



## Performance Evaluation of Satellite Rainfall Data in the Bheri River Basin, Nepal

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Received date: 09 April, 2024, Manuscript No. JHHE-24-145270;

Editor assigned date: 12 April, 2024, PreQC No. JHHE-24-145270 (PQ);

Reviewed date: 29 April, 2024, QC No. JHHE-24-145270;

Revised date: 06 February, 2025, Manuscript No. JHHE-24-145270 (R);

Published date: 13 February, 2025, DOI: 10.4172/2325-9647.1000364.

### Abstract

Nepal is a mountainous country with very difficult terrain so, there are not available Meteorological stations. In such conditions, Satellite Precipitation Products (SPPs) can be used for water resources studies. The Bheri River Basin is studied in this research. Hydrological model is developed for the Bheri River Basin using HEC-HMS. Calibration and Validation was done with ground rainfall data at two stations, Jamu and Samaijghat. For the calibration, the values of NSE, PBIAS and  $R^2$  were 0.73, -12 and 0.77 at Jamu and 0.80, -5.5 and 0.83 at Samaijghat. For the validation, the values of NSE, PBIAS and  $R^2$  were 0.70, 0.3 and 0.72 at Jamu and 0.80, -3.9 and 0.81 at Samaijghat. For the same model, performance of the model was evaluated by measuring NSE, PBIAS and  $R^2$  by providing bias adjusted GPCP1DD rainfall data which resulted in satisfactory model performance at Jamu and good at Samaijghat.

**Keywords:** SPPs; Bheri River Basin; GPCP1DD; Bias adjusted; Calibration; Validation

### Introduction

Understanding the hydrological processes taking place in a river basin is aided by hydrological modeling of the basin. With the development of multiple types of hydrological models, scenario analysis and hydrological simulations of watershed dynamics have become more practical. Hydrological models such as HEC-HMS, SWAT, MIKE-SHE, HBV, etc. are available [1]. HEC-HMS stands for Hydrologic Engineering Center-Hydrologic Modeling System, developed by the US Army Corps of Engineers [2]. The entire hydrologic cycle of dendritic watershed systems is simulated by HEC-HMS [2].

Nepal is a Mountainous country. Nepal lies in between latitude  $26^{\circ} 22' N$  to  $30^{\circ} 27' N$  and longitude  $80^{\circ} 4' E$  to  $88^{\circ} 12' E$ . The geographical topography of Nepal is very different within small distance. So, there is high variation in rainfall pattern. The availability of data for hydrological modeling is limited by poorly spaced rainfall gauge networks and small number of observation years in remote and

hilly areas [3]. Satellite based rainfall data are widely utilized because they are easily available and can address the limitations of ground rainfall gauge stations. Some of the examples of satellite based rainfall data are Integrated Multi-satellite Retrievals for GPM (IMERG), Tropical Rainfall Measuring Mission (TRMM) Multisatellite Precipitation Analysis (TMPA), Climate Hazards group InfraRed Precipitation with Stations (CHIRPS) and Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks for Climate Data Record (PERSIANN-CDR) [4].

Several studies of SPPs have been studied in different parts of Nepal for their applicability. In different elevation range of Nepal, among PERSIANN-CDR, TMPA, IMERG and CHIRPS, the performance of PERSIANN-CDR was good than other rainfall products [4]. The performance of APHRODITE and MSWEP V2.8 were better than CHIRPSV2.0 in the Arun river basin. In the Karnali river basin, the TMPA product was found to be used as an alternative rainfall product. In West Rapti river basin, among various SPPs the performance of IMERG was found best. The applicability of different precipitation products has been studied in different river basins of Nepal but it is found that Global Precipitation Climatology Project One-Degree daily precipitation product has not been studied. Studying the strength of GPCP-1DD in nearby regions, among 10 different SPPs, GPCP-1DD performed well in the Chitral River Basin, Pakistan. Among TMPA, PERSIANN-CDR and GPCP-1DD, GPCP-1DD outperformed than others in the Vietnam river. So, this research aims to fill the research gap by evaluating the performance of GPCP-1DD.

Considering agriculture and water resource, the Bheri river basin is an important basin of Nepal. Different water resource projects are in developing phase in this basin. So, the applicability of GPCP-1DD in the Bheri river basin will be studied in this research.

### Materials and Methods

#### Study area

The Bheri River basin lies in between latitude  $28^{\circ} 20' N$  to  $29^{\circ} 25' N$  and longitude  $81^{\circ} 16' E$  to  $83^{\circ} 41' E$ . The Bheri river is one of the major tributaries of the Karnali river. Its length is about 400 km long. The area of the Bheri river basin is 13,870 sq km [5]. The three main tributaries of the Bheri river are Thuli Bheri, Sani Bheri and Uttar Ganga. The Bheri river is fed by rainfall and snow melt from mountain [5]. Figure 1 shows the study area of the Bheri river basin.

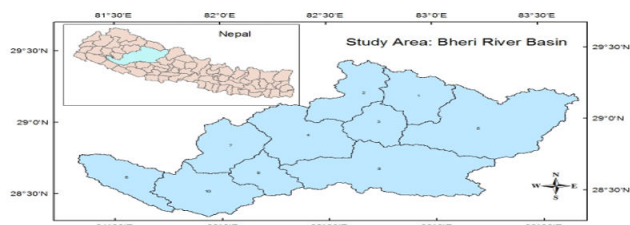


Figure 1: Study area.

Digital Elevation Model (DEM) is a prerequisite for basin modeling [6]. It represents ground surface terrain in digital format. Different properties of basin like Basin area, River length, basin slope, etc., are extracted from DEM and are applied in HEC-HMS model.

A 30 m resolution raster DEM was used for this study, developed by USGS (United States Geological Survey). The projected coordinate system of this study is WGS 1984 UTM Zone 44 N. The DEM of the Bheri river basin is shown in the Figure 2 below.

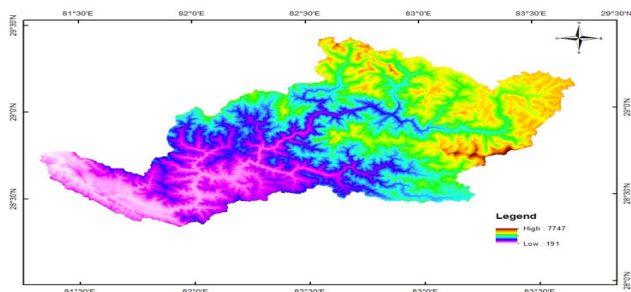


Figure 2: DEM of the Bheri river basin at Jamu.

S. no.	Station no.	Location	Latitude	Longitude	Elevation (m.)	Data range
1	269.5	Samaijghat	28° 31' 02" N	81° 39' 25" E	500	1997-2006
2	270	Jamu	28° 45' 20" N	81° 21' 00" E	246	1997-2006

Table 1: Hydrological stations in Bheri river basin.

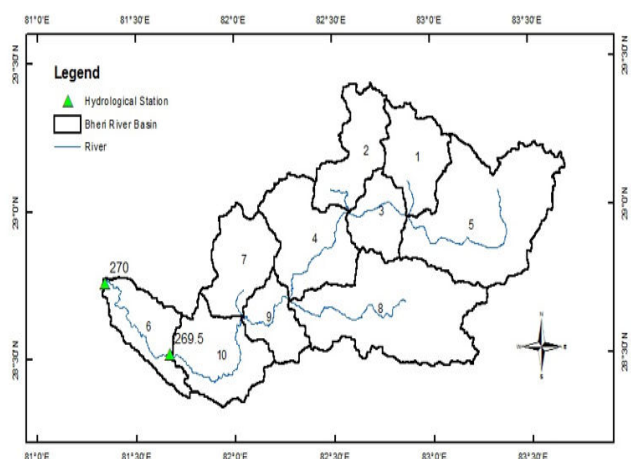


Figure 3: Hydrological stations in Bheri river basin.

The methodology for obtaining the main objective of the study is divided into three steps. First step consists of extraction of GPCP-1DD rainfall data and evaluating those data with respect to ground rainfall data based on the statistical indices. Second step consists of determining the applicability of GPCP-1DD rainfall by simulating GPCP-1DD rainfall data in the calibrated hydrological model and comparing its result with the observed discharge and finally, evaluating the energy generation of selected hydropower projects from GPCP-1DD rainfall data with respect to simulated ground rainfall data. The overall methodology for the completion of this study is given in the Figure 4.

## Data

For evaluating the performance of GPCP-1DD with ground rainfall gauge stations data, daily rainfall data from the period of 1<sup>st</sup> Jan 1997 to 31<sup>st</sup> Dec 2015 has been selected (Table 1). Ground rainfall stations data are obtained from Department of Hydrology and Meteorology (DHM), Nepal and rainfall data of GPCP-1DD is downloaded from website (Figure 3) [7].

The hydrological stations used for the study are:

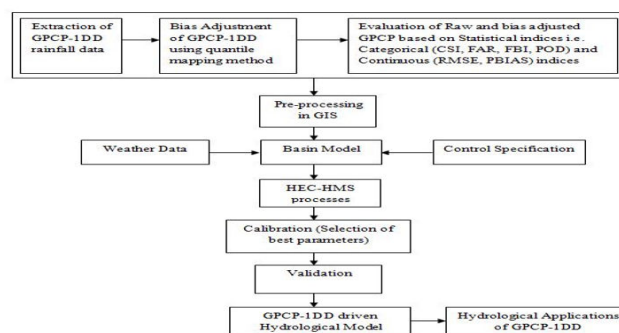


Figure 4: Methodological framework.

## Evaluation of GPCP-1DD rainfall

**Extraction of GPCP-1DD rainfall:** We downloaded the rainfall data of GPCP-1DD from [7]. Then, we extracted the required rainfall data for the same location of the ground rain gauge stations of the Bheri river basin.

**Bias Adjustment of GPCP-1DD:** Random biases are expected to exist in raw SPPs. Therefore, bias adjustment is applied to SPPs prior to evaluation. We have used Climate Data Bias Corrector (CDBC) tool to remove the existing bias in raw rainfall data. The CDBC tool uses quantile mapping technique for bias adjustment. After correcting the bias in Global Climate Model (GCM) rainfall data using this tool, the performance was good with respect to the ground rainfall data [8]. This tool can be downloaded for free on GitHub website [9].

**Evaluation of raw GPCP and bias adjusted GPCP:** Evaluation of GPCP-1DD rainfall has been done based on statistical indices *i.e.*, Categorical Statistical Indices (CSI, FAR, FBI and POD) and continuous statistical indices (RMSE and PBIAS).

In terms of measures relating to performance, we have assessed how well Satellite Precipitation Products (SPPs) detect precipitation in

comparison to different measurements from rain gauges. The following criteria are used to identify heavy precipitation:

- "True" when a daily rainfall of  $\geq 1$  mm is shown by both SPPs and rain gauge data.
- "False" when GPCP indicate rainfall in non-rainy days with respect to observed rainfall
- "Miss" when GPCP does not detect rainy days with respect to observed rainfall
- "Inclusive" when both GPCP and ground rainfall data detects daily rainfall  $< 1$  mm

With the above criteria CSI, FAR, FBI and POD are calculated as follows:

- Critical Success Index,  $CSI = T / (T + M + F)$
- False Alarm Ratio,  $FAR = F / (T + F)$
- Frequency Bias Index,  $FBI = (T + F) / (T + M)$
- Probability of Detection,  $POD = T / (T + M)$

In the above parameters, T means True, F means False and M means Miss.

And the continuous statistical indices are evaluated by following measures:

**Root Mean Square Error (RMSE):** By comparing the variations between the GPCP rainfall and observed rainfall, RMSE gives information on the performance of GPCP [10-15]. Smaller the value of RMSE better is the performance of GPCP. It is calculated by:

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (GPCP_i - Observed_i)^2}{n}}$$

where,  $GPCP_i$  and  $Observed_i$  are individual rainfall data of GPCP and ground station and n is the total number of data

**Percent Bias, PBIAS:** PBIAS measures the mean difference between GPCP and observed rainfall data and evaluates the performance of GPCP with respect to observed rainfall [16]. It is calculated by:

$$PBIAS = \frac{\sum_{i=1}^n (GPCP_i - Observed_i)}{\sum_{i=1}^n Observed_i}$$

where,  $GPCP_i$  and  $Observed_i$  are individual rainfall data of GPCP and ground station

### Assessing the performance of GPCP-1DD in hydrological model

For assessing the applicability of GPCP-1DD, we evaluated the performance of this rainfall data in HEC-HMS model. First of all, the hydrological model of the Bheri river basin is developed by confirming calibrating and validating process with the observed data [17]. Then, the model is driven with GPCP data as an input and evaluation is done on the basis of performance parameters of the simulated discharge with respect to observed discharge (Figure 5).

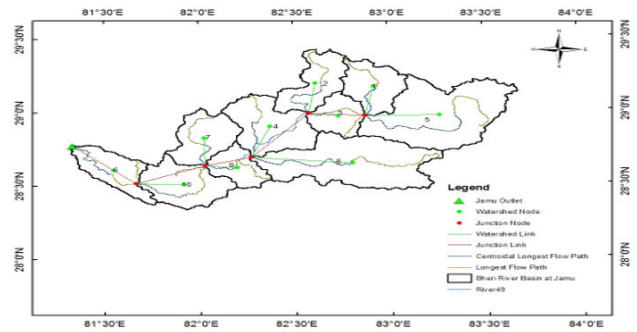


Figure 5: HEC-HMS model of the Bheri river basin.

## Result and Discussion

### Evaluation of raw GPCP and bias adjusted GPCP

The box plot of categorical statistical indices and continuous statistical indices for the evaluation of performance of raw GPCP and bias adjusted GPCP is shown the Figure 6 below:

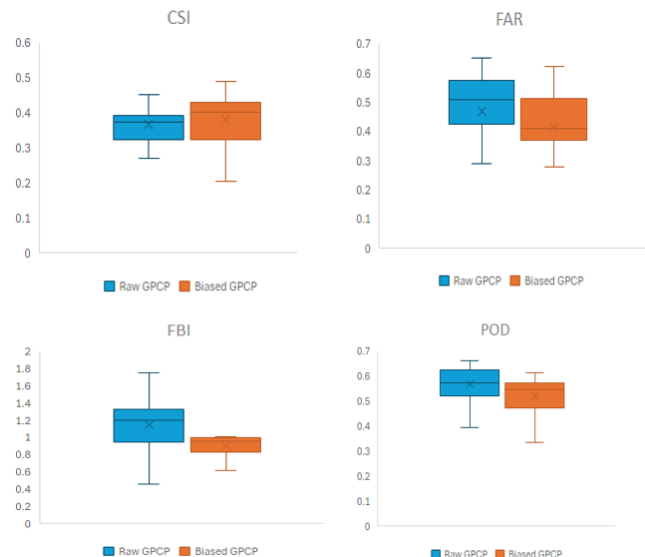
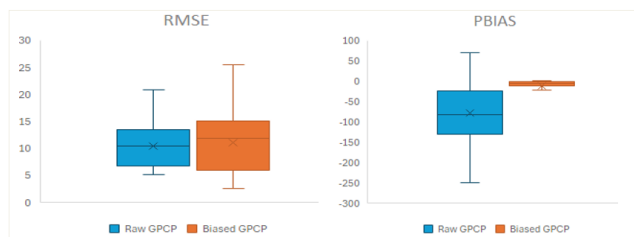


Figure 6: Categorical statistical indices for raw and bias adjusted GPCP.

From above Figure 6, bias adjusted GPCP has better critical success index than raw GPCP while for detection of rainfall event, raw GPCP performed better than bias adjusted GPCP. Considering false alarm ratio, bias adjusted GPCP has lower value of FAR than raw GPCP which means bias adjusted GPCP has lower false detection of rainfall than raw GPCP. As FBI of raw GPCP is greater than 1, raw GPCP has overestimation of rainfall events [18].

From Figure 7, it is seen that in terms of both RMSE and PBIAS, bias adjusted GPCP showed better performance than raw GPCP.

So, from the overall evaluation of performance based on statistical indices, bias adjusted GPCP showed better performance and hence it is used for further study in hydrological model [19].



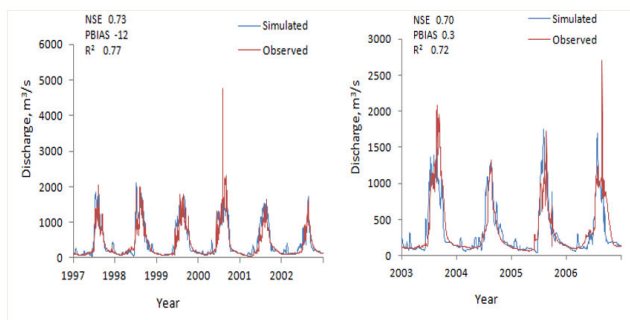
**Figure 7:** Continuous statistical indices for raw and bias adjusted GPCP.

### Effectiveness of biased GPCP for hydrological application

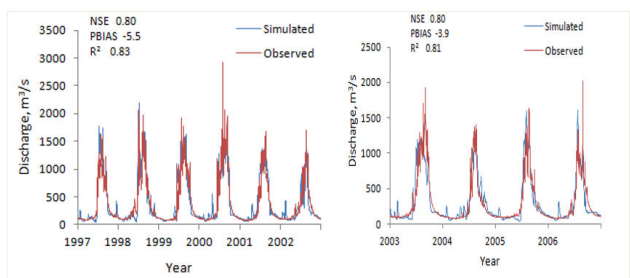
The precipitation data of biased adjusted GPCP and observed data were driven in the model for determining their effectiveness for reproducing hydrological conditions. The step wise process is given below:

**Calibration and validation of the model:** For the calibration of the model, simulation was done from 1<sup>st</sup> January 1997 to 31<sup>st</sup> December 2002 and for the validation of the model, simulation was done from 1<sup>st</sup> January 2003 to 31<sup>st</sup> December 2006 at Jamu and Samaijghat stations respectively. The result is shown below:

From the below Figure 8, it is seen that model was calibrated at Jamu with NSE, PBIAS and  $R^2$  values as 0.73, -12 and 0.77 respectively and validated with NSE, PBIAS and  $R^2$  values of 0.7, 0.3 and 0.72 respectively [20]. Similarly, from Figure 9, for Samaijghat station, model was calibrated with NSE, PBIAS and  $R^2$  values as 0.8, -5.5 and 0.83 respectively and validated with NSE, PBIAS and  $R^2$  values of 0.8, -3.9 and 0.81 respectively. This addresses the model performance was very good at both stations.

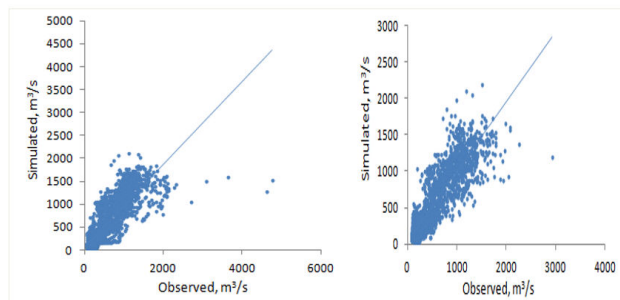


**Figure 8:** Calibration and validation at Jammu.



**Figure 9:** Calibration and validation at Samaijghat.

From Figure 10, the scatter plot between the simulated and observed discharge at Jamu and Samaijghat stations can be seen which resulted good correlation [21].

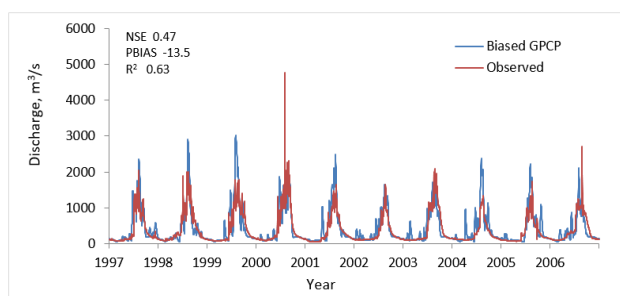


**Figure 10:** Scatter plot of simulated and observed discharge at Jamu and Samaijghat.

### Performance of model with biased adjusted GPCP

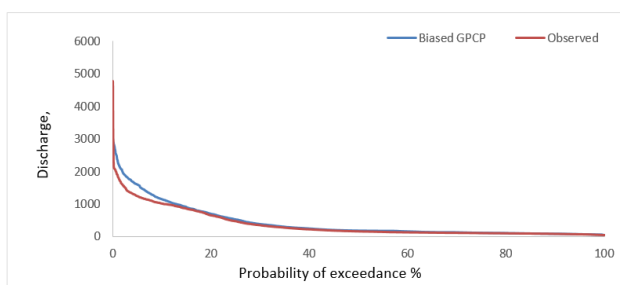
The daily rainfall data of bias adjusted GPCP was driven in the calibrated model for determining its performance. The performance of the model with its rainfall data as an input is shown below.

From the below Figure 11, bias adjusted GPCP driven model at Jamu showed NSE, PBIAS and  $R^2$  values of 0.47, -13.5 and 0.63 respectively. This addressed satisfactory performance of the model at Jamu with bias adjusted GPCP as an input [22].



**Figure 11:** Biased GPCP at Jamu.

From the above Figure 12, bias adjusted GPCP driven model at Samaijghat showed NSE, PBIAS and  $R^2$  values of 0.57, -11 and 0.72 respectively. This addressed good performance of the model at Samaijghat with bias adjusted GPCP as an input [23].



**Figure 12:** FDC of Biased GPCP at Jamu.

From the below Figure 13, bias adjusted GPCP driven model at Samaijghat showed NSE, PBIAS and  $R^2$  values of 0.57, -11 and 0.72 respectively. This addressed good performance of the model at Samaijghat with bias adjusted GPCP as an input [24].

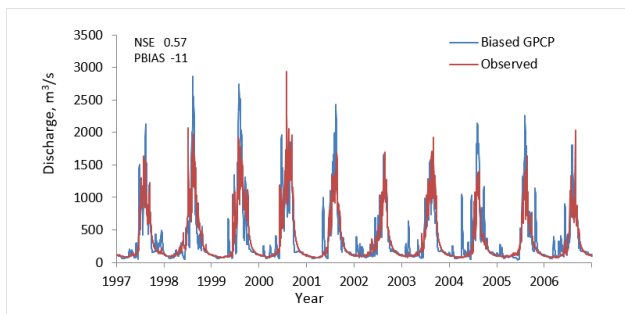


Figure 13: Biased GPCP at Samaijghat.

Figures 13 and 14 show the flow duration curve of Bias adjusted GPCP and Observed data at Jamu and Samaijghat stations to see how much similar is the flow curve between them. At both stations, Bias adjusted GPCP fails to capture the peak flow [25]. The extreme flows are also overestimated by GPCP whereas, good performance in capturing medium flows and low flows.

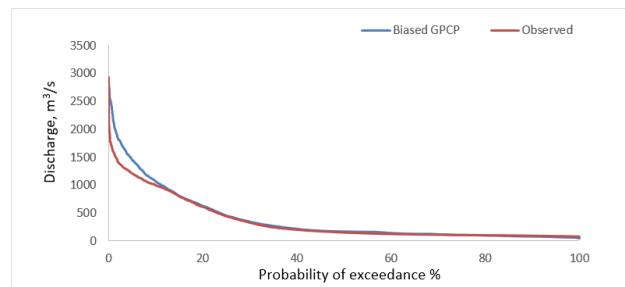


Figure 14: FDC of biased GPCP at Samaijghat.

Bias adjusted GPCP failed to capture the peak flow [26]. It is possible that the temporal resolution (1 day) and spatial resolution ( $1^\circ \times 1^\circ$ ) of GPCP is insufficient to record short duration high intensity rainfall event that cause peak flow. From the FDC of both stations, it is seen that the extreme flows are overestimated than the observed discharge. Considering the safety, GPCP-1DD rainfall data can be used for flood forecasting, risk assessments and infrastructure designs because overestimation is always better than underestimate (Tables 2-9) [27].

Sub Basin	Longest flow path, length (km)	Longest flow path slope (m/m)	10-85 flow path length (km)	10-85 flow path slope (m/m)	Area (km <sup>2</sup> )
1	89.915	0.052038	67.436	0.038911	964.15
2	67.662	0.065428	50.746	0.044062	1005
3	66.404	0.059996	49.803	0.045358	688.65
4	64.991	0.058653	48.743	0.03623	1446.6
5	134.314	0.02888	107.485	0.024569	2801.5
6	60.773	0.058875	45.579	0.044274	883.46
7	141.77	0.041772	106.327	0.028318	1009.9
8	89.614	0.020298	67.21	0.005237	2679.9
9	90.694	0.020718	68.02	0.004851	648.17
10	62.333	0.022877	46.749	0.010824	1237.3

Table 2: Characteristics of sub basins.

Reach	Length (km)	Slope (m/m)
R30	36.07	0.016634
R50	59.718	0.012676
R80	38.835	0.003116
R230	72.8	0.00261
R90	65.519	0.0029

Table 3: Characteristics of reach.

Sub basin	Initial storage (%)	Maximum storage (mm)	Crop coefficient
1	7.5	7.5	1

10	5	7.575	1
2	7.5	7.5	1
3	7.5	7.5	1
4	5	7.575	1
5	7.5	7.5	1
6	5	7.57	1
7	5	7.5751	1
8	5	7.5748	1
9	5	7.5751	1

**Table 4:** Simple canopy.

Sub basin	Initial storage (%)	Maximum storage (mm)
1	9	7.5751
10	6	11.306
2	9	7.575
3	9	7.5743
4	6	11.306
5	9	7.5751
6	6	11.287
7	6	16.875
8	6	7.575
9	6	7.5738

**Table 5:** Simple surface.

Sub basin	Initial deficit (mm)	Maximum deficit (mm)	Constant loss rate (mm/hr)
1	7.5	7.5	0.1515
10	7.575	7.575	0.15149
2	7.5	7.5	0.2261
3	7.5	7.5	0.15142
4	7.575	7.575	0.15149
5	7.5	7.5	0.1506
6	7.5699	7.5699	0.15147
7	7.575	7.575	0.1515
8	7.5748	7.5748	0.15143
9	7.5751	7.5751	0.15149

**Table 6:** Deficit and constant loss.

Sub basin	Time of concentration (hr)	Storage coefficient (hr)
1	41	72
10	31	59
2	30	52
3	31	58
4	29	54
5	32	60
6	24	45
7	29	53
8	32	60
9	34	52

**Table 7:** Clark unit hydrograph.

Sub basin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	11	6	6	10	8	4	4	16	12	18	17	12
2	11	6	6	10	8	4	3	17	12	18	16	12
3	11	6	6	10	7	4	4	12	11	18	17	11
4	11	7	11	10	8	5	4	25	12	18	17	14
5	12	6	10	12	8	4	4	47	22	21	20	18
6	11	6	10	11	7	4	3	15	12	17	18	12
7	11	7	9	10	8	4	3	17	12	18	18	13
8	12	6	10	11	8	4	4	46	21	20	19	18
9	11	6	11	9	7	5	3	11	10	17	17	11
10	11	7	9	11	8	4	4	22	10	18	18	13

**Table 8:** Monthly base flow (m<sup>3</sup>/sec).

Reach	Muskingum K (hr)	Muskingum X	No. of sub reaches
R230	43.006	0.03	1
R30	39.564	0.139	1
R50	47.656	0.3275	1
R80	95.996	0.04	1
R90	44.665	0.1	1

**Table 9:** Muskingum routing.

### Conclusion

The applicability of GPCP1DD rainfall data is evaluated in the Bheri River Basin on the basis of performance and magnitude based indices. The major conclusions from this study are as follows;

On direct comparison with ground rainfall data, regarding multiple statistical performance indicators, quantile mapping bias adjusted GPCP-1DD resulted improvement in the performance than raw GPCP-1DD.

Bias Adjusted GPCP-1DD driven HEC-HMS model for the Bheri river basin produced satisfactory performance at Jamu with NSE, R<sup>2</sup> and PBIAS values of 0.47, 0.63 and -13.5 and good performance at Samajjighat with NSE, R<sup>2</sup> and PBIAS values of 0.57, 0.72 and -11. It showed good performance in capturing medium flows and low flows but it overestimated the extreme flows. Considering safety, GPCP-1DD rainfall data can be used for flood forecasting, risk assessments and infrastructure designs.

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