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Research Article

Precipitation Concentration in Bangladesh over Different Temporal Periods

Md. Anarul Haque Mondol,[1] **Al-Mamun**,[2] **Mehedi Iqbal**,[1] **and Dong-Ho Jang**[2]

[1]*Department of Geography and Environment, Jahangirnagar University, Savar, Dhaka 1342, Bangladesh*
[2]*Department of Geography, College of Social Science, Kongju National University, Singwan-Dong, Gongju-si, Chungnam-do 32588, Republic of Korea*

Correspondence should be addressed to Dong-Ho Jang; gisrs@kongju.ac.kr

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Precipitation concentration is an important component of climate, and an unbalanced distribution of precipitation can yield excess or scarcity of water resources, which in turn can influence plant growth, flood risk, and water resource use. The precipitation concentration index (PCI) is a well-known indicator for the measurement of temporal precipitation in a short or long area. The purpose of this study was to analyze precipitation concentration rates in different regions of Bangladesh using the precipitation concentration index (PCI) and the inverse distance weighting method. In this study, the rainfall data from 30 meteorological observatory stations across Bangladesh were collected for the period 1980 to 2011. We defined periods of varying lengths (i.e., annual, supraseasonal, seasonal, and three- and two-month rainfall concentrations) and compared their PCI values. The results showed that precipitation concentrations were mostly irregular when rainfall was concentrated within two to four months of the year. Higher PCI values were mainly identified in the eastern region and have strong seasonal influences, whereas lower PCI values were mostly observed in the northern region. The analyses of periodic variation and precipitation in Bangladesh generally follow through the SW–NE direction due to the summer monsoon, while during the winter monsoon, they follow the N–S direction where JAS and JFM showed higher and lower PCI values. We observed variations in PCI among different regions using the Kruskal–Wallis test of the mean PCI on a decadal scale (1980–1989, 1990–1999, and 2000–2011). The result showed that significant changes in the precipitation occurred during the period of 1980–2011. At a two-month scale, significant changes were identified during transition periods where PCI values were lower from 2000 to 2011 than those in the earlier decades.

1. Introduction

Climate change due to global worming is a major concerning issue in the world. Precipitation is changing on global and regional scales by the influence of warming [1–4]. For regions prone to hydrological disasters (e.g., Bangladesh), the implications of these changes are particularly significant [5]. It has been suggested that water cycle modification is one of the most notable consequences of global atmospheric warming [6]. Precipitation intensity, amounts, and patterns are expected to change, and extreme weather events such as droughts and floods are likely to occur more frequently [7]. The amount and intensity of precipitation can influence soil erosion, slope instability, plant growth, and agricultural practices [8, 9] as well as modify fluvial systems, groundwater recharge, water disposal, and hydroelectric projects [10, 11]. Precipitation conveyance and measurement can provide a better understanding of the exact mechanisms driving these phenomena for disaster prediction and water management [12].

The IPCC–2007 report found a precipitation increase from 1900 to 2005 north of latitude of 30° [13], and Bangladesh, which is one of the most flood-prone areas of the world, was highlighted as one of the most vulnerable countries [14]. The variation of precipitation distribution in Bangladesh is a unique characteristic for climatic change. In the Bay of Bengal, the hydrological cycle is dominated by very high spatial and temporal variability; and predictions for the end of the 21st century show a high degree of uncertainty [15]. Due to the monsoon season, precipitation concentration increased dramatically while that in the winter season decreased. For the case of dynamic combination, generally Bangladesh faced extreme floods and longer periods of droughts [5, 16, 17]. The north-western part of the country, drought is a common phenomenon and became a growing concern in the recent years. The report confirmed a precipitation decrease in tropical areas and an increase in areas affected by drought in tropical and subtropical areas since the 1970s [13]. Several studies in the world indicate that global warming has strong influence on precipitation variation as well as extreme weather events like floods, droughts, and thunderstorms [18, 19, 20]. Bangladesh is renowned for agricultural-based country where about 80% of people are directly or indirectly involved in agricultural activities as their main profession [21]. Precipitation and its intensity are important factors on the Bangladesh climate for agricultural production [22]. Due to global warming, hydrological changes are the most significant impacts of climate change in Bangladesh. The study of precipitation concentration intensity on seasonal variation is essential for agriculture, disaster mitigation, and water resources planning and management in Bangladesh in the context of global climatic change [23].

Although many studies in Bangladesh have considered general rainfall and temperature characteristics, few have studied the intensity and distribution of rainfall in this region [22]. Furthermore, most research has been performed on an annual or six months basis and smaller temporal-scale analyses are lacking. Although there is no single research method that can comprehensively examine changes in precipitation over time, it is worth considering how different methods can be applied to certain situations [24]. For example, some studies have applied a precipitation variability focus in regions influenced by extreme precipitation events [25]. Several straightforward indicators can be used to assess variability and analyze hydrological processes [26]. Among them, the precipitation concentration index (PCI) [27] is recommended since it provides information on long-term total variability of the rainfall amount [26, 28, 29]. Iskander et al. [22] used the PCI to show an irregular precipitation distribution across Bangladesh, especially in the southeast region, and other trend analysis studies have examined long-term changes in precipitation over Bangladesh [30, 31].

This study analyzed the spatial and temporal precipitation variability using the PCI calculated from dense precipitation datasets collected by the Bangladesh Meteorological Department (BMD). A geographic information system (GIS) was used for the development of a regional variation map to which we applied the inverse distance weighted method. The PCI was calculated for annual, supraseasonal, seasonal, and three- and two-month data over a period of 30 years (1980–2011). This enabled decadal comparisons (1980–1989, 1990–1999, and 2000–2011) between four regions, covering the whole study area.

2. Data and Methods

2.1. Study Area. Bangladesh is a low-lying river-dominated country consisting primarily of flat plains. It occupies an area of 147,570 km^2 and geographically extends from 20°34′ N to 26°38′ N and from 88°01′ E to 92°41′ E. Most of the population lives in rural areas and directly or indirectly depends on agricultural activities. A sub-tropical monsoon climate is strongly active, and the country is sometimes affected by tropical cyclones [32]. The country experiences a vast amount of rainfall annually. On average, 78% of rainfall in Bangladesh occurs during the monsoon and is caused by weak tropical depressions that are carried from the Bay of Bengal by wet monsoon winds [33, 34]. Precipitation concentration varies within the country, and the mean annual precipitation varies from a maximum of 5,690 mm in the northeast to a minimum of 1,110 mm in the west [21]. Bangladesh has 30 meteorological observatories (Figure 1), all of which were included in this study. To better understand rainfall variation, the country was divided into four regions: north-northwest, central, east-southeast, and south-southwest.

2.2. Study Process. In this study, precipitation concentration changes at different temporal intervals were compared for the four regions of Bangladesh. Data were collected from the BMD from 1980 to 2011 and used as the input data for PCI analysis. Dataset quality is an important indicator for obtaining good results and was carefully controlled before the data were released. Generally, all stations were found to be homogeneous; therefore, the datasets from each station were included in this analysis. First, we performed a comparative correlation between the PCI values for the two- and three-month temporal intervals to understand specific variations. Then, we defined uniform, moderate, irregular, and highly irregular precipitation distributions and seasonal variations for specific regions. For the spatial analysis of precipitation, we interpolated data from all weather stations onto a regular grid. Finally, we analyzed the annual, supraseasonal, seasonal, and three- and two-month PCI values using the Kruskal–Wallis test to identify statistical significance among the decades. The major objective of this research was to analyze rainfall trend and irregular distribution over the study area at various temporal intervals.

The geographic information system (GIS) tools have been used for the PCI mapping. Under the geostatistical analysis, the inverse distance weighted (IDW) method was considered in the study to interpolate the PCI data of the country. In interpolation, the power was considered as 2, the searching neighborhood was standard, the neighborhoods were at least 10 and neighbors to include was 15, major semiaxis was 1.52, minor semiaxis was 1.52, and the

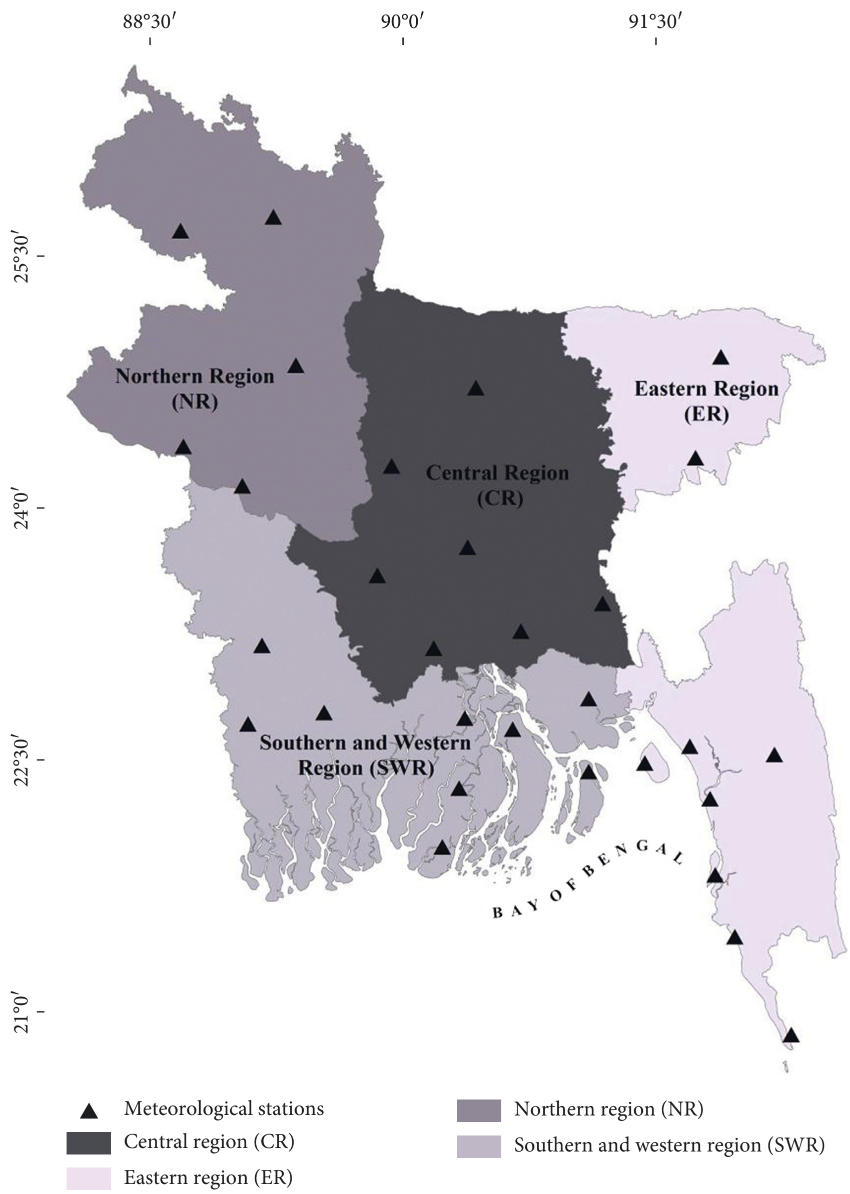

Figure 1: Map of the study area.

angle was 0. The inverse distance weighting (IDW) is an established deterministic method for the precipitation concentration index mapping and one of the most frequently used deterministic models in spatial interpolation [35–37].

2.3. PCI Methods. PCI is an indicator of rainfall concentration and rainfall erosivity [28]. The PCI values were calculated on an annual scale for each grid point using data from all stations based on the equations of Oliver [27]:

$$\mathrm{PCI}_{\mathrm{annual}} = \frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} P_i\right)^2} * 100, \tag{1}$$

where P_i is the total precipitation in month i. The PCI was also calculated on a supraseasonal scale (Equation (2)) from January–June (JJ) and July–December (JD) and on a seasonal scale (Equation (3)) for the winter (November–February, NDJF), summer or premonsoon (March–June, MAMJ), and monsoon (July–October, JASO):

$$\mathrm{PCI}_{\mathrm{supra-seasonal}} = \frac{\sum_{i=1}^{6} P_i^2}{\left(\sum_{i=1}^{6} P_i\right)^2} * 50, \tag{2}$$

$$\mathrm{PCI}_{\mathrm{seasonal}} = \frac{\sum_{i=1}^{4} \mathrm{P}_i^2}{\left(\sum_{i=1}^{4} \mathrm{P}_i\right)^2} * 33.3333. \tag{3}$$

We also calculated the three- and two-month PCI intervals (Equations (4) and (5), respectively) to break down the annual, seasonal, and supraseasonal precipitation distribution and concentration:

$$\mathrm{PCI}_{\text{three-month interval}} = \frac{\sum_{i=1}^{3} P_i^{\,2}}{\left(\sum_{i=1}^{3} P_i\right)^2} * 25, \quad (4)$$

$$\mathrm{PCI}_{\text{two-month interval}} = \frac{\sum_{i=1}^{2} P_i^{\,2}}{\left(\sum_{i=1}^{2} P_i\right)^2} * 16.67. \quad (5)$$

As defined by Oliver [27], the PCI values of less than 10 represent a uniform precipitation distribution (i.e., low precipitation concentration), the PCI values from 11 to 15 denote a moderate precipitation concentration, the values from 16 to 20 denote an irregular distribution, and the values above 20 represent strong irregularity (i.e., high precipitation concentration). According to the analysis of the PCI formulae, on annual, seasonal, and supraseasonal scales, a PCI value of less than 10 indicates perfect uniformity of precipitation distribution (i.e., the same or highly similar amounts of rainfall in each month). At all scales, a PCI value of 16–20 indicates that the total precipitation is concentrated in half of the period, and a PCI value greater than 20 indicates that the total precipitation is concentrated in one-third of the period. For example, this last value indicates that most annual precipitation occurs within four months, most supraseasonal precipitation occurs within two months, and most seasonal precipitation occurs within one month. In other words, intensive rainfall is considered to be uniform if it occurs throughout the time period, but if it occurs within a narrow subset of the time period, then its distribution is considered to be irregular.

To investigate the temporal changes in PCI, the PCI values were calculated for ten decadal subperiods: 1980–1989, 1990–1999, and 2000–2011. The statistical significance of the difference between decadal periods at each grid point was assessed using a trend test with different levels of probability categorized as follows: exceptionally likely ($p < 0.01$), extremely likely ($p > 0.05$), very likely ($p < 0.10$), and very low probability ($p > 0.10$).

3. Results and Discussion

3.1. Annual PCI. The annual PCI values were moderate with some irregularities (Figure 2). During the six-month analysis, the JJ (January–June) period was very irregular, whereas the JD (July–December) period showed a moderate precipitation distribution. A moderately irregular distribution was observed when the four regions shared similar climatic conditions. The distribution of the annual PCI varied from <14 in the north–east (along Sylhet, Srimangal) to >18 in the north and south–east (Figure 3(a)) near the Bay of Bengal, where a moderate-to-irregular precipitation distribution was observed. The western and central areas showed significant variations and irregular distributions.

3.2. Supraseasonal PCI. The PCI on a supraseasonal scale demonstrated a complex precipitation distribution across the study area. During the JJ period, the PCI continued to show moderate-to-high irregularities. The north–west and south–southeast areas had higher PCI values (>20). The central (excluding Dhaka) and west areas also showed comparatively higher values, while low but irregularly distributed values were observed in the central to north–east regions (Figure 3(b)). During the summer (MAMJ), the central and western regions experienced strong storms, locally known as “Kalbaishaki” which are characterized by high rainfall and the potential for devastating damage. For the JD period, lower PCI values (<14) were observed over most of the study area, except for a small region in the south–east near Cox’s Bazar (Figure 3(c)) and were characterized by a moderately irregular precipitation distribution.

3.3. Seasonal PCI. Three distinct seasons are recognized in Bangladesh: the premonsoon or summer season (MAMJ), the monsoon/rainy season (JASO), and the postmonsoon or winter season (NDJF) [38]. Normally, the premonsoon and postmonsoon seasons receive little rainfall. On average, 80% or more of the country’s annual rainfall occurs during the monsoon season. For all regions, the postmonsoon/monsoon seasons showed strongly irregular/uniform precipitation distributions (Figures 3(d) and 3(f)). Rainfall in Bangladesh during the monsoon season is driven by tropical depressions in the Bay of Bengal [33]. These monsoon depressions have a south-to-north trajectory, with turns towards the northwest and west deflected by the Meghalaya Plateau. Owing to the height of this plateau, uplifted moisture condenses, leading to particularly heavy rainfall over northwestern Bangladesh [33]. A moderate precipitation distribution was most common in the premonsoon season, although the north–west and south–east areas showed comparatively higher values (>12) than the west, central, and northeast areas (Figure 3(e)). Temperature has a significant influence on rainfall; during summer, temperatures can reach 45°C or greater, and in winter, they can fall to 5°C in some areas [21].

3.4. Three-Month PCI. The three-month PCI values were highest in the north and south–east and lowest in the central and north–east regions, depending on the annual weather conditions. The JFM period showed irregular PCI values for all regions, with higher values in the south–east than those in the north–west (Figure 3(g)). The AMJ period showed moderately uniform premonsoon PCI values (Figure 3(h)), which is a period that normally experiences increasing rainfall from April to reach moderate levels during May and June [39]. Early rainfall during this period can sometimes cause flooding. The lowest PCI values during the JAS period were less than 10 (Figure 3(i)) and were characterized by uniform precipitation concentrations across the study area. Moreover, the periods of JFM and OND showed strong irregularities in the PCI values corresponding to the dry season [39]. Overall, the north–west area showed the highest PCI values (>20), while the central, south, and east areas had moderate values and irregular distributions. Comparatively lower values were observed in the south–east, near the Chittagong Hill Tracts (Figure 3(j)), where the distribution was moderate.

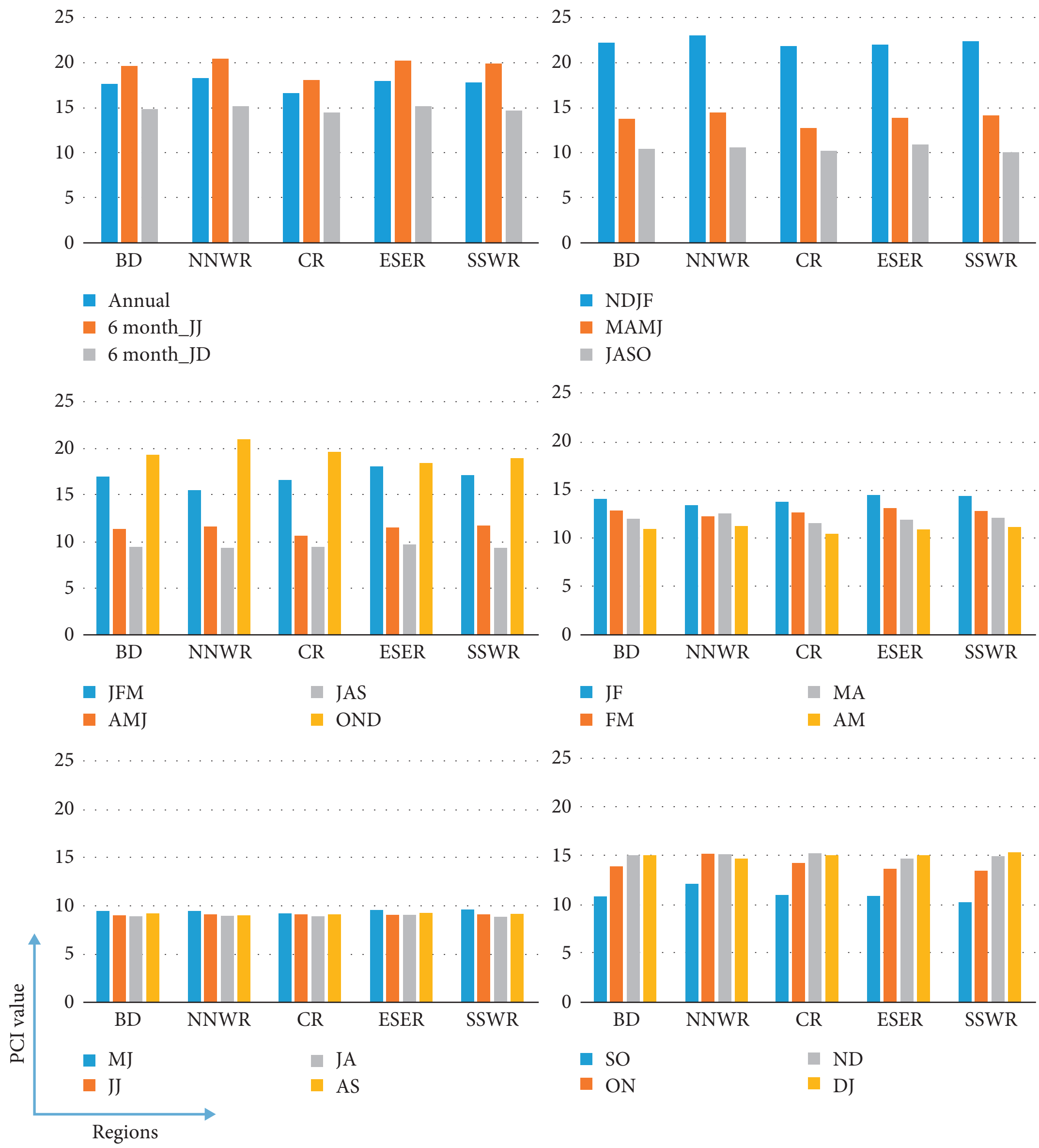

Figure 2: Mean PCI values during 1980–2011. BD, Bangladesh; NNWR, north-northwest region; CR, central region; ESER, east-southeast region; SSWR, south-southwest region.

3.5. Two-Month PCI. The results from two-month data analysis showed relatively moderate-to-uniform precipitation distributions and no strong irregularities for any region (Figure 2). Moderate rainfall was distributed relatively evenly in JF, FM, MA, and AM, and MJ, JJ, JA, and AS were especially uniform. Meanwhile, SO, ON, ND, and DJ had moderate-to-irregular distributions. The analysis showed that rainfall concentrations were most heterogeneous in nonrainfall seasons (JF, FM, MA, AM, ON, and ND) and in the transition period before and after the monsoon. For all regions, precipitation was most regular during the monsoon season (Figures 4(e)–4(h)). For the JF period, the south-southeast region showed a more moderate precipitation distribution than the north–west region, while the opposite was observed for the ON period (Figures 4(a) and 4(j)). During the SO period, some anomalies were found in the northwestern, central, and southeastern areas (Figure 4(i)). These are consistent areas of high altitude where soil conditions and growth capabilities differ from the rest of the country.

3.6. Decadal Analysis of PCI. The decadal analysis showed that the annual PCI values varied over time and exhibited an irregular distribution. Significant changes in the PCI values between 1980 and 1989 and between 1990 and 1999 were found for the extreme northwestern and southeastern regions. The west-central and northeastern regions had similar values, but from 1990 to 1999, the central region changed significantly. From 2000 to 2011, the PCI changed significantly with the northwestern and southeastern regions displaying irregularities, while the central

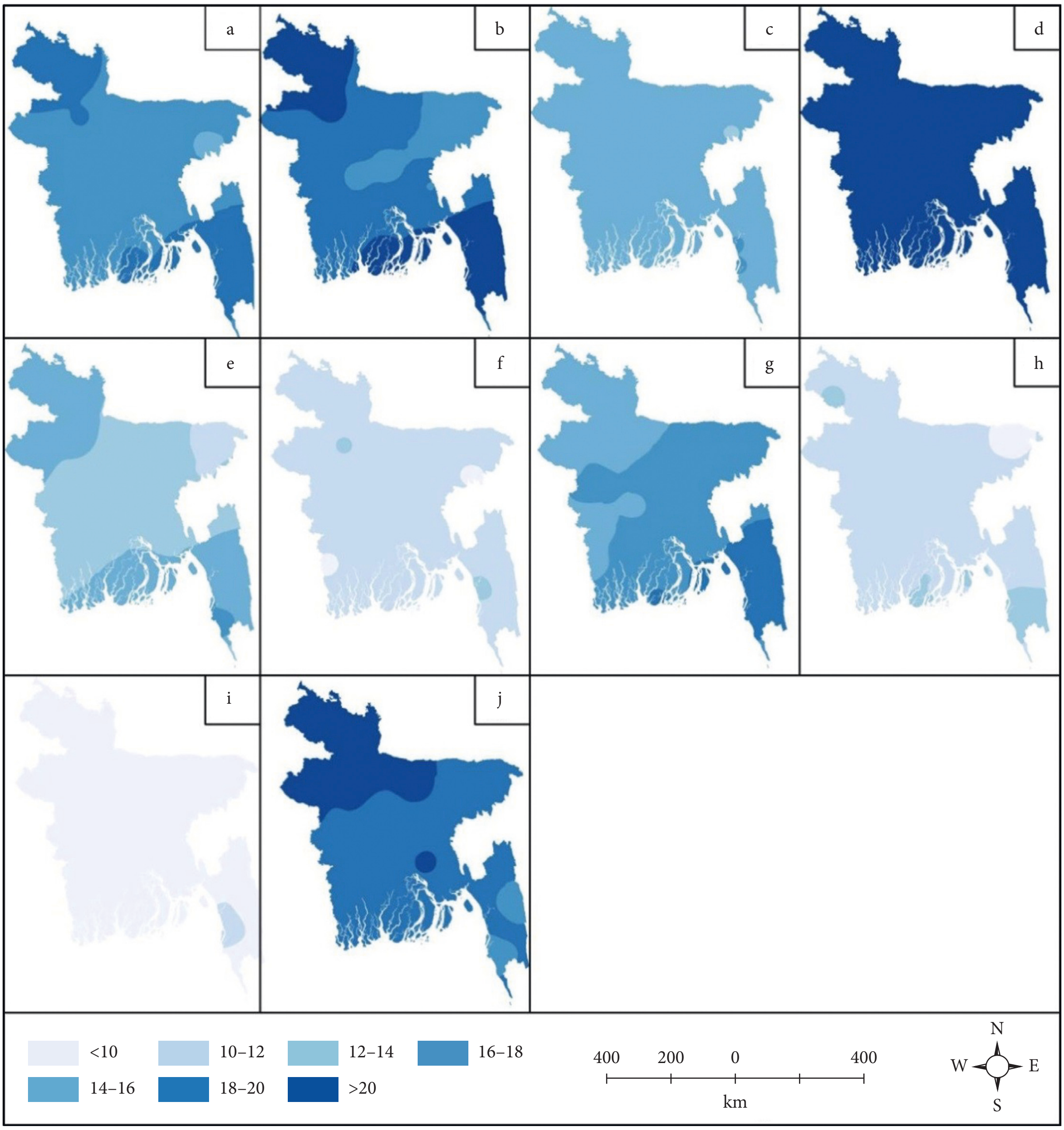

Figure 3: (a) Annual; (b, c) supraseasonal (b = JJ, c = JD); (d–f) seasonal (d = NDJF, e = MAMJ, f = JASO); (g–j) three months (g = JFM, h = AMJ, i = JAS, j = OND).

and northeastern regions showed irregular distributions (Figures 4(a)–4(c)).

When analyzed on a six months basis, the PCI values of the JJ period for the decades 1980–1989, 1990–1999, and 2000–2011 showed significant irregularities. High precipitation concentrations occurred in the north-northwest and south-southeast regions, but the precipitation distribution was irregular from the central to northeast regions (Figures 4(d)–4(f)). This coincided with the spring and hot season, where precipitation was more irregularly distributed. For the six-month period of JD, a moderate precipitation distribution was observed. Only the northern and eastern regions had PCI values that fell within the irregular distribution class (Figures 4(g)–4(i)).

The PCI calculated on a seasonal scale varied across the study area, from values of less than 10 to more than 20. During winter (NDJF), strong irregularities occurred in all decades (1980–1989, 1990–1999, and 2000–2011) while, irregular distributions occurred in the south–west and north–east regions during 1980–1989 and 1990–1999 (Figures 5(a)–5(c)). In summer (MAMJ), the PCI values showed a moderate precipitation distribution, with the north–west and south to south–east regions showing a highly moderate distribution (Figures 5(d)–5(f)). The monsoon

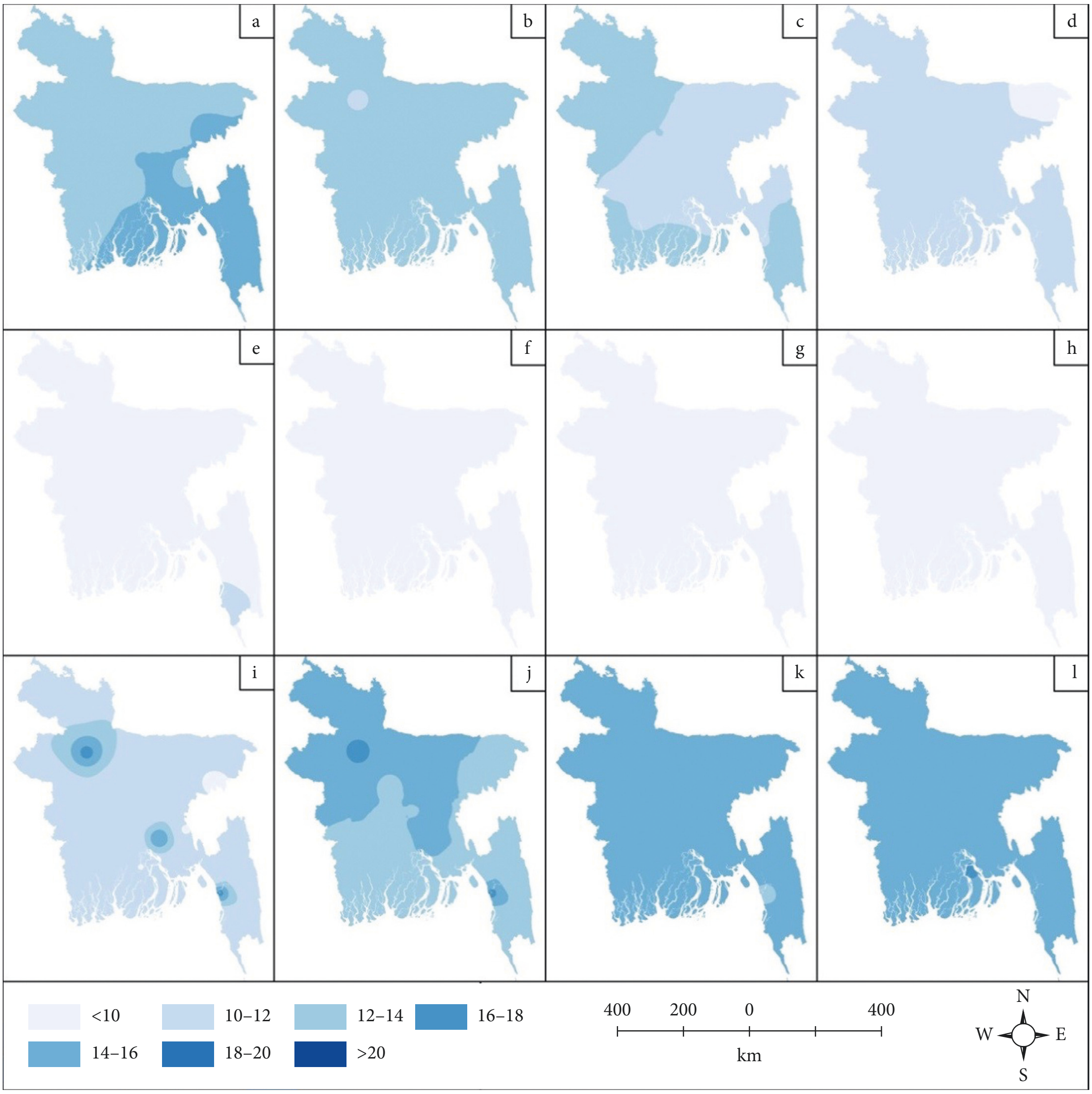

Figure 4: Mean two-month PCI during (a) JF; (b) FM; (c) MA; (d) AM; (e) MJ; (f) JJ; (g) JA; (h) AS; (i) SO; (j) ON; (k) ND; (l) DJ.

season (JASO), when precipitation was generally more uniformly distributed, had lower PCI values (Figures 5(g)–5(i)). However, during the monsoon, extensive rainfall increases the incidence of devastating natural disasters (e.g., floods).

The PCI values calculated on a three month scale showed complex distributions. JFM had moderate and irregular distributions during 1980–1989 and 1990–1999 but irregular and strongly irregular values during 2000–2011 (Figures 6(a)–6(c)). During the AMJ period, which generally exhibited a moderate distribution, only the north–east region showed a uniform distribution (Figures 6(d)–6(f)). A uniform precipitation distribution was observed for the JAS period, although some changes were observed in the south–east region (Figures 6(g)–6(i)). The lower PCI values were common during this time reflect the influence of monsoons. The most irregular and strongly irregular distributions were observed in the OND period, which was influenced by winter weather. The OND period showed the strongest irregularities in precipitation distribution during 2000–2011 (Figure 6).

3.7. Significant Differences in Regional PCI. We observed differences in the mean annual precipitation among the four regions. The decadal analysis revealed a significant differentiation during the decades of 1980–1989 and 1990–1999, while 2000–2011 showed no significant differences (Table 1). For the supraseasonal analysis, significant differentiation was observed during 1990–1999 for the JJ period and during 2000–2011 for JD period (Figures 7 and 8).

Differentiation was observed for MAMJ in all decades except 2000–2011. Differentiation was observed for NDJF

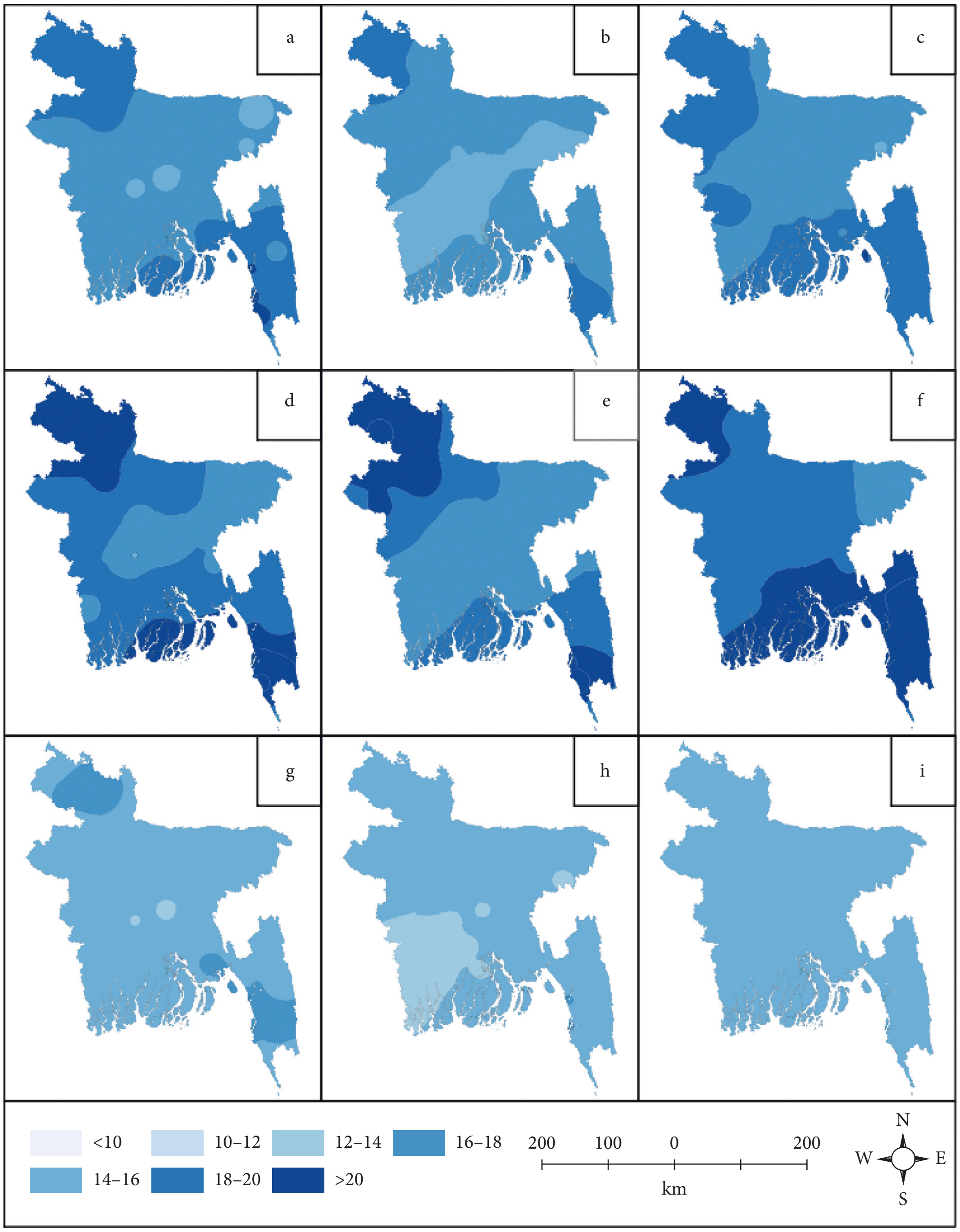

Figure 5: Decadal analysis of annual PCI for (a) 1980–1989; (b) 1990–1990; (c) = 2000–2011. Six-month PCI of JJ for (d) 1980–1989; (e) 1990–1990; (f) 2000–2011. Six-month PCI of JD for (g) 980–1989; (h) 1990–1990; (i) 2000–2011.

during 1990–1999 and for JASO during 2000–2011. The three month PCI showed differences in mean precipitation concentrations for most decades, although for the monsoon period (JAS), we observed no differentiations in mean precipitation concentration across the country. For most decades, the three month PCI values showed variations in precipitation concentration, with the exception of JFM and JAS during 1990–1999 and 1980–1989. The two month PCI values showed that precipitation variation mostly occurred during seasonal transition periods. Precipitation concentration changes were lower from 2000 to 2011 than in the earlier decades. Most climate research has suggested that annual rainfall will increase and winter rainfall will decrease in South Asia owing to global climate change [40, 41].

3.8. Trend of PCI over the Period of 1980–2011 in Bangladesh. Various studies have indicated due to climate change rainfall pattern in Bangladesh is most likely to change which would

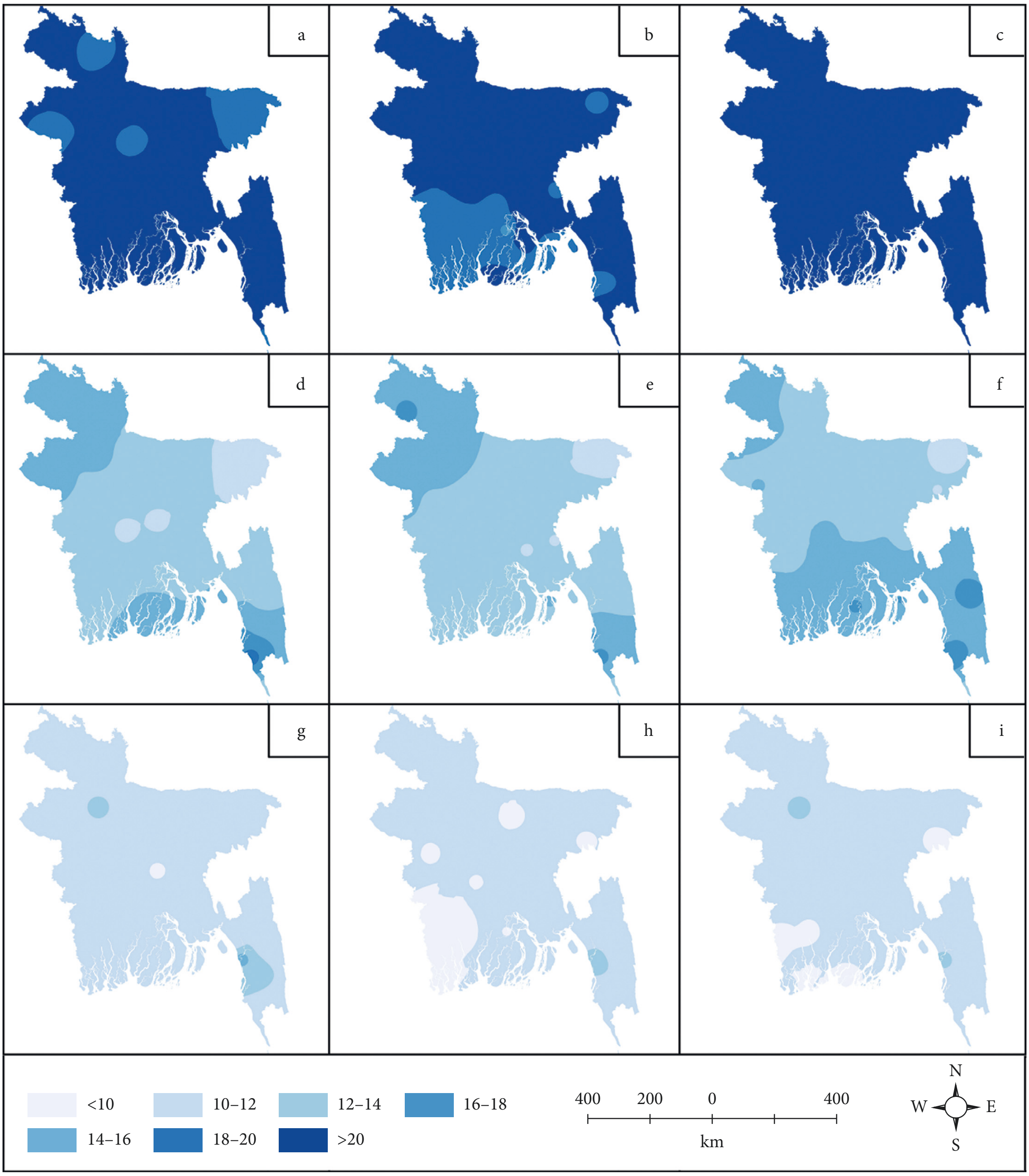

Figure 6: Decadal analysis of seasonal PCI of NDJF for (a) 1980–1989, (b) 1990–1990, and (c) 2000–2011; MAMJ for (d) 1980–1989, (e) 1990–1990, and (f) 2000–2011; JASO for (g) 1980–1989, (h) 1990–1990, and (i) 2000–2011.

have adverse impacts on lives and livelihoods of millions of people [4]. A positive trend in annual rainfall and negative trend in winter rainfall (Figures 9 and 10) means that the rainfall of Bangladesh is concentrating in the monsoon and premonsoon months [5]. The annual trend of PCI has increased by maximum in majority of the stations for most of the periods whereas the SupraSeasonal PCI of July–December has decreased in two third of the stations (Table 2). Moreover, same conditions were found during Monsoon periods. A negative trend of PCI means concentration of rainfall during monsoon in some parts of Bangladesh is increasing. Therefore, this indicates that the irregularities of Rainfall during Monsoon Season (June- September) are less. During Winter Season (November–February) a positive trend of PCI values are evident. Therefore this indicates that the irregularities of Rainfall during Winter Season are high (Figure 11).

Table 1: The regional differences in the mean PCI using the Kruskal–Wallis test during 1980–1989, 1990–1999, and 2000–2011 in Bangladesh.

Timescale[a]	p value			
	Mean	1980–1989	1990–1999	2000–2011
PCI annual	0.036*	0.031*	0.021*	0.097
Supraseasonal (JJ)	0.061	0.063	0.004*	0.219
Supraseasonal (JD)	0.063	0.092	0.089	0.018*
NDJF	0.333	0.227	0.02*	0.105
MAMJ	0.015*	0.012*	0.003*	0.091
JASO	0.237	0.216	0.159	0.034*
JFM	0.011*	0.024*	0.068	0.014*
AMJ	0.014*	0.011*	0.005*	0.026*
JAS	0.455	0.204	0.033*	0.19
OND	0.003*	0.005*	0.068*	0.001*
JF	0.011	0.227	0.107	0.028
FM	0.125	0.332	0.773	0.05*
MA	0.026*	0.018*	0.028*	0.028*
AM	0.025*	0.003*	0.024*	0.018*
MJ	0.051*	0.067*	0.005*	0.192
JJ	0.508	0.032*	0.642	0.371
JA	0.394	0.424	0.023*	0.235
AS	0.368	0.361	0.199	0.114
SO	0.027*	0.344	0.026*	0.052*
ON	0.005*	0.009*	0.062*	0.001*
ND	0.362	0.611	0.607	0.477
DJ	0.135	0.497	0.39	0.39

[a]Letters denote the months of the year (e.g., JJ is January–June and JD is July–December). *Infinity of number.

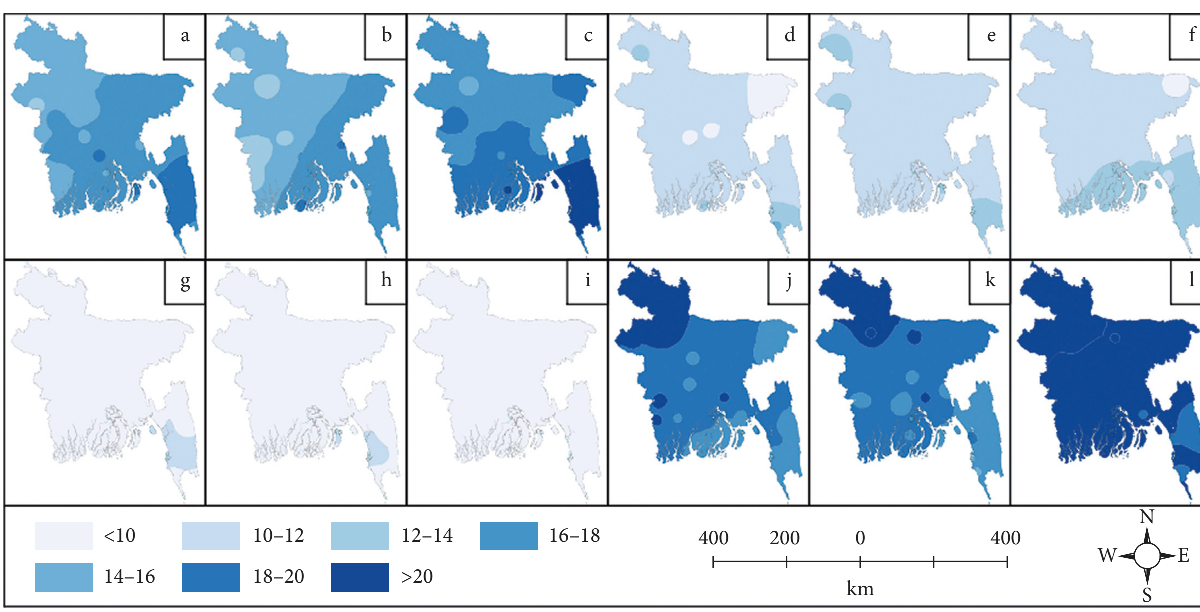

Figure 7: Decadal analysis of the three-month PCI for JFM during (a) 1980–1989, (b) 1990–1990, and (c) 2000–2011; AMJ during (d) 1980–1989, (e) 1990–1990, and (f) 2000–2011; JAS during (g) 1980–1989, (h) 1990–1990, and (i) 2000–2011; OND during (j) 1980–1989, (k) 1990–1990, and (l) 2000–2011.

3.9. Implications of Variation of PCI in Bangladesh. Rainfall variability in space and time is one of the most relevant characteristics of the climate of Bangladesh where hydrological disaster is a common phenomenon [5]. The volume, timeliness, distribution, and duration of rainfall in each season are major concerns to farmers. Most of the people in our country area depend on crop and livestock production for livelihood and household incomes [42]. Rainfall-related hazards and disasters (like drought and flood) require farmers to implement measures in altering

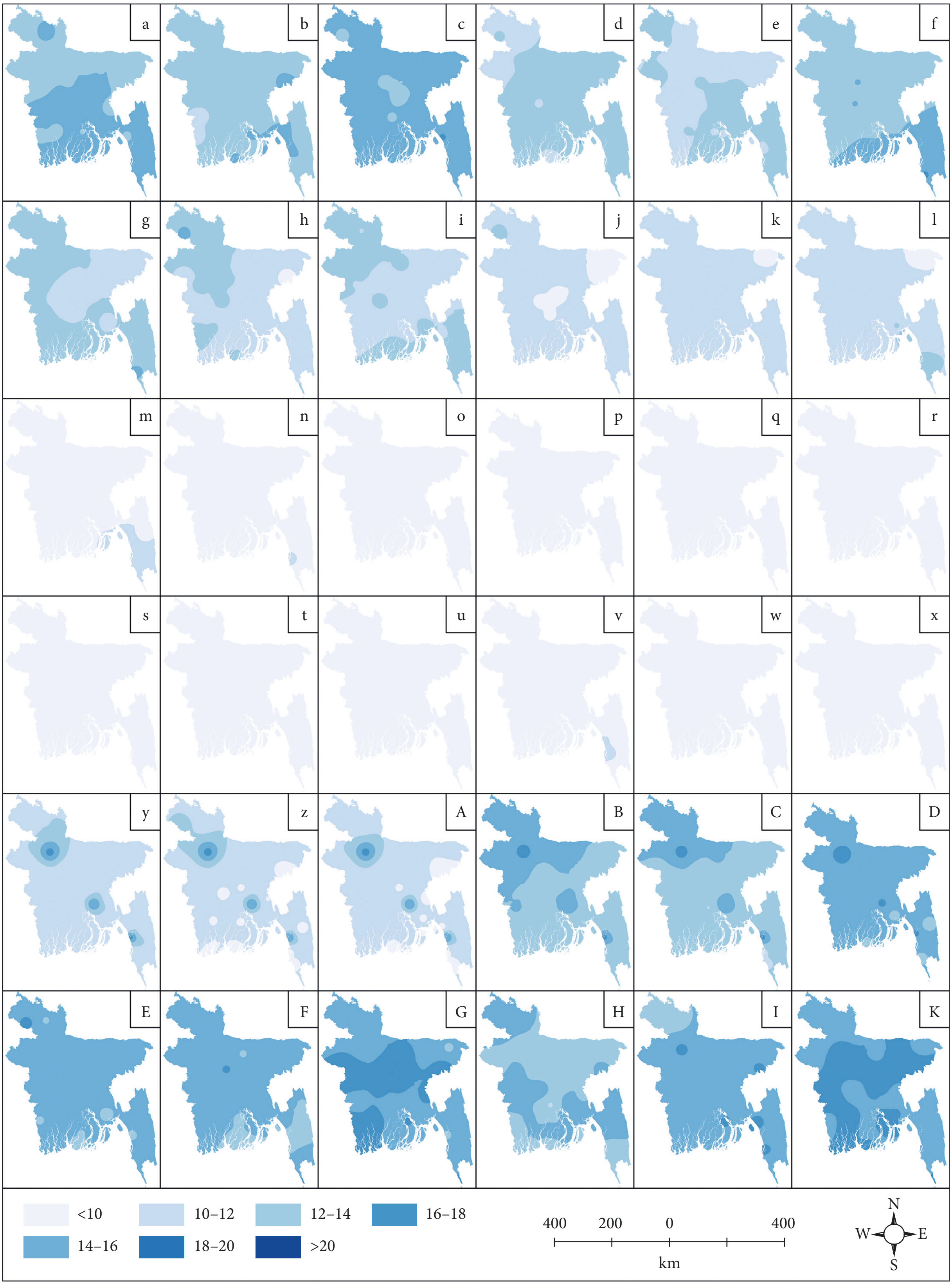

Figure 8: Decadal analysis of the two-month PCI (a, b, c) JF; (d, e, f) FM; (g, h, i) MA; (j, k, l) AM; (m, n, o) MJ; (p, q, r) JJ; (s, t, u) JA; (v, w, x) AS; (y, z, A) SO; (B, C, D) ON; (E, F, G) ND; (H, I, J) DJ for the representative decades 1980–1989, 1990–1999, and 2000–2011 over Bangladesh.

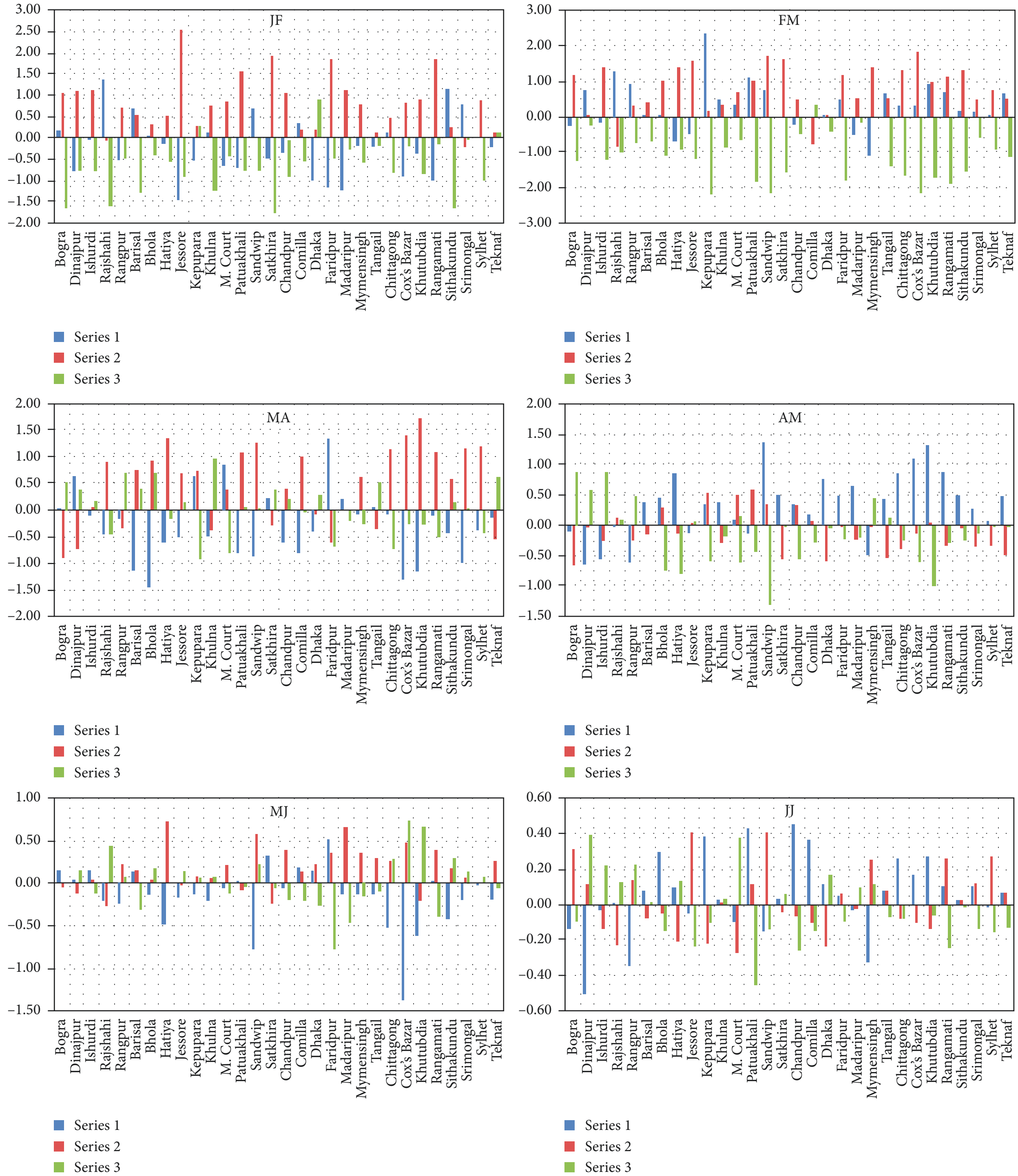

Figure 9: Continued.

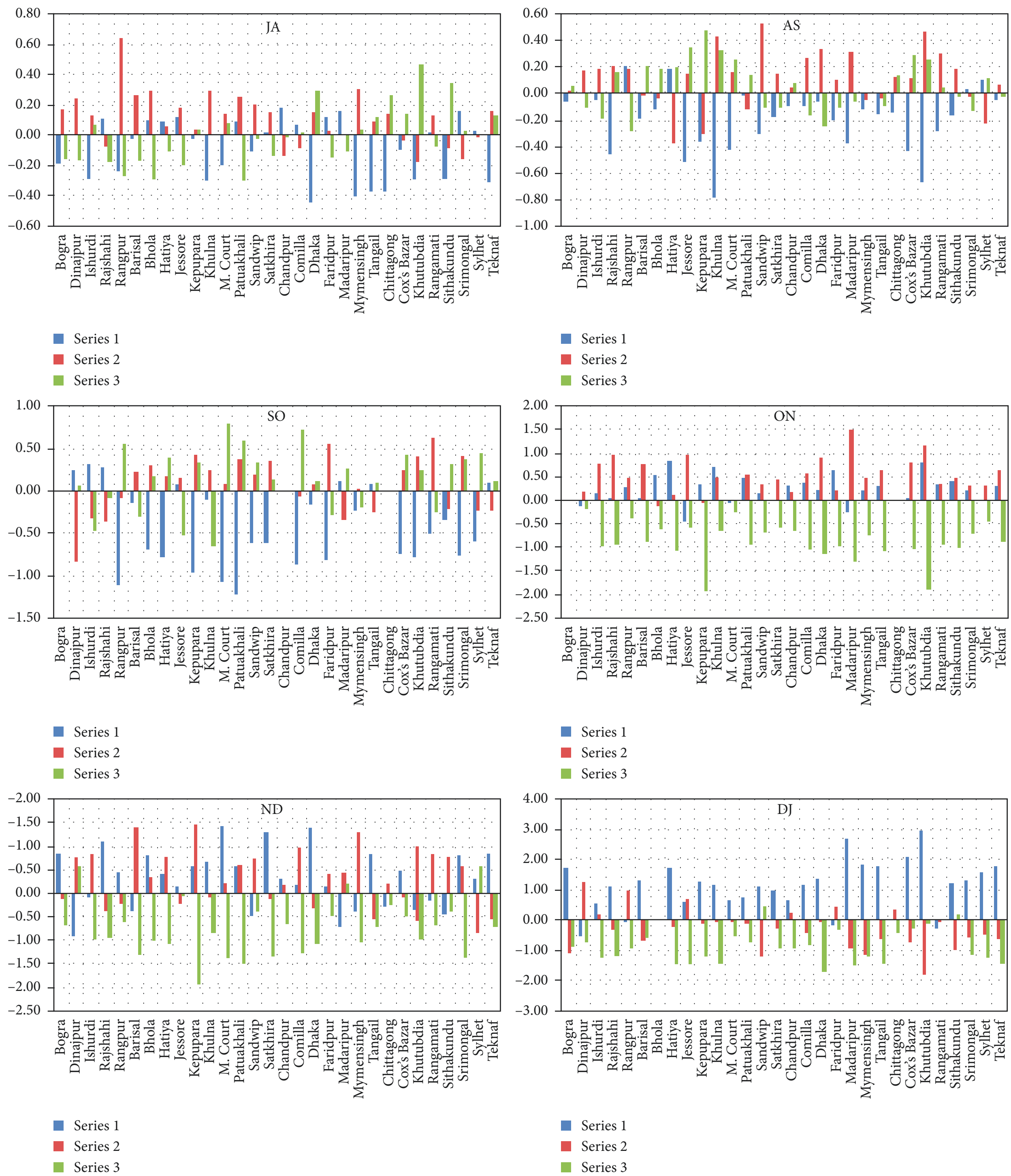

Figure 9: Two-month PCI changes in different periods from long-term mean PCI (1980–2011) (series 1 = 1980–1989, series 2 = 1990–1999, and series 3 = 2000–2011).

the cropping system, planting or sowing times, crop varieties, and change crop types in the country [43]. The PCI can be used as an indicator of hydrological hazard risks such as floods and droughts [44]. PCI can help quantifying the relative distribution of the rainfall patterns [28].

4. Conclusion

Bangladesh experiences a monsoon climate and has a floodplain topography, making it prone to hydrological disasters. In this study, we considered the rainfall distribution over different spatial and temporal scales from 1989 to 2011.

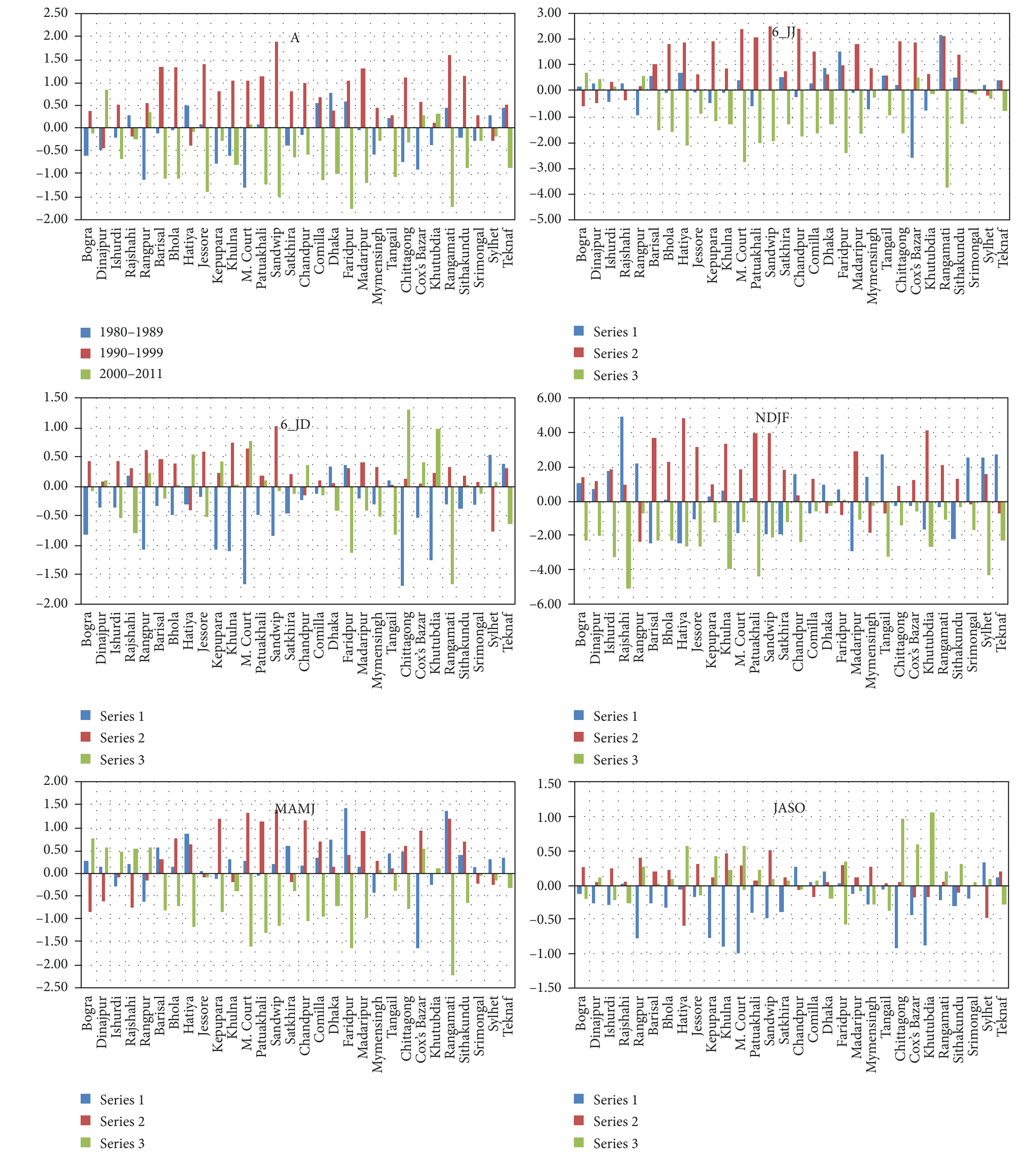

Figure 10: Annual to seasonal PCI changes in different periods from long-term mean PCI (1980–2011) (series 1 = 1980–1989, series 2 = 1990–1999, and series 3 = 2000–2011).

The results showed that precipitation is the most uniform during the monsoon season. For all regions, the annual PCI values were moderate and irregular, and the six-month (JJ and JD) PCI values were irregular to moderate. For the seasonal and three-month analyses, the values were generally moderately irregular. Finally for shorter two-month intervals (MJ, JJ, JA, and AS), most PCI values showed a uniform precipitation distribution. In general, the northwestern and southeastern areas of Bangladesh showed the highest PCI values, reflecting an irregular precipitation distribution. The results showed that the rainfall in Bangladesh is moderately seasonal, with an intensity increasing from the premonsoon to the monsoon season, driven by weak tropical depressions from the Bay of Bengal. Most

Table 2: PCI trend over the period of 1980–2011.

Station	Annual	6 month_JJ	6 month_JD	NDJF	MAMJ	JASO	JFM	AMJ	JAS	OND	JF	FM	MA	AM	MJ	JJ	JA	As	SO	ON	ND	DJ
Bogra	0.03	0.01	−0.01	0.16	0.00	0.02	0.05	0.00	0.01	0.09	0.10	0.06	0.01	−0.04	0.01	0.00	0.01	0.00	0.00	0.00	0.06	0.10
Dinajpur	−0.05	−0.01	−0.02	0.21	−0.02	−0.02	0.10	−0.02	0.00	0.10	0.01	0.03	0.01	−0.06	−0.01	−0.05	0.00	0.01	0.00	0.01	−0.03	0.04
Ishurdi	0.06	0.02	0.02	0.25	0.00	0.01	0.12	0.01	0.00	0.08	0.05	0.06	0.00	−0.05	0.02	0.00	−0.01	0.00	0.03	0.06	0.03	0.08
Rajshahi	0.04	0.05	0.04	0.40	0.01	0.01	0.16	0.00	0.01	0.11	0.13	0.07	0.03	0.00	−0.03	0.00	0.01	−0.03	0.02	0.05	0.06	0.09
Rangpur	−0.05	−0.07	−0.04	0.16	−0.06	−0.04	0.11	−0.05	0.01	0.04	0.02	0.09	−0.02	−0.05	−0.02	−0.03	0.01	0.03	−0.07	0.01	0.03	0.04
Barisal	0.06	0.11	−0.01	0.05	0.06	−0.02	0.12	0.06	0.00	0.13	0.08	0.03	−0.04	0.00	0.02	0.01	0.00	−0.01	0.01	0.03	0.04	0.12
Bhola	0.07	0.10	−0.01	0.20	0.04	−0.02	0.10	0.02	0.01	0.13	0.02	0.08	−0.06	0.05	−0.02	0.02	0.02	−0.01	−0.04	0.06	0.08	0.00
Hatiya	0.03	0.13	−0.03	0.02	0.09	−0.03	0.09	0.04	−0.01	0.19	0.02	0.01	−0.03	0.07	−0.02	0.00	0.01	−0.01	−0.05	0.08	0.09	0.15
Jessore	0.07	0.06	0.01	0.06	0.01	−0.01	0.05	0.00	0.00	−0.02	−0.03	0.03	−0.03	−0.01	−0.02	0.01	0.01	−0.04	0.02	0.00	−0.02	0.08
Kepupara	0.01	0.04	−0.06	0.10	0.03	−0.05	0.14	0.01	−0.02	0.16	−0.04	0.21	0.09	0.05	−0.02	0.03	0.00	−0.03	−0.05	0.04	0.12	0.12
Khulna	0.05	0.10	−0.03	0.21	0.05	−0.04	0.12	0.02	−0.03	0.12	0.05	0.07	−0.07	0.03	−0.02	0.00	−0.01	−0.04	0.04	0.03	0.07	0.10
M. Court	−0.03	0.16	−0.10	0.07	0.09	−0.07	0.08	0.06	−0.01	0.11	0.00	0.02	0.07	0.03	0.00	−0.01	−0.01	−0.03	−0.07	0.02	0.15	0.07
Ppatuakhali	0.09	0.10	−0.01	0.23	0.08	−0.02	0.20	0.05	0.01	0.15	0.02	0.14	−0.02	0.04	−0.01	0.04	0.02	−0.01	−0.07	0.06	0.08	0.08
Sandwip	0.05	0.10	−0.04	0.04	0.06	−0.03	0.24	0.04	−0.02	0.11	0.04	0.11	−0.02	0.11	−0.05	−0.01	−0.01	0.00	−0.04	0.04	0.00	0.04
Satkhira	0.04	0.13	−0.01	0.06	0.05	−0.02	0.24	0.03	−0.01	0.04	0.06	0.10	−0.01	0.03	0.01	0.00	0.01	0.00	−0.03	0.02	0.12	0.09
Chandpur	0.03	0.10	−0.03	0.21	0.07	0.01	0.06	0.05	0.01	0.06	0.04	0.03	−0.02	0.05	0.01	0.04	0.01	−0.01	0.00	0.00	0.04	0.08
Comilla	0.10	0.13	0.01	0.06	0.08	0.00	0.07	0.05	0.02	0.09	0.04	0.00	−0.02	0.05	0.02	0.03	0.01	0.00	−0.07	0.08	0.10	0.09
Dhaka	0.10	0.12	0.04	0.04	0.08	0.02	0.12	0.06	0.02	0.12	−0.08	0.04	0.01	0.03	0.02	0.00	−0.03	0.02	−0.01	0.06	0.13	0.14
Faridpur	0.14	0.22	0.08	0.01	0.16	0.03	0.15	0.12	0.03	0.13	−0.03	0.12	0.12	0.03	0.06	0.01	0.01	0.00	0.00	0.06	0.00	0.01
Madaripur	−0.03	0.16	−0.10	0.07	0.09	−0.07	0.08	0.06	−0.01	0.11	0.00	0.02	0.07	0.03	0.00	−0.01	−0.01	−0.03	−0.07	0.02	0.15	0.07
Mmymensingh	0.02	0.01	0.03	0.08	−0.01	0.01	0.06	0.00	0.00	0.06	0.02	−0.01	0.02	−0.03	0.00	−0.02	−0.02	0.00	0.02	0.02	0.02	0.12
Tangail	0.09	0.10	0.06	0.30	0.06	0.03	0.13	0.05	0.02	0.16	0.02	0.11	0.01	0.03	0.00	0.01	−0.01	0.01	0.00	0.06	0.04	0.15
Chittagong	0.01	0.09	−0.13	0.06	0.05	−0.09	0.10	0.02	−0.06	−0.01	0.02	0.08	0.05	0.04	−0.03	0.03	−0.03	0.00	0.00	0.00	0.00	0.03
cox's Cox's bBBazar	−0.03	−0.12	−0.04	0.02	−0.09	−0.05	0.09	−0.09	−0.02	0.11	−0.04	0.11	0.00	0.06	−0.09	0.01	−0.01	−0.03	−0.05	0.06	0.03	0.11
Khutubdia	−0.03	−0.01	−0.13	0.09	−0.01	−0.11	0.09	−0.02	−0.07	0.25	0.02	0.08	−0.02	0.10	−0.06	0.02	−0.04	−0.05	−0.04	0.14	0.04	0.11
Rangamati	0.13	0.30	−0.01	0.03	0.18	−0.02	0.09	0.11	−0.01	0.08	−0.07	0.13	0.04	0.06	0.03	0.02	0.00	−0.01	−0.01	0.08	0.03	0.00
Sithakundu	0.06	0.09	−0.01	−0.01	0.04	−0.02	0.12	0.00	−0.03	0.13	0.09	0.08	0.01	0.02	−0.04	0.01	−0.03	0.00	−0.03	0.07	0.00	0.02
Srimongal	0.01	0.04	0.00	0.22	0.03	−0.01	0.10	0.02	0.01	0.12	0.02	0.05	−0.05	0.04	−0.02	0.00	0.00	0.01	−0.05	0.04	0.10	0.11
Sylhet	0.03	0.04	0.01	0.28	0.02	0.01	0.12	0.02	0.00	0.11	0.05	0.06	0.00	0.01	−0.01	0.00	0.00	0.00	−0.05	0.00	−0.05	0.18
Teknaf	0.09	0.09	0.06	0.27	0.05	0.03	0.14	0.05	0.02	0.15	0.01	0.10	0.01	0.03	0.00	0.01	−0.01	0.01	0.00	0.05	0.04	0.15

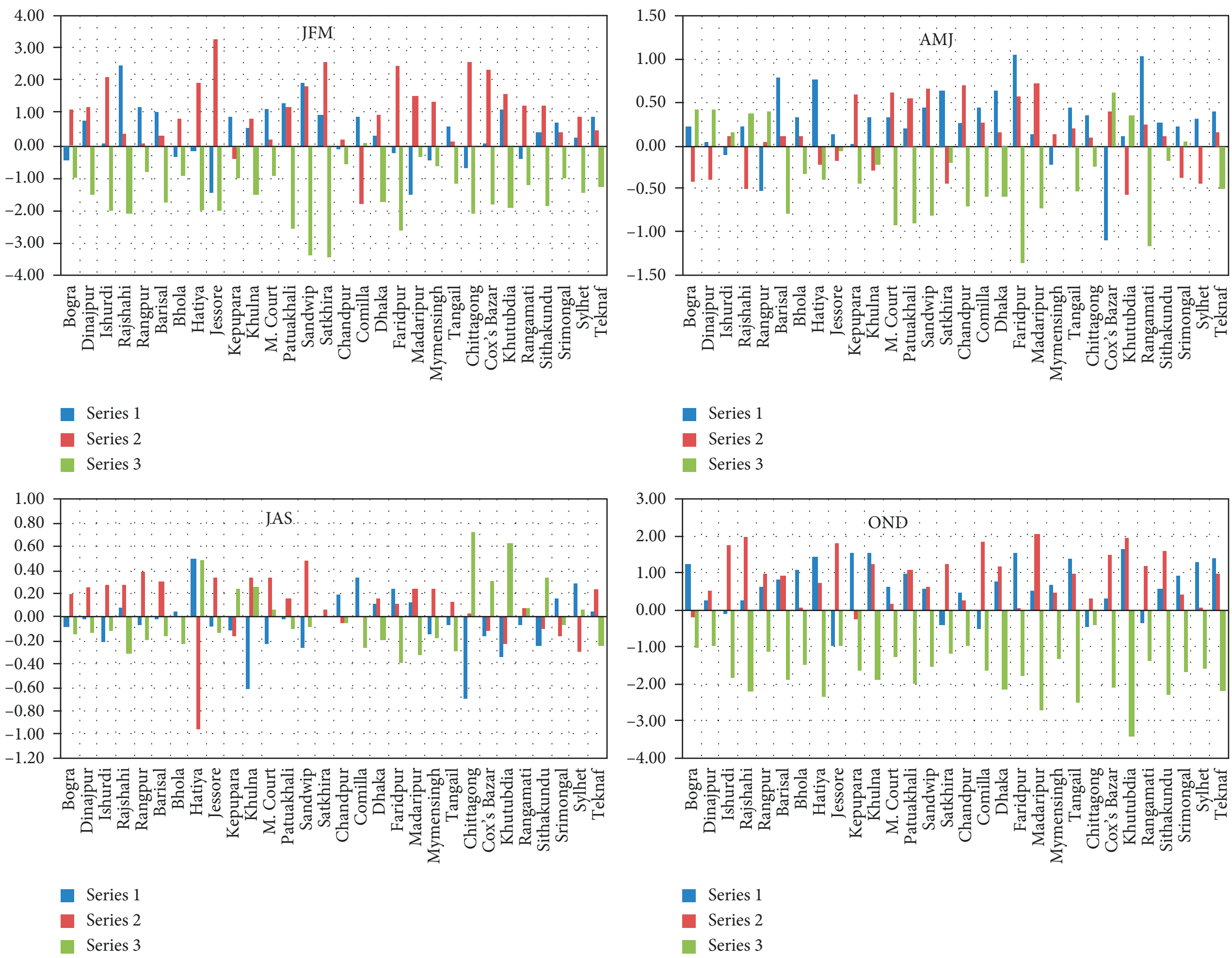

Figure 11: Three-month PCI changes in different periods from long-term mean PCI (1980–2011) (series 1= 1980–1989, series 2 = 1990–1999, and series 3 = 2000–2011).

premonsoon rainfall occurs in the central and western regions, where agricultural production is extensive. The decadal analysis (1980–1989, 1990–1999, and 2000–2011) showed that the annual PCI values have varied over time and exhibited irregular distributions. The north–west and south–east regions had strong irregularities during 2000–2011, while the shorter JJ and JD six-month periods showed significant and moderate irregularities, respectively. The seasonal analysis showed that the JASO period exhibited a uniform subtropical monsoon climate; therefore, the three-month JAS period also showed a uniform distribution. The two-month PCI analyses indicated that precipitation variation was mostly found in seasonal transition periods. For short time periods, precipitation was strongly linked to season. Short-term variations also increased during the decade 2000–2011, during which the OND period saw the most irregular precipitation distribution.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Authors' Contributions

Md. Anarul Haque Mondol and Al-Mamun designed the research idea, analyzed the data, and wrote the manuscript; Mehedi Iqbal contributed for critical evaluation of the manuscript. Dong-Ho Jang revised the manuscript critically and provided important intellectual content.

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