HYDROLOGIC EVALUATION OF HIGH-RESOLUTION SATELLITE PRECIPITATION PRODUCTS: CASE STUDY ON DABUS WATERSHED, UPPER BLUE NILE BASIN, ETHIOPIA

International Conference on Nile and Grand Ethiopian Renaissance Dam (GERD)

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Presentation Outlines

- ☞ Introduction
- ☞ Materials and Methods
- ☞ Results and Discussions
- ☞ Conclusions and Recommendations

☞ Introduction

❖Hydrological modeling for runoff simulations requires accurate rainfall data as a model input.

❖But in many developing countries like Ethiopia, the rainfall observation network is relatively sparse.

❖Rainfall estimates are mainly derived from two **sources**:-

- ➢ Rain gauge station observations and
- ➢ Ground radar measurements

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- ❖ However, recently **satellite** rainfall products have emerged as an alternative or supplement to conventional rainfall observations for hydrological modeling. Such as,

- ➢ TRMM and CHIRP

- ❖ Satellite system that provides rainfall are separated in to GEO and LEO satellites.

- ❖ Accordingly, this study was intended to evaluate the suitability of TMPA_3B42v7 and CHIRPS_2 satellite rainfall estimates for runoff simulation.

Statement of the Problem

❖Satellite rainfall estimates have potential use for hydrological modeling.

But model performance depends on;

- satellite product type
- watershed size and
- hydro-climatic region.

❖However, those studies didn't cover Dabus watershed and most of the studies were limited to short simulation periods.

❖ Moreover, in Dabus watershed the influences of

- water withdrawal
- land cover and climate change have not been quantified yet due to scarce rainfall data for rainfall-runoff modeling.

Objectives of the Study

General objectives

- ❖To evaluate CHIRPS_2 and TMPA_3B42v7 satellite rainfall products for hydrologic simulation.

Specific objectives

- ❖To evaluate the ability of satellite rainfall products to characterize rainfall patterns and capture the magnitude of rainfall.
- ❖To assess the skill of satellite rainfall products as an input into a hydrologic model for stream flow simulation.
- ❖To evaluate the performance of HEC-HMS model using satellite and ground based rainfall products.

Description of the Study Area

❑ Location

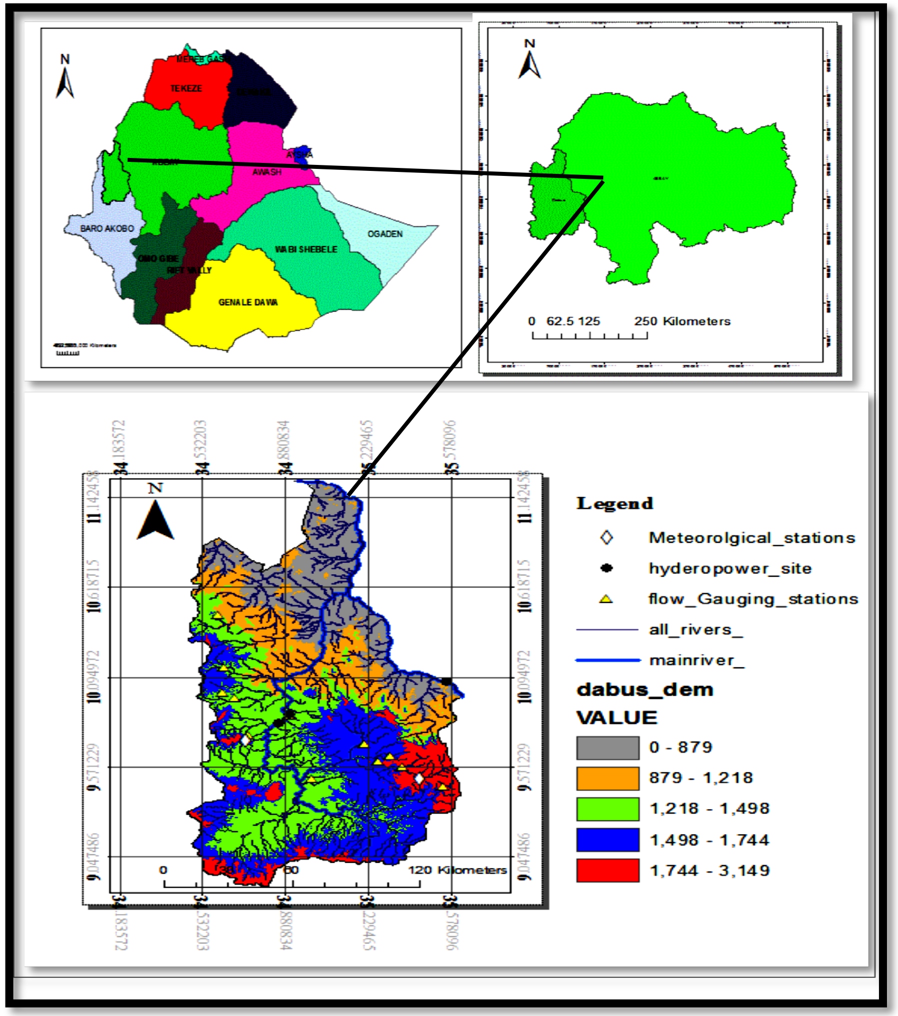
❖In South-Western Ethiopia Benishangul-Gumuz region, 664 km around the Grand Ethiopian Renaissance Dam (GERD)

❖9°0’0” - 11°50’0”N Latitude and

❖34°30’0” - 35°58’40”E Longitude

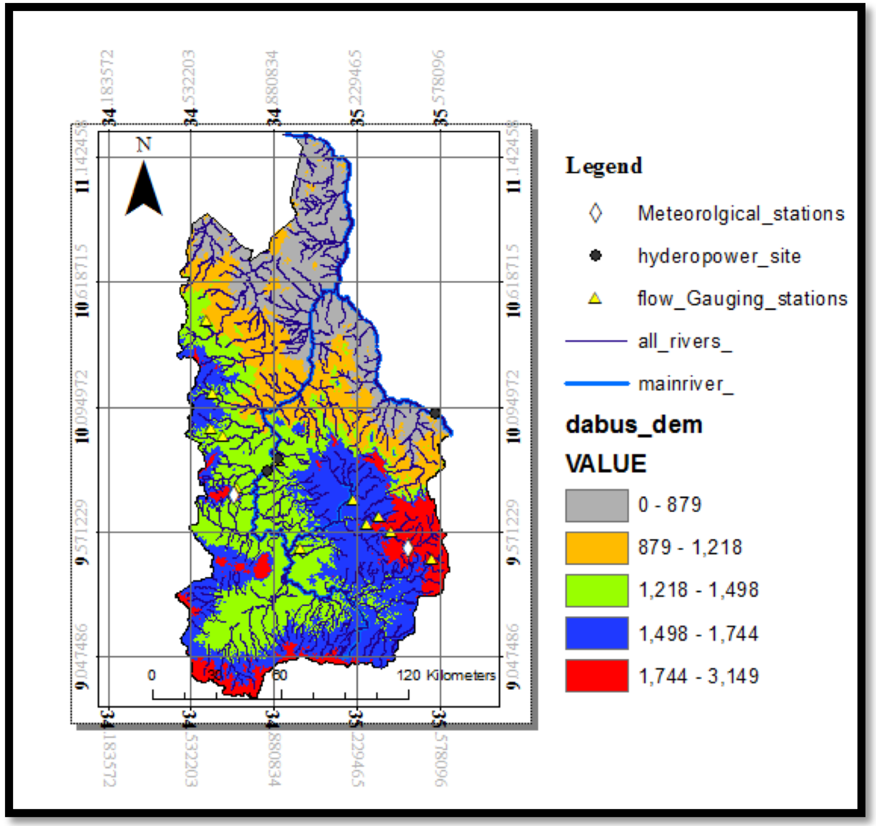
❖ Drainage area of about 21,032 Km^2.

❖Out of this 600 to 900 km^2 area is swamp.



❑ Topography

- ❖ Consists of rugged topographies with different
  - ➢ valleys
  - ➢ Ridges and
  - ➢ steep slopes
- ❖ Elevation varies from 0 – 3,149 masl.

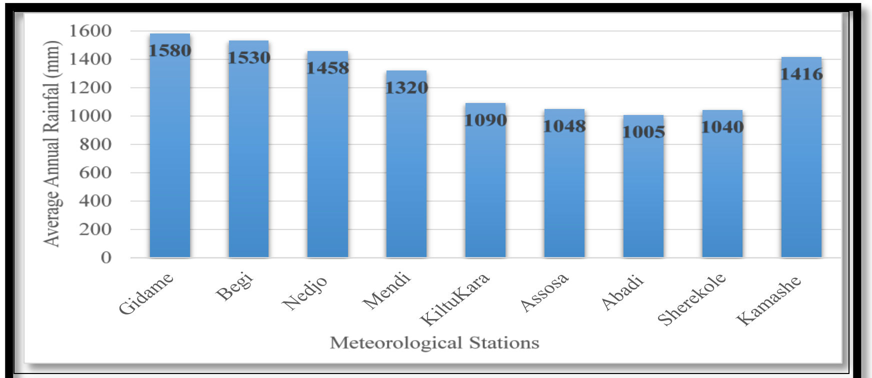


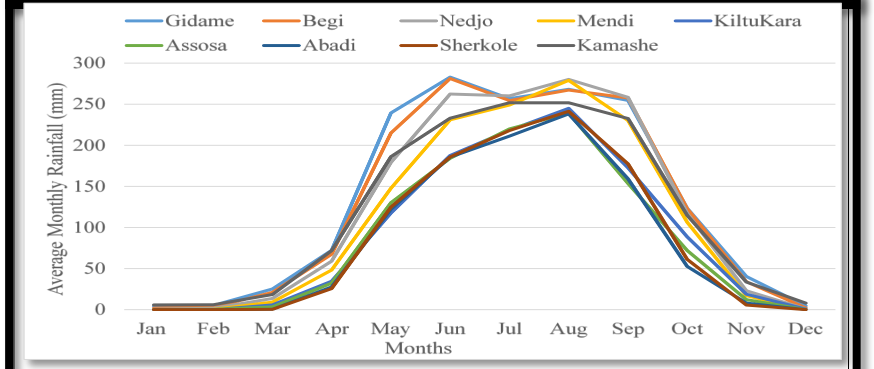
❑ Climate

❖Rainfall

➢ Characterized with unimodal rainfall distribution.

➢ About (70-90)% total rainfall occurs in rainy summer (Kiremt) seasons.





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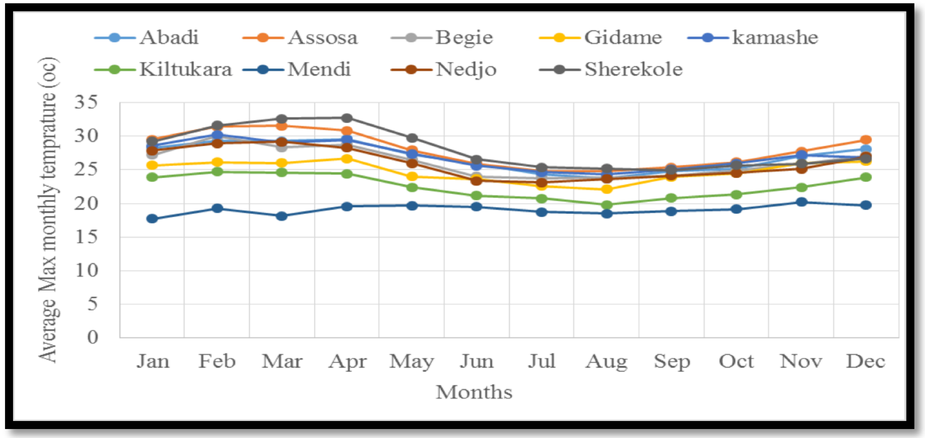
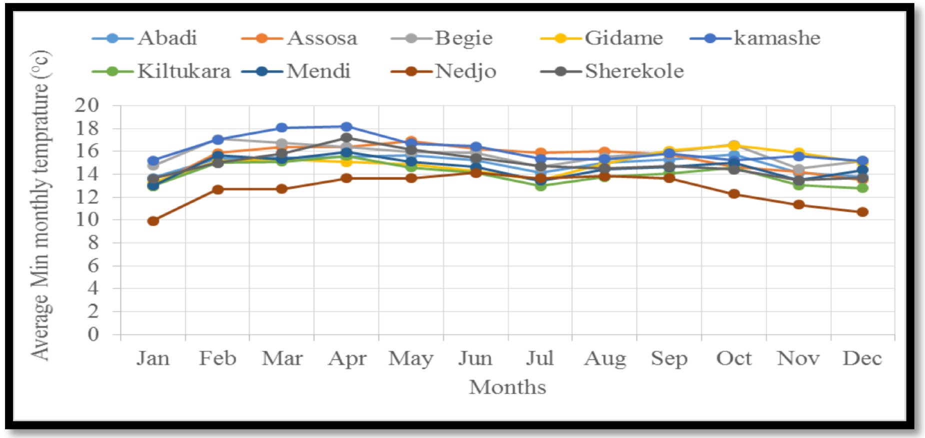
❖ Temperature

- ➢ Maximum monthly temperature varies 17^oc – 33^oc.

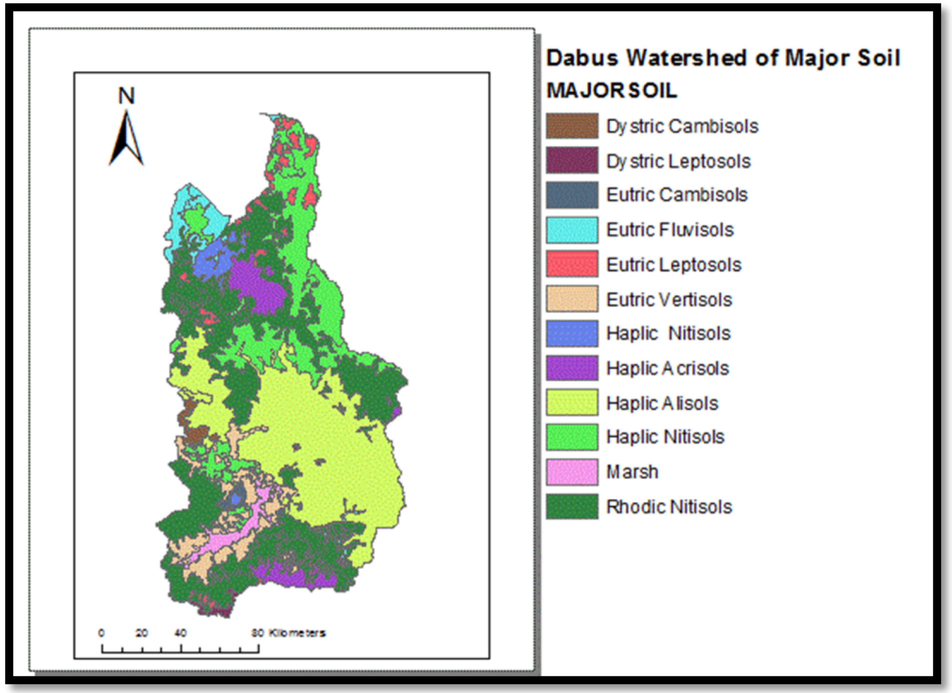


- ➢ Minimum monthly temperature varies 10^oc – 18^oc.



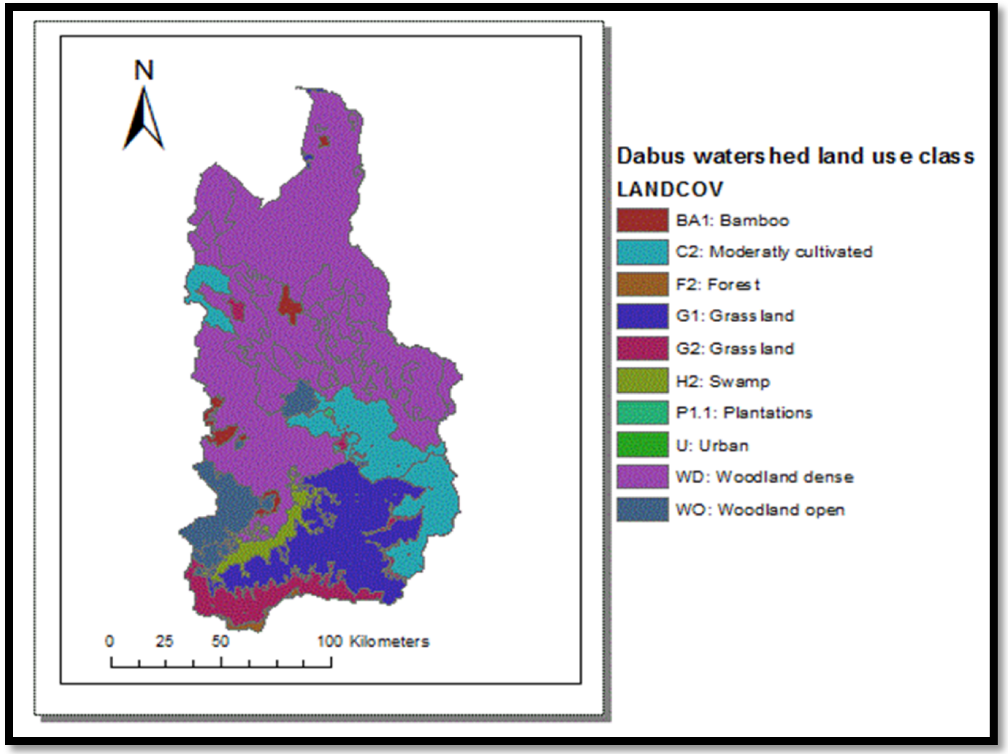
❑ Soil

- ❖Haplic Alisols
- ❖Rhodic Nitisols
- ❖Haplic Nitisols
- ❖ Eutric Fluvisols



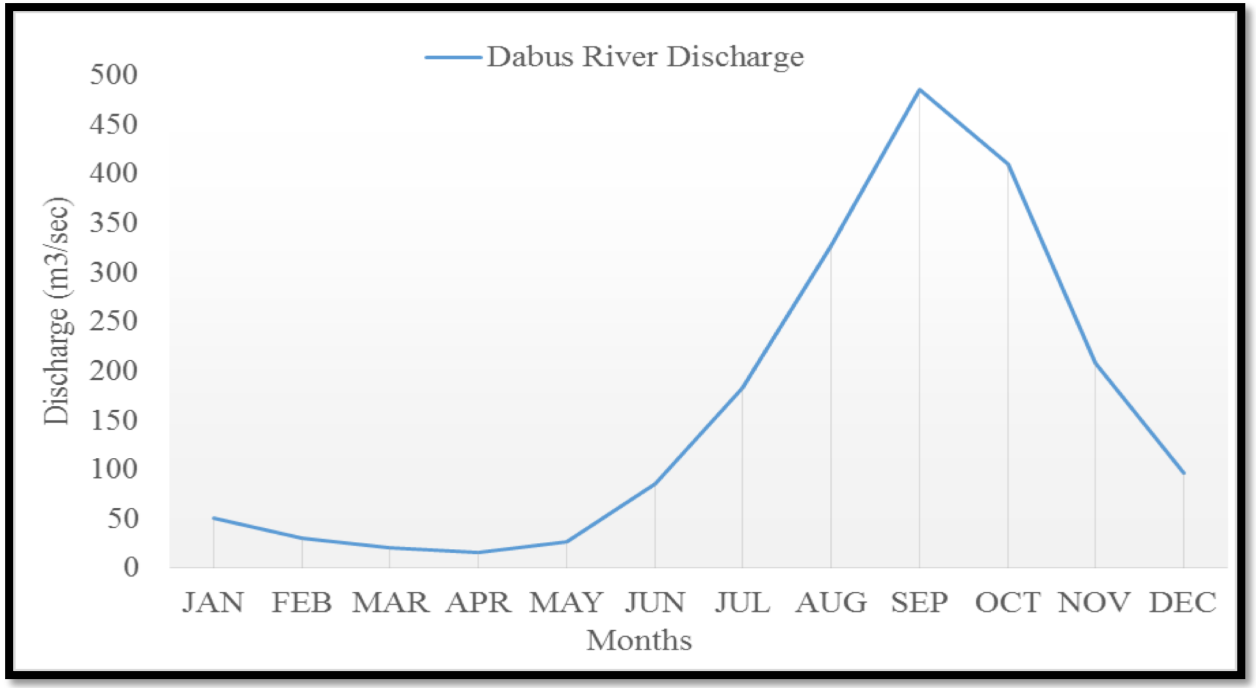
❑ Land Use Land Cover

- ❖Wood land
- ❖Moderately cultivated
- ❖Grass land
- ❖Swamp



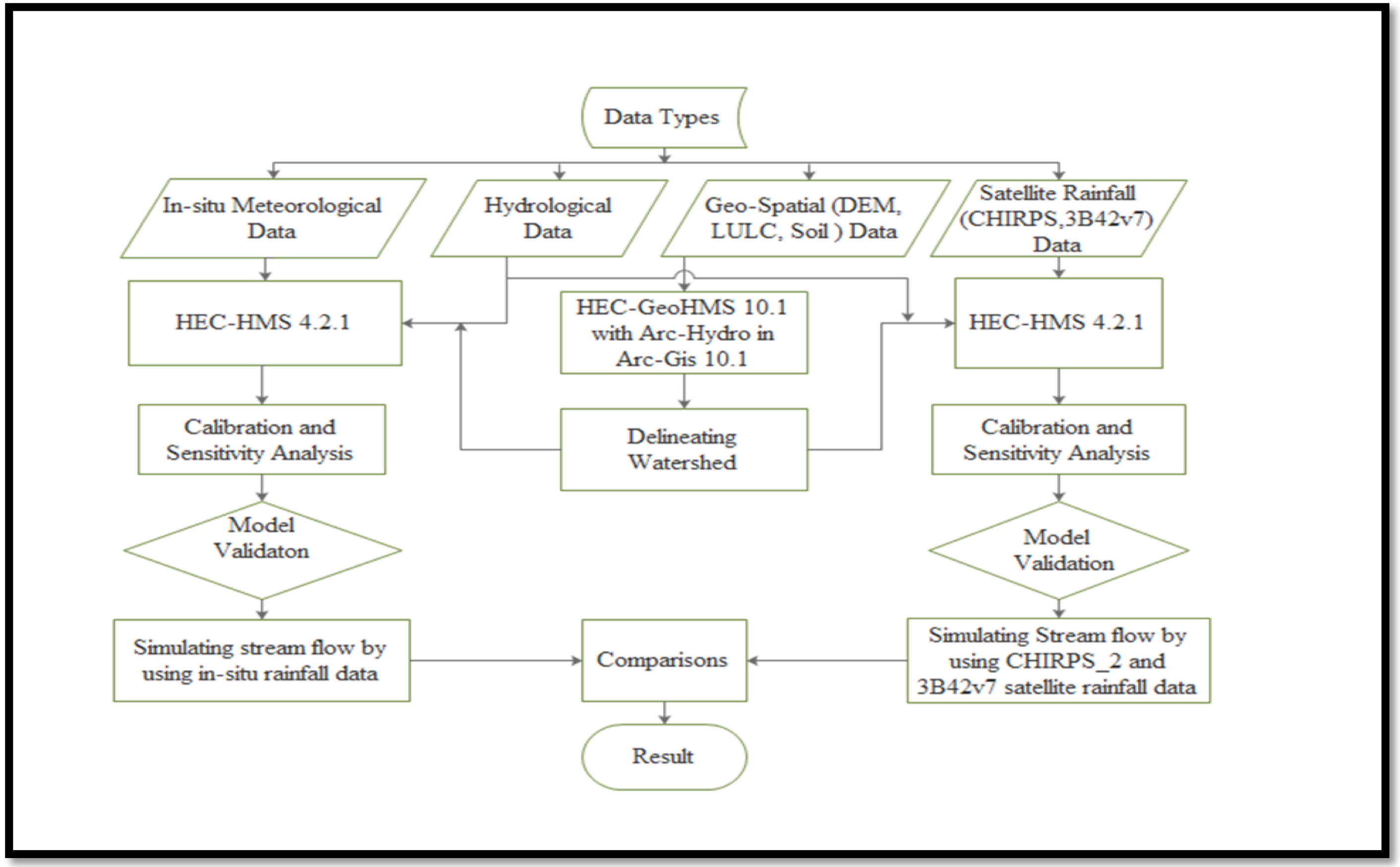
❑ Hydrology

- ❖Gauging station installed downstream of the **Dabus** river.
- ❖Has an average annual daily flow of **161** m^3/sec.



☞ Materials and Methods

❖Conceptual frame work of the study area which describes the overall procedure of this thesis work.



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Types of Data and Sources

Data types	Spatial resolution	Temporal resolution	Source	Duration
In-situ meteorological	Point	Daily	NMSA	2000 - 2015
CHIRPS_2	$0.25^\circ \times 0.25^\circ$	Daily	http://chg.geog.ucsb.du/data/chirps	
TMPA_3B42v7	$0.25^\circ \times 0.25^\circ$	Daily	https://pmm.nasa.gov/	
Hydrological	Areal	Daily	MoWIE	
DEM	30m×30m	-	SRTM	
LULC	30 arc sec	-	FAO land use dataset 2013	
Soil	30 arc sec	-	FAO	

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- ❖After collecting essential information filling and checking quality of data is needed.
- ❖Missing of data will be occur due to,
- ➢natural or
- ➢man-made factors
- ❖For this study invers distance weighting (IDW) was applied for filling the missing data.

$$\mathrm{P(x)} = \sum_{\mathrm{i=1}}^{\mathrm{n}} \frac{\mathrm{wi\ pi}}{\sum_{\mathrm{i}} \mathrm{wi}}$$

Where, $w_i = \frac{1}{\mathrm{di}^{\mathrm{n}}}$

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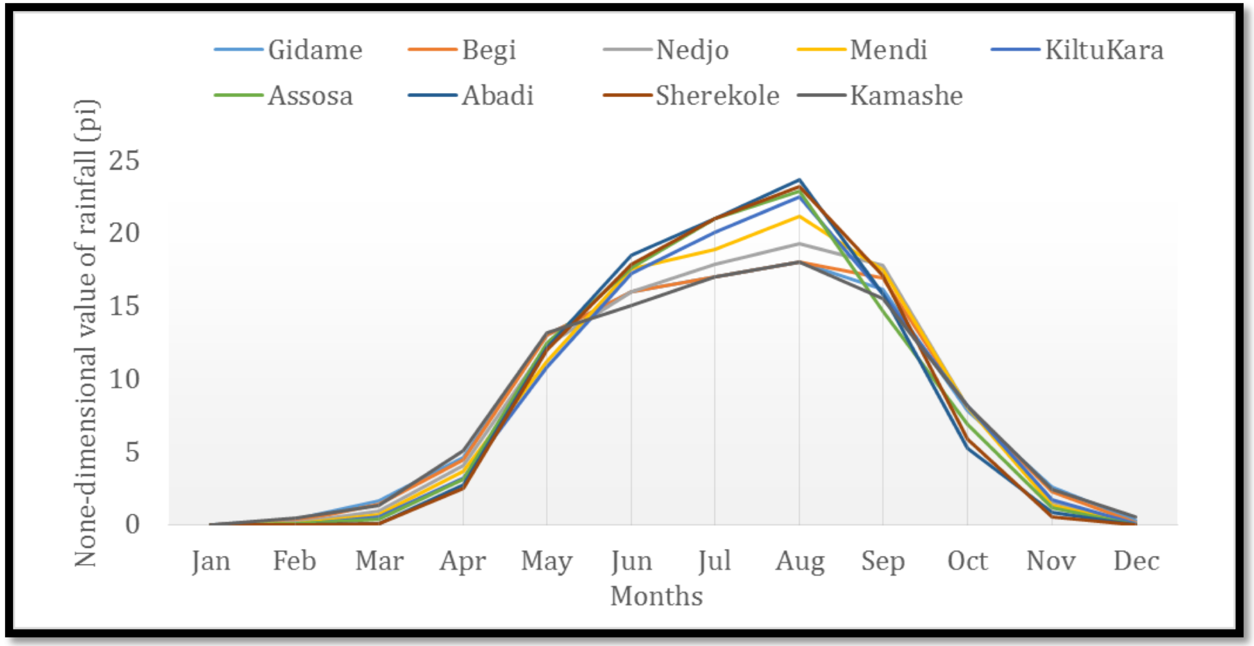
Checking Homogeneity of Meteorological Stations



❖The selected rainfall stations were non-dimensionaised and plotted together to analyze their homogeneity.

❖The maximum rainfall occurs between May to September in all stations which shows the homogeneity of the stations.

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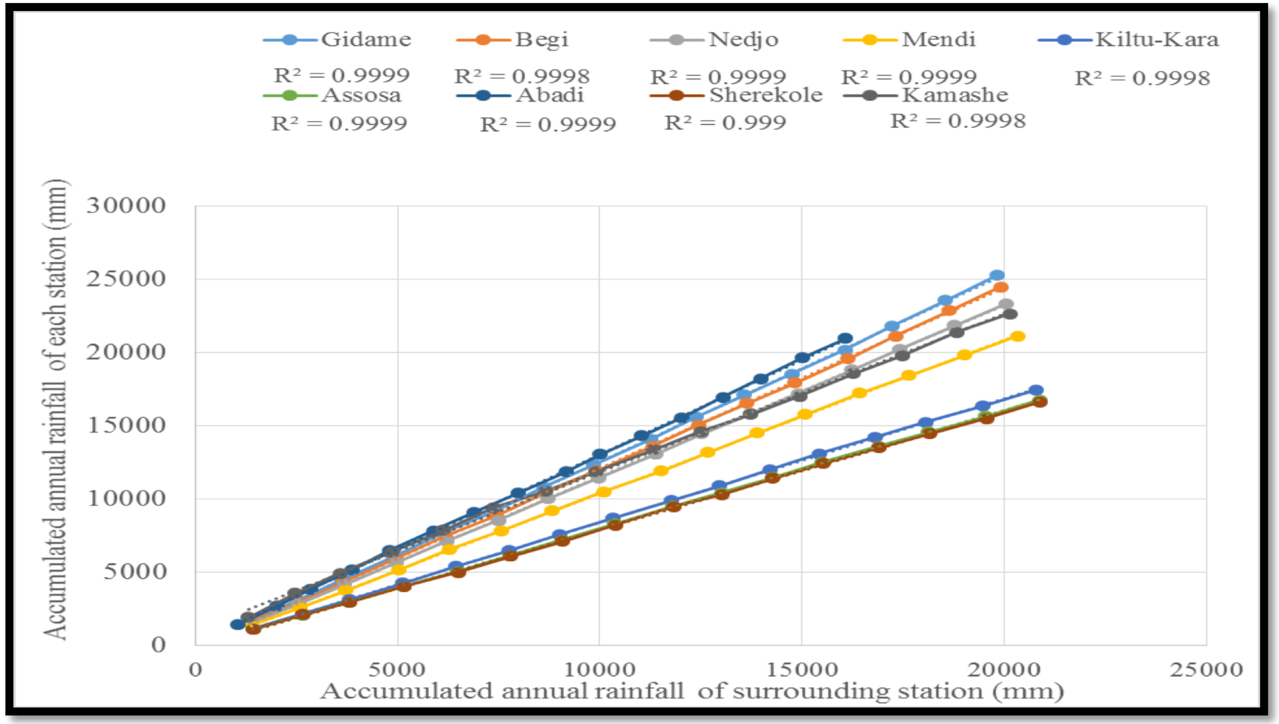
Checking Consistency of Meteorological Stations



- ❖Done using double mass curve analysis.
- ❖The selected stations were consistent since the graph of the plot forms straight line without break.

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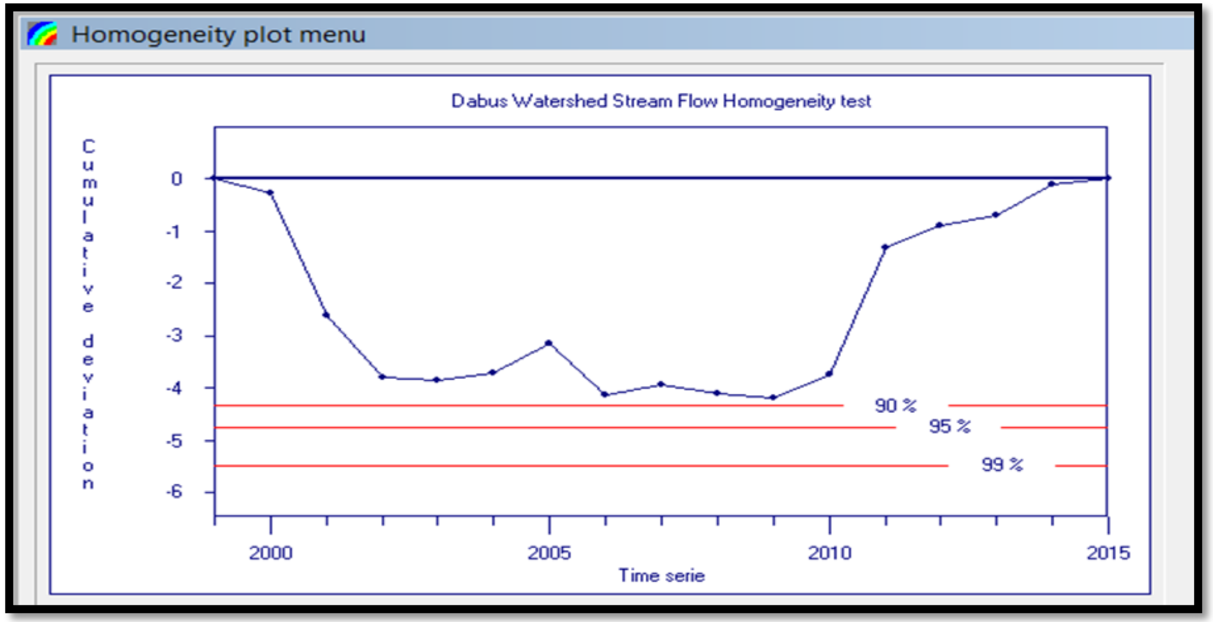
Stream flow Homogeneity Test



- ❖Done using Rainbow software.
- ❖The rescaled cumulative deviations from the mean would not crossed one of the horizontal 90, 95 and 99% probabilities lines, which shows the homogeneity of the annual data series.

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Processing of Satellite Rainfall Estimates

- 5844 files for each of the satellite rainfall estimates were downloaded.
    - TMPA_3B42v7
    - CHIRPS_2
- Those estimates were obtained on a Network Common Data Form (NetCDF) gridded format.
- Then, **Panoply** NetCDF data viewer was used to extract the rainfall data in suitable format for further analysis.
- Bias correction of Satellite rainfall products were performed using power transformation methods.

$P^* = a \times P^b$ where, a and b are constants

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Model Setup

❖HEC-HMS model contain **four** components;

➢basin model

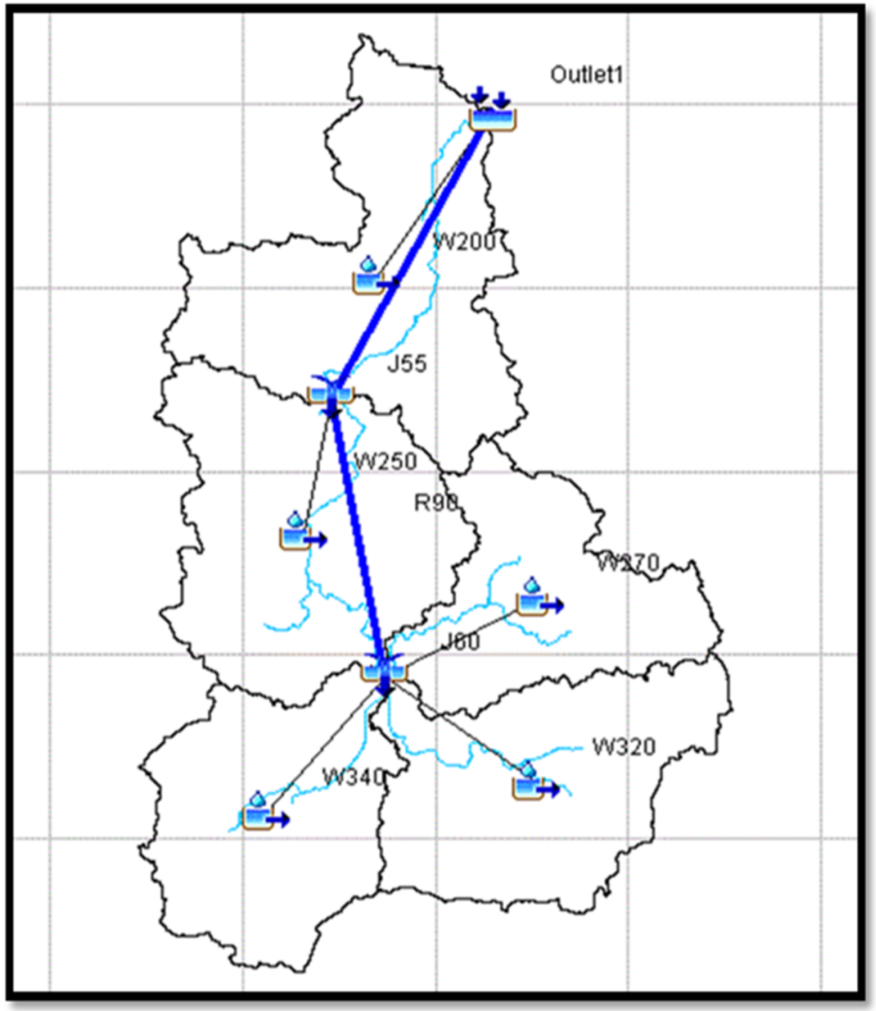
➢meteorological model

➢control specification and

➢input data

❖HEC-GeoHMS and Arc-Hydro were used to delineate sub-basins and other watershed features from DEM of the study area.

❖Input data to HEC-HMS were pre-process using HEC-GeoHMS under GIS environment.



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Sensitivity Analysis

- ❖Sensitivity analysis used to select parameters of the hydrologic model that have highest impact on model result.
- ❖sensitivity analysis can be local or global.
- ❖HEC-HMS (GUI) model was used to identify the sensitive parameter using local analysis method.
- ❖Max –ve or +ve Objective sensitivity function value has high impact on model result.

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Model Calibration and Validation

- ❖Calibration is a process of changing model parameter values until model results match acceptably the observed data.
- ❖Validation is testing model capability to simulate observed data.
- ❖A split sample procedure of **daily** stream flow data were used.
- ➢2000 for "warm-up" to mitigate unknown initial conditions.
- ➢2001-2010 for calibration and
- ➢ 2011-2015 for validation.

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Model Performance Evaluation

- ❖ R^2, describes the proportion of the **total variance** in the observed data that can be explained by the model.
- ❖ E_{NS}, indicates the degree of **fitness** of the observed and simulated hydrographs.
- ❖ PBIAS, measures the **average tendency** of the simulated data to be larger or smaller than observed data.
- ❖ PEPF and RVE

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Ranges of Model Performance Evaluation criteria

Efficiency criteria	Ranges	Target Value
E_{NS}	-∞ and 1	1 but 0.6 -1 is acceptable
R^2	0-1	1
PBIAS	-∞ to ∞	0
RVE	-∞ to ∞	very good -5% to 5% and satisfactory -10% to -5% and 5% to 10%
PEPF	>>	>>

☞ Results and Discussions

Performance of Satellite Rainfall Estimates

- ❖Both of the selected satellite rainfall products were underestimated and overestimated the rainfall.
- ❖In-situ and TMPA_3B42v7 satellite rainfall products showed higher difference in Assosa and Kiltukara stations.
- ❖In-situ and CHIRPS_2 satellite rainfall products were indicated wider difference in Begie and Abadie stations.
- ❖The difference between in-situ and satellite rainfall estimates showed elevation dependent trends. **Sta.docx**

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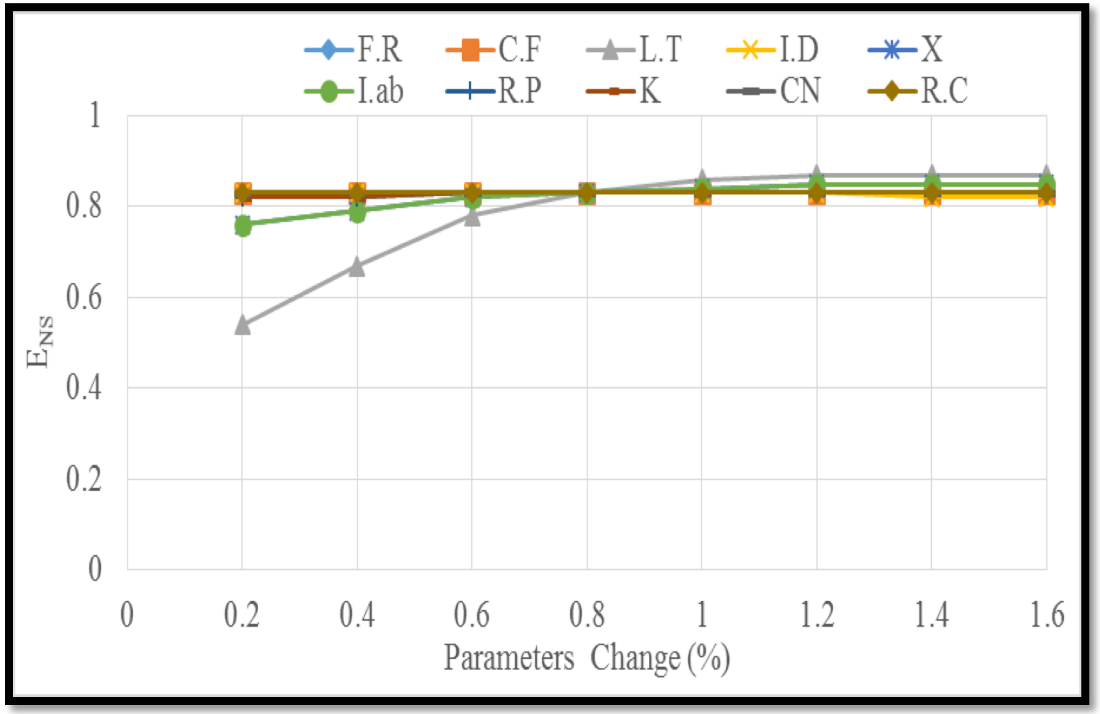
Modeling with in-situ Rainfall Data

Sensitivity Analysis

❖Lag time (L.T)

❖ Initial abstraction(I.ab)

❖Initial discharge (I.D)



❖Based on the value of objective sensitive function L.T was ranked as most sensitive flow parameter.

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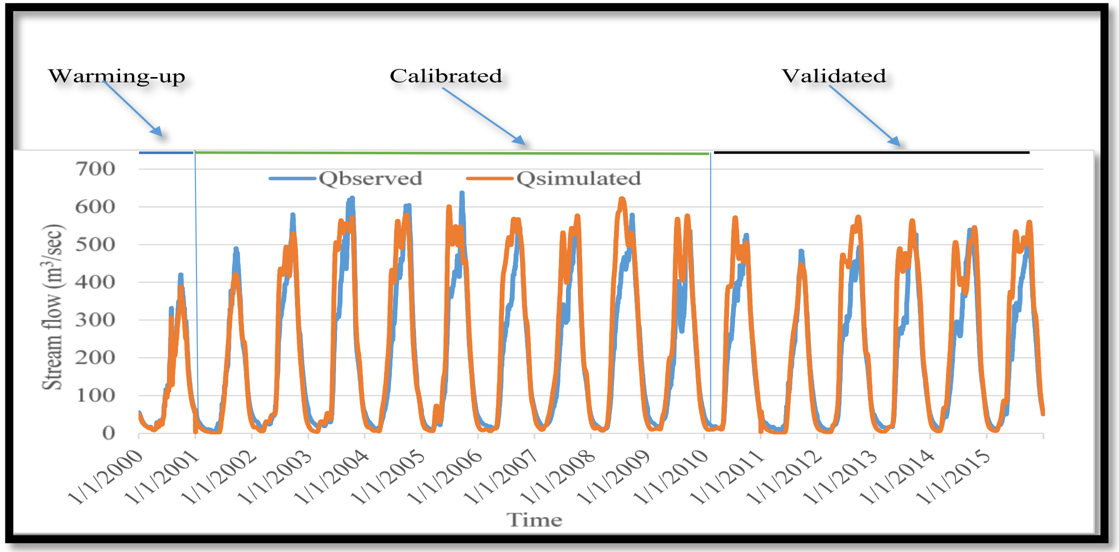
Calibration and Validation of in-situ rainfall data

	Objective function				
Period	E_{NS}	R^2	PBIAS (%)	PEPF (%)	RVE
Calibration (2001-2010)	0.843	0.954	-14.648	2.364	5.557
Validation (2011-2015)	0.791	0.952	-19.638	-6.346	6.634



- ❖Although, Observed and simulated graph matched well overestimation of observed stream flow were occurred.

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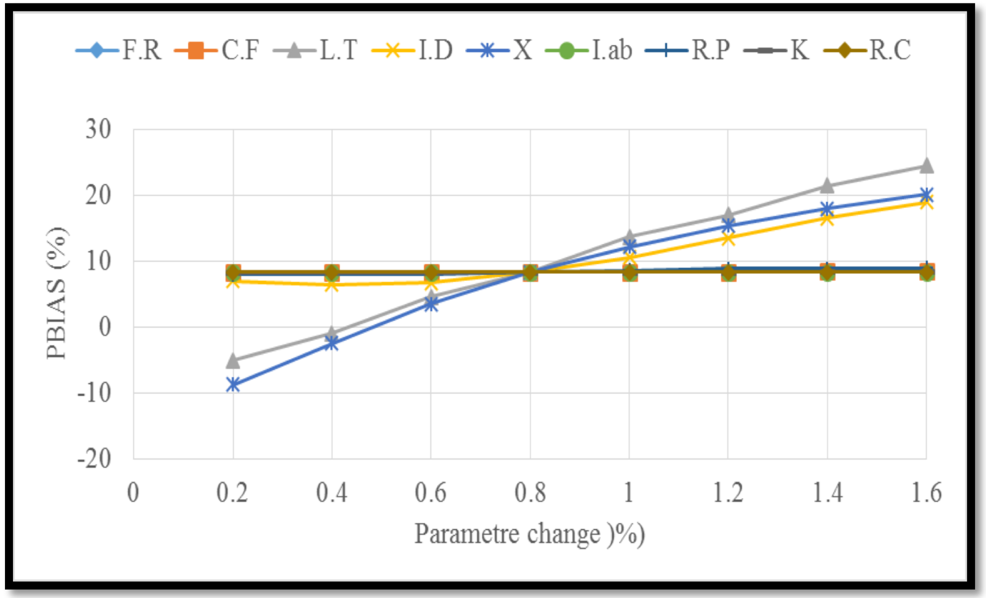
Modelling with CHIRPS_2 Satellite Rainfall Products

Sensitivity Analysis

- ❖Muskingum (x)
- ❖Lag time (L.T)
- ❖Initial discharge(I.D)



❖Even if, the sensitivity percentage values were slightly different the above parameters were common for both satellite rainfall estimates.

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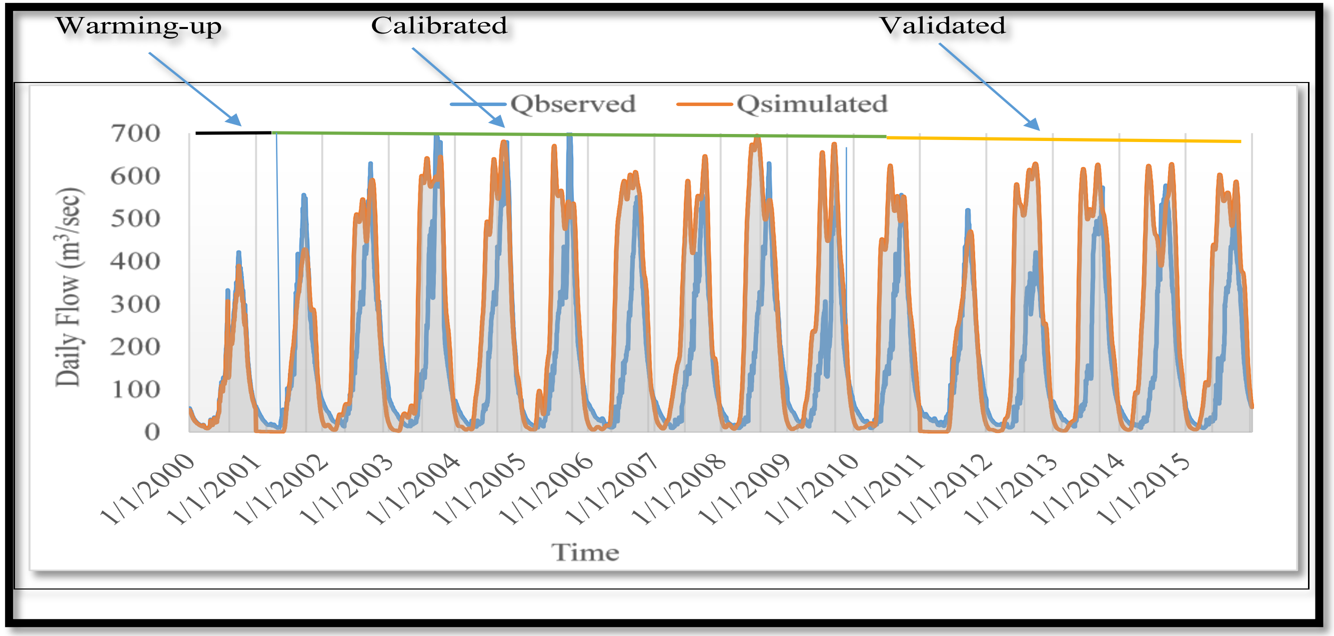
Calibration and Validation of CHIRPS_2 rainfall products

	Objective function				
Period	E_{NS}	R^2	PBIAS (%)	PEPF (%)	RVE
Calibration (2001-2010)	0.685	0.777	-18.425	4.042	7.893
Validation (2011-2015)	0.513	0.704	-21.467	-6.075	8.562



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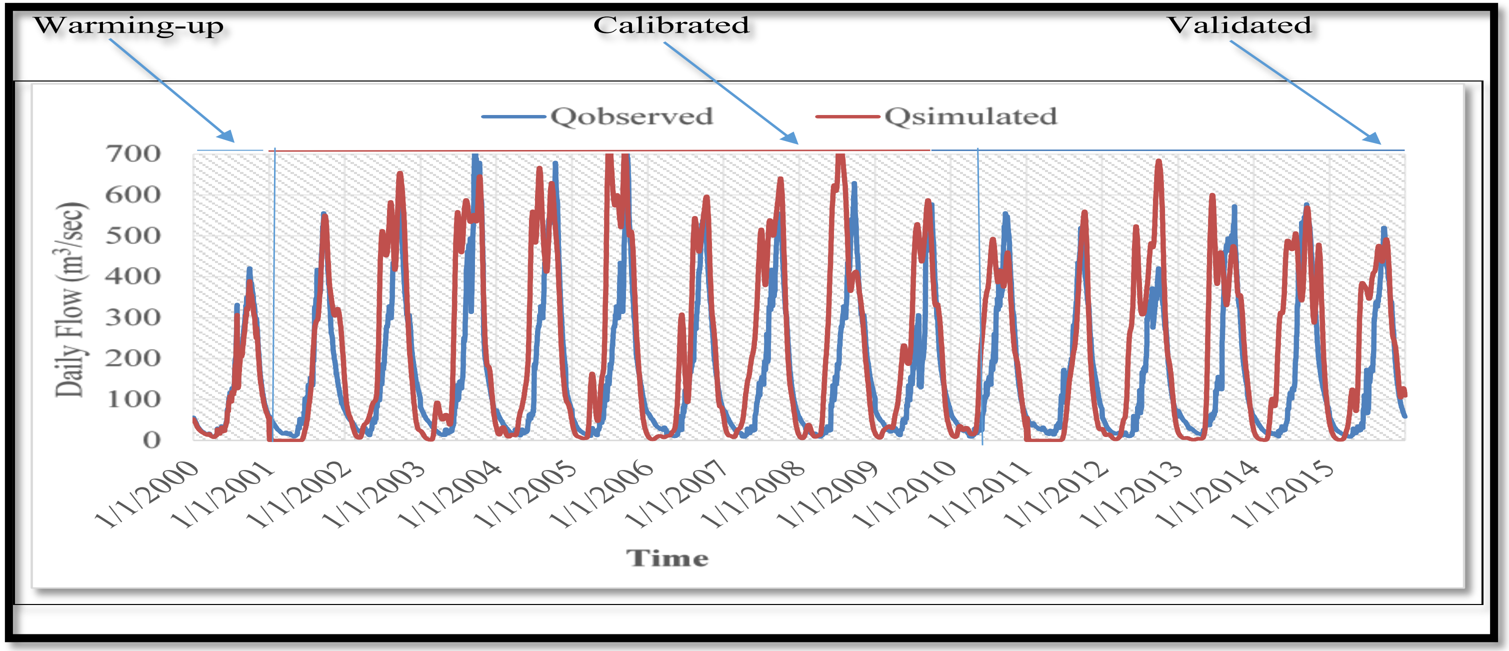
Modelling with TMPA_3B42v7 Satellite Rainfall Products

	Objective function				
Period	E_{NS}	R^2	PBIAS (%)	PEPF (%)	RVE %
Calibration (2001-2010)	0.755	0.786	-11.325%	7.335	9.893
Validation (2011-2015)	0.714	0.705	-17.357%	-5.075	10.00



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HEC-HMS Model Performance Comparisons for Satellite Rainfall

	Calibration period (2001-2010)					Validation Period (2011-2015)				
Rainfall Type	R^2	E_{NS}	PBIAS (%)	PEPF (%)	RVE (%)	R^2	E_{NS}	PBIAS (%)	PEPF (%)	RVE (%)
CHIRPS_2	0.777	0.685	-18.42	4.042	7.89	0.704	0.513	-21.46	-6.07	8.56
TMPA-3B42v7	0.786	0.755	-11.32	7.335	9.89	0.705	0.714	-17.35	-5.07	10.0

❖HEC-HMS model was showed relatively better performance in stream flow simulation for TMPA_3B42v7 than CHIRPS_2 satellite rainfall estimates.

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HEC-HMS Model Performance for in-situ and Satellite Rainfall estimates

In-situ rainfall	Objective function					**TMPA_3B42v7**	Objective function				
Period	E_{NS}	R^2	PBIAS (%)	PEPF (%)	RVE (%)	Period	E_{NS}	R^2	PBIAS (%)	PEPF (%)	RVE %
Calibration (2001-2010)	0.843	0.954	-14.648	2.364	5.557	Calibration (2001-2010)	0.755	0.786	11.325	7.335	9.893
Validation (2011-2015)	0.791	0.952	-19.638	-6.346	6.634	Validation (2011-2015)	0.714	0.705	17.357	-5.075	10.00

- ❖HEC-HMS model scored better results for in-situ precipitation products than satellite rainfall estimates.

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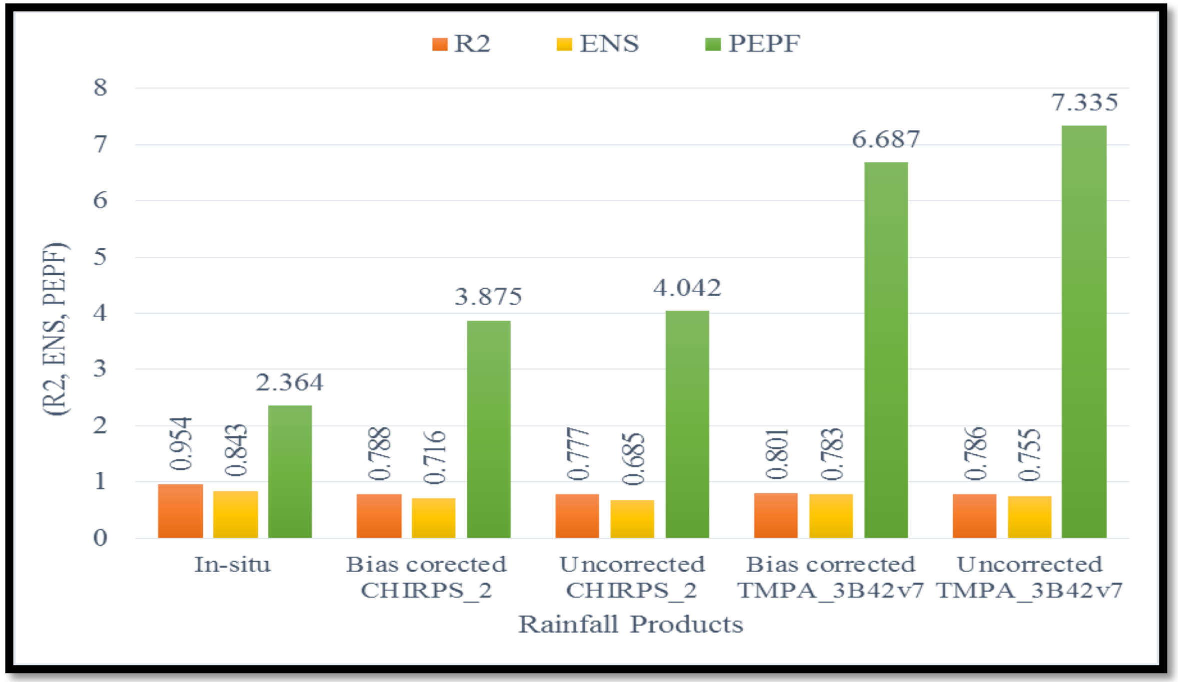
Effects of Bias Correction of Satellite Rainfall Products



❖The performance of satellite rainfall products increased when bias corrected satellite rainfall estimates used.

☞ Conclusions

- ❖Lag time, Muskingum x, k and initial discharge were the most sensitive.
- ❖Calibration and Validation results of HEC-HMS model using in-situ rainfall data's were rated as ‘Good’ for the study area.
- ❖Calibration and Validation results of HEC-HMS model using TMPA_3B42v7 and CHIRPS_2 estimates were rated as ‘Satisfactory’.
- ❖Low HEC-HMS model performance was reported when CHIRPS_2 satellite rainfall estimates used.
- ❖Relatively good performance of HEC-HMS model was resulted while using in-situ rainfall data.
- ❖Bias corrected satellite rainfall products were showed slightly better result than uncorrected satellite rainfall estimates.
- ❖The performance of bias corrected satellite rainfall estimates still less than performance of in-situ rainfall products.

☞ Recommendations

- ❖Applying physically distributed hydrologic model which incorporate land use land cover changes may lead to get better results.
- ❖Applying different type of bias correction techniques including correction for topography may increase the model performance.
- ❖Applying studies which includes climate change with land use land cover and sediment inflow to the watershed using satellite rainfall may be important for the safety of Grand Ethiopian Renaissance Dam (GERD).

THANK YOU FOR YOUR ATTENTION!!!