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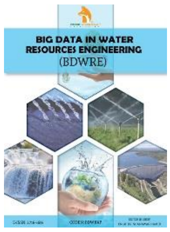

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RESEARCH ARTICLE

A TREND ANALYSIS OF RAINFALL IN KHULNA DISTRICT OF BANGLADESH

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ABSTRACT

Bangladesh, despite having a subtropical monsoon climate characterized by a waterless winter and warm summer, is one of the peak susceptible countries to climate change. Recently, climate change has garnered significant attention from academics, researchers, and policymakers globally. This study examines the trends in annual as well as monthly rainfall in the Khulna district of Bangladesh over a 20-year period (2003-2022). The aim is to provide current insights into weather patterns, particularly rainfall, in the Khulna district. Secondary data on rainfall were obtained from the Regional Inspection Center (RIC), Bangladesh Meteorological Department in Gallamari, Khulna. Descriptive statistics i.e., mean, standard deviation, and coefficient of variation were estimated to describe the annual and monthly distribution of rainfall. Trend analyses were conducted using bivariate analysis, and simple regression was engaged to assess the relationship between years with rainfall data. The results revealed that monthly rainfall did not follow a consistent pattern, with both increasing and declining trends were detected over the years. When annual rainfall was plotted against years, a negative relationship was identified ($y = -12.877x + 27742$, $R^2 = 0.0489$). Similarly, mean monthly rainfall showed a declining trend over time ($y = -1.0731x + 2311.9$, $R^2 = 0.0489$). However, these relationships were not statistically significant. The study underscores the need to implement various adaptation strategies to ensure sustainable agricultural production in the Khulna region. It also suggests the necessity of enhanced monitoring methods due to the instability of temperature and rainfall patterns.

KEYWORDS

Bangladesh, Khulna District, Rainfall, Trend Analysis.

1. INTRODUCTION

Climate variability denotes changes in climate patterns, like variations in rainfall and temperature, which can cause short-term deviations from typical conditions. These deviations, whether beneficial or harmful, are compared to the normal climate patterns observed over a long period, typically 30 years (Audu and Kotani, 2012). Bangladesh, a South Asian country, ranks highly among the top climate-vulnerable countries in the globe (Jahan and Ali, 2017; Harmeling, 2008; Rajib et al., 2015) owing to its unique geographic position, supremacy of floodplains, low altitude, high population mass, and significant dependency on natural wealth. Extreme temperatures, heavy rainfall, and seasonal variations create distinct characteristics that set Bangladesh's climate apart from other tropical countries (Hossain et al., 2014). Additionally, evidence on long-period climatic trends in Bangladesh are inconsistent and scarce (Mondal et al., 2012).

Bangladesh encounters a hot and humid climate affected by pre-monsoon, monsoon, and post-monsoon seasons, frequently coming about overwhelming precipitation and destroying storms. From an environmental and meteorological perspective, Bangladesh has four distinctive seasons: 1) winter (December - February), 2) pre-monsoon (March - May), 3) rainy (monsoon) (June - September), and 4) post-monsoon (October - November) (Islam and Uyeda, 2007; Ahasan et al., 2010)

Rainfall is the primary mechanism through which water returns commencing the atmosphere to the Earth's exterior, connecting weather, climate, plus hydrological cycles (Kuchment, 2004; Rosenfeld et al., 2008). It is a crucial factor in evaluating both floods and droughts (Chattopadhyay and Edwards, 2016). Bangladesh, characterized by a rainfall-driven climate, receives substantial rainfall, with an average annual precipitation of approximately 220 cm (Mirza et al., 2008). Historical data shows no significant trend in Bangladesh's annual rainfall (Ahmed et al., 1992). However, a study of extended-period monsoon precipitation patterns at 12 locations in Bangladesh revealed no general trend in seasonal rainfall but did identify specific tendencies in monthly precipitation (Rahman et al., 1997). The monsoon season acts as the primary raining period in the country, accounting for around 72% of the yearly rainfall during this time (Ahasan et al., 2008). Other studies suggest that over 75%-85% of the whole annual rainfall occurs during the monsoon season with the leading two months of the rainy season contributing about 71% of its entire rainfall (2001-2004) across Bangladesh (Roy, 2013; Hossain et al., 2014; Bhuiyan et al., 2014). According to the Bangladesh Meteorological Department (BMD), most rainfall occurs through the pre-monsoon and monsoon periods in Bangladesh (Mondal et al., 2020).

The Khulna district of Bangladesh, with massive low-lying zones protected by man-created polders, is highly vulnerable to climate change-induced hazards. This region faces significant socio-economic challenges and is prone to frequent disasters such as heavy rainfall, flooding, storms, salinity, and drought (Bhuiyan et al., 2018). Bangladesh needs effective policy responses for adaptation to climate change challenges. Empowering local communities and leveraging local resources are critical for sustainable adjustment to climate altered impacts. Observing climate inconsistency along with its effects at the local level, and enabling communities to organize their own adaptation strategies, is the most effective way to build resilience. Although numerous studies have

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examined climate change at the national and international levels, there is a lack of research at the local level (Alam et al., 2010; Rakib, 2018; Rashid et al., 2014; Shahid, 2010; Shirin et al., 2022; Khattak and Ali, 2015; Lacerda et al., 2015; Kruger and Nxumalo, 2017; Byakatonda et al., 2018; Cattani et al., 2018; Abaje and Oladipo, 2019). It is important to note that detecting trends in long-period hydrological information is of significant scholarly and applied importance (Kundzewicz and Robson, 2000).

Therefore, this study focuses on how climate change manifests at the local level in the southern parts of Bangladesh. The goal is to characterize the temporal variability and trends in rainfall over two decades to accurately represent local climate changes. Understanding precipitation variability and trends at the local level will help anticipate the impacts of changing climate and inform coping strategies for the local population.

1.1 Research Gap

Rainfall is one of the most vital climate parameters that determine the environmental conditions of a region, significantly impacting agricultural productivity. The statistical and trend analyses of rainfall are indispensible for realizing climate change. While numerous global studies have assessed rainfall variability and trends to understand climate change impacts, few studies have concentrated on the significance of precipitation variability of southern Bangladesh, particularly in the Khulna district. The main objective of the inquiry is to analyze trends in monthly as well as annual rainfall using regression analysis.

2. Material and Methods

2.1 Study Area

The Khulna district is located between 21°41' and 23°00' N latitudes and between 89°14' and 89°45' E longitudes, with an elevation of just 9.0 meters above mean sea level. According to the Köppen climate classification, Khulna experiences a tropical hot and humid climate. The district is significantly influenced by the monsoonal rains of South Asia, though it receives less precipitation compared to other regions of Bangladesh for its geographic location and the moderating effects of the Sundarbans in the south. Khulna receives 1878.4 mm of average rainfall annually, with approximately 87% occurring between May and October (www. Wikipedia.org). During winter, the region gets a mean of just 35 mm rainfall (BWDB, 2019).

2.2 Data Collection and Tabulation

The study utilized secondary information. Rainfall data was obtained by the researchers from the Regional Inspection Center (R.I.C) of the Bangladesh Meteorological Department (BMD) in Gallamary, Khulna. Monthly and yearly rainfall (in millimeters) was collected for the years 2003-2022 (Table 1). After collecting the data, it was carefully compiled and thoroughly examined. A master sheet was prepared to tabulate the data, consolidating all individual variables into one comprehensive dataset.

2.3 Data Analyses

A trend is explained by the general direction of a sequence of data over a prolonged period, or as the long-term alteration in a dependent variable over time (Webber and Hawkins, 1980). In this study, trends were detected by analyzing the association between precipitation and time. Regression analysis, as used to estimate relationships between a dependent variable and one or more independent variables, was engaged to examine the functional relationship concerning years with mean monthly rainfall. Additionally, the average, standard deviation, and coefficient of variation of precipitation were calculated using MS Excel.

3. Results and discussion

3.1 Variability in total annual rainfall (2003-2022)

Table 1 presents the variability in total annual rainfall in Khulna from 2003 to 2022. An analysis of the yearly total rainfall (in mm) over this 20-year period reveals significant fluctuations in the amount of rainfall. The data shows a wide array of rainfall amounts, with most values fell between 1090 and 2070 mm. Abdullah et al., after analyzing 72 years of rainfall data (1951-2022), reported that annual rainfall in Khulna typically ranged between 1214 mm and 1561 mm (Abdullah et al., 2014). However, several years within the studied period exceeded this higher limit.

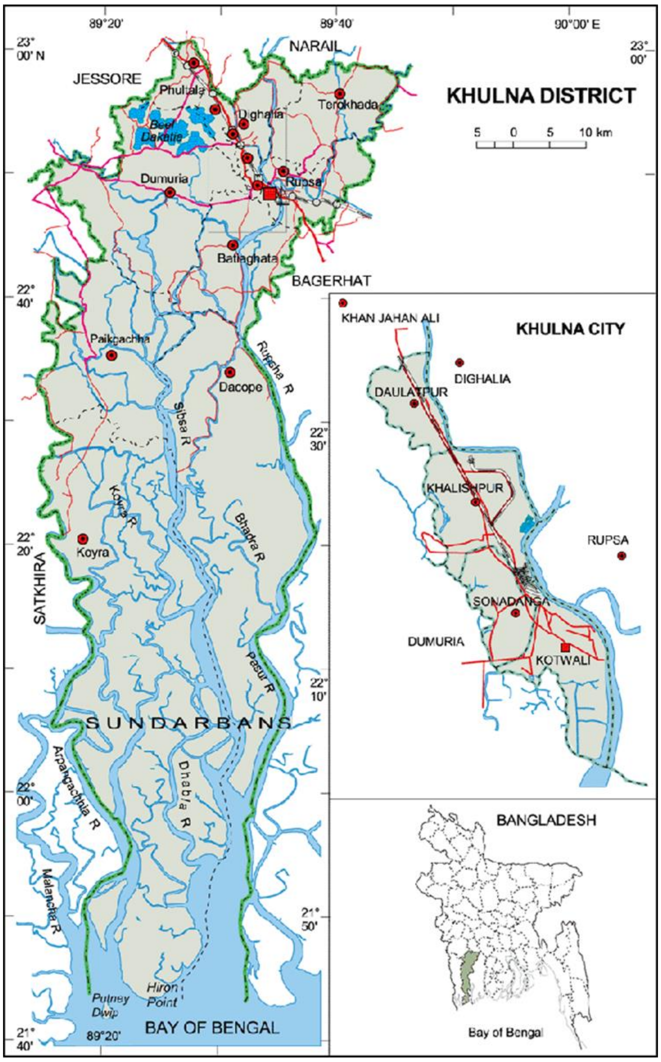

Figure 1: Location of the study area (Khulna district in Bangladesh).

The peak accumulative rain occurred in 2015, with an aggregate of 2337 mm, indicating an abnormally extreme time of precipitation. During 2017, a sum of 2280 mm was documented, making it the second-top regarding annual enjoyed precipitation. In majority of the year

total yearly rainfall summed between 1400 and 2220 mm, which were 937 and 117 mm lesser than the highest noted rainfall in Bangladesh. The lowest annual rainfall of 1090 mm was recorded in 2018, highlighting the variability and instability of Bangladesh's annual precipitation. Even years with nominal rainfall early one can receive a substantial volume by the end of the period. The 20-year database of Bangladesh's yearly precipitation displayed an irregular fashion, with some years getting heavy rainfall but others keep on relatively dry. This variability gave emphasis to the uncertainty and vulnerability in Bangladesh's precipitation patterns, where even years with low initial rainfall can end up with substantial totals by year's end. The results of this investigation are well supported by the declarations of Abdullah et al. (2024), who identified a similar pattern in Bangladesh's annual rainfall.

3.2 Relationship between years and total yearly rainfall

The association between different years with total yearly precipitation is illustrated in Figure 2. The data shows a decreasing trend in total annual rainfall, with an average yearly reduction of 12.877 mm, although this decline is not statistically significant. This suggests that Khulna has experienced a reduction of 257.54 mm from total yearly rainfall over the last two decades. The findings of the present study agreed to those of researchers, who showed a decrease in the annual mean total rainfall of 8.08 mm over 43 years at the Labhandi Observatory in Raipur, Chhattisgarh, India (Khavse et al., 2015). Similarly, a study in 2019 directed an investigation on changes in precipitation patterns in Anand, middle Gujarat, utilizing climate information between 1958 and 2017 (Mandloi et al., 2019). Their research discovered a decrease in rainfall about 0.017 mm per annum over the last 6 decades. Another researchers studied rainfall and temperature tendencies considering 1980-2014 data for six centers in the Kashmir valley, India, by means of the Mann-Kendall test. They found a reducing trend in rainfall, with a greater degree of decline in high elevated areas (Ul Shafiq et al., 2018).

Table 1: Total annual and mean monthly rainfall (mm) in Khulna over years (2003-2022)

Year	Total annual rainfall (mm)	Mean monthly rainfall (mm)
2003	1709	142.42
2004	1977	164.75
2005	1940	161.67
2006	2137	178.08
2007	2130	177.50
2008	1575	131.25
2009	1996	166.33
2010	1358	113.17
2011	1948	162.33
2012	1646	137.17
2013	2070	172.50
2014	1461	121.75
2015	2337	194.75
2016	2222	185.17
2017	2183	181.92
2018	1090	090.83
2019	1940	161.67
2020	1571	130.92
2021	1944	162.00
2022	1291	107.58
Mean rainfall (mm)	1771.45	152.19

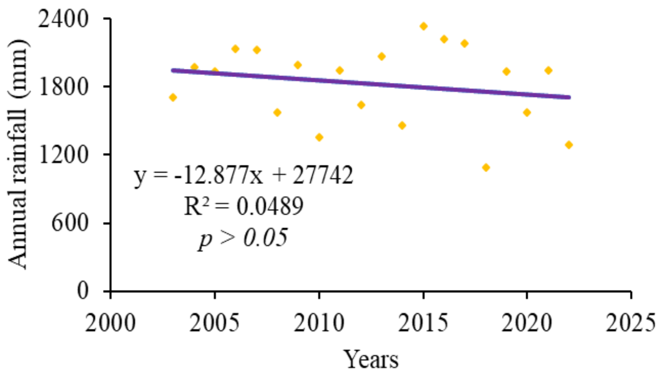

Figure 2: Functional relationship between years and annual rainfall (mm) in Khulna district.

The variation in mean monthly rainfall mirrored the pattern observed in total annual rainfall (Table 1). In 2015, the highest mean monthly rainfall was recorded at 194.75 mm, followed by 2017 with 190.00 mm. On the other hand, the lowermost average monthly rainfall of 90.83 mm occurred in 2018. This variation in mean monthly rainfall likely reflects the differences in total annual rainfall across the years, as shown in Table 1. The relationship between monthly average rainfall (mm) and time demonstrated a slight negative trend ($y = -1.0731x + 2311.9$, $R^2 = 0.0489$) (Figure 3), indicating a minor reduction in average monthly rainfall over the study period. Although the decrease in mean monthly rainfall amounted to 21.462 mm over the investigation time, the R^2 value of 0.0489 suggests that the relationship between rainfall and time is complex and not easily captured by a simple linear model. This low R-squared value emphasizes the need for a deeper understanding of the factors influencing rainfall dynamics in the region. Similarly, a study demonstrated that changes in precipitation are often minor (Zarenistanak et al., 2014).

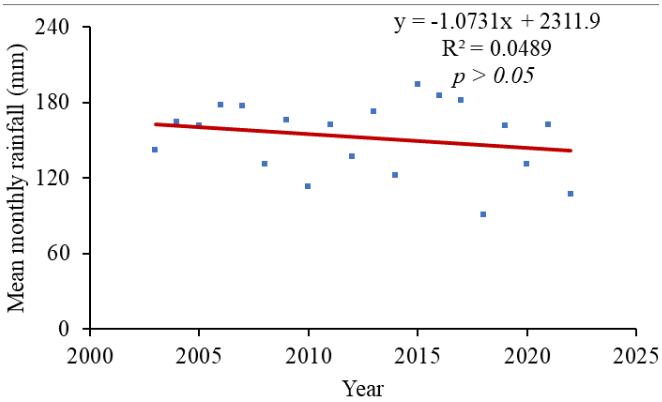

Figure 3: Functional relationship between years and mean monthly rainfall (mm) over years.

3.3 Variation in monsoon rainfall

This segment presents the results of a scrutiny of seasonal precipitation arrangements in Khulna district over the research period, with a focus on the pre-monsoon, rainy, post-monsoon, and winter seasons. The periodic variation in average rainfall is illustrated in Figure 4, highlighting a momentous impact of the monsoon season in our country, because the total rainfall narrowly followed the typical designs noticed during this period. Between 2003 and 2022, amounts of rain differed from 726 mm and 1906 mm. In 2015, Khulna recorded its highest rainy season rainfall over the past 2 decades, totaling 1906 mm. The rainfall pattern from 2003 to 2022 showed a zigzag trajectory, indicating fluctuations over the 20-year period. In most years, monsoon rainfall exceeded 1,000 mm, except in 2010 (830 mm), 2018 (743 mm), and 2022 (726 mm), with 2022 marking the lowest recorded rainfall at 726 mm. During the previous 20 years, Khulna has received a mean monsoon season rain of 1298.75 mm. These findings align with those of researchers who also observed a zigzag pattern in monsoon rainfall after analyzing 72 years of data in Bangladesh (Abdullah et al., 2024). Approximately 80% of Bangladesh's total rainfall takes place during the monsoon time, driven by fragile tropical depressions carried into the country from the Bay of Bengal by the damp monsoon airstreams (Bosu et al., 2020).

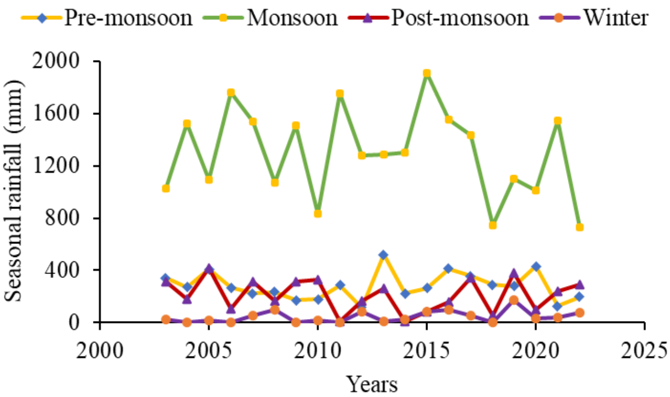

Figure 4: Seasonal trends in average rainfall (mm) in Khulna over 20 years.

The significant increase in monsoon season rainfall can largely be attributed to climate variability, which has led to more intense, short-period rainfall happenings in the area (Vivekanandan et al., 2008). This increase in rains might also be influenced by factors such as more intense cyclones making landfall on the coast, growing sea level temperatures, as well as planetary effects on the sun-earth environs (GEC, 2011; Rao and Vivekanandan, 2008; Mukherjee, 2008).

Figure 4 illustrates the seasonal precipitation patterns in Khulna for the 20 years. In most years, rainfall ranged between 100 mm and 300 mm, with the exceptions of 2003, 2005, 2013, 2016, 2017, and 2020, where annual rainfall exceeded 300 mm. Notably, we observed a little ascending trend in 2005, 2013, 2016, and 2020, terminating in a best ever maximum of 519 mm in 2013 - the highest over 20 years. During 2005, rainfall reached 410 mm, in 2016 it was 413 mm, and in 2020 it improved to 433 mm. Conversely, rainfall quantities were below 200 mm during 2009, 2010, 2012, 2021, and 2022, with the lowest recorded rainfall of 116 mm occurring in 2012. The mean pre-monsoon rainfall over the 20-year period was approximately 280.7 mm. Abdullah et al. described an average pre-monsoon rainfall of 335.37 mm in Bangladesh during the period from 1951 to 2022 (Abdullah et al., 2024).

Post-monsoon rainfall in Khulna varied from 9 mm to over 400 mm. The lowest documented precipitation during the study period was 9 mm in 2011, while majority of the rain amounts fell in between 100 mm and 420 mm. The mean post-monsoon rainfall over the past 20 years was 212.5 mm. Winter rainfall in Khulna also displayed a distinct zigzag pattern between 2003 and 2022. The amount of precipitation differed from 0 mm and 171 mm, offering the highest recorded rainfall of 171 mm in 2019. In 2004 and 2006, rainfall was at its lowest, with virtually no recorded rainfall. The average winter rainfall in Khulna over the past 20 years was 44.4 mm.

3.4 Variation in monthly rainfall

Over period, the investigation of monthly precipitation arrays has headed to a thorough understanding of precipitation dispersal in Khulna. January, with a mean rainfall of 13 mm (Table 2), has recorded the second-lowest rainfall over the last 2 decades. February saw a slight increase, averaging 33 mm, indicating dry weather despite the rise. In March, there was a shrinkage in rainfall than February, with a mediocre of 19 mm over the past 20 years, though rainfall was anticipated to rise, signaling the onset of rainy season. April's average rainfall of 59 mm begins to impact the region's ecosystems.

Table 2: Monthly average rainfall (mm) in Khulna over years (2003-2022)

Month	Average rainfall(mm)	Range (mm)	Standard deviation(mm)	CV (%)
January	13	0-67	24.22	186.31
February	33	0-166	49.51	150.03
March	19	0-155	22.41	117.95
April	59	0-179	48.03	81.41
May	179	63-430	95.24	53.21
June	285	76-468	114.00	40.00
July	400	116-924	202.69	50.67
August	325	107-643	168.44	51.83
September	274	106-621	98.30	35.87
October	158	3-420	108.16	68.45
November	43	0-202	67.13	156.12
December	08	0-51	14.93	186.62

The study of the 20-year period shows that Khulna experienced significantly higher rainfall in May, with an average of 179 mm, marking a noticeable climate shift due to the increased precipitation. June saw even more rainfall, averaging 285 mm, suggesting substantial rainfall during this month. July remains the wettest month in Khulna, with an average of 400 mm, highlighting the variability in climate and the prospective for substantial rainy season precipitation. August continued to experience substantial rainfall, averaging 325 mm, slightly less than July, possibly indicating changes in the monsoon pattern. In September, rainfall typically decreased compared to June, July, and August, with a 20-year average of 274 mm. This decrease suggests the approaching end of the rainy season. October's average rainfall of 158 mm (Table 2) signals the conclusion of the monsoon season. November saw an average of 43 mm, while December recorded the lowest average rainfall over the past 20 years, at just 8 mm, making it the driest month. High variability (CV > 100%) was observed in the months of January, February, March, November, and December, indicating periods of both intense and scanty precipitation. April and November showed comparatively lower variability (CV < 100%), while May, July, and September had moderate variability (CV ≈ 50%), indicating relatively stable rainfall. June and September exhibited the lowest CVs (CV ≤ 40%), suggesting more consistent rainfall in these months.

As presented in Table 2, monthly average rainfall is the highest in monsoon months, peaking in July, and lowest in the winter months, with January recording the least rainfall. These findings align with Bosu et al., who also reported that July had the highest and January the lowest monthly mean rainfall (Bosu et al., 2020). The monthly trends in mean rainfall in Khulna from 2003 to 2022 followed a unimodal distribution pattern, with the peak in July. Additionally, smaller peaks were observed in August and September (Figure 5). As expected, most rainfall occurs from June to October. A study in 2019 similarly noted that the lowest precipitation occurred during the winter months of December, January, and February, while the highest occurred during the monsoon months of June through September (Noorunnahar and Hossain, 2019).

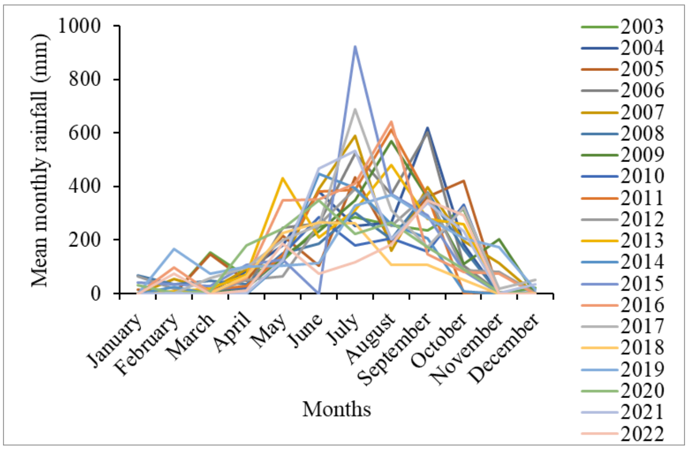

Figure 5: Monthly trends in average rainfall (mm) in Khulna over 20 years.

3.5 Trend analysis of monthly mean precipitation

The tendencies in total monthly rainfall during the years were analyzed using linear regression lines. The regression pattern, along with corresponding equations and coefficients of determination relating each month from January to December, were illustrated in Fig. 6 (a) and Fig. 6 (b) and summarized in Table 4. As described in Figure 6 (a) and Figure 6 (b), monthly rainfall increased in February, April, May, June, November, and December, while it exhibited a decreasing trend in January, March, July, August, September, and October. These findings were similar to the conclusions of a study in 2015, where it's identified an irregular rainfall distribution pattern in Chhattisgarh, India (Khavse et al., 2015).

In Khulna, the highest increase in mean monthly rainfall was observed in May, with an increase of 54.496 mm over the past 20 years. Conversely, the most significant decrease in mean monthly rainfall occurred in September, with a reduction of 241.48 mm during the same period. These results align with Khavse et al., conclusions, where the highest increase in total monthly rainfall at the Labandi Raipur Station, India, was observed in July, with a rise of 64.1 mm from 1971 to 2013, while the most significant decrease occurred in August, with a reduction of 61.8 mm in the equivalent era (Khavse et al., 2015).

Table 3: Regression equations for all the months in a year (2003-2022) of mean monthly rainfall (mm) in Khulna district

Month	Regression equation	R^2	p value
January	$y = -0.1789x + 371.13$	0.0023	0.836
February	$y = 2.7248x - 5457.3$	0.1407	0.105
March	$y = -3.2038x + 6478.5$	0.1700	0.070*
April	$y = 1.1632x - 2282.9$	0.0243	0.522
May	$y = 1.582x - 3001.9$	0.0115	0.671
June	$y = 0.2218x + 166.63$	0.0001	0.985
July	$y = -0.1391x + 674.58$	0.00005	0.965
August	$y = -0.3594x + 1037.6$	0.0002	0.934
September	$y = -12.074x + 24660$	0.2716	0.0178**
October	$y = -3.4887x + 7198.8$	0.0306	0.449
November	$y = 0.2406x + 449.91$	0.0005	0.929
December	$y = 0.6346x - 1269.7$	0.0718	0.256

* Significant at 10% level, ** Significant at 5% level

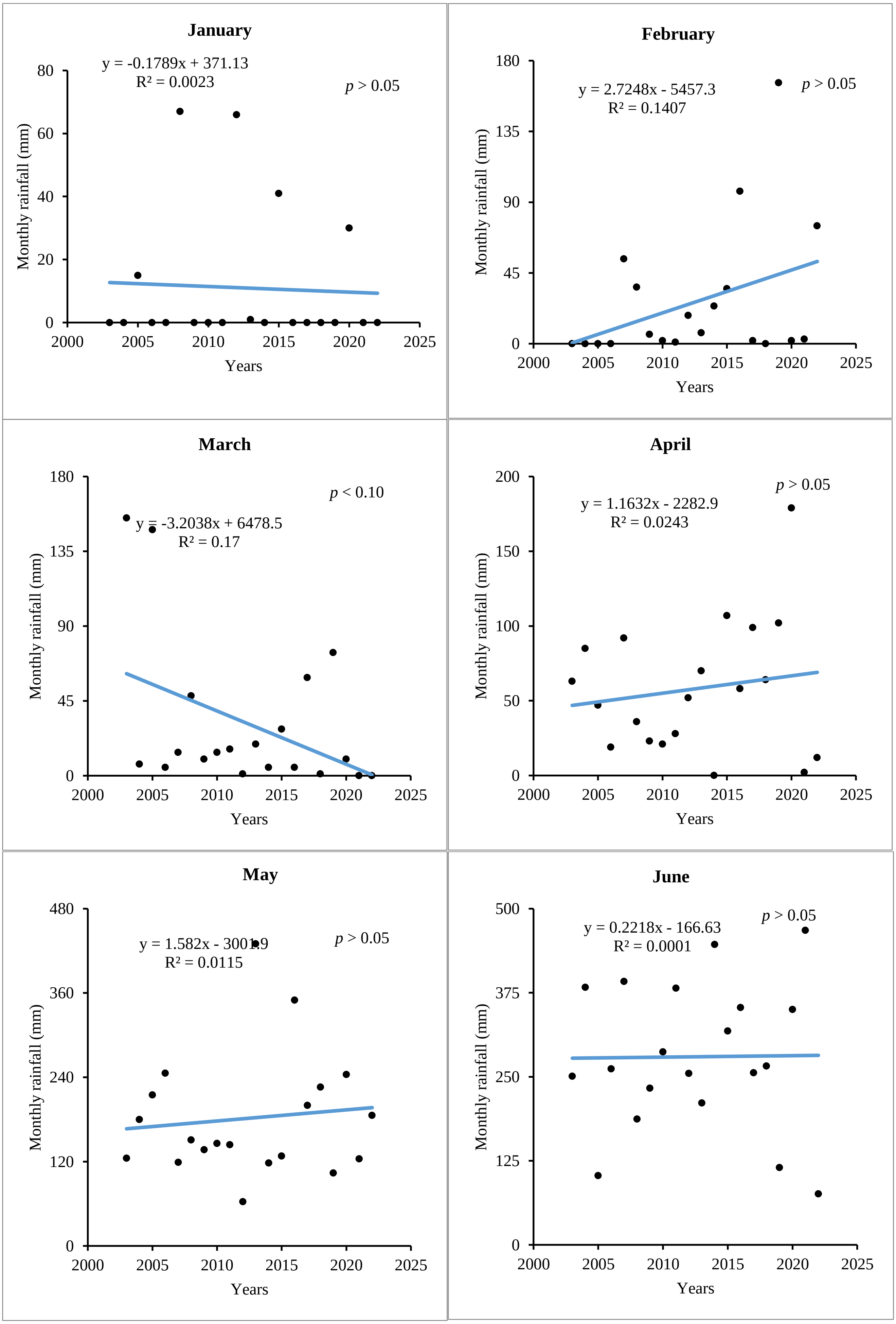
January
y = -0.1789x + 371.13
R² = 0.0023
p > 0.05
Monthly rainfall (mm)
Years
February
y = 2.7248x - 5457.3
R² = 0.1407
p > 0.05
Monthly rainfall (mm)
Years
March
y = -3.2038x + 6478.5
R² = 0.17
p < 0.10
Monthly rainfall (mm)
Years
April
y = 1.1632x - 2282.9
R² = 0.0243
p > 0.05
Monthly rainfall (mm)
Years
May
y = 1.582x - 3001.9
R² = 0.0115
p > 0.05
Monthly rainfall (mm)
Years
June
y = 0.2218x - 166.63
R² = 0.0001
p > 0.05
Monthly rainfall (mm)
Years

Figure 6 (a).

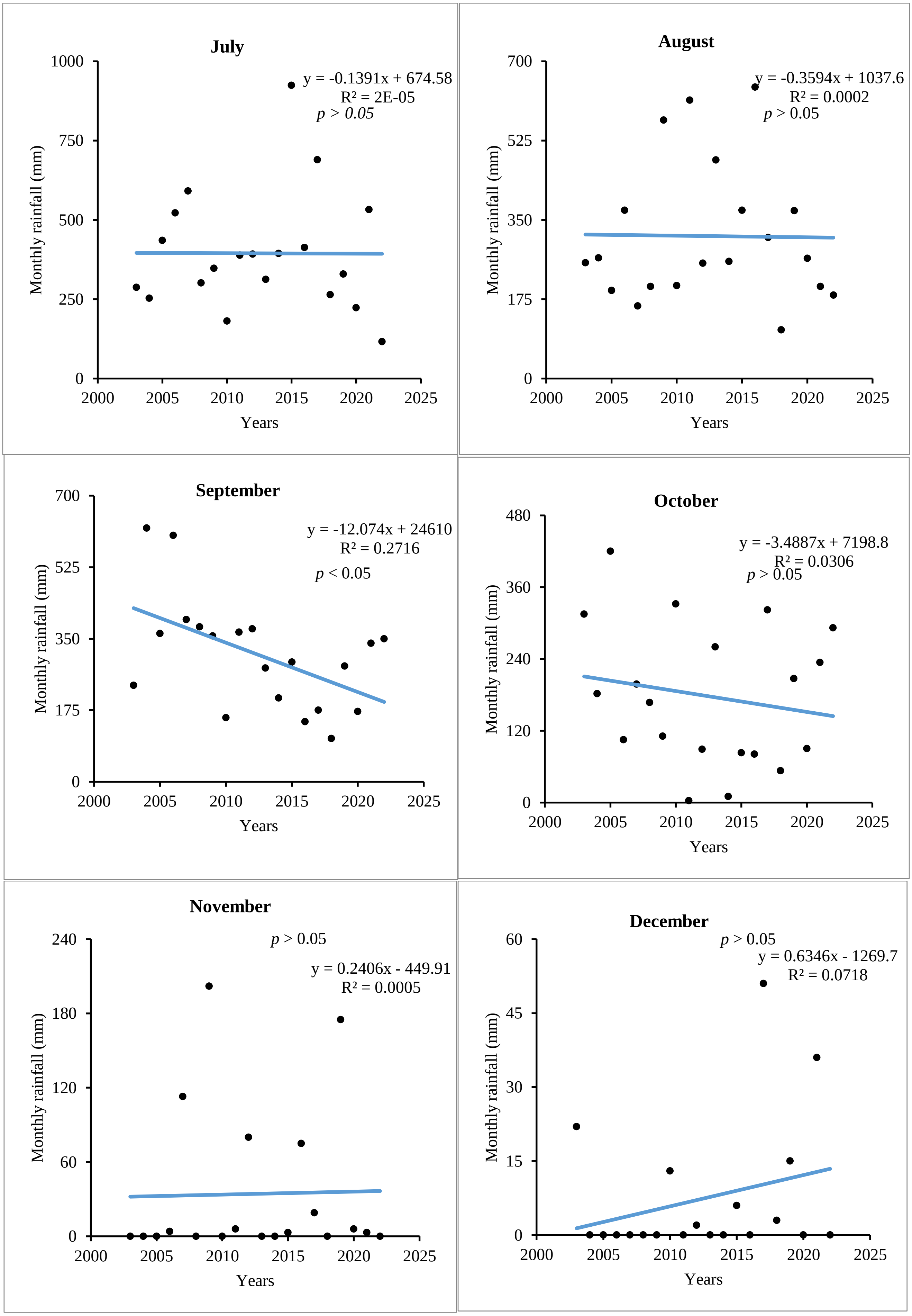

Figure 6 (b).

Figures. 6 (a), and **6 (b)**. Trend analyses of mean monthly rainfall (mm) in Khulna over years.

4. Conclusion

This study was conducted to examine rainfall variability in the Khulna district using historical data from 2003 to 2022. The analysis of annual total rainfall revealed significant fluctuations, with the maximum rainfall of 2337 mm recorded in 2015 and the lowermost annual rainfall of 1090 mm in 2018. The mean monthly rainfall was found the highest during the monsoon season, peaking in July, while the lowest rain happened in the winter period, with January having the least precipitation. Again, the seasonal trends in mean monthly rainfall in Khulna over the years (2003-2022) followed a unimodal distribution pattern, with July being the peak month. The study indicated that mean monthly rainfall increased in February, April, May, June, November, and December, while it decreased in January, March, July, August, September, and October. Over the analysis period, both the annual and average monthly precipitation decreased by 12.877 mm and 1.0731 mm, respectively. The present study renders valuable intuitions and a fresh outlook for policymakers and managers, enabling them to take practical actions in response to climate alteration. The findings are also beneficial in developing climate resilient options for various areas of Bangladesh, as well as for conducting climatology studies and assessing the effect of climate change across the country. Based on the study's outcomes, it is crucial to highlight that water resources face significant threats in the context of a changing climate.

References

Abaje, I.B., Oladipo, E.O., 2019. Recent changes in the temperature and rainfall conditions over Kaduna State, Nigeria. Ghana Journal of Geography, 11(2), Pp. 127-157.

Abdullah, M., Idrak, F., Kabir, P., Bhuiyan, M.A.H., 2024. Suitability of rainwater harvesting in saline and arsenic affected areas of Bangladesh. Heliyon, 10, Pp. e34328. https://doi.org/10.1016/j.heliyon.2024.e34328

Ahasan, M.N., Chowdhury, M.A., Quadir, D.A., 2008. Few Aspects of the Flood Disaster Caused by Heavy Rainfall over Bangladesh. Proceedings of SAARC Seminar on Application of Weather and Climate Forecasts in the Socio-Economic Development and Disaster Mitigation, Dhaka, 5-7 August 2007. Pp. 79-94.

Ahasan, M.N., Chowdhary, M.A.M., Quadir, D.A., 2010. Variability and trends of summer monsoon rainfall over Bangladesh. Journal of Hydrology and Meteorology, 7, Pp. 1-17.

Ahmed, S.M.U., Hoque, M.M., Hussain, S., 1992. Floods in Bangladesh: A Hydrological Analysis. Final Report No. R01/92, Institute of Water and Flood Management (IWFM), BUET, Bangladesh.

Alam, M.M., Hossain M.A., Ara, M. 2010. Long term variations of climate over different stations of Khulna and Barisal divisions of Bangladesh. Journal of Engineering Science, 1(1), Pp. 1-7.

Audu, P., Kotani, K., 2012. Impact of variation in climatic factors on crop yield: A case of rice crop in Andhra Pradesh, India. The International University of Japan Economics and Management Series, EMS-2012. Pp. 17

Bhuiyan, M.T.H., Bhuyan, M.D.I., Chowdhury, M.N., Wahid, C., Faruque, S.B., 2014. Characteristics of diurnal variation of summer monsoon rainfall over Bangladesh and its adjacent areas. Journal of Emerging Trends in Engineering and Applied Sciences, 5, Pp. 217-221.

Bhuiyan, M.D.I., Islam, M.M., Bhuiyan, M.E.H., 2018. A trend analysis of temperature and rainfall to predict climate change for Northwestern region of Bangladesh. American Journal of Climate Change, 7, Pp. 115-134. http://www.scirp.org/journal/ajcc

Bosu, H., Rashid, T., Mannan, A., Meandad, J., 2020. Trends of rainfall and temperature in Bangladesh: A comparative analysis of CMIP5 results and meteorological station data. The Dhaka University Journal of Earth and Environmental Sciences, 9 (2), Pp. 9-18.

BWDB., 2019. Summary of Rainfall in Bangladesh for the Period of 2017 and 2018. Bangladesh Water Development Board (BWDB), Dhaka, Bangladesh. Pp. 30.

Byakatonda, J., Parida, B.P., Kenabatho, P.K., Moalafhi, D.B., 2018. Analysis of rainfall and temperature time series to detect longterm climatic trends and variability over semi-arid Botswana. Journal of Earth System Science, 127(25), Pp. 2-25.

Cattani, E., Merino, A., Guijarro, J.A., Levizzani, V., 2018. East Africa rainfall trends and variability 1983–2015 using three long-term satellite products. Remote Sensing, 10(6), Pp. 931. https://doi.org/10.3390/rs10060931

Chattopadhyay, S., Edwards, D.R., 2016. Long-term trend analysis of precipitation and air temperature for Kentucky, United States. Climate, 4 (10), Pp. 2-15.

GEC., 2011. Trends of Changing Climate and Effects on Eco-Environment of Kachchh District, Gujarat. Project Report, Gujarat Ecology Commission (GEC), Gandhinagar, Gujarat. Pp. 86.

Harmeling, S. 2008. Global Climate Risk Index 2009. Weather-Related Loss Events and Their Impacts on Countries in 2007 and in a Long-Term Comparison. Germanwatch e.V., Berlin.

Hossain, M.S., Roy, K., Datta, D.K., 2014. Spatial and temporal variability of rainfall over the South-West coast of Bangladesh. Climate, 2, Pp. 28-46. https://doi.org/10.3390/cli2020028

https://en.wikipedia.org/wiki/Khulna. Accessed on 29 August, 2024.

Islam, M.N., Uyeda, H., 2007. Use of TRMM in determining the climatic characteristics of rainfall over Bangladesh. Remote Sensing of Environment, 108, Pp. 264-276. https://doi.org/10.1016/j.rse.2006.11.011

Jahan, M.S. and Ali, S.A. 2017. Enhancing resilient livelihood of coastal communities of Bangladesh. Ulashi Sreejony Sangha, Jessore, Bangladesh.

Khavse, R., Deshmukh, R., Manikandan, N., Chaudhary, J.L., Kaushik, D., 2015. Statistical analysis of temperature and rainfall trend in Raipur district of Chhattisgarh. Current World Environment, 10(1), Pp. 305-312.

Khattak, M.S., Ali, S., 2015. Assessment of temperature and rainfall trends in Punjab Province of Pakistan for the period 1961-2014. Journal of Himalayan Earth Sciences, 48(2), Pp. 42-61.

Kruger, A.C., Nxumalo, M.P., 2017. Historical rainfall trends in South Africa: 1921–2015. Water System Analysis, 43(2), Pp. 285-297.

Kuchment, L.S., 2004. The Hydrological Cycle and Human Impact on It. in: Hoekstra, A.Y. and Savenije, H.H.G., (Eds.), Water Resources Management Encyclopaedia of Life Support Systems (EOLSS), Developed under the Auspices of the UNESCO, Eolss Publishers, Oxford. Pp. 1-40.

Kundzewicz, Z.W. and Robson, A., 2000. Detecting Trend and Other Changes in Hydrological Data. World Climate Program Data and Monitoring. WMO/TD-No. 1013, Geneva.

Lacerda, F.F., Nobre, P., Sobral, M.C., Lopes, G.M.B., Chou, S.C., 2015. Long-term temperature and rainfall trends over Northeast Brazil and Cape Verde. Earth Science and Climatic Change, 6(8), Pp. 296. doi:10.4172/2157-7617.1000296

Mirza, M.Q., Warrick, R.A., Ericksen, N.J., Kenny, G.J., 2008. Trends and persistence in precipitation in the Ganges, Brahmaputra and Meghna river basins. Hydrological Sciences Journal, 43, Pp. 845-858.

Mondal, A.S.M., Islam, S., Madhu, M.K., 2012. Spatial and Temporal Distribution of Temperature, Rainfall, Sunshine and Humidity in Context of Crop Agriculture, Comprehensive Disaster Management Program (CDMP II). Ministry of Disaster Management and Relief, Dhaka.

Mondal, K.K., Akhter, M.A.E., Mallik, M.A.K., 2020. Temporal trend analysis of historical climatic data at North Eastern hilly region of Bangladesh using Mann-Kendall test. Journal of Engineering Science, 11, Pp.19-25. https://doi.org/10.3329/jes.v11i2.50894

Mondloi, K., Kamani, G.J., Chinchorkar, S.S., 2019. Study of change in rainfall pattern in Anand (Middle Gujarat) in the last 60 Years (1958-2017). Current World Environment, 14(1), Pp. 128-133.

Mukherjee, S., 2008. Cosmic influence on the sun-earth environment. Sensors, 8, Pp. 7736-7752.

Noorunnahar, M., Hossain, M.A., 2019. Trend analysis of rainfall data in divisional meteorological stations of Bangladesh. Annals of Bangladesh Agriculture, 23(1), Pp. 49-61.

Rahman, M.R., Salehin, M., Matsumoto, J., 1997. Trend of monsoon rainfall pattern in Bangladesh. Journal of Water Resources, 14, Pp. 121-138.

Rajib, M.A., Rahman, M.M., Rakib, Z.B., Khondoker, M.T.H., Iskander, S.M., Hassan, M.M. and Mortuza, M.R. 2012. Application of RCM-Based Climate Change Indices in Assessing Future Climate: Part I Temperature Extremes. In: World Environmental and Water Resources Congress 2012: Crossing Boundaries. American Society of Civil Engineers, Reston. Pp. 1-7.

Rakib, Z., 2018. Characterization of climate change in southwestern Bangladesh: Trend analyses of temperature, humidity, heat index, and rainfall. Climate Research, 76(3), Pp. 241–252. https://doi.org/10.3354/cr01535

Rao, P., Vivekanandan, E., 2008. Impact of Climate Change on Indian Marine Fisheries. Bay of Bengal News, March - June 2008, Central Marine Fisheries Research Institute (CMFRI), Kerala, India. Pp. 32-37.

Rashid, M.H., Afroz, S., Gaydon, D., Muttaleb, A., Poulton, P., Roth, C., Abedin, Z., 2014. Climate change perception and adaptation options for agriculture in southern Khulna of Bangladesh. Applied Ecology and Environmental Sciences, 2(1), Pp. 25–31. https://doi.org/10.12691/aees-2-1-4

Rosenfeld, D., Lohmann, U., Raga, G.B., ODowd, C.D., Kulmala, M., Fuzzi, S., Andreae, M.O., 2008. Flood or drought: How do aerosols affect precipitation? Science, Pp. 321, 1309-1313. https://doi.org/10.1126/science.1160606

Roy, M., 2013. Time series, factors and impacts analysis of rainfall in North-Eastern Part in Bangladesh. International Journal of Scientific and Research Publications, 3, Pp. 1-7.

Shahid, S. 2010. Recent trends in the climate of Bangladesh. Climate Research, 42(3), Pp. 185-193.

Shirin, T., Saha, T., Rahaman, M.H., Chowdhury, M.A., Bari, E., Das, T.K., Rahman, M.M., 2022. Trends and spatial heterogeneity of climate extremes in the southwestern region of Bangladesh. Chinese Journal of Urban and Environmental Studies, 10(04), Pp. 1-25. https://doi.org/10.1142/S2345748122500233

Ul Shafiq, M., Rasool, R., Ahmed, P. Dimri, A.P., 2018. Temperature and precipitation trends in Kashmir valley, Northwest Himalayas. Theoretical and Applied Climatology, 235, Pp. 293-304. doi: 10.1007/s00704- 018-2377-9

Vivekanandan, E., Ali, M.H., Jasper, B., Rajagopalan, M., 2008. Thermal thresholds for coral bleaching in the Indian Seas. Journal of the Marine Biological Association of India, 50(2), Pp. 209- 214.

Webber, J., Hawkins, C., 1980. Statistical Analysis Application to Business and Economics. Harper and Row, New York.

Zarenistanak, M., Dhorde, A.G., Kripalini, R.H., 2014. Trend analysis and climate change point detection of annual precipitation and temperature series over southwest Iran. Journal of Earth System Science, 123 (2), Pp. 281-295.