IMPACT OF CLIMATE CHANGE ON EXTREME RAINFALL CHANGING PATTERNS IN THE SOUTHWEST REGION OF BANGLADESH USING SDSM AND HADCM3 MODEL

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ABSTRACT

Bangladesh is one of the most climate-vulnerable countries in the world to the negative impact of climate change. In recent years, the country has been experiencing the frequent occurrence of extreme rainfall due to impact of climate change. Particularly, the southwestern region of the country has been severely affected by the extreme rainfall induced water logging and urban flash flooding, which demands the assessment of extreme rainfall changing patterns in the region due to the impact of climate change. To address the research gap, we have utilized the historical (1961-2020) and downscaled rainfall (2021-2100) data obtained from the fifth phase of the Coupled Model Intercomparison Project (CMIP5) data. The current study has adopted the statistical downscaling model (SDSM) to downscale future rainfall based on the well-known global climate model, HadCM3 under its two climate change scenarios including A2 (high emission) and B2 (moderate emission) scenarios. Khulna district, located in the southwestern Bangladesh, is selected to demonstrate the case study for exploring the potential impact of climate change on existing and future extreme rainfall changing patterns. Several indices are adopted to calculate the extreme rainfall in the baseline and three future time periods, namely near-future (2025-2050), mid-future (2051-2075), and far-future (2076-2100). This research identifies remarkable changes in extreme rainfall indices based on HadCM3 downscaled rainfall for A2 (high emission) and B2 (moderate emission) scenarios. The extreme rainfall analysis for Khulna and southwest Bangladesh indicates substantial increases across all indices when compared to the 1980–2005 baseline. In the A2 scenario, Rx1day rises by about 31% in 2025–2050, 16% in 2051–2075, and 2% in 2076–2100, while Rx5day shows increases of 32%, 21%, and 2% respectively. R95p days grow by 140%, 86%, and 26%, and R99p days by 338%, 165%, and 9% across the same patterns. R95pTOT and R99pTOT follow a similar trend, with very large rises early in the century and smaller rises show later. In the B2 scenario, Rx1day increases by 31%, 22%, and 3%, while Rx5day rises 29%, 21%, and 3%. R95p days grow by 127%, 97%, and 37%, and R99p days by 276%, 168%, and 31%. The R95pTOT and R99pTOT represent remarkable enhancement within this near and far future, a gradual moderation is following yet the extreme rainfall is higher than the baseline. The transformation will increase the vulnerability of Khulna and the broader southwest region of Bangladesh as well as will result in drainage congestion, pressure on embankments, losses in aquaculture, and deterioration of water quality related tendency. The anticipated increase in extreme rainfall due to the impact of climate change underscores the critical need for climate-resilient stormwater management, adaptive drainage systems, and sustainable urban infrastructure development and management.

Keywords: *Extreme Rainfall, Rainfall Indices, SDSM, HadCM3, Statistical Downscaling.*

1. INTRODUCTION

Climate change is considering as the most important concern for this world, which impact has been expanded on the environment, natural ecosystems, populations and economy. The global temperatures have been increasing day by day due to the impact of climate change also modifying the hydrological cycle, and increases the occurrence of extreme precipitations worldwide (Ghosh & Adhikary, 2025; Islam et al., 2024). Bangladesh, being a low-lying deltaic country, is considered as one of the high vulnerable countries to the negative impact of climate change (Rana & Adhikary, 2024). The hydro-meteorological disasters including floods, water-logging, storm surges, and cyclones are expected to occur as the occurrence of extreme rainfall are anticipated to occur with the greater frequency due to the impact of climate change (Rana et al., 2024; Siddik et al., 2024). The long resilience culture and ecosystem services highly depend on reliable extreme rainfall assessment and predictability which is vital for the environmental and economic stability of Bangladesh. However, the extreme rainfall patterns are highly variable in spatial and temporal scales, and are fluctuated with the length, intensity or frequency across the country (Nath et al., 2024). As a result, the overall water availability is affected, which greatly impacts the agricultural productivity, urban stormwater management, and infrastructure longevity (Islam et al., 2022). Hydrological, geomorphological characteristics and environmental ecosystems have already been impacted by the climate changed induced frequent occrrence of excess rainfall in different regions of Bangladesh (Mishu et al., 2025; Rana et al., 2025; Nath et al., 2024; Rana et al., 2024; Azad et al., 2023) including the southwest region having a low elevation topography (Rana and Adhikary, 2023).

The Hadley Centre Coupled Model version 3 (HadCM3) is a coupled atmosphere-ocean global climate model (GCM) developed at the Hadley Centre in the United Kingdom (Rana & Adhikary, 2024), which was one of the major models used in the IPCC Third Assessment Report in 2001. GCMs such as HadCM3 are poorly suited for localised climate impact analysis owing to their coarse resolution. Therefore, it is necessary to downscale GCMs for local level climate change studies. The statistical downscaling model (SDSM) to get around this problem. Using this method, it is possible to link large-scale weather predictions to localised rainfall data in the actual world (Rana et al., 2025; Siddik et al., 2024; Al-Mukhtar & Qasim, 2019). In addition to being fast at calculating things, it is widely used in Bangladesh to make more precise climate predictions, such as temperature, rainfall, and other meteorological factors (Rana and Adhikary, 2023). The current study aims to explore how climate change induced rainfall occurrences could affect the southwestern region of Bangladesh, particularly when it comes to the occurrence of extreme rainfalls, using the SDSM and HadCM3 models. The climate change downscaling model is calibrated using the historical data obtained from the Bangladesh Meteorological Department (BMD) for 1981-2000 period and validated the model accuracy for 2001-2015 period. The Special Reports on Emission Scenarios (SRES) of HadCM3 model including A2 (high-emission) and B2 (moderate-emission) are used to make future climate projections for three time periods: the near future (2025–2050), the mid future (2051–2075), and the far future (2076–2100). The current study seeks to assess the expected changes in extreme rainfall patterns in the southwest region to facilitate the study of regional hydrological systems, formulation of climate adaptation policies, and the design of climate-resilient infrastructures.

2. METHODOLOGY

2.1 The Study Area

The current study attempts to explore the climate change induced extreme rainfall changing patterns in Khulna, which is situated in the southwest region of Bangladesh as shown in Figure 1. Khulna is chosen as the study area because it is well acknowledged as one of the most climate-change induced vulnerable locations in the country (Rana & Adhikary, 2023). Khulna lies in an area that is around 4,389 square kilometers and is between 21°30′ and 23°00′ N latitude and 88°45′ and 89°58′ E longitude. Jessore and Narail share its northern border, Bagerhat shares its eastern border, Satkhira shares its western border, and the Bay of Bengal shares its southern border. The lower Ganges Delta has tidal estuaries, intricate river systems, and flat alluvial plains. The Rupsha, Bhairab, Passur, and Sibsa Rivers are few of these features that have a profound effect on the hydrology and overall ecosystem of the study area (Suhan & Adhikary, 2024). Khulna has a tropical monsoon climate, which can be divided into three seasons. The pre-monsoon season, which runs from March to May, is hot and has a lot of thunderstorms. The monsoon season, which runs from June to October, has a lot of rain and some flooding (Wahid et al., 2025). The post-monsoon season, which runs from November to February, is cooler and drier. The region gets between 1,700 and 1,900 mm of rain each year, and around 80% of the rain falls during the monsoon season. The typical high temperature is between 32ºC and 35ºC, while the low temperature may be anywhere from 12ºC to 18ºC (Zubaer & Islam, 2023).

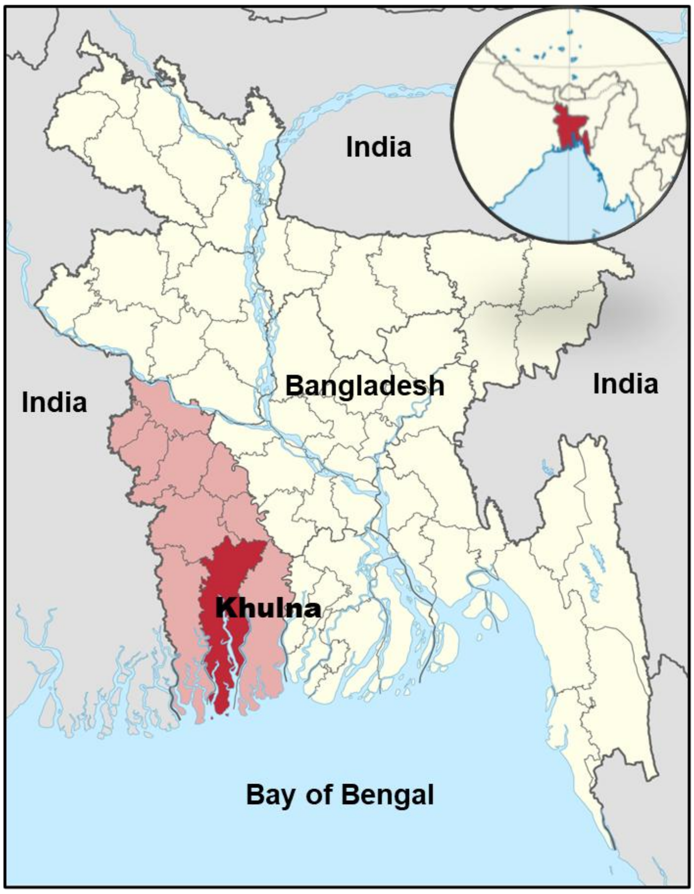

Figure 1: Location of Khulna in the southwest region of Bangladesh

2.2 Data Used

In the current study, two main datasets were used to assess and predict extreme rainfall characteristics in Khulna, which are presented in Table 1. The first dataset consists of daily rainfall records of Khulna climate station, which were collected from BMD over a long period of time, from 1961 to 2020.

Table 1: Details of the datasets used in the current study

Dataset Type	Source	Duration	Description
Observed Daily Rainfall of Khulna Station	BMD	1961–2020	Historical rainfall data used for calibration and validation
HadCM3 GCM Predictors	IPCC CMIP5 (SRES A2, B2 Scenarios)	1961–2100	Large-scale atmospheric predictors used for downscaling

The second dataset contains several atmospheric predictor variables that were made using the HadCM3 model as part of the CMIP5 framework created by the Intergovernmental Panel on Climate Change (IPCC) (Hossain et al., 2024; Rana et al., 2025). The scenarios were based on two Special Reports on Emission Scenarios (SRES): A2, which shows a high-emission path with fast population growth and little thought for the environment, and B2, which shows a moderate-emission path focused on sustainable development and lower carbon intensity.

2.3 Statistical Downscaling Model

This study used the statistical downscaling model (SDSM) decision centric (SDSM-DC, Version 5.2) (Wilby et al., 2002) to statistically downscale daily precipitation data from comprehensive atmospheric predictors to the local station level. SDSM was adopted because of its simplicity in use and widely accepted applications all over the world (Al-Mukhtar & Qasim, 2019; Rana et al., 2023; Rana et al., 2024; Siddik et al., 2024; Rana et al., 2025). The strategy contained several steps that had to be done to make sure that the data was good, the model was reliable, and the predictions were accurate. The initial step was to get historical rainfall data from the BMD and do a full quality check on it. It was very important to finish this phase to make sure that the rainfall data accurately reflected the area's climate variability and provide a strong base for model calibration. After doing the necessary quality checking, a fourth-root transformation was used to change the data. Because precipitation is so erratic and uneven, daily rainfall data generally doesn't follow a normal distribution. This update was made to make the data less skewed and more stable in terms of the variance it contains. Normalizing the dataset made the statistical links between the predictor and the predictand variables stronger and more linear, which made the model's predictions better (Rana et al., 2025).

2.4 Model Calibration and Validation

The cliamte change downscaled model is calibrated and validated agains the historical data. The calibration and validation process of the downscaled model is outlined in Table 2.

Table 2: Details of the SDSM–HadCM3 calibration and validation under climate change scenarios

Description	Statistical Downscaling Model (SDSM)	Based on HadCM3 GCM outputs
Calibration Period	Historical period used to fit the model	1981–2000
Validation Period	Period used to test model performance	2001–2015
Calibration Method	Regression fitting between large-scale predictors (HadCM3/NCEP) and local rainfall	Conditional process
Emission Scenarios	Future climate change projections based on HadCM3	A2: High emission scenario B2: Moderate emission scenario
Simulation Periods (Time Slices)	Future 30-year intervals for the analysis	Near Future: 2025–2050 Mid Future: 2051–2075 Far Future: 2076–2100
Generated Output	Downscaled daily rainfall series for each scenario and time slice	Used for trend and extreme rainfall analysis

2.5 Bias Correction

Bias correction was applied to the downscaled data using the mean bias correction (MBC) method to adjust systematic errors compared to the observed baseline. The bias correction was computed by Equation (1) as given in the following.

$$Rainfall_{corrected} = Rainfall_{simulated} \times \frac{Rainfall_{observed\ mean}}{Rainfall_{simulated\ mean}} \quad (1)$$

2.6 Calculation of Extreme Rainfall Indices

In the current study, different indices were used to calculate extreme rainfall values, wich are given in Table 3. These indices are used because they are widely used by researchers (Fathian et al., 2020; Shahid, 2011). These indices were calculated using the RClimDex software, based on the observed historical records as well as the downscaled daily rainfall data.

Table 3: Summary of extreme rainfall indices used in the current study

Index	Definition	Unit	Description
Rx1day	Annual maximum 1-day precipitation	mm	Measures the intensity of the single heaviest rainfall day
Rx5day	Annual maximum consecutive 5-day rainfall	mm	Captures short-duration flood events
R95p	Number of days with rainfall >95th percentile	days	Represents heavy rainfall days
R99p	Number of days with rainfall >99th percentile	days	Represents very heavy rainfall days
R95pTOT	Total rainfall from >95th percentile days	mm	Contribution of heavy rainfall to annual total
R99pTOT	Total rainfall from >99th percentile days	mm	Contribution of very heavy rainfall to annual total

2.7 Trend Analysis

The Mann–Kendall (MK) test was used to assess the extreme rainfall trend. The MK test is a common non-parametric statistical method for finding patterns in time-series data. It is often used in environmental and hydrological research, such as studies of rainfall, temperature, and streamflow. It helps figure out whether a variable is showing a monotonic trend of growth or decline over time, without having to make any assumptions about the distribution, such normality. In this analysis, each data point in a time series is compared to all the data points that come after it to figure out how many changes were positive and how many were negative.

The test statistic (S) is calculated by the difference between the counts of positive and negative differences. The significance of the trend is then assessed using the Z-value and corresponding p-value as given in the following: (i) if Z > 0, it indicates an increasing trend, and (ii) if Z < 0, it indicates a decreasing trend.

When the p-value falls below the established significance level (i.e., 0.05), the trend is considered statistically significant. In this method, the slope (Q_i) is computed for all possible pairs of data points in the time series using Equation (2) as given in the following.

$$Q_i = \frac{X_j - X_k}{j - k} \quad (2)$$

Where $X_j$and X_k are data values at time $j$and k (with $j > k$). Once all possible slopes are calculated, the median of these slopes is taken as the Sen's Slope (Q). By using the Sen's Slope, the trend can be estimated as follows: (i) a positive Q value indicates an increasing trend, and (ii) while a negative Q value indicates a decreasing trend in the variable.

3. RESULTS AND DISCUSSION

3.1 Model Calibration and Validation

The correlation coefficient (CC), R between real and simulated rainfall datasets shows how the SDSM model collaboate with the patterns of rainfall in Khulna over time. The calibration period from 1981 to 2000 shows a strong positive linear relationship between observed and simulated rainfall, with a R value of 0.82. The model appropriately reflects rainfall patterns based on historical data. In the validation period (2001–2015), CC score of 0.78 is obtained, which demonstrates a good agreement between the observed and simulated rainfall values. This indicates that the model is reliable for simulating independent datasets that were not used for calibration. The correlation data show that the SDSM–HadCM3 system properly forecasted Khulna's rainfall from year to year and season to season. The correlation normally goes down during validation since the model is tested on fresh data, which creates more variable in the actual world. The correlation study demonstrates that the SDSM effectively downscales rainfall in coastal Bangladesh as well as to get information on regional rainfall forecasts and how climate change affects things.

3.2 Projected Changes in Extreme Rainfall

Table 4 presents the future changes in extreme rainfall patterns over the study area under different climate change scenarios. As can be seen from the table, climate change will sharply increase extreme rainfall in the near future (2025–2050) period, with the highest rises in heavy-rain indices (up to 338%). The growth becomes moderate in the mid future (2051–2075) period and stabilises in the far future (2076–2100) period. Thus, the study area is expected to face the greatest flood and waterlogging risks early in the century due to the impact of climate change induced extreme rainfalls, especially under the A2 scenario. It is also seen from Table 4 that the extreme rainfall over the study area will rise sharply in the near future (2025–2050) period, with large increases in indices like Rx1day, R95p, and R99p. The growth becomes moderate during mid future (2051–2075) period and slows further in the far future (2076–2100) period. Flood and heavy-rain risks are like to occure the highest in the early–mid century, with scenario B2 showing smaller increases than A2.

Table 4: Future changes in extreme rainfall patterns under climate change scenarios

Scenario	Time Period	Rx1day	Rx5day	R95p	R99p	R95pTOT	R99pTOT
A2	2025–2050	+31%	+32%	+140%	+338%	+128%	+256%
	2051–2075	+16%	+21%	+86%	+165%	+90%	+142%
	2076–2100	+2%	+2%	+26%	+9%	+15%	+12%
B2	2025–2050	+31%	+29%	+127%	+276%	+110%	+198%
	2051–2075	+22%	+21%	+97%	+168%	+94%	+154%
	2076–2100	+3%	+3%	+37%	+31%	+28%	+33%

3.3 Temporal Pattern of Change

The A2 (high-emission) and B2 (moderate-emission) scenarios both show that the southern half of Bangladesh, especially Khulna, would have the heaviest rain between 2025 and 2050. This is shown the increases in indices like Rx1day, Rx5day, R95p, and R99p. In the middle and late centuries, there seems to be a gradual stabilisation, which suggests that rainfall intensity first increases and then stays about the same. This pattern probably shows how greenhouse gas saturation and changes in regional monsoons affect each other. This shows how important it is to have early adaptation plans to deal with the effects of heavy rain in the first half of the century.

Figure 2 shows the changes in extreme rainfall indices for Khulna considering the A2 scenario of HadCM3 model. Under the A2 and B2 emission scenarios, extreme rainfall indices rises. Between 2025 and 2050, the A2 scenario sees severe rains increase, with R99p and R99pTOT growing by 338% and 256%, respectively. The Rx1day and Rx5day indices also increases more than 30%. Even if the intensity dropped somewhat from 2051 to 2075, extremes are still higher than the past, which shows that the trend of intensification is still going strong. In the late 21st century (2076–2100), rainfall extremes settle at high levels, which means that regional climates will slowly but change as greenhouse gas levels rise.

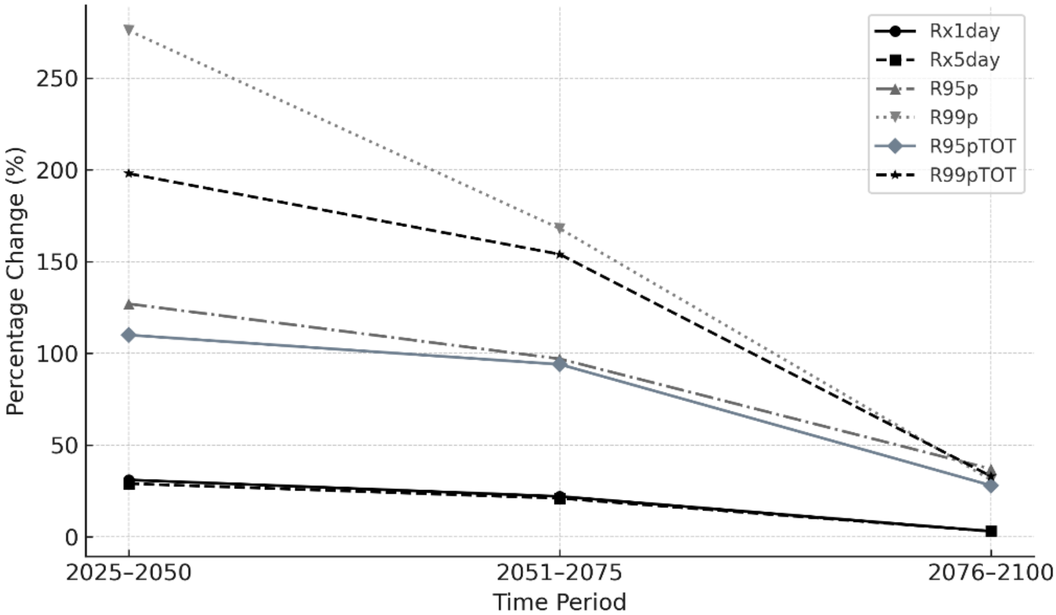

Figure 2: Changes in extreme rainfall indices for the A2 scenario of HadCM3 model

Figure 3 presents the changes in extreme rainfall indices for Khulna considering B2 scenario of HadCM3 model. As can be seen from Figure 3, a similar but less important trend of change may be detected. The indices R99p and R99pTOT are expected to rise by around 276% and 198%, respectively, in the near future (2025–2050). This means that there will be more severe rainfall events, but it will be less intense than in the A2 scenario. The next mid-future (2051–2075) and far-future (2076–2100) periods exhibit minor decreases across all indices, indicating a tempered escalation in rainfall extremes under a more sustainable emission pathway.

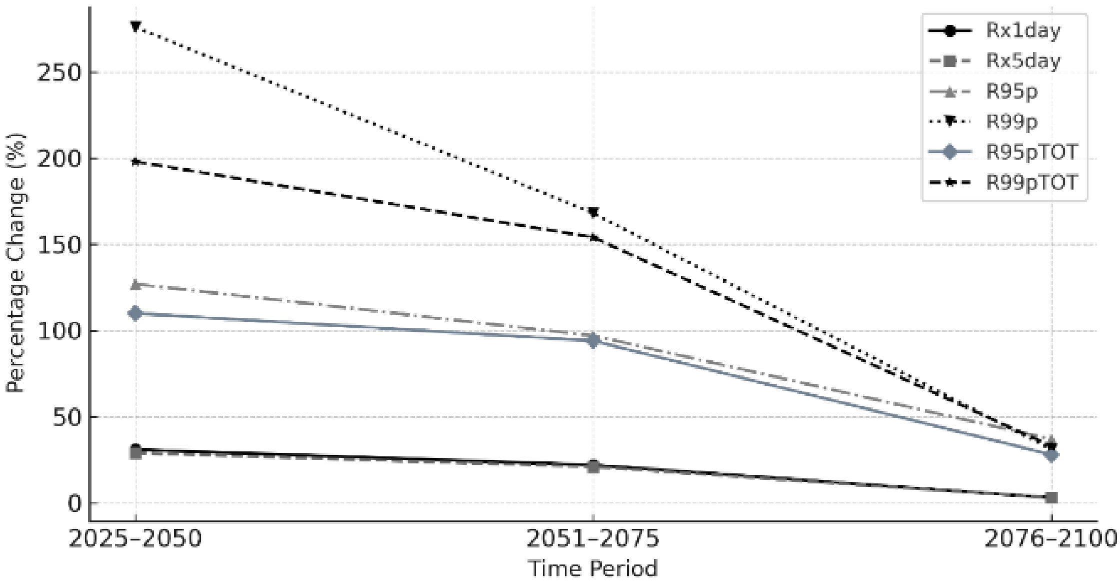

Figure 3: Changes in extreme rainfall indices for the B2 scenario of HadCM3 model

Table 5 shows the monthly rainfall trend analysis using the Kendall's Tau and Sen's Slope techniques. If these values are positive, it indicates that the trend is increasing. If the values are negative, it means the trend is decreasing. The results show that rising in August, September, November, and throughout the year. This suggests that it rains more during the late monsoon and post-monsoon periods. Most other months show trends that are either not statistically significant or weak, which means that rainfall patterns are rather stable throughout the year.

Table 5: Summary of the trend analysis results for monthly rainfall changes

Months	Kendall's Tau	Sen's Slope	Remarks on Trend
Jan	0.18	0.01	Increasing
Feb	0.15	0.02	Increasing
Mar	0.08	0.03	Not Significant
Apr	-0.05	-0.15	Not Significant
May	0.06	0.31	Not Significant
Jun	-0.03	-0.30	Not Significant
Jul	0.00	-0.06	Not Significant
Aug	0.17	1.51	Increasing
Sep	0.22	1.98	Increasing
Oct	0.06	0.36	Not Significant
Nov	0.16	0.05	Increasing
Dec	0.11	0.00	Not Significant
Annual	0.15	4.58	Increasing

3.4 Implications of Extreme Rainfall Changes on the Southwest Region

Table 6 shows that both the A2 and B2 scenarios predict significant increases in extreme rainfall, especially during the near future (2025-2050) period, when the risks of floods and waterlogging are at their highest. The mid future (2051–2075) period shows minor increases, while the far futrue period modifications stabilize under both scenarios. It worth mentioning that the changes in extreme rainfall trend for the A2 scenario always becomes stronger than that of the B2 scenario.

Table 6: Details of climate change induced extreme rainfall trend analysis and probable impact

Scenario	Period	Overall trend	% Increase in rainfall extremes	Probable impact
A2	2025–2050	Sharp increase	30–300%	High flood & waterlogging risk
	2051–2075	Moderate increase	10–160%	Persistent high rainfall
	2076–2100	Stabilized	<30%	Mild rise
B2	2025–2050	Significant increase	25–270%	Moderate flooding
	2051–2075	Moderate	20–160%	Slight reduction
	2076–2100	Stable	<40%	Mild impact

Figure 4 shows the amount of rainfall that is expected to change each month in the A2 scenario until 2100. There will be an increase in rain throughout the middle of the monsoon season. The early part of the century highlights the most increase, but towards the end of the century, the rain starts to level out. The comparison shows that the A2 emission pathway has higher monsoon maxima over time.

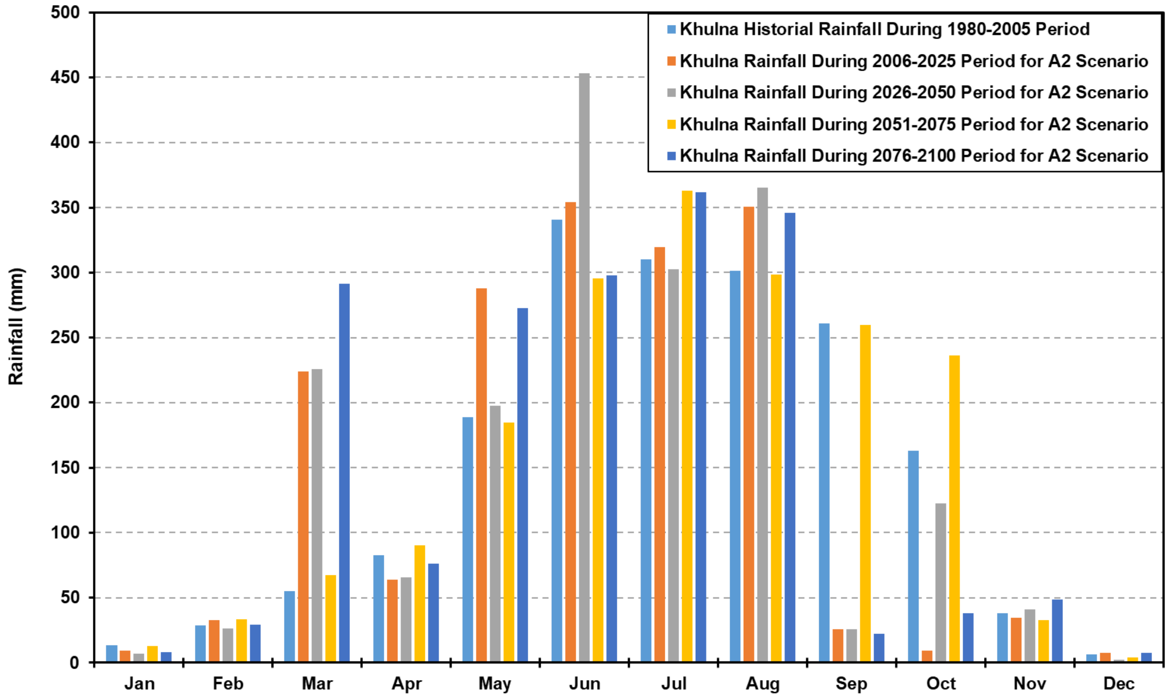

Figure 4: Projected rainfall in different periods up to 2100 for the A2 scenario of HadCM3 model

Figure 5 shows the rain is expected to fall each month in the B2 scenario until 2100. It shows that rain during the monsoon season would rise a lot, although not as much as in the A2 scenario. The middle of the century sees steady increases, whereas the end of the century sees more stable precipitation patterns in the lower-emission scenario.

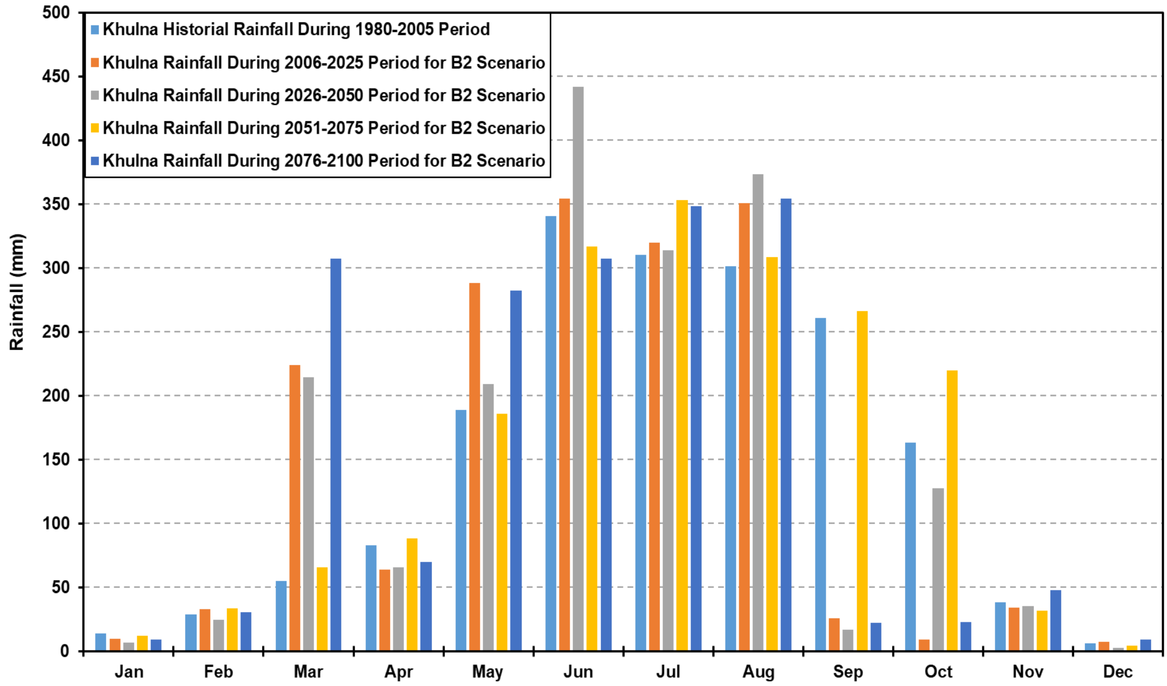

Figure 5: Projected rainfall in different periods up to 2100 for the B2 scenario of HadCM3 model

The aforementioend analysis of the current study indicates that high and moderate-emission scenarios exacerbate intense rainfall in the Khulna–Jessore area of southwest Bangladesh. SDSM–HadCM3 provides that heavy rain occurrences (R99p and R99pTOT) will be up by 338% and 256% from 2025 to 2050. Heavy rain may cause flash floods, flooding in cities, and stress on coastal drains and embankments. The monsoons in South and Southeast Asia are becoming stronger, which means more rain. When it becomes warmer, moisture convergence rises, which makes precipitation events stronger. Results from regional studies are similar. A recent climate study in coastal Bangladesh revealed that more variable monsoons, higher sea levels, and cyclones have made waterlogging and salt stress worse in the Pirojpur and Bagerhat districts. A study found that heavy rain and tidal floods removed more than 80% of dense plants and decreased agricultural yield. More rain during the monsoon season makes land usage worse. Studies of water flow suggest that the northeast of India is getting more rain, including severe rain that lasts for just one day, which makes flooding more likely. These things don't happen as often in central India. The east-west topographical mismatch and growing rainfall dipole in South Asia suggest that precipitation is moving faster over the Bay of Bengal.

In semi-arid and drought-affected locations like northern Bangladesh and Sinjar, Iraq, yearly rainfall reduces and dry months grow, according to study. The results are like those of a Bangladeshi study that indicated Rajshahi–Rangpur had 4% to 12% less rain. This shows that the difference between the humid south and the dry north is becoming bigger. These patterns illustrate hydroclimatic polarisation, with the south and coast at danger of flooding and the north being drier. Urbanisation changes rural communities, giving us indirect information on how climate and society interact across the world. A Chinese geographical study revealed that flood risk and land-use requirements displace people situated in areas prone to heavy rainfall and waterlogging. Floods and drainage problems also force people to leave their homes in Khulna and Bhabodaho.

The predictions made in this research are more believable since this values are in line with data from across the globe and in the same area. The anticipated increase in intense rainfall in southwest Bangladesh signifies a markedly unstable hydrological system. The effects are complicated: there will be more floods in cities, embankments and polder systems will become less stable, and farmers will have trouble with waterlogging and salt retention. This shows that this area require adaptation techniques that are distinctive to each area. These designs should incorporate drainage systems that can adapt to climate change, repairs to embankments, and agricultural systems that can handle salt and last for a limited time. To lessen the effects of climate change and make people less vulnerable, here need to concentrate on community-based water management and spatial planning.

4. CONCLUSIONS

The results of this study suggest that climate change is expected to significantly exacerbate heavy rainfall occurrences in the southwestern region of Bangladesh. These changes suggest that there is a higher chance of serious water-related problems and stress on ecosystems in the next decades. The anticipated increase in the occurrences of extreme rainfall will impose significant pressure on the current urban water infrastructure and drainage systems, especially in Khulna. The current study has estimated significant changes in extreme rainfall indices based on HadCM3 downscaled rainfall for A2 (high emission) and B2 (moderate emission) scenarios. The extreme rainfall analysis for Khulna indicates substantial increases across all indices when compared to the 1980–2005 baseline. In the A2 scenario, Rx1day rises by about 31% in 2025–2050, 16% in 2051–2075, and 2% in 2076–2100, while Rx5day shows increases of 32%, 21%, and 2% respectively. R95p days grow by 140%, 86%, and 26%, and R99p days by 338%, 165%, and 9% across the same patterns. R95pTOT and R99pTOT follow a similar trend, with very large rises early in the century and smaller rises show later. In the B2 scenario, Rx1day increases by 31%, 22%, and 3%, while Rx5day rises 29%, 21%, and 3%. R95p days grow by 127%, 97%, and 37%, and R99p days by 276%, 168%, and 31%. The R95pTOT and R99pTOT represent remarkable enhancement within this near and far future, a gradual moderation is following yet the extreme rainfall is higher than the baseline. The transformation will increase the vulnerability of Khulna and the broader southwest region of Bangladesh as well as will result in drainage congestion, pressure on embankments, losses in aquaculture, and deterioration of water quality related tendency.

The anticipated increase in extreme rainfall due to the impact of climate change underscores the critical need for climate-resilient stormwater management, adaptive drainage systems, and sustainable urban infrastructure development and management.

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We are thankful to the Bangladesh Meteorological Department (BMD) for providing the rainfall data to carry out this study.

DECLARATION OF USE OF AI

AI tools were used for grammar correction, paraphrasing, and improving clarity in some cases where necessary. However, no AI tools were used for analysis, interpretation of results, and/or writing discussion. We also declare that all research design, methodological formulations, codings, software operation, analysis of results and its interpretation, preparaton of Tables and Figures in this paper are the authors' own work.

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