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Hydrological Model Evaluation of Ground, GPM IMERG, and CHIRPS precipitation data for Shabelle Basin in Ethiopia

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Abstract: Consistent and accurate precipitation measurement is a fundamental input component of the hydrological model. However, most developing countries, including Ethiopia, lack consistent and precise precipitation measurements. Nevertheless, satellite-based precipitation data may play a crucial role in bridging the data gap and providing precipitation inputs for rainfall-runoff models in regions with limited ground data. The study compares the ground precipitation data from the Ethiopian meteorological agency and SWALIM to the satellite-based GPM_IMERG and CHIRPS precipitation products. HEC-HMS software was used to model rainfall-runoff simulation, and the study area's spatial characteristics and model development were processed with ArcGIS and HEC- GeoHMS. Since the data on hand is enough and fit for continuous event assessment, the deficit and constant loss method, a continuous event-based loss method, was tested, and found good model performance results. The onhand 14 years of precipitation and discharge data were divided into seven years for calibration and seven years for validation. Using Nash–Sutcliffe efficiency (ENS), coefficient of determination (R^2), Root Mean Square Error (RMSE), and percentage bias objective functions, the performance of the satellite precipitation was evaluated. During calibration periods (Jan 2013 to Dec 2009), the model performance showed ENS values of 0.65, R^2 values of 0.68, RMSE values of 0.6, a percent bias of 0.58% for the metrological stations, ENS values of 0.61, R^2 values of 0.64, RMSE values of 0.6, a percent bias of 5.38% for CHIRPS, and ENS values of 0.63, R^2 values of 0.66, RMSE values of 0.7, and a percent bias of 18.9% for GMP_IMERG satellite precipitation products. During validation periods (Jan 2010 to Dec 2016), the model performance showed ENS values of 0.75, R^2 values of 0.78, RMSE values of 0.6, a percent bias of -16.9% for the metrological stations, ENS values of 0.71, R^2 values of 0.74, RMSE values of 0.6, a percent bias of -22.12% for CHIRPS2, and ENS values of 0.76, R^2 values of 0.76, RMSE values of

0.5, and a percent bias of -0.03% for GPM_IMERG satellite precipitation products. The study showed that the HEC-HMS model performed well and gave very good results for the hydrological model for the CHIRPS and GPM_IMERG rainfall products. The study also indicates that the model outperformed well during the validation period. Overall, the study found that the simulated GPM_IMERG product gave better results than the simulated CHIRPS product.

Keywords: CHIRPS, GPM_IMERG, HEC-HMS, ArcGIS, Satellite Precipitation Product.

1. INTRODUCTİON

Rainfall plays a vital role in the survival of humans, animals, and plants. It is an essential constituent in describing climate and water resource availability. Yet, insufficient rainfall leads to drought and Mater scarcity, causing crop failure. Excess rain brings surface runoff that turns into floods. It might lead to extensive destruction, causing casualties and human losses and destroying private resources and significant public infrastructures like hospitals, schools, and governmental buildings. Accurate and reliable rainfall data will result in an excellent hydrological model. Still, existing and functioning onsite rain gauge stations failed to support a straight-up hydrological simulation, mainly due to many missing data and incorrect readings [1]. When simulating large basin hydrological models like the Shabelle basin with complicated topography, the rain gauge distribution networks often result in weak simulation results [2].

Therefore, knowing spatial and temporal rainfall distribution and its variations over time play a significant role in hydrological modeling and water budget estimations [3] better rainfall estimation through precise and accurate observation, the better the hydrological model performance. Correct and precise rainfall estimates or measures help flood forecasting systems, early flood warnings, and drought mitigation measures. Unfortunately, the measured rainfall data has low accuracy because of the lack of proper rain gauge networks and poor data collection, particularly in developing regions [4]. Ground-based rain gauge measurements are considered the actual rainfall and, if positioned correctly, will give a reliable and accurate rainfall-runoff model [5]. However, in developing countries, meteorological stations are not appropriately set, causing uncertainties that significantly affect hydrological model results. To prevent these challenges, [5] recommend using satellite-based precipitation.

In recent decades, open access precipitation products (OPPs) have contributed an assuring alternative for finding spatial and temporal rainfall variability and have been widely used for hydrological studies [2], [3]. In developing countries like Ethiopia, where rain gauge networks are scarce with limited rainfall data availability, satellite-based precipitation helps simulate reliable hydrological modeling.

Over the last few decades, many high-resolution satellite-based precipitation data have been uncovered and used for different hydrological studies to evaluate their performance [3]. The Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS) and Integrated Multi-SatellitE Retrieval for Global Precipitation Measurement (GPM-IMERG) are among the most used satellite-based rainfall products. CHIRPS is a “satellite-gauge” type rainfall product that gives an excellent spatial resolution of 0.050, which is equivalent to 30.32 km2 per one gauge station. This unique ideal resolution has helped the extensive use of CHIRPS recently. GPM

IMERG and CHIRPS Precipitation products are evaluated through both direct and indirect comparisons with station gauge-measured precipitation data and other products[6]–[9] Satellite-based remote precipitation products are rapidly progressing with better and high spatial resolutions providing them to be combined with additional in-situ data for field-level technological decisions[10] [11]. A recent study in Ethiopia by [5] assessed three satellite-based precipitation datasets and concluded that CHIRPS performed best among them. Several researchers have evaluated GPM-IMERG precipitation products with other satellite-based precipitation products and rain gauge station data [3], [7]. This study compares the ground-based rainfall data from the Ethiopian meteorological agency and SWALIM to the satellite-based IMERG and CHIRPS precipitation using HEC-HMS for model rainfall-runoff simulation. Spatial characteristics and model development of the study area are processed with the help of ArcGIS and HEC-GeoHMS.

2. MATERİALS AND METHOD

1.1 Study area

The Shebelle River originates at an elevation of about 4000 m.a.s.l. from the Bale Mountain ranges of the Galama and the Ahmar in Ethiopia. Shabelle basin is a transboundary river that starts from the Ethiopian highlands and ends in Somalia with a total catchment area of about 297,000 km^2 [13]. Initially, the river flows in the southern and eastern directions.

Areas surrounding the Shabelle river have an average annual rainfall of 425mm, although mountain areas and areas close to the border between Ethiopia and Somalia are about 1500 mm and 200mm, respectively[14].

Ethiopia possesses two-thirds of the Shabelle river, while Somalia possesses the remaining third. The length of the Shabelle River in Ethiopia, from its source to the Somali border, is approximately 1300 kilometers. Shabelle River spans an additional 1,236 kilometers of gently sloping terrain from Somalia's border before adding its water directly to the Indian Ocean.

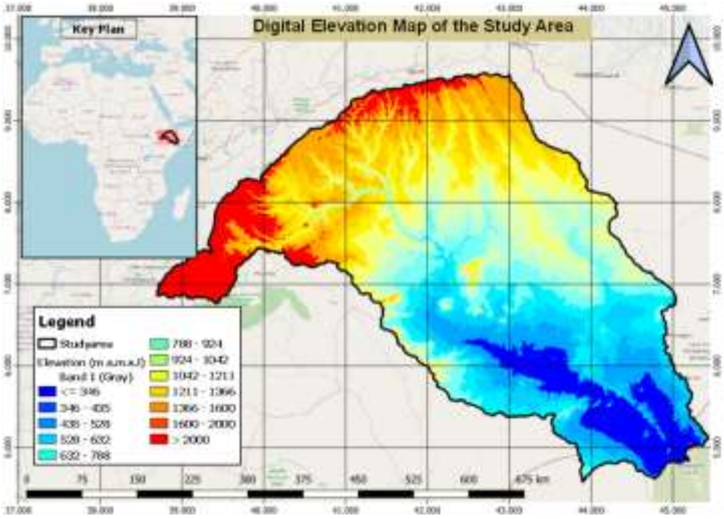

Fig. 1 Location and Digital Elevation Map of the Study Area

Somalia has had hydro-meteorological data since the 1950s, but due to the prolonged civil war, the hydro-meteorological stations could not collect data and record no data, leading to many gaps in rainfall and flow data.

1.2 Data Source and Processing

The fundamental data required for hydrological modeling using HEC-HMS comprised digital elevation model DEM -a primary input data for basin characteristics and delineation for HEC-GeoHMS, ground-based rain gauge station, CHIRPS precipitation data, and GPM-IMERG satellite-based precipitation product.

1.2.1 Digital Elevation Model (DEM)

A digital elevation model DEM represents the topography of the watershed. The DEM used for this study is SRTM (Shuttle Radar Topography Model) with 30m spatial resolution provided by the National Aeronautics and Space Administration (NASA) https://www2.jpl.nasa.gov/srtm/.

DEM delineates the watershed and helps define the basin characteristics and sub-basin parameters.

1.2.2 Ground-Based Gauge Station

This study uses daily rainfall data (2003-2016) from Ethiopian Meteorological Agency and SWALIM Somali Water and Land Information Management. Thirteen Insitu rain gauge stations- twelve in Ethiopia and one in Somalia-located in and around the Shabelle river were used to calculate the daily areal rainfall distribution estimation using the Thiessen polygon method, where lines are created with the help of ArcGIS software by joining all rain gauge stations in and around the catchment. Locations of the rain gauge stations are shown in Figure 3. After comprehensive and proper evaluations of observed rainfall and stream-flow data, fourteen years of data from Jan-2003 to Dec-2016 were considered and used for this study.

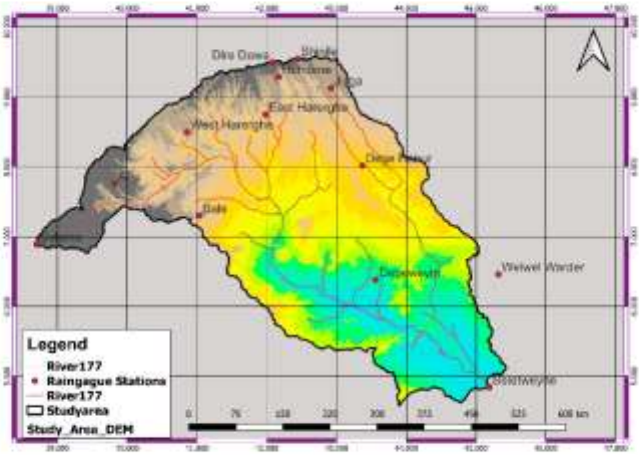

Fig. 2 Location of the upper stream rain gauge station on Shabelle River

1.2.3 CHIRPS precipitation data

CHIRPS (Climate Hazards Group InfraRed Precipitation with Stations data), developed by the U.S. Geological Survey Earth Resources Observation and Science Center, has been available since early 2014 [15]. The CHIRPS precipitation product provides high-resolution daily precipitation data at a spatial resolution of 0.050x0.050 ranging from 1981 to the present. The latest CHIRPS precipitation product is Version 2.0, released in Feb 2015 and available freely at http://chg.geog.ucsb.edu/data/chirps/ [5].

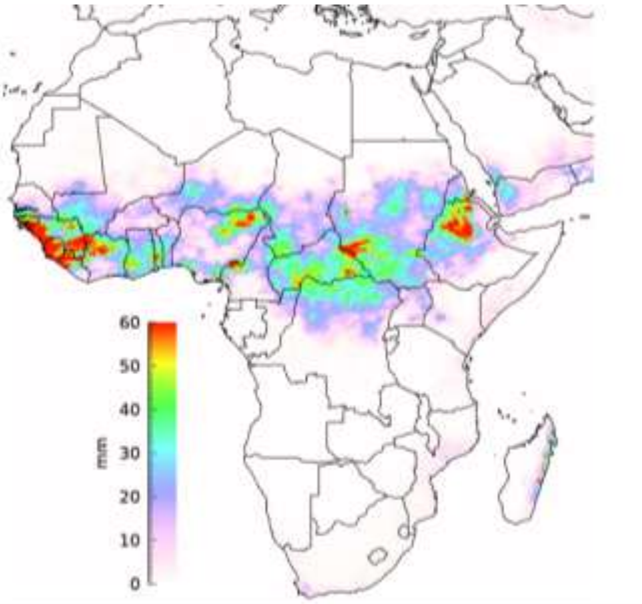

Fig. 3 Preliminary CHIRPS v2.0 Pentad 2021.07.4 (https://chc.ucsb.edu/data/chirps/)

1.2.4 GPM-IMERG precipitation data

The Integrated Multi-satellite GPM (IMERG) algorithm uses data from many GPM satellites to estimate the amount of precipitation falling over a large part of the Earth's surface, and this algorithm is especially useful for regions that do not have ground-based precipitation measuring instruments [16]. The spatial and temporal resolutions of GPM-IMERG precipitation estimations are 0.1° and 30 minutes, respectively. The GPM-IMERG precipitation data is accessible for free download at https://giovanni.gsfc.nasa.gov/giovanni/and http://pmm.nasa.gov/dataaccess/downloads/gpm. Map accumulated daily rainfall data of GPM_IMERG version 6 of the study area for the periods between (1st January 2003 to 30th December 2016) were downloaded via https://giovanni.gsfc.nasa.gov/giovanni.

1.2.5 Stream-gauge data

Somalia began recording its hydro-meteorological data with significant gaps in the early 1950s. Due to a protracted civil war and disturbance in the country, no data was collected between 1990 and 2000, creating a significant data gap. 2002 marked the beginning of SWALIM's restoration of data collection and rehabilitation of existing gauges. The quality of post-war data is superior but only lasts a few years. Thus, it may not be suitable for model calibration and validation. Since the outlet of the study area was chosen for Beletwayne, the stream gauge data for Beletwayne station was obtained from SWALIM. The period of stream gauge data used for this study is from January 2003 to December 2016. The discharge data is divided into two parts: 7 years of data for calibration and seven years for validation.

1.3 Hydrological Model

Recent advancements in Geographic Information Systems (GIS) have made hydraulic and hydrological modeling of a watershed system possible. Since many organizations, agencies, and private and public companies are now exchanging spatial information over the internet, integrating GIS with hydraulic and hydrological modeling gives a lot of ways to study, analyze, and understand the watershed system. HEC-HMS is free and open-source software that is GIS-compatible. HEC-HMS is composed of fundamental software management components.

A.Majidi has applied HEC-HMS to simulate precipitation and runoff by simulating and applying five different rainfall events. The model's calibration was performed using sensitivity studies and the optimization method. The lagtime was identified as a sensitive component, and the study concluded that HEC-HMS software can be used to model hydrologic simulations of Iran's Abnama watershed [17].

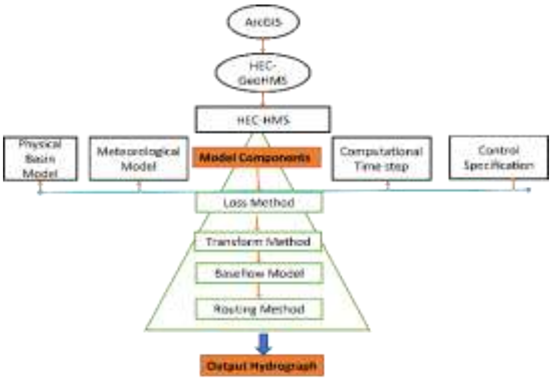

Figure 5 Major Component of the HEC-HMS model for this study

The HEC-HMS model was utilized to simulate and analyze rainfall-runoff effects on the Bagmaty basin in Vietnam. They found that the simulated peak discharge closely resembles the actual peak discharge [18].

In Illinois, Momcilo et al. used the HEC-HMS model and daily rainfall data as input parameters to look at changes in peak discharge caused by more rain at 12 different stations and found that the results were accurate [19].

1.4 Calibration and Validation

1.4.1 Calibration

To consider the results of a hydrological model accurate and sensible, the model parameters should be calibrated and validated using observed stream flow. The observed flow should be compared to the simulated flow to determine if the model works well with the observed flow and evaluate how well the model fits with the observed flow. In this study, the model parameters were calibrated to get reliable results, and the model fit better. Depending on the type of loss and transform method chosen to apply to the study, some parameters must be adjusted either manually or automatically. Calibration involves adjusting the parameters until the simulated model results best match the observed results. The period between January 2003 and December 2010 was considered the input calibration data, using the Clark unit's hydrograph as a transform method for the deficit and constant loss models.

1.4.2 Validation

The calibrated model parameters should also be validated to ensure that they perform well beyond the set discharge conditions used for calibration. In this study, fifty percent of the data was used for model calibration, and the other fifty percent was used for model validation. Thus, seven years of rainfall and discharge data (Jan 2003–Dec 2009) were used to calibrate the model, and the next seven years (Jan 2010–Dec 2017) were used for the model for validation.

1.5 Model Performance

The model's accuracy, consistency, and adaptability should be considered when evaluating its performance. This study examined how well the HEC-HMS model performed by visually comparing observed and simulated hydrographs and using objective functions to evaluate how similar the simulated and observed hydrographs were to each other. Moreover, statistical methods were used to determine how accurate and reliable the simulations of the models were compared to the observed values. Necessary statistical measures, such as the coefficient of determination (R2), percentage bias (PBIAS), Nash and Sutcliffe simulation efficiency (NSE), and root-mean-square error (RMSE), were used to evaluate how well the model performed. The HEC-HMS model's performance was evaluated by comparing the simulated and observed stream flow using the following criteria:

Nash and Sutcliffe simulation efficiency (NSE)

The Nash–Sutcliffe efficiency (NSE; Nash and Sutcliffe, 1970) is a frequently applied statistic, partly because it standardizes a model's performance on an understandable scale [20]. NSE is computed by

$$NSE = 1 - \frac{\sum_{t=1}^{N}[q_{obs}(t) - q_{sim}(t)]^2}{\sum_{t=1}^{N}[q_{obs}(t) - \overline{q}_{obs}]^2}$$

Where NSE is Nash-Sutcliffe Efficiency, N is the total number of time steps, qobs(t) is observed discharge at a time step t, qsim(t) is the simulated discharge at time step t, and (qobs)¯ is the mean observed discharge over the entire simulation period of length N. NSE ranges between − ∞ and 1, with the target value being NSE = 1. NSE = 1 shows an excellent similitude between the observed and simulated data; NSE = 0 indicates that the model simulations have the same explanatory power as the mean of the observations, and NSE < 0 suggests that the model is a poorer forecaster than the mean of the observations [20].

Coefficient of determination (R2)

The coefficient of determination (R2) quantifies how accurately a statistical model predicts a given result. The dependent variable of the model represents the outcome. The minimum possible value of R2 is 0, and the maximum value is 1. R2 is computed by

$$R^2 = \frac{\left[\sum_{i=1}^{n} (Q_{\text{sim},i} - \bar{Q}_{\text{sim},i})(Q_{\text{obs},i} - \bar{Q}_{\text{obs},i})\right]^2}{\sum_{i=1}^{n} \left[(Q_{\text{sim},i} - \bar{Q}_{\text{sim},i})\right]^2 \sum_{i=1}^{n} \left[(Q_{\text{obs},i} - \bar{Q}_{\text{obs},i})\right]^2}$$

Where Qsim,i is the simulated discharge at time step i, Qobs,i is the observed discharge at time step i, Q¯sim,i is the average simulated discharge, and Q¯obs,i is the average observed discharge.

Root-Mean-Square Error (RMSE)
The root mean squared error (RMSE) is the square root of the mean of all error squares. RMSE is extensively applied and is regarded as a good error measure for overall predicted values.

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (S_i - O_i)^2}$$

where n is the number of observed data accessible for analysis, Si is the simulated values of the data, and Oi is the observed data.
Percentage Bias (PBIAS)
The percentage of bias (PBIAS) measures the likelihood of the average predicted value being bigger or smaller than the average observed value. The best value for PBIAS% is 0, and small values show that the simulation model is accurate. Overestimation is shown by a negative value, whereas positive values indicate underestimation. The percentage of bias is estimated by

$$\text{PBIAS} = \frac{\sum_{i=1}^{n} (Q_{o,i} - Q_{s,i})}{\sum_{i=1}^{n} (Q_{o,i})} \times 100$$

Recommended statics model performance ratings from [21] and [22] were used for the result interpretation.

Table 1. Recommended statistics model performance rating [22]

Performance rating	NSE	R^2
Very Good	0.75 to 1.0	0.75 - 1.0
Good	0.65 to 0.75	0.65 - 0.75
Satisfactory	0.50 to 0.65	0.50 - 0.65
Unsatisfactory	<0.5	<0.5

3. RESULTS

a. Comparison of in-situ and satellite precipitation products

This study collected precipitation data from ground rainfall gauges and two satellite-based precipitation products, GPM IMERG and CHIRPS 2.0, over a 14-year period, from 2003 to 2016. Based on mean values, the GPM_IMERG precipitation product overestimates the rainfall data of the basin, whereas the CHIRPS2.0 precipitation product slightly underestimates. There was less discrepancy between the station rain gauge and satellite-based rainfall data, resulting in less change in rainfall estimates over time. CHIRPS_2 precipitation products performed better in capturing annual precipitation patterns than GPM_IMERG satellite precipitation products. The estimated average rainfall from the two satellite precipitation products, CHIRPS and GPM_IMERG, and station rain gauges was 428mm, 439mm, and 443mm, respectively.

Table 2. Summary of daily ground rain-gauge and satellite-based precipitation products

Type of Precipitation Data	Min (mm)	Max (mm)	Mean (mm)	Std. dev	CV
Ground Data	0.00	428.80	96.79	83.89	0.87
CHIRPS Product	0.00	439.50	90.48	85.12	0.94
GPM_ IMERG Product	0.00	443.80	116.14	90.55	0.78

Based on the determination coefficient R2 and Nash and Sutcliffe simulation efficiency (NSE), CHIRPS precipitation products outperform GPM_IMERG, which has an R2 of 0.93 and an NSE of 0.90, respectively, whereas GPM_IMERG products have an R2 0.8 and an NSE of 0.79. Both satellite-based precipitation products perform very well according to the ranges [23], but CHIRPS_2 precipitation products provide the best results.

Table 3. R2 and NSE results for In-situ, CHIRPS, and GPM_IMERG products.

Rainfall Type	Coefficient of determination R2	Nash and Sutcliffe simulation efficiency (NSE)
In-situ vs CHIRPS Product	0.93	0.90
In-situ vs GPM_IMERG Product	0.8	0.79

Figure 6 shows the CHIRPS_2 mean monthly rainfall map for a period of fourteen years (January 2003– December 2016) in the study area. The R software evaluated CHIRPS data downloaded from http://chg.geog.ucsb.edu/data/chirps/.

Highlands and lowlands have different mean monthly precipitation. Upstream precipitation increases throughout the rainy season. The typical monthly precipitation for the months of

March, April, June, July, and August ranges from 40 to 200 millimeters. November, December, and January show the lowest mean monthly rainfall of a maximum of 40 mm for the entire basin.

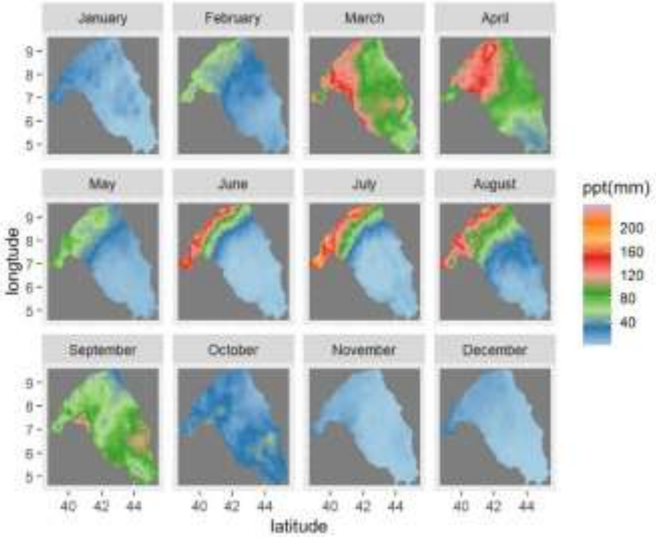

Fig. 6 CHIRPS Mean Monthly Rainfall Data (2003-2016)

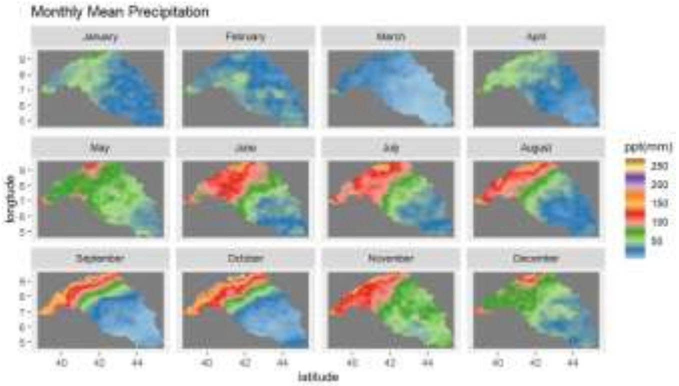

Fig. 7 GPM_IMERG Mean Monthly Rainfall Data (2003-2016)

Figure 7 displays the study area's GPM_IMERG mean monthly rainfall map for fourteen years (January 2003–December 2016), downloaded from https://giovanni.gsfc.nasa.gov/giovanni and analyzed with the R program. It shows higher precipitation from May to December, and from January to April, it shows lower precipitation. The maximum mean monthly rainfall from GPM_IMERG satellite-based precipitation products is estimated at around 240 mm in September, October, and November.

Figure 8 displays the station gauge rainfall data for fourteen years (January 2003 to December 2016). Daily, monthly, and annual time series boxplot and histogram analyses were done using the R program. From the monthly time series and boxplot, it can be seen that there is an increase in precipitation from March to May, which is a rainy season, and again from September to November, which is another rainy season.

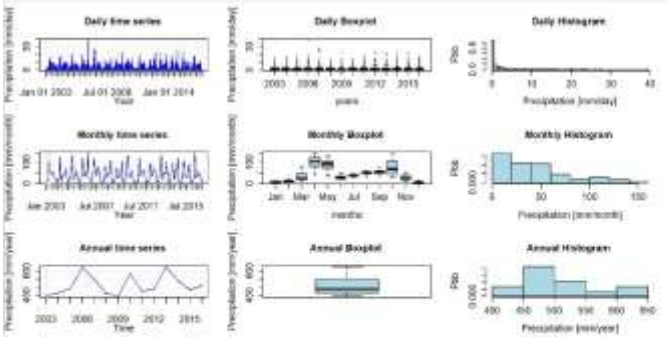

Fig. 8 Station Gauge Precipitation Analyse

Figure 9 shows the CHIRPS precipitation products analysis, whereas figure 10 shows the GPM_IMERG satellite precipitation product analysis. The two satellite-based precipitation and in-situ rain gauge analyses show that April and October have the highest rainfall records. The annual boxplot shows precipitation of 525 mm/year, 566 mm/year, and 477 mm/year from the in-situ rain gauge, CHIRPS, and GPM_IMERG precipitation products, respectively. Based on the annual time series, the CHIRPS product overestimates the annual precipitation, while the GPM_IMERG product underestimates it.

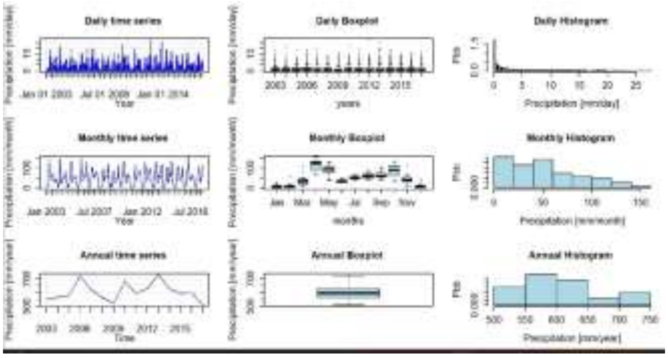

Fig. 9 CHIRPS Satellite Precipitation Analyse

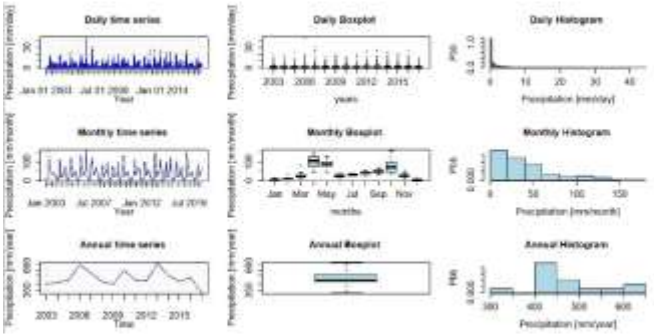

Fig. 10 GPM_IMERG Satellite Precipitation Analyse

b. HEC-HMS Model Results

i. Model Calibration Results

HEC-HMS, which has been utilized successfully for more than 30 years, was applied in this study to evaluate the hydrological performance of the model. In this study, the hydrological model was calibrated over a period of seven years (January 2003–December 2009) using ground-measured rainfall data and two satellite-based precipitation products (CHIRPS and GPM_IMERG). The hydrological model performance of the calibrated data was evaluated using the determination of coefficient (R2), the root means square error (RMSE), the Nash and Sutcliffe simulation efficiency (NSE), and the percent bias of the ground measured data, and the two satellite precipitation products (CHIRPS and GPM_IMERG). The results showed good performance between the observed flow and the simulated flow, with an R2 of 0.68, 0.66, and 0.64 for the simulated station flow, simulated GPM_IMERG flow, and simulated CHIRPS flow, respectively, throughout the calibration period. The results also indicated ENS of 0.65, 0.63, and 0.61 of the simulated station flow, simulated GPM_IMERG, and simulated CHIRPS flow over the calibration period, respectively. The determination of coefficient R2 shows that the simulated station and GPM_IMERG flow results are in a good range, whereas the simulated CHIRPS results are within the satisfactory range. According to the NSE results, only the simulated flow is within the scope of good performance, whereas the simulated CHIRPS and GPM IMERG are within the satisfactory range. Table 4 provides a summary of the model evaluation performance results.

Figure 11 compares the observed flow hydrograph to the simulated station, CHIRPS, and GPM_IMERG flow hydrographs over the calibration period (Jan 2003–Dec 2009). Figures 12, 13, and 14 show the R2 comparison results between the observed flow and the simulated station flow, simulated CHIRPS flow, and simulated GMP_IMERG flow, respectively, over the calibration period.

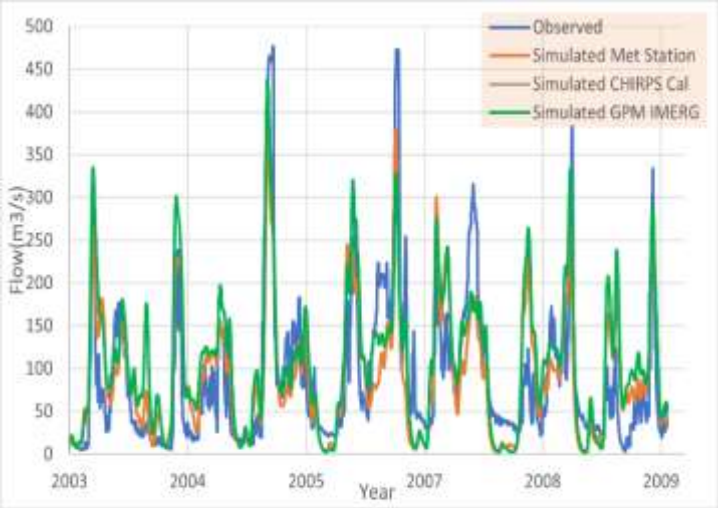

Fig. 11 Calibration of results of Observed and Simulated flow over the calibration period

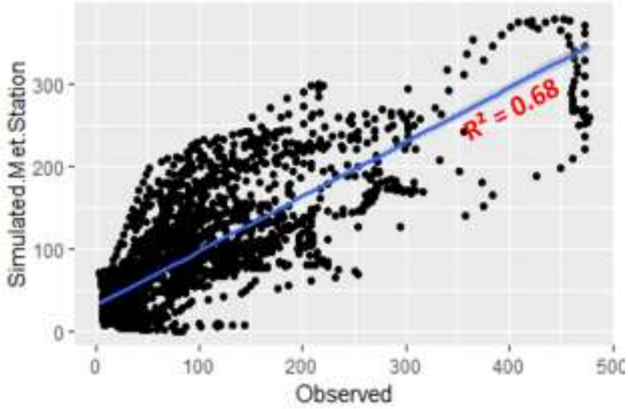

Fig. 12 Comparison observed flow vs Simulated met station flow over the calibration period (Jan 2003 – Dec 2009)

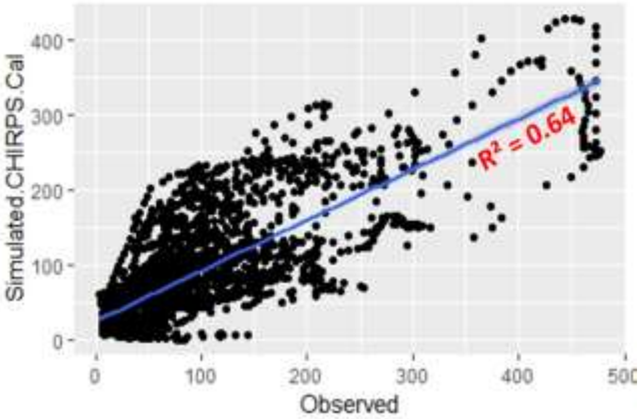

Fig. 13 Comparison observed flow vs Simulated CHIRPS flow over the calibration period (Jan 2003 – Dec 2009)

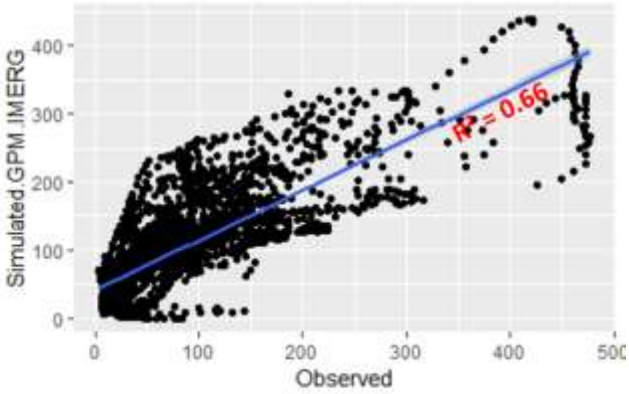

Fig. 14 Comparison observed flow vs Simulated GPM_IMERG flow over the calibration period (Jan 2003 – Dec 2009)

Table 4. Model performance evaluation results of the calibrated data

01Jan2003-30Dec2009	**Model Performance Evaluation of the Calibrated data**			
	R2	**NSE**	**RMSE**	**Percent Bias**
Met Station Data	0.68	0.65	0.6	0.58%
CHIRPS	0.64	0.61	0.6	5.30%
GPM IMERG	0.66	0.63	0.7	18.90%

Based on the observed and simulated station, CHIRPS, and GPM IMERG flow results for the calibration periods (2003-2009) and the guidelines given by [17]. for hydrological model performance evaluation, the HEC-HMS model was rated as "good" and "satisfactory" for the Shabelle basin of this study.

ii. Model Validation results

After calibrating the observed flow against the simulated flow of various precipitation products (station, CHIRPS, and GPM IMERG), validation was performed to determine if the calibrated parameter produced superior results. A seven-year validation period (January 2010–December 2016) was done by comparing the observed flow values to the simulated flow hydrographs.

The validation results of the observed, simulated station flow, simulated CHIRPS flow, and GPM IMERG flow hydrograph are shown in Figure 15.

The same model performance evaluation criteria were used, and R2 values of 0.78, 0.76, and 0.74 were obtained for the simulated station flow, simulated CHIRPS flow, and simulated GPM IMERG flow, respectively. Excellent NSE results of 0.75, 0.71, and 0.75 were also found. The model shows that it performed well during the validation period. The simulated GPM_IMERG percent bias results are very good, whereas the simulated CHIRPS overestimates the flow.

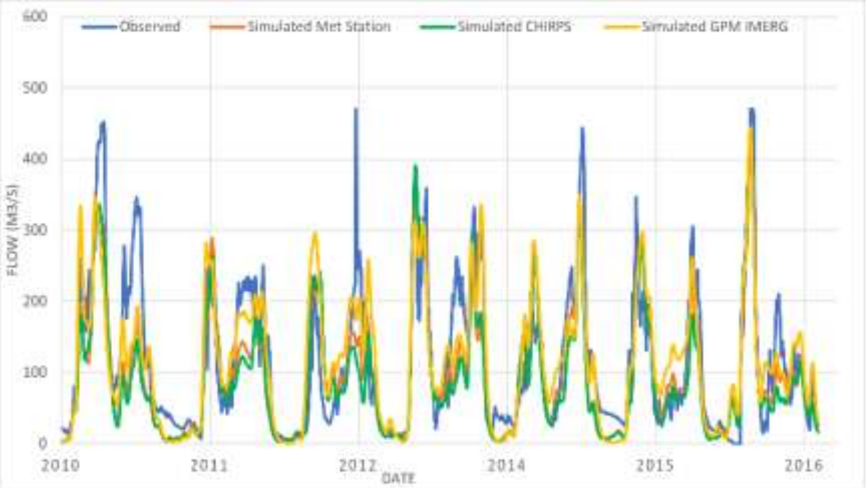

Fig. 15 Validation of results of Observed and Simulated flow over the validation period (Jan 2010- Dec 2016)

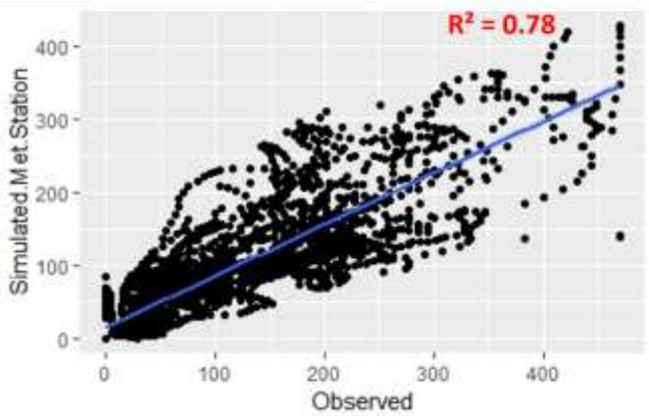

Fig. 16 comparison of observed flow and simulated ground-based rainfall measurement for the validation period (Jan 2010– Dec 2016)

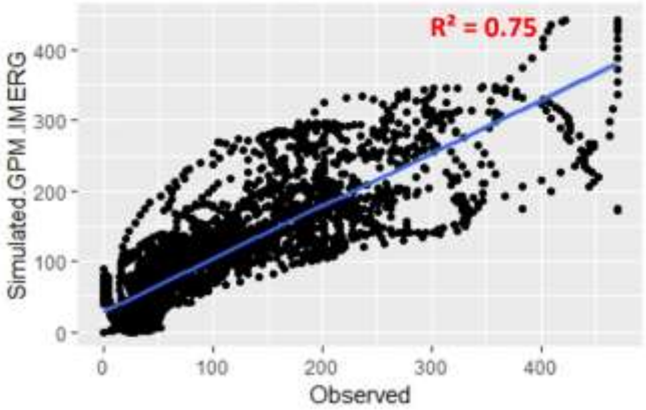

Fig. 17 comparison of observed flow and simulated GMP_IMERG flow for the validation period (Jan 2010– Dec 2016)

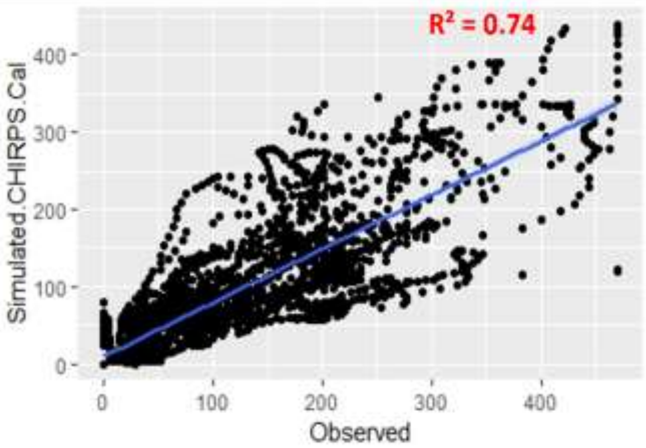

Fig. 18 comparison of observed flow and simulated CHIRPS flow for the validation period (Jan 2010– Dec 2016)

Table 5. Model performance evaluation results of the validated data

01Jan2010-30Dec2016	**Model Performance Evaluation of the validated data**			
	R2	**NSE**	**RMSE**	**Percent Bias**
Met Station Data	0.78	0.75	0.6	-16.69%
CHIRPS	0.74	0.71	0.6	-22.12%
GPM IMERG	0.76	0.75	0.5	-0.03%

4. DISCUSSION

The study compares the rainfall data over a period of fourteen years (January 2003- December 2016) to evaluate the performance between in-situ recorded rainfall data from the meteorological stations and two satellite-based precipitation products (CHIRPS and GPM_IMERG). The data was divided in two; data for calibration (January 2003-December 2009) and data for model validation (January 2010 to December 2016). Statistical model performance evaluation was done using Nash–Sutcliffe efficiency (ENS), coefficient of determination (R2), Root Mean Square Error (RMSE), and percentage bias objective functions. According to [23], both satellite-based precipitation products show very good results for model calibration and validation. The three precipitation products (Ground-based rainfall, CHIRPS, and GPM_IMERG precipitation products) were analyzed statistically before applying to the model.

CHIRPS precipitation products show an R2 of 0.93 and an NSE of 0.90 "Very Strong" compared to ground-based rainfall observation, whereas GPM_IMERG products have an R2 of 0.8 and an NSE of 0.79. The results showed that the two remote sensing precipitation products (CHIRPS and GPM_IMERG) correlated significantly with in-situ rain gauge observations.

The HEC-HMS model applied to this study showed “very good” results both during the calibration and validation of the observed flow hydrographs and the simulated flow hydrographs of the simulated ground station rainfall observation, simulated CHIRPS, and the simulated GPM_IMERG.

Tables 4 and 5 demonstrate that the model successfully captured the time series of stream flow and its trend through the calibration and validation periods. The results showed very good performance in terms of R^2 and NSE results. Simulated station results showed an R^2 of 0.68 (good) and 0.78 (very good), and NSE of 0.65 (good) and 0.75 (very good) for the calibration and validation period, respectively. The simulated GPM_IMERG flow results showed an R^2 of 0.66 (good), 0.76 (very good), and NSE of 0.63 (satisfactory), 0.75 (very good) for the calibration and validation, respectively. The simulated CHIRPS flow result displayed an R^2 of 0.64 (satisfactory), 0.74 (good), and NSE of 0.61 (satisfactory), and 0.71 (good) for the calibration and validation, respectively. The results are inconsistent with the finding of [6], which was done in Crime. The results also show that GPM_IMERG outperforms CHIRPS in the model calibration and validation, which agrees with the finding of (crime). The results display that the hydrological model performs very good during the validation period than the calibration period, which contradicts the study done by [20] in Ethiopia.

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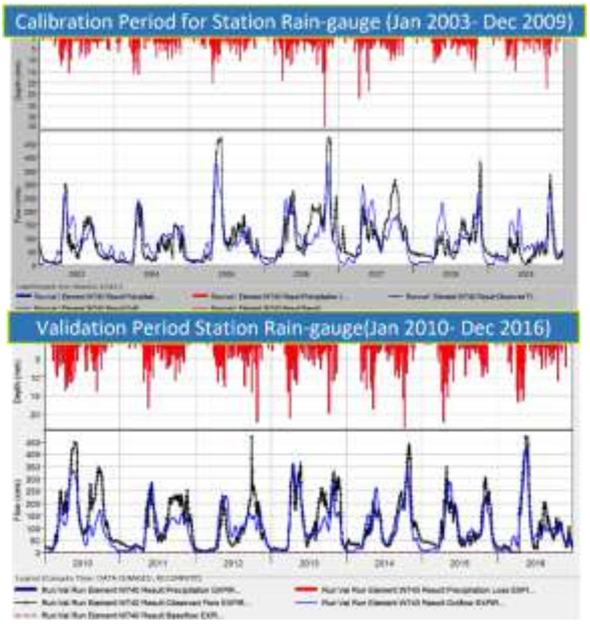
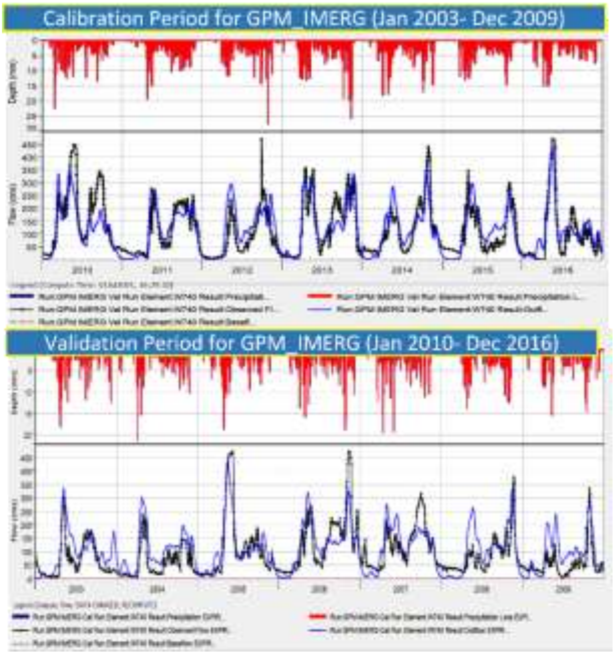

Calibration Period for Station Rain-gauge (Jan 2003- Dec 2009)

Validation Period Station Rain-gauge(Jan 2010- Dec 2016)

Fig. 19 Observed and simulated flow hydrograph of Shabelle River using ground-based rainfall observations for the calibration and validation period


Calibration Period for GPM_IMERG (Jan 2003- Dec 2009)

Validation Period for GPM_IMERG (Jan 2010- Dec 2016)

Fig. 20 Observed and simulated flow hydrograph of Shabelle River using GPM_IMERG for the calibration and validation period

Figures 19, 20, and 21 compare the observed flow hydrograph and the simulated station flow, the simulated CHIRPS flow, and the simulated GPM_IMERG flow hydrographs, respectively, for both the model calibration and validation period.

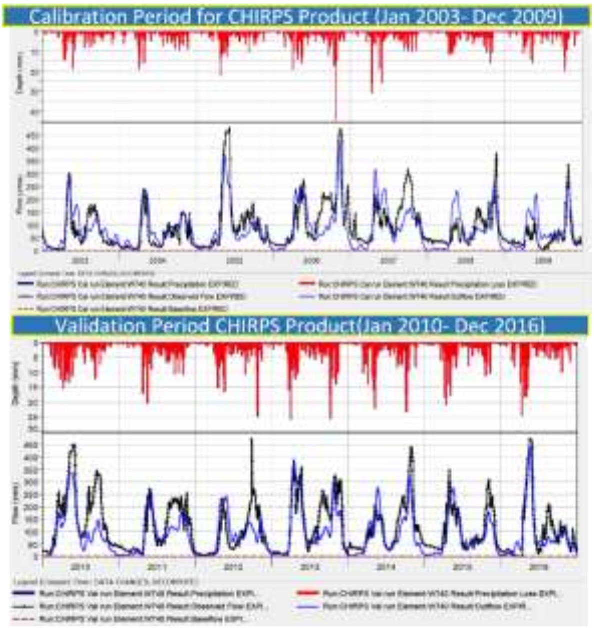


Fig. 21 Observed and simulated flow hydrograph of Shabelle River using CHIRPS for the calibration and validation period

5. CONCLUSION

The HEC-HMS model is used in the study to evaluate the hydrological model's performance. The study compared ground-based rainfall observations from the Ethiopian Meteorological Agency and the Somali Water and Land Information Management (SWALIM) to two remote sensing precipitation products (CHIRPS and GPM IMERG). The data were collected between January 2003 and December 2016, with the first half (January 2003–December 2009) calibrating the model and the second half (January 2010–December 2016) being used to validate the model. The rainfall-runoff simulation was modeled using HEC-HMS software, and the spatial aspects of the study area and model development were handled using ArcGIS and HEC-GeoHMS. The 14 years of precipitation and discharge data available were split into seven years for calibration and seven years for validation. The performance of the satellite precipitation was evaluated using the Nash-Sutcliffe efficiency (ENS), coefficient of determination (R2), root mean square error (RMSE), and percentage bias objective functions. CHIRPS precipitation products outperform GPM IMERG in terms of R2 and Nash-Sutcliffe simulation efficiency (NSE), with an R2 of 0.93 and an NSE of 0.90, respectively, whereas GPM IMERG products have an R2 of 0.8 and an NSE of 0.79. The R program was used to perform daily, monthly, and annual time series boxplot and histogram analyses. The monthly time series and boxplot show that precipitation increases from March to May, a wet season, and again from September to November, another rainy season.

According to the ranges, both satellite-based precipitation products perform admirably.

The study found that the HEC-HMS model functioned well and produced very good results for the CHIRPS and GPM IMERG rainfall products. According to the study, the model performed effectively over the validation period. Overall, the study discovered that the simulated GPM IMERG product outperformed the simulated CHIRPS product.

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