MODELING STREAMFLOW RESPONSE TO CLIMATE CHANGE IN WAMKURUMADZI RIVER, IN MALAWI

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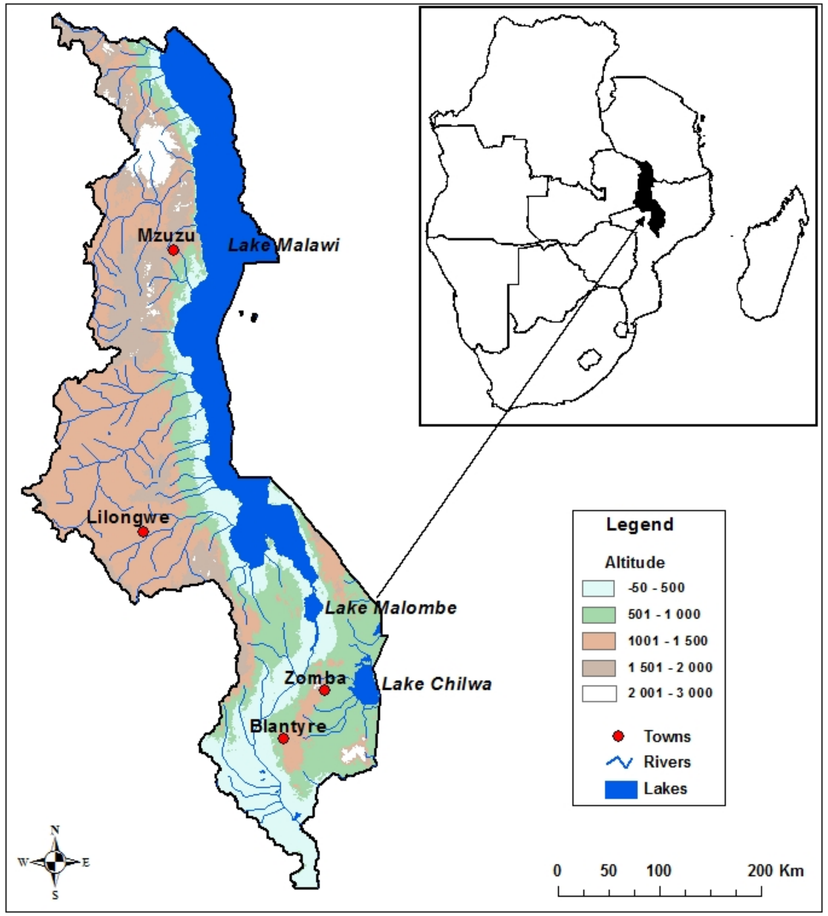
Outline

- Introduction and Motivation
- Study Area and Methodology
- Results
- Summary
- Future work



Map of Malawi showing its elevation and location in Southern Africa (Nhamo *et.al*. 2016)

- Malawi has one of the most erratic rainfall patterns in Africa, with frequent recurrence of droughts and floods.
- Rainfall is driven ENSO (El Nino Southern Oscillation and by the north-south passage of the ITCZ (Intertropical Convergence Zone).

Occurrence of extreme events e.g floods (e.g. 1996/97, 2000-2003), and dry spells (e.g. 2015)

Key tributary of the Shire River basin which supports more than 90% of Malawi’s hydropower and irrigation

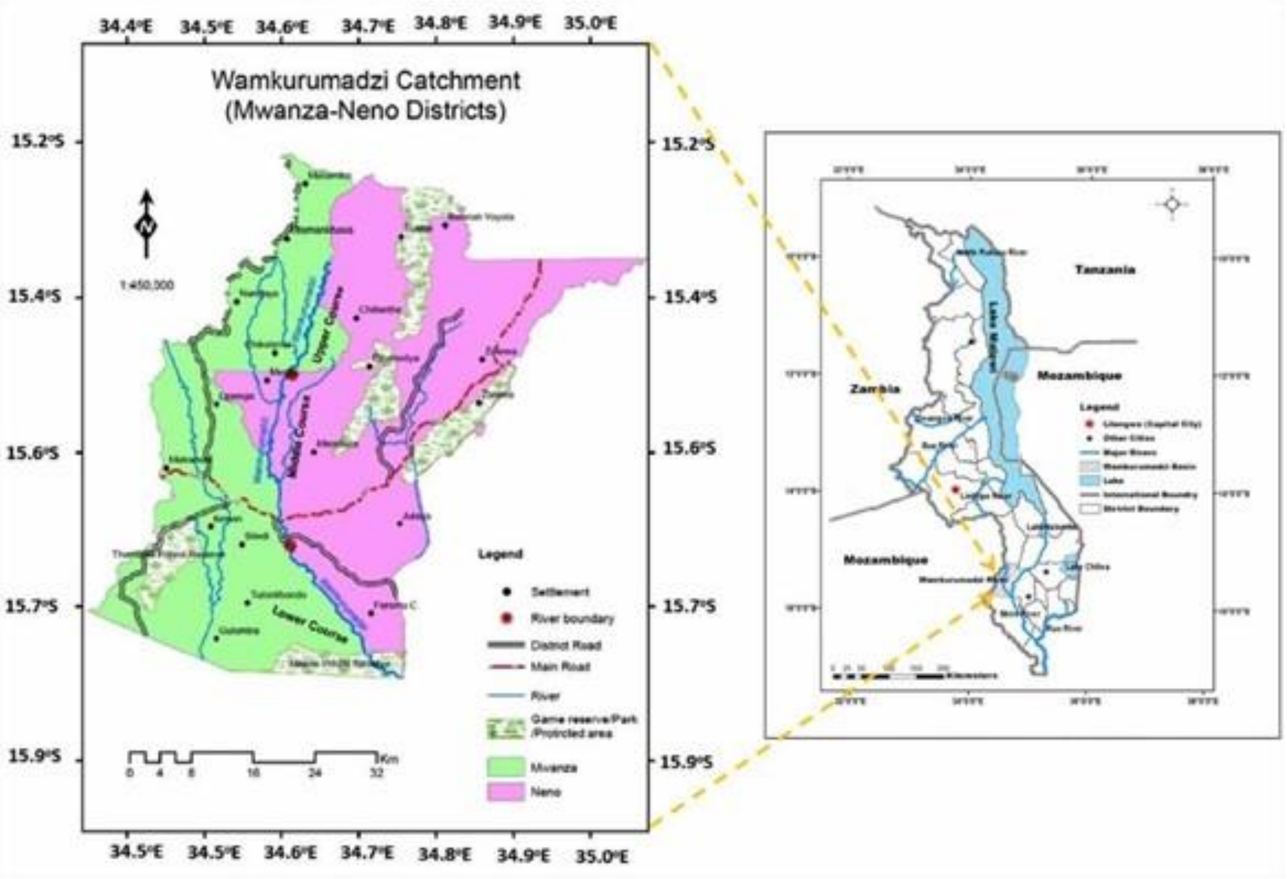
Increase in anthropogenic activities in the catchment.

Main objective

To evaluate the impact of change climate on the river flow regime of the Wamkurumadzi River in southern Malawi

Specific objectives

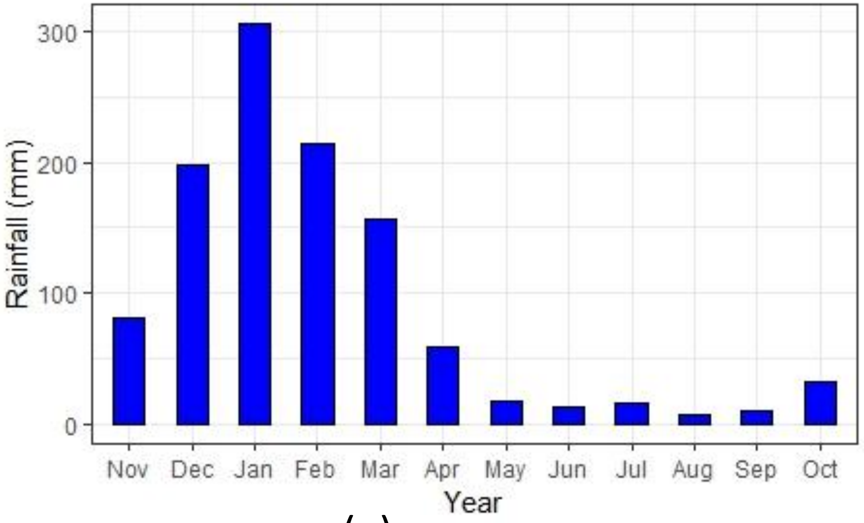
- To assess temporal trends in the hydroclimatology in the catchment
- To examine streamflow variations at annual and seasonal time scale
- To compare model simulations of historical and projected hydrological characteristics



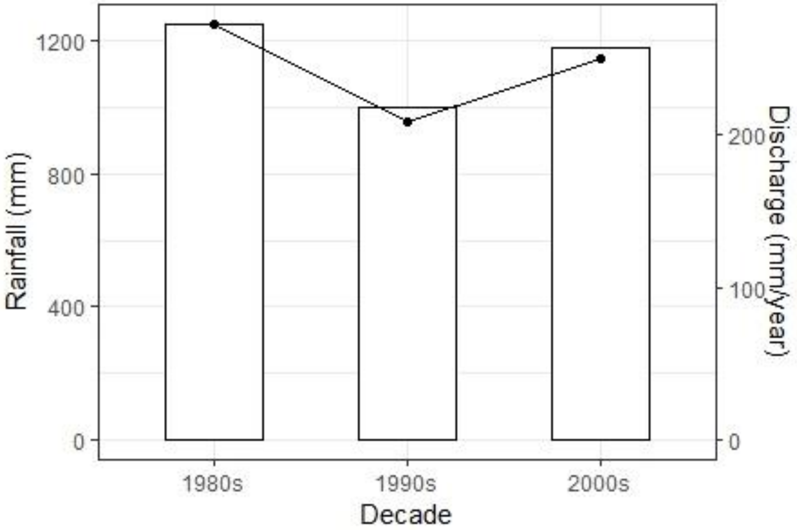
- Wamkurumadzi is a perennial river, contributing to Shire river flow
- Total catchment area: 586km²
- Topography: steep sloping varying between 12°and 25°
- Mean annual temperature in the catchment ranges between 8-32°C
- Annual average rainfall ranges between 800-1200mm per annum in the low lying valley and in the highlands respectively.

No.	Data type	Description	Data acquisition
1	Meteorological dataset (Rainfall &Temperature)	Observed daily rainfall and maximum and minimum temperature for 31-year-period i.e. 1981-2015	Department of Climate Change and Meteorological Services.
2	Discharge data	Observed daily river discharge for 31-year-period i.e. 1981-2015	Ministry of Agriculture and Water Development
3	Digital Elevation Model (DEM)	Terrain elevation (30m × 30m)	National Spatial Data Centre in Malawi
4	Soil Map	Soil classification and physical properties	UN/FAO Digital soil map of the world (http: www.fao.org/)
5	Land use map	Land use classification (30m × 30m Landsat images)	Landsat image for 2015 was downloaded from the USGS website (https://earthexplorer.usgs.gov) and processsed in ArcGIS

No.	Station name	Latitudinal (°S)	Longitudinal(°E)	Elevation (M.a.s.l)	Type
1	Mwanza Met	-15.617	34.5167	649	Meteorological
2	Neno Met	-15.4	34.65	899	Meteorological
3	Mulongolola	-15.65	34.59	355	Hydrological



(a)



(b)

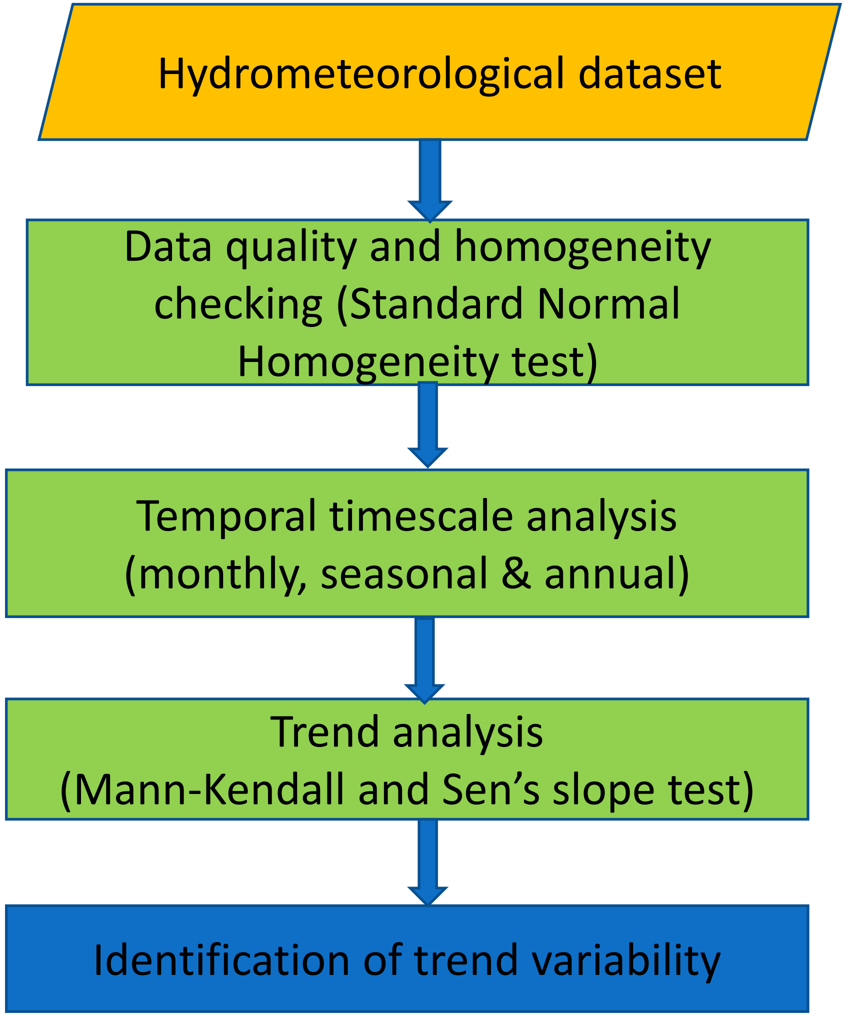
(a) Average monthly rainfall from 1981-2015

Hot wet season: November to April

Cool dry season: May to October

(b) Inter-decadal rainfall in the Wamkurumadzi catchment from 1981-2015

- A relatively high rainfall period in 1980s was followed by relatively lower rainfall in the 1990s which subsequently picked up again in the 2000s.



Temporal trend analysis

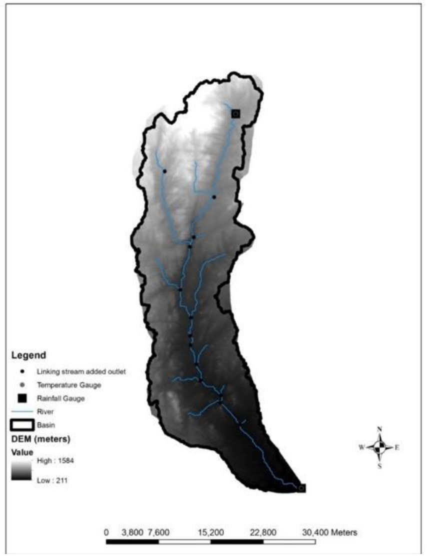
1) Mann-Kendall test

- $S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i)$
- Where;
- $\operatorname{sgn}(x_j - x_i) = \begin{cases} -1 \; for \; (x_j - x_i) < 0 \\ 0 \; for \; (x_j - x_i) = 0 \\ +1 \; for \; (x_j - x_i) > 0 \end{cases}$

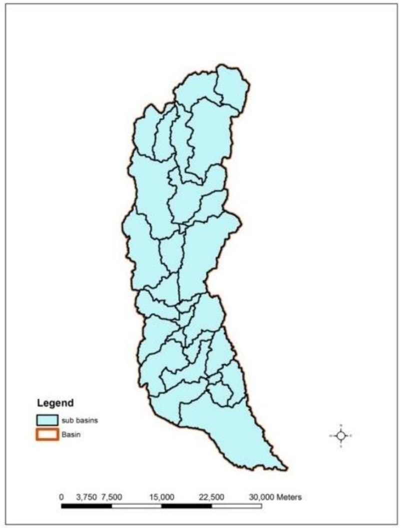
2) Sen's slope test:

- $Q_i = \frac{x_j + x_k}{j-k}$ for i= 1…N

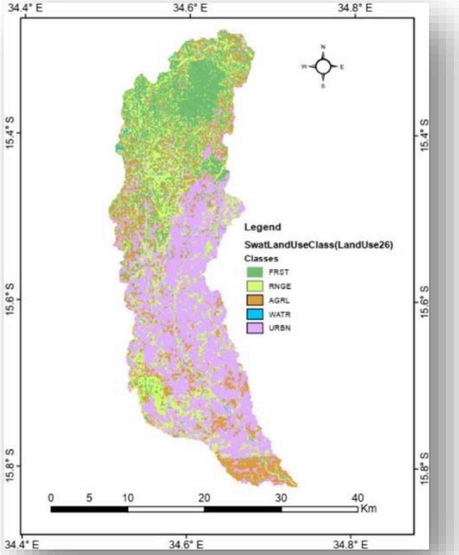
Modeling: SWAT model



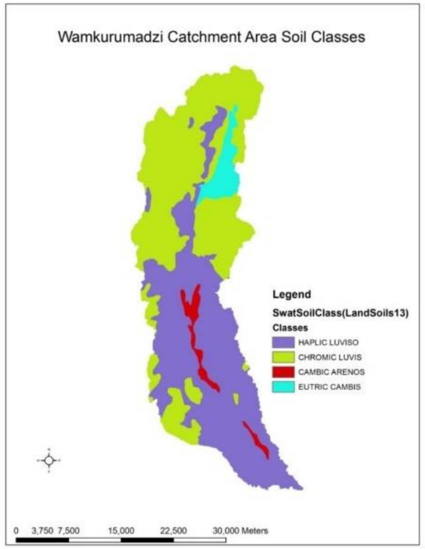
Digital Elevation model of the catchment area and the location of the weather stations



Delineation of the subbasins (a total of 29)



Land use map



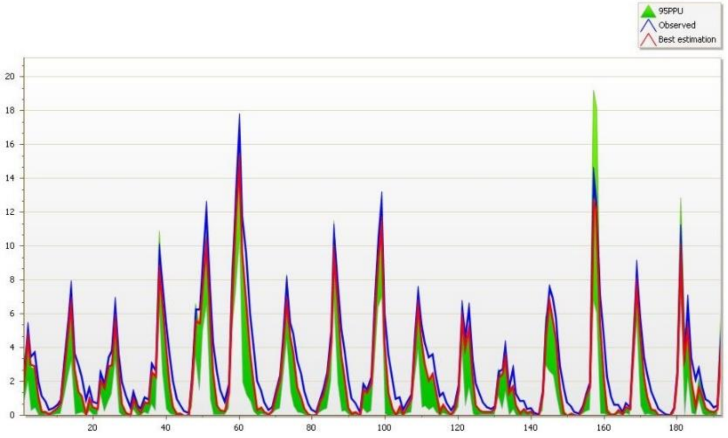
Soil map

Meteorological data

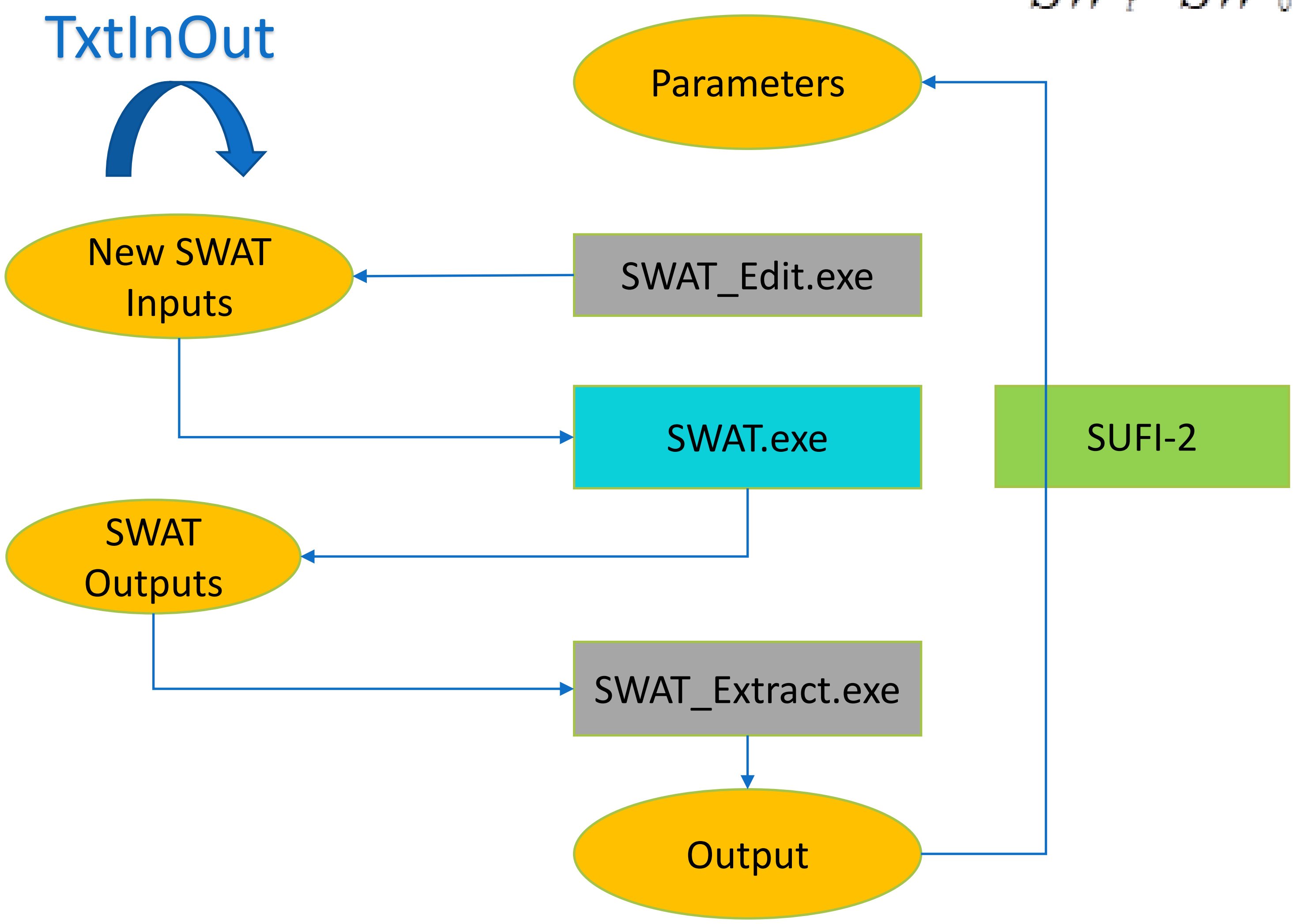
SWAT Model Calibration and Validation

Discharge data

Output



$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})$$



Model calibration was done using the Sequential Uncertainty Fitting Ver-2 (SUFI-2) algorithm.

Series of iterations and numerous simulations were performed with each iteration fed with the results of the previous one.

Statistical approaches for SWAT Model performance

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}$$

$$R^2 = \left\{\frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\left[\sum_{i=1}^{n}(O_i - \bar{O})\right]^{0.5}\left[\sum_{i=1}^{n}(S_i - \bar{S})\right]^{0.5}}\right\}^2$$

$$PBIAS = \left[\frac{\sum_{i=1}^{n}(O_i - S_i) \times 100}{\sum_{i=1}^{n} O_i}\right]$$

- $RSR = \frac{RMSE}{STDEV_{O_i}} = \frac{\sqrt{\sum_{i=1}^{n}(O_i - S_i)^2}}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{S}_i)^2}}$
- Model performance (for streamflow) can be satisfactory If;
- NSE > 0.50
- RSR ≤ 0.75
- PBIAS ± 25%
- R^2 ranges between 0 to 1 with values >0.5 considered acceptable (higher values indicate less error variance)

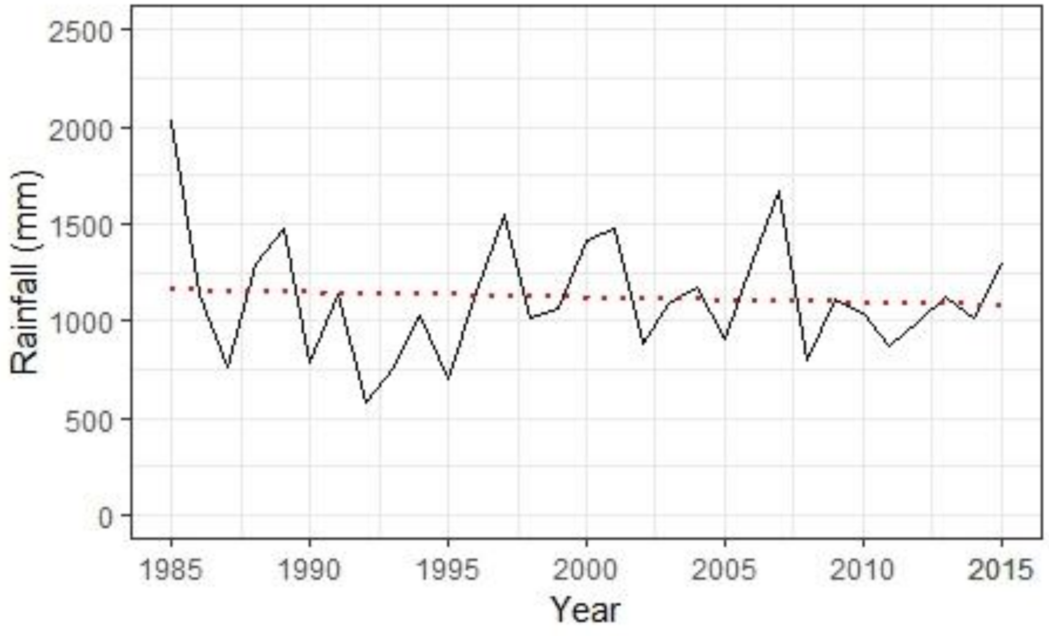
Series	Rainfall			Temperature			Discharge		
	p-value	Sen's slope	Trend	P-value	Sen's slope	Trend	p-value	Sen's slope	Trend
November	0.932	-0.033	Negative	0.680	0.0171	Positive	0.102	0.062	Positive
December	0.977	0.04	Positive	0.255	0.016	Positive	0.002*	0.333	Positive
January	0.02*	3.646	Positive	0.206	-0.015	Negative	0.016*	0.137	Positive
February	0.268	-2.262	Negative	0.754	0.002	Positive	0.091	-0.134	Negative
March	0798	0.281	positive	0.690	0.004	Positive	0.459	-0.024	Negative
April	0.809	-0.125	Negative	0.334	-0.017	Negative	0.776	0	Positive
May	0.168	-0.251	Negative	1	-0.0002	Negative	0.504	-0.017	Negative
June	0.032*	-0.327	Negative	0.306	0.021	Positive	0.082	-0.061	Negative
July	0.638	-0.021	Negative	0.670	0.009	Positive	0.068	-0.042	Negative
August	0.123	-0.175	Negative	0.426	0.014	Positive	0.007*	-0.054	Negative
September	0.032*	-0.3	Negative	0.027	0.287	Positive	0.003*	-0.053	Negative
October	0.003*	-1.181	Negative	0.191	0.029	Positive	0.002*	-0.055	Negative
Hot wet season	0.394	0.014	Positive	0.65	-0.004	Negative	0.011*	0.102	Positive
Cool dry season	0.002*	-0.015	Negative	0.609	0.008	Positive	0.102	-0.040	Negative
Annual	0.955	-0.074	Negative	0.57	0.007	Positive	0.222	0.031	Positive

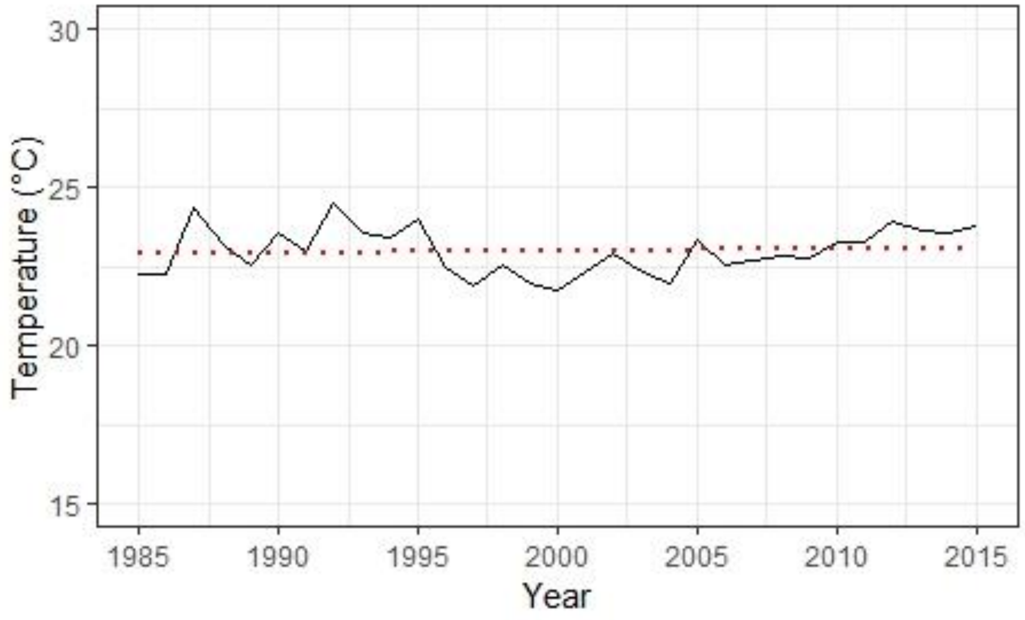
Significant increasing trend at α=0.05

Significant decreasing trend at α=0.05

Trend in annual rainfall in the catchment from 1981-2015
Slope of the mean areal rainfall showing decreasing trend though not statistically significant

Annual mean temperature in the catchment from 1981-2015
Slope showing an increasing trend though not statistically significant



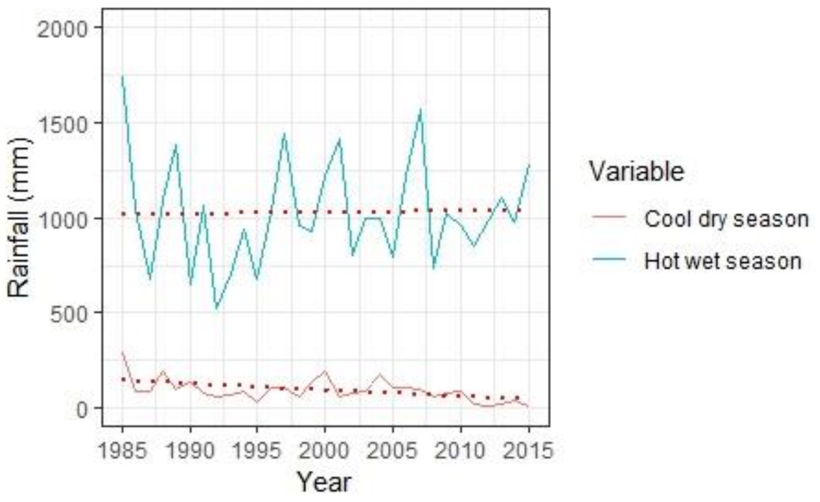


(a) Seasonal rainfall variations for Wamkurumadzi catchment
Cool dry season: statistically significant negative trend at α=0.05
Hot wet season: Increasing trend though not significant

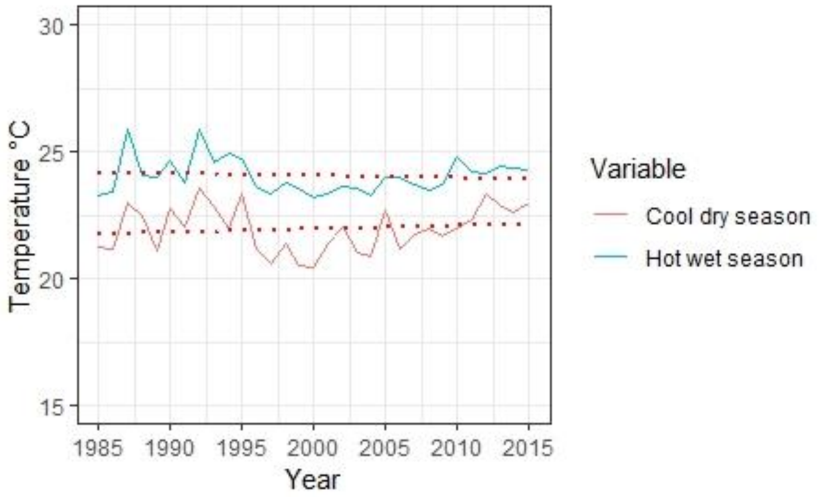
(c) Seasonal streamflow variations for Wamkurumadzi catchment
Cool dry season: statistically significant negative trend at α-0.05
Hot wet season: increasing trend though not significant

(b) Seasonal temperature variations for Wamkurumadzi catchment
Cool dry season: Increasing trend though not statistically significant
Hot wet season: decreasing trend though not statistically significant

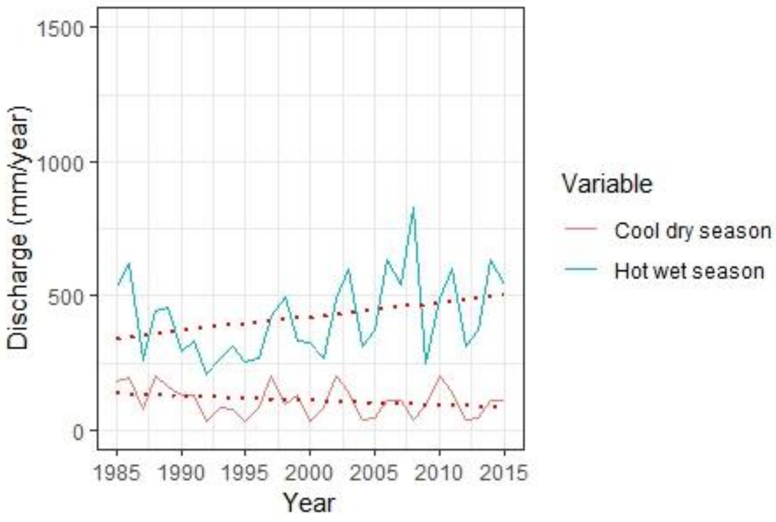
(a)



(b)



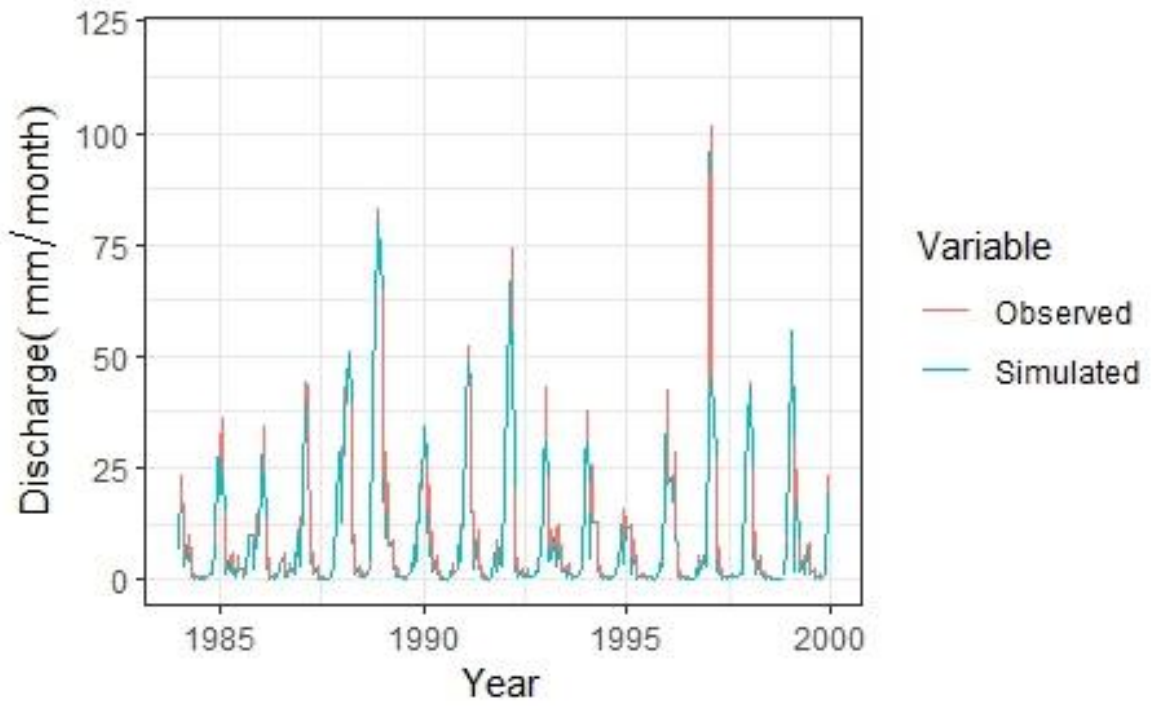
(c)



Parameter	Description	Initial range	Rank	Fitted value
CN2.mgt	SCN runoff number for moisture condition	-25 to 25	1	20
SOL_AWC().sol	Available water capacity of the soil layer	-25 to 25	2	20
SURLAG.bsn	Surface runoff lag time	0 to 10	3	3
ALPHA_BF.gw	Base flow alpha factor	0.00 to 1.00	4	0.9
GW_REVAP.gw	Ground water “revap” coefficient	-0.036 to 0.036	5	0.0288

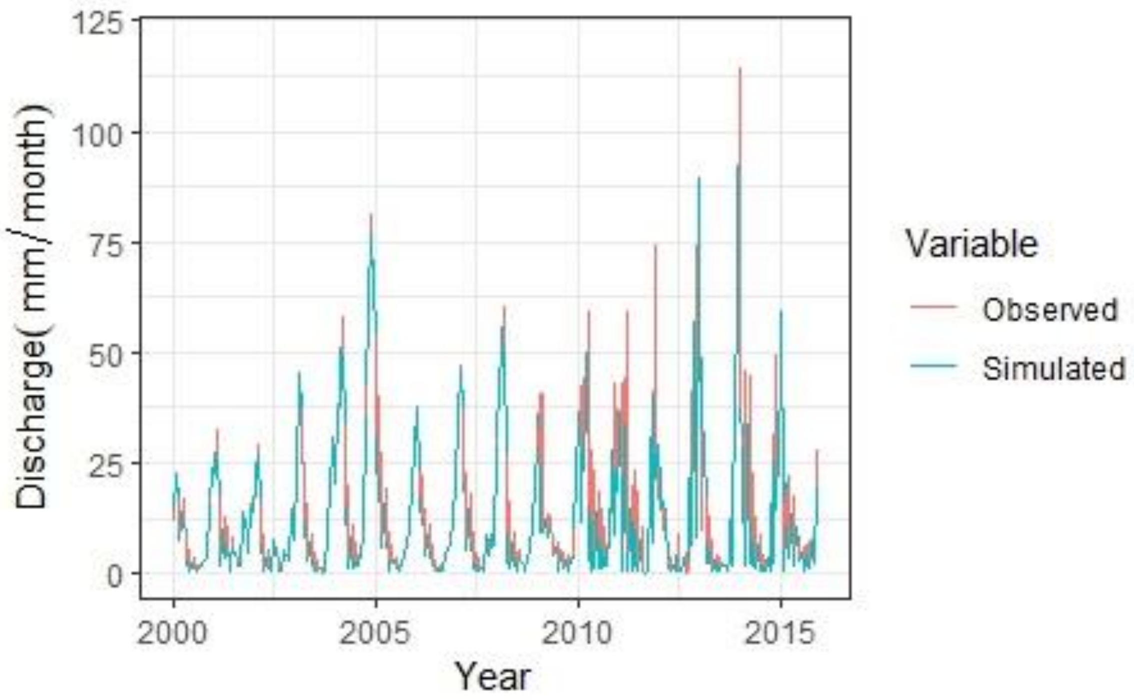
a) Monthly Calibration (1985-1999)

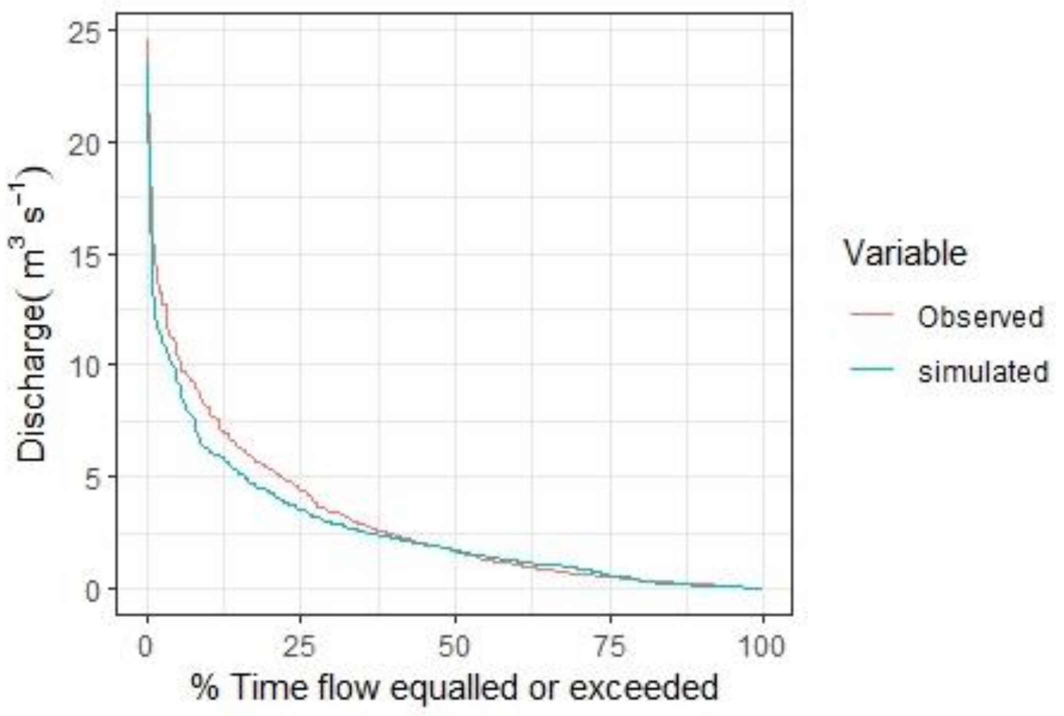
R^2=0.712
NSE=0.78
RSR=0.47
PBIAS=17.2



b) Monthly Validation (2000-2015)

R^2= 0.98
NSE= 0.71
RSR=0.27
PBIAS=22.9





Flow duration curve for observed and simulated discharge

- The monthly exceedance curve captured extremely high flows with exceedance probability below about 2% and the lower flows with exceedance probability above 40%.

- Rainfall and streamflow trends for the cool dry season showed a decreasing trend that was statistically significant at $\alpha=0.05$ especially during the months of June, September and October.
- Trend results for the streamflow suggest a predominance of statistically significant increasing trend during the hot wet season and in the months of January and December.
- Insignificant increasing trends were observed for the mean annual temperature. However, the results show that the period 1981-1999 was generally warmer than the period after the 2000.
- These results highlight the sensitivity of the Wamkurumadzi River to climate forcing mechanisms especially changes in rainfall.
- SWAT model can capture extremely high and low flows.

- Compare the performance of the global meteorological forcing against gauge observations in driving the hydrological models to simulate hydrological regime.
- Evaluate the sensitivity of different hydrological models in capturing hydrological extremes (i.e. floods and droughts) when forced with global meteorological forcing and gauge observation dataset.
- Assess the hydrological response to future climate change with the use of NASA Earth Exchange Global Daily Downscaled Projections (NED-GDDP) Coupled Model Intercomparison Project 6 (NEX-GDDP-CMIP6) dataset.

Acknowledgement

- This study is financially supported by the Norwegian Programme for Capacity Development in Higher Education and Research for Development (NORHED II - 63826) and the Research Council of Norway (FRINATEK Project No. 274310).


THANK YOU FOR YOUR ATTENTION!