Application of SWAT+ for hydrological Modeling of the Kobo-Golina River in the Data-Scarce Upper Danakil Basin, Ethiopia

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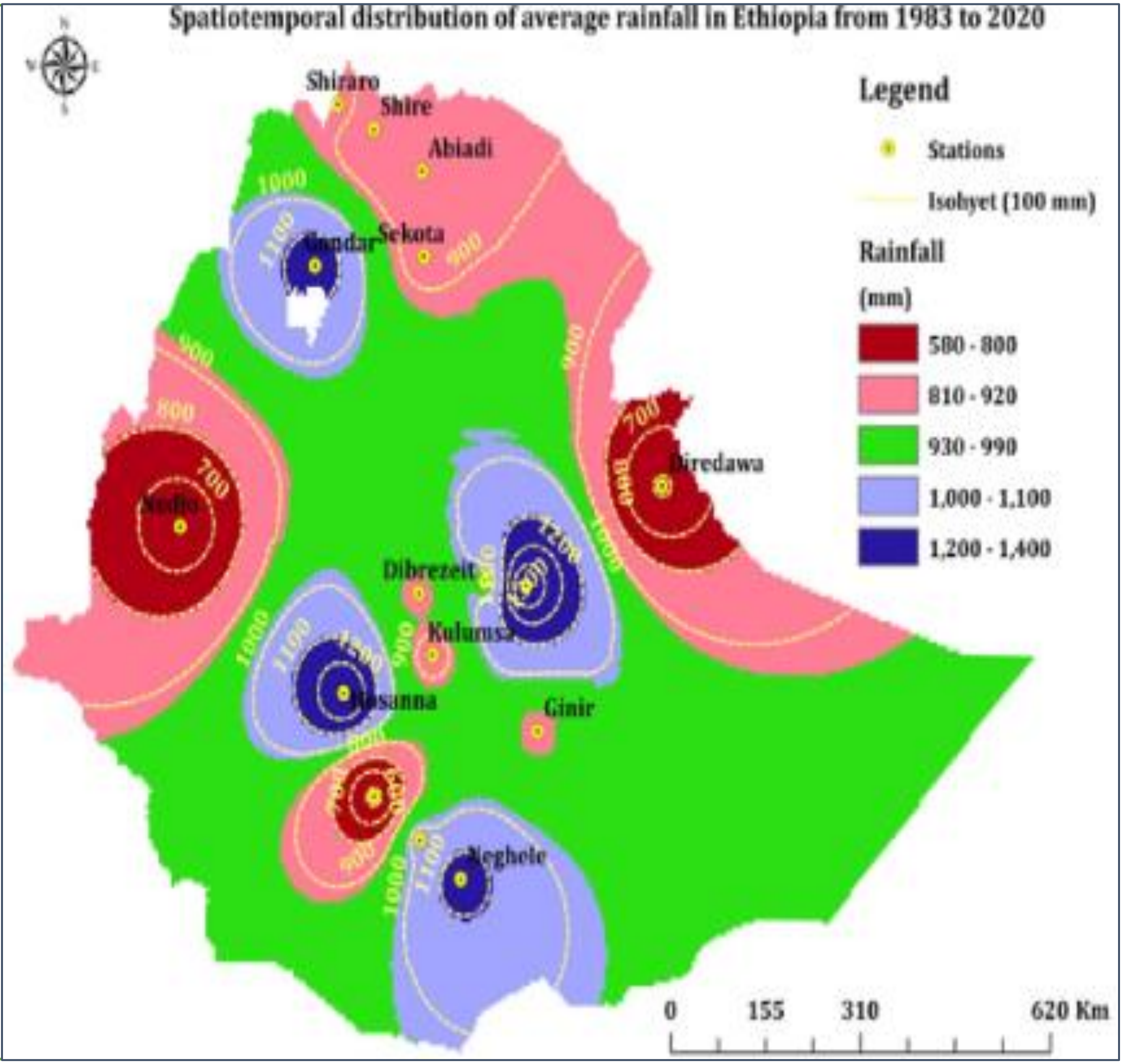
Introduction

- In Ethiopia, **spatiotemporal** variability of rainfall with **unwise use** of the available potential has caused **water scarcity** *[Aftab, O et al 2018 & Adane, Z et al 2021].*
- Nearly **27 million (23%)** of Ethiopia's population lives in areas of **high water stress** *[Adane, Z et al 2021].*
- nearly all of Ethiopia's basins are at risk of extreme water stress by 2030 *(World Bank 2018)*
- Irrigation areas all over the country are also **under water stress.**



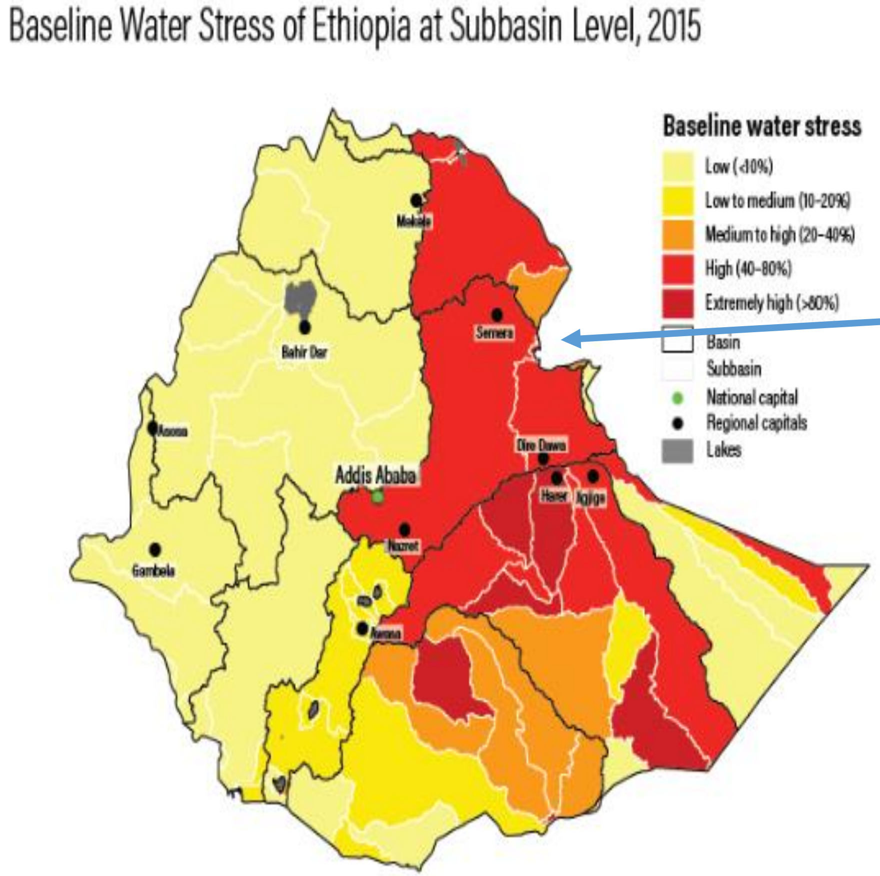


Fig 1. Falkenmark Index, for Africa (*Jemmali, H. 2018*)

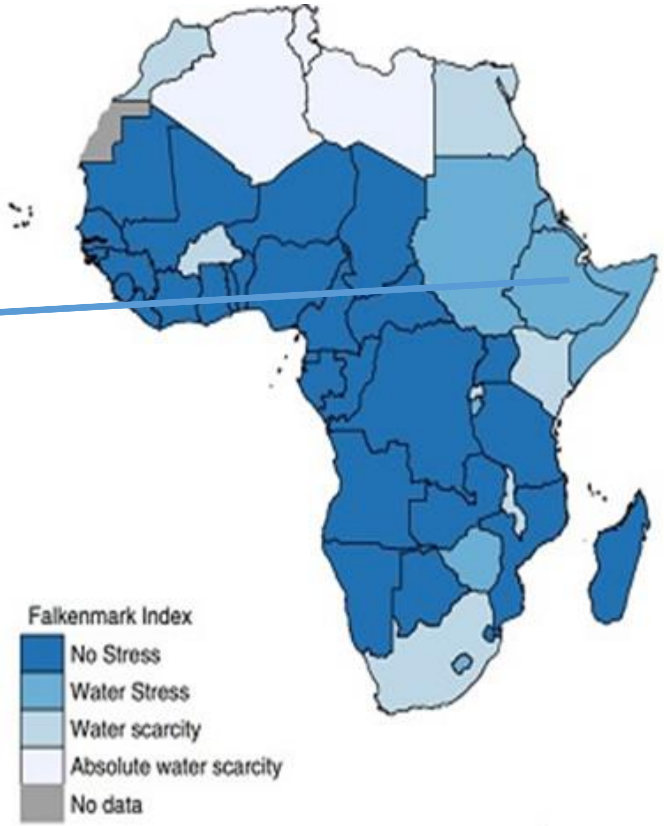


Table 1. Water barrier differentiation proposed by Falkenmark (1989)

Index (m^3 per capita)	Category/Condition
>1,700	No Stress
1,000-1,700	Stress
500-1,000	Scarcity
<500	Absolute Scarcity

Source: World Resources Institute (WRI)

Note: Baseline water stress represents total annual water withdrawals relative to available water resources

Water stress is a big issue then..

Materials and Methods

Location of the study area

- located in the **Northeast part of the Amhara** region (Wollo) in Ethiopia
- Extends from **11°55′33.6″ to 12°14′20.4″** N latitude and **39°22′30″ to 39°49′44.4″** E longitude.

❖ **1040 km2** at an outlet of the Golina River

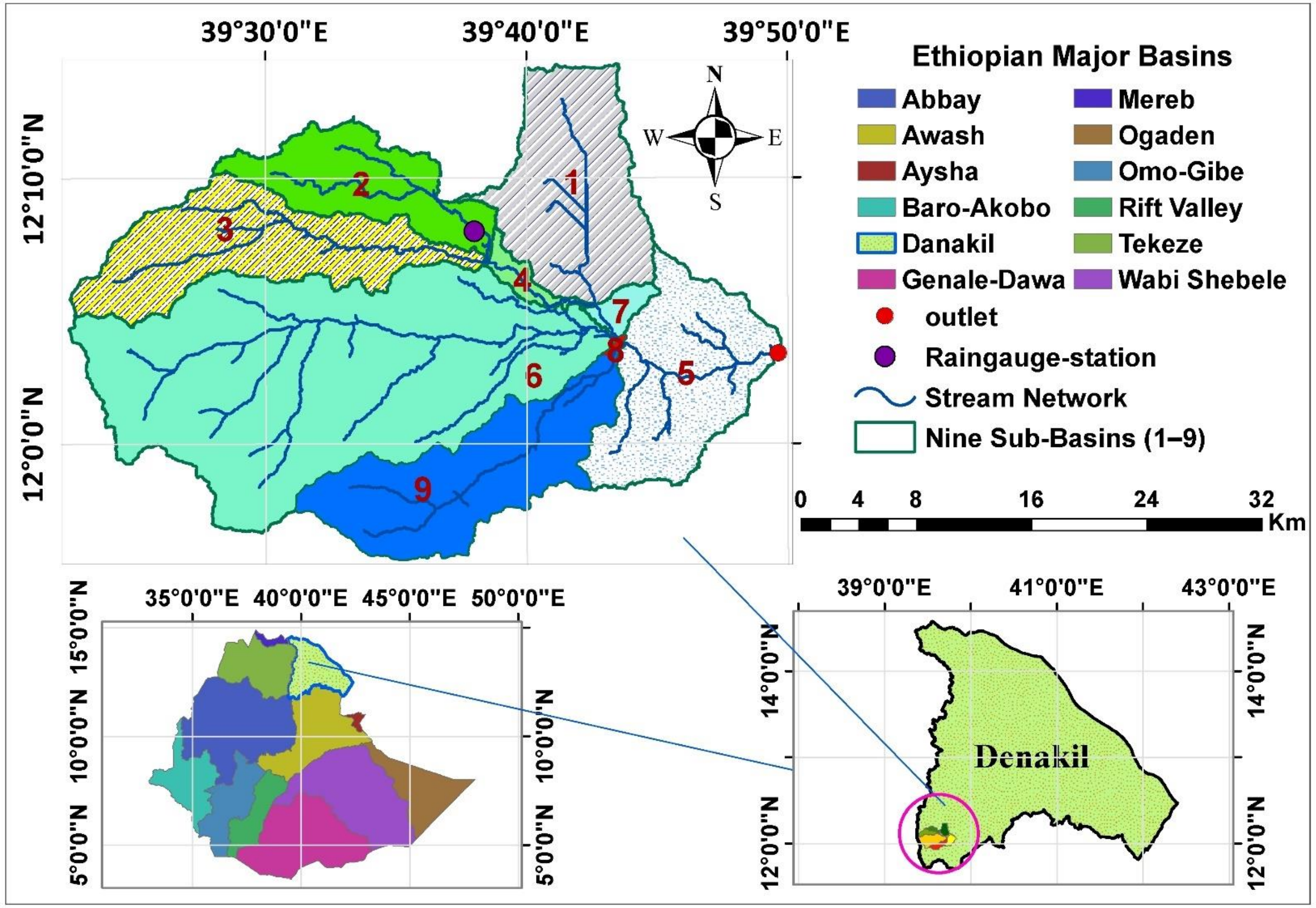


Fig 2. Location of study area

❖ Elevation **varies from 1117 to 3972** m and with a mean elevation of 1971 m.

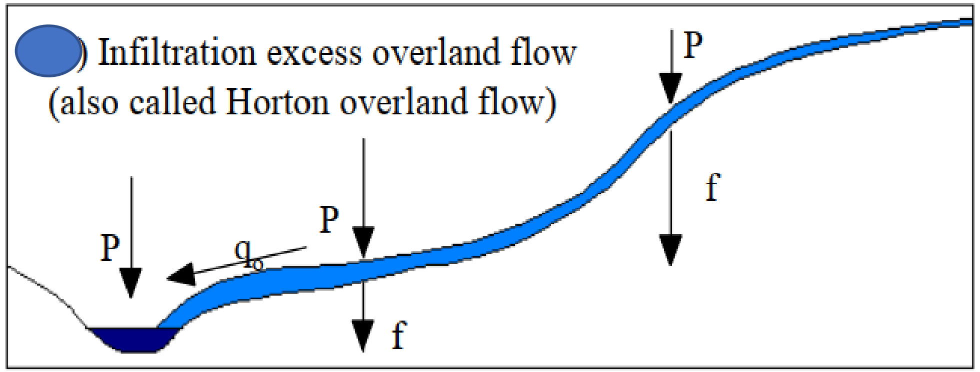
❖ Mean annual rainfall of **727 mm (2003–2005)** and has **a bi-modal** type of rainfall.

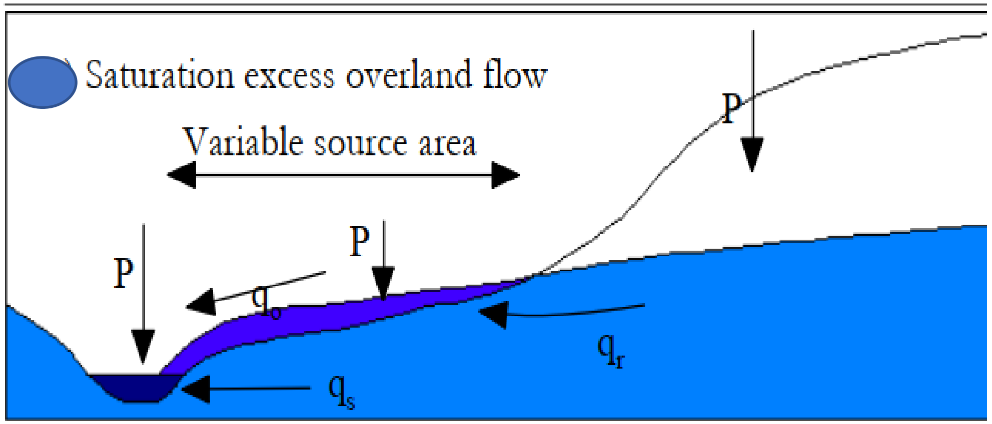
Introduction……………………………………………………………..…..Cont'd

- **Kobo-Golina basin**,
  - is one of the drought-prone areas in the country,
  - studies showed that there exists high groundwater potential,
    - ❑due to **erratic rainfall =>** Drought Compensation=> **Irrigation**
    - ❑Both surface and **groundwater irrigation** has been practiced in the basin since 1999 *[Adane, A et al.2015, Tadesse, N et al.2015, Kidane, H. Et al 2022].*
- Though irrigation is **under development,**
  - ❑**poor water management** *[Adane, A et al.2015, Tadesse, N et al.2015 and Abera, K et al.2020 16]* is a big problem.
- **lack of sufficient and updated hydrological information** is *aggravating the challenge.*
- *There are few hydrological studies in the area and these studies need an* update based on **recent technologies and hydrological models like SWAT.**
  - ✓**As a result, the well-known and widely applicable SWAT model is employed to study the hydrology of the basin**

Introduction……………………………………………………………….…..Cont'd.

- **Runoff generation mechanisms:**
  - infiltration-excess (i.e., runoff is generated when the **rainfall intensity becomes larger than the infiltration rate** of water into the soil).
  - saturation-excess (i.e., runoff is generated when the soil becomes saturated) and **infiltration rate exceeds rainfall intensity**
- Few previous studies conducted in the humid and semi-humid tropical highlands of Ethiopia showed a **saturation excess runoff process** *[Tegenu A. et al, 2011, Seifu A. et al 2016, Steenhuis, T.S. et al. 2019].*
- A limitation of the SWAT model is that **locations of saturation excess overland flow** in hilly and mountainous regions with an impermeable layer at shallow depth cannot be **simulated realistically**





following Beven, 2000

Introduction ………………………………………………………Cont'd

- **SWAT-hillslope (SWAT-HS)** and SWAT-with-impervious-layers **(SWAT-wil)** are modified versions of the Soil and Water Assessment Tool (SWAT) for the simulating variable saturated area (VSA) hydrology in mountainous regions where **infiltration rate exceeds rainfall intensity (saturation excess condition).**
- For such conditions, **SWAT+** was recently developed to separate upland and floodplain regions to better simulate the **saturation excess runoff** *[Bieger, K et al 2017].*
- By allowing **the floodplain soils to become saturated**, which **results in a much higher curve number**, the integration of **LSUs in SWAT+** is an important step toward accounting not only for **infiltration excess** but also for **saturation excess overland flow**. (*Bieger, K et al 2017].*

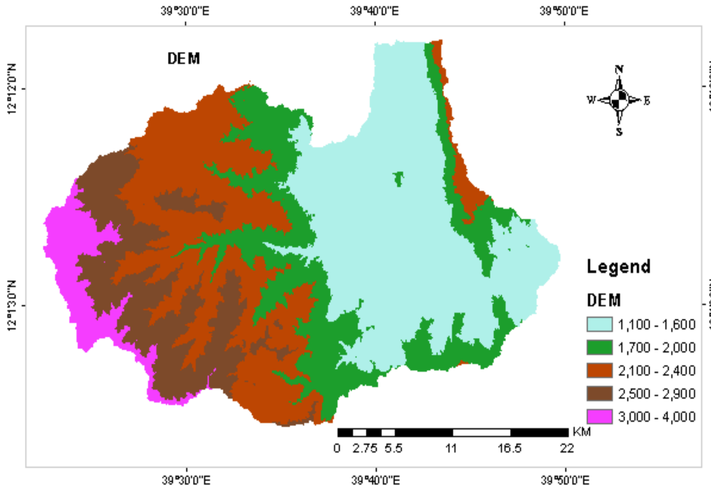
Introduction ……………………………………………Cont'd

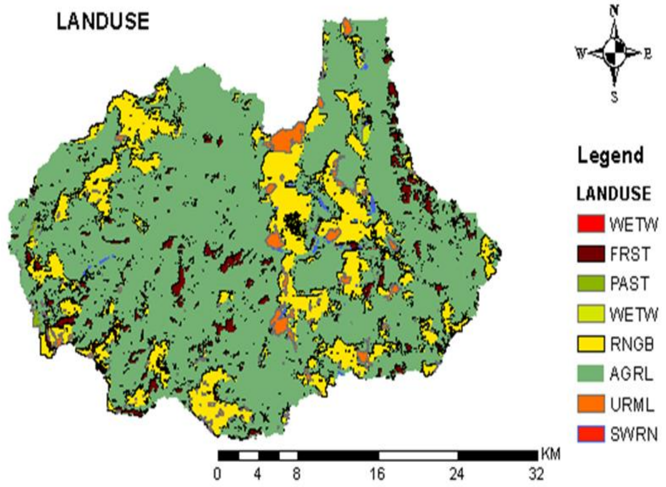
- At this time, **open-source remote sensing technologies** are offering alternative input data and simplifying the application of the SWAT model *[Bennour, A et al 2021 & Wedajo, G.K. et al 2021].*
- **The objective of this research**
  - ✓To model the hydrology of the Kobo-Golina river basin by **SWAT+** using **open-source reanalysis and remote sensing data** both as input and calibration data.
    - ✓Application of SWAT+ to characterize the catchment,
    - ✓To see the impact of multivariable calibration on the performance of the model based on stream flow and MODIS AET.

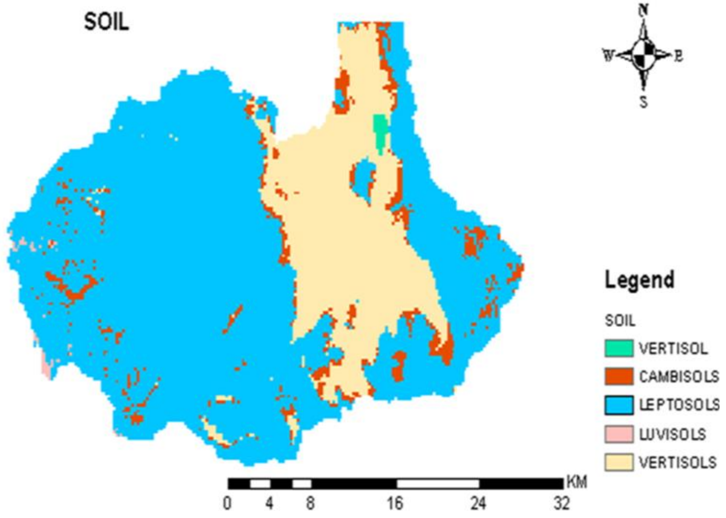
Datasets for SWAT model

- **The area lacks sufficient observed climate and hydrological data,**
- **Climate and hydrological data**
  - Precipitation data from three meteorological stations for **validation of CHIRPS** precipitation data,
  - **CFSR** climate data (Temperature, humidity ,sunshine hour and wind)
  - Measured river flow data for validation of GLOFAS reanalysis river flow data
- **Model Input data**
  - Daily **CHIRPS precipitation** and
  - Daily max. and min. temperature, daily relative humidity, solar radiation, and wind speed found within SWAT+ CSFR_World weather generator was used to simulate the model
- **Model calibration and Validation data**
  - **Global Flood Awareness System GLOFAS** (0.1°x 0.1°) monthly reanalysis river flow,
  - Monthly MODIS AET

Spatial Data (DEM, SOIL & LANDUSE) for SWAT+ HRU definition AND LANDUSE)







10m resolutions ESRI Sentinel-2 **Land Use/Land cover** for SWAT+HRU definition

250m resolution **soil property map** (AFSIS,2015) for SWAT+HRU definition

DEM (30X30) for SWAT+HRU definition

Materials and Methods……..Cont'd

- **SWAT+ Editor 2.0.4** was utilized to set up the project, edit SWAT+ inputs, run the model, and check the QSWAT+ model.
  - Discretization of the model provided 9 subbasins and 696 HRUs.
  - HRU thresholds of 20% for land use, 10 % for soil type and 20 % for slope were applied in the SWAT+ set up, whereby areas below these thresholds were not considered in the simulations (No full HRU)

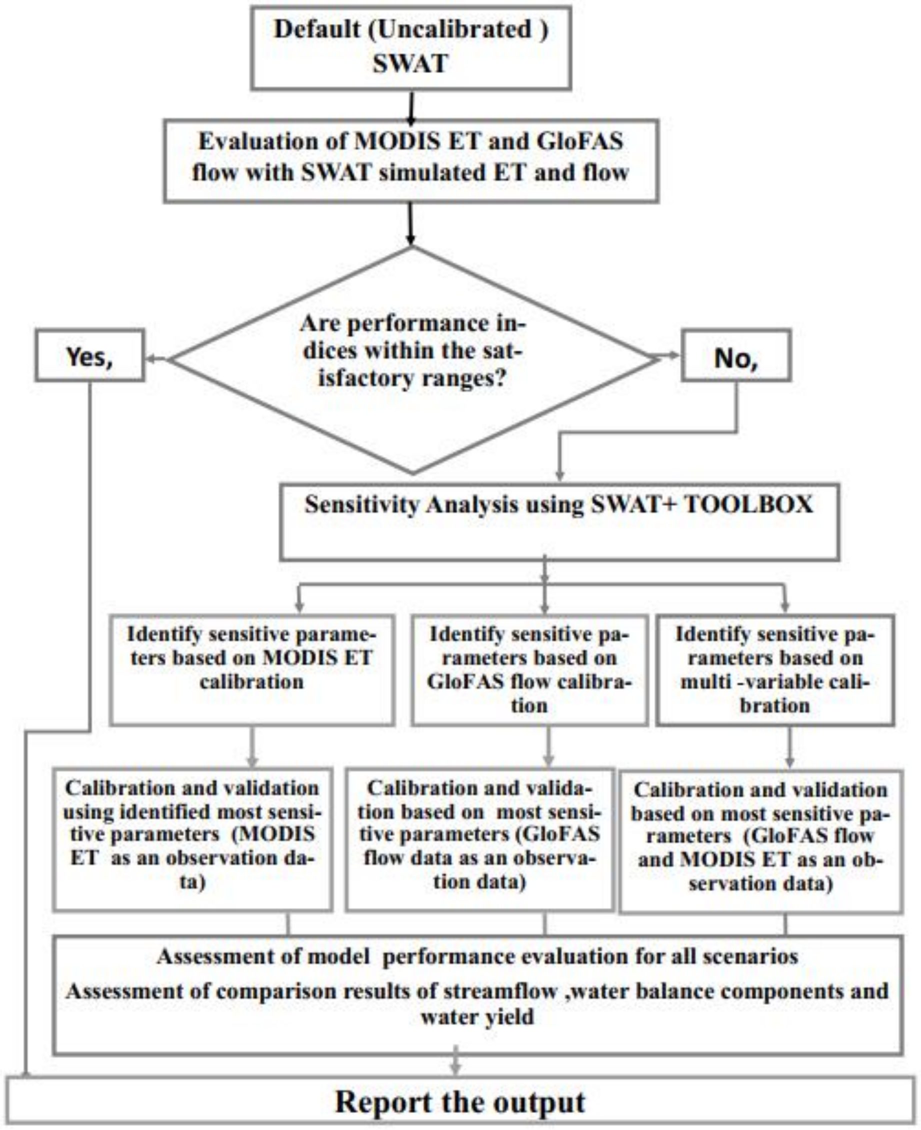


Fig 3. Flow chart for Methodology

Materials and Methods……..Cont'd

- Potential evapotranspiration=> **Penman-Monteith equation**
- surface runoff=>The **SCS Curve Number method**
- stream flow routing within the subbasin channel=>**Muskingum routing method** was used to

❖ **Finally, model simulations were performed at a daily time step from 1991 to 2021. The three-year warm-up period was considered to run the model**

Materials and Methods……..Cont'd

Sensitivity Analysis

- ❖ **Sensitivity analysis, calibration, and validation** of model parameters were carried out using **SWAT+ TOOLBOX Version 0.7.6**. **SWAT+ TOOLBOX** is an independent tool from SWAT+.

- The initial model parameters were selected referring to existing literature *[Saltelli, A et al 2008, Onyutha, C et al 2016 and Moriasi, D.N et al 2007]*.

- ❖ **13 parameters were selected & first-order sensitivity analysis** was done related to

  i) **MODIS AET** only and **GloFAS** flow only scenario **separately** and

  ii) both **MODIS** AET and GloFAS flow **concurrently** using the Variance-based sensitivity analysis (Sobol) method.

- **1300 seed was selected to run 36,400 samples** until the most sensitive parameters were attained.

- ❖ Parameters which **have sensitivity values of zero was supposed to be removed but decided to remain there as they are.**

- The reason why they go with the most sensitive parameter is that they will be very important **if they are further subjected to calibration in other models like MODFLOW and GWFLOW**

Model calibration and validation

- Following the sensitivity analysis, model calibration was done **using both GloFAS flow and MODIS AET** at the monthly time step.
- Two calibration strategies were investigated.
    - First, **single-variable calibration** was considered. In the single variable calibration scenario, parameters were calibrated based on GloFAS flow at the main outlet and MODIS AET at the entire basin separately.
    - Finally, SWAT model parameters were calibrated/validated in the **multi-variable calibration scenario** employing both MODIS AET and GloFAS flow concurrently.

Model performance Evaluation and verification

- ❖The **objective function** used during the calibration and validation in all scenarios was the **Nash-Sutcliffe efficiency (NSE).**
- ❖For assessing the performance of the model, we used the model performance rating given by **Moriasi et al.2007.**

Table 2. Morias NSE, RSR, and PBIAS values (Morias et al 2007)

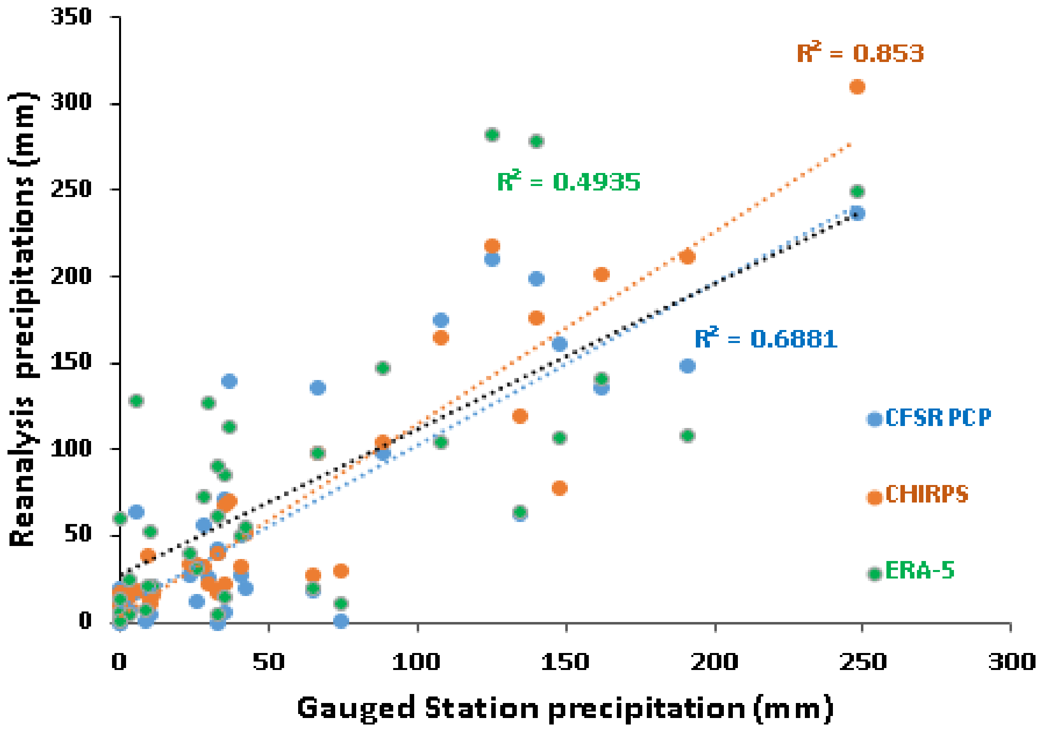
Performance rating	NSE	RSR	PBIAS %
Very good	$0.75 \leq NSE \leq 1.00$	$0.00 \leq RSR \leq 0.5$	$\lvert PBIAS \rvert < 10$
Good	$0.65 < NSE \leq 0.75$	$0.5 < RSR \leq 0.6$	$10 < \lvert PBIAS \rvert \leq 15$
Satisfactory	$0.5 < NSE \leq 0.65$	$0.6 < RSR \leq 0.7$	$15 < \lvert PBIAS \rvert \leq 25$
Unsatisfactory	$NSE < 0.5$	$RSR > 0.7$	$\lvert PBIAS \rvert > 25$

NSE, Nash-Sutcliffe efficiency; RSR, RMSE-observations standard derivation ratio; PBIAS, Percentage bias.

Result and discussion

Validation of Reanalysis of climate and hydrological data

Correlation of measured rainfall with CHIRPS and streamflow data with GloFAS streamflow



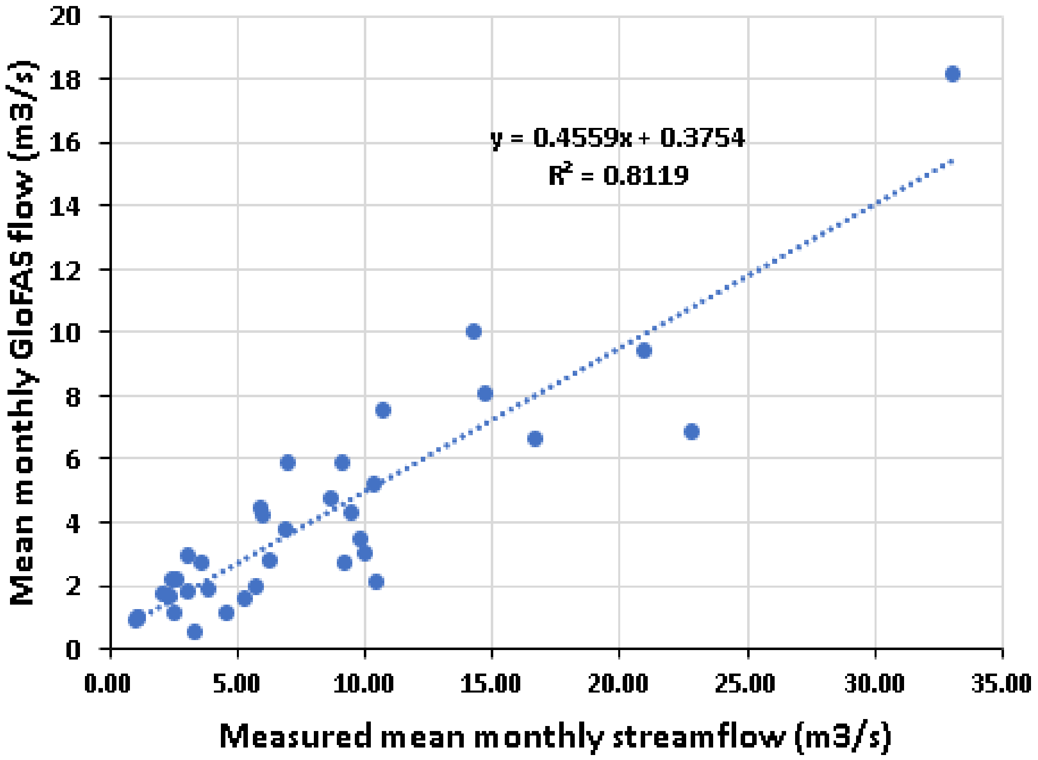


Figure 4. Scatter plot and correlation coefficient determination of A) rain gauge station and CHIRPS rainfall data B) measured streamflow and GloFAS flow data at the upper Golina weir site

SWAT model performance evaluation

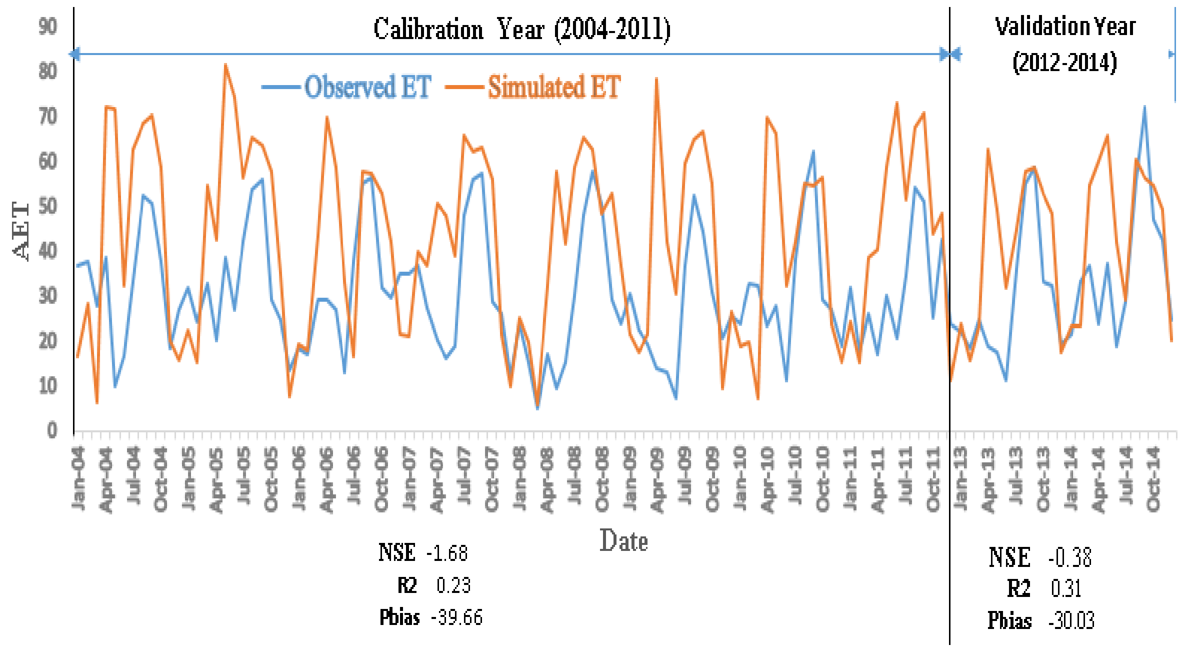
i) SWAT+ performance at default (uncalibrated) stage

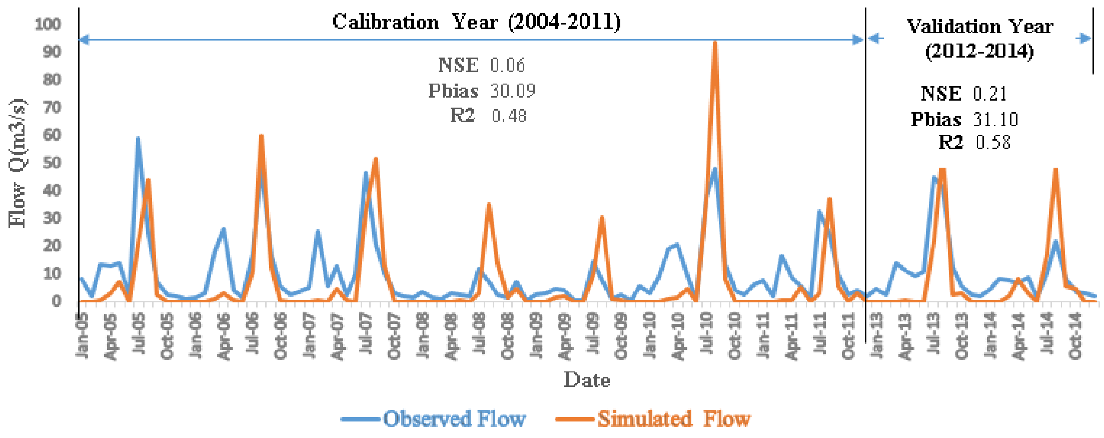
Model Scenario	Variable	Performance evaluation for the calibration period (2004-2011)	Performance evaluation for the Validation period (2012-2014)
Default	GloFAS river flow	NSE 0.06 R^2 0.48 PBias 30.09 RSR 0.96	NSE 0.21 R^2 0.59 PBias 31.10 RSR 0.88
	MODIS AET	NSE -1.68 R^2 0.23 PBias -39.66 RSR 1.63	NSE -0.38 R^2 0.31 PBias -30.03 RSR 1.17

Table 3. Model run output at default stage

- **The results of the default run support the need to improve the SWAT model's performance further.**
- **As a result, the SWAT model outputs were subjected to further calibration and validation**

Uncalibrated SWAT





Sensitivity analysis Result

Table 4. Sensitivity analysis of calibrated parameters with their optimal values and rank

SWAT parameter	Description	GloFAS flow-based calibration		MODIS AET- based calibration		GloFAS flow and MODIS ET Based (MV) calibration	
		1st-order sensitivity value	Rank	1st-order sensitivity value	Rank	1st-order sensitivity value	Rank
r_ cn2.hru	**SCS Curve Number**	**0.74102**	**1**	**0.10819**	3	**0.9615**	**1**
v_ esco.hru	Soil evaporation compensation factor	-0.002006	8	**0.03333**	5	**0.01367**	5
a_ canmx.hru	Maximum canopy storage	**0.000**	NS	**0.000**	NS	**0.000**	NS
r_bd.sol (mg/cm**3)	Moist bulk density	**0.00002**	6	**0.000**	NS	**0.000**	NS
r_ bd.sol (g/m**3)	Moist bulk density	**0.00279**	5	**0.00228**	7	-0.0084	6
v_ alpha.aqu	Base flow alpha factor	-0.00636	10	**0.000**	NS	-0.0175	7
a_ k.sol	Saturated hydraulic conductivity	-0.02341	9	**0.01093**	6	**0.0243**	4
v_ epco.hru	Plant uptake compensation factor	**0.06178**	3	**0.20932**	2	-0.03118	9
a_ awc.sol	**Available water capacity of the soil layer**	**0.14531**	2	**0.59164**	**1**	**0.1950**	**2**
v_ perco.hru	Percolation coefficient	**0.04321**	4	**0.04886**	4	**0.0561**	3
v_ revap_min.aqu	Threshold depth of water in the shallow aquifer for "revap" or percolation to the deep aquifer to occur	**0.000**	NS	**0.000**	NS	**0.000**	NS
r_cn3_swf.hru	Pothole evaporation coefficient	-0.0005	7	**0.00087**	8	-0.02426	8
v_ flo_min.aqu	Minimum aquifer storage to allow return flow	-0.13588	11	**0.00**	NS	-0.05953	10

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- The **common parameters** that were determined to be sensitive in all circumstances were
  - **runoff curve number (CN2.hru), available water capacity of the soil layer (awc.sol)** and **Percolation coefficient (perco.hru).**
- When considering **GloFAS flow alone** and **multi-variable simulation**,
  - **CN2 was the first highly sensitive parameter** to demonstrate substantial effects.,
- whereas **in the case of simulation of AET only**,
  - available water capacity of the soil layer (awc.sol) was the first **most sensitive** parameter.

Model calibration and validation……………………………..Cont'd

Table 5. Model calibration and validation efficiencies for all scenarios

Model Scenario	Variable	Performance evaluation for the calibration period (2004-2011)	Performance evaluation for the Validation period (2012-2014)
Calibration/validation based on GloFAS flow only	Comparison between raw GloFAS flow and simulated flow data	**NSE=** 0.67 **R^2** = 0.68 **PBias=** -6.607 **RSR=** 0.572	**NSE** 0.54 **R^2** 0.54 **PBias** -3.348 **RSR** 0.68
	Comparison between raw MODIS AET and simulated AET data	**NSE** = 0.51 **R^2** = 0.58 **PBias** = 1.18 **RSR** = 0.7	**NSE** 0.64 **R^2** 0.64 **PBias** 3.32 **RSR** 0.60
Calibration/validation based on MODIS AET only	Comparison between raw MODIS AET and simulated AET data	**NSE** = 0.64 **R^2** = 0.65 **PBias=** 1.68 **RSR** = 0.599	**NSE** 0.69 **R^2** 0.73 **PBias** 4.77 **RSR** 0.554
	Comparison between raw GloFAS flow and simulated flow data	**NSE** = 0.5 **R^2** = 0.5 **PBias=** 2.36 **RSR** = 0.74	**NSE** 0.4 **R^2** 0.5 **PBias** -16.23 **RSR** 0.752
Calibration/validation based on both GloFAS and MODIS AET	Comparison between raw GloFAS flow and simulated flow data	**NSE** = 0.67 **R^2** = 0.68 **PBias=** -9.675 **RSR** = 0.57	**NSE** 0.54 **R^2** 0.54 **PBias** -6.22 **RSR** 0.67
	Comparison between raw MODIS AET and simulated AET data	**NSE** = 0.56 **R^2** = 0.63 **PBias** = 3.857 **RSR** = 0.66	**NSE** 0.68 **R^2** 0.70 **PBias** 5.347 **RSR** 0.56

Single and multivariable calibration scenarios

- The **single calibration variable**, either streamflow or evapotranspiration led to high performance in terms of the calibration/validation variable but impaired performance in the other variable,
- whereas, the **multi-variable calibration scenario** reasonably attained the minimum satisfactory performance limit for both variables when compared with the single-variable calibration scenario.
  - Similar studies conducted in Morocco [*López, P.L et al 2017], in the Myanmar river basin [Sirisena, T.A.J.G et al 2020], in the Karkheh river basin of Iran [Rientjes, T.H.M et al 2013]*, and over the continental USA [Ferguson, C.R et al 2010] agreed with our findings.

Qualitative evaluation of the model

- Relying solely on performance indicator values **(NSE, R^2, RSR, PBias)** will not ensure that the model performs well.
- **Qualitative evaluation** was also assessed through **a graphical comparison** of model-simulated variables with that of satellite-based AET and GloFAS river flow within the calibration and validation period.

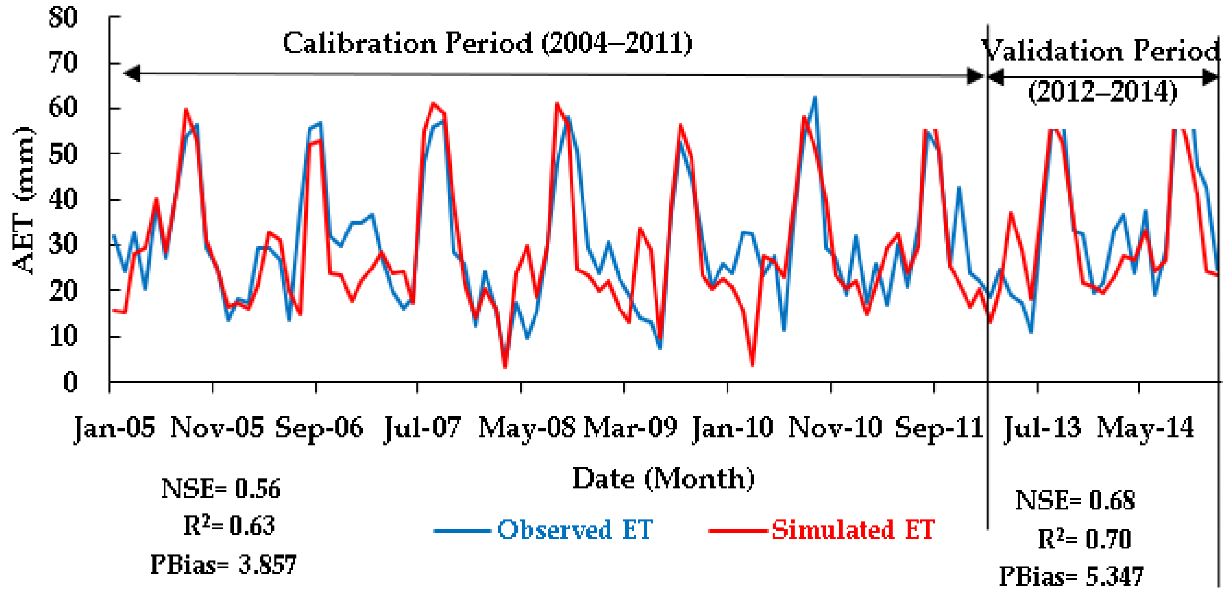


Fig 5. MODIS AET and simulated AET based on Calibration of multiple variables

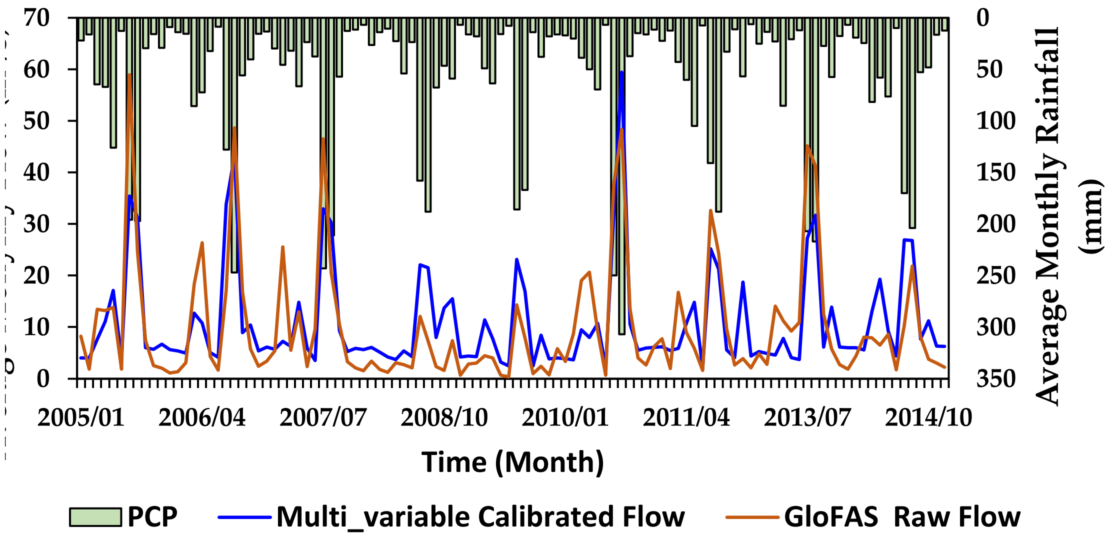


Fig 6. GloFAS flow and simulated hydrographs based on Calibration of multiple variables

Water Balance Assessment

❖ Since the multivariable calibration scenario gives **reasonable performance for both variables,** the parameters are employed to run the model for both the calibration and validation period (2001–2014) at a time to **estimate the water balance terms and characterize catchment hydrology.**

❖ **SWAT+ with landscape unit (SWAT + LSU)** *assumed surface flow and lateral flow* ***run-on*** *as an additional source of water in the catchment*. **Therefore the catchment receives 771.63 mm of water annually.**

P+ SQ runon+ LATQ runon= SQ+LATQ+PERC+AET ???????

- The annual average precipitation (w/o considering run-on) is **729 mm**. The percentage of precipitation falling in the **dry (October to January), short rainy season (February to June),** and the **major rainy season (July, August, and September)** are *11.9%, 27.64%, and 60.47%,* respectively.
- Similar studies in the Kobo area confirmed that the majority of the rainfall (50%) of the total annual rainfall is derived from the **long rain seasons (July, August, and September)** in the Kobo area [Eshetu, Z et al.2020]

Water Balance……………………………………………………………………Cont'd

- Table 7. **Mean annual Water Balance components** of Kobo-Golina catchment (2002–2014)

Year	Annual input water (PCP+Run On)	SURQ	LATQ	Perc.	Water Yield	AET	Run_On	Sum of water balance components
2002	685.75	174	8.95	147	329.95	359	32.75	688.95
2003	854.29	314	11.7	164	489.7	365	55.29	854.7
2004	682.85	199	9.36	148	356.36	329	36.85	685.36
2005	833.7	258	12	171	441	385	47.7	826
2006	779.39	282	11.2	160	453.2	324	50.39	777.2
2007	824.6	239	14.3	182	435.3	391	46.6	826.3
2008	719.25	222	10.6	154	386.6	328	41.25	714.6
2009	641.87	165	9.22	143	317.22	334	31.87	651.22
2010	**902.1**	**332**	**15.6**	**190**	**537.6**	**350**	**62.1**	**887.6**
2011	728.82	224	10.1	162	396.1	353	40.82	749.1
2012	834.4	272	14.1	178	464.1	363	51.4	827.1
2013	753.5	194	13.2	171	378.2	367	39.5	745.2
2014	821.1	238	13.9	182	433.9	384	46.1	817.9
Annual average	**729.1/773.9**	**239**	**11.86**	**165.5**	**416.8**	**356.3**	**44.8**	**773.17**

Water Balance,……………………………………………………….....Cont'd

❖**The annual water balance components with a** **higher value are observed during the highest rainy year (2010)**, whereas, in dry years in which the rainfall is below average (2002, 2004, 2008, 2009, 2011, and 2013), the contribution of water balance components to the water budget **decreased significantly.**

- Previous studies in the upper Blue Nile of Ethiopia [*Abebe, S.A. et al 2022, Leta, M.K et al 2021]* have shown the same trend in that the **contribution of water balance components declined with the fall of rainfall**.

❖It is **observed that surface runoff, lateral flow, and percolation increase with the increase in rainfall.**

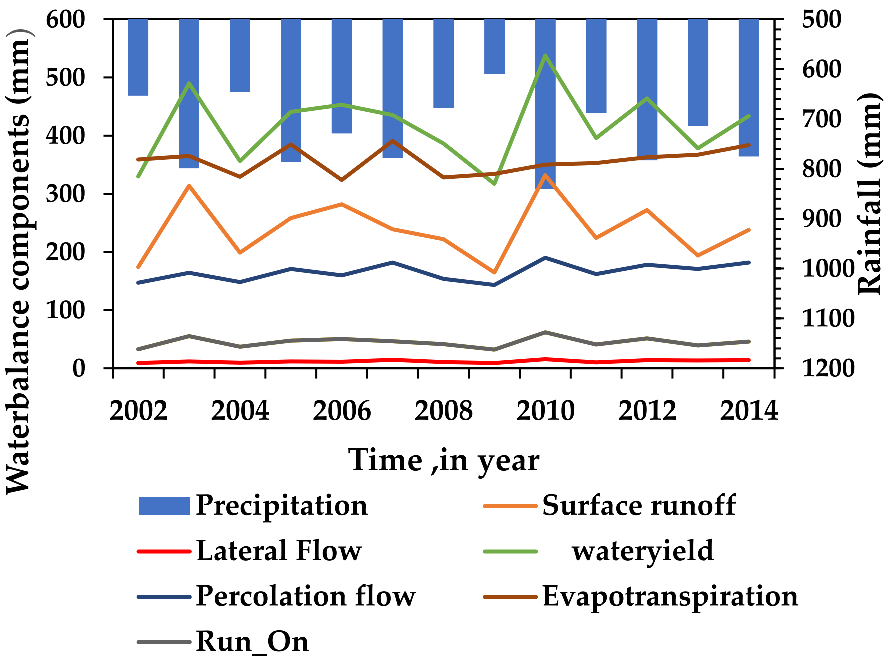


Fig 7. Distribution of mean annual value of simulated water balance components (2002–2014).

Water Yield, and Total Water Storage Assessment

$$\text{Water Yield (WY)} = \text{SURQ} + \text{LATQ} + \text{Qgw/Perc} - \text{Tloss} \quad (6)$$

where

SURQ is the surface runoff;
LATQ is the lateral flow;
Qgw/Percolation is the groundwater contribution to streamflow;
Tloss is the transmission loss.

Total water storage (WS) is also analyzed to see whether there is excess or deficit of water in the catchment for the given month. Either release or storage of water is expected for different months. Water storage is calculated by deducting runoff and AET from precipitation. Two cases are considered to see the water storage condition of the basin:

Case (i) If PCP (Precipitation) > WY + AET (Positive storage), excess water infiltrated and stored as soil moisture and groundwater (GW) storage.

Case (ii) If PCP (Precipitation) < WY + AET (Negative storage), implying water deficit will be compensated from the storage.

Water Yield Assessment

- The **monthly water balance** was also evaluated to see the **water yield and storage condition** of the catchment.

❖ **As a result, water yield followed the same pattern in that it increased with the increase in rainfall.**

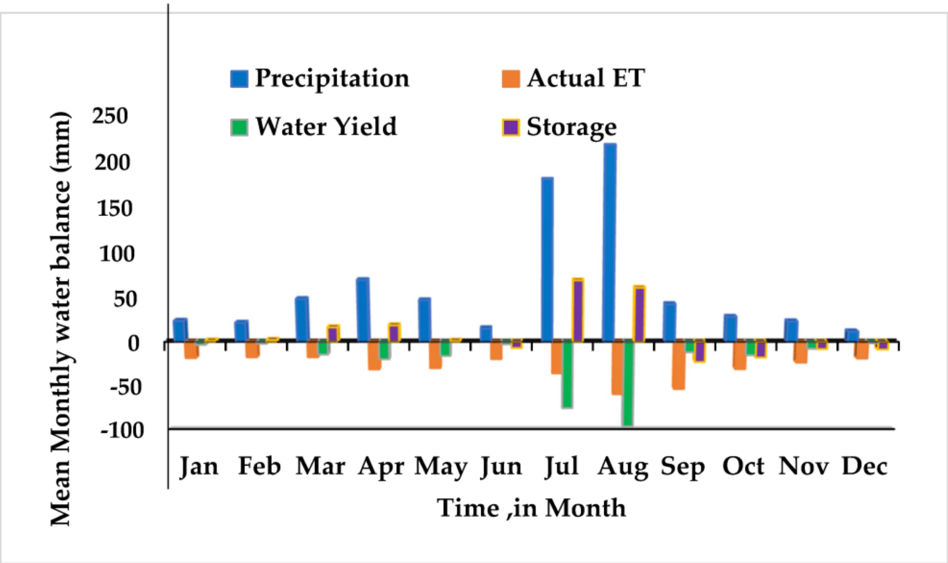


Fig 9. Mean monthly simulated (2002–2014) water balance Kobo-Golina (Long time simulated value based on parameters from multivariable calibration)

Total Water Storage Assessment……………………….Cont'd

- ❖Following the rainfall and runoff pattern, **positive storage** is obtained (water is stored in soil and ground) for March and April **(short rainy season)** and July and August **(main rainy season).**
- ❖This is due to the high precipitation and limited evapotranspiration in the rainy seasons, whereas, in the rest of the months (dry season), **negative storage** was observed, and as a result, water that was stored during the wet seasons is released from the soil and ground to **compensate** for the deficiency.
- Following the precipitation and runoff patterns, maximum positive storage (both in soil and ground) was observed in July (+46.7 mm/month) and August (+26.85 mm/month). Maximum negative storage was observed in September (−53.46 mm/month) and October (−36.36 mm/month).
- ❖The water stored in the soil during the rainy season will be lost as **evapotranspiration in the dry season**

Surface Runoff Conditions

- ❖ **The spatial pattern of surface runoff follows the rainfall pattern of the catchment.**
- ❖ A **significant amount of rainfall** generated a considerable amount of runoff.
- The simulated average annual basin surface runoff (SURQ) is **239.46 mm.**
- This shared **30%** of the **input water** of the watershed. The simulated maximum and minimum monthly runoff are attained in August and December with a value of 86.12 mm and 0.67 mm, respectively.
- ❖ **Surface runoff generation was found higher in the floodplain areas than in upland areas** (**Figure 8**a).
- A previous modeling study conducted by *[Bezabih, S et al 2022]* around the study area using WetSpass and MODFLOW revealed that the share of surface runoff in the water balance is 27%, which is similar to the findings of the current study.

Streamflow Conditions

- **Figure 10** showed that the **stream flow closely follows the precipitation pattern of the basin**.

❖The **Mann–Kendall trend test indicated that the daily streamflow showed a significant increasing trend** (**$p < 0.05$**).

- The simulated minimum and maximum mean annual stream flow at the basin outlet are 7.95 m^3/s and 13.2 m^3/s (2010), respectively. =>**0.41BCM**

❖ **The maximum flow occurs in the highest rainy year and the lowest flow is observed in the small rainy year (2009).**

- Previous studies showed similar results that in areas where saturation excess runoff dominates, daily discharge is the function of daily rainfall *[Enku, T et al 2020, Abebe, W.B et al 2020 and Li, M et al 2021].*

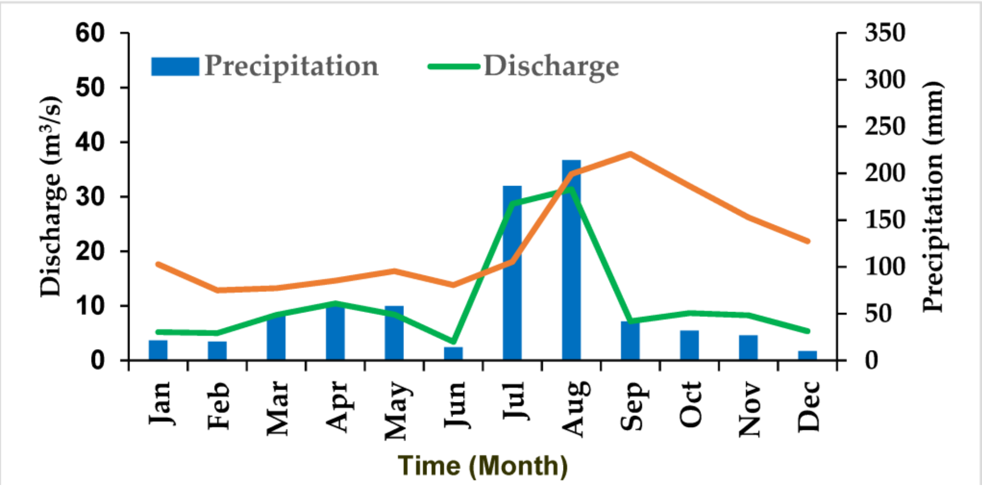
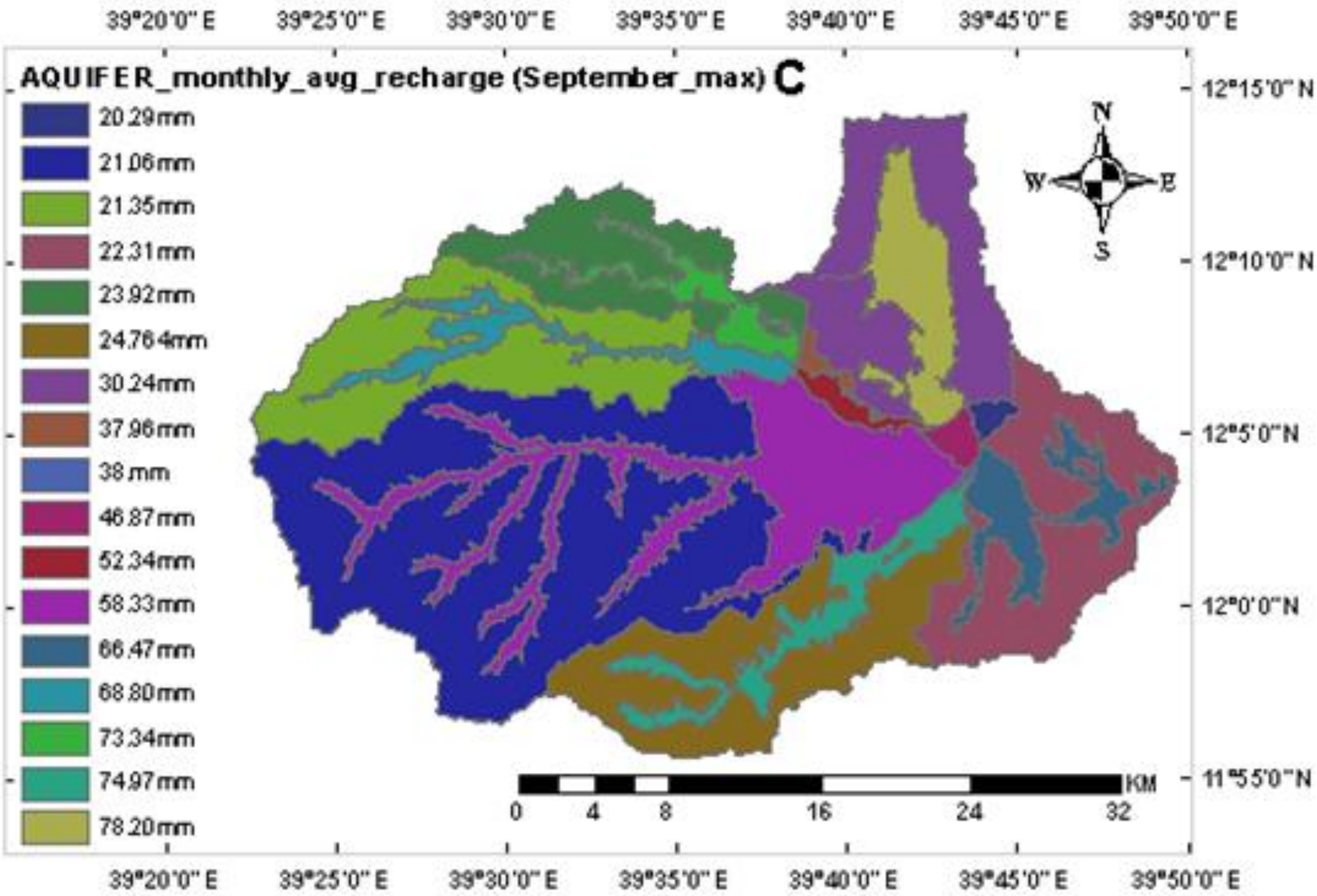


Fig 10. A rainfall-runoff pattern of the Kobo-Golina sub-basin at the main outlet (2002–2014)

Recharge Conditions

- ❖**We did not directly validate** the reliability of groundwater recharge, but validated simulating streamflow instead, assuming that streamflow has a strong correlation to groundwater recharge;
- ❖Based on this fact, **the simulated model recharge value showed an increasing trend from the upland to the floodplain areas. (Alluvial deposit)**
- The minimum and maximum annual recharge are 208 and 276 mm with mean annual recharge of 244.36 mm.
- The maximum mean monthly simulated recharge is obtained in September (one month later than the month of maximum rainfall) with a value of 78.2 mm.Presentation\Figure 11.docx
- ❖Since the dominant soil in the floodplain area is **VertiSols**, it has a good water-holding capacity and as a result, has a good potential for **recharge to the shallow aquifer**



39°20'0" E
39°25'0" E
39°30'0" E
39°35'0" E
39°40'0" E
39°45'0" E
39°50'0" E
AQUIFER_monthly_avg_recharge (September_max)
C
20.29mm
21.06mm
21.35mm
22.31mm
23.92mm
24.764mm
30.24mm
37.96mm
38 mm
46.87mm
52.34mm
58.33mm
66.47mm
68.80mm
73.34mm
74.97mm
78.20mm
N
W
E
S
12°15'0" N
12°10'0" N
12°5'0" N
12°0'0" N
11°55'0" N
0
4
8
16
24
32
KM

Conclusions

- Understanding the hydrological processes and applying a good hydrological model is the most important aspect of water resource management works.
- The issue is very critical in developing nations like Ethiopia where there are **numerous ungauged catchments.**
- A way out has to be established to tackle the challenge, and hydrological models were considered as one of the means.
- The **SWAT+ with LSU option** was used to characterize the hydrology of the ungauged catchments of Kobo-Golina.
- **The study suggested that both surface water harvesting and groundwater exploitation can be sought in floodplain areas while conserving the uplands.**
- **It was also found that the use of open-source remote sensing data for model simulation is promising for ungauged areas.**

Conclusion…………………………………………………..……..Cont'd

- **CHIRPS reanalysis rainfall** and **CFSR climate data** can be used as alternative input data for model simulation in the study area.
- The SWAT+ model simulations also demonstrated that **MODIS AET** and **GloFAS flow** present good potential for hydrological model calibration in the study region.
- **Multi-variable calibration** reasonably attained the minimum satisfactory performance limit for both variables (AET and stream flow). As a result multivariable calibration has to be taken as an advantage to improve the performance of the model.
- The **SWAT+ with LSU (Landscape unit)** model setup is very promising with regard to a better representation of hydrological processes in the **saturated excess humid areas.**
- This approach paves a new path for characterizing ungauged catchments by SWAT+ hydrological models based on open-source satellite data in saturated excess humid and semi-arid regions.
- The SWAT+ with LSU may be used to assess the hydrological processes and quantification of the water balance terms in catchments with similar hydrological and geomorphological features.

Thank you for your attention

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