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VERIFICATION OF APHRODITE PRECIPITATION DATASET IN BANGLADESH

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ABSTRACT

We investigated the preformance of Asian Precipitation-Highly-Resolved Observational Data Integration Towards Evaluation (APHRODITE) of water resources precipitation products in Bangladesh taking rain gauge data as reference for a 3-year period (2003-2005). Various statistical and categorical indices such as coefficient of correlation (CC), bias, relative bias (RB), mean absolute error (MAE), root mean square error (RMSE), probability of detection (POD), and false alarm ratio (FAR), were applied to measure the performance of the product. With CC value of 0.85, bias of 0.91, RB of -9.5%, MAE of 7.7 mm, and RMSE of 15.2 mm the product tended to underestimate rainfall values during the study period. Although, the POD score of 1.00 demonstrated very good skill in detecting the occurrence of rainfall events, FAR value of 0.25 indicated a considerable amount of false alarms. Moreover, as the precipitation threshold increased, the underestimation became more prominent over the study region. Analysis on the basis of location of the rain gauges also showed that APHRODITE consistently underestimated rainfall values with the increase of extreme rainfall thresholds.

Keywords: *APHRODITE; Bangladesh; Extreme; Gauge-based rainfall observation; Precipitation; Threshold.*

1. INTRODUCTION

Precipitation is one of the most important components of hydrologic cycle and precise estimation of this component is very crucial as it affects human life directly and indirectly. Rain gauge and ground-based radar are the most popular conventional tools to measure rainfall at point and regional scales, respectively. However, rain gauge data suffers from spatial representativeness error whereas ground-based radar has different types of error such as inappropriate Z-R relationship, beam blockages, bright band effects, and so on. Furthermore, ground-based rainfall measurement facilities (i.e. rain gauge and radar) are very sparse in most parts of the world except few developed countries due to their high costs to establish and maintaining infrastructures. Therefore, many projects and organizations are involved to generate gauge-based precipitation dataset at finer spatial and temporal resolutions for ungauged and sparsely gauged basins around the globe such as Asian Precipitation-Highly-Resolved Observational Data Integration Towards Evaluation (APHRODITE) of water resources (Yatagai *et al.*, 2009; Yatagai *et al.*, 2012), the Global Precipitation Climatology Centre (GPCC; Schneider *et al.*, 2008), the University of Delaware (UDEL; Willmott and Matsuura, 1995), the University of East Anglia's Climate Research Unit (CRU; Mitchell and Jones, 2005), and Precipitation Reconstruction over Land (PREC/L; Chen *et al.*, 2002) dataset.

APHRODITE project aims to produce state-of-the-art precipitation dataset with high spatial and temporal resolution for Asia. This product is produced using the rain gauge data obtained from a dense rain gauge network consisting of 5000~12000 rain gauge stations across Asia. This is the only continental-scale long term (1951-2007) precipitation products for Asia based on rain gauge data. The product can be used for climate change analysis, water resources management, improved statistical downscaling, warnings and forecasting's related purposes, evaluation of satellite precipitation products, and validation of regional climate models. Moreover, APHRODITE algorithm improves the estimation of orographic rainfall by integrating rain gauge measurements, remotely sensed data, and geographic information (Yatagai *et al.*, 2012). It also applies a superior quality control method (Hamada *et al.*, 2012) which reduces the errors automatically and objectively. Current APHRODITE data covers Monsoon Asia, Russia, Middle East, and Japan. Figure 1 shows the mean annual precipitation over Monsoon Asia derived from APHRODITE data during 2003-2005.

Currently, APHRODITE data is being used to validate satellite rainfall products (Duncan and Biggs, 2012; Jamli, 2015; Jamandre and Narisma, 2013) and to analyse climate change (Gillies *et al.*, 2012; Wang and Gillies, 2013). Gillies *et al.* (2012) investigated the changes in winter precipitation over China using APHRODITE precipitation data as reference. Duncan and Biggs (2012) evaluated TMPA 3B42-V6 satellite rainfall estimates relative to ground-based APHRODITE precipitation data over Nepal. Jamli (2015) validated PERSIANN (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks) satellite precipitation products through comparison with APHRODITE dataset over Iran.

This effort intends to verify APHRODITE dataset in Bangladesh using ground-based rain gauge records to exploit its performance to be used as reference observation. Rain gauge observation can be applied for the validation of satellite-retrieved rainfall estimates. However, rain gauge provides point estimates whereas satellite pixel represents an averaged value within an area of 11 km × 11 km (for 0.10° grid box) or 27 km × 27 km (for 0.25° grid box). Therefore, comparison of a pixel with a point estimate may affect the validation results significantly. For the precise estimation of errors and uncertainties of satellite dataset, it is necessary to compare satellite pixel with a reference pixel. However, most of the developing countries of the world such as Bangladesh does not have any gridded reference precipitation data. Nevertheless, the rain gauge network of Bangladesh is very sparse throughout the country. For this reason, APHRODITE precipitation products have the potentiality to be used as a key decisive source of rainfall information for the evaluation of satellite rainfall estimates in Bangladesh.

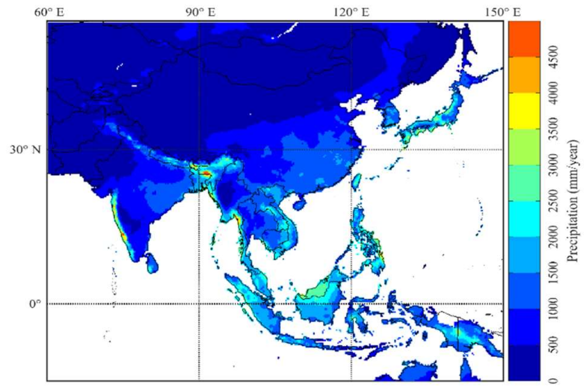

Figure 1: Mean annual rainfall (mm/year) during 2003-2005 over Monsoon Asia derived from APHRODITE precipitation products

2. STUDY AREA AND DATA SETS

2.1 Study Area

Bangladesh is located in South Asia between 20°-27° latitude and 88°-93° longitude (Figure 2). It is bordered by India in West, East, and North and Bay of Bengal in South (Figure 1). Bangladesh has a tropical monsoon climate and receives heavy rainfall during monsoon period from June to September. Rainfall varies substantially in space and time in Bangladesh. Natural calamities that come from extreme rainfall such as floods and landslides are very common in the study area.

2.2 Rain Gauge Data

Rain gauge data are collected from Bangladesh Meteorological Department (BMD). Quality controlled 3 h rainfall accumulations of 34 rain gauges are used in the present study (Figure 2). Rain gauges are operated in Coordinated Universal Time (UTC) time scale. Rainfall accumulation at 18 UTC represents accumulated rainfall between 15 UTC and 18 UTC. Daily accumulations are computed from the 3 h data to synchronize with the daily accumulations of APHRODITE data.

2.3 APHRODITE Data

In this research, APHRODITE V1101 precipitation products with daily temporal and 0.25° × 0.25° (latitude and longitude) spatial resolution are evaluated in Bangladesh. Geographical coverage of the dataset extends between -15° S-55° N latitude and 60° E-150° E longitude. The gauge data for APHRODITE precipitation products were collected from three sources: i) Global Telecommunication System (GTS)-based data, ii) precompiled data from other projects or organizations, and iii) APHRODITE's own collection. For the V1101 product, an updated automatic quality control scheme was applied to remove erroneous gauge observations throughout the whole domain and the entire study period. However, few issues were handled manually such as i) to check invalid dates and shifted columns, ii) to check each station whether there is location information or not, and iii) to prepare a list of stations with erroneous data for exclusion.

To produce daily climatology the following steps were applied: i) quality controlled daily (except GTS data) data are accumulated to produce monthly accumulations, ii) monthly accumulations, including those obtained in step 1, are collected and the average value is obtained if the station has more than 5 years data, iii) the world climatology is produced at 0.05° resolution, iv) the ratios of the monthly accumulations (computed in step 2) to the world climatology values (computed in step 3) are found out for each month, v) the ratios obtained in step 4 are interpolated using Sheremap (Willmott *et al.*, 1985) at 0.05° resolution, vi) the interpolated scores of step 5 are multiplied with the world climatology computed in step 3, vii) the first six components of the fast Fourier transform of the values obtained in step 6 are accepted as the daily climatology.

APHRODITE algorithm interpolates the ratios of the daily precipitation to the daily climatology using angular distance weighting scheme as follows: i) a small weight is provided to a cell on the leeward side of a high ridge if the ridge is situated between the target cell and the nearest rain gauge, ii) a large weight is assigned to a target cell on a slope that inclines to a rain gauge, iii) a lookup table is prepared for each month to define the correlation distance, which is obtained from the global 20-km mesh model developed by Meteorological Research Institute (MRI) of the Japan Meteorological Agency (JMA) and used to define the weighting function.

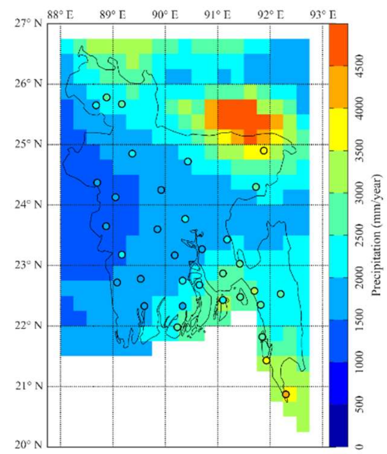

Figure 2: Mean annual rainfall (mm/year) during 2003-2005 over Bangladesh derived from APHRODITE data. Circles denote rain gauge locations and the face colour of each circle represents Mean annual rainfall (mm/year) during 2003-2005 at that location.

3. METHODOLOGY

To verify the detection capability of APHRODITE precipitation products, the following statistics are used (Islam and Cartwright, 2020; Moazami *et al.*, 2013):

$$CC = \frac{\sum_{i=1}^{N}\left(P_{A_i}-\overline{P_A}\right)\left(P_{O_i}-\overline{P_O}\right)}{\sqrt{\sum_{i=1}^{N}\left(P_{A_i}-\overline{P_A}\right)^2}\sqrt{\sum_{i=1}^{N}\left(P_{O_i}-\overline{P_O}\right)^2}} \quad (1)$$

$$Bias = \frac{\sum_{i=1}^{N} P_{A_i}}{\sum_{i=1}^{N} P_{O_i}} \quad (2)$$

$$RB = \frac{\sum_{i=1}^{N}\left(P_{A_i}-P_{O_i}\right)}{\sum_{i=1}^{N} P_{O_i}} \times 100 \quad (3)$$

$$MAE = \frac{\sum_{i=1}^{N}\left|P_{A_i}-P_{O_i}\right|}{N} \quad (4)$$

$$RMSE = \left[\frac{\sum_{i=1}^{N}\left(P_{A_i}-P_{O_i}\right)^2}{N}\right]^{1/2} \quad (5)$$

where P_{A_i} and P_{O_i} are the ith data of APHRODITE and rain gauge observations respectively. N is the total number of APHRODITE and rain gauge data pair. $\overline{P_A}$ and $\overline{P_O}$ are the mean APHRODITE and rain gauge estimates respectively. Coefficient of correlation (CC) is used to measure the conformity between APHRODITE and rain gauge observations. The value of CC lies between -1 and +1. -1 denotes a perfect negative correlation whereas +1 represents a perfect positive correlation. The value of 0 indicates no correlation between the two datasets. Bias is defined as the ratio of the sum of APHRODITE data to the sum of the rain gauge data. Bias greater than 1 indicates overestimation of rainfall while less than 1 indicates underestimation. Bias value of 1 shows no bias in the estimated precipitation products. Relative bias (RB) represents systematic bias of APHRODITE rainfall data. Mean absolute error (MAE) is employed to show the mean error of the precipitation product. Root mean square error (RMSE) presents the magnitude of mean error alike MAE, however, RMSE provides larger weight to greater error.

In addition, two categorical indices i.e. probability of detection (POD) and false alarm ratio (FAR) are computed to assess the skill of APHRODITE rainfall estimates. POD is defined as the ratio of the correct identification of rainfall occurrences to the total number of reference rainfall occurrences whereas FAR reveals the ratio of the false identification of precipitation to the total number of APHRODITE precipitation occurrences (Islam and Cartwright, 2020; Islam, 2018).

$$POD = \frac{N_H}{N_H+N_M} \quad (6)$$

$$FAR = \frac{N_F}{N_H+N_F} \quad (7)$$

where

$$N_H = \sum_{i=1}^{N}\left(\left(P_{A_i} > 0 \,\&\, P_{O_i} > 0\right) \,\&\, \left(P_{A_i} \geq 1 \mid P_{O_i} \geq 1\right)\right) \quad (8)$$

$$N_M = \sum_{i=1}^{N}\left(\left(P_{A_i} = 0 \,\&\, P_{O_i} > 0\right) \,\&\, \left(P_{A_i} \geq 1 \mid P_{O_i} \geq 1\right)\right) \quad (9)$$

$$N_F = \sum_{i=1}^{N}\left(\left(P_{A_i} > 0 \,\&\, P_{O_i} = 0\right) \,\&\, \left(P_{A_i} \geq 1 \mid P_{O_i} \geq 1\right)\right) \quad (10)$$

4. RESULTS AND DISCUSSION

Figure 3 shows the scatterplot of daily APHRODITE data and rain gauge observations greater than or equal to 1 mm for the entire study period (2003-2005) in Bangladesh. It is worth mentioning here that a rainfall threshold 1 mm/day is considered to differentiate between rain and no rain. APHRODITE product demonstrates reasonable agreement with the reference rain gauge data at lower rainfall accumulations (below 50 mm/day). About 90% of the rainfall observed by the rain gauges is below 50 mm/day. From Figure 3 one can see that APHRODITE underestimates rainfall values substantially particularly above 100 mm/day. Overall, the accuracy of the product decreases consistently with the increase of the amount of rainfall accumulated by the gauges.

Third column of Table 1 summarizes the statistics of Figure 3. In this column, the values of bias (0.91) and RB (–9.5%) confirm that APHRODITE underestimates the rainfall accumulations over the study area. However, CC (0.85) shows good correspondence of APHRODITE data with reference observations. The scores of 7.7 mm and 15.2 mm for MAE and RMSE, respectively, reveal a considerable difference between APHRODITE and gauge data.

Table 1: Comparison of error statistics for different rainfall thresholds (P denotes rainfall accumulation in mm).

	Unit	Rainfall thresholds		
		$P \geq 1$	$P \geq 50$	$P \geq 100$
N	--	15810	1417	329
CC	--	0.85	0.58	0.37
Bias	--	0.91	0.70	0.65
RB	%	-9.5	-29.5	-35.4
MAE	mm	7.7	33.2	59.1
RMSE	mm	15.2	44.2	73.5
POD	--	1.00	1.00	1.00
FAR	--	0.25	0.01	0.02

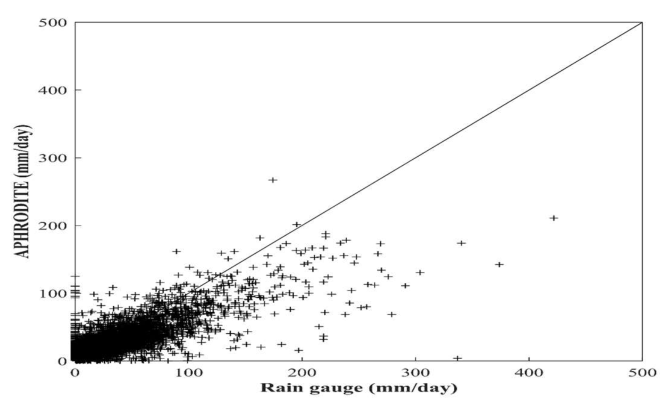

Figure 3: Comparison of APHRODITE precipitation data with rain gauge observations for daily temporal accumulation during 2003-2005.

The value of 1.00 for POD denotes excellent rainfall detection capability of the product, while FAR represents that the product gives a considerable number of false alarms during the study period. As the rainfall threshold increases from 1 mm to 50 mm, the skill of the product decreases significantly (compare fourth column with third column of Table 1). CC and bias decrease from 0.85 to 0.58 and from 0.91 to 0.70, respectively. Moreover, the product shows 211%, 331%, and 191% increase in RB, MAE, and RMSE, respectively. In fact, Table 1 shows increasingly worse error statistics as the rainfall threshold increases (from left to right). For rainfall accumulations greater than or equal to 100 mm, APHRODITE exhibits very limited rainfall detection skill. However, FAR scores decrease remarkably with the rainfall threshold whereas POD remains constant.

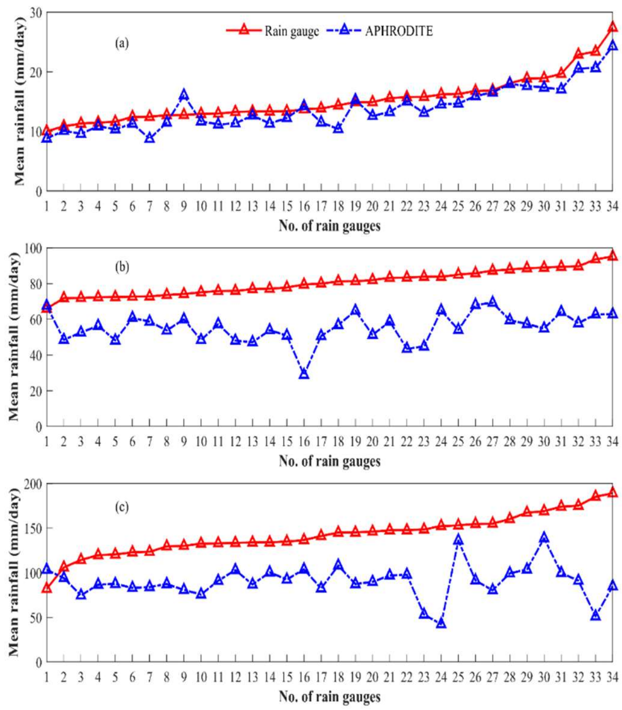

Figure 4: Mean daily rainfall accumulation at each gauge locations as measured by rain gauges and APHRODITE data for (a) $P \geq 1$, (b) $P \geq 50$, (c) $P \geq 100$ during 2003-2005 (P indicates rainfall accumulation in mm).

Figure 4 represents mean daily rainfall values at the 34 rain gauge locations for the various rainfall thresholds. Figures 4a, 4b, and 4c are computed according to the ascending order of the mean daily collections of the rain gauges. When entire data are included in the analysis, the difference between APHRODITE and rain gauge accumulations are very small at most of the rain gauge locations (Figure 4a). The difference increases substantially as the rainfall thresholds increase [Figures 4(b-c)]. It is worth pointing out here that the maximum limit of y axis of Figures 4a, 4b, and 4c are not the same. Figures 4b and 4c highlight that the underestimation of APHRODITE becomes more significant with the increase of the thresholds. Furthermore, Figure 4 confirms the findings of Table 1.

Jamandre and Narisma (2013) compared APHRODITE precipitation products with station observations in the Philippines. They found that APHRODITE performed well within 20-50 mm/day precipitation range and underestimated extreme rainfall accumulations (above 50 mm/day). In the present study, relatively better performance of APHRODITE rainfall dataset when entire data are considered in the analysis may be ascribed to the fact that the overestimation at lower rainfall amounts compensating the underestimation at higher rainfall values (Figure 3). Moreover, higher rainfall values are also underestimated during the study period in Bangladesh (above 50 mm/day).

5. CONCLUSIONS

Accurate estimation of precipitation is very important for hydrological modelling, extreme weather forecasting and monitoring, and climate analysis. Unfortunately, ground-based rainfall measurement facilities are very sparse or non-existent in most parts of the world, especially in the developing countries such as Bangladesh. There are several freely available (ground-based and space-borne) precipitation products which can be used in the ungauged basins. However, it is necessary to evaluate the rainfall products against available reference observations before incorporating the data into practical applications.

Accordingly, this study aimed to verify APHRODITE precipitation dataset with respect to available rain gauge measurements in Bangladesh. This ground-based product is produced using very dense rain gauge network over Monsoon Asia. In this effort, APHRODITE was evaluated using various statistical and categorical skill metrics for daily temporal accumulation and different rainfall thresholds.

The computed CC, bias, RB, MAE, and RMSE scores indicated that APHRODITE tended to underestimate the rainfall during the study period. As the extreme rainfall threshold increased, the error statistics showed very serious underestimation. However, false alarm ratios decreased considerably with the thresholds. Location wise analysis of the product also revealed that APHRODITE underestimated the rainfall values and this underestimation increased with the increase of extreme precipitation thresholds. Therefore, it is suggested that appropriate correction method should be applied before incorporating this product into any kind of practical applications in Bangladesh.

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