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Spatial and Temporal Analysis of Rainfall and Temperature Trends of Bangladesh during 1989 to 2019 and the Possible Impacts of Rainfall and Temperature Changes

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A B S T R A C T

This paper analyzed the temperature and rainfall data series of 35 meteorological stations distributed throughout Bangladesh over 30 years (1989 to 2019) to present the trend and time series analysis of these climatic variables. Also, the possible impacts of temperature and rainfall changes on different sectors are discussed here. Statistical methods like the Mann Kendall test and Sen's slope test were used to detect trend variation in temperature and rainfall patterns. Maps were generated using Geographical Information System (GIS) to visually represent the magnitude of change observed in the study. The result shows a change of mean temperature in Bangladesh with an upward trend (0.25 °C per decade) in the pre-monsoon season. The southern, south central and southeastern areas like, Patuakhali (0.47°C per decade), Sandwip (1.0°C per decade), Khepupara (0.73°C per decade), Syedpur (1.1°C per decade), Faridpur (0.8°C per decade), Teknaf (0.8°C per decade), Hatia (1.12°C per decade) and Chandpur (0.47°C per decade) are found to be prone to increase of maximum temperature in all seasons. The highest upward trend in minimum temperature is observed in the northwestern, northeastern, central and southern parts of Bangladesh like, Chittagong (0.65°C per decade), Barisal (0.4°C per decade), Srimangal (1.05°C per decade), Dhaka (0.54°C per decade) and Bogra (0.42°C per decade). Southern areas like Sandwip (34 mm/year) and Chittagong (24 mm/year) has faced maximum increase in rainfall amount in monsoon and pre monsoon seasons. Decrement of rainfall is mostly faced by central regions, like Madaripur (-17.55 mm/year) and Faridpur (-12.28 mm/year) throughout monsoon and winter seasons. But in post monsoon season, these two stations have faced an exceptionally higher increment of rainfall which is almost 32.75 mm/year and 32.38 mm/year respectively.

Keywords: *Spatial and Temporal Analysis, Rainfall, Temperature, Trend Analysis, Bangladesh*

1. Introduction

Climate change encompasses any alterations in the long-term patterns of climate, regardless of whether they arise from natural fluctuations or are caused by human activities (Solomon et al., 2007). Nowadays, the climate change and its detrimental impacts are among the primary concerns for humanity (Kuri, 2014). Climate change and variability imposes stress on both our societies and the environment (Isfat & Raihan, 2022). The warming of our planet has far-reaching effects on multiple aspects, including the weather system, hydrology, ecology, and environment. Precipitation and temperature are essential climatic factors that have a substantial influence on the hydrological processes of a watershed (Mfwango et al., 2022). Research indicates that positive shifts in temperature and rainfall have a notable but detrimental effect on rice production in Malaysia (Zhang et al., 2023). Declining trend of rainfall is found in Ghana, whereas the temperature is increasing. Both factors possess the capability to hinder the role of agriculture in reducing poverty, ensuring food security, supporting livelihoods, and fostering economically beneficial growth for the impoverished (Asare-Nuamah & Botchway, 2019). The standard time period for assessing these variables is typically 30 years, as defined by the World Meteorological Organization (WMO). According to the fifth Intergovernmental Panel on Climate Change (IPCC) report, noteworthy trends in temperature and precipitation have been observed globally, but with variations in magnitude across different regions (Intergovernmental Panel on Climate Change, 2014). Temperature increases are being observed worldwide; however, the warming pattern is not consistent across the entire globe (Jones & Moberg, 2003; Nick et al., 2009; Lorentzen, 2014). Additionally, in conjunction with global warming, substantial evidence supports the occurrence of changes in rainfall patterns at both global (Hulme et al., 1998) and regional levels (Yu & Neil, 1993; Rodriguez-Puebla et al., 1998)

Bangladesh is one of those countries that are the most vulnerable to extreme climate change due to its geographical location. (Siddique et al., 2022, Ali, 1999; Shahid, 2011; Islam & Nursey-Bray, 2017; Vij et al., 2018). Bangladesh is a delta island located on the coastline of the Bay of Bengal, known for its agriculture-based economy. As a result of its geographical location, the country experiences a range of climatic phenomena, which have a substantial impact on the environment of Bangladesh as a whole (Kuri, 2014). Bangladesh is one of the most flood-prone countries in the world due to its geographic position. Also, drought in the northwestern part of the country is a common phenomenon. The country experienced several extreme dry and wet periods in the past 50 years. Heavy rainfall in the monsoon of 2007, together with the onset of flooding by Himalayan-fed rivers, resulted in a severe flood in Bangladesh which affected more than 9 million people in more than half of the districts of the country.

The IPCC has emphasized the importance of obtaining more detailed information regarding climate change at regional and local levels, which is of particular interest to different nations and economic groups, as it allows for a better understanding of the impacts and implications specific to their respective regions (Intergovernmental Panel on Climate Change, 2014). Hence, it is crucial to have country-level data on climate variability and change in order to adapt to these changes and develop effective strategies to address associated challenges. Additionally, the spatial distribution of meteorological data is increasingly significant as it serves as input for spatially explicit models at the landscape, regional, and global levels (Li et al., 2006; Rahman et al., 2014). Spatial technologies, including geographic information system (GIS) and numerical modeling techniques, have emerged as highly effective tools for conducting ecological and environmental assessments. These technologies enable comprehensive analysis and evaluation of spatial data, facilitating a deeper understanding of ecological processes and environmental dynamics (Krivtsov, 2004; Rahman & Saha, 2007; Rahman & Saha, 2008; Rahman & Saha, 2009; Rahman et al., 2009; Rahman et al., 2014; Rahman et al., 2015).

While numerous studies worldwide have concentrated on climate change and researchers from various countries are actively seeking solutions to mitigate its adverse effects, Bangladesh has lagged behind in this area of research and development. However, a number of studies have been found on temperature variability in Bangladesh (Jones, 1995; Singh, 2001; Shahid, 2010; Shahid, 2011; Shahid et al., 2012; Guangqi Li, 2015), but most of them have primarily focused on the daily maximum and minimum temperature variables before the year 2008, often without taking into account all the available records from the meteorological stations. (Shahid, 2010b) and (Shahid et al., 2012) reported that over the past fifty years (1961 to 2008), there has been a significant increase in temperature. Notably, the winter season has experienced a more pronounced warming trend compared to the summer season. Furthermore, the diurnal temperature range during the winter and pre-monsoon periods in Bangladesh has decreased. Conversely, the temperature range has shown an increase during the monsoon season. On the other hand, (Shahid, 2009) and (Shahid, 2010a) concluded that based on the analysis of data spanning approximately 50 years prior to 2007, there has been a slight increase in precipitation. (Guangqi Li, 2015) also identified that in recent years, there has been a notable rise in the daily maximum temperature in southeastern Bangladesh, accompanied by a decline in both the daily minimum and mean temperatures. However, limited research has been conducted on rainfall trends and extremes, though a few studies highlighting the rainfall patterns across the country (Ahmed & Karmakar, 1993; Kripalani et al., 1996; Ahmed & Kim, 2003; M. N. Islam & Uyeda, 2008).

Thus, in this paper, spatial and temporal analysis of rainfall and temperature trends of Bangladesh during last thirty years (1989 to 2019). Additionally, this paper explores the possible consequences of temperature and rainfall changes on various sectors. The aim was to evaluate the extent of changes statistically and spatially based on historical data collected from 35 meteorological stations across the country. Specifically, the study examined changes in maximum and minimum temperatures, as well as changes in rainfall patterns during the pre-monsoon, monsoon, post-monsoon, and winter seasons.

2. Study area

In this study we try to analyze the spatio-temporal pattern of temperature and rainfall in Bangladesh using recent observed data. Bangladesh is a country of south-east Asia which covers an area of 147,570 square km, surrounded by India in three sides and Myanmar by one side. It extends from 20°34’N to 26°38’N latitude and from 88°01’E to 92°41’E longitude (Rashid H. E, 1991). The Indian States of West Bengal, Assam, Meghalaya and Tripura border Bangladesh in the west, north and east respectively. The southern part of this country is covered by Myanmar, along with Bay of Bengal. The total administrative length of the land border line is about 4,246 km. 93.9% of this is shared with India and about 6.1% with Myanmar. The country is adjacent in the south to the Bay of Bengal. Though Bangladesh is a small country, the length of the coastline is about 580 km, making it one of the largest coastlines of the world. The Bay of Bengal is well-known for its cyclones, which whip up its water, sending them crashing onto the coastal lines of the offshore lands, occasionally causing flash floods. Bangladesh is exposed to the largest mangrove forest of the world, Sundarban. Climate of Bangladesh is characterized by tropical monsoon climate. Bangladesh has four distinct seasons: the pre-monsoon hot season (summer) from March through May, rainy monsoon season which lasts from June through September, a sub-humid cool season (post monsoon) from October to November, and a cool dry winter season from December through February. However, March may also be considered as the spring season, and the period from mid-October through mid-November may be called the autumn. Mean annual temperature everywhere is about 25°C, whereas mean monthly temperatures range between 18°C in January and 30°C in April-May. Extreme temperature ranges between 40°C and 43°C, except near the coast where the range is narrower. The length of the winter with minimum temperatures below 15°C ranges between 35 and 40 days near the coast to over 100 days in the extreme northwest.

During the monsoon, the average rainfall varies from about 890 mm in the western districts of Rajshahi, Bogra, Kushtia and Jessore to more than 2,030 mm in the southeastern and northeastern parts of the country, with a maximum exceeding 5,000 mm in the extreme northeast at the Foot Hills of the Shillong Massif. The high rate of precipitation results in regularly occurring floods. Besides the summer rains known as the monsoon, the winter depressions originating from the Mediterranean and the so-called nor 'westers in April and May contribute to the annual precipitation. The Nor ‘wester-period shows a comparable trend with about 250 mm precipitation in the west and about 635 mm in the east. During the dry season from November to March, precipitation amounts to 50 mm, with the maximum in December.

3. Data and methods

Meteorological data including daily rainfall, maximum temperature and minimum temperature of the period of 1989-2019 were collected from Bangladesh Meteorological Department (BMD). 35 stations from 28 districts, which have meteorological facilities, of all over Bangladesh were considered for this study. During this study, missing data was a limitation. Some of the stations had missing meteorological data of several years, like Chattogram (2002-2004) data were missing due to airport station renovation works, as per the source of BMD. Besides, Mongla station did not have data of 1990 rainfall and temperature. Hatia station did not have complete data of 1990-1994 climate records. Ambagan station was founded in 1999 hence data before this time was not available. Syedpur station could not provide data of 1990. For Mann-Kendall test, these values were replaced by the average value of the same month but from the previous and subsequent years. Therefore, a shorter series of measurements were used during analysis. The non-parametric Mann–Kendall trend test was used to analyze the trends in climate. The Sen's slope method was used to estimate the magnitude of change. Confidence levels of 95% was set as thresholds for determining significant temperature and rainfall trends. The magnitude of change was plotted on maps using Geographical Information System (GIS) software.

3.1 Mann-Kendall test

The Mann-Kendall test is a non-parametric statistical test that is suitable for analyzing data that does not follow a normal distribution. It is also less affected by sudden changes or discontinuities in time series data, making it robust for analyzing inhomogeneous datasets. This test has gained significant recognition and endorsement from the World Meteorological Organization. It is widely recommended for public use and has been employed to assess trends in various types of data, including climatic, hydrological, and water resource data (Tabari et al., 2011; Jaiswal et al., 2015). In this test, each value in the series is sequentially compared with others. The Mann-Kendall statistics start with an initial value of zero, indicating no trend. The value of S is incremented by 1 when a data point from a later time period is higher than a data point from an earlier time period, and vice versa. The final value of S is determined by the net result of these increments, reflecting the overall trend in the data.

If x1, x2, x3…. xi represent n data points where xj represents the data point at time j, then S can be written as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign\ (x_j - x_k) \qquad (1)$$

Where, n is the total length of data, xj and xk are two generic sequential data values and function sign (x_j-x_k) assumes the following values:

sign (x_j-x_k) =1, if x_j-x_k > 0

= 0, if x_j-x_k = 0

= -1, if x_j-x_k < 0

The probability associated with S and the sample size, n, is then computed to statistically quantify the significance of the trend. Normalized test statistic Z (z-test) is performed as follows:

$$Z = \frac{s-1}{\sqrt{var\ (s)}}\ ;\ if\ s > 0 \quad (2)$$

$$Z = \frac{s+1}{\sqrt{var\ (s)}}\ ;\ if\ s < 0 \quad (3)$$

The null hypothesis of no trend is rejected if |Z|>2.575, |Z|>1.96, and |Z|>1.465 at the 99%, 95%, and 90% significance level, respectively. Value of the Mann Kendall statistics is assumed to be zero, indicating no trend. Here, S For example, the trend is rising if Z > 1.465, falling if Z < -1.465 and no trend if -1.465 < Z < 1.465 at 90% significance level (Hafijur Rahaman Khan et al., 2019).

3.2 Sen's slope method

The Sen's slope method is considered superior to linear regression because it involves calculating slopes for every pair of ordinal time points and then utilizing the median of these slopes as an estimate of the overall slope (Shahid et al., 2012). If there is a linear trend within a time series, an accurate estimation of the true slope, representing the change per unit time, can be obtained through a straightforward nonparametric procedure (Sen, 1968). This means that in the case of continuous monotonic increasing and a decreasing function of time, f(t) is defined as:

$$F(t) = Q_t + B \qquad (4)$$

Where Q is the slope and B is a constant.

To get the slope, Q in the equation, first the slopes of all data pairs are calculated by,

$$Q' = \frac{(X_{t'} - X_t)}{(t' - t)} \qquad (5)$$

Where,

Q' = Slope between the points of $x_{t'}$ and x_t

$x_{t'}$ = Data measurement time at t0

x_t = Data measurement time at t

Sen's estimator of the slope is simply given by the median slope,

$Q = Q'_{(N+1)/2}$; if N is odd

$= \{Q'_{(N+1)/2} + Q'_{(N+2)/2}\}/2$; if N is even

Where the number of calculated slopes is N. A 100(1-α) % two-sided confidence interval about the slope estimate is obtained by the nonparametric technique based on the normal distribution (Hafijur Rahaman Khan et al., 2019).

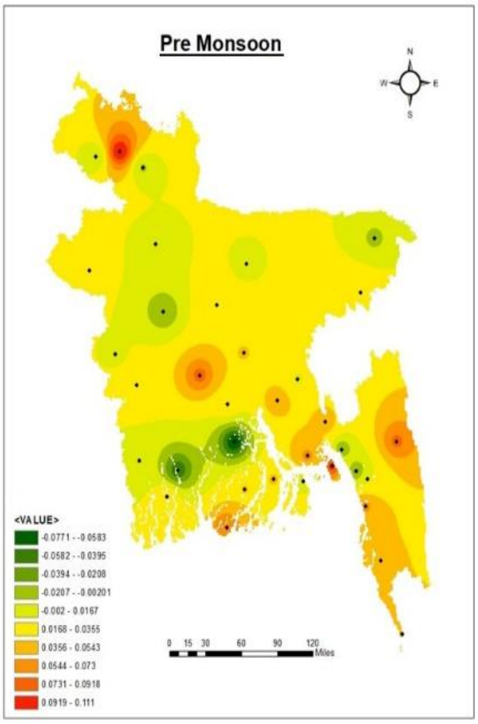
4. Results and discussion

4.1 Maximum Temperature

It's seen that in all seasons, maximum temperature of Chattogram, Cox's Bazar, Sylhet, Feni, Bhola, Satkhira, Khulna and Barisal station have a significant positive trend in 95% confidence limit. The rest of the stations have a non-significant trend (either positive or negative) in 95% confidence limit. The most substantial increase in maximum temperature during the monsoon is observed in Teknaf, with an increment of 0.08°C per year. M. Court experiences the highest decrement (-0.06°C per year). In the post-monsoon, Hatia sees the highest increment in maximum temperature (0.09°C per year), whereas Teknaf encounters the most significant decrement (-0.05°C per year). Syedpur records the highest increment in maximum temperature during the pre-monsoon, with an increase of 0.11°C per year, while Barisal faces the greatest decrement (-0.07°C per year). In the winter, Rangamati witnesses the highest increment in maximum temperature (0.042°C per year), while Khepupara experiences the most substantial decrement (-0.09°C per year). The relationship of monotonic trend with time (measured by Kendall's tau value) is presented in Table 1.

The maps of Bangladesh during pre-monsoon (Fig-1a), monsoon (Fig-1b), post monsoon (Fig-2a) and winter (Fig-2b) depict how much maximum temperature is changing with time during 1989 to 2019 (measured by Sen's slope test).

a



b

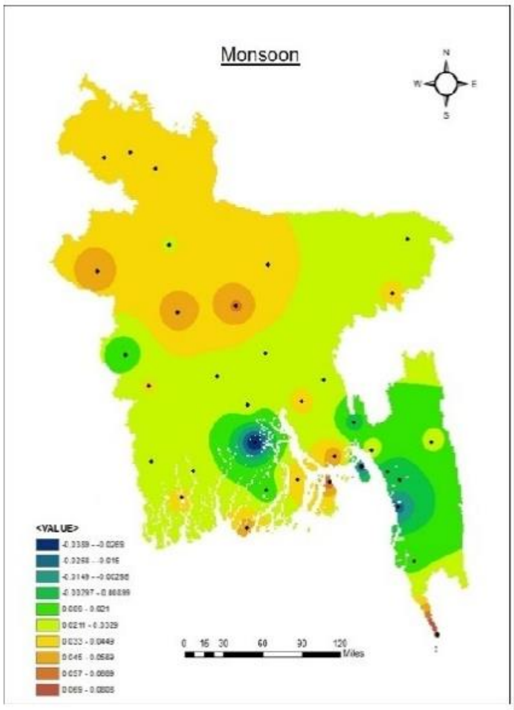


Fig. 1 Sen's Slope Test Result of Maximum Temperature in (a) Pre-Monsoon, and (b) Monsoon.

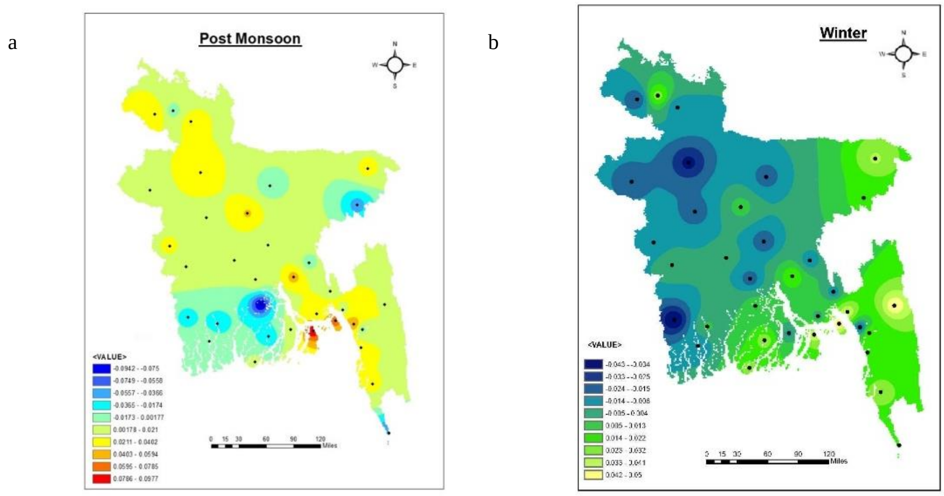


Fig. 2 Sen's Slope Test Result of Maximum Temperature in (a) Post-Monsoon, and (b) Winter.

Table 1 - Kendall Tau value of Maximum Temperature during Pre-Monsoon, Monsoon, Post Monsoon and Winter in 35 stations of Bangladesh.

1. Station	2. Location		3. Season			
	4. Y	5. X	6. Pre-Monsoon	7. Monsoon	8. Post Monsoon	9. Winter
10. Ambagan	11. 22.471826	12. 91.773848	13. 0.105	14. 0.554	15. 0.0158	16. -0.132
17. Barisal	18. 22.7776	19. 90.291373	20. 0.214	21. 0.5	22. 0.26	23. 0.0733
24. Bhola	25. 22.387368	26. 90.767265	27. 0.143	28. 0.33	29. 0.157	30. -0.0963
31. Bogra	32. 24.837808	33. 89.34208	34. -0.00894	35. 0.496	36. 0.136	37. -0.273
38. Chandpur	39. 23.205902	40. 90.814854	41. 0.398	42. 0.601	43. 0.519	44. 0.204
45. Chattogram	46. 22.390107	47. 91.906959	48. 0.184	49. -0.0429	50. -0.0376	51. 0.136
52. Chuadanga	53. 23.692076	54. 88.847332	55. -0.113	56. 0.32	57. 0.023	58. -0.0622
59. Comilla	60. 23.43295	61. 91.063103	62. 0.124	63. 0.39	64. 0.0197	65. -0.116
66. Cox's Bazar	67. 21.541278	68. 92.069615	69. 0.378	70. 0.425	71. 0.27	72. 0.273
73. Dhaka	74. 23.705095	75. 90.409694	76. -0.0285	77. 0.345	78. 0.0179	79. -0.134
80. Dinajpur	81. 25.749187	82. 88.612977	83. -0.123	84. 0.641	85. 0.425	86. -0.157
87. Faridpur	88. 23.470741	89. 89.875887	90. 0.0714	91. 0.643	92. 0.377	93. -0.0233
94. Feni	95. 22.983232	96. 91.398607	97. 0.268	98. 0.349	99. 0.136	100. -0.118
101. Hatia (Noakhali)	102. 22.3667	103. 91.125	104. 0.402	105. 0.426	106. 0.538	107. 0.293
108. Ishurdi	109. 24.134745	110. 89.433218	111. -0.111	112. 0.505	113. 0.227	114. -0.155
115. Jessore	116. 23.366583	117. 89.107725	118. 0.0749	119. 0.631	120. 0.318	121. 0.0143
122. Khepupara	123. 21.888561	124. 90.206378	125. 0.458	126. 0.539	127. 0.343	128. 0.289
129. Khulna	130. 22.205029	131. 89.473504	132. 0.0679	133. 0.419	134. 0.171	135. -0.138
136. Kutubdia	137. 22.110148	138. 91.883303	139. 0.346	140. 0.588	141. 0.357	142. 0.224
143. Madaripur	144. 23.171288	145. 90.214399	146. -0.0357	147. 0.252	148. 0.007	149. -0.152
150. Mcourt	151. 22.633629	152. 91.178983	153. 0.439	154. 0.684	155. 0.254	156. -0.00714
157. Mongla	158. 22.4833	159. 89.6083	160. 0.337	161. 0.373	162. 0.308	163. 0.0762
164. Mymensingh	165. 24.633579	166. 90.443658	167. -0.0518	168. 0.508	169. 0.145	170. -0.157
171. Patuakhali	172. 22.285931	173. 90.42053	174. 0.477	175. 0.59	176. 0.365	177. 0.304
178. Rajshahi	179. 24.564395	180. 88.534859	181. -0.0446	182. 0.574	183. 0.267	184. -0.132
185. Rangamati	186. 22.783357	187. 92.262351	188. 0.266	189. 0.463	190. 0.32	191. 0.35
192. Rangpur	193. 25.632009	194. 89.185843	195. -0.113	196. 0.53	197. 0.377	198. -0.0963
199. Sandwip	200. 22.524174	201. 91.478795	202. 0.563	203. 0.603	204. 0.567	205. 0.435
206. Satkhira	207. 22.577725	208. 89.139713	209. -0.182	210. 0.145	211. -0.273	212. -0.298
213. Sitakund	214. 22.695495	215. 91.597768	216. 0.484	217. 0.654	218. 0.362	219. 0.346
220. Srimangal	221. 24.331672	222. 91.827195	223. 0.118	224. 0.496	225. 0.375	226. 0.196
227. Syedpur	228. 25.802179	229. 88.904813	230. 0.037	231. 0.644	232. 0.392	233. 0.177

234. Sylhet	235. 24.896318	236. 91.991093	237. 0.307	238. 0.603	239. 0.513	240. 0.29
241. Tangail	242. 24.199843	243. 90.084202	244. 0.21	245. 0.694	246. 0.446	247. 0.0787
248. Teknaf	249. 20.77765	250. 92.330642	251. 0.202	252. 0.343	253. 0.342	254. 0.184

4.2 Minimum Temperature

Temperature of Srimangal, Chattogram, Rajshahi, Sylhet, Satkhira, Khulna and Barisal station is found to have a significant positive trend in 95% confidence limit in all seasons. The rest of the stations have a non-significant trend (either positive or negative) in 95% confidence limit. Barisal experiences the most significant increase in minimum temperature during the monsoon, with an increment of 0.05°C per year. There is no decrease observed in the minimum temperature during the monsoon. Khulna sees the highest increase in minimum temperature during the post-monsoon, with an increment of 0.45°C per year, while Sandwip encounters the highest decrement (-0.08°C per year). Chattogram witnesses the highest increment in minimum temperature during the pre-monsoon (0.065°C per year), whereas Sitakund faces the most substantial decrement (-0.02°C per year). Khulna records the highest increment in minimum temperature during the winter, with an increment of 0.06°C per year, and Sandwip experiences the highest decrement (-0.08°C per year). The relationship of monotonic trend with time (measured by Kendall's tau value) is presented in Table 2.

The maps of Bangladesh during pre-monsoon (Fig-3a), monsoon (Fig-3b), post monsoon (Fig-4a) and winter (Fig-4b) depict how much minimum temperature is changing with time during 1989 to 2019 (measured by Sen's slope test).

a b

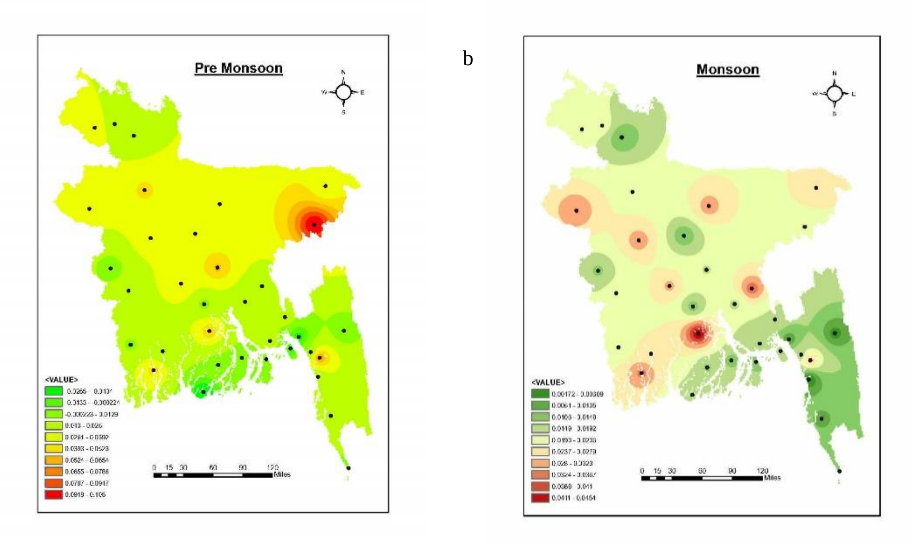


Fig. 3 Sen’s Slope Test Result of Minimum Temperature in (a) Pre-Monsoon, and (b) Monsoon.

a b

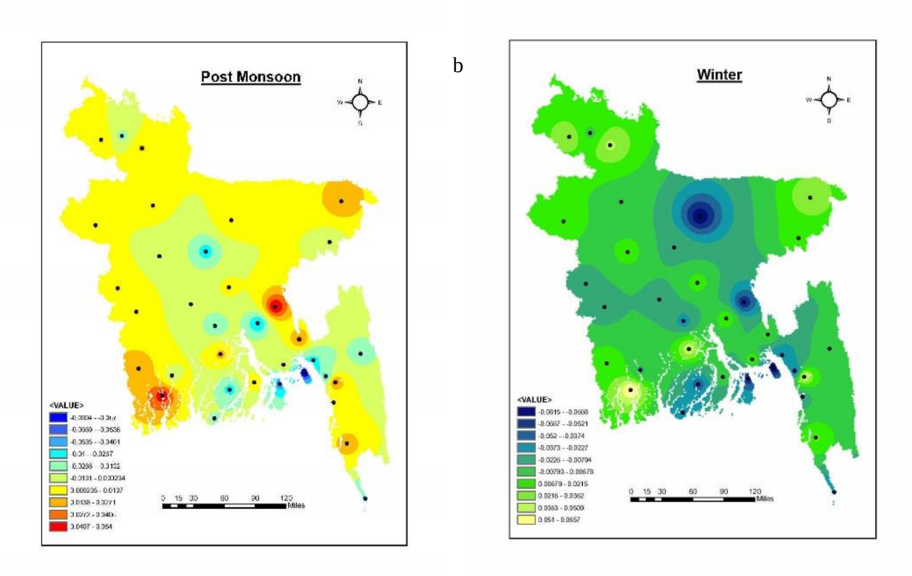


Fig. 4 Sen’s Slope Test Result of Minimum Temperature in (a) Post-Monsoon, and (b) Winter.

Table 2 - Kendall Tau value of Minimum Temperature during Pre-Monsoon, Monsoon, Post Monsoon and Winter in 35 stations of Bangladesh.

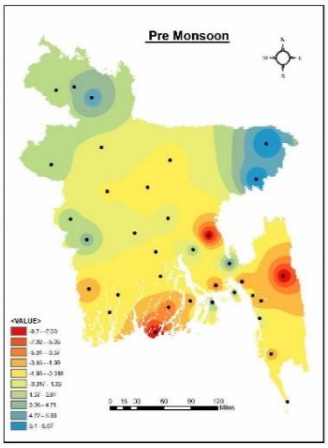
255. Station	256. Location		257. Season			
	258. Y	259. X	260. Pre-Monsoon	261. Monsoon	262. Post Monsoon	263. Winter
264. Ambagan	265. 22.471826	266. 91.773848	267. 0.0851	268. 0.426	269. -0.266	270. -0.34
271. Barisal	272. 22.7776	273. 90.291373	274. 0.278	275. 0.578	276. 0.122	277. 0.31
278. Bhola	279. 22.387368	280. 90.767265	281. 0.0222	282. 0.34	283. 0.126	284. 0.037
285. Bogra	286. 24.837808	287. 89.34208	288. 0.431	289. 0.322	290. 0.0416	291. -0.0149
292. Chandpur	293. 23.205902	294. 90.814854	295. 0.175	296. 0.41	297. -0.101	298. 0.122
299. Chattogram	300. 22.390107	301. 91.906959	302. 0.317	303. 0.409	304. 0.218	305. 0.342
306. Chuadanga	307. 23.692076	308. 88.847332	309. 0.0842	310. 0.371	311. 0.0743	312. -0.158
313. Comilla	314. 23.43295	315. 91.063103	316. 0.119	317. 0.624	318. 0.388	319. -0.256
320. Cox’s Bazar	321. 21.541278	322. 92.069615	323. 0.242	324. 0.238	325. 0.215	326. 0.222
327. Dhaka	328. 23.705095	329. 90.409694	330. 0.337	331. 0.297	332. 0.0396	333. 0.119
334. Dinajpur	335. 25.749187	336. 88.612977	337. 0.421	338. 0.455	339. 0.0891	340. 0.16
341. Faridpur	342. 23.470741	343. 89.875887	344. 0.287	345. 0.54	346. -0.0941	347. -0.163
348. Feni	349. 22.983232	350. 91.398607	351. 0.15	352. 0.405	353. 0.249	354. 0.109
355. Hatia (Noakhali)	356. 22.3667	357. 91.125	358. 0.00725	359. 0.142	360. -0.247	361. -0.323
362. Ishurdi	363. 24.134745	364. 89.433218	365. 0.222	366. 0.581	367. -0.0739	368. 0.0736
369. Jessore	370. 23.366583	371. 89.107725	372. 0.158	373. 0.356	374. 0.0743	375. -0.158
376. Khepupara	377. 21.888561	378. 90.206378	379. -0.188	380. 0.352	381. -0.167	382. -0.323
383. Khulna	384. 22.205029	385. 89.473504	386. 0.341	387. 0.496	388. 0.38	389. 0.441
390. Kutubdia	391. 22.110148	392. 91.883303	393. 0.243	394. 0.0471	395. 0.0792	396. -0.134
397. Madaripur	398. 23.171288	399. 90.214399	400. 0.114	401. 0.203	402. -0.208	403. -0.171
404. Mcourt	405. 22.633629	406. 91.178983	407. 0.182	408. 0.333	409. 0.0074	410. 0.118
411. Mongla	412. 22.4833	413. 89.6083	414. 0.0899	415. 0.37	416. -0.0584	417. -0.0837
418. Mymensingh	419. 24.633579	420. 90.443658	421. 0.2	422. 0.652	423. 0.106	424. -0.257
425. Patuakhali	426. 22.285931	427. 90.42053	428. 0.0792	429. 0.327	430. -0.287	431. -0.417
432. Rajshahi	433. 24.564395	434. 88.534859	435. 0.246	436. 0.626	437. 0.0138	438. 0.212
439. Rangamati	440. 22.783357	441. 92.262351	442. 0.0222	443. 0.143	444. -0.116	445. 0.0691
446. Rangpur	447. 25.632009	448. 89.185843	449. 0.214	450. 0.257	451. 0.0792	452. 0.292
453. Sandwip	454. 22.524174	455. 91.478795	456. -0.0659	457. 0.106	458. -0.399	459. -0.39
460. Satkhira	461. 22.577725	462. 89.139713	463. 0.0856	464. 0.361	465. 0.217	466. 0.101
467. Sitakund	468. 22.695495	469. 91.597768	470. -0.0693	471. 0.208	472. -0.332	473. -0.302
474. Srimangal	475. 24.331672	476. 91.827195	477. 0.443	478. 0.475	479. -0.0395	480. 0.158
481. Syedpur	482. 25.802179	483. 88.904813	484. 0.255	485. 0.431	486. -0.122	487. 0.101
488. Sylhet	489. 24.896318	490. 91.991093	491. 0.297	492. 0.584	493. 0.18	494. 0.234
495. Tangail	496. 24.199843	497. 90.084202	498. 0.297	499. 0.342	500. -0.213	501. -0.178
502. Teknaf	503. 20.77765	504. 92.330642	505. 0.0891	506. 0.337	507. -0.277	508. -0.311

4.3 Rainfall

It's found from the study that, in all seasons, rainfall of Bhola, Cumilla and Satkhira station have a significant negative trend in 95% confidence limit. The rest of the stations have a non -significant trend (either positive or negative) in 95% confidence limit. Rainfall is scarce in the country during the winter. It is found that the amount of winter rainfall is decreasing in western and northeast climatic region regions (area of extremes) of Bangladesh. Faridpur experiences the most significant winter decrement, with a reduction of 12.28 mm per year. An unchanging winter rainfall was found for Feni (0 mm per year). Sandwip experiences the highest increase in monsoon rainfall, with an increment of 34mm per year. Conversely, Madaripur faces the most significant monsoon decrease, with a reduction of 17.55 mm per year. Madaripur also sees the largest post-monsoon increase (32.75 mm per year), while Sitakund encounters the most substantial post-monsoon decrement (-4.58 mm per year). Chattogram witnesses the largest pre-monsoon rainfall increment (24mm per year), whereas Khepupara in Noakhali encounters the highest pre-monsoon decrement (-8.70 mm per year). The relationship of monotonic trend with time (measured by Kendall's tau value) is presented in Table 3.

The maps of Bangladesh during pre-monsoon (Fig-5a), monsoon (Fig-5b), post monsoon (Fig-6a) and winter (Fig-6b) depict how much rainfall is changing with time during 1989 to 2019 (measured by Sen's slope test).

a



b

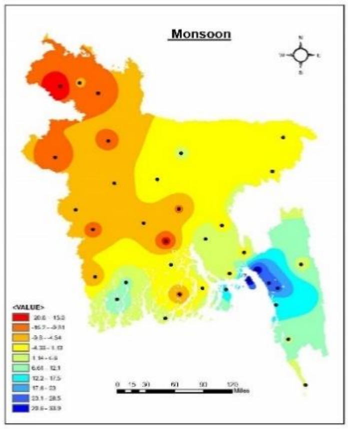
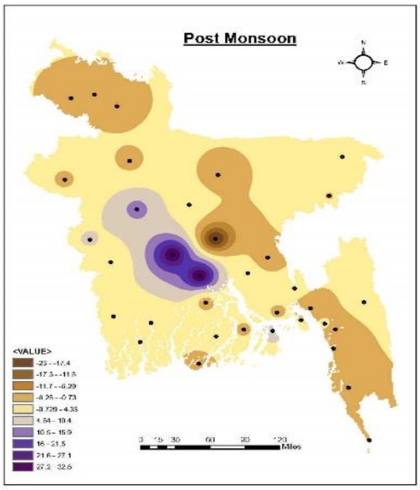


Fig. 5 Sen's Slope Test Result of Rainfall in (a) Pre-Monsoon, and (b) Monsoon.

a



b

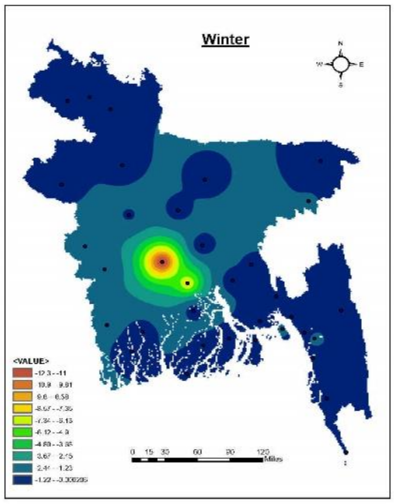


Fig. 6 Sen's Slope Test Result of Rainfall in (a) Post-Monsoon, and (b) Winter.

Table 3 - Kendall Tau value of Rainfall during Pre-Monsoon, Monsoon, Post Monsoon and Winter in 35 stations of Bangladesh.

509. Station	**510. Location**		**511. Season**			
	512. Y	**513. X**	**514. Pre-Monsoon**	**515. Monsoon**	**516. Post Monsoon**	**517. Winter**
518. Ambagan	519. 22.471826	520. 91.773848	521. -0.0947	522. 0.171	523. 0.0105	524. -0.112
525. Barisal	526. 22.7776	527. 90.291373	528. -0.0148	529. 0.0197	530. -0.0955	531. -0.176
532. Bhola	533. 22.387368	534. 90.767265	535. -0.0887	536. -0.0173	537. -0.0715	538. -0.251
539. Bogra	540. 24.837808	541. 89.34208	542. 0.0591	543. -0.259	544. -0.138	545. -0.193
546. Chandpur	547. 23.205902	548. 90.814854	549. 0.0739	550. 0.0985	551. 0.0296	552. -0.143
553. Chattogram	554. 22.390107	555. 91.906959	556. -0.0933	557. 0.193	558. -0.13	559. -0.305
560. Chuadanga	561. 23.692076	562. 88.847332	563. 0.0567	564. -0.0952	565. 0.16	566. -0.395
567. Comilla	568. 23.43295	569. 91.063103	570. -0.23	571. -0.0123	572. -0.119	573. -0.216
574. Cox's Bazar	575. 21.541278	576. 92.069615	577. -0.0476	578. 0.0739	579. -0.146	580. -0.154
581. Dhaka	582. 23.705095	583. 90.409694	584. 0.0148	585. -0.168	586. -0.207	587. -0.122
588. Dinajpur	589. 25.749187	590. 88.612977	591. 0.053	592. -0.394	593. -0.106	594. -0.122
595. Faridpur	596. 23.470741	597. 89.875887	598. -0.00247	599. -0.141	600. 0.36	601. -0.281
602. Feni	603. 22.983232	604. 91.398607	605. -0.136	606. -0.0271	607. 0.0185	608. -0.00495
609. Hatia (Noakhali)	610. 22.3667	611. 91.125	612. 0.113	613. 0.133	614. 0.236	615. -0.166

616. Ishurdi	617. 24.134745	618. 89.433218	619. -0.0419	620. -0.167	621. 0.217	622. -0.231
623. Jessore	624. 23.366583	625. 89.107725	626. 0.2	627. -0.185	628. -0.069	629. -0.0691
630. Khepupara	631. 21.888561	632. 90.206378	633. -0.261	634. 0.0788	635. -0.0856	636. -0.165
637. Khulna	638. 22.205029	639. 89.473504	640. -0.0419	641. 0.197	642. 0	643. -0.162
644. Kutubdia	645. 22.110148	646. 91.883303	647. 0.0148	648. 0.153	649. -0.0567	650. -0.204
651. Madaripur	652. 23.171288	653. 90.214399	654. -0.00988	655. -0.34	656. 0.374	657. -0.217
658. Mcourt	659. 22.633629	660. 91.178983	661. -0.0788	662. -0.0246	663. -0.0542	664. -0.218
665. Mongla	666. 22.4833	667. 89.6083	668. -0.0927	669. 0.145	670. 0.0313	671. -0.166
672. Mymensingh	673. 24.633579	674. 90.443658	675. -0.0321	676. 0.0296	677. -0.123	678. -0.21
679. Patuakhali	680. 22.285931	681. 90.42053	682. -0.197	683. -0.195	684. -0.0874	685. -0.267
686. Rajshahi	687. 24.564395	688. 88.534859	689. 0.168	690. -0.315	691. -0.0739	692. -0.179
693. Rangamati	694. 22.783357	695. 92.262351	696. -0.187	697. 0.0591	698. 0.0821	699. -0.276
700. Rangpur	701. 25.632009	702. 89.185843	703. 0.258	704. -0.197	705. -0.183	706. -0.318
707. Sandwip	708. 22.524174	709. 91.478795	710. 0.037	711. 0.339	712. -0.0142	713. -0.298
714. Satkhira	715. 22.577725	716. 89.139713	717. -0.158	718. -0.133	719. -0.0106	720. -0.155
721. Sitakund	722. 22.695495	723. 91.597768	724. -0.113	725. 0.271	726. -0.18	727. -0.253
728. Srimangal	729. 24.331672	730. 91.827195	731. 0.151	732. -0.0222	733. -0.037	734. -0.144
735. Syedpur	736. 25.802179	737. 88.904813	738. 0.153	739. -0.225	740. -0.0865	741. -0.372
742. Sylhet	743. 24.896318	744. 91.991093	745. 0.128	746. -0.0271	747. 0.0874	748. -0.132
749. Tangail	750. 24.199843	751. 90.084202	752. -0.117	753. -0.00795	754. 0.136	755. -0.227
756. Teknaf	757. 20.77765	758. 92.330642	759. -0.0321	760. 0.00985	761. -0.069	762. -0.00926

4.4 Possible impacts of temperature and rainfall change

Bangladesh, a low-lying deltaic nation in South Asia, is highly vulnerable to the effects of climate change. From the study, it's indicated that the urban areas of Bangladesh are already facing increasing daily temperatures and decreasing of rainfall. Also, some areas are found with increased rainfall. The impacts of these climatic changes will certainly be diverse. According to an IPCC estimation, climate change and its impacts could cause Bangladesh to lose 17% of its land and 30% of its food production by 2050 (Solomon et al., 2007)

Extreme heatwaves may become more frequent, exposing vulnerable communities to health risks and potential crop failure. The changing climate may pose substantial risks to agriculture, the backbone of Bangladesh's economy. Unpredictable rainfall patterns, prolonged dry spells, and increased temperature fluctuations can disrupt planting and harvesting cycles, affecting crop yield and productivity. Farmers may face difficulties in choosing suitable crop varieties and face the challenge of water scarcity during the dry season. The monsoon plays a crucial role in replenishing Bangladesh's water resources. However, erratic rainfall patterns and intense downpours will lead to both drought and floods, disrupting water availability and management. Observations have shown that there is a surge in the demand for water in urban regions of Bangladesh during the pre-monsoon season, primarily due to an uptick in domestic consumption. The elevated temperatures resulting from climate change may lead to a significant rise in water demand, placing more pressure on urban water supply systems that are already under stress (Shahid et al., 2015). The scarcity of clean water during dry spells will increase the risk of waterborne diseases, while floods will inundate low-lying regions, causing displacement and destruction of infrastructure. Also, landslides in Chattogram; which is ated in the southeast hilly area, may potentially surge as a consequence of rising extreme rainfall. Therefore, the amplified occurrence of heavy rainfall events, driven by climate change, might lead to more frequent floods and result in the loss of lives and property in Bangladesh (Shahid et al., 2015). Climate change impacts biodiversity and ecosystems in Bangladesh. Rising sea levels and salinity intrusion threaten the Sundarbans, the world's largest mangrove forest and a UNESCO World Heritage site, endangering unique flora and fauna. Migration patterns of various animal species may also disrupt, leading to changes in predator-prey relationships. Climate change endangers human health, and the occurrence of rare diseases has been on the rise in Bangladesh (Malekela & Lusiru, 2022). The frequency and intensity of heatwaves are associated with heat-related illnesses and deaths, particularly among vulnerable populations. (Hashizume et al., 2008) reported an increase in rotavirus diarrhea in Dhaka by 40.2 % for each 1°C increase in temperature above 29°C. Moreover, inconsistent rainfall patterns can contribute to the spread of waterborne diseases, such as cholera and diarrhea, during the monsoon season. Studies have revealed that both the maximum and minimum temperatures play a crucial role in the transmission cycles of dengue disease (Hossain et al., 2023). (Banu et al., 2014) stated that a temperature increase of 3.3°C without any adaptation measure and changes in socioeconomic condition will cause an increase of 16,030 dengue cases in Dhaka. Conversely, dengue cases have shown a decrease with higher levels of rainfall (Hossain et al., 2023). Bangladesh's coastline is highly susceptible to the impacts of climate change, with rising sea levels and increased frequency of cyclones posing significant threats to coastal communities. Coastal erosion and saltwater intrusion into agricultural lands and freshwater sources may lead to loss of livelihoods and food insecurity.

From the discussion, it is found that, the impact of temperature and rainfall change in Bangladesh may be evident across various sectors, affecting agriculture, water resources, biodiversity, public health, and coastal areas. Increased rainfall can trigger floods and wreak havoc on water management systems, while reduced rainfall as well as increased temperature may lead to droughts, which stands as a significant contributor to the process of desertification (Big-Alabo & Akpan, 2021). As water scarcity intensifies due to the disappearance of marshy lands and the growth of the population, the impact will worsen day by day. Additionally, the likelihood of natural disasters will escalate in response to these climate changes.

5. Conclusion

The goal of this study was to assess the Spatial and Temporal trend of Rainfall and Temperature of Bangladesh based on statistical analysis of the related climatic dataset during 1989 to 2019 and explore the possible impacts of changing of the climatic parameters. The analysis was conducted with the use of Mann-Kendall test and Sen's Slope analysis methods to detect trend variation and GIS was used for the visual representation of the results. The analysis shows that maximum increase in rainfall amount during monsoon, post monsoon and pre monsoon occur in Sandwip, Madaripur and Chittagong respectively. A notable finding is, no case of significant rainfall increments was found during winter season. Maximum decrease in rainfall amount during monsoon, post monsoon, pre monsoon and winter are Madaripur, Chittagong, Khepupara and Faridpur respectively. Maximum increase in average minimum temperature during monsoon, post monsoon, pre monsoon and winter are noticed in Barisal, Khulna, Chittagong and Khulna respectively. Maximum decrease in average minimum temperature during post monsoon, pre monsoon and winter are seen in Sandwip, Sitakund and Sandwip respectively, but no case of decrement was found during monsoon and period. Moreover, maximum increase in average maximum temperature during monsoon are seen in Teknaf, while post monsoon, pre monsoon and winter are experienced by Hatia, Syedpur and Rangamati respectively. Lastly, maximum decrement in average maximum temperature during monsoon, post monsoon, pre monsoon and winter is noticed in M.Court, Teknaf, Barisal and Khepupara respectively. Also, the consequences of temperature and rainfall change in Bangladesh may affect numerous fields. As a highly climate-vulnerable nation, Bangladesh must continue to strengthen its adaptation and mitigation efforts to build resilience and protect its people and ecosystems from the adverse effects of climate change. International collaboration and support are crucial to address these challenges and secure a sustainable future for this deltaic nation.

However, there are lot of scopes for future researches. With updated data, more fruitful research can be produced. Unlike this research, more climatic variables like wind speed, sunshine and humidity can be introduced and correlated to find new trend pattern within them.

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