Application of advanced Wflow/sbm model with the CMIP6 climate projection for flood prediction in the Lake Tana Basin, Ethiopia

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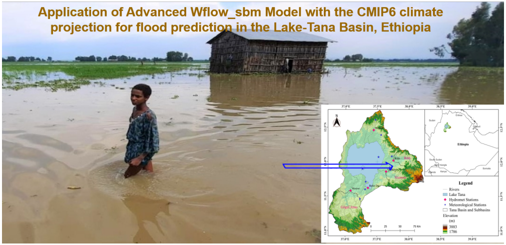
Outline

Study area and methods

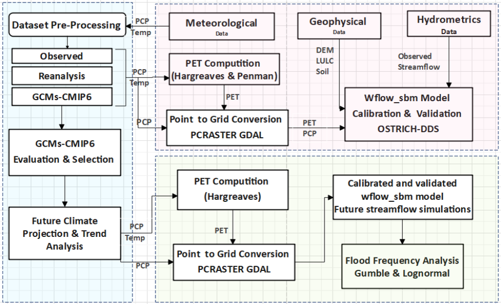
LTB is the origin of BNB located in Ethiopia, E.Africa.

Drainage area: 15,100 km^2



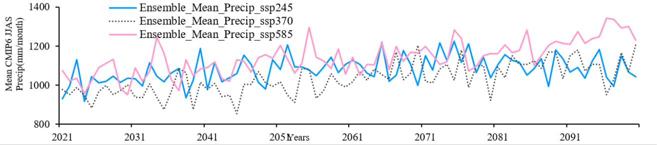
Study Framework

* Input data pre-processing
* Point to grid conversion
* Model calib. and valid.
* Future climate projection
* Streamflow analysis

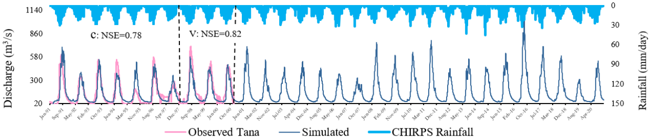


Results

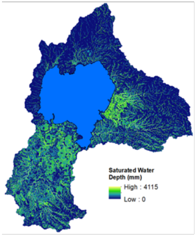
- Top 5 ensemble mean model projections under three scenarios for mean annual Precipitation (mm).



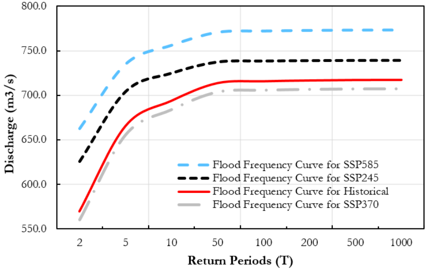
- Observed and simulated discharge and rainfall in the basin outlet for the calibration (C) and validation (V) periods.



- The Wflow sbm model run outputs of saturated water depth which indicates the possible flooding areas.



- FF curve under Projected CMIP6 Scenarios.



Wflow/sbm can be used in data-poor environments.

Introduction

- Flood-related hazards are becoming more frequent and globally widespread because of changes in climate and land use (Brown et al., 2018).
- Significant advances in remote-sensing techniques, the integration of meteorological and hydrological modelling capabilities, advancements in knowledge and algorithms for analysis increases the reliability of flood forecasts (Kim, 2018, Chokkavarapu1, 2019).
- However, there is limited effort to utilize such advancements in hydrological modelling of the Tana Basin.
- Few studies have been conducted in the gauged watersheds of the Lake Tana basin to assess flood risks. e.g., (Desalegn et al., 2016; Hagos, 2011; Zelalem et al., 2018).
- To design appropriate climate change adaptation and mitigation strategies, recent and high-resolution climate models should be also considered.
- The objective of this study is to show how climate simulations can be used to generate reliable local predictions of flood and runoff for the Tana basin.

Study Area

Lake Tana Basin

LTB is the origin of Blue Nile Basin located in Ethiopia, East Africa.

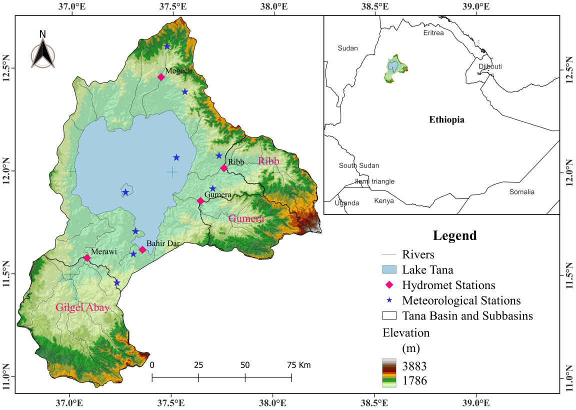
Drainage area: 15,100 km^2

Elevation: 1791 to 4084 m

Annual precip.:1395mm

Mean annual temp : 20 ℃

Major land use: Cultivated crop area, Pasture grazing, Forestry, Urban-residential and Wetland

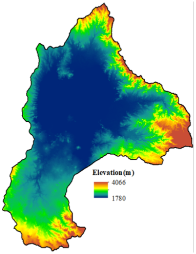


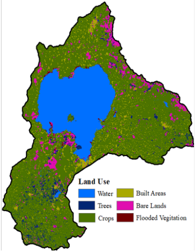
Methods

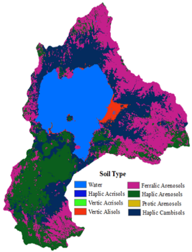
Input Datasets and Preprocessing

Static maps:

- **DEM**: 30m resolution-SRTM- https://earthexplorer.usgs.gov
- **LULC**: 10 m resolution- https://earthexplorer.usgs.gov/
- **Soil**: 250 m resolution-https://soilgrids.org/







Climate forcing:

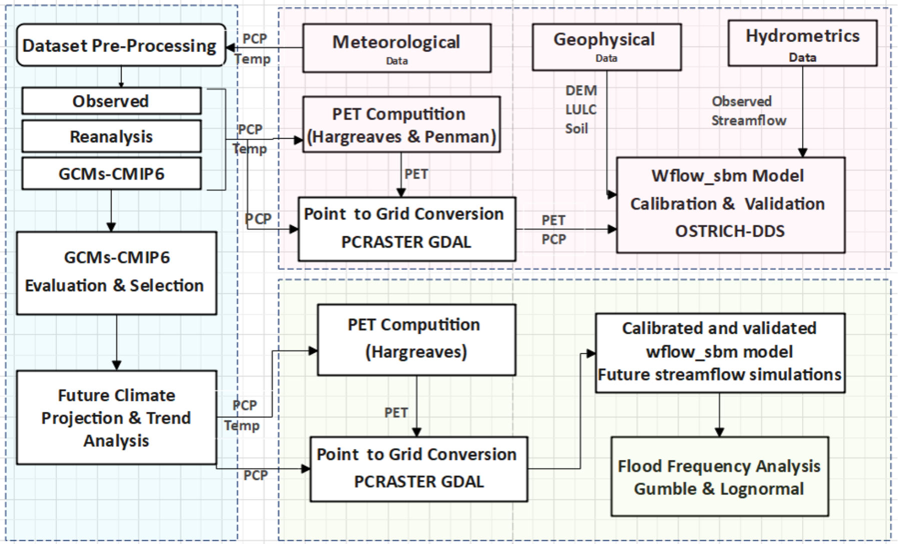
Datasets	Sources
Meteorological Obs.	Ten Stations (1991–2020)- NMA of Ethiopia.
24 Model CMIP6 Datasets	Downscaling – ClimDown-BCCAQ from ESGF
Reanalysis Datasets	10 from KNMI CE
Stream flow	Four Stations (1991-2007) from MoWE
PET Computation	ERA5 and CFSRv2 – Hargreaves method

- All inputs converted into time series maps
- Projected into GCS-WGS-84 and resampled(200 m)
- Cropped to the basin of extent using the PCRaster algorithms and GDAL

CMIP6 Products Bias Correction and Evaluation

- **Bias Correction:** Quantile mapping (R Package:qmap)
- **Reanalysis validation:** With observations using R Package- HydroGOF
- **Evaluations of 24 CMIP6 Models**: With Rea/Observed; Stastical Error Metrics and Taylor diagram
- **Error Minimization for model selection**: Compromise programming(CP) (Salman, 2020)
- **Future Climate Projection and Trend Analysis**:
  Mann–Kendall trend test (R package: trend); P and Z value

Workflow



Dataset Pre-Processing
PCP
Temp
Meteorological
Data
Geophysical
Data
Hydrometrics
Data
Observed
Reanalysis
GCMs-CMIP6
PCP
Temp
PET Computition
(Hargreaves & Penman)
DEM
LULC
Soil
Observed
Streamflow
PET
Wflow_sbm Model
Calibration & Validation
OSTRICH-DDS
PCP
Point to Grid Conversion
PCRASTER GDAL
PET
PCP
GCMs-CMIP6
Evaluation & Selection
PET Computition
(Hargreaves)
Calibrated and validated
wflow_sbm model
Future streamflow simulations
Future Climate
Projection & Trend
Analysis
PCP
Temp
PET
Point to Grid Conversion
PCRASTER GDAL
PCP
Flood Frequency Analysis
Gumble & Lognormal

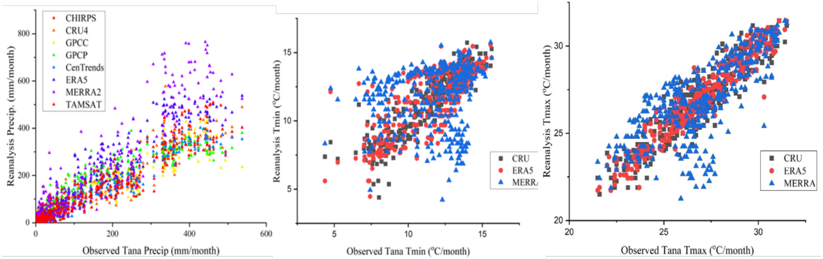
Results

Rea/Satellite Climate Datasets Validation (1991-2020)

– **Precipitation**: CHIRPSv2 (NSE =0.74, R2= 0.76, KGE =0.87, NRMSE =0.5)

– **Max Temp**: ERA5 (NSE = 0.92, R2= 0.76, KGE =0.87, NRMSE = 27.7)

– **Min Temp**: CRU4 (NSE =0.80, R2=0.81, KGE = 0.90, NRMSE =0.45)



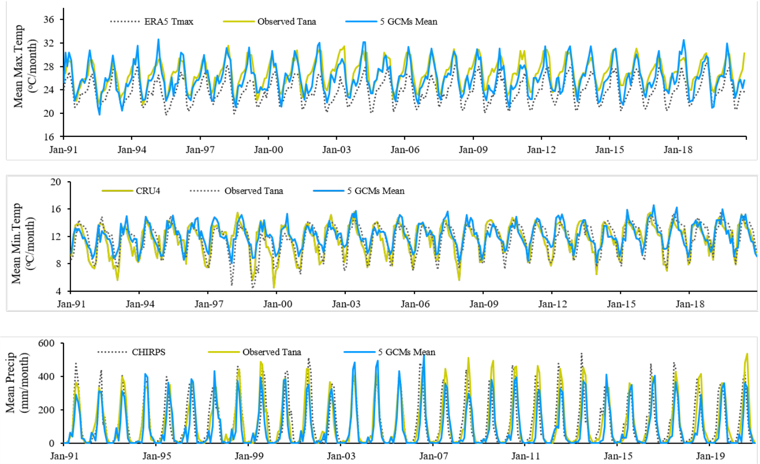
Scatter-plot of observed,reanalysis and satellite products

CMIP6 Products Bias Correction and Evaluation

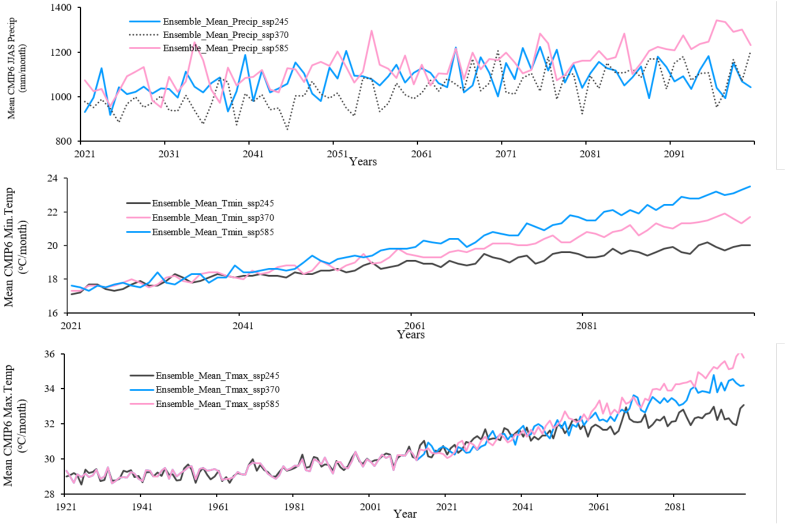
– RQUANT: were able to remove biases in CMIP6 models' products.

– After evaluation and CP application the ff models were chosen.

Top 5 models for Precip.	Top 5 models for Tmin	Top 5 models for Tmax
AWI.CM.1.1.MR	CanESM5.p1	GFDL.ESM4
EC.Earth3	CanESM5.p2	CanESM5.CanOE.p2
EC.Earth3.Veg	CanESM5.CanOE.p2	CanESM5.p2
MPI.ESM1.2.HR	MIROC.ES2L.f2	CanESM5.p1
GFDL.ESM4	CNRM.CM6.1.HR.f2	GISS.E2.1.G.p3



Temporal distribution of CMIP6 five model ensemble mean and rea/satellite products

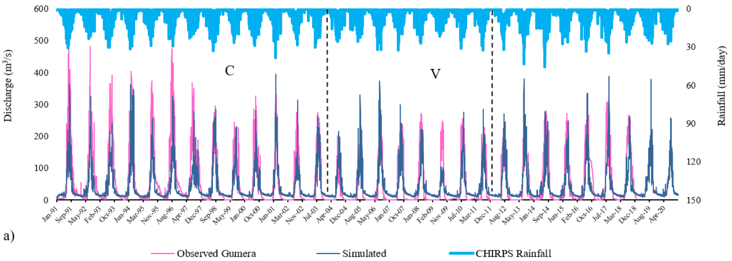


Mann–Kendall trend: Z value: 3.4 to12.25 and P-value: less 0.0004

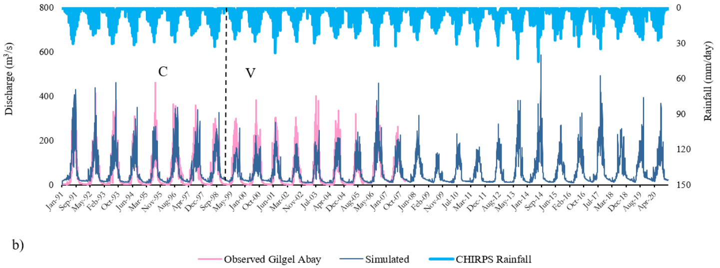
Wflow/sbm Model Calibration and Validation

Model Independent Tool-OSTRICH-DDS algorithm

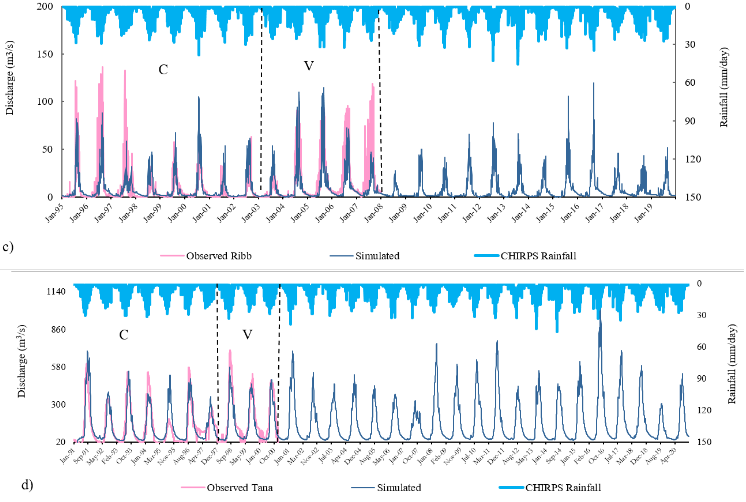
Watersheds	Calibration								Validation	
	NSE	R^2	PBIAS	KGE	RSR	rSD	NRMSE	md	NSE	R^2
Lake Tana Basin	0.78	0.78	-14	0.86	0.47	0.92	46.6	0.78	0.82	0.85
Gilgel Abay	0.67	0.68	6.8	0.78	0.56	0.87	56.5	0.75	0.67	0.68
Gumera	0.64	0.66	-15.3	0.63	0.60	0.70	59.9	0.72	0.65	0.66
Ribb	0.49	0.50	-18.9	0.54	0.72	0.71	72.4	0.72	0.46	0.50


Discharge (m³/s)
Rainfall (mm/day)
C
V
Observed Gumera
Simulated
CHIRPS Rainfall

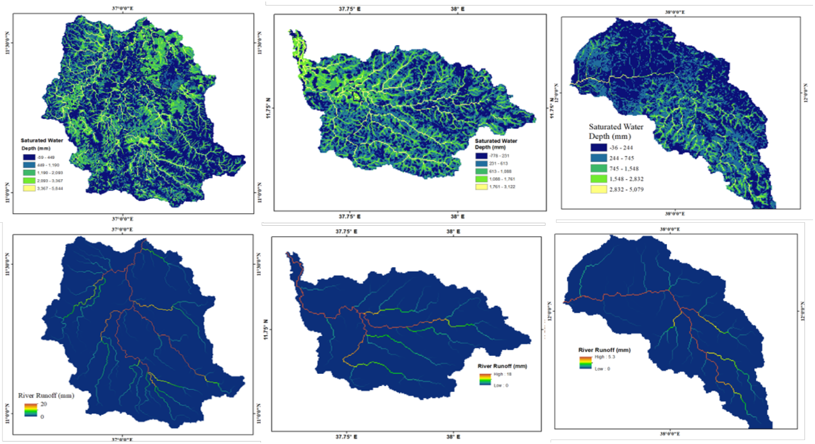
a)


Discharge (m³/s)
Rainfall (mm/day)
C
V
Observed Gilgel Abay
Simulated
CHIRPS Rainfall

b)

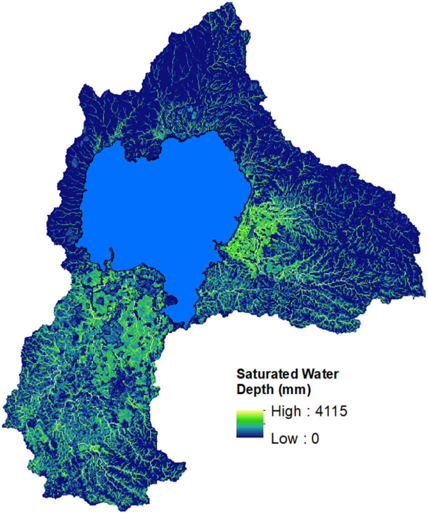


Observed (pink) and simulated (blue) discharge and rainfall (upper) in (a) Gumera, (b) Gilgel Abbay, (c) Ribb and (d) Lake Tana basin outlet for the calibration (C) and validation (V) period.



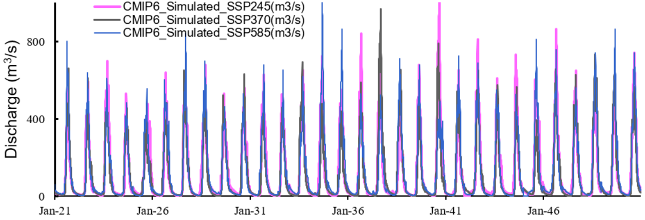
Saturated water depth which indicates the possible

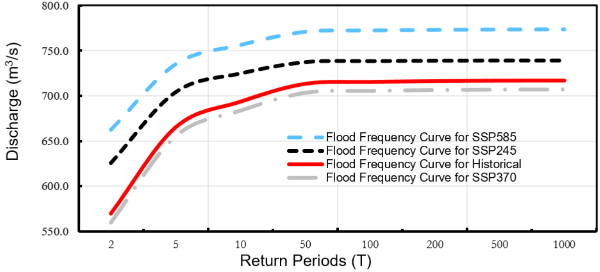
flooding areas and river runoff magnitudes at 3 sub basins.



Saturated water depth which indicates the possible flooding areas

FF Analysis under Projected CMIP6 Scenarios





FF analysis for Lake Tana basin under projected climate change of three scenarios'

Discussions

CMIP6 climate models evaluation and projection

- Reanalysis and satellite products were used without validation and systemic bias correction with local observation (Conway and Hulme, 1993; Jury, 2014; Legesse Gebre, 2015; Roth et al., 2018, Getachew et al., 2021).
- CHIRPS, ERA5 and CRU4 (Dinku et al., 2018; Fenta et al., 2018)
- Climate projections and model choices are more confidently made.

Wflow/sbm model development and flood prediction

- The Wflow/sbm is advantageous over other distributed hydrological models (Hassaballah et al., 2017; M. Werner et al., 2013)
- Infiltration and saturation excess runoff generation mechanism

- The overland flow in the valley bottoms close to the rivers are similar to (Easton et al., 2010; Zimale et al., 2018), and consistent with field observations around Lake Tana (Moges et al., 2017). Likely, because of

  Increased spatial resolution,

  Better characterization of the drainage network,

  Better delineation of the basin and its sub-basins, and

  More accurate parameterization of soil and land cover.

- In the Wflow/sbm nested model: the Modified Puls Approach made it possible to simulate discharge from Lake Tana with good performance, which was not possible in earlier studies.

Conclusion

- The Wflow/sbm modelling approach reasonably identified overland runoff areas in Lake Tana Basin.
- It simulated peak flood events in the three tributaries.
- The coupling of this model with climate model scenarios of CMIP6 resulted a forecasting maximum annual discharge in the basin.
- Wflow/sbm can be used to compute rainfall-runoff simulation in data-poor environments.

Acknowledgments

Thank you for your attention