

Precipitation extremes and anomalies of the Indian Sundarban 1984-2018

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सार – स्थानिक और लौकिक संदर्भ में जलवायु परिवर्तनशीलता को समझने के लिए $0.5 \times 0.5^\circ$ स्थानिक संकल्प के ग्रिड वर्षा डेटा उत्पादों का विश्लेषण किया गया था। अध्ययन क्षेत्र में गेज स्टेशन डेटा अवलोकनों के अभाव में संसाधित ग्रिडेड डेटा उत्पादों की डेटा विश्वसनीयता की जांच की गई। हालांकि, इस अध्ययन क्षेत्र में स्थानिक और लौकिक डेटा उत्पादों के तुलनात्मक विश्लेषण के कार्यान्वयन गायब हैं। नासा पावर डेटा (एनपीडी) और क्लाइमेट रिसर्च यूनिट (सीआरयू टीएस 4.03) डेटा की 1984-2018 से जांच की गई थी। डेटा उत्पादों को ग्रिड के अनुसार चुना गया, उनकी तुलना की गई और उनकी व्याख्या की गई। वार्षिक और मानसूनी वर्षा पैटर्न का भी अध्ययन किया गया। भिन्नता के गुणांक (CV), विसंगति और वर्षा एकाग्रता सूचकांक (PCI) का उपयोग करके डेटा परिवर्तनशीलता का विश्लेषण किया गया है। त्रुटि और अंतर को निर्धारित करने के लिए R^2 , MAE, RMSE, MAPE और BIAS का सांख्यिकीय विश्लेषण किया गया था। स्वतंत्र ग्रिड बिंदु को ध्यान में रखते हुए, एमएपीई और बीआईएस ने संकेत दिया कि केवल ग्रिड 4 ने क्रमशः 12.7% और 17% के साथ बाकी की तुलना में बेहतर प्रदर्शन किया। डेटा उत्पादों के संबंध में परिणाम औसत और ग्रिड दोनों संदर्भों में महत्वपूर्ण अंतरों को दर्शाते हैं। एनपीडी एक बढ़ती हुई प्रवृत्ति को दर्शाता है, जबकि सीआरयू वर्ष 1984-2018 से घटती प्रवृत्ति का प्रतिनिधित्व करता है। जटिल भूभाग में किसी भी संसाधित माध्यमिक ग्रिड डेटा उत्पादों के कार्यान्वयन से पहले, त्रुटि के परिमाण का महत्वपूर्ण मूल्यांकन और परिमाणीकरण एक पूर्वापेक्षा है, जैसे सुंदरवन, जहां गेज स्थित डेटा अनुपलब्ध है।

ABSTRACT. Gridded precipitation data products of $0.5^\circ \times 0.5^\circ$ spatial resolution were analysed to understand the climatic variability in a spatial and temporal context. Data reliability of processed gridded data products were examined in the absence of gauge station data observations in the study area. However, the implementations of comparative analysis of the spatial and temporal data products in this study area are missing. The NASA Power Data (NPD) and Climate Research Unit (CRU TS 4.03) Data were scrutinized from 1984-2018. The data products were selected, compared, and interpreted grid wise. Annual and monsoonal precipitation pattern was also studied. Data variability has been analyzed using the Coefficient of Variation (CV), Anomaly, and Precipitation Concentration Index (PCI). The statistical analysis of R^2 , MAE, RMSE, MAPE and BIAS was performed to quantify the error and differences. Considering the independent grid point, the MAPE and BIAS indicate that only grid 4 performed better than the rest with 12.7% and 17%, respectively. The results regarding the data products illustrate significant differences both in averaged and grid wise context. The NPD shows an increasing trend, whereas CRU represents a decreasing trend from the year 1984-2018. Before the implementation of any processed secondary gridded data products in complex terrain, the critical evaluation and quantification of the magnitude of error is a prerequisite, like the Sundarbans, where the gauge stationed data is unavailable.

Key words – OSE, FSOI, Tropical cyclone.

1. Introduction and problem statement

Precipitation is a significant element that regulates the overall climatic conditions of a region. In the recent

past, the frequency/recurrence of the cyclones followed by the erratic rainfall increased in the Bay of Bengal. Climate change in terms of extremities of cyclones in the eastern coastal region of the Indian subcontinent is a

matter of concern. The vulnerability of the coastal inhabitants can be implicit by the intensity and magnitude of the cyclones that resulted in the floods. The frequency of tropical cyclones and erratic precipitation patterns has devastating consequences for both the environment and the ecosystem.

The changing pattern of rainfall influences the quantum and distribution of runoff, soil moisture and groundwater reserves. It also affects the occurrence of droughts and floods (Das *et al.*, 2014). Pal and Al-Tabbba (2011) carried out an analysis of the rainfall data for the period of 1954-2003. They concluded that there was a decreasing trend in the spring and the monsoon rainfalls and increasing trends in the autumn and the winter rainfalls over India.

Pant and Hingane (1988) analysed the mean annual and southwest monsoon rainfall of India for the period 1901-1982. They found a positive trend over Punjab, Haryana, West Rajasthan, East Rajasthan, and West Madhya Pradesh. Rupa Kumar *et al.* (1992) reported a significant increase in monsoon rainfall along the west coast, central peninsula, and northwest India, while a significant decreasing trend observed over the northeast and northwest peninsula, and northeast India. Subbaramayya and Naidu (1992) analysed the monsoon rainfall trends in different meteorological subdivisions of India for the period of 1871-1988.

Rabindranath *et al.* (2011) and Sam *et al.* (2019) reported that the Indian Subcontinent is likely to experience warming over 3 to 5 °C with a significant change in flood and drought frequency and intensity. Radhakrishnan *et al.* (2017) and Sam *et al.* (2019) studied a significant declining trend in the rainfall pattern of India in the last 30 years (1901-2014) with seasonal variability. On the other hand, a decreasing trend of annual rainfall (1901-2013) has observed over 8% of the area and significant increasing show over 10% of the total area in India by Kaur *et al.* (2017) and Sam *et al.* (2019). Rajendran *et al.* (2013) and Sam *et al.* (2019) projected spatially varying increasing trend of Indian summer monsoon rainfall over Indo-Gangetic plain.

The impact of environmental factors on temperatures has been estimated with various statistical methods, especially with different regression techniques (Hart and Sailor, 2009; Yokobori and Ohta, 2009; Ivajn_si_c *et al.*, 2014; Suomi, 2018). Development of remote sensing methods and better availability of geographic information system (GIS) datasets have increased GIS-based local climate research during the last decades (Roth *et al.*, 1989; Chapman and Thornes, 2003; Peeters, 2016; Suomi, 2018).

More than 50% of the total inhabitants of the Sundarbans are heavily dependent on rainfed agriculture. The characteristics of the precipitation can be elucidated by its intensity, magnitude, distribution, and, most importantly, the onset and the cessation of the rainy season. The impact of the changes in rainfall characteristics would lead to 20-60% losses of agricultural productions by 2025 (Butt *et al.*, 2005; Halimatou *et al.*, 2017). Timely monitoring of rainfall trends and variability is essential to investigate and explain the socio-economic problems related to agroclimatic conditions. The impact of temperature on agriculture is of principal significance since 1 °C rise is linked to a 2.7% reduction in growths in agricultural outputs (Dell *et al.*, 2012; Halimatou *et al.*, 2017). The Sundarbans serves as a critical component for protecting the millions of inhabitants.

The analysis of precipitation patterns is a prerequisite to study the impact of climatic change on the regional and global scale. There are no reported works on the statistical interpretation and quantification of error of the gridded products of precipitation in Indian Sundarbans. The present study aims to address the research gap by evaluating the multiple secondary gridded precipitation datasets with different temporal resolutions. We hypothesize that there is no difference between the two sets of gridded precipitation data sources. The various analytical methods were employed to analyze the significant changes in precipitation over the years and clear differentiation between CRU and NPD grids. Further, we apply spatial variation using the interpolation technique.

2. Materials and method

2.1. Study area

2.1.1. Location and biophysical situation

The Sundarbans, one of the most extensive contiguous mangrove forests (Ghosh *et al.*, 2015), is approximately 10,000 km sq., of which 60% lies within Bangladesh and 40% in India. Sundarban Biosphere Reserve (SBR) spreads over 13 blocks (an administrative division of the district) of South 24 Parganas and six blocks of North 24 Parganas districts of West Bengal, India (Sahana *et al.*, 2016). The Sundarbans are situated on the delta created by the Ganges, Brahmaputra, and Meghna rivers in the Bay of Bengal (Ghosh *et al.*, 2015). The study area (Fig. 1) is bordered by Muriganga River on the west and Harinbhahga and Raimangal rivers on the east. It is a part of the tide-dominated lower deltaic plain. The Sundarbans is a tropical mangrove forest situated in the south of the tropical of Cancer. The Indian Sundarbans constitute 106 islands, and 50% of the total islands

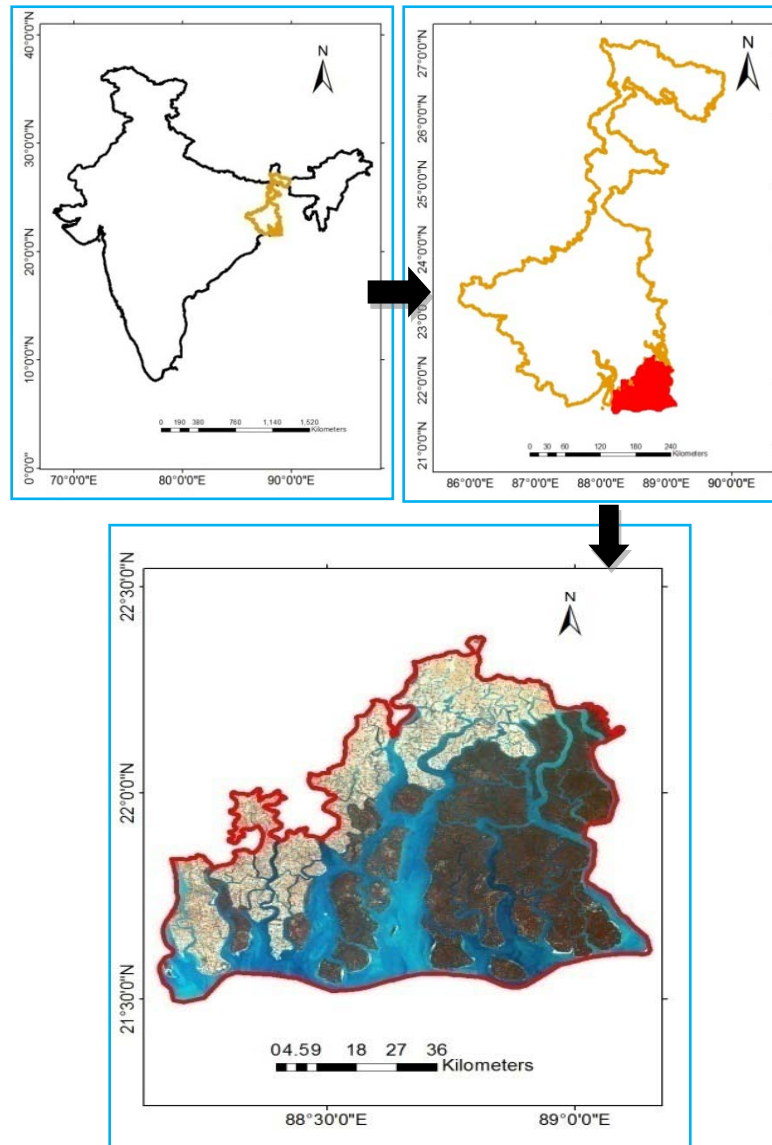


Fig. 1. The study area

are inhabitants. The Sundarbans comprises of three parts, *i.e.*, transition zone, buffer zone, and core area. Based on the bio-geophysical characteristics, the Sundarbans eco region can be categorized into three distinct divisions', *viz.*, the beach or sea face, the swamp forests, and the mature delta. The continuous rise in sea level is now a significant adverse effect on the existence of this fragile ecosystem (Pramanik, 2015).

The deltaic mangrove region enjoys a tropical climate with a dry season between November and May and a wet monsoonal period from June to October. The annual precipitation is approximately between 1200 mm and 2200 mm. Tropical cyclones resulted in flooding occurs regularly. The temperature is moderate due to this

region's proximity to the Bay of Bengal in the south (Sahana *et al.*, 2016). The maximum and minimum temperatures vary from 26 °C to 34 °C and 11 °C to 25 °C, respectively. The diurnal tidal activity is a distinct characteristic of a deltaic mangrove region where during high tide water rises around 6 to 10 ft height as a result of which the plants near the edge of the islands got inundated and during low tide extensive mudflats is noticeable in both the sides of the river.

2.1.2. Socioeconomic and demographic features of the Sundarbans

Socio-economically the region is underprivileged and impoverished rural population. It is home to

4.5 million people (Sahana *et al.*, 2016; Census of India, 2011). Agriculture and fishing are an essential source of livelihood for the people living in the fragmented islands of the Sundarbans. Further, the brackishness of rivers makes agriculture difficult, and productivity uncertain. Moreover, winter cultivation is virtually non-existent for want of freshwater (Sahana *et al.*, 2016). Soil loss, soil salinity, and land fragmentation have resulted in reduced agricultural output. Extreme changes in precipitation have altered seasonal average soil salinity. The ingress of saline water as a result of cyclonic activities and extreme precipitation events further make/create the agricultural land unproductive/uncultivable for 2 to 3 consecutive years. Due to its peculiar nature and limitations of the geographical location, the means of transport and communication in the deltaic areas are not well developed.

2.2. Research design

2.2.1. Data type and source

In this study, due to scarcity of primary stationed data, the secondary processed globally interpolated gridded datasets were relied on to understand the local weather patterns and the climatic scenario of the world. Precipitation datasets were obtained from different sources with a spatial resolution of $0.5^\circ \times 0.5^\circ$. The beginnings of the temporal coverage of the datasets are different. Monthly mean precipitation datasets were obtained from Climatic Research Unit (CRU) with the latest version TS 4.03 for the period of 1901 to 2018. The CRU data was downloaded from Centre of Environmental Data Archival (<http://badc.nerc.ac.uk>) (Taxak *et al.*, 2014) and NPD from NASA Power Data Assess <https://power.larc.nasa.gov/data-access-viewer/>. Climatic Research Unit (CRU) global gridded data is developed at the University of East Anglia, England (Shi *et al.*, 2017). The CRU data are available in two formats: Net CDF, and space-separated ASCII text, this ensures maximum availability for the diverse users of the dataset (Harris *et al.* 2020). CRU datasets have been widely used in climatic studies and different countries (Mahmood *et al.*, 2019; Zandler *et al.*, 2019). The station anomalies are spatially interpolated into 0.5×0.5 - degree grids covering the global land surface excluding Antarctica, and combined with an existing climatology to obtain absolute monthly values (Shi *et al.*, 2017). Daily precipitation datasets were acquired from NASA Power Data (NPD). The erroneous observations and missing data were coded with -99 in NASA Power Data (NPD). The beginning of the NASA power data is available from 1984. This study area covers six grids, both in NPD and CRU. These datasets are based on the combination of satellites and observed data.

2.2.2. Data analysis techniques

The NPD daily precipitation data product was converted to the monthly data from the available year 1984-2018 at each grid for the entire study area. The monthly data were cumulated over the monsoon season (June-September) to obtain a total monsoonal rainfall at the grid level (Das *et al.*, 2014). Yearly and grid-level anomalies were calculated for the last 35 years (1984-2018) from the respective long-term average. The monthly distribution of precipitation was calculated for 1984-2018 for both the datasets. There are numerous techniques for the analysis of meteorological data, particularly rainfall and temperature. The present study involves percentage departure from mean (Anomalies), Coefficient of Variation (CV), Precipitation Concentration Index (PCI), Coefficient of Determination (R^2), Mean Absolute Error (MAE), Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE) and BIAS. Further more, spatial interpolation technique was used to detect the spatial variability over the study area. The data analysis technique was performed using Arc GIS and Excel.

CRU : Monthly data was obtained for each grid on annual scale.

NPD : Daily precipitation data were converted into monthly data and annual series was prepared for each grid.

$$CV = \frac{\sigma}{\mu} \times 100$$

Where, CV is the coefficient of variation; σ is standard deviation and μ is the mean precipitation.

$$R^2 = \left\{ \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \right\}^2$$

where, n is the number of values, x_i is the observed station value, y_i is the predicted value of the gridded dataset of month i , \bar{x} is the mean of observed station values, and \bar{y} the average of the gridded dataset values (Zandler *et al.*, 2019). In this case, the NPD dataset was considered as x and y as CRU.

$$ANOMALY = \frac{(x_i - \bar{x}_i)}{s}$$

$$PCI = \frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} P_i\right)^2}$$

$$MAE = \frac{1}{n} \sum_{t=1}^n |x_t - y_t|$$

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

$$MAPE = \frac{1}{n} \sum_{t=1}^n \left| \frac{At - Ft}{At} \right|$$

$$BIAS = \frac{1}{n} \sum_{t=1}^n (x_t - y_t)$$

2.2.3. Interpolation and geospatial analysis

The interpolation technique is an essential tool to analyse the spatial data. Inverse Distance Weighting (IDW) interpolation is a method to predict a value for an unmeasured location by using the measured values surrounding the prediction location. The measured values closest to the predicted location have a more significant influence on the predicted value than those farther away. IDW presupposes that each determined point has a local control that diminishes with distance.

3. Results and discussion

3.1. Preliminary analysis

The CRU and NPD depicts almost similar patterns of rise and fall in the annual trend of precipitation until the period of 2014 (1984-2014), 2015 onwards NPD shows an increasing trend. The range between the two sets of gridded precipitation data differs immensely from 913.07 mm (CRU) to 1917.78 mm (NPD). The maximum and minimum recorded precipitation of CRU and NPD varies from 2401.65 mm to 1488.58 mm and 3131.87 mm to 1214.08 mm, respectively. The abrupt increases in NPD precipitation in the last three years require an insight into the regional analysis, verified during the field survey. According to the residents of this area, the precipitation pattern has become more irregular, and the intensity of precipitation has increased recently. The standard deviation varies from 248.62 mm to 393.09 mm for CRU and NPD. The skewness of the CRU source of precipitation distribution exhibit both positive (0.054) and negative (-0.082), indicating that the annual rainfall during the period 1901-2018 and 1984-2018 respectively are approximately symmetrical (Fig. 2).

The NPD precipitation distribution shows a predominantly positive skewness with 1.84 indicating a

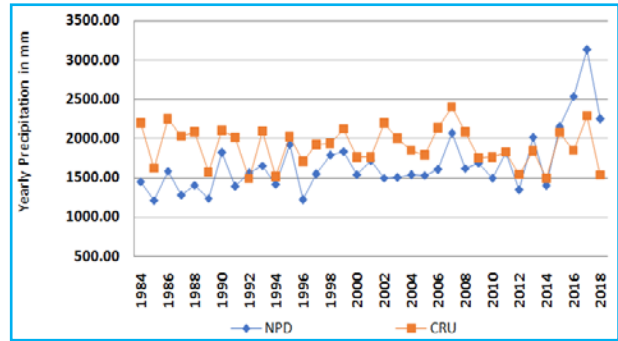


Fig. 2. Precipitation pattern of NPD and CRU (1984-2018)

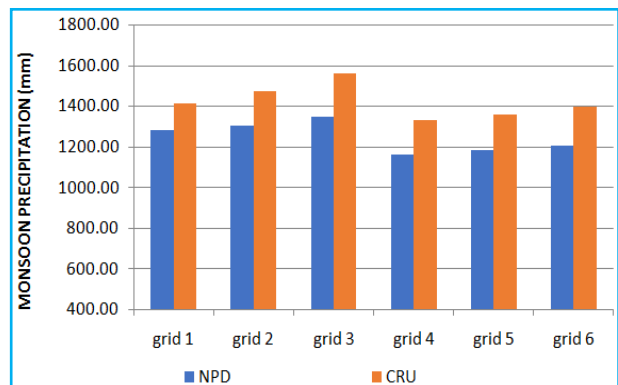


Fig. 3. Grid wise total Monsoonal Precipitation distribution

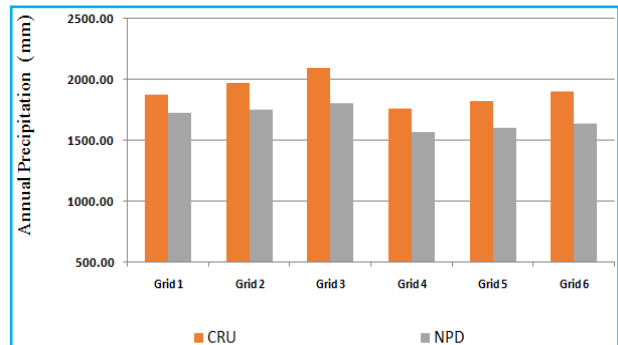


Fig. 4. Grid wise Precipitation distribution of CRU and NPD

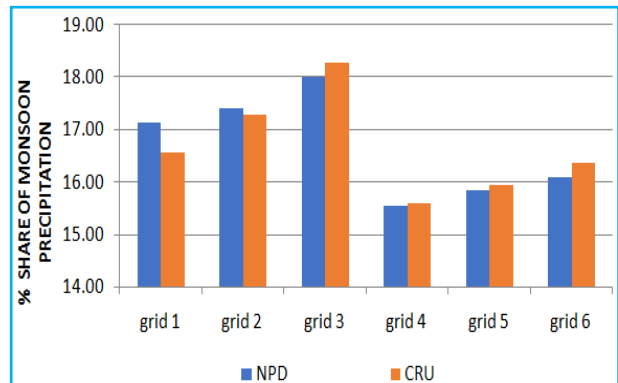
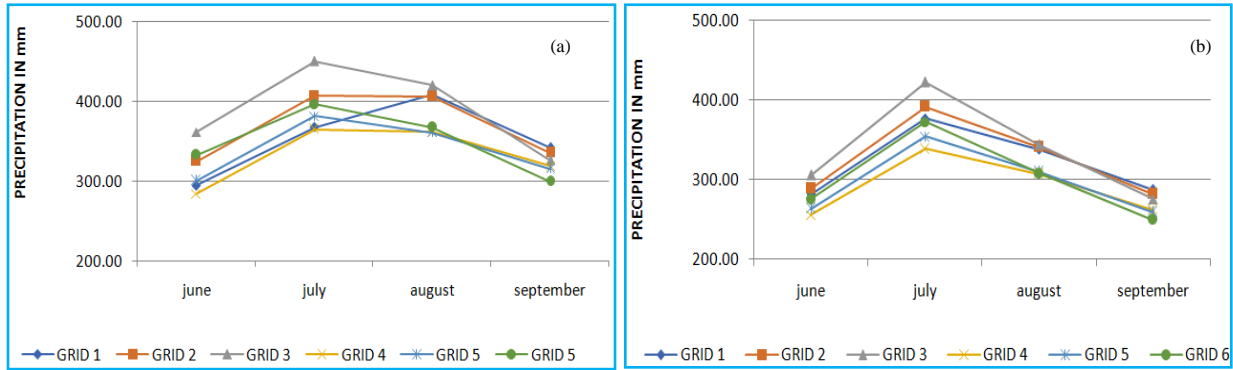
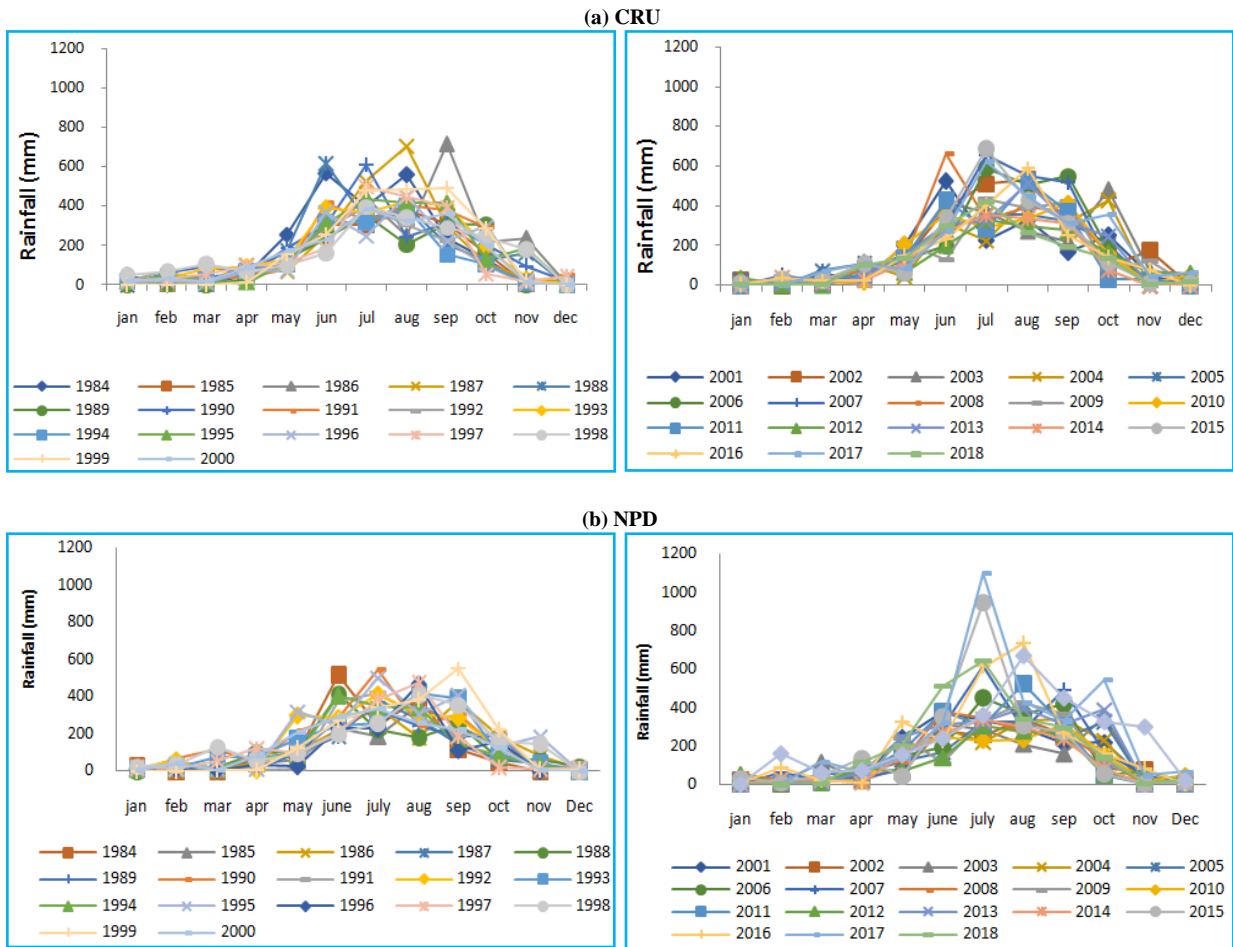


Fig. 5. Percentage Share of monsoonal precipitation of each grid



Figs. 6(a&b). Precipitation distribution during Jun to Sep (a) CRU and (b) NPD



Figs. 7(a&b). Monthly precipitation distribution of CRU and NPD from 1984-2000 and 2001-2018

highly asymmetrical distribution. Kurtosis varies from - 0.89 (CRU) to 4.62 (NPD), exhibit that the outlier characteristics of the distribution is less extreme in the case of CRU and more extreme in NPD. The kurtosis values of CRU and NPD imply a platykurtic and leptokurtic distribution curve. The coefficient of variation

(CV) of the mean annual precipitation during the study period was 13.06% CRU and 23.39% NPD. The preliminary analysis of the yearly precipitation distribution concludes that the NPD shows more variability and inconsistency in the data than CRU.

TABLE 1
Temporal Precipitation Concentration Index (PCI) of NPD and CRU (1984 -2018)

Index	Description	Number of Years (1984-2018)	
		NPD	CRU
< 10	Low precipitation concentration (almost uniform)	0	0
11- 15.5	Moderate concentration	6	6
15.6-20.5	High concentration	26	27
>20.5	Very high concentration	3	2
Mean (1984-2018)	High Concentration	15.65	17.09

TABLE 2
Performance of quantitative measures of each grid compared between NPD and CRU during 1984-2018

Grid	Lat.	Long.	R^2	P value Significance level [$p < 0.05$]	MAE (%)	RMSE (%)	BIAS (%)	MAPE
G 1	21.75	88.25	0.15	0.1	16.61	19.75	17.50	17.50
G 2	21.75	88.75	0.1	0.11	21.68	25.75	12.93	22.83
G 3	21.75	89.25	0.05	0.29	25.82	36.27	15.88	31.23
G 4	22.25	88.25	0.25	0.04	16.07	19.15	12.17	17.0
G 5	22.25	88.75	0.16	0.14	24.38	24.38	13.82	21.58
G 6	22.25	89.25	0.073	0.40	29.84	36.35	16.17	31.27

3.2. Seasonal and grid wise analysis of precipitation

The study area receives maximum precipitation during the monsoon season (Jun-Sep) (Fig. 3). Fig. 4 indicates that Grid 3 receives maximum annual and monsoonal rainfall, compared to other 5 grids. The location of this grid might be playing a significant role as this grid lays southeast part of the Sundarbans where the density of the forest is comparatively higher, and most of the cyclonic path coincides and dissipate. This geographical setting would encourage more cyclonic rainfall post-monsoon. Fig. 5 shows that the percentage share of the monsoonal precipitation varies grid wise, grid three shares the largest, while grid 4 and 5 share the lowest, below 16% each.

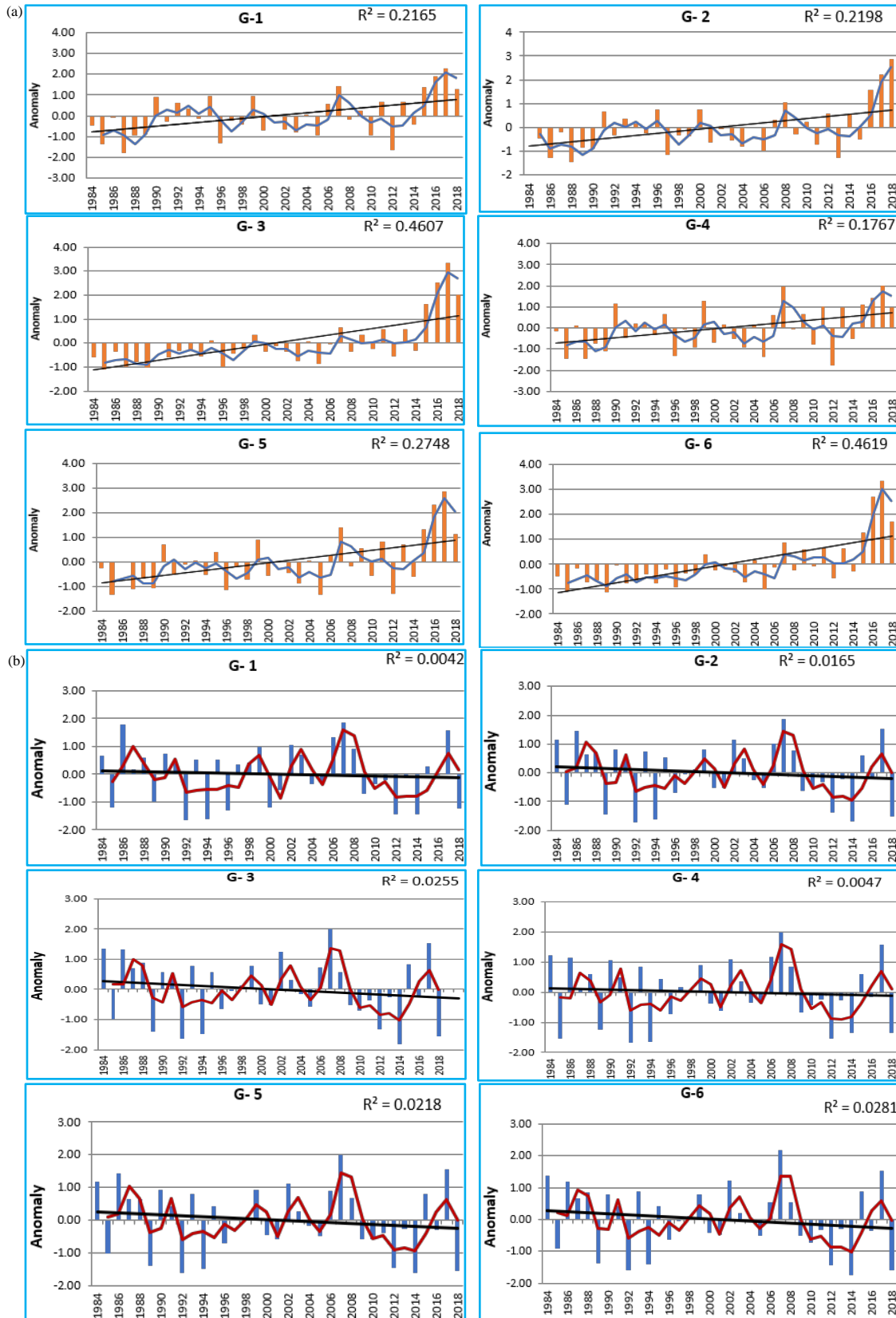
3.3. Anomaly

An anomaly helps to identify the deviation of yearly and decadal precipitation from the mean. The precipitation anomaly of NPD and CRU witnessed a wide range of differences from -1.2 to +3.7 and -1.5 to +2, respectively (Fig. 6). The increase in interannual variability becomes

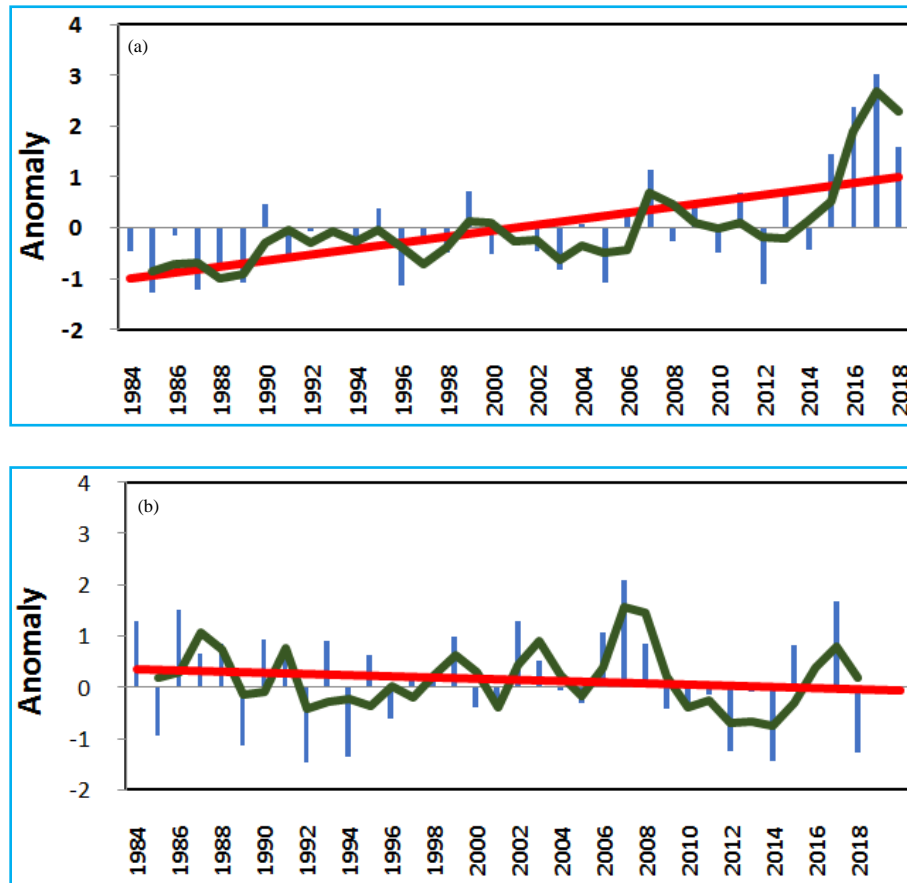
more pronounced subsequent to 2009 in NPD. The trend of CRU standardized anomaly is weak, indicating a negative inclination from 2014 onwards. The whole historical series was calculated at a 95% confidence level, and the value represents 0.34 and 0.33 in NPD and CRU, respectively [Figs. 7(a&b)]. Figs. 8&9 show the grid wise anomalies of the annual precipitation pattern from 1984-2018.

3.4. Quantitative measures and spatial analysis

The quantitative measures were calculated separately for each grid to illustrate the spatial performance differences between the two datasets. Quantitative measures showed a significant difference between the two products, both grid wise and in observation periods. Results of R^2 were different and weakly associated with mostly nonsignificant values of all the grids ($p < 0.05$). MAPE indicates that only Grid 4 performed comparatively better with an amount of 17%. The averaged and the gridded data indicate very high errors in this period. The R^2 values of the G 6 showed low performance with nonsignificant p -value. Among the entire grids, G 4 performs better in terms of R^2 , MAE,



Figs. 8(a&b). Temporal trends of precipitation Anomaly of Grids (a) NPD and (b) CRU (1984-2018)



Figs. 9(a&b). Temporal trends of precipitation Anomaly of (a) NPD and (b) CRU (1984-2018)

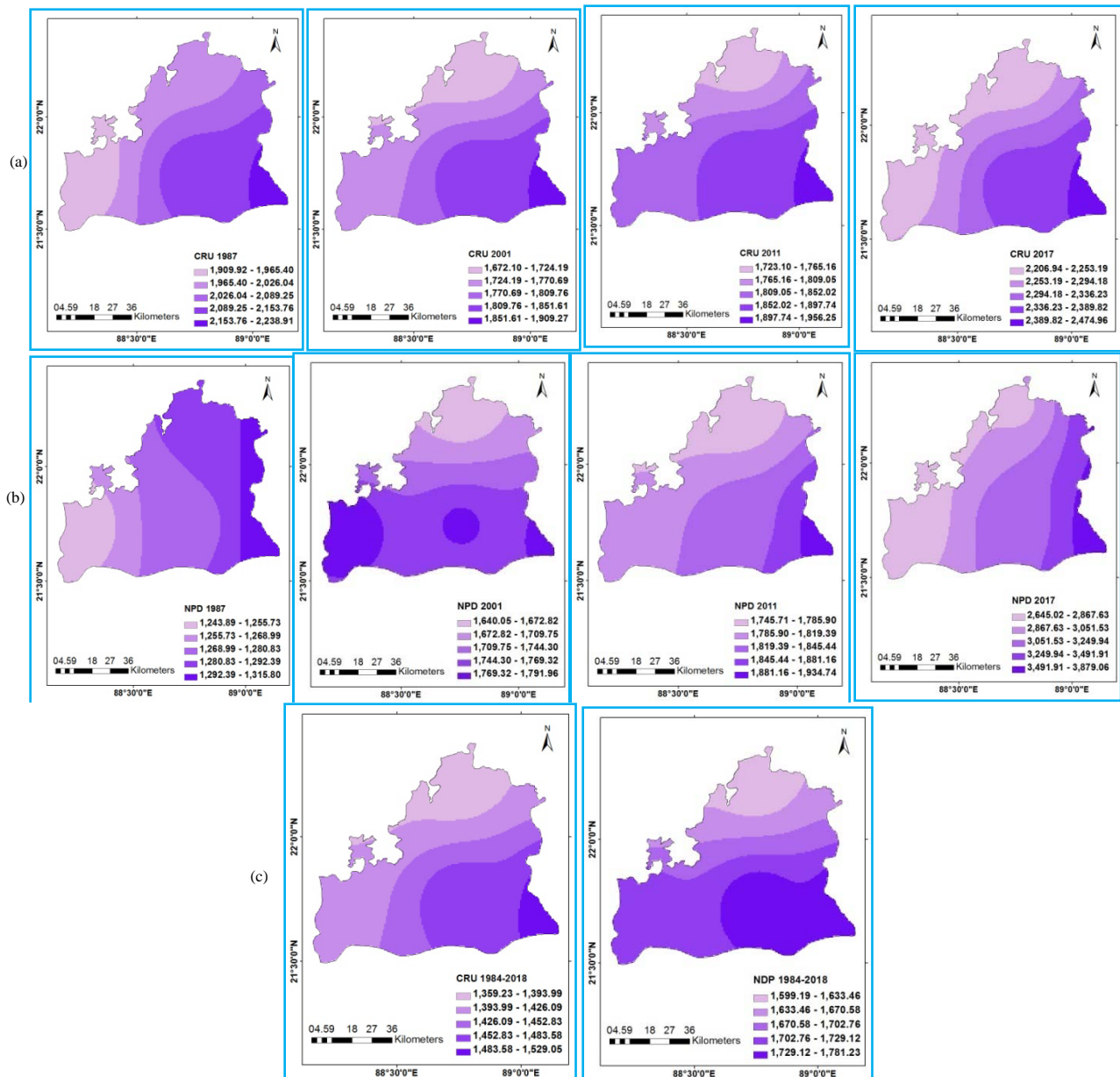
RMSE and MAPE. The precipitation analysis shows that the error between the two gridded datasets was considerable.

Spatiotemporal analysis is a vital part of this study to analyse the distribution pattern of the precipitation critically. Figs. 10(a-c) shows the difference between the spatial distribution of CRU and NPD datasets were notably significant and prominent. Over the years, the spatial pattern of CRU was somewhat analogous and consistent, whereas there is much fluctuation in NPD distribution pattern. The only geospatial similarity between the two datasets in the annual and temporal pattern of precipitation is the higher magnitude of precipitation concentration over the south-eastern part of the Indian Sundarbans. It is observed that the forest cover density is higher in the southeast part of the Indian Sundarbans due to the location of the Reserve Forest and no active human interference. The coastal proximity and the forest density play a vital role in the distribution of the precipitation pattern (Sheil and Murdiyarso, 2009).

The studied years were selected according to the maximum and minimum difference between NPD and CRU's annual precipitation pattern. The differences were 749.04, 46.27, 7.47 and -840.61 for the years 1987, 2001, 2011, and 2018. The averaged annual precipitation (1984-2018) distribution pattern was also mapped.

4. Conclusions

The scarcity of the stationed data in the study area limits the understanding of the precipitation regime's real-time distribution scenario. The widely used CRU and most reliable brand of NPD gridded dataset products show a wide range of discrepancies during 1984-2018. The precipitation anomaly witnessed a sharp increasing trend in NPD products from 2002 and a sluggish declining pattern in CRU since 2009. CV of the annual precipitation distribution concludes that the NPD shows more variability and inconsistency as compared to CRU. The grid level spatial and temporal analysis shows a substantial quantitative error. The only similarities of the



Figs. 10(a-c). Spatial distribution of precipitation in the year 1987, 2001, 2011, 2017 (a) CRU (b) NPD and (c) Averaged annual precipitation (1987-2018) of CRU and NPD

products are the monsoonal distribution, *i.e.*, the onset and cessation period. The precipitation distribution during the monsoon season in the study area is reasonably consistent. This study incorporated the statistical measures, *i.e.*, R^2 , MAE, RMSE, MAPE and BIAS, to compare between the two gridded products. Statistically insignificant relationship of grids was observed between the datasets, except grid 4. The null hypothesis is rejected at a $p < 0.05$ significance level. Hence, the alternative hypothesis was accepted, *i.e.*; there is a significant difference between the two gridded data products.

To interpret the climatic variability of a region, quantification and comparison of the appropriate data products is prerequisite. Every gridded data product has pros and cons / shortcomings, thus requires scrutiny. Because of the selection of wrong data products may lead to adversely affect the planning processes of water resource management, policymakers, and most importantly, the farmers, in this case, data need to be verified and validated with the other available data products and also with the available datasets using station-based gauge data observations of adjoining areas of the

study area. Further study can be done by downscaling the appropriate data product to study the climatic variability intensely and to anticipate the climate change impacts on the study area. The current research findings provide an insight into the preliminary analysis of the precipitation. Further investigation needs to consider in one of the most sensitive eco-climatic zones of the earth, the Sundarbans.

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Disclaimer : The contents and views expressed in this research paper/article are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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