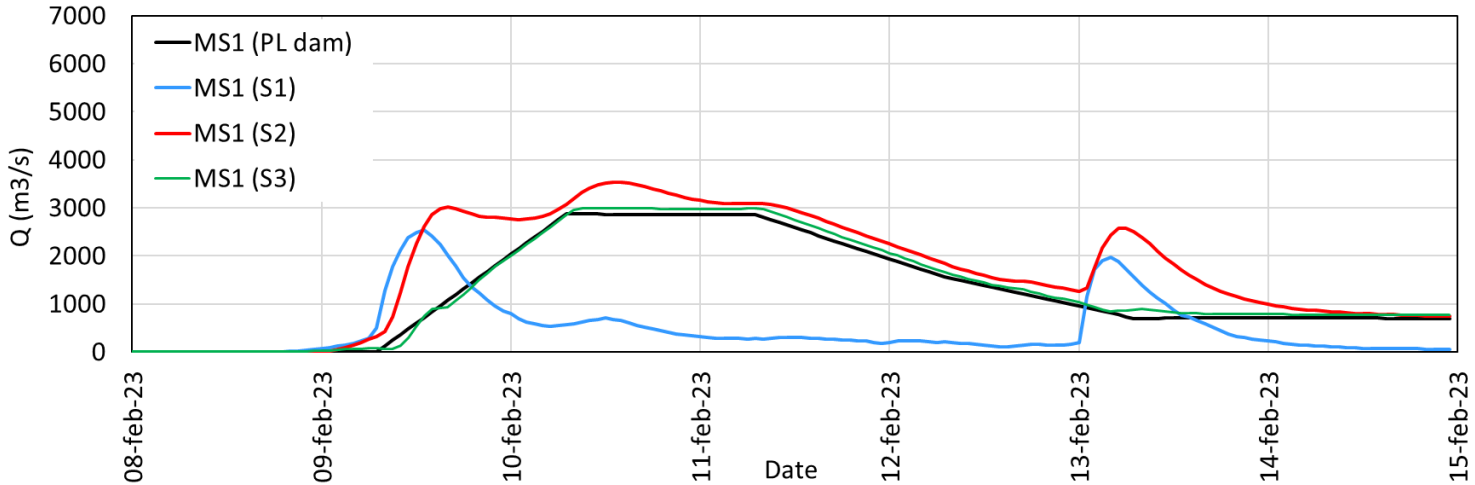


Inflow discharge into the PL reservoir

- Daily averaged values (Iber + Observed)
- Hourly values (Iber)

MS1: Model validation



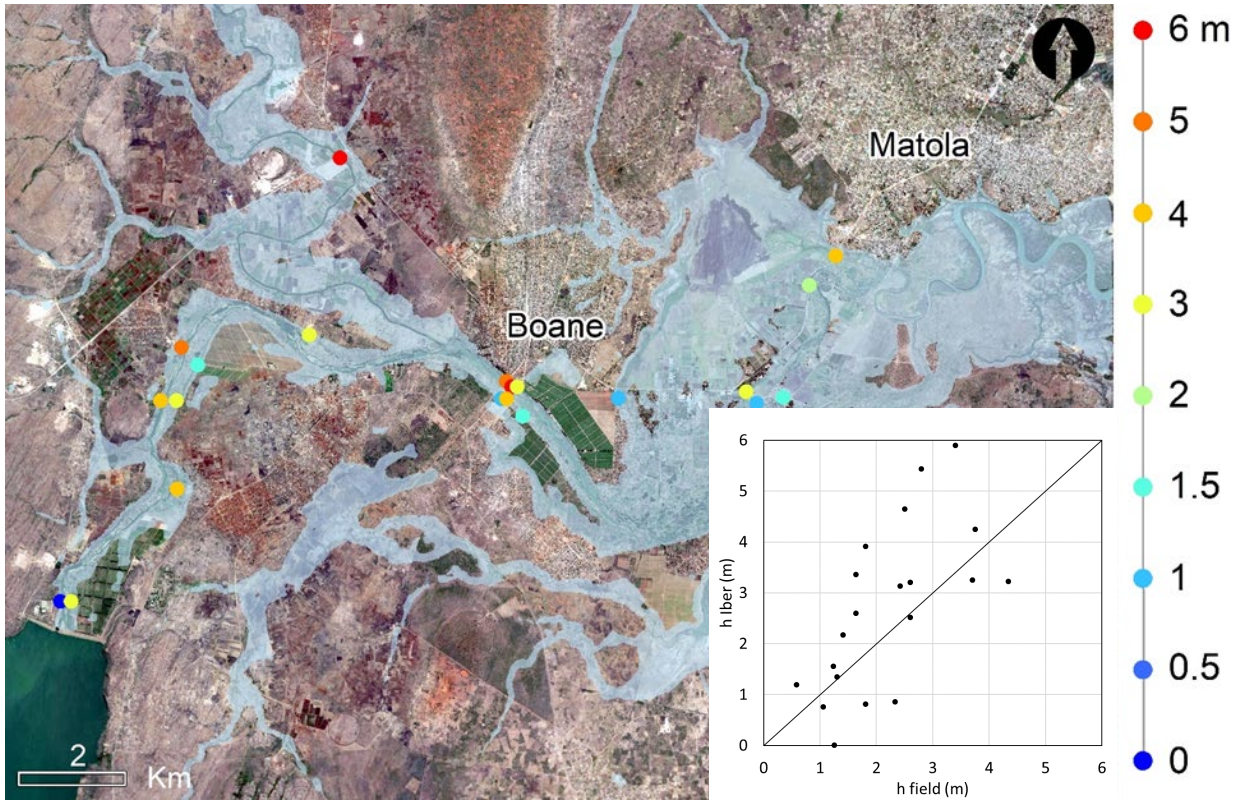


MS1: Model validation

- On 20-21 March 2023, the neighbourhoods of Boane district most damaged by the flood were visited by technicians from ARA-Sul, in order to estimate the level reached by the waters during the flood event.
- A total of 20 water marks were identified on buildings and other infrastructure, and the maximum water depth reached during the flood was estimated as the difference between the elevation of the inundation mark and the terrain at that location.
- The comparison between the observed and predicted depths has a Mean Error (ME) of 0.50 m and a Mean Absolute Error (MAE) of 1.06 m.

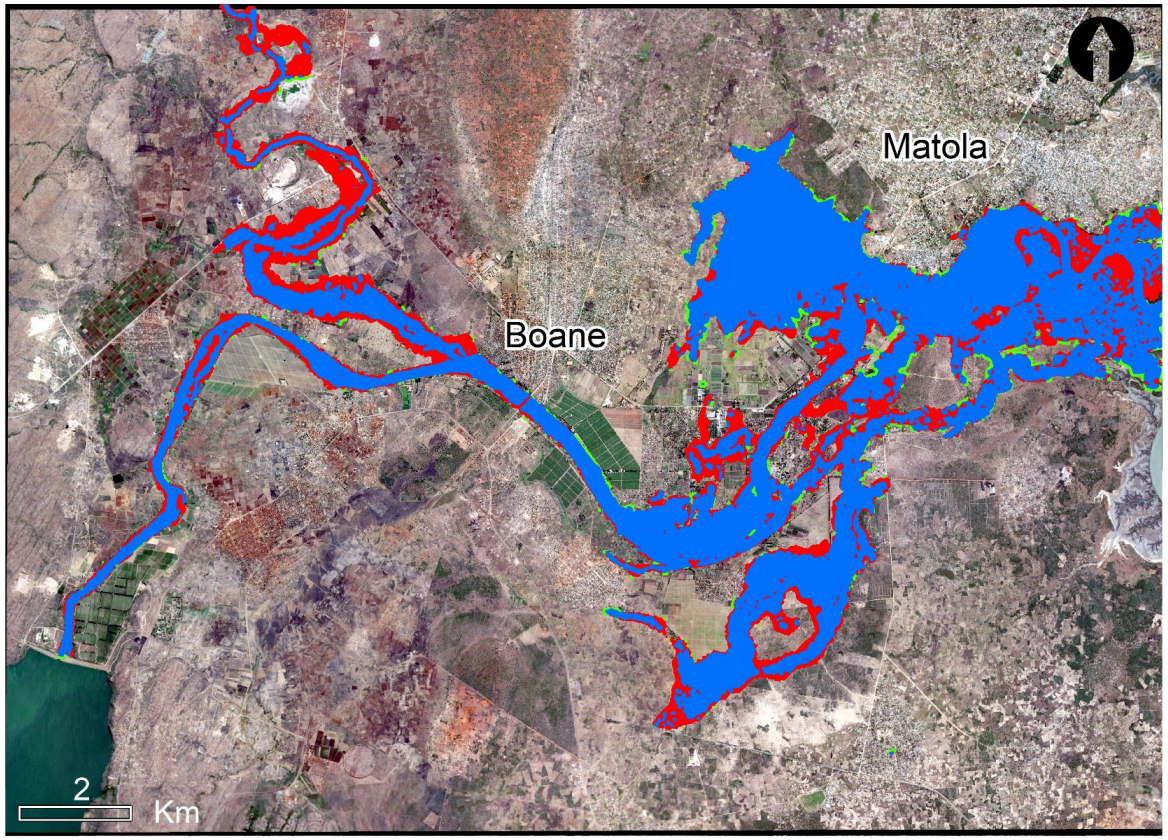
Possible reasons for the mismatch:

- Water marks are a minimum estimation
- Uncertainty on the measurements
- Uncertainty on DEM (global RMSE of 1.7 m)



MS1: Model validation

- There is 1 available image, taken from the satellite Sentinel-1, that covers the AOI
- The image was used to estimate the water extent with a pixel resolution of 10 m



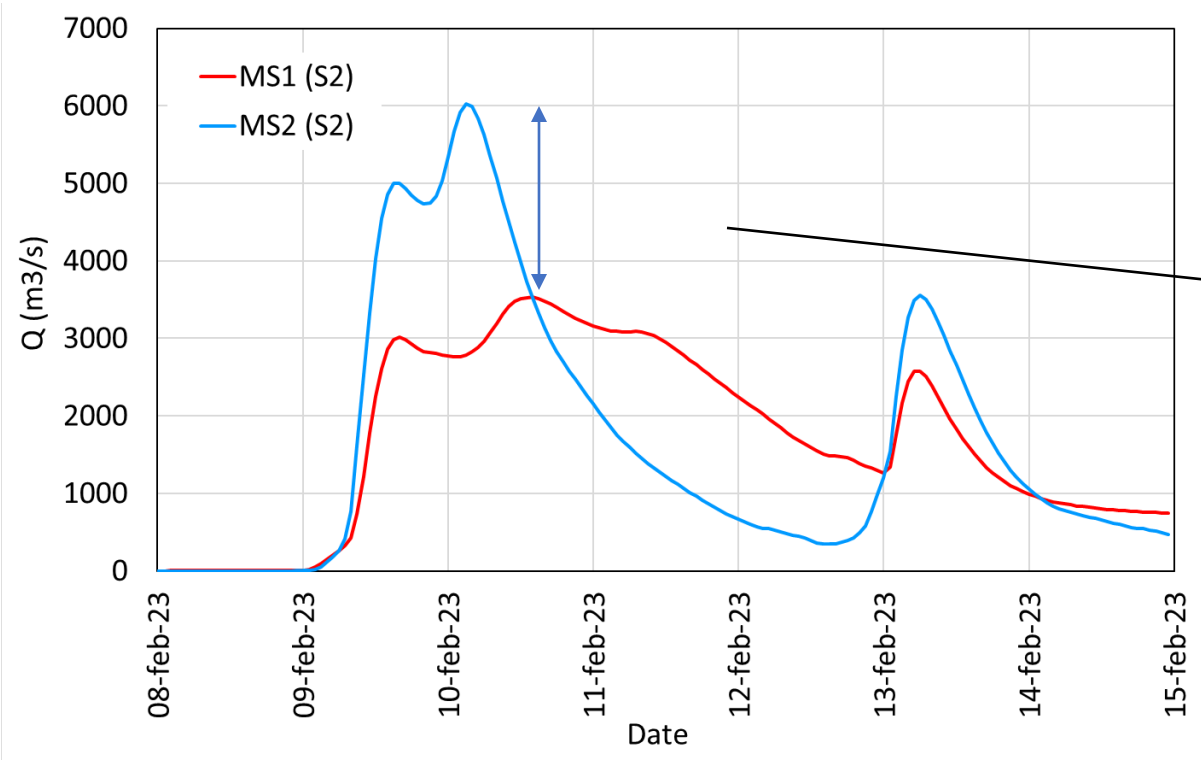
Overlap MS1: Modelled with Iber Observed SNAP processed

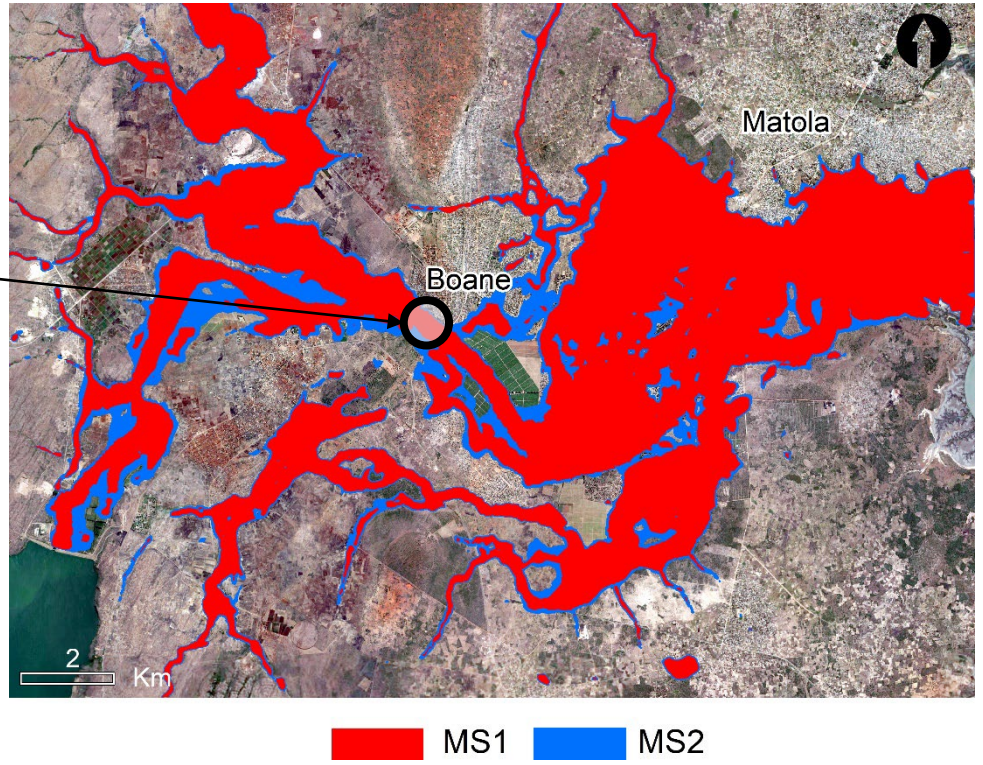
- **Hit Ratio**. HR = 0.96
- **False Alarm Ratio**. FAR = 0.37
  - Riparian vegetation tends to mask the water surface observed by the satellite
  - Small water depths are difficult to identify

MS2: absence of PL reservoir

- **What would have happened in the absence of the PL reservoir?** The maximum discharge would have been 2,500 m^3/s higher

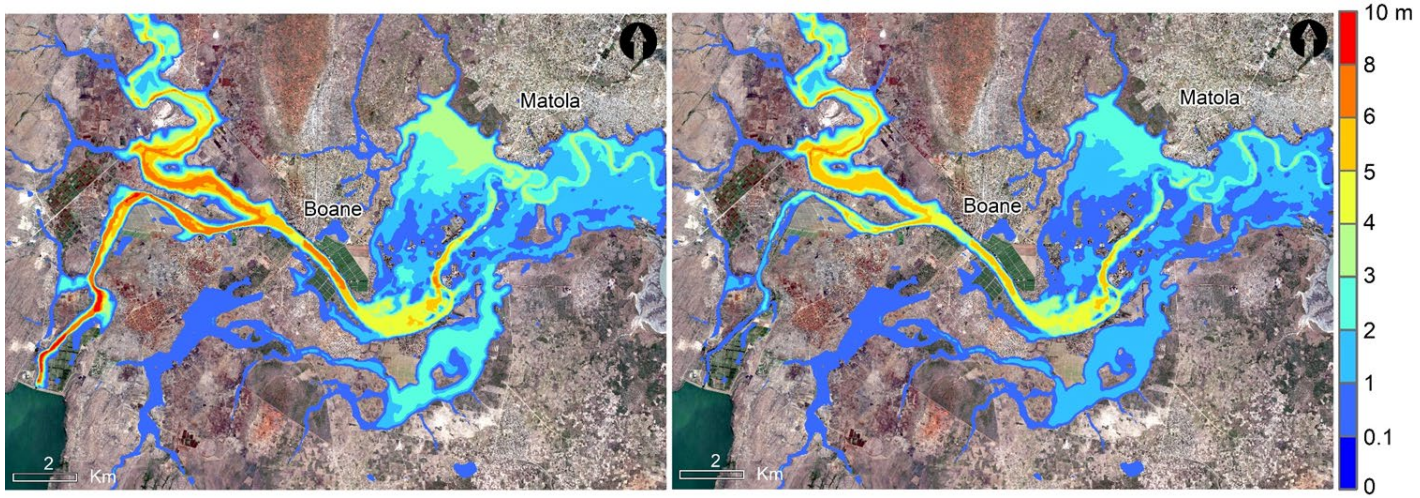
Hydrographs computed at the location of the former Boane hydrometric station for MS1 and MS2

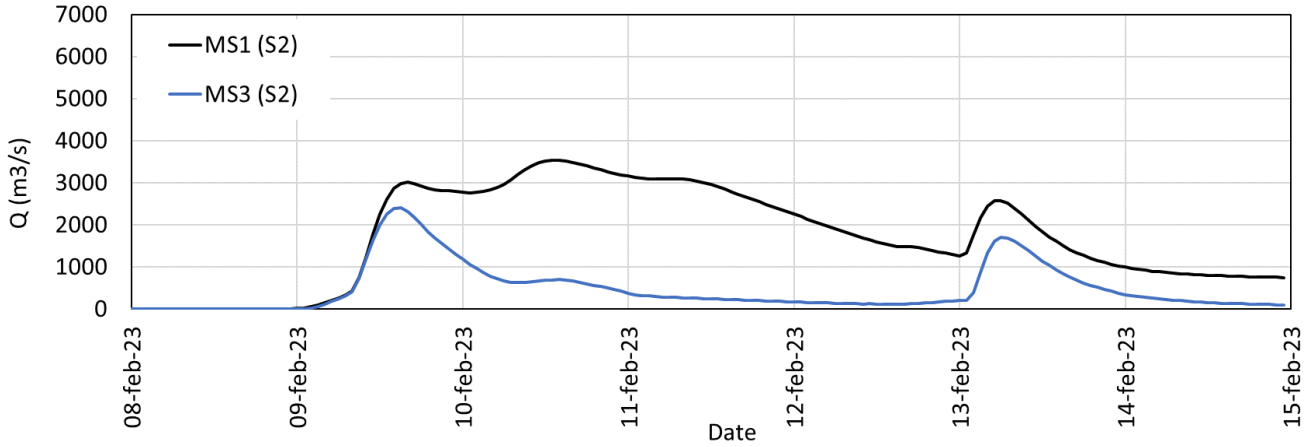




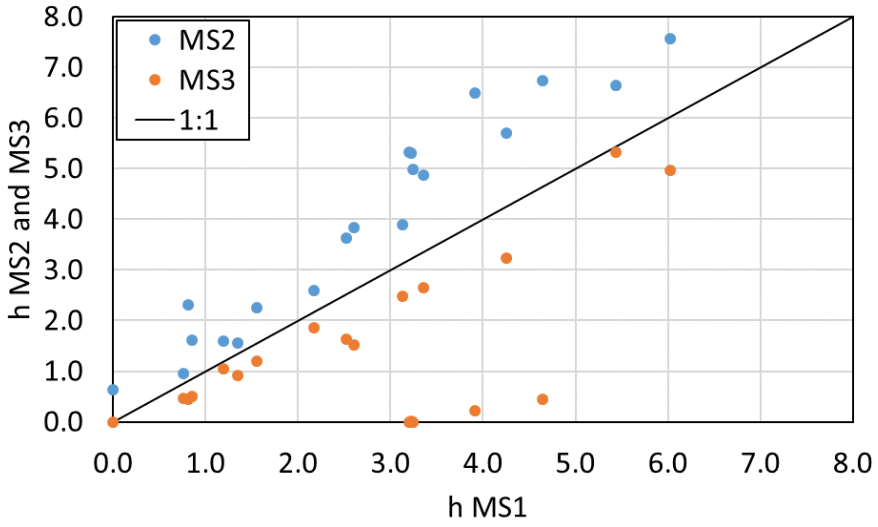
MS3: Larger reservoir

- **What would have happened if the PL reservoir had been able to retain the total inflow hydrograph that arrived there during the storm event? Flooding only from the unregulated D-PLD subbasin**



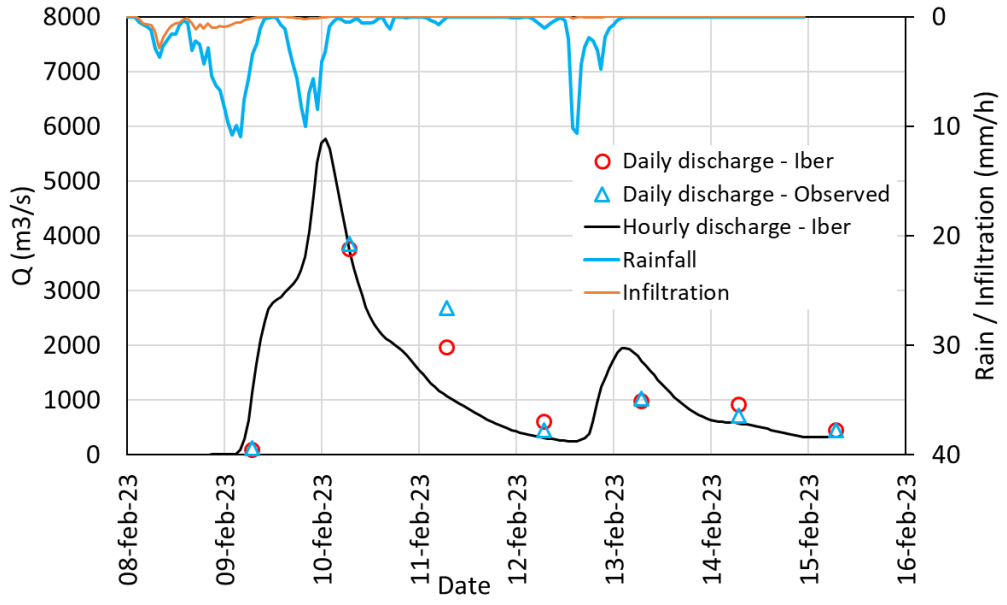


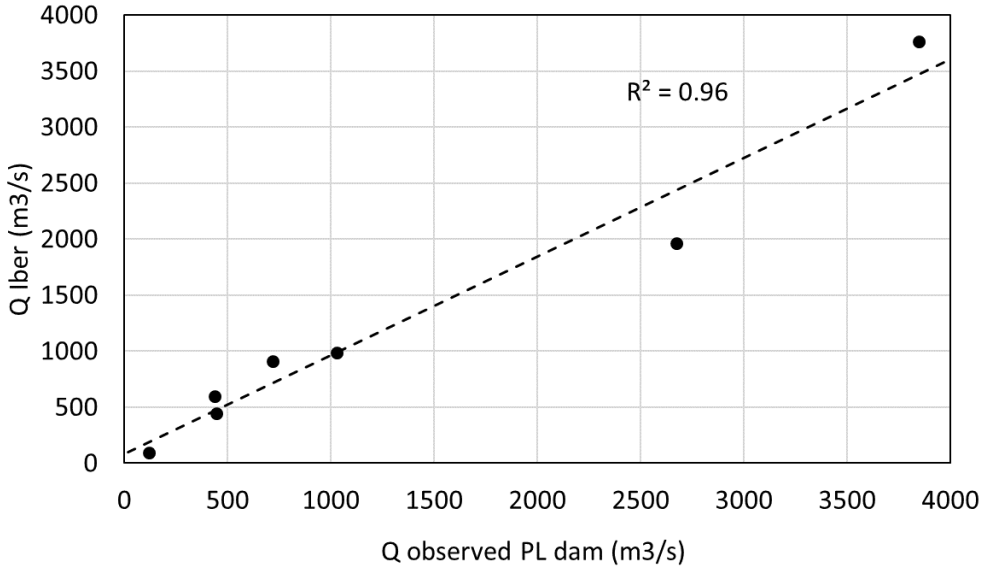
Water depths computed at the 20 control points within the AOI, comparing MS2/MS3 vs. MS1



Conclusions

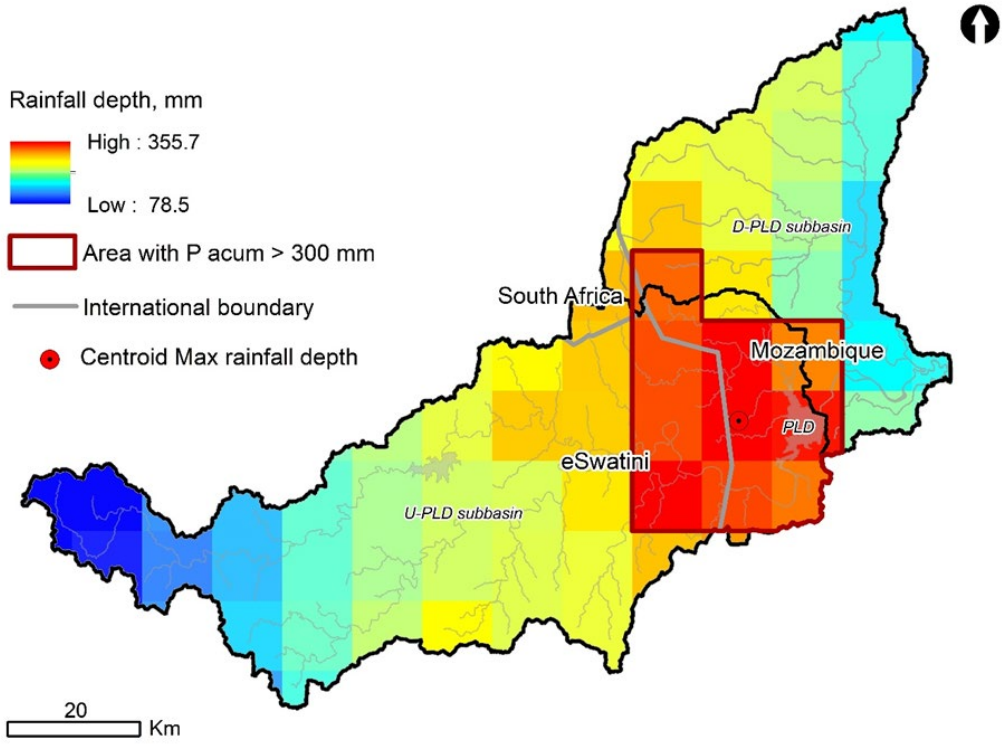
- Integrated hydrological-hydraulic models based on the 2D-SWE (as Iber) combined with global data sources are efficient tools in reproducing the flood hazard during extreme rainfall events in data-scarce catchments of several thousands of km^2.





Conclusions

- In the February 2023 floods, the highest cumulative rainfall depth during the event occurred around the PL reservoir, near the outlet of the U-PLD subbasin, contributing to reducing the response time of the basin and increasing the peak discharge into the PL dam.



Conclusions

- The PL reservoir contributed to reduce the flood hazard in Boane during the February 2023 event.
- Even if there had been a reservoir capable of absorbing the entire volume of the hydrograph generated in its upstream basin, the extension of the inundation in the AOI would have been significant.

Scenario	Qmax in S2 ($m^3 s^{-1}$)	Flooded area in AOI (km^2)	Average depth in AOI (m)
MS1	3,500	84	2.1
MS2	6,000	94	2.9
MS3	2,300	76	1.6

Conclusions

- It is currently possible to delineate flood hazard maps under different scenarios using freely available numerical tools and input data, thus contributing to more efficient flood risk management.

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European Space Agency

Special thanks to:

- ✓ The Head of the Water Resources Department of the Regional Water Administration of Southern Mozambique, Dr. Lizete Días, and technicians Ernesto Tivane and Leonel Bila, for the data provided from the Pequenos Libombos Dam, as well as for the field work carried out in the Boane district in the days following the flood.

- ✓ To the management staff from the AquaMoz project (Augas de Galicia/Xunta de Galicia, Cooperación Galega and Ingeniería sin Fronteras Galicia) for additional support provided.

Obrigado pela atenção

Khanimambo ¡

Continuamos a trabalhar juntos…