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Climate Change in Bangladesh: Evidence from Temperature, Precipitation, and Rainfall

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Abstract: *Lying on the Bay of Bengal most of the area of Bangladeshis less than 10 m above sea level and ranked 160 out of 181 countries for climate vulnerability to climate change. Nowadays climate change is a great challenge for most countries in the world and Bangladesh has already faced significant challenges to climate change although making only a small contribution to global emissions. The impact of climate change in Bangladesh is severe by already affecting livelihoods, food, and water security, ecosystems, and infrastructure, etc and climate-related hazards will be severe in the future. Bangladesh has already been facing a gradual increase in temperature and precipitation, while overall weather patterns erratic and less predictable than before. The rainfall pattern has also changed significantly due to climate change. The main objective of this paper is to analyze the changing pattern of temperature, precipitation and rainfall patterns due to climate change. The study of this paper tries to build an overall climate scenario in Bangladesh by analyzing the temperature, precipitation, and rainfall changes over time. The result of this study finds that the overall temperature tends to increases by 1^0C, 1.6 ^{0}C, 2^0 C, and 2.4^0 C in the year 2030, 2050, 2070 and 2100. Precipitation also projected to increases in 2030, 2050 and 2070. The rainfall pattern will change significantly in the last half of the century.*

Keywords: *Climate change, Coupled Model Intercomparison Project 5 (CMIP 5), GCM, Bangladesh.*

I. Introduction

Bangladesh located in the northeastern part of South Asia and the total area is 1, 47,570 sq. k.m or 56,977 sq. miles. Bangladesh is often called a riverine country and one of the world's largest deltas in the world remaining a large part of the delta less than three meters above the sea level. Bangladesh is mainly an agricultural country and agricultural sectors occupy around 40.6% (in 2016-17) of the labor force in the country. Almost half of the Bangladeshi is directly or indirectly involved in agricultural-related work and rice is the single-most-important producing an agricultural product. GDP in Bangladesh is growing roughly 6 percent per year since 2005 while service sectors' contribution to GDP is more than half. Bangladesh is generally a subtropical monsoon climate and year can be divided into four seasons such as winter from December to February; pre-monsoon from March to May; monsoon from June to September and post-monsoon from October to November. About 80 percent of the annual rainfall occurs in monsoon season and average rainfall varies from 1429 to 4338 millimeters. Bangladesh is highly dependent on agriculture and rainfall is a major issue in Bangladesh's agricultural production. Most of the farmer in Bangladesh depends on rainfall heavily. So a slight rainfall pattern change in Bangladesh will make a serious consequence in agriculture. Bangladesh agriculture is highly vulnerable to climate change, particularly sensitive to temperature, precipitation and rainfall pattern and climate change accelerating the intensity such as an increase in temperature and rainfall, irregular rainfall pattern etc. Bangladesh is a country where agricultural activities depend entirely on nature and climate change degrading this situation more intensely. Erratic rainfall, high and low temperature is hampering the agricultural production of Bangladesh in various ways. Food security is now a great challenge in Bangladesh and Climate change is multiplying the crisis by declining cultivated land area in many parts. This paper tries to build a detailed analysis of the future climate scenario. The primary objective of this paper is to give a view of existing climate variability and examine the future projection based on CMIP 5 climate database.

II. Historical Trend of Climate in Bangladesh

Most of the area in Bangladesh is low-lying and vulnerable to climate change. The annual mean temperature in Bangladesh is approximately 26°C across the country and the hottest time begins from April to May. The mean temperature is about 29°C from June to September. Average rainfall varies from 1500 mm to 2150 mm and rises in some parts to 2900 mm to 4200 mm. Monsoon season in Bangladesh is very important for agriculture because almost 80% of the annual rainfall occurs during this season. Bangladesh is dependent on agriculture and will continue to depend on her economic growth. Most of the rural area households depend on agriculture for their basic needs such as income and livelihoods.

The analysis of this section gives details about existing climate variability in Bangladesh based on the World Bank study complied by Yu et al (2010). Figure 1 shows the trend of annual and seasonal precipitation from 1960 to 2000. The highest amount of precipitation recorded during the June, July, and August months, while December, January, and February month (winter) remains low compared to other seasons. Annual precipitation is also recorded high compared to seasonal precipitation. It is clear from the graph that the precipitation pattern is in fluctuated trend during the annual and seasonal periods (see Figure 1).

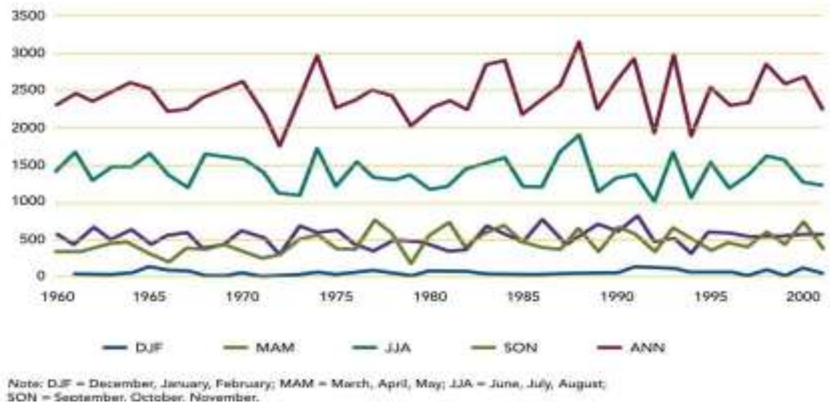

Figure 1 Annual and Seasonal Precipitation (in MM)
Source: Yu, W.H., et al. (2010)

Table 1 shows the pick discharges of the three main rivers in Bangladesh. It is clear from the table that the peak discharges timing of the three rivers does not coincide on average. The Brahmaputra peak time is in July and August, while the Ganges peak time is in August and September. On the other hand, The Brahmaputra starts to escalate in March and the Ganges starts rising in early June. All three rivers had discharge peaks within one week each other in 1998 and cause flood all over Bangladesh. The Ganges and Brahmaputra were also peaked early in 2004 (see Table 1).

Table1 Pick Discharge and Timing during Extreme Flood Years

Extreme Years	Brahmaputra		Ganges		Meghna		Return Period (area)	Return Period (area)
	Date	m3/s	Date	m3/s	Date	m3/s		
1974	7-Aug	91,100	3-Sep	50700	-	21100	7	7
1980	20-Aug	61200	22-Aug	57800	7-Aug	12400	2	2
1984	20-Sep	76800	17-Sep	56500	17-Sep	15400	2	4
1987	16-Aug	7300	20-Sep	75800	4-Aug	15600	9	10
1988	31-Aug	98300	4-Sep	71800	18-Sep	21000	79	34
1998	9-Sep	103100	11-Sep	74280	-	18600	100	52
2004	12-Jul	83900	19-Jul	77430	-	16300	10	20
Average		67490		51130		13370		
Min		40900		31500		7940		

Source: The Bangladesh Water Development Board

The trend in daily mean water level in the coastal zone and the historical rise in the sea-level are shown in Table 2. Observations from 13 stations over 12 to 42 years are summarized in the table below. It can be seen from the table that there is no change at the Chandpur station and the changes in Hiron point station are statistically significant ranges from 5.6 mm/yr. The water level at Cox's Bazar increases at a rate of 1.4 mm/yr and Companyganj at a rate of 3.9 mm/year. It is clear from the table that the trends are positive at all stations.

Table 2 Water level Trends at Different Stations along the Coastline

Station Name	Station Location	Duration	No. of Year	Trend(mm/yr)
Hiron Point	passur	1977-2002	26	5.6*
Khepupara	Nilakhi	1959-1986	22	2.9
Galachipa	Lohalia	1968-1988	21	3.3
Dasmunia	Tentulia	1968-1986	19	1.3
Kyoyaghat	Tentulia	1990-2002	12	3.6
Daulatkhan	Lower Meghna	1959-2003	31	4.3
Nilkamal	Lower Meghan	1968-2003	33	2.3
Chadpur	Lower meghan	1947-2002	50	0
Companiganj	Little FeniDakatia	1968-2002	32	3.9
Chittagong	Karnafuli	1968-1988	16	3.1
Dohazari	Sangu	1969-2003	32	2
Lemsikhali	Kutubdia Channel	1969-2003	27	2.1
Cox's Bazar	Bogkhali	1068-1991	22	1.4

*statistically significant to $P<0.05$

Source: The Bangladesh Water Development Board

From the above analysis, it is evident that Bangladesh has already been facing climate change-related hazards. Climate change has already made significant changes in precipitation and this change made an immense threat to Agricultural sectors in Bangladesh. In Bangladesh, climate change has been observed different parts and weather patterns have been more erratic and less predictable than before (World Bank 2011). There was a significant increase in rainfall in some areas but annual rainfall did not change significantly between the period 1960 and 2003 (Shahid, S., 2009). The rainy season has become shorter and the length of the cool and dry season decreased. Sea-level is also rising significantly and led to an increase in soil salinity in many parts of Bangladesh especially in coastal areas.

III. Climate Change and Agriculture

Climate change hazard such as an increase in temperature and precipitation and changes in rainfall pattern is very common in Bangladesh. Agriculture is the main source of earning for the majority of people in Bangladesh. Most agricultural lands in Bangladesh surrounded in coastal areas and agriculture in those areas highly vulnerable due to global climate change.Agricultural sector contribution to Bangladesh's GDP is around 16 % and the majority of the rural area people depend on agriculture-related work completely.Over the past few centuries, the links between food production and climate have been studied, and it has found that human activities e.g. fossil- fuel combustion and deforestation has a direct impact on climate change (T. F. Stocker et al., 2013). Climate change can affect food security in numerous ways. Since the mid-18th century, there is an increasing trend in temperature and the changes in precipitation patterns observed in many areas.The global temperature almost increases by 0.85 °C between 1880 and 2012. Developing countries, especially Asian ones, will suffer more due to climate change and Bangladesh is no exception.The changes in temperature and altered precipitation patterns have already affected the productivity of crops in many parts of Bangladesh. Bangladesh is enriched with an ideal climate and soil condition to grow a variety of crops all year-round. Rice is the main crop in Bangladesh and accounts for 70 percent of daily caloric intake (Ricepedia, 2016) and climate change has a direct impact on rice production. It has been found from previous studies that rice production has been declining in many parts due to climate change. By using a crop model Karim, et al. found that the high temperature reduce rice yields six regions in Bangladesh and the average temperature rise of 2 and 4 degrees has taken into consideration for analysis. Another study also found the same that a 1°C increase in maximum temperature results decreases in Aman rice production by 2.94, 53.06 and 17.28 tons. Basak et al. found a 20% and 50% rice yield reduction for the year 2050 and 2070 at 12 locations in Bangladesh. Other studies by Miah, 2010 found HYV Boro rice is being affected by high temperature and salinity intrusion. Bangladesh's national rice annual growth rate will reduce from 2.9 to 2.55 percent because of climate change during the period 2005-2050 (World Bank, 2010). Another study held by IPCC found that rice and wheat production will decline by 8 percent and 32 percent.Rainfall is a major factor forcrop production in Bangladesh. More than 80% of the yearly rainfall occurs from June to October. One study found that 1 mm increases in rainfall affect the reproductive, vegetation and ripening stages of crop. It can be said from the above analysis that the Bangladesh is on the verge of big challenges to agriculture due to climate change.

IV. Methodology

Model Used in this Paper

Climate models are used to analyze how the climate will progress over time. Different climate modeling institutions use different plausible representations of the climate system, which is why climate projections differ between modeling institutes. Climate models allow us to make understand what amount of temperature and precipitation changes under future climate scenarios (Lean, Rottman, Harder, & Kopp, 2005). Climate models take into consideration many factors such as emission conditions and historical data. In this research paper, four different emission scenarios such as RCP 8.5, RCP 6.0, RCP 4.5 and RCP 2.6 are taken into consideration which is called representative concentration pathway. RCPs correspond to radiative forcing level of 8.5 W/m2 for RCP 8.5; 6.0 W/m2 for RCP 6.0, 4.5 W/m2 for RCP 4.5, and 2.6 W/m2 for RCP 2.6. In this study, 16 CMIP5 coupled models such as BCC-CSM1-1, BCC-CSM1-1-m, CCSM4, CESM1-CAM5, CSIRO-MK3-6-0, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GISS-E2-H, GISS-E2-R, HadGEM2-AO, HadGEM2-ES, MIROC5, MIROC-ESM, MIROC-ESM-CHEM, and NorESM1-M under the Representative Concentration Pathway (RCP) emission scenarios have been taken consideration for the analysis of climate scenario in Bangladesh. In this research paper, various climate models are used to avoid uncertainty because one specific model may increase the uncertainty of the result. All Models of this paper uses historical climate simulation and future climate change scenarios. For the historical projection from 1991 to 2016 and for the future projection from 2020 to 2100 analysis are used for changes in temperature, precipitation, and rainfall.

Database

Data are taken from the Climate Modelling Intercomparison Project (CMIP5) database and this database consists of combinations of various present and future emission scenarios. The CMIP-5 data form the basis of the climate scenarios under the 5th assessment report of IPCC. To visualize available climate data for Bangladesh, the first step is to select the future time of interest (compared to a historic baseline time of 1991-2016). In this paper four different future times have been taken consideration to analysis the future climate change impact such as below:

(1) 2020-2039 (approximating 2030);

(2) 2040-2059 (approximating 2050);

(3) 2060-2079 (approximating 2070); and

(4) 2080-2099 (approximating 2099)

Once selected a particular time frame, relevant climate data will be accessible through interactive online interphase. Climate change can be assessed over an entire year or for a specific month for all variables, except for consecutive dry days and 5-day rainfall- which can only be assessed annually. The selection of a specific month can be important for looking at impacts during particularly vulnerable times of the year. There are 20 derivative climate metrics available as part of this application 9 temperature-based climate metrics, and 11 precipitation-based climate metrics. Different climate variables are important for assessing different types of climate impacts such as drought, flood, heat stress, energy use, etc. Four greenhouse gas Representative Concentration Pathways are provided in the Climate Analysis Tool and describes possible future climate scenarios over the next 81 years.

V. Results Analysis

Season plays a considerable role in the patterns of temperature and precipitation on which the economy, development, and culture of Bangladesh depend. This study attempts to use new RCP emission scenarios to understand the impact of temperature, precipitation, and seasonal rainfall pattern. Information on future climate has been taken from various general circulation models (GCM) considering CO2 emission scenarios to analyze the total possible future variability in precipitation, temperature, and rainfall. All RCP scenarios result indicates that the end of the 21st century mean annual temperature tends to increase by 3°C and daily maximum and minimum temperature will be intense. A slow increase of temperature is observed at RCP 2.6 and RCP 6 emission scenarios whereas an accelerated warming trend are observed at RCP 8.5 scenario in 2030 and 2050. The RCP 8.5 remains high compared to all set of Representative Concentration Pathways (RCPs). As showed in Table 3, slight increase in mean temperature in the annual cycle is observed at RCP 2.6 and RCP 6 scenario. A significant increase in temperature (average 2.5°C) during all year round is observed for RCP 8.5. It is evident from the table that temperature will increase up to 2.5°C during pre-monsoon (MAM) and post-monsoon (ON) period at the RCP 8.5 emission scenario which remains high compared to all emission scenarios. In contrast, the RCP 6 scenario average temperature will increase 1-1.5°C in pre-monsoon (MAM), monsoon (JJAS) and winter (DJF) season. Meanwhile, at RCP 2.6 and RCP 4.5 scenario temperature will increase by 0.46°C and 1°C. It is evident from the result that the winter period December to February (DJF) temperature will increase all scenarios and shows a significant rise in this period. The RCP 8.5 scenario remains high in all seasons in Bangladesh which negatively impacts Bangladesh food production. Finally, it can be seen projected temperature increases all over Bangladesh between 2°C to 3°C from 2030 to 2100 (see Table 3).

Table 3. Temperature Change under different RCP emission scenario

		2030	2050	2070	2099
RCP 2.6	MAM	29.205	29.407	29.611	29.55
	JJAS	29.196	29.418	29.508	29.512
	ON	25.207	25.445	25.631	25.546
	DJF	20.81	21.105	21.269	21.213
RCP 4.5	MAM	29.44	29.92	30.261	30.547
	JJAS	29.309	29.609	30.03	30.214
	ON	25.39	25.791	26.195	26.446
	DJF	20.907	21.443	22.035	22.225
RCP 6	MAM	29.177	29.585	30.169	30.732
	JJAS	29.103	29.496	30.001	30.522
	ON	25.263	25.567	26.191	26.819
	DJF	20.811	21.204	21.885	22.522
RCP 8.5	MAM	29.347	30.337	31.303	32.33
	JJAS	29.245	30.043	30.938	31.802
	ON	25.305	26.251	27.269	28.25
	DJF	20.934	22.018	23.075	24.331

Source: Generated by Author

Note: MAM=March, April, May; JJAS=June, July, August, September; ON=October and November; DJF=December, January, and February.

Precipitation is projected to increase during the wettest time of the year, whereas the precipitation during the dry season (DJF) is projected to change little or decrease slightly. A slight decrease in the daily precipitation will make profound changes in the hydrology cycle all over Bangladesh. If these trends are continuous then it will increase drought frequencies and rainfall intensity in Bangladesh. As shown in Table 4, Seasonal changes of precipitation for four future time slices are determined under different emission scenarios. The result shows changes in precipitation pattern by the end of the 21st century that indicates maximum increase observed during the monsoon season in the 2030s and 2050s at RCP 4.5 and RCP 8.5 scenario. It is clear from the Table that the annual precipitation is projected to increase all over Bangladesh, with a larger increase in RCP 8.5 at the end of the century. The last half of the century will be worse compared to the first half of the century. At RCP 2.6 and RCP 4.5 scenario, the annual precipitation over Bangladesh also shows decreasing trends late century whereas a slight increase in the winter season (DJF) and monsoon season (JJAS). In the future, precipitation will decrease almost all parts of the country during the winter season (DJF). Under the RCP 2.6 and RCP 4.5 scenario, amount of precipitation will increase during the early parts of the 21st century and decrease last part of the century, while at RCP 6 and RCP 8.5 scenario is in increasing trend all over Bangladesh last part of the century (see Table 4).

Table 4 Precipitation Change under different RCP emission scenario

		2030	2050	2070	2099
	MAM	52.284	54.175	52.688	50.833
RCP 2.6	JJAS	254.75	252.81	253.72	250.44
	ON	70.317	71.498	73.125	72.536
	DJF	21.763	21.675	20.475	21.166
	MAM	49.952	52.87	55.809	54.419
RCP 4.5	JJAS	254.62	264.87	263.47	271.66
	ON	67.666	72.958	76.564	75.208
	DJF	19.479	19.624	20.999	22.082
	MAM	51.356	50.993	51.692	56.387
RCP 6	JJAS	255.53	251.54	260.12	268.64
	ON	68.798	71.451	69.834	73.863
	DJF	21.734	21.022	19.607	21.665
RCP 8.5	MAM	51.671	53.713	53.92	58.781
	JJAS	259.96	264.4	278.46	287.44
	ON	71.04	72.563	75.894	76.837
	DJF	20.64	18.895	20.02	19.799

Source: Generated by Author

Note: MAM=March, April, May; JJAS=June, July, August, September; ON=October and November; DJF=December, January, and February.

Monsoonal rainfall in Bangladesh is very important from the agricultural point of view. As shown in Table 5, the GCM model result indicates single-day rainfall increases during the monsoon season (JJAS) at RCP 2.6, RCP 4.5 and RCP 6 scenario, while an increase in rainfall remains high at RCP 8.5 scenario. Rainfall becomes more intense during the period 2070 to 2099. From the results, it is evident that the largest single-day rainfall occurs at RCP 8.5 and RCP 6 emission scenarios, meanwhile the RCP 2.6 scenario remains less intense compares to other emission scenarios. In contrast, rainfall increases to a small degree are observed during winter (DJF) season in every RCP scenario and decreases is observed in pre-monsoon (MAM) and post-monsoon (ON) scenario in most of the RCP scenario (See Table 5).

Table 5 Largest Single Day Rainfall - (MM) Graph under different RCP emission scenario

		2030	2050	2070	2099
	MAM	-0.303	-0.024	0.29979	0.461
RCP 2.6	JJAS	2.5856	2.327	3.7267	2.8606
	ON	0.6362	0.2637	0.5225	0.7422
	DJF	-0.373	-0.348	-0.572	-0.28
	MAM	0.2024	0.294	0.8987	1.0326
RCP 4.5	JJAS	2.6563	4.8413	5.1479	5.5618
	ON	-0.377	0.5867	1.4072	1.5059
	DJF	-0.985	-0.828	-0.462	0.0834
	MAM	-0.614	0.2313	0.0032	1.2076
RCP 6	JJAS	3.4875	2.4855	3.771	5.6956
	ON	-0.352	0.2791	0.1921	1.9513

	DJF	-0.076	-0.5	-1.203	-0.599
RCP 8.5	MAM	0.3891	0.3927	1.4434	2.2359
	JJAS	3.3807	5.7501	9.0815	12.397
	ON	0.0133	0.6154	2.3482	3.3563
	DJF	-0.285	-0.961	-0.996	-1.038

Source: Generated by Author

Note: MAM=March, April, May; JJAS=June, July, August, September; ON=October and November; DJF=December, January, and February.

The number of rainfall greater than 50 MM is in decreasing trend in pre-monsoon (MAM) and post-monsoon (ON) period, while the increasing trend is observed in winter (DJF) seasons most of the RCP scenarios which indicated more rainfall in the winter season. In monsoon season (JJAS) rainfall pattern is in increasing trend first half of the century and then decreases in the last half of the century at all emission scenarios. The rainfall scenario at RCP 8.5 remains always high compared to other scenarios. The rainfall pattern of the last half of the century will be worse compared to the first half of the century (see Table 6).

Table 6. Number of Rainfall greater than 50 MM Graph under different emission scenario

		2030	2050	2070	2099
	MAM	0	0.006	0.0009	0.0028
RCP 2.6	JJAS	0.0708	0.0539	0.0958	0.0605
	ON	0.0058	0.0015	0.0189	0.0108
	DJF	0.0015	0	-0.004	0
	MAM	0.0161	0.0169	0.0303	0.0487
RCP 4.5	JJAS	0.0973	0.1352	0.1681	0.1964
	ON	0.0013	0.0124	0.0202	0.0215
	DJF	-0.002	-0.005	0	0.0045
	MAM	-0.004	0.0099	0.0248	0.0361
RCP 6	JJAS	0.1167	0.0716	0.0884	0.1538
	ON	0	0.0087	0.0106	0.0307
	DJF	-0.002	-0.002	-0.005	-0.002
RCP 8.5	MAM	0.0202	0.0262	0.0601	0.082
	JJAS	0.1133	0.1427	0.2561	0.3838
	ON	0.0056	0.0179	0.0413	0.0573
	DJF	-0.002	-0.004	-0.003	-0.002

Source: Generated by Author
Note: MAM=March, April, May; JJAS=June, July, August, September; ON=October and November; DJF=December, January, and February.

Based on the above analysis it can be easily said that an increase in the temperature, changes in precipitation and rainfall pattern will be more intense in the future and this will eventually impact the socio-economic structure of Bangladesh.

VI. Conclusion

In this study, CMIP 5 multi-model has been analyzed to investigate the changes in temperature, precipitation, and rainfall. The result indicates that both temperature and precipitation will increase in Bangladesh. The increases in temperature extremes over Bangladesh at RCP 8.5 are higher compared to the rest of the RCP emission scenario. The RCP 8.5 scenario will be worse compared to other emission scenarios in both cases in the following century. RCP 4.5 scenario follows the same pattern. Bangladesh is expected to heat by changing rainfall patterns, increasing temperature and changing precipitation patterns in the following century. Most GCM models result shows an increasing trend of temperature and precipitation at all RCP scenarios. Bangladesh is an agriculture-based country and highly dependent on rainfall. Results indicate that the rainfall pattern will change significantly and effect entirely on crop production in Bangladesh. The result already indicates a significant decline in winter (DJF) rainfall all over Bangladesh which will affect winter crops, while pre-monsoon (MAM) rainfall decreasing trend and monsoon (JJAS) rainfall are in increasing trend most of the RCP scenarios in Bangladesh. The accompanying increased high temperatures could increase water demand for soil and this will lead to a food crisis in many parts of Bangladesh. Changes in rainfall patter could have a serious impact on winter crops in Bangladesh. The adverse impacts of climate change will fall on the poorest people because a majority of them are dependent on agriculture as a source of food and income. As Bangladesh is a developing country so it is necessary to put more emphasis on climate change issues such as increasing temperature, changes in precipitation and rainfall pattern. Besides, further studies regarding temperature, precipitation and rainfall are still necessary.

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