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Trending Regional Precipitation Distribution and Intensity: Use of Climatic Indices

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Abstract

Trends and variability of annual precipitation total, annual number of rainy days and two climate change related precipitation indices named Simple Daily Intensity Index (SDII) and Precipitation Concentration Index (PCI) have been investigated in this study. The analysis was based on daily and monthly precipitation data of 35 observatory stations all over Bangladesh for the study period of 1971-2010. Mann Kendall test was performed to detect the trend and Sen's slope method to determine the magnitude of change. The results indicate statistically significant (95% confidence level) negative trend in 4 stations and significant positive trend in 2 stations for annual precipitation total. Significant positive trend in 9 stations for annual number of rainy days, significant negative trend in 6 stations for SDII and for PCI, and significant negative trend in 6 stations were found all over Bangladesh in this study. The values of PCI indicate strongly irregular precipitation distribution in South Eastern Region (SER) and mostly irregular distribution in other regions. On the other hand values of SDII indicate strong precipitation intensity in SER and mostly moderate intensity in other regions all over the country.

Keywords

Bangladesh, Climate Change Indices, Precipitation, PCI, SDII

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1. Introduction

Climate variability and its unfriendly concomitants are of growing concern worldwide. The climate of Bangladesh is undergoing changes and extremes are becoming more unprecedented every year. Floods, cyclones or droughts are often in its colossal mood here, which are aggravated by climate change and its variability being experienced more frequently in Bangladesh than ever before. Change of precipitation trends is in its way because of climate change. According to the intergovernmental panel on climate change (IPCC) report [1], Bangladesh will experience 5% to 6% increase of rainfall by 2030. Bangladesh has been termed by IPCC as one of the most vulnerable countries in the world, which is prone to climate change. Global warming induced changes in temperature and rainfall are already evident in many parts of the world, as well as in this country [2]. High intensity of rainfall and uneven temporal and spatial distribution is creating flooding and longer dry spells are evoking droughty conditions [3]. As a whole, these have profound impact on agriculture [4] and food security of the country will be at risk [5].

In the past three decades, higher Precipitation Concentration Index (PCI > 20) has been recorded in semi-arid and tropical humid environments in the cardamom hill slopes, south western ghats, India, which implies very long dry periods for up to 3 - 5 months [6]. During the last 50 years, Simple Daily Intensity Index (SDII) values for the countries of the western Indian Ocean have been showing significant negative trend for most of the observatory stations and positive trend in only a few of the stations [7]. Specifically for Bangladesh, although a number of studies have been carried out on average precipitation and temperature pattern [8]-[11], research on intensity and distribution of rainfall has hardly been done.

2. Data and Methodology

Daily and monthly precipitation data of 35 BMD (Bangladesh Meteorological Department) stations (**Figure 1**) were used for this study. For the convenience of analysis, whole study area was divided into five regions as North Western Region (NWR), North Eastern Region (NER), Central Region (CR), South Western Region (SWR) and South Eastern Region (SER) (**Figure 1**).

The Simple Daily Intensity Index (SDII) [7] [12] is defined as follows:

Let RR_{wj} be the daily precipitation total for the wet days W ($RR \geq 1$ mm) in period j. If W is the number of the wet days within the period j, then:

$$SDII_j = \frac{\sum_{W=1}^{W} RR_{wj}}{W} \tag{1}$$

The Precipitation Concentration Index [6] [13], being proposed as an indicator of rainfall concentration and rainfall erosivity [14], was calculated on an annual scale for each station according to Equation (2):

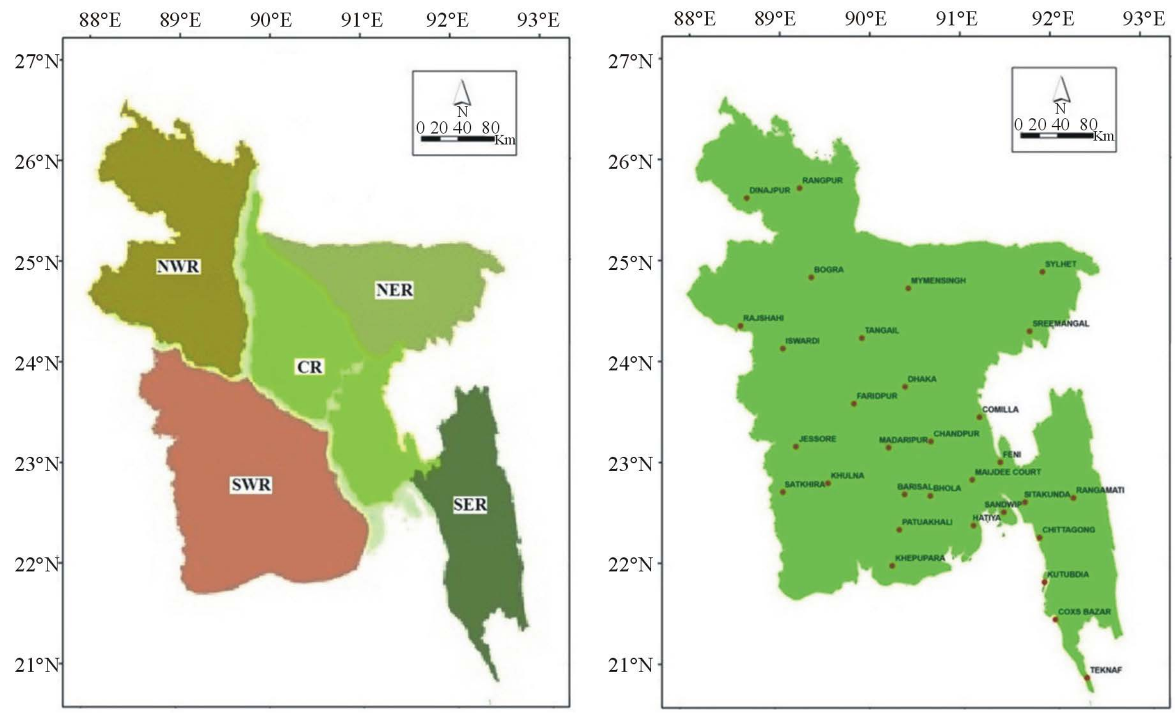
$$PCI = \frac{\sum_{i=1}^{12} P_i^2}{(P_t)^2} \times 100 \tag{2}$$

where P_i is the monthly precipitation in month i and P_t is the annual precipitation total. **Table 1** lists different value ranges of SDII and PCI with their relative significances.

Mann-Kendall test [15] [16] was used to analyze the trends in annual rainfall total, annual number of rainy days, SDII and PCI; in addition, the Sen's slope method [17] was applied to determine the magnitude of change. Confidence level of 95% was taken as threshold to classify the significance of positive and negative trends.

3. Results and Discussion

SDII and PCI both are extreme precipitation indices which measure intensity and distribution uniformity of rainfall events respectively. SDII depends on annual rainfall amounts and annual number of rainy days. Therefore, trends of both annual rainfall amounts and annual number of rainy days have effects on trends of SDII. Mann-Kendall trend test values for annual rainfall amounts, annual number of rainy days, SDII and PCI are shown in **Table 2** and **Figure 2**. Results show insignificant negative trends in 15 stations, significant negative trends in 4 stations, insignificant positive trends in 14 stations and significant positive trends in 2 stations for annual rainfall amounts. For annual rainy days, the numbers are 11, 0, 15, and 9; for SDII the numbers are 17, 6, 12, and 0 and for PCI the numbers are 15, 6, 14, and 0 respectively.



(a) (b)

Figure 1. (a) Study area with regions: Bangladesh (b) BMD stations.

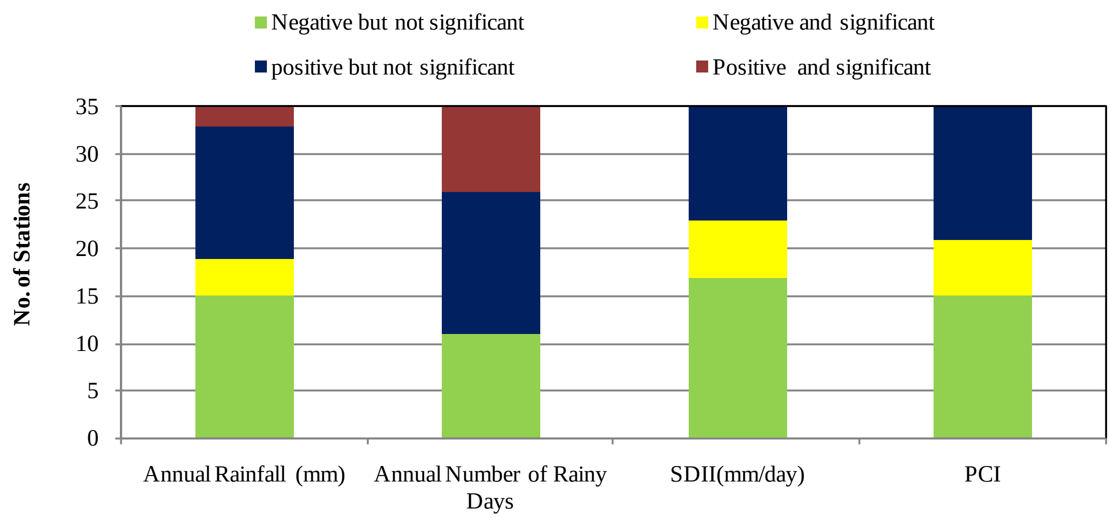


Figure 2. Summary of the results obtained for the trends of the four study parameters using Mann-Kendall test.

Table 1. Significance of SDII and PCI values [6] [7] [12] [13].

SDII Value	Significance (Intensity)	PCI Value	Significance (Temporal Distribution)
To 15 inclusive	Low intensity	To 10 inclusive	Uniform distribution
Over 15 to 20	Moderate intensity	Over 10 to 15	Moderate distribution
Over 20 to 25	High intensity	Over 15 to 20	Irregular distribution
Over 25 to 30	Strong Intensity	Over 20	Strongly irregular distribution
Over 30	Very strong intensity		

Table 2. Trends of annual rainfall total, annual number of rainy days, SDII and PCI for the study period at different BMD stations.

Region	Stations	Trends (unit/year)			
		Annual Rainfall Total (mm)	Annual Number of Rainy Days	SDII (mm/day)	PCI
NWR	Bogra	−1.9	0.01	−0.026	−0.064*
	Dinajpur	−3.69	−0.063	−0.033	−0.085*
	Ishurdi	−9.48	0.07	−0.128*	−0.011
	Rajshahi	−9.50*	0.059	−0.109*	−0.033
	Rangpur	10.08	0.167	0.038	−0.064*
	Saidpur	15.15	1.25	−0.149	−0.134
CR	Dhaka	−1.64	−0.286	0.025	0.018
	Tangail	−1.93	−0.03	−0.054	0.045
	Mymensingh	1.32	0.216	−0.055	−0.071*
	Faridpur	−9	0.093	−0.108	−0.007
	Madaripur	−12.25*	−0.164	−0.062	0.065
	Chandpur	−24.41*	−0.467	−0.098*	−0.092
	Comilla	4.86	0.458*	−0.008	0.035
	Feni	−3	−0.25	0.034	−0.008
	M. Court	−1.03	1.019*	−0.165*	−0.041
NER	Srimangal	9.18	0.889*	−0.045	−0.081*
	Sylhet	−3	0.167	−0.072	−0.028
SER	Rangamati	9.28	0.500*	−0.007	−0.046
	Kutubdia	−8.06	0.609*	−0.149*	−0.073
	Cox's Bazar	8.32	0.304	0.042	−0.059
	Teknaf	19.13*	0.2	0.11	−0.033
	Chittagong	11.62	−0.008	0.106	−0.033
	Ambagan	−6.22	−0.938	0.187	0.175
SWR	Hatya	17.66	0.104	0.117	0.045
	Chuadanga	8.87	−0.071	0.086	0.034
	Jessore	7.5	0.375*	0.016	0.032
	Khulna	−3.7	0.025	−0.053	−0.071
	Mongla	−4.74	−0.29	0.077	0.108
	Satkhira	4.35	0.075	0.03	−0.071*
	Barisal	−2.76	0.068	−0.025	0.044
	Bhola	−14.08*	−0.347	−0.066	0.017
	Khepupara	14.18*	0.583*	−0.018	0.016
	Potuakhali	0.56	0.5	−0.066	0.019
	Sitakunda	−6.93	0.500*	−0.17	−0.007
	Sandwip	3.21	0.456*	−0.131*	0.021

The asterisk (*) denotes statistically significant figures at 95% confidence level.

Intensive rainfall can be uniform if it occurs all over the time period, but if it occurs within a short instance of the time period then its distribution can be called irregular. Accordingly, when both SDII and PCI shows similar trend, rainfall will become uniform and less intensive (decreasing trend) or irregular and intensive (increasing trend). On the contrary, when the two trends are opposite, outcomes may be uniform and intensive or irregular and less intensive. Thus, in NWR and NER rainfall tends to be uniform and less intensive (**Table 2**). In other regions mixed effects are evident.

Six cases of SDII trend change related to the trend of annual rainfall amounts and annual number of rainy days are detected in this study (shown in **Table 3**). In case-I, trends of SDII increase although trends of both annual rainfall amounts and annual number of rainy days decrease. It may be due to the milder trend declination of annual rainfall amounts compared to the annual number of rainy days. In case-II, increasing trend of annual rainfall amounts is steeper than that of annual number of rainy days. Cases III and VI (**Figures 3(a)-(c)**) are

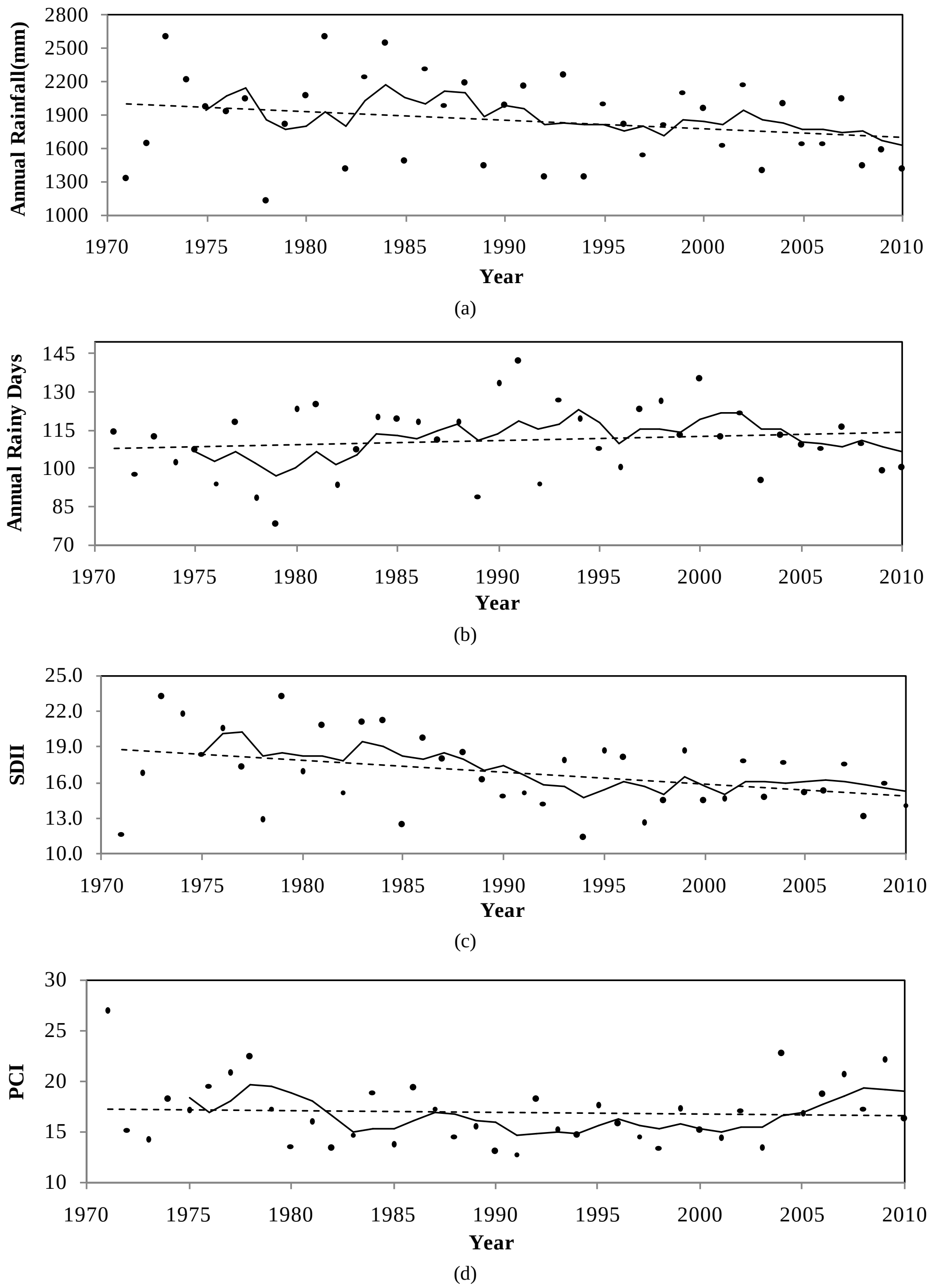


Figure 3. Temporal evolution of (a) Annual rainfall amounts (mm) (b) Annual number of rainy days (c) SDII (d) PCI in Faridpur (one of the BMD stations) for the study period of 1971-2010 along with 5-year moving average (black line) and linear trend (dotted line).

easy to understand as Equation (1) explains. Cases IV and V are the opposite of cases I and II.

The values of PCI shows irregular to strongly irregular precipitation distribution in North Western Region (NWR) and mostly strong irregularity in South Eastern Region (SER); also irregular distribution is evident in Central Region (CR), North Eastern Region (NER) and South Western region (SWR) (**Table 4**). While the values of SDII shows moderate to high precipitation intensity in NWR, moderate to strong intensity in CR and

Table 3. Cases of SDII change (1971-2010).

Cases	Trend of SDII (mm/day)	Trend of Annual Rainfall Amounts (mm)	Trend of Annual Number of Rainy Days
I	Increase	Decrease	Decrease
II	Increase	Increase	Increase
III	Increase	Increase	Decrease
IV	Decrease	Decrease	Decrease
V	Decrease	Increase	Increase
VI	Decrease	Decrease	Increase

Table 4. Average value of SDII and PCI for the study period at different BMD stations and their significance according to values (**Table 1**).

Region	Stations	SDII (mm/day)	PCI	Comments on SDII Value in Terms of Intensity	Comments on PCI Value in Terms of Temporal Distribution
NWR	Bogra	16.641	18.66	Moderate	Irregular
	Dinajpur	20.475	20.112	High	Strongly Irregular
	Ishurdi	16.277	17.925	Moderate	Irregular
	Rajshahi	15.386	18.303	Moderate	Irregular
	Rangpur	20.765	19.023	High	Irregular
	Saidpur	22.158	19.394	High	Irregular
CR	Dhaka	17.37	16.227	Moderate	Irregular
	Tangail	16.491	16.255	Moderate	Irregular
	Mymensingh	18.718	19.345	Moderate	Irregular
	Faridpur	16.787	16.858	Moderate	Irregular
	Madaripur	17.471	16.684	Moderate	Irregular
	Chandpur	18.865	18.694	Moderate	Irregular
	Comilla	18.226	16.954	Moderate	Irregular
	Feni	24.735	19.63	High	Irregular
	M.court	26.535	19.356	Strong	Irregular
NER	Srimangal	17.568	17.04	Moderate	Irregular
	Sylhet	25.374	16.44	Strong	Irregular
SER	Rangamati	19.708	17.856	Moderate	Irregular
	Kutubdia	26.443	20.155	Strong	Strongly Irregular
	Cox's Bazar	28.681	20.331	Strong	Strongly Irregular
	Teknaf	32.459	21.373	Very strong	Strongly Irregular
	Chittagong	24.502	19.965	High	Irregular
	Ambagan	25.19	19.298	Strong	Irregular
SWR	Hatya	25.298	19.368	Strong	Irregular
	Chuadanga	14.81	19.191	Low	Irregular
	Jessore	15.522	17.71	Moderate	Irregular
	Khulna	16.196	17.913	Moderate	Irregular
	Mongla	16.012	16.787	Moderate	Irregular
	Satkhira	15.428	18.423	Moderate	Irregular
	Barisal	17.548	17.206	Moderate	Irregular
	Bhola	19.454	17.681	Moderate	Irregular
	Khepupara	22.648	18.247	High	Irregular
	Potuakhali	21.898	19.7	High	Irregular
	Sitakunda	26.863	18.278	Strong	Irregular
	Sandwip	30.909	19.611	Very Strong	Irregular

NER, mostly strong intensity in SER and low to very strong intensity in SWR (**Table 4**).

Spatial distribution of trends for annual rainfall amounts (mm), annual number of rainy days, SDII and PCI over the study period of 1971-2010 is shown in **Figure 4**. Annual rainfall amount (mm) decreases over the central region (maximum significant negative trend of −24.41 mm/year in Chandpur), and increases in south eastern region (maximum significant positive trend of 19.13 mm/year in Teknaf) (**Figure 4(a)**) and mixed changes prevail over other regions. Annual number of rainy days increases over eastern and northern parts (maximum significant positive trend of 0.889 day/year in Srimangal) and decreases in central part (**Figure 4(b)**). SDII shows mixed spatial trends and decrease over northern and southern part; also in central part decreasing pattern is prevalent (**Figure 4(c)**). Trends of PCI (**Figure 4(d)**, **Figure 3(d)**) show decrease over northern and south eastern parts and increase over south western region.

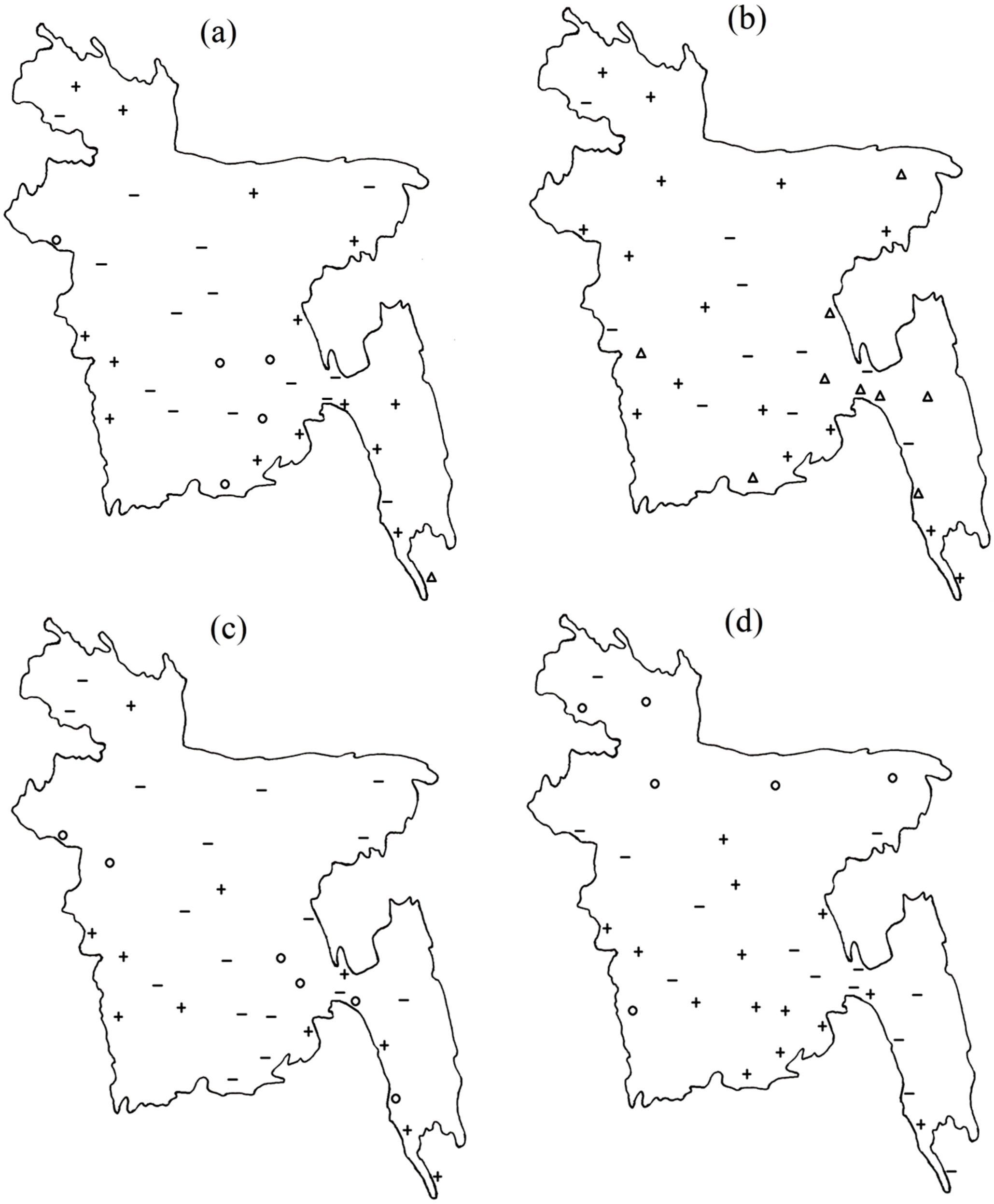


Figure 4. Spatial distribution of trends of (a) Annual rainfall amounts (mm) (b) Annual number of rainy days (c) SDII and (d) PCI over the study period of 1971-2010 (+ for positive, − for negative, o for negative and significant, Δ for positive and significant change).

As a whole, this paper shows a guideline to apply climate indices in detecting intensity and temporal distribution of precipitation pattern on regional scale. Our analysis yields some grimacing results for South Eastern Region (SER) and a little part of South Western Region (SWR) (Sitakunda, Sandwip, Hatya) since precipitation is of high intensity and strong irregularity there. Such irregular and highly intensive precipitation can have high erosion-potential. This may reduce the elevation of these regions over mean sea level making it prone to being engulfed by the sea as sea water surface is continually rising due to climate change [1].

Due to erosion, silt charges in river water increase. Consequently conveyance capacity of river gets low as silts settle down to the river bed. This can cause longer lasting floods. Moreover, due to sudden highly intensive rainfall, flash floods and water clogging may occur in cities due to the lack of drainage facilities. Bangladesh is a country which largely depends on its agriculture and hydroelectricity. So the findings of this study can also be useful for developing various decision-support tools in different hydrologic, ecological and agricultural applications.

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