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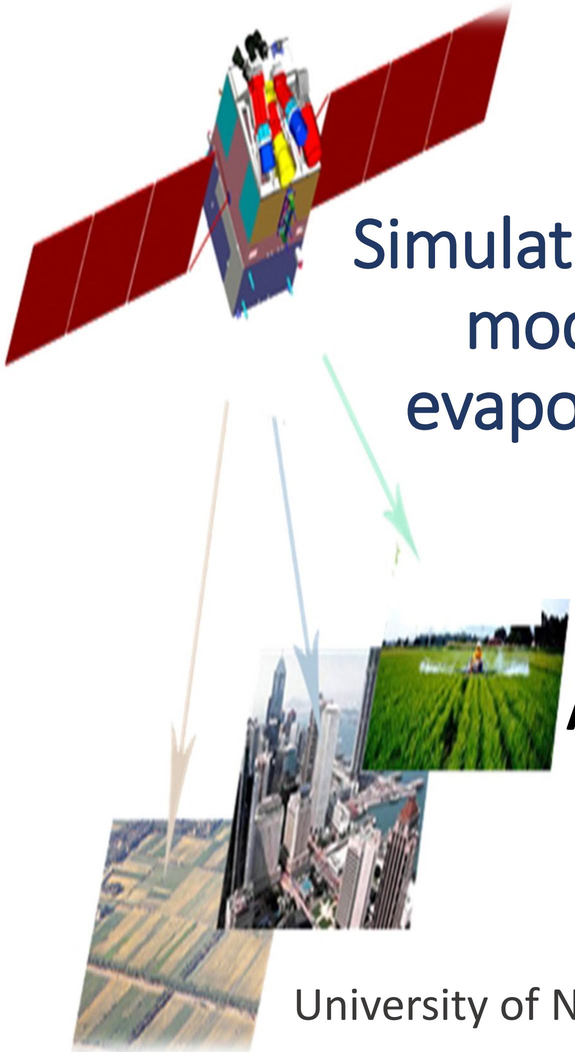

Simulating stream flow using an eco-hydrological model calibrated with global land surface evapotranspiration from remote sensing data

Abolanle Elizabeth Odusanya, Christoph Schürz, Karsten Schulz, and Bano Mehdi

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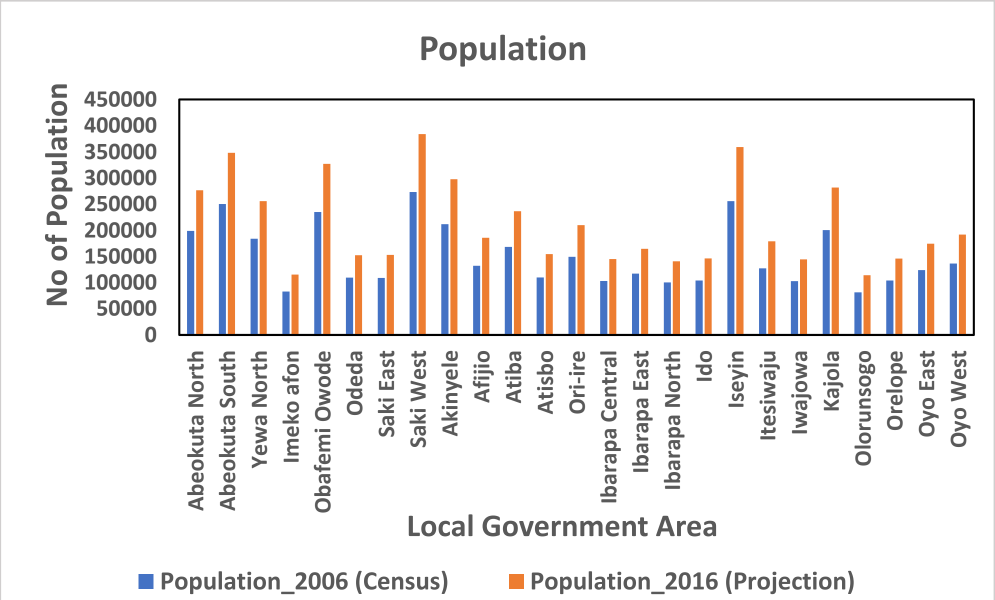
Friday 21, September, 2018

Motivation & Project Background

- Ogun river is the main source of public water supply for two states (Lagos & Ogun) in Nigeria
- With the increasing population and their socio-economic activities, the Ogun river is susceptible to point and non-point source pollution (e.g high phosphorus load)



Source: National Bureau of Statistics

- No reliable hydrological gauging stations
- No standard water quality monitoring stations

Objectives

Lack of ground observation to accurately model the watershed is a challenging task

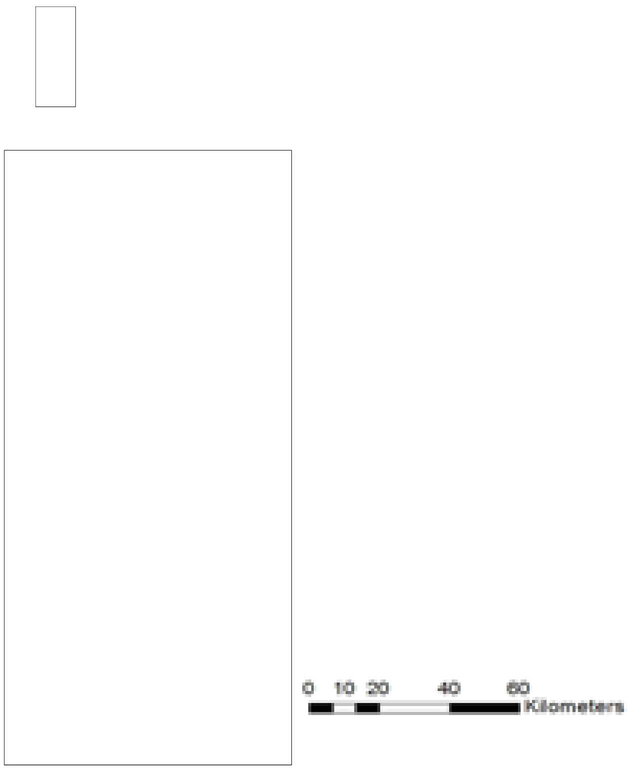
1

To use global AET data to calibrate and validate SWAT model to indirectly simulate stream flow

2

To validate the simulated stream flow using similar neighbouring catchment stream flow

Study Area - Ogun River Basin



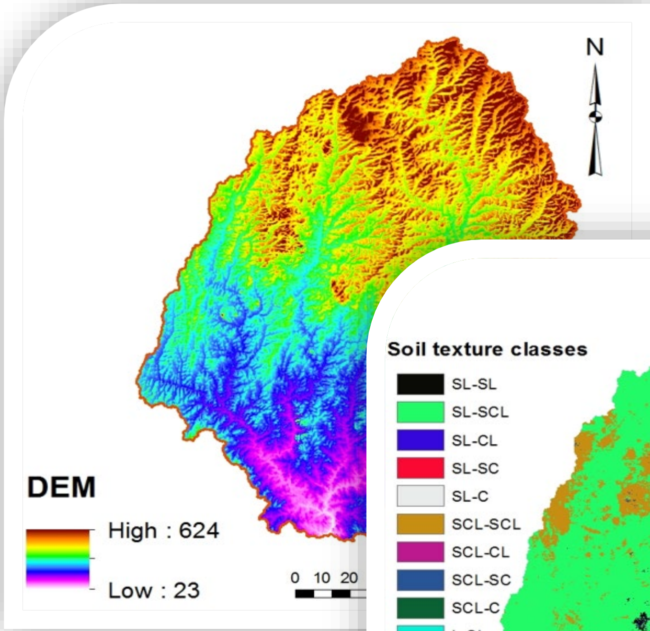
- Ogun River Basin located in tropical rainy climate SW Nigeria (20,292km^2)
- Mean annual precipitation is 1224mm
- Mean annual temperature is about 27^{0}C
- Mean annual PET (Hargreaves)= 1720 mm
- Mean annual AET (simulated) = 692 mm

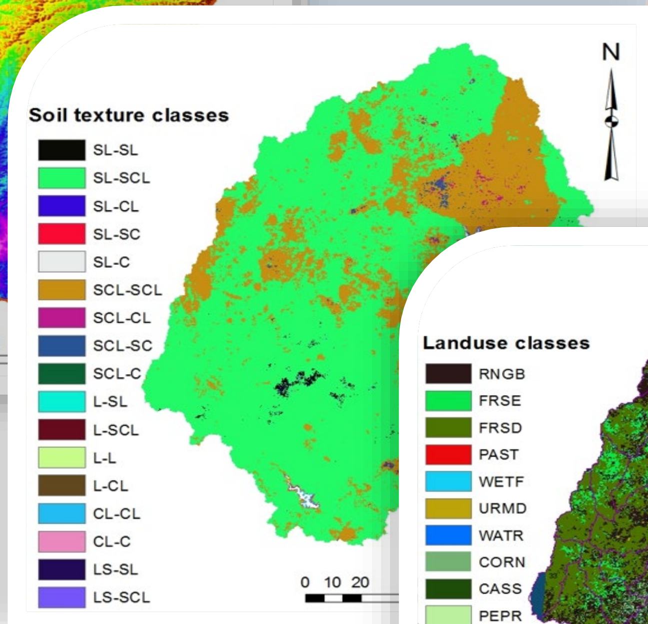
SWAT Model Inputs

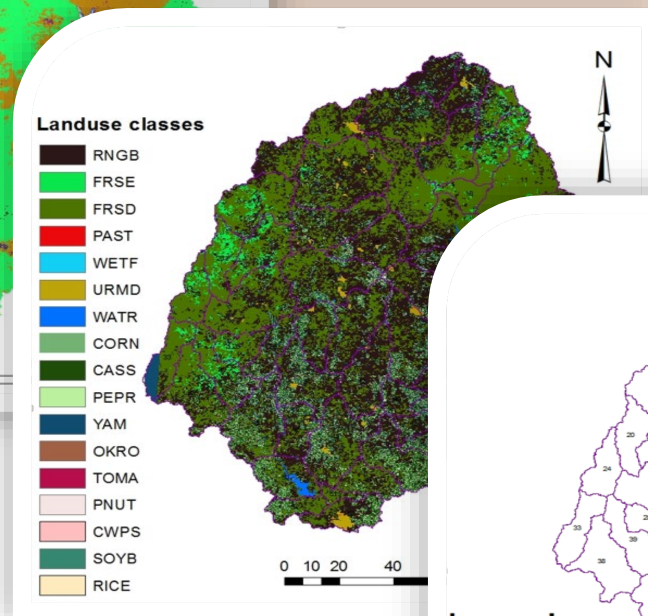
- ✓ 30m DEM (SRTM)
- ✓ 250m soil property map with 17 soil classes (AFSIS)
- ✓ 300m land cover map with 17 landuse classes (European Space Agency)

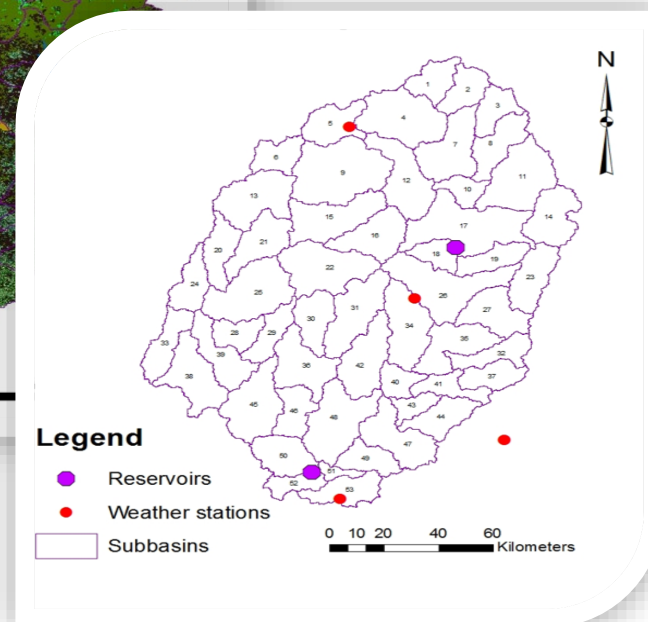
- ✓ Observed daily temperature and precipitation data
- ✓ Daily reservoirs outflow data
- ✓ Agricultural management practices data

- ✓ 53 subbasins
- ✓ 1397 HRU









3 different PET equations selected & SWAT setup names

- Hargreaves : $\lambda E_o = 0.0023 \cdot H_0 \cdot (T_{mx} - T_{mn})^{0.5} \cdot (\overline{T}_{av} + 17.8)$

  SWAT setup is refers to **SWAT-HG**

- Priestley-Taylor : $\lambda E_o = \alpha_{pet} \cdot \frac{\Delta}{\Delta + \gamma} \cdot (H_{net} - G)$

  SWAT setup is refers to **SWAT-PT**

- Penman-Monteith: $\lambda E = \frac{\Delta \cdot (H_{net} - G) + \rho_{air} \cdot c_p \cdot [e_z^o - e_z]/r_a}{\Delta + \gamma \cdot (1 + r_c/r_a)}$

  SWAT setup is refers to **SWAT-PM**

Global AET Data

MODIS

- MOD16 AET
- Spanning 2000-2012 (1km^2)
- Based on Penman-Monteith algorithm

- Input into Eqn. driven by satellite data

- The AET is derived from PET using multipliers to halt plant transpiration & soil evaporation

GLEAM

- GLEAM_v3.0a, AET
- Spanning 1980-2014 (0.25^0)
- Based on Priestley-Taylor algorithm

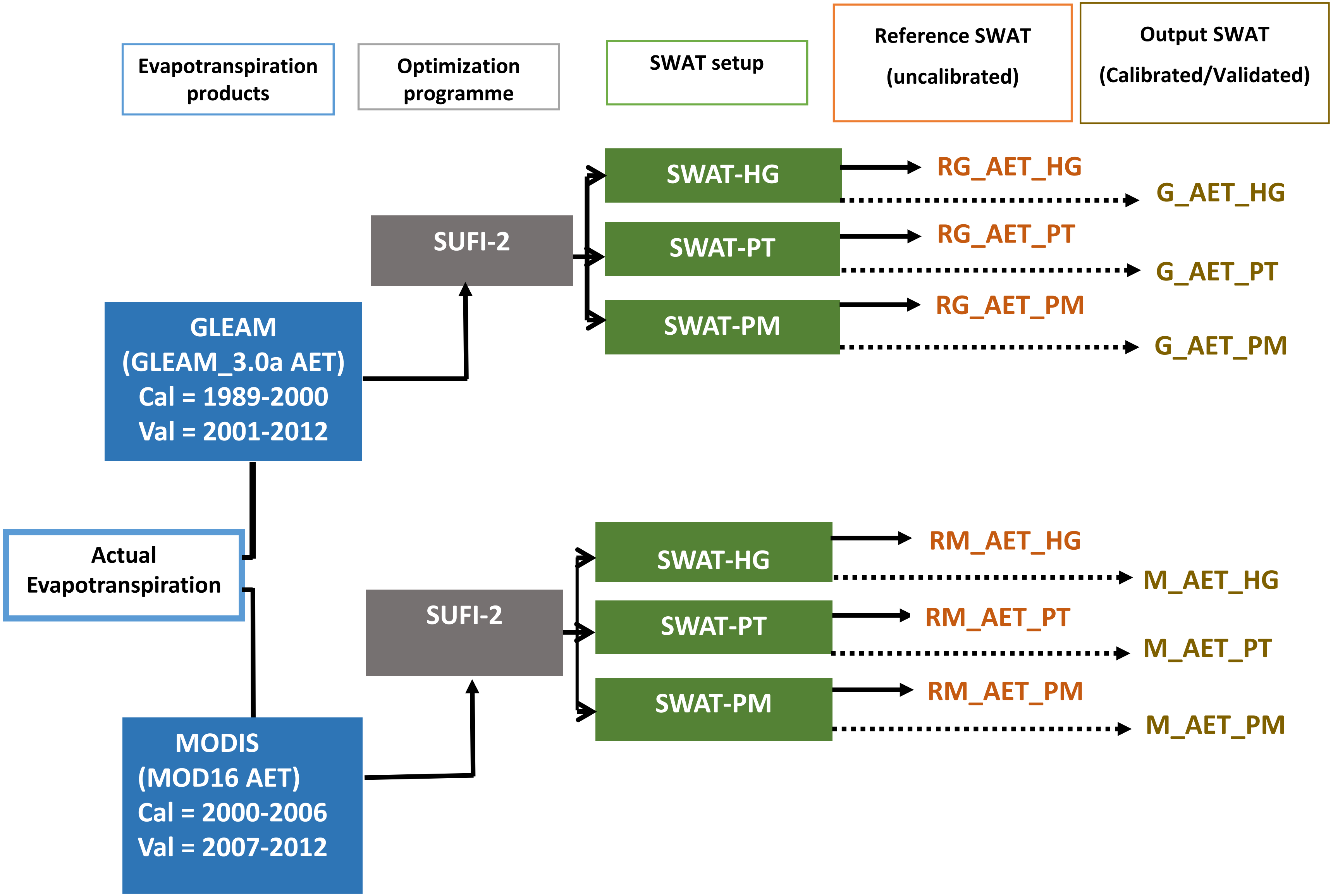
- Input into Eqn. driven by satellite data

- The AET is derived from PET using a multiplicative stress factor based microwave vegetative optical depth used as a proxy for the vegetative water content & root zone soil moisture simulations

Calibration/Validation Acronymns

Acronyms	Description
G_AET_HG	SWAT-HG simulated AET calibrated/validated with GLEAM_v3.0a AET
G_AET_PT	SWAT-PT simulated AET calibrated/validated with GLEAM_v3.0a AET
G_AET_PM	SWAT-PM simulated AET calibrated/validated with GLEAM_v3.0a AET
M_AET_HG	SWAT-HG simulated AET calibrated/validated with MOD16 AET
M_AET_PT	SWAT-PT simulated AET calibrated/validated with MOD16 AET
M_AET_PM	SWAT-PM simulated AET calibrated/validated with MOD16 AET

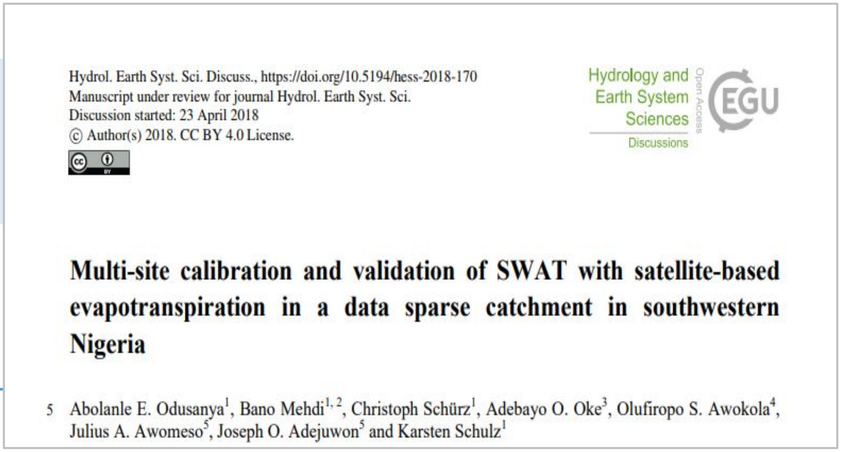
Calibration/Validation Procedure



SWAT Calibration/Validation of AET Results

Model Run	Statistics	Calibration	Validation
G_AET_HG	KGE	0.77	0.68
	NSE	0.61	0.45
G_AET_PT	KGE	0.69	0.64
	NSE	0.43	0.32
G_AET_PM	KGE	0.65	0.60
	NSE	0.34	0.20
M_AET_HG	KGE	0.52	0.28
	NSE	-0.1	-0.83
M_AET_PT	KGE	0.46	0.18
	NSE	-0.20	-1.08
M_AET_PM	KGE	0.41	0.19
	NSE	-0.37	-1.25

For more detailed results:


Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2018-170
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Discussion started: 23 April 2018
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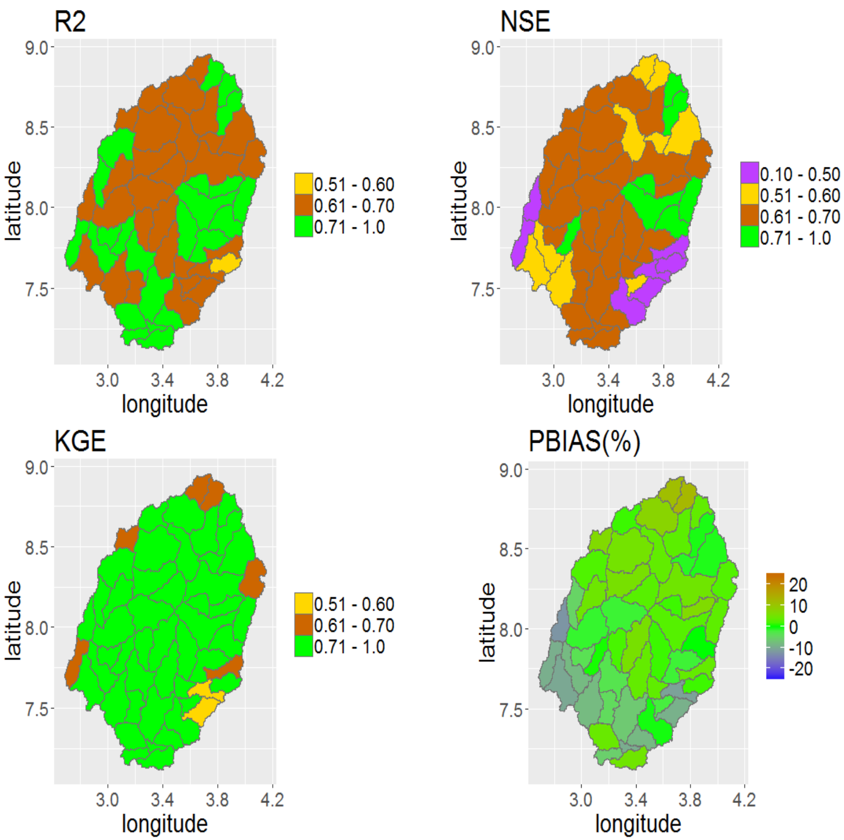
Hydrology and Earth System Sciences Open Access Discussions

Multi-site calibration and validation of SWAT with satellite-based evapotranspiration in a data sparse catchment in southwestern Nigeria

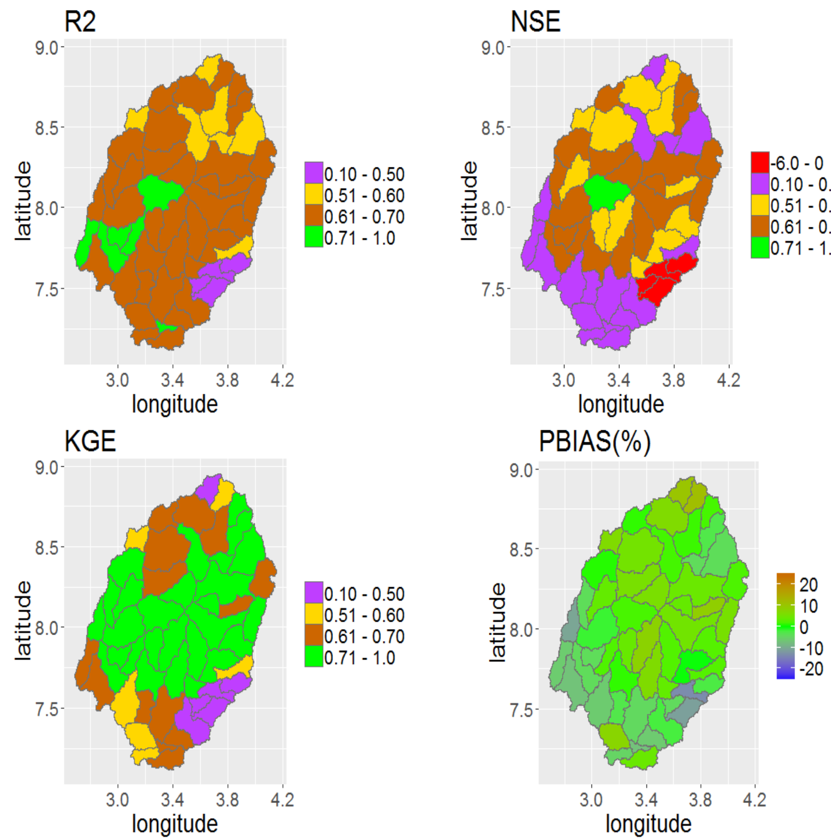
Abolanle E. Odusanya[1], Bano Mehdi[1,2], Christoph Schürz[1], Adebayo O. Oke[3], Olufiropo S. Awokola[4], Julius A. Awomeso[5], Joseph O. Adejuwon[5] and Karsten Schulz[1]

Results of Calibration/Validation for GAET_HG

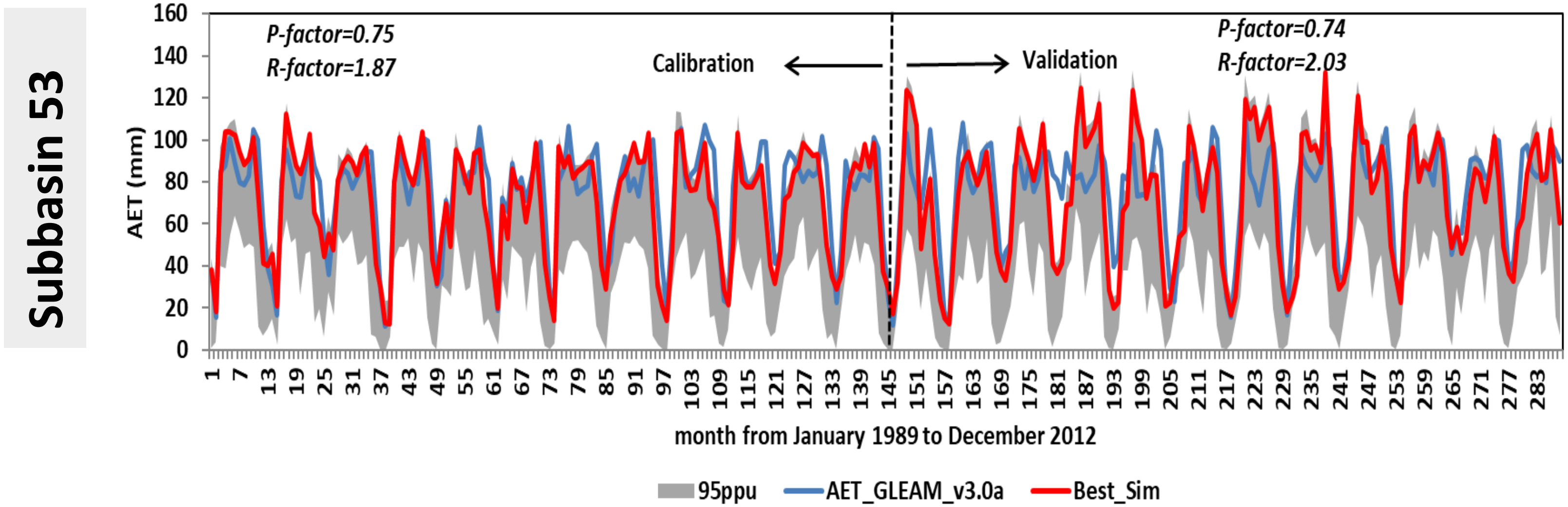
Calibration



Validation



AET Simulation Uncertainty Results for GAET_HG



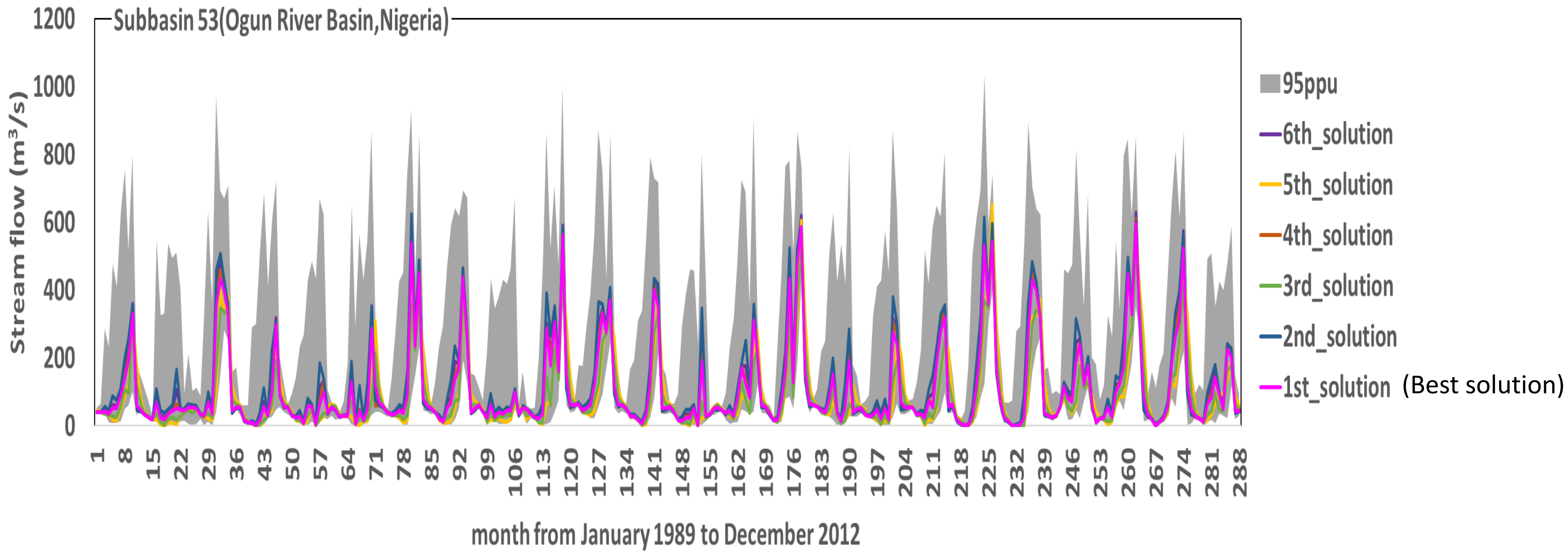
Calibration range for the watershed
P-factor= 0.50-0.90
R-factor= 1.40-2.4

Validation range for the watershed
P-factor= 0.60-0.88
R-factor= 1.43-2.5

The Predictive uncertainty adequate in the 53 subbasins, thou the R-factor was quite large indicating large model uncertainty

Streamflow Simulation GAET_HG

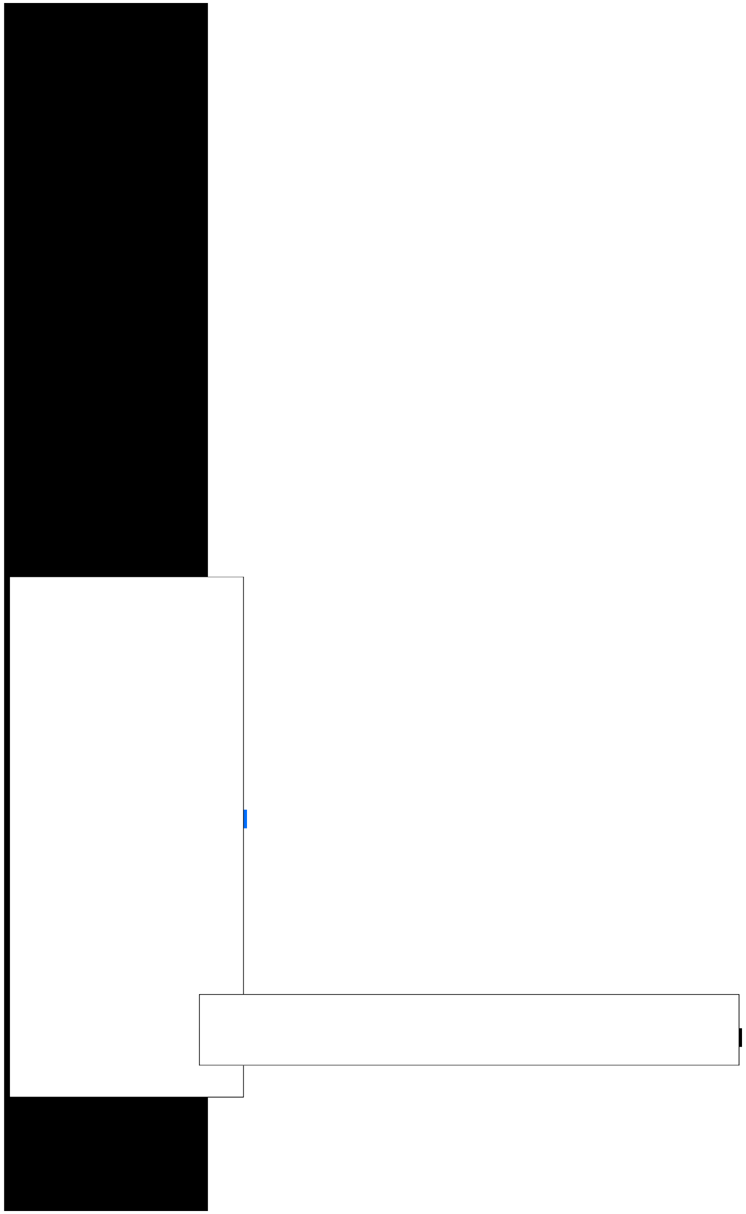
NSE Threshold = 0.59



How valid are the stream flow simulations with AET data?

- The best simulation with NSE as objective function
- 3 neighbouring catchments
- Catchment similarity analysis

Catchment Proximity



Catchment Physiographic Characteristics

Description of variables	Ogun	Queme_Bonou	Queme_Save	Mono
Watershed area (Km^2)	20,292	48,784	23,497	20,289
Elevation (m) **min** **max**	23 624	-5 628	95 628	53 887
Geology	Precambrian Basement	Precambrian Basement	Precambrian Basement	Precambrian Basement
Dominant soil type (%)	Ferric Luvisols (86.9)	Ferric Luvisols (69.9)	Ferric Luvisols (81)	Ferric Luvisols (64.7)
Dominant land use (%)	Broadleaved deciduous (33.6)	Broadleaved deciduous (50.2)	Broadleaved deciduous (60.3)	Broadleaved deciduous (40.6)
Slope (degrees) **min** **max**	0 66.5	0 67.4	0 66.6	0 61.0

Catchment Hydro-climatic Characteristics

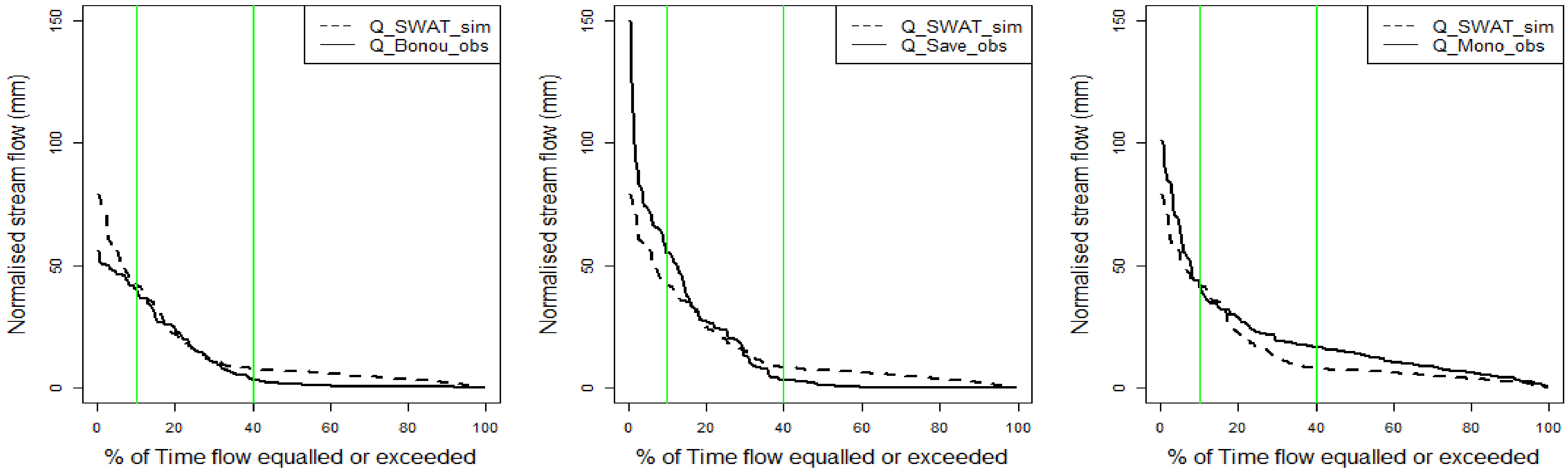
Description of variables	Ogun	Queme_Bonou	Queme_Save	Mono
Mean annual rainfall (mm/yr)	1205	1216	1216	1332
<u>Rainfall Pattern</u> **Upstream** **Downstream**	 Bi-modal Bi-modal	 Uni-modal Bi-modal	 Uni-modal Bi-modal	 Bi-modal
Koppen climate classification	Tropical savannah (Tropical wet and dry)	Tropical savannah (Tropical wet and dry)	Tropical savannah (Tropical wet and dry)	Tropical savannah (Tropical wet and dry)
Mean annual Temperature (^{0}C)	27.1	27.8	27.8	26.6
Drainage Density (km/km^2)	8.2	14.3	5.3	8.7

Statistical Indices Describing Catchment Behaviour

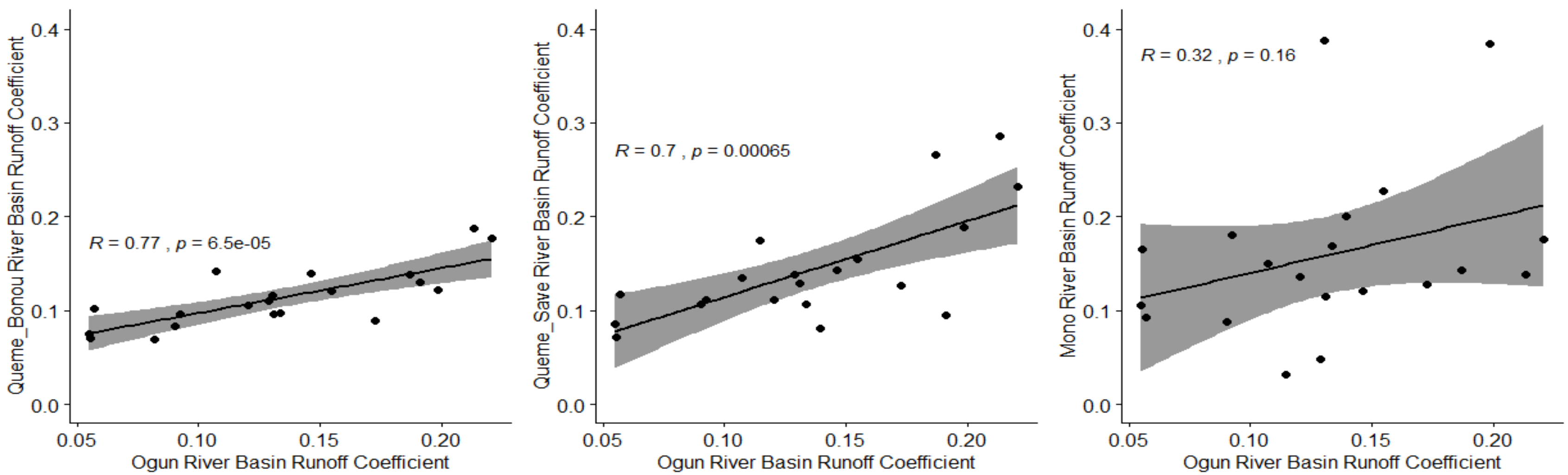
Index	Ogun	Queme_Bonou	Queme_Save	Mono
Mean runoff coefficient	0.13	0.11	0.14	0.15
Annual aridity Upstream Downstream	 0.70 0.73	 0.61 0.68	 0.61 0.68	 0.71 0.69
Coefficient of variation	0.37	0.28	0.41	0.56
High flow segment volume of FDC (ex.p <0.1)	78.2	53.8	137.5	100
low flow segment volume of FDC(ex.p <0.4-1)	11.9	9	11.7	15.9

Plot of Statistical Indices Describing Catchment Behaviour (1)

i. Flow duration curve pattern

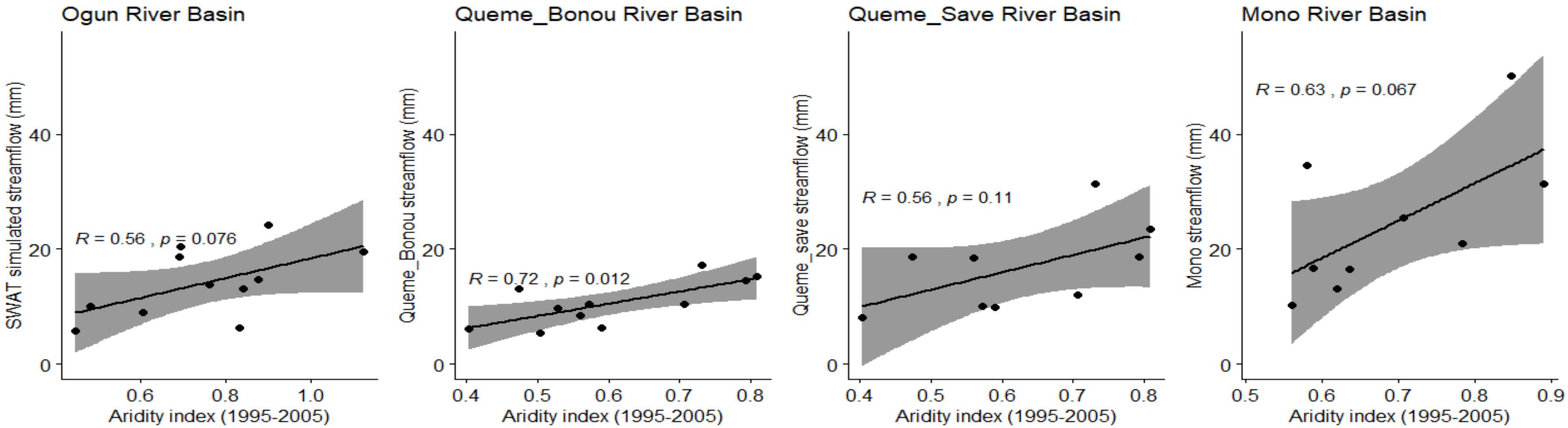


ii. Runoff coefficients correlation

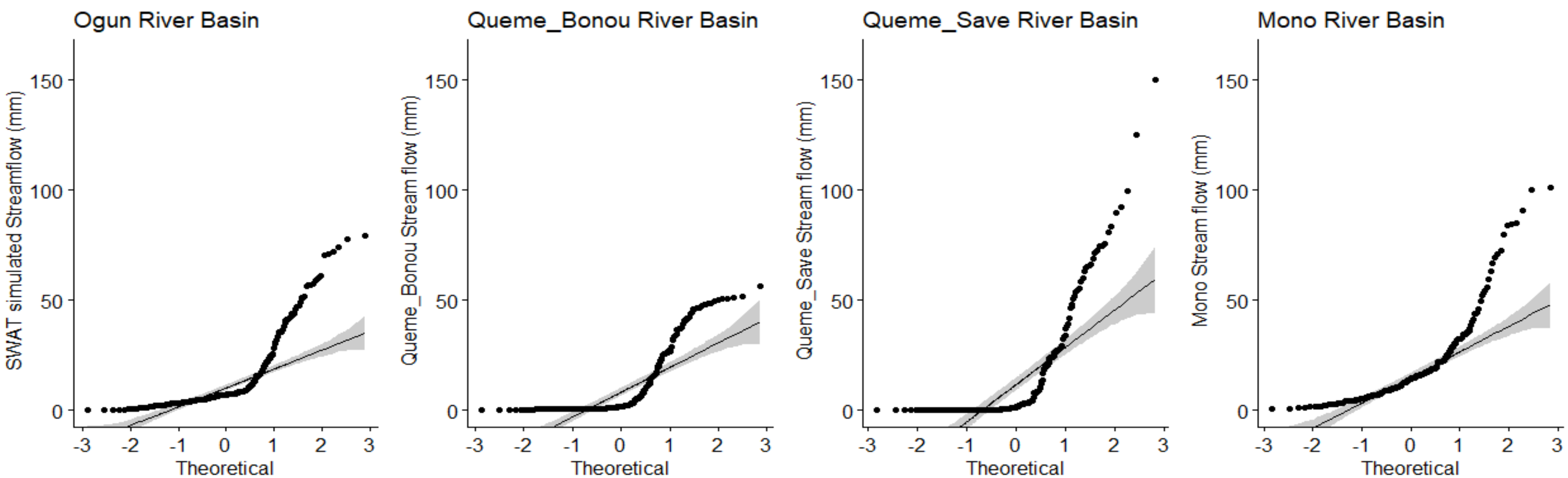


Plot of Statistical Indices Describing Catchment Behaviour (2)

iii. Aridity index and stream flow correlation

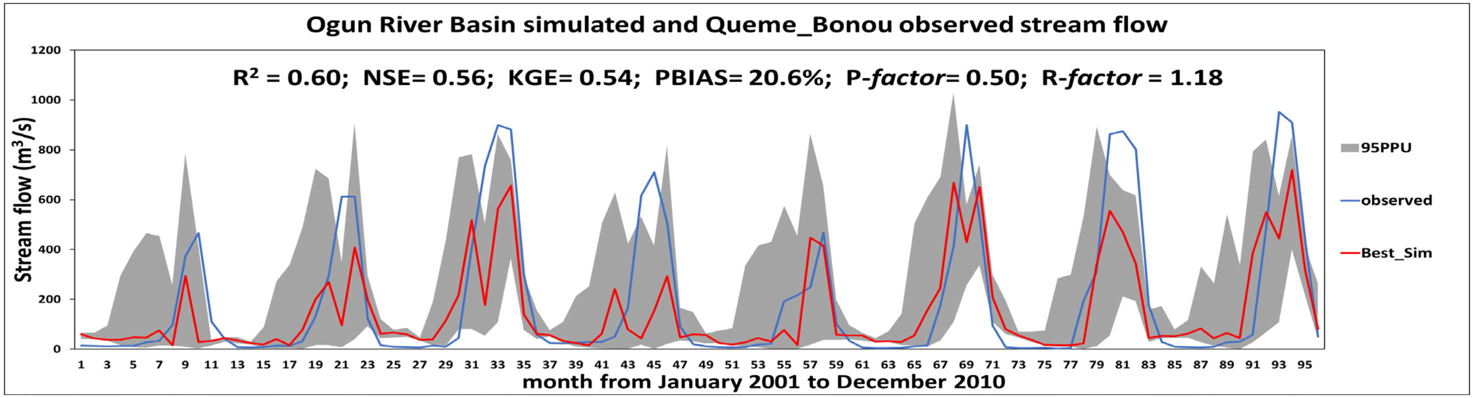


iv. Streamflow Q-Q plot

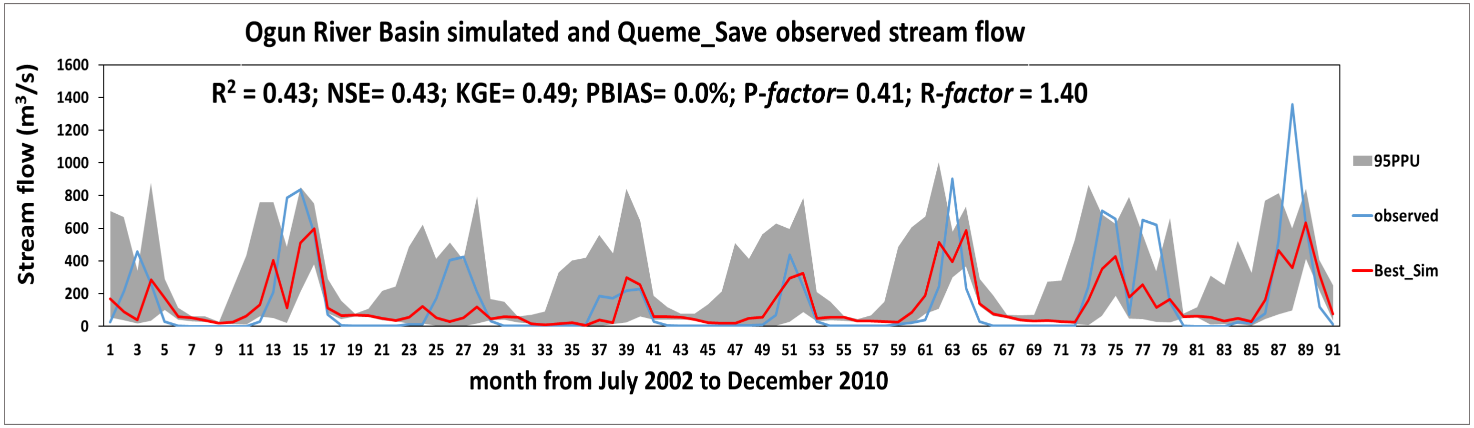


Validation of Ogun Simulated Streamflow

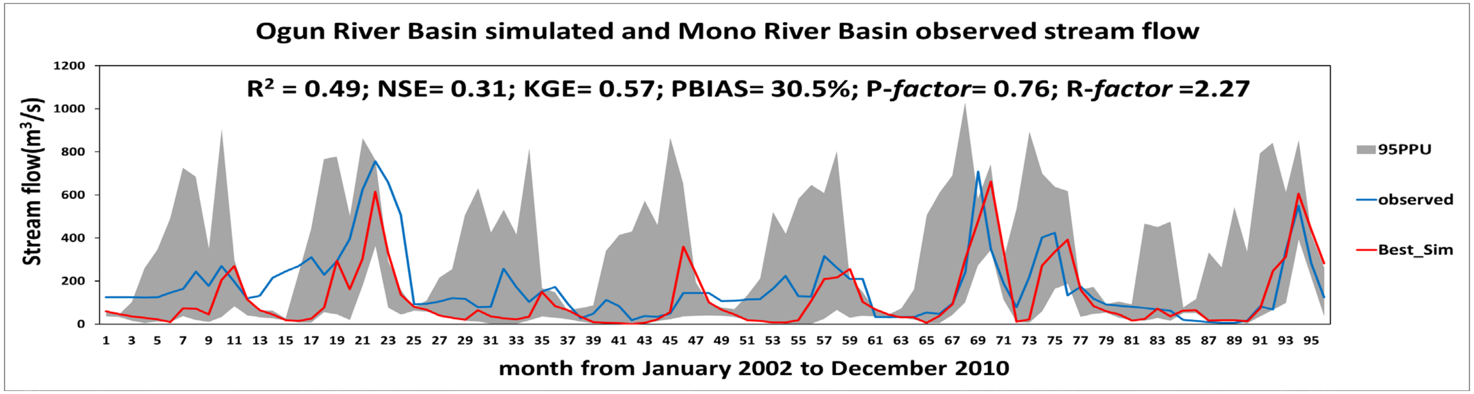
Queme_Bonou



Queme_Save



Mono



Conclusions

- Our results showed that global AET products can be used for calibrating the SWAT model for ungauged basins.

- Specifically, when the SWAT model was used with the Hargreaves PET equation in simulating AET and was calibrated using the GLEAM_v3.0a AET product the highest model performance was obtained.

- Using neighbouring catchments provided helpful indicators to independently validate the SWAT simulated streamflow.

- **We recommend the use of all three available PET equations in SWAT to estimate AET whenever the model calibration is carried out with any satellite based AET products**


Thank you!
Any Questions?
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3 diff PET equations are applied to SWAT

- Hargreaves (SWAT-HG):

$$\lambda E_o = 0.0023 \cdot H_0 \cdot (T_{mx} - T_{mn})^{0.5} \cdot (\overline{T}_{av} + 17.8)$$

where λ is the latent heat of vaporization (MJ kg^{-1}), E_o is the potential evapotranspiration (mm d^{-1}), H_0 is the extraterrestrial radiation (MJ m^{-2} d^{-1}), T_{mx} is the maximum air temperature for a given day (°C), T_{mn} is the minimum air temperature for a given day (°C), and $\overline{T}_{av}$ is the mean air temperature for a given day (°C).

- Priestyl-Taylor (SWAT-PT):

$$\lambda E_o = \alpha_{pet} \cdot \frac{\Delta}{\Delta + \gamma} \cdot (H_{net} - G)$$

where λ is the latent heat of vaporization (MJ kg^{-1}), E_o is the potential evapotranspiration (mm d^{-1}), α_{pet} is a coefficient, Δ is the slope of the saturation vapor pressure-temperature curve, *de/dT* (kPa °C^{-1}), γ is the psychrometric constant (kPa °C^{-1}), H_{net} is the net radiation (MJ m^{-2} d^{-1}), and G is the heat flux density to the ground (MJ m^{-2} d^{-1}).

- Penman-Monteith (SWAT-PM):

$$\lambda E = \frac{\Delta \cdot (H_{net} - G) + \rho_{air} \cdot c_p \cdot [e_z^o - e_z]/r_a}{\Delta + \gamma \cdot (1 + r_c/r_a)}$$

where λE is the latent heat flux density (MJ m^{-2} d^{-1}), E is the depth rate evaporation (mm d^{-1}), Δ is the slope of the saturation vapor pressure-temperature curve, *de/dT* (kPa °C^{-1}), H_{net} is the net radiation (MJ m^{-2} d^{-1}), G is the heat flux density to the ground (MJ m^{-2} d^{-1}), ρ_{air} is the air density (kg m^{-3}), c_p is the specific heat at constant pressure (MJ kg^{-1} °C^{-1}), e_z^o is the saturation vapor pressure of air at height z (kPa), e_z is the water vapor pressure of air at height z (kPa), γ is the psychrometric constant (kPa °C^{-1}), r_c is the plant canopy resistance (s m^{-1}), and r_a is the diffusion resistance of the air layer (aerodynamic resistance) (s m^{-1}).

Uncalibrated SWAT (Default)Results

Model Run	Statistics	Uncalibrated
RG_AET_HG	KGE NSE	0.51 -0.38
RG_AET_PT	KGE NSE	0.55 -0.28
G_AET_PM	KGE NSE	0.46 -0.36
RM_AET_HG	KGE NSE	0.42 -2.8
RM_AET_PT	KGE NSE	0.43 -2.6
RM_AET_PM	KGE NSE	0.35 -2.48

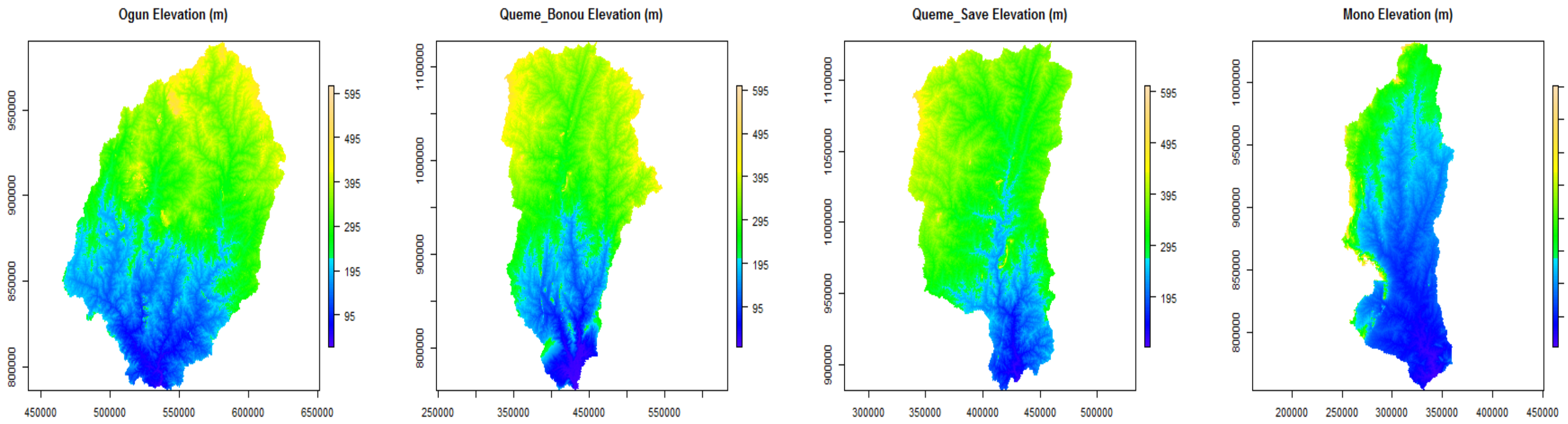
Catchment similarity analysis

Landuse spatial distribution

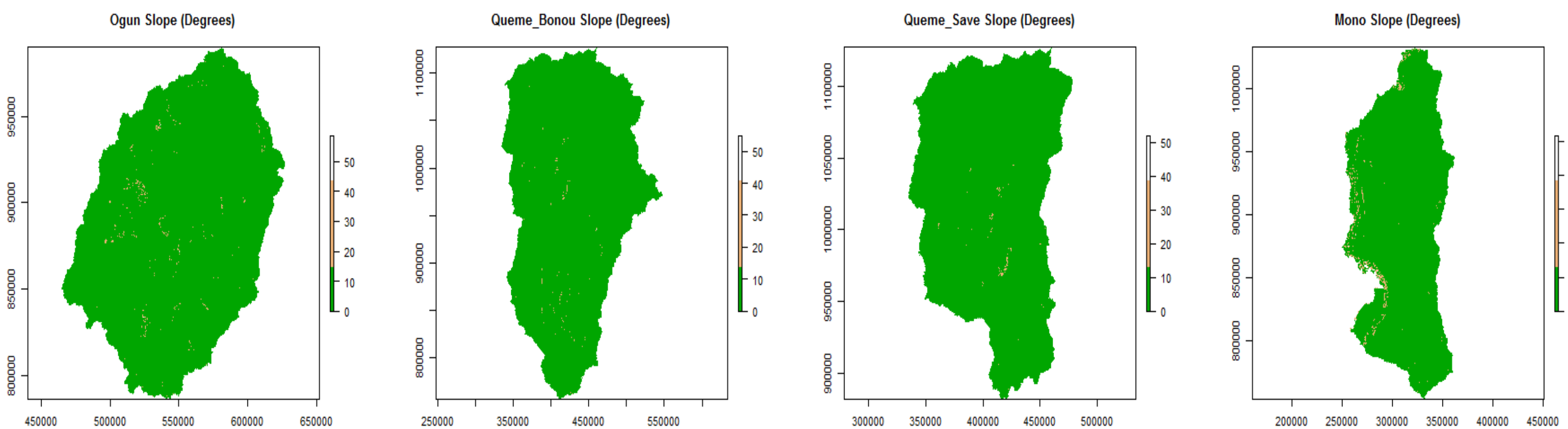
Soil spatial distribution

Catchment similarity analysis

Elevation spatial distribution

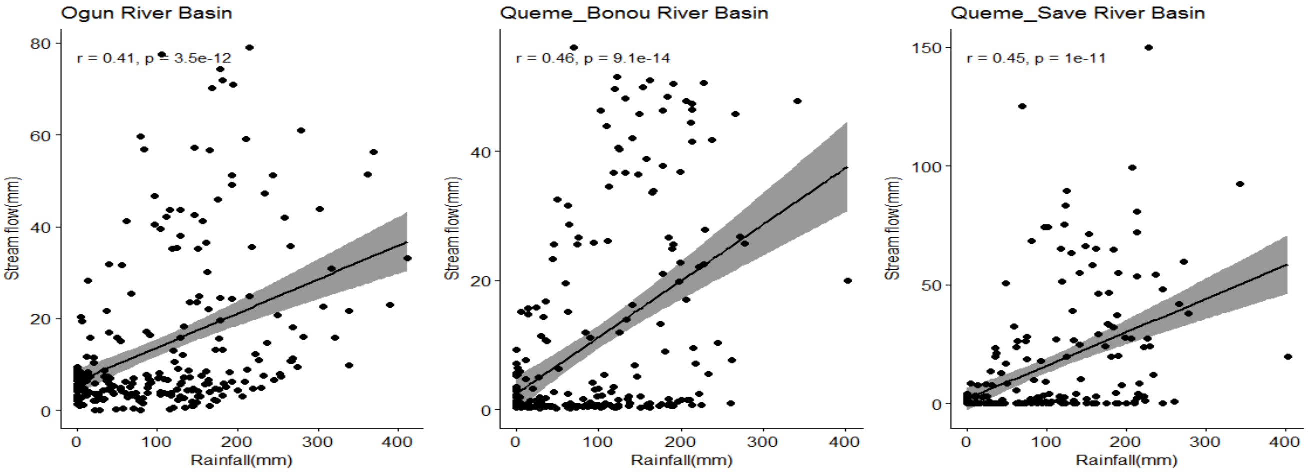


Slope spatial distribution

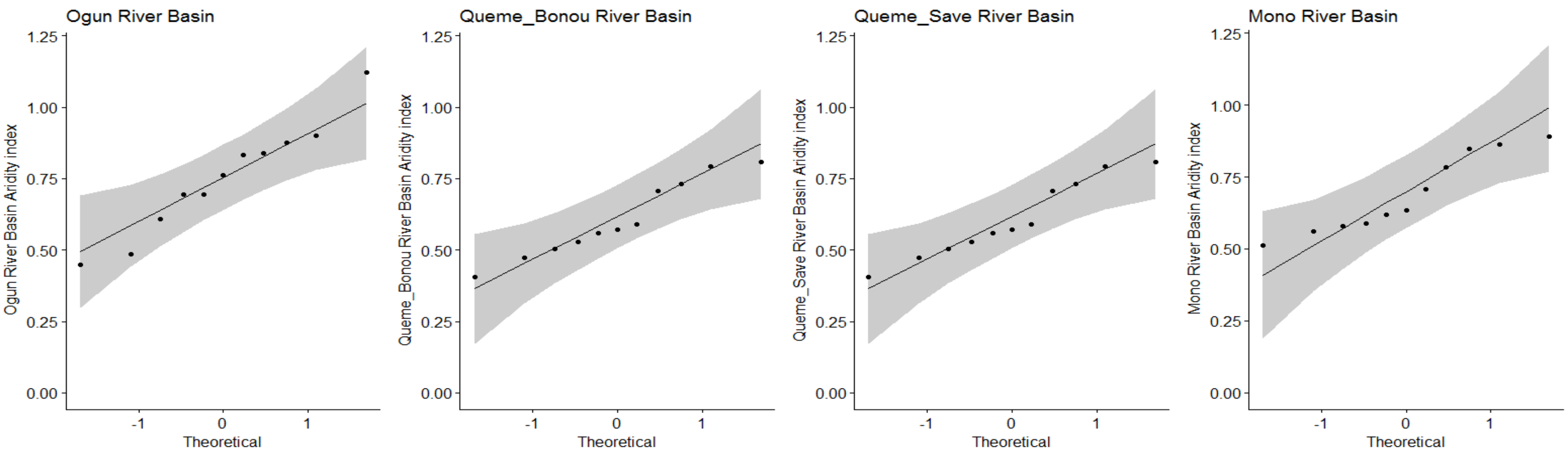


Catchment similarity analysis

Rainfall-Runoff relationship

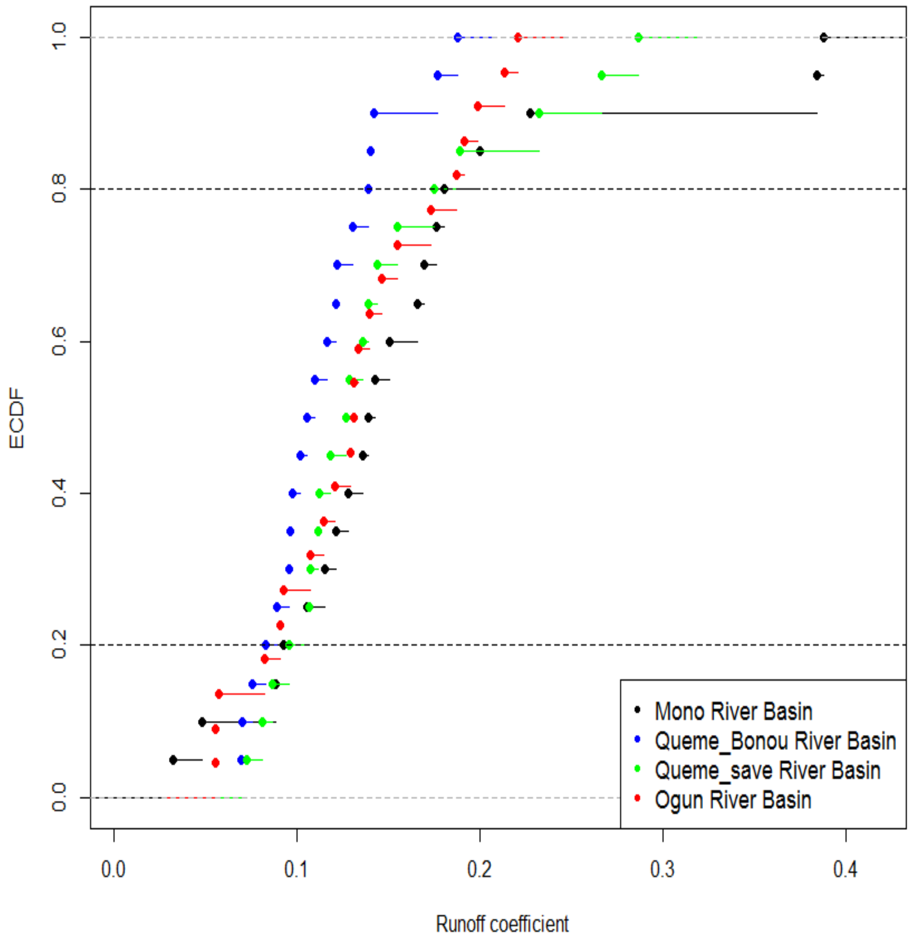


Aridity index Q-Q plot

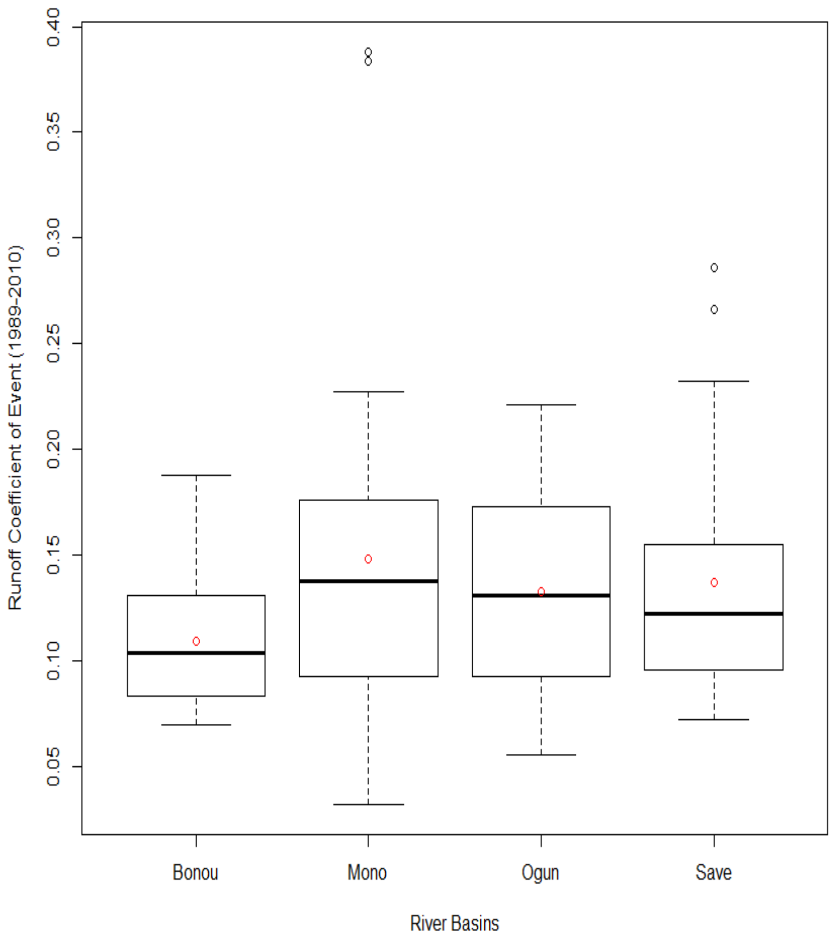


Catchment similarity analysis

Runoff coefficient ECDF



summary statistics of basins runoff coefficient of events



Ongoing/future research

On-going work

- Using GUESS framework for nutrient calibration in the data sparse catchment

Future work

- To quantify the impact of agricultural landuse change on the water quality of Ogun River
- To Assess the impact of climate change on water quality and quantity of the watershed
- To develop best management practices that will be formulated into policy

Recommendations

1

Testing the three available PET equations in SWAT to estimate AET whenever the model calibration is carried out with any satellite based AET products

2

Independent validation of hydrological model with a ground truth observation data whenever models are calibrated with solely satellite based AET