Spatiotemporal Trends of Temperature Extremes in Bangladesh Under Changing Climate Using Multi-statistical Techniques

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Research Article

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Abstract

The rise in the frequency and magnitude of extreme temperature phenomena across the globe has led to the recurrent incidence of global climate hazards, which have had severe effects on socioeconomic development. The daily maximum and minimum temperature datasets of 27 sites in Bangladesh were used to detect spatiotemporal trends of temperature extreme over Bangladesh during 1980-2017 based on ten temperature extreme indices using multi-statistical modeling namely linear regression, Pearson correlation coefficient and factor analyses. Besides, mutation analyses based on the Mann-Kendall test, Sen's slope estimator

27 and Pettit test were employed to show the changing trend in extreme temperature. Results

28 show that except for warmest days, the warm indices showed an increasing trend, mainly

29 since the 2000s, while the growth rate was faster, and the response to global climate warming

30 was sensitive. The cold indices demonstrated a reverse trend since the 2010s. Diurnal

31 temperature range (DTR) and summer days (SU) increased faster, implying that the rising

32 speed of daily max temperature was higher than of daily min-temperature in Bangladesh. The

33 detrended fluctuation analysis (DFA) revealed a continuous increase in temperature extreme

34 in the future except for cold days. The probability distribution functions (PDF) analysis

35 revealed an evident variation of the curves in recent decades compared to the past three

36 decades. Besides the warm night, DTR and SU primarily control the general warming trend

37 of temperature extremes over Bangladesh during the study period. The mutation of the warm

38 indices occurred before the cold index, indicating that the warm indices were more sensitive

39 to global climate warming. The temperature extremes recognized in our research suggest that

40 elevated warm temperature extremes due to global climate warming may have huge

41 implications on the sustainable development of Bangladesh in the forthcoming period.

1. Introduction

Temperature extremes have critical effects on ecosystem imbalance, agricultural productivity, water resources and sustainable socioeconomic development (Easterling et al. 2000; Ciais et al. 2005; Schmidli and Frei 2005; Benestad and Haugen 2007; Allen et al. 2010; Rammig and Mahecha, 2015; Guo et al. 2019). Variations in temperature extremes in a warming climate have paid considerable attention in recent years due to the enormous impact of severe temperature occurrences on society and ecosystems (Bandyopadhyay et al., 2012; Sun et al., 2014). Furthermore, the scientific community has emphasized measure to tackle the climate change impact on ecosystems and human livelihoods for disaster prevention and mitigation (Smith 2011; Jiang et al. 2012; Endfield 2012; Garcia-Cueto et al. 2014; Sharma et al. 2018). As climate extreme events increased in many parts of the world, including Bangladesh (Hasan et al. 2013; Shahid et al. 2016; Mahmud et al. 2018; Khan et al. 2019). Thus, it is crucial to investigate spatiotemporal changes in Temperature Extremes for sustainable development over Bangladesh.

Extreme temperature phenomena are changing across the globe due to global warming (Alexander et al. 2006; Aguilar et al. 2005; Hidalgo-Muñoz et al. 2011; Coumou and Rahmstorf 2012; Abiodun et al. 2013; Coumou et al. 2013; Omondi et al. 2014). The fact is that global and local average temperatures are increasing, which have no bearing on the occurrence of extreme events (Finkel et al. 2018; Gleixner et al. 2020). However, severe temperatures may be more vital than mean temperatures for productivity and human survival, and local extreme temperature changes could significantly impact global mean temperature changes (Finkel et al., 2018; Gao et al., 2017; Katz et al., 1992). Several studies have reported that the frequency of warm temperature indices is increasing, while the frequency of cold temperature indices is decreasing (Alexander et al. 2006; Tank et al. 2006; Piccarreta et al. 2015; Sheikh et al. 2015; Guan et al. 2015; Sun et al. 2016; You et al. 2017; Ullah et al. 2019). All these studies looked at average temperature trends and temperature extremes, but the latter only looked at monthly

1

and yearly maximum and minimum values as extremes. The Expert Team on Climate Change Detection and Indices (ETCCDI) has identified extreme temperature indices to illustrate better temperature extremes, commonly used in climate change-related studies in various parts of the world (Zhang et al., 2011). Therefore, a deep understanding of temperature extremes' trends and fluctuations is essential for developing accurate estimates of future climate change projections and answering scientific researchers', climate change analysts and decision-makers unique concerns.

Bangladesh is one of the world's top ten countries that could be severely affected by climatic extreme (Eckstein et al., 2017). The most immediate impacts of climatic extreme in Bangladesh, as elsewhere globally, are mainly due to increased daily temperatures and temperature-related extreme phenomena (Shahid et al., 2016). Temperature extremes have been observed in the country's agriculture (Sikder and Xiaoying, 2014) and other sectors (Shahid et al., 2016). Temperature variability is most likely to result in significant yield reductions in the agricultural industry in the future (Ghose et al., 2021). Plant development, pollination, and reproductive processes are all affected by higher temperatures (Tank et al., 2006; Sacks and Kucharik, 2011). A short period of unusually high or low temperatures can significantly negatively impact crop growth and yield (Mearns et al., 1984). Due to temperature extremes, total rice production in Bangladesh is expected to decline by 7.4% per year from 2005 to 2050 (Sarker et al., 2012). Therefore, significant attempts should be made to estimate not only changes in mean temperature sequence but also changes in the frequency, magnitude, and duration of extreme temperature events (Easterling et al., 2000; Jones et al., 2001; Moberg and Jones, 2005; Alexander et al., 2006). However, the characteristics of climate extremes are poorly understood at the regional level. So, it is urgently needed to keep track of spatiotemporal variations in temperature extremes regularly at the regional level, including Bangladesh.

In Bangladesh, many studies were performed to investigate the spatiotemporal variations of extreme climate indices (Hasan et al., 2013; Shahid et al., 2016; Mahmud et al., 2018). These studies reported that warm temperature events (cold temperature events) are rising (decreasing). However, the studies mentioned above are either concentrated on the two regions, and a limited number of meteorological stations (Mahmud et al. 2018), short time scales and a limited number of temperature indices (Khan et al., 2019), different data sources (Hasan et al., 2013). Besides, it is unclear whether and how those indices affect temperature extremes in Bangladesh both spatially and temporally. In addition to this, previous studies have not shown the long-term connection among extreme temperature indices using Detrended Fluctuation Analysis (DFA). To close the aforementioned research gaps, this study has four objectives:

1. To examine the spatiotemporal trends of temperature extremes from 1980 to 2017 in Bangladesh.
2. To identify the association among extreme temperature indices.
3. To predict long-term connection among ten temperature extremes indices.
4. To analyze the factor affecting the extreme temperature variation over Bangladesh.

The novel aspect of this research is that the trends and the associated connection of extreme temperature were analyzed in Bangladesh to understand their spatial and temporal variability. The findings will serve as a scientific foundation for future severe event prediction and hazard mitigation and prevention.

2. Data and Method

2.1 Study Area Description

Bangladesh is a sub-tropical country of South Asia situated in between latitude 20° 34' N to 26° 38' N and longitude 88° 01' E to 92° 41' E (Fig. 1) with complex hydro-geologic settings (Jerin et al., 2021; Ghose et al., 2021). Excluding some hilly area of Bangladesh, maximum portions of the land area in the floodplain (80%) region (Rahman and Islam, 2019; Islam et al., 2021). In Bangladesh, the monthly

113   average temperature ranges from 5.8°C (January) and 35.7°C (August), whereas the monthly average

114   precipitation varies between 1mm (January) and 350mm (July). The annual average temperature is

115   26°C, and the average yearly rainfall is about 2400 mm (Islam et al. 2020; Jerin et al., 2021). Seasonal

116   variations in rainfall are indistinguishable characteristics of its climate. The country's climate is

117   characterized by a hot and humid summer with heavy rain and a dry and mildly cold winter. Winter

118   (December to February), pre-monsoon (March to May), monsoon (June to September), and post-

119   monsoon (October to November) are the four predominant seasons of the country (Islam et al. 2021;

120   Salam et al. 2020). Bangladesh has an average daily mean relative humidity of 80% and a 3.72 mm/day

121   evapotranspiration rate, respectively (Salam and Islam, 2020). The coldest month is January and the

122   hottest months in Bangladesh between April and October.

123   *2.2 Data source and quality control of the dataset*

124   Daily minimum and maximum temperature data are collected from Bangladesh Meteorological

125   Department (BMD). Though BMD has 43 weather stations across the country, 27 sites were selected for

126   this study because of the lack of availability of long-term temperature data. Thus, the daily Tmin and

127   Tmax data of 38 years from 1980 to 2017 were used in this study with missing values of less than 4%.

128   The selected stations are uniformly scattered all over the country, which is assumed to be a perfect

129   representation for the whole country. Our study was analyzed variations in extreme temperature indices

130   based on daily minimum and maximum temperatures for 1980–2017. Many temperature series were

131   omitted from our analysis due to inhomogeneity. Missing data at each site were filling-up from the

132   records of nearby locations. In addition, the sites discarded due to the unavailability of data for a more

133   extended period was also used to fill up the missing values (Rahman et al. 2019). The BMD followed

134   the World Meteorological Organization (WMO) guidelines for weather data record and collection.

135   Nevertheless, the quality control of the dataset is still imperative before investigating climatic extremes

136   because incorrect outliers influence the extremes significantly (Gao et al., 2015).

137   Quality control of site observation was initially done through systematic checking of data, namely,

138   positive records of climate variables; Tmin is lower than Tmax, and temperature less than 45ºC. The

139   time-series data were identified to be homogeneous and consistent at all locations (Hans, 1986). The

140   BMD staff also approved all data records through a data quality check. Serial autocorrelation is one of

141   the critical problems in trend analysis (Praveen et al., 2020). Assessment of serial autocorrelation in time

142   series for different lags showed correlation at $p<0.05$, except for a few cases. Data were quality-

143   controlled by RClimDex1.1.

144   In this study, 10 extreme temperature indices were chosen from the indicators recommended by the

145   Expert Team for Climate Change Detection Monitoring and Indices (ETCCDMI). Recently, these 10

146   indices have been extensively adopted in extreme temperature study (Zhou et al., 2020; Islam et al.,

147   2021). The indices were computed by using the RClimDex software package developed by ETCCDI

148   (http://cccma.seos.uvic.ca/ETCCDI). Table 1 presents a detailed description of these ten indices.

149   *2.3 Pettitt's Test*

150   Pettitt's test is a non-parametric test introduced by Pettitt (1979) applied to detect a change point in any

151   time series data with its significance test (Islam et al., 2020). In this study, Pettitt's test is used for

152   detecting change points among different extreme temperature indices. This test employed Mann-

153   Whitney statistic U_t, that examines if the two sets of sample x_1, x_2, x_3, …x_t and x_{t+1}, x_{t+2}, x_{t+3} …x_n are

154   from the similar population or not (Mu et al. 2007). The U_t can be expressed as:

$$U_t = \sum_{i=1}^{t} \sum_{j=t+1}^{n} \text{sign}(x_t - x_j) \qquad (1)$$

$$\text{sign}(x_t-x_j) = \begin{bmatrix} 1, & if(x_i-x_j) > 0 \\ 0, & if(x_i-x_j) = 0 \\ -1, & if(x_i-x_j) < 0 \end{bmatrix} \qquad (2)$$

155   The K (test statistic) and ρ (confidence level) for the n (sample length) are defined by Eq. (3-4):

$$K = Max\ |U_t| \qquad (3)$$

$$\rho = \exp\left(\frac{-K}{n^2 + n^3}\right) \qquad (4)$$

156   The null hypothesis is rejected if ρ is lower than the specified significance level. The p (significance

157   probability) can be expressed as:

$$p = 1 - \rho \qquad (5)$$

158   *2.4 Detrended Fluctuation Analysis (DFA)*

159   Detrended fluctuation analysis (DFA) is a novel method for assessing the long-term relationship in the

160   non-stationary time series data analysis, which is firstly presented by Peng et al. (1994) for the

161   investigation of DNA. The DFA method can prevent the wrong identification of artificial relationships

162   by eliminating local trends of the different time series (Rahman and Islam, 2019; Islam et al., 2021).

163   Nowadays, this method has been employed mainly to identify long-range associations among natural

164   systems following continuous improvement (Li and Zhang, 2007). In this paper, DFA is used for

165   predicting upcoming trends in extreme temperature indices. The following procedure can calculate it:

166   For extreme climate series $\{x_k, k = 1, 2, ... N\}$, In which N represents the series length and x represents

167   mean. The cumulative deviation of the original series can be computed as:

$$y(i) = \sum_{k=1}^{n}(x_k - \bar{x})\ (i = 1, 2 \ldots \ldots \ldots N) \qquad (6)$$

168   Then the latest series y_i is ordered into Ns different sub-intervals through s length by Eq. (7):

$$N_s = int\left(\frac{N}{s}\right) \qquad (7)$$

169   For confirming the information as the series is not divisible, it is categorized again into inverse way. As

170   a result, a total of 2Ns subintervals is created. Then Polynomial fitting is executed for each sub-interval

171   v (v = 1, 2, …2Ns) data to achieve the trend function $y_{v(i)}$ in that series. The original series trend in sub-

172   function is filtered out by executing Eq. (8):

$$y_{s(i)} = y(i) - y_{v(i)} \quad i = (1, 2, \dots \dots \dots N) \tag{8}$$

173   wherein, $y_{v(i)}$ is second order polynomial though it can be first or higher order polynomial. To eliminate

174   the trend and computing of the each-interval variance is calculated by Eq. (9-10):

$$F^2(v, s) = \frac{1}{s}\sum_{i=1}^{s}\{y[(v-1)s + i] - y_v(i)\}^2 \quad (i = 1, 2, \dots \dots N_s) \tag{9}$$

$$F^2(v, s) = \frac{1}{s}\sum_{i=1}^{s}\{y[N - (v - N_s)s + i] - y_v(i)\}^2 \quad (i = N_s + 1, N_s + 2, \dots \dots 2N_s) \tag{10}$$

175   The estimation of the second order wave function of the entire series by following Eq. (11):

$$F(s) = \sqrt{\frac{1}{2N_s}\sum_{v=1}^{2N_s} F^2(v, s)} \tag{11}$$

176   Power law relationship series of F(s) and s variations are computed by using Eq. (12):

$$F(s) \sim s^a \ or \ lnF(s) = a \ lns + b \tag{12}$$

177   The datasets are close fitted using least square method in dual logarithmic where 'a' (slope) of the trend

178   is scaled DFA index. The whole procedure is randomly divided and independent if there is a=0 and 0 < a

179   < 0.5 denotes the short-term relation with dependent process demonstrate that the time series data are

180   inversed to the prevailing trend. On the other hand, 0.5 < a < 1 indicates the continuous series and

181   approaching trend is same to the previous. When 'a' is nearby to 1, the greater the change of similarity

182   and a=1 denotes the procedure is 1/f sequence like a non-stationary casual cycle along with 1/f spectrum

183 classified by scale invariance and a long-term relationship. Moreover, a ≥ 1.5 denotes the procedure is

184 brown-noise sequence.

185 *2.5 Trend analysis using multi-statistical techniques*

186 The nonparametric Mann-Kendall (MK) test is employed to detect a trend in extreme temperature

187 indices (Islam et al., 2019; Islam et al., 2021). It is renowned for its robustness in analysing non-

188 normally sequenced datasets and lower sensitivity to missing value (Islam et al., 2021). A trend free pre-

189 whitening (TFPW) method was employed to remove serial auto-correlation (Praveen et al. 2020; Jerin et

190 al., 2021). Correspondingly, Sen's slope (SS) estimator (Sen, 1968) was employed to determine the

191 frequency of change in extreme temperature indices. The elaborate process of the MK test and SS are

192 found in Islam et al. (2019) and Praveen et al. (2020).

193 Pearson's correlation coefficient was applied to reveal the relationship among extreme temperature

194 indices. The factor analysis was employed to detect extreme temperature factors across Bangladesh

195 (Rahman and Islam, 2019). The univariate linear regression analysis was used to identify the trend rate

196 of extreme temperatures indices in Bangladesh and each site (Donat et al., 2014). We Used the R studio

197 software to perform the M-K mutation test (Gallant and Karoly, 2010; Panda et al., 2014) and use the

198 student t-test to confirm the mutation change point and, increasing the credibility of the mutation

199 outcome.

200 **3. Result**
201 *3.1 Linear Regression Trends Analysis*

202 The rate of the inter-decadal tendency of every single extreme temperatures index was quantified by

203 employing the linear regression technique, and its significance was examined (Figure 2). Based on the

204 time scale, the warm indices of extreme temperature demonstrated an increasing trend except for TXX

205 showed a decreasing trend during 1980-2015. The rate of the magnitude of DTR, SU, TXX, TNX,

TX90p, and TN90p were 8.7e days/decades, 0.21 days/decades, 0.037 oC/decades, 0.01 oC/decades, 0.11 days/decades, and 0.12 days/decades, respectively (Figure 2), denoting that the warm indices of extreme temperature are rising significantly in Bangladesh. Among them, the rising rate of DTR and TNX were relatively shorter during the study period 1980 to 2015. At the same time, the increasing rate of other indices was comparatively larger, mainly the rising rate of SU, which was the fastest, whose tendency of inter-decadal magnitude rate attained 0.21 days/decades (Figure 2b). As shown in Figure 2, except for TXX, the rest of the warm indices demonstrated an increasing trend from the 1990s to 2000, representing that there can be a warming occurrence in this period. DTR, SU and TX90 were changed smoothly before 2010, while abrupt upward change started since 2010 (Figure 2a, b, f). TN90 showed a comparatively short variation before the 1990s; after that, it had large fluctuations and showed an upward trend (Figure 2e). TNX exhibited changes that started after 1995; before 1995, the fluctuation was short (Figure 2h). The overall decreasing trend showed in TXX during the total study period, and two significant changes were in the 1990s and 2010s (Figure 2j). Based on the discussion mentioned above, the warm indices of extreme temperature exhibited an overall upward trend in the study period except for TXX in this research. Since 1995, the warm indices showed a rapid upward trend in line with the global warming trend.

The cold indices of extreme temperatures TNN, TXN, TN10 and TX10 all exhibited decreasing trend, and the rate of magnitude were -0.019 oC/decades, -0.049 oC/decades, -0.15 days/decades and -0.078 days/decades, respectively. This demonstrates that these cold indices had a significant decreasing trend, of which the TN10 had the biggest decline and TNN had the most minor decrease that was also a certain tendency of global warming. Figure 2c shows that the TN10 significantly fluctuated before 2010, and from 2011 to 2015, the fluctuation was extremely short. TX10 demonstrated a decreasing trend where significant fluctuation had started since 1985 (Figure 2d). In Figure 2g, the TNN had the most noticeable

229 change and fluctuation from the 2000s, while the most significant fluctuation was after 2010. The

230 temporary fluctuation showed from 1980 to 1995 while the most considerable fluctuation and variation

231 exhibited after 1995 with decreasing trend in TXN (Figure 2f). By observing the above assessment,

232 TX10, TN10, TXN and TNN all exhibited a downward trend; notably, TX10, TN10 showed a rapid

233 decline speed.

3.2 Long-Term Connection analysis Using DFA

235 To explore the trend behaviours of fluctuation in forthcoming temperature extremes, a long-term

236 association assessment was conducted employing DFA, and the results are demonstrated in Figure 3a –

237 j. The Figure 3 illustrates that the DFA ranging exponent in DTR, SU, TN10, TX10, TN90, TX90, TNN,

238 TNX, TXN, and TXX was 0.96, 0.65, 0.86, 0.38, 0.76, 0.85, 0.63, 0.71, 0.75 and 0.86 respectively. In

239 the study period 1980 to 2015, they all had a strong association, showing that the forthcoming

240 behaviours of trend in each single warm and cold temperature extremes are similar to the fluctuation

241 trend. Indeed, the warm temperature extremes will rise, and cold temperature extremes will decline in

242 the forthcoming period. The rate of change in the warm temperature indices (SU, TNX, and TN90) will

243 increase continuously than the other warm indices. The DFA values of these warm indices are not closer

244 to 1. In cold temperature indices, TN10 will continue to decrease than the other cold temperature indices

245 except for TX10 due to its DFA value being larger than the other cold indices. We explored that the

246 sequence values of the DFA exponent of warm indices (SU, TNX, TN90) are less than the cold

247 temperature extreme (TN10). It demonstrates that the forthcoming trend pattern in temperature extreme

248 has a strong long-term association with the current state and forthcoming trend pattern. By contrast, the

249 DFA exponent value of the warm indices is higher than DTR, TXX, TX90, while in cold indices, the

250 exponent value of DFA is lower than TNN, TXN and TX10.

251 In Table 1, the correlation matrix of 10 temperature indices has been exhibited. We assessed the

252 significant associations between the Warm and cold indices (p<0.01) in this current study. There is a

253 strong significant negative relationship between warm indices and cold indices. In contrast, the warm

254 indices SU, DTR and TXX have a significant positive relationship with cold indices TNN, TXN and

255 TN10, respectively, where their coefficient was 0.395, 0.389 and 0.348, respectively (p<0.01). The most

256 significant positive relationship is between TX90 and SU, where the coefficient was 0.756 (p<0.01). The

257 warm temperature indices were a significantly positive association with one another. On the other hand,

258 the significant negative relationship has shown in cold temperature indices, while the relationship

259 between TXN and TNN has a significant positive association (p<0.05). The index selected in this

260 present work can have good indicators of climate warming over Bangladesh.

261 *3.3 Spatial patterns of extreme temperature indices*

262 The spatial changes in temperature extremes are exhibited in Figure 4. Nearly -081 to 1.12 days/decade

263 was the change rate of DTR where southern and western parts had an increasing trend, and at the same

264 time, another part faced the decreasing trend while 58% and 29% of areas under decreasing and

265 increasing trends, respectively (Figure 4a). In Figure 4b, 65% of sites remain under the increasing trend

266 of SU, and the change tendency rate was -0.93 to 1.44 days/decade; the southern part demonstrated

267 decreasing tendency. TN10 had a decreasing trend in the south and south eastern regions, where 84% of

268 areas occupied the decreasing trend (Fig. c). The trend change rate of TN10 was -0.5 to 1.22

269 days/decade in Figure 4c. The trend rate of TX10 was -1.37 to 0.3 days/decade, decreasing trend found

270 in northern and southern parts, and 23% of areas remain under increasing direction (Figure 4d). The

271 change rate of TN90 was -0.25 to 1.63 days/decade, and the northern and southern parts met the

272 increasing trend where 50% of areas were under increasing trend (Figure 4e). Figure 4f exhibits that

273 TX90 had -1.6 to 1.45 days/ decade change rate and 67% area under increasing and 25% area under

decreasing rate where western and southern part faced increasing trend and the other part met decreasing trend. The change rate of TNN was -1.50 to 1.51 days/decade, with 69% of station stayed under increasing tendency in the northern, western and southern regions (Figure 4g). TNX had a -1.14 to 1.50 rate of change; 80% of areas demonstrated a declining trend in the western and southern region (Figure 4h). In Figure 4i, the change rate was within -1.44 to 1.15 days/decade for TXN, and the higher decreasing rate was in the southern region; 73% station was under decreasing trend. The variation rate in TXX varied from -1.41 to 1.03 days/decade, where 56% of areas show a declining pattern in the southern part of the study area (Figure 4j). The trending behaviour of extreme temperature indices varied spatially, further assured by temporal distribution in the earlier part.

3.4 Factor analysis of temperature extreme indices

Factor analysis was carried out to detect the most influential factor affecting extreme temperature indices. F1, comprising TN90, SU and TNX indices of temperature, the overall variance of temperature data is 40.76%, which denotes the warm night primarily controls the general warming trend of temperature extremes over Bangladesh from 1980 to 2015 (Table 3). Daily temperature range (DTR), SU, and TX90 control F2 calculated 22.40% of the whole variance, ensuring the rising of DTR is the principal factor that affects changes in yearly temperature. The DTR reflects the association between the minimum and maximum temperatures. About 11.83% of the total variance accounted for F3, where Min Tmax (TXN) dominates the third factor. For F4, the coldest days (TNN) and warmest days (TXX) are the major dominant factors that represent the overall variance of 9.49% and 4.88%, indicating the warming climate has occurred daily minimum and maximum temperatures to rise significantly. In most cases, warm and cold extremes have a significant statistical association with the average annual temperature (You et al., 2011).

3.5 *Variation of probability distribution functions of temperature extreme*

297   Due to the variations in temperature extremes, the relative indices were chosen to explore the

298   probability distribution function (PDF) of extreme temperature phenomena (Figure 5) in the previous

299   four decades. The frequency has declined in cold extremes while the frequency has increased in warm

300   indices in a recent decade over Bangladesh, which also is consistent with temporal trend analysis. The

301   cold extremes were moved negatively (Figure 4c, 4e, 4g and 4i) while warm extremes (Figure 4a, 4b,

302   4d, 4f, 4h and 4j) positively shifted to their upper trails. The movement of negative and positive of the

303   curve of PDF denotes that frequency is declined of cold extremes and increased in frequency of warm

304   extremes. It is worth mentioning that the variations of the PDF curve are more evident in recent decades

305   than in the past three decades. In warm indices, the highest peak was found in 1990 to 1999 and 2000 to

306   2009 for DTR, SU and TXX. The recent two decades were for TNX, and 1980 to 1989 was for TN90,

307   and 1990 to 1999 was for TX90. In cold indices, the maximum peak was found in the decades of 2000 to

308   2009 for TN10, TX10 and TXN and 1980 to 1989 was for TNN.

309   *3.6 Rate of change analysis using Sen's Slope Estimation*

310   The ordinary non-parametric system improved by (Zaiontz 2020) was employed to account for the

311   slopes present in the rate of trend using the Sen's slope estimators (Fig. 6). The positive mark represents

312   the increasing slope, and the declining slope denotes the negative impact. Figure 6a shows that the

313   lowest negative Sen's slope value was -0.764, primarily found in the northeastern part, and the highest

314   value was found in the southeastern region. The highest positive Sens value was 8.821 for SU (Figure

315   6b), which generally exhibited in the northeastern part, while -3.019 was the lowest negative value for

316   TN10 (Figure 6c) which maximum distributed in the northern region of Bangladesh. In Figure 6d, the

317   lowest negative value was -2.279 for TX10, primarily found in Bangladesh's northeastern and southern

318   parts. The north and northeastern parts of Bangladesh have distributed the highest Sen's slope value

319   3.649 for TN90 (Figure 6e). The highest positive value was 5.312 for the TX90 (Figure 6f), which

320 mainly occupied southern and northern parts. The lowest value was -0.906 for the TNN (Figure 6g),

321 which was commonly found in the country's southern region. Figure 6h exhibits that the northeastern

322 part met the lowest negative value of TNX, which was -0.089. For TXN (Figure 6i), the lowest negative

323 value was -1.4, mostly occupying the northern part of Bangladesh. The highest positive value was 0.406,

324 which was distributed in the southern part of Bangladesh.

325 *3.7 Mutation Analysis of Extreme Temperatures Indices*

326 The M-K change point detection analysis was performed for each extreme temperature index, and the

327 change year was selected by combining the sliding t-test technique (Table 4). Table 4 shows that overall

328 Bangladesh, the warm indices (DTR, SU, and TX90) and the cold indices (TNN and TX10) did not

329 change, but the remaining warm (TN90, TNX, TXX) and cold indices (TN10, and TXN) were changed

330 significantly ($p<0.05$). The station-wise warm and cold indices were muted. For warm index, in different

331 stations, the points of change happened in the last 20th and the beginning of the 21st century where

332 stations like Patuakhali, Rangpur for SU, Mymensingh, Patuakhali and Sitakundu for TXX, and Bhola,

333 Jashore, Patuakhali and Mymensingh for TX90 met the change point in the 1980s and later in 2008. In

334 cold indices, their mutation point was also the beginning of the 21st and last of the 20th, where

335 Rangamati and Sitakundo for TNN, Chattogram and Teknaf for TN10 faced the mutation point after

336 1987 and 2005. The points of mutation of all indexes of temperature extremes passed 0.05 level of test

337 of significance. It can be observed that the mutation point is varied from region to region. In those

338 stations, warm indices such as TXX and TX90 were muted in 1986, 1987 while cold indices including

339 TNN and TN10 were muted in 1988 and 1989. Overall, the mutation points of warm indices were before

340 cold indices and other indices. Similarly, it implied that the warm indices were more sensitive to global

341 climate warming than cold indices.

342 **4. Discussion**

343 Extreme weather occurrences have drawn attention to the massive dominance of extreme climate

344 changes on life, nature and human production in recent years (Weaver et al. 2014; Li et al., 2013). Due

345 to getting how extreme climate influences the natural environment and society. It is significantly

346 essential to assess climate extremes' spatial and temporal change trend. In this present study, we

347 evaluated the temporal and spatial changes in temperature extremes in Bangladesh in the previous 36

348 years (1980-2015). The results exhibited that the trend of warm indices increased while TXX showed

349 decreasing trend and the cold indices are meeting decreasing trend. This result is consistent with Li et al.

350 2020, where they explored that the warm indices including WSDI, TR20, SU25, Tx90p and Tn90p are

351 increasing, and the cold indices such as CSDI, ID0, FD0, Tx10p and Tn10p are decreased. Zhou et al.

352 (2020) explored those warm indices in China showed an increasing trend while cold indices exhibit a

353 declining tendency except TXN and TNN, which agrees with the present study. Sun et al. (2015)

354 investigated that cold extremes are significantly declining in China, similar to the current research. The

355 warm occurrences are increased and decreased considerably the cold events stated by Ren et al. (2010),

356 which is in line with the present study. The warm days are increased by 0- 0.3 days/ decade in china (Shi

357 et al. 2018). Jiang et al. (2016) assessed that the cold indices TX10 and TN10 are declined whether the

358 warm indices TX90 and TN90 increase in the Tibetan plateau. Cold extremes and warm extremes

359 exhibited downward and upward trend, respectively, in the assessment of Yu and Li (2016), which is

360 similar to the current research findings. We have explored the correlation between warm indices and

361 cold indices. Warm and cold indices with each other were investigated. Those warm temperature indices

362 (SU, TNX, and TN90) will be increasing in future than the other warm indices, while cold indices TN10

363 will decline in coming days than other cold indices by using the DFA exponent.

364 The warm and cold extremes were significantly negatively correlated except for the relationship

365 between SU and TNN, DTR and TXN, TXX and TN10. This outcome is consistent with Yu et al.

366 (2015). A similar study has also done by You et al. (2013); You et al. (2011), Zhai and Pan, (2003).

367 DTR is increasing in the southern and western part of Bangladesh for the SU, and southern part met the

368 decreasing tendency, south and southeastern part demonstrating the decreasing trend for TN10, TX10

369 met the decreasing trend in the south and northern part. TN90 show the increasing trend in the north and

370 southern part of Bangladesh, south and western region met increasing trend for TX90. Approximately

371 69% of the northern, western and southern parts of Bangladesh met increasing tendency of TNN, -1.14

372 to 1.50 was the change rate of TNX and different parts of the country were faced decreasing. A rising

373 trend, southern part experiences the decreasing trend for TXN and TXX analyzed by spatial distribution

374 in this current research work. Similar research work is also done by Zhou et al. (2020) where they found

375 that the warm and cold indices are facing increasing and decreasing pattern in different parts of the study

376 area. Li et al. (2020) found that TNN and TXX spatially varied, which agrees with the present study's

377 outcomes. Some studies performed in North-Eastern regions of India are in good agreement with our

378 finding (Jhajharia et al. 2014). Dabral et al. (2016) indicated that minimum temperature is rising in the

379 north-eastern part of India which is quite dissimilar to this finding. Results indicate that the frequency

380 and intensity of warm night is enhancing in the North-Eastern region of India (Jhajharia and Singh 2011;

381 Dabral et al. 2016), similar to our study.

382 Yu and Li (2014) investigated the spatial distribution of temperature indices in line with the current

383 study's findings. The almost same study conducted by Zhao and Chen (2021), You et al. (2011), Nie et

384 al. (2012). The present study assessed the principal factor, which was DTR, and it also influences the

385 variation of annual temperature, and its total variance was 22.40%. This outcome is consistent with Yu

386 and Li 2014 where they found that SU25 is the principal factor of yearly temperature change. You et al.

387 2011 also explored similar findings. By using the probability distribution function, it discovered that

388 warm indices are shifted positively. Cold indices are moved negatively, which further indicated that the

389 warm indices are following an increasing trend while cold indices are decreasing trend and the density

390 peak was different for each temperature extremes. The variations were most remarkable in the recent

391 decades in this research study. This result is almost similar to Yu and Li (2014). Liu et al. (2021) found

392 that the temperature extremes varied differently in different regions while the significant variations were

393 in recent decades, consistent with the present study. The outcome of Fu and Ding (2021) is in line with

394 the current research.

395 In this study, we have analyzed the change point of temperature extremes where we found that the

396 change point of warm and cold indices was last of the twentieth and beginning of the twenty-one

397 century. Zhou et al. (2020) investigated that the mutation point for warm indices was beginning in the

398 twenty-first century, which is in good agreement with the present research work. Liu et al. (2021)

399 explored the change point of temperature extremes. By contrast, the daily maximum temperature altered

400 quicker than the daily minimum temperature. The main reason is the probable urbanization impact on

401 the extreme temperature indices (Zhou and Ren, 2011). The urbanization impact may be aggravated by

402 extreme temperature trends associated with daily maximum temperature in Bangladesh. However, the

403 rapid urbanization impacts of extreme temperature indices related to daily minimum temperatures were

404 generally trivial (Duan et al., 2012).

405 Therefore, the increasing pattern of warm indices and decreasing cold indices have already influenced

406 vegetation succession, soil and farm production over Bangladesh. There will be more intense

407 consequences and uprising extreme weather occurrences and temperature forecasted in the coming days.

408 The achieved outcomes have scientific and practical implications, which assist policy-makers in

409 developing suitable measures to safeguard vegetation change and lessen the detrimental impacts

410 triggered by extreme climatic phenomena. Our study aims to understand extreme climatic phenomena in

411 Bangladesh. Environmental factors such as soil moisture content, potential evapotranspiration, pan

412   evaporation and land use/land cover changes should be considered in future studies. The extreme

413   temperature influences vegetation dynamics in future based on CMIP6 datasets in Bangladesh deserves

414   further investigation.

415   **5. Conclusion**

416   This paper aims to detect temporal and spatial trends of extreme temperatures in Bangladesh in the past

417   37 years (1980–2017) using multi-statistical modeling approaches. The results show that warm

418   temperature indices in Bangladesh were increasing in the last four decades except for the warmest days

419   (TXX), especially before the 2000s, while cold temperature indices showed a decreasing trend after

420   2000. DTR and SU showed an upward trend in the country, indicating that the rising rate of daily

421   maximum temperature in the past four decades was more than that of daily minimum temperature. This

422   confirms that Bangladesh is uninterruptedly developing towards a warmer trend, which is a negative

423   response to global climate warming. Spatially, the change rate of warm indices was the largest in the

424   northwest region and the smallest in the eastern part. Besides, the change speed of DTR at each station

425   was less than that of other indices, whose change tendency rate was the smallest in the central region

426   and the decrease speed was more prominent in the northern part. The outcomes of DFA showed a long-

427   range association among extreme temperature indices, implying that warm and cold indices will

428   continue their present trend in the upcoming years, except for cold days will not sustain their current

429   trend in the future. By using the probability distribution functions, the variations of the curves are more

430   evident in recent decades than in the past three decades. Based on factor analysis, the warm night

431   primarily controls the general warming trend of temperature extremes over Bangladesh from 1980 to

432   2017. Mutation analysis revealed that the mutation points of the warm index were before cold index and

433   other indices, indicating that warm indices were more sensitive to global climate warming than cold

434   indices. The increase in the warm indices and the decrease in the cold indices have eventually impacted

agricultural crop production, soil fertility and vegetation dynamics in northwest Bangladesh. Rising temperature and the increase in extreme climatic phenomena forecasted in the future will have a more intense impact on sustainable development. Thus, to confirm the country's sustainable development, governments at all levels should systematically take adequate countermeasures based on climate change characteristics and constantly develop their capacity to cope with extreme climatic phenomena.

Ethical approval

Not applicable

Consent to Participate

Not applicable

Consent to Publish

Not applicable

Data availability

Data are available upon request on the corresponding author

Author contributions

A.R.M.T.I., J.M., and H.M.T.I., B.G., designed, planned, conceptualized, drafted the original manuscript, and H.M.T.I, and Y.R., were involved in statistical analysis, interpretation; H.M.T.I., Y.R., and J.M., contributed instrumental setup, data analysis, validation; Z.H., and S.A.B., contributed to editing the manuscript, literature review, proofreading; B.G., J.M., Z.H., and A.R.M. T.I., were involved in software, mapping, and proofreading during the manuscript drafting stage.

Conflict of interest

There is no conflict of interest to publish this work.

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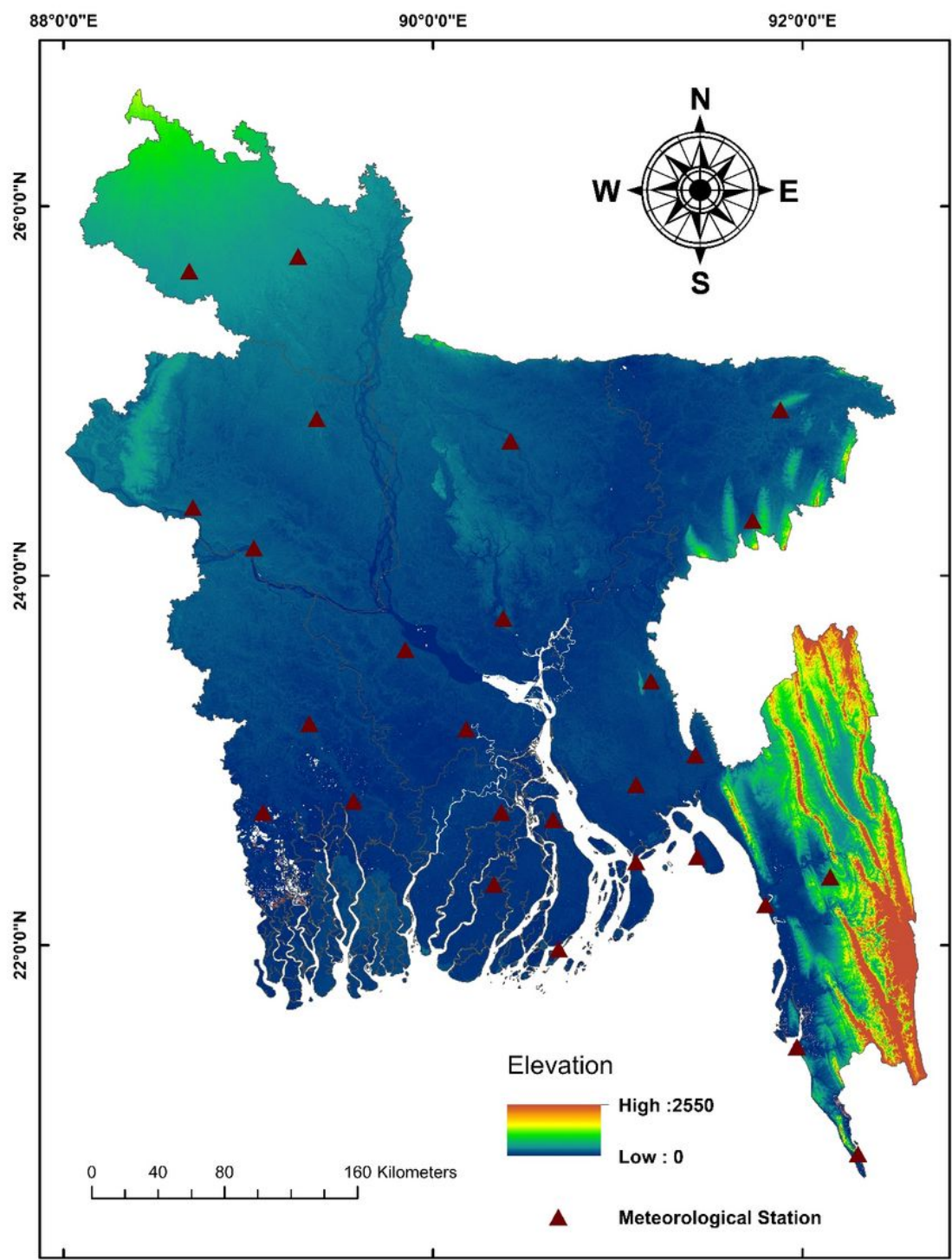684   1961–2008. Clim. Res. 50, 125–139.

685

Figures

Figure 1

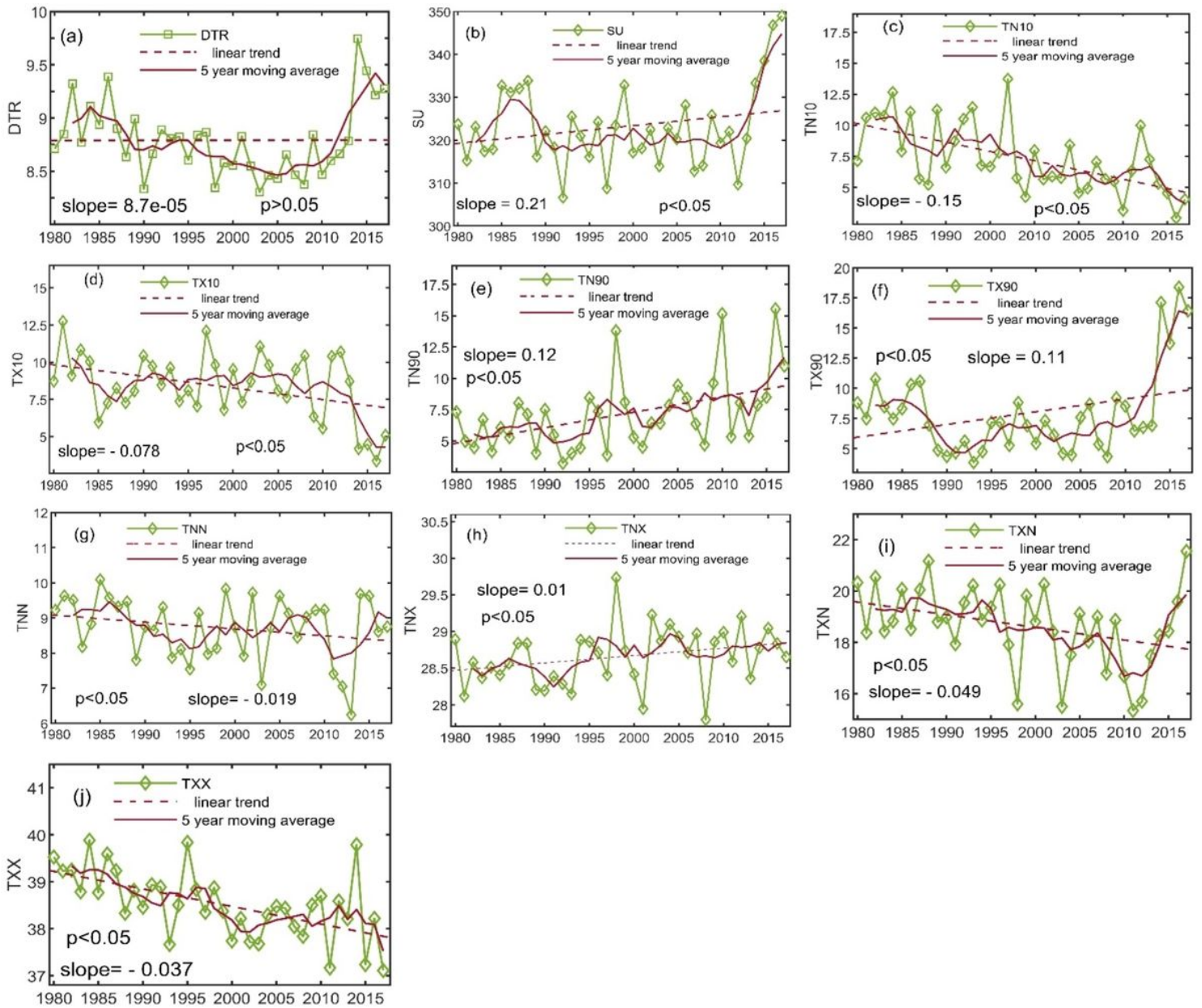Geographical location of the study area showing meteorological sites

Figure 2

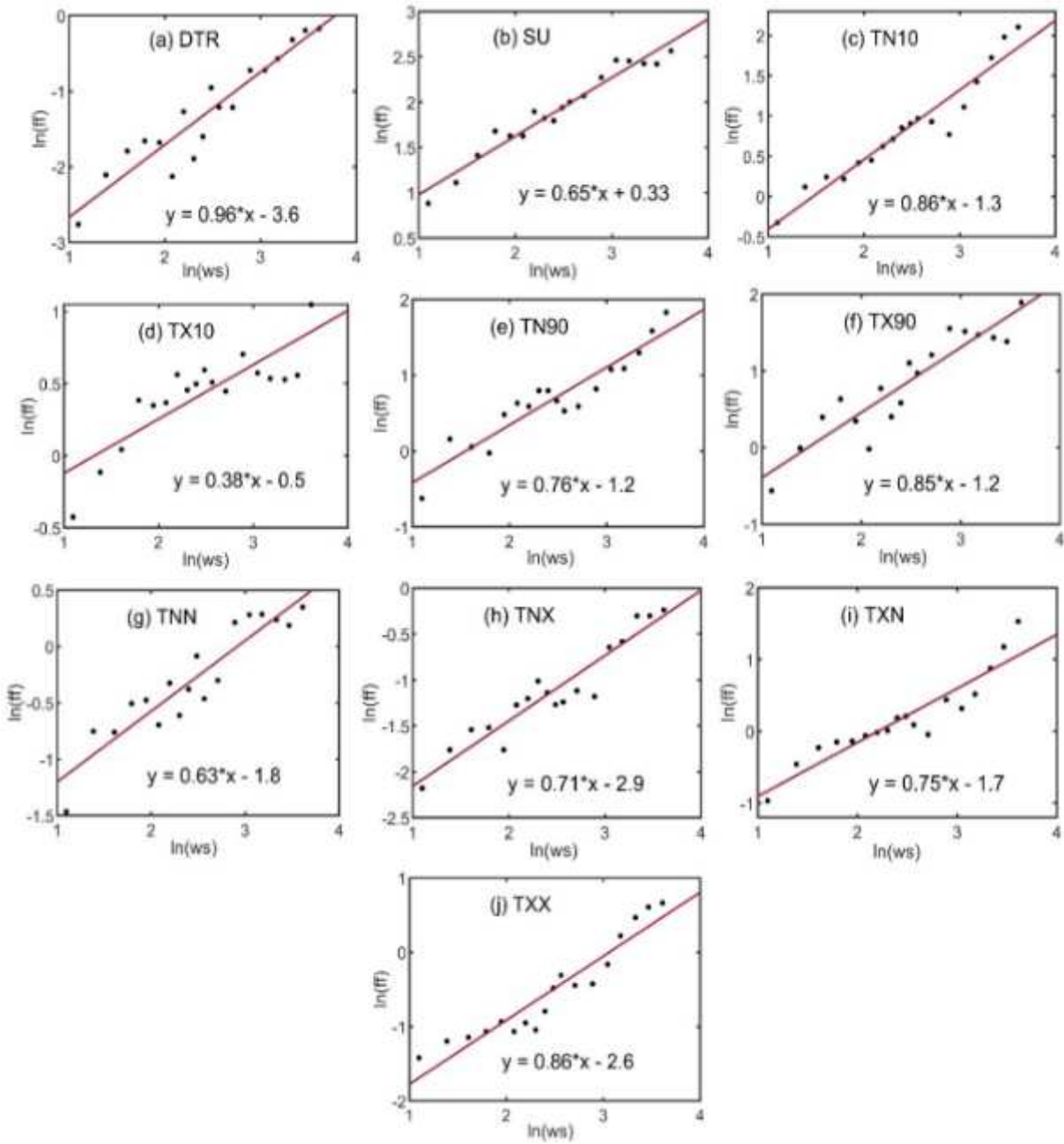Linear regression trends for 10 extreme temperature indices during 1980-2017 over Bangladesh

Figure 3

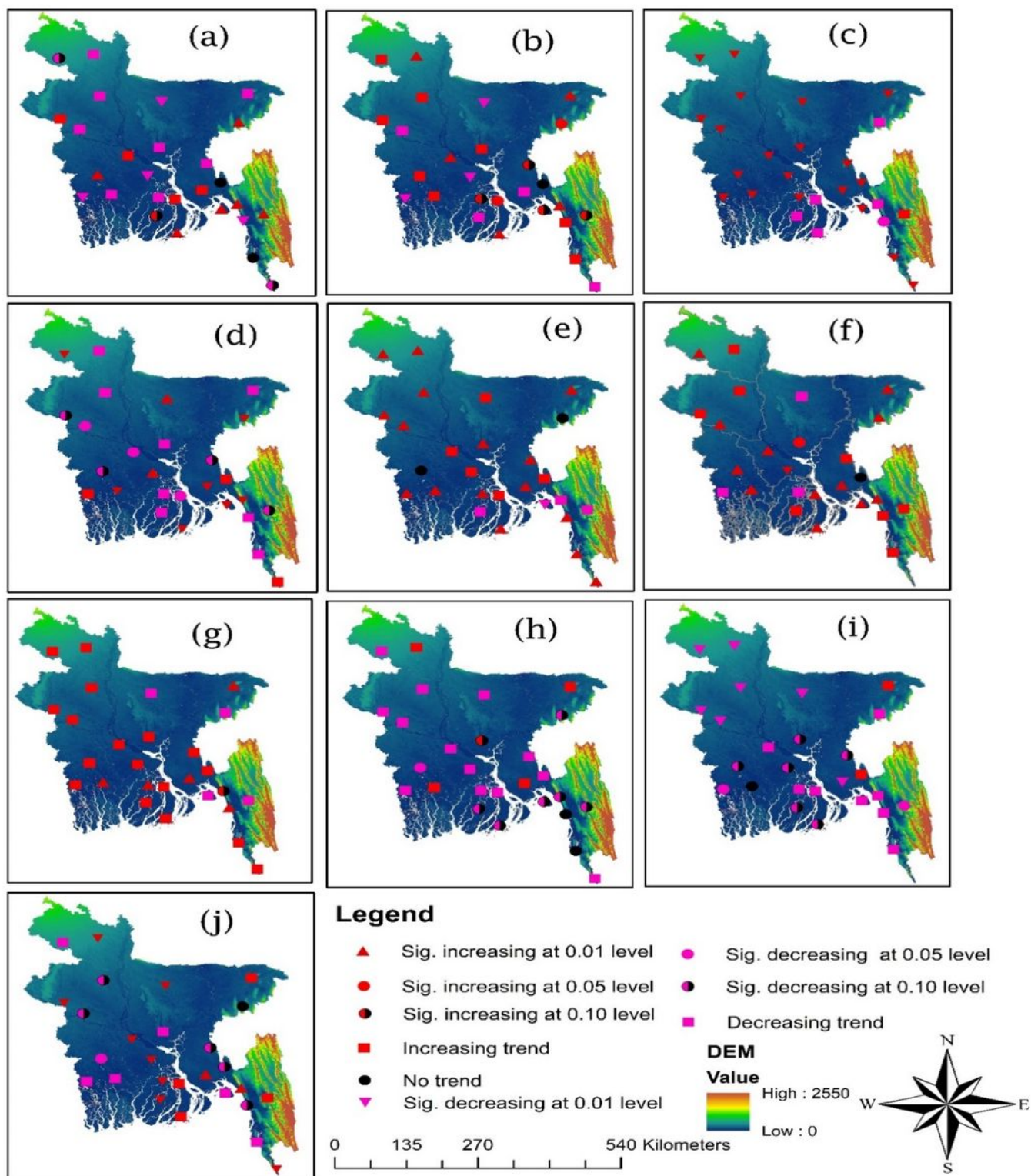DFA long-term relationships of extreme temperature indices in the forthcoming period across Bangladesh

Figure 4

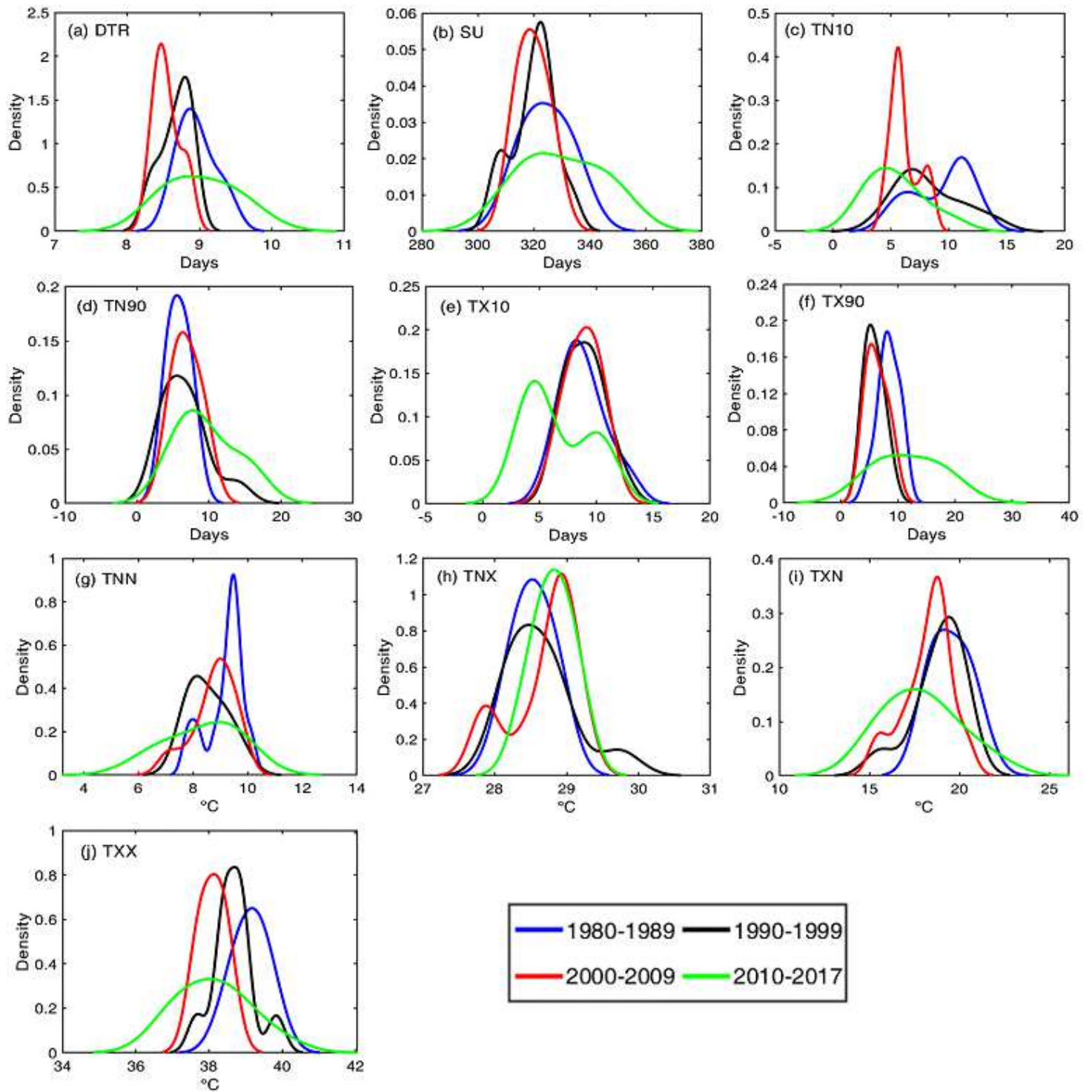Spatial distribution patterns of decadal trends in 10 temperature indices over Bangladesh during 1980 to 2017.

Figure 5

The probability distribution function (PDF) of extreme temperature indices in the last four decades in Bangladesh

Figure 6
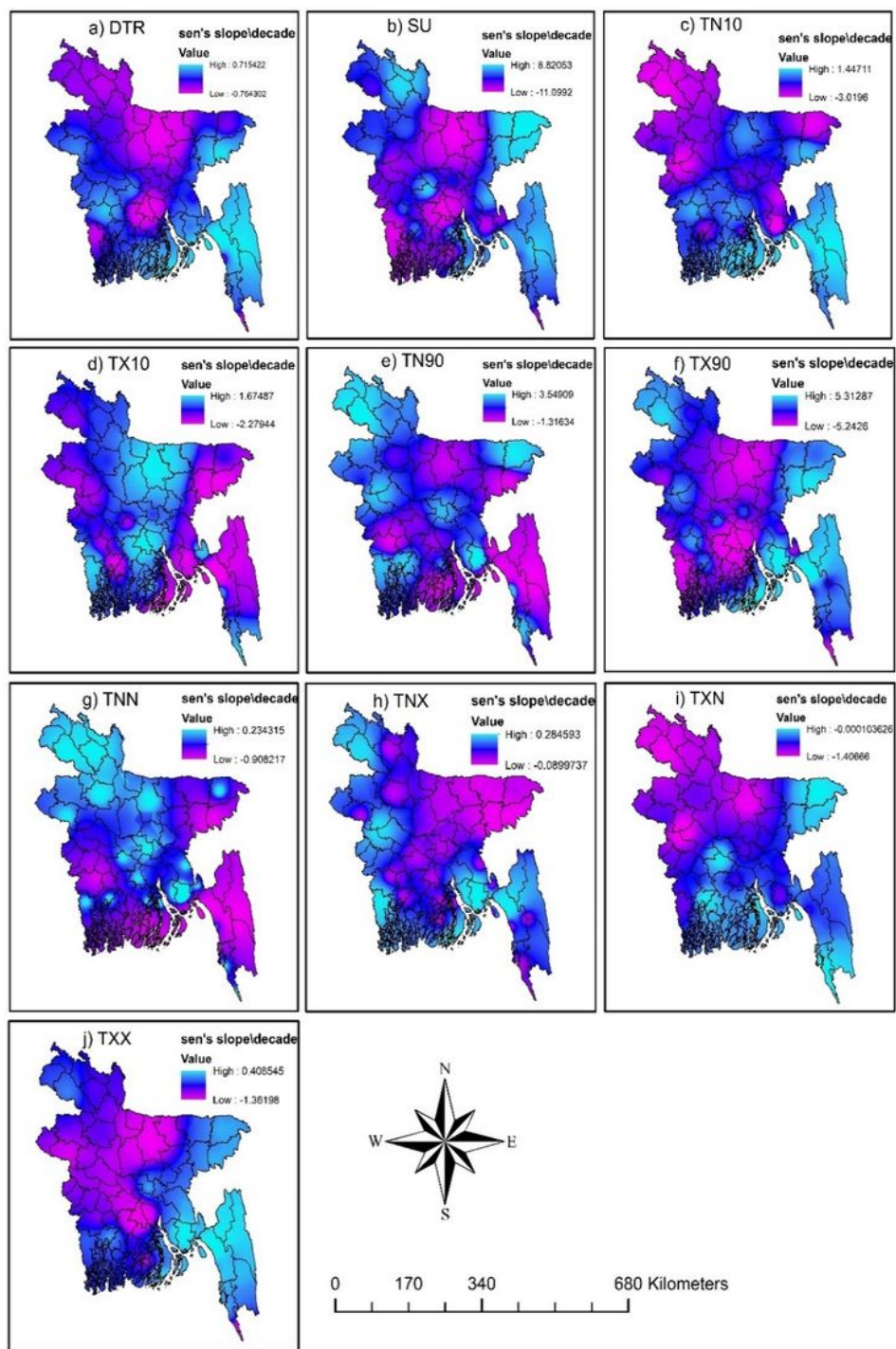
The rate of trend pattern of extreme temperature indices from 1980-2017 in Bangladesh