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Impact of Temperature Change on Reference Evapotranspiration in Dhaka City

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Abstract

In Dhaka city, the ambient temperature is changing as a consequence of changing climate and urbanization. The alteration in temperature is one of the most significant influencing factors that affect Reference Evapotranspiration (ETo). The study is comprehensively designed to examine the pattern of change in ETo over the period from 1953 to 2018. To fulfill the purpose of the study, temperature data of Dhaka throughout this period have been used. The trend of ETo has been analyzed for four different seasons: Pre-monsoon (March-May), Monsoon (June September), Post-monsoon (October- November), and winter (December- February). To evaluate the statistical significance of these patterns, a Mann-Kendall rank statistical significance test has been used. The result shows different trends for different seasons. There has been downward trending during the pre-monsoon and winter seasons, where the upward trending has been found during Monsoon and Post monsoon periods. All these trends are statistically significant at the 95% significance level.

Keywords: Climatic variability, Temperature change, Mann Kendall Trend Test, Seasonal variation, Reference Evapotranspiration

1 Introduction

Bangladesh is often perceived to be one of the countries where climate change is most susceptible (1). Because of its topography and geographical location, Bangladesh suffers the consequences of its natural resources, sustainable livelihoods, and the fundamental well-being of the people (2). Moreover, vulnerability increases because of the challenges the country faces in adapting to the changing climate and in mitigating the responsible climatic factors such as light, water, rainfall, temperature, air, relative humidity, wind speed, etc (3). Climate change is defined as an average change in the circumstances of the climatic condition that may be proven by some identifiable variability of its attributes over time, which lasts for a prolonged period, generally decades or more (4). Pieces of evidence are intensifying that we are in the midst of an era of climate change, triggered by human behavior to nature (5). As per the IPCC's assessment report, the worldwide average surface temperature has risen about 0.6 °C since 1861 with predictions of an increase of 2 to 4 degrees over the next 100 years (5). This upturn in temperature will substantially disturb the hydrological cycle through the alterations in the precipitation and evapotranspiration rate.

ETo and other hydrological parameters such as runoff, soil moisture, and groundwater are all impacted by variations in meteorological variables (6). Evapotranspiration is the crucial contributor of water vapor to the atmospheric demand and thus it maintains the balance between the energy and hydrological processes (7). Reference Evapotranspiration (ETo) acts as a pivotal component for hydrological practices, water resources designing, watershed management, as well as for the agricultural sector (8).

By employing data of long-term period, this study has aimed at assessing the impacts of changes in ambient temperature on Reference Crop Evapotranspiration in Dhaka City and also at verifying the trend of these changes using some statistical method.

2 The context and purpose of the study

Although a range of studies has been carried out to provide insights into the fluctuations in rainfall and temperature in Bangladesh, the assessment of trends in ETo and the driving forces behind those trends have not yet been studied. Thus, it is essential to figure out ETo variations extensively and how the meteorological factors affecting these alterations as ETo plays an important role in both water cycle as well as hydrological processes. ETo is highly sensitive to variations in meteorological parameters that are pivotal for its computations. Now the open questions arise in this context:

1. Are all sites of Bangladesh changed in ETo trend or part of the country both annually and seasonally?
2. Which meteorological variables caused ERref variations?
3. What are the meteorological variables that influence the ETo the most?
4. Is there any periodicity of ETo in the seasonal and annual

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scales?

The answers to these questions remain unsolved. An inclusive study of ETo trends and the relevant meteorological parameters across Bangladesh is required to design a water resource management plan for any place in Bangladesh (9). Moreover, the relationship between cities and climate change is complicated (10). City-centered activities contribute to significant amounts of greenhouse gas emissions (11). Again, at the same time, cities are also more vulnerable to climate change impacts compared to villages. Dhaka is now ranked as the eighth-largest city in the world and a substantial proportion of Bangladesh's greenhouse gases are emitted there, while co-emissions are related to overall emissions worldwide (12). The purpose of this study is to highlight the decadal changing trend of annual and seasonal ETo in Dhaka city.

In the present study, the statistical significance of the trend in Reference Evapotranspiration (ETo) anomaly has been determined using a Mann-Kendall rank statistical test (13) at the 95 percent significance threshold.

3 Materials and Methodology

A climatic analytical study requires the observation and collection of long-term data, usually of two to three decades, for measuring the actual changes. In this present study, the primary data has been collected from the Bangladesh Meteorological Department (BMD) recorded data for Dhaka city. In this study, the methodologies employed by Yamane et.al, 2013 have been followed for calculating the ETo (14). Temperature data have been used, ranging from 1953 to 2018, for calculating ETo. This study has examined the decadal fluctuations in the seasonal potential evapotranspiration from 1953 to 2018. As the temperature is a critical parameter for the modification of the trend of evapotranspiration, only this parameter has been taken for this study. Reference evapotranspiration (ETo) was calculated using the FAO developed ETo Calculator, which uses the Penman-Monteith equation.

$$\gamma ETo = \frac{0.408\Delta\,(R_n - G) + \gamma\,\frac{900}{T+27}\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34U_2)} \qquad (1)$$

where ETo is reference crop evaporation [mm/day], G is soil heat flux density [MJ m^{-2} day^{-1}], Δ is slope vapour pressure curve [$KPa^{o}C^{-1}$], T is air temperature at 2 meter height [^{o}C], R_n is net irrigation at crop surface [$MJm^{-2}day^{-1}$], γ is psychometric constant [$KPa^{o}C^{-1}$], U_2 is wind speed at 2m height [ms^{-1}], e_s is saturation vapour pressure [KPa], e_a is actual vapour pressure [KPa], and e_s-e_a is saturation vapour pressure deficit [KPa].

Seasons are the subject of this research. A year in Bangladesh is divided into six seasons in general. Though these seasons have some recognizable traits, some of them have very slight distinguishable characteristics. So, this study has segmented a whole year into four seasons, namely: Pre-monsoon (March-May), Monsoon (June September), Post-monsoon (October-November), and winter (December- February) (15). The averages of ETo have been derived from four different periods: 1953-1970, 1971-1990, 1991-2010, and 2011-2018 and the oscillations in these average values have been scrutinized. The deviations from baseline values have been examined, where the baseline values have been considered as the mean of all the annual values of ETo between 1972 and 2000 (14). The deviations of the annual values from the baseline values have been expressed as anomaly data for every year. Sen's slope has been used to detect the trend/pattern and rate of alteration in ETo per year for the four seasons considered in this study.

4 Result

4.1 Decadal trend of seasonal ETo in Dhaka City

As discussed in the Materials and Methodology section, 12 months of a year has been divided into four seasons. The climate change-induced decadal alterations of these seasons have been discussed below:

4.1.1 Pre-monsoon

The study shows the negative fluctuation of Reference crop evaporation during the pre-monsoon season. Figure 1 reveals that the highest average value for ETo during the Pre-monsoon time was 4.74 mm/day from 1953- 1970, which gradually decreased to 4.57mm/day for 1971-1990.

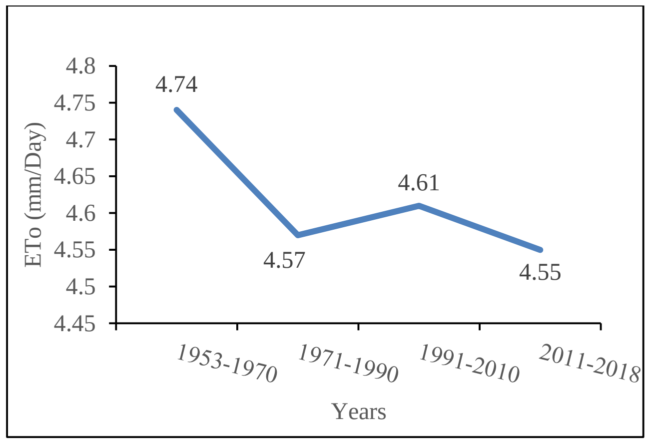

Figure 1: Decade wise trend of Reference Crop Evapotranspiration during Pre-monsoon season in Dhaka city

Again, the observations of the subsequent decades throughout the years 1991-2010 show that the Reference crop evaporation steadily increased up to an average of 4.61 mm/Day. Eventually, during 2011-2018, the pre-monsoon ETo dropped to an average of 4.55 mm. Consequently, though the ETo in the pre-monsoon is fluctuated in the past four decades, the overall condition is presenting a declining trend year by year.

Figure 2 illustrates the deviation of Reference crop evaporation from the baseline value. The period 1953-1970 shows the highest average ETo above the baseline, whereas the successive periods show relatively lower average ETo below the baseline. The deviations below the baseline value signify that the lowest deviance occurred during 1991-2010, whilst the highest deviance in the negative direction took place between 2011 and 2018. However, the overall trend of change in the ETo value during these seasons portrays that the negative deviances could never surpass the positive one, implying that the peak variance occurred in 1953-1970 in the positive direction. Thus, in the initial years of this study, the values of Reference crop evaporation were relatively higher than the years afterward. Figure 3 is the illustration of the trend of change in ETo throughout pre-monsoon season. It demonstrates that from 1953 to 2018, ETo value shows a downward pattern of change, falling at a rate of 0.3 mm every 100 years. The P-Value is 0.029, which is significantly lower than 0.05. This also strongly validates that there is a declining trend in Reference crop evaporation every year at a slow pace. Kendall's tau value is -0.186 which also verifies the negative trending of the value of Reference crop evaporation throughout the Pre-monsoon season.

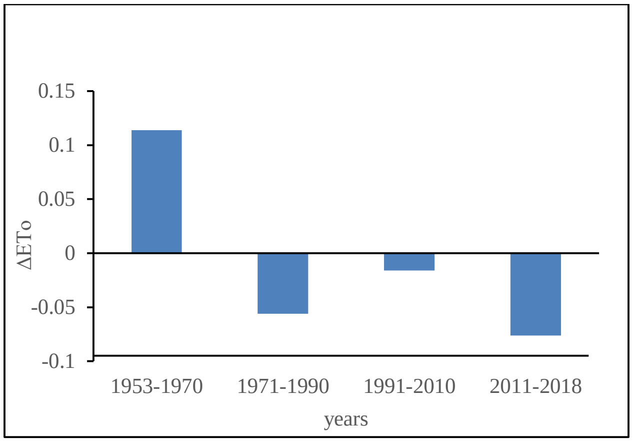

Figure 2: Deviation of Reference Crop Evapotranspiration from baseline during Pre-monsoon season

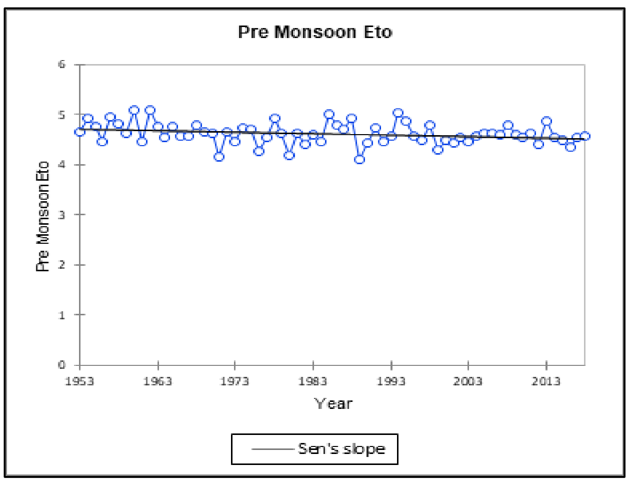

Figure 3: Trend of change of Reference Crop Evapotranspiration during Pre-monsoon season

4.1.2 Monsoon

The analyses of each period considered in this study show that the average values of Reference crop evaporation (ETo) have continuously risen during the monsoon. The lowest average value of ETo was 3.33mm/Day during 1953-1970. And then, the average values of ETo gradually increased up to 3.45mm/Day, 3.67mm/Day, and 3.8mm/Day in the subsequent periods-1971-1990, 1991-2010, and 2011-2018 respectively. The variances between two successive periods are not so high. The highest increment was found from 1971-1990 to 1991-2010. Figure 5 is graphically representing the deviation of the average values from the baseline value. The average values of reference evapotranspiration during 1953-1970 and 1971-1990 were below the baseline which indicates that the values were lower than the baseline value. It gradually began to rise after 1990 and the average values during the periods 1991-2010 and 2011-2018 are greater than the baseline value. As per the overall scenario, the maximum rise has been noted during the years 2011-2018.

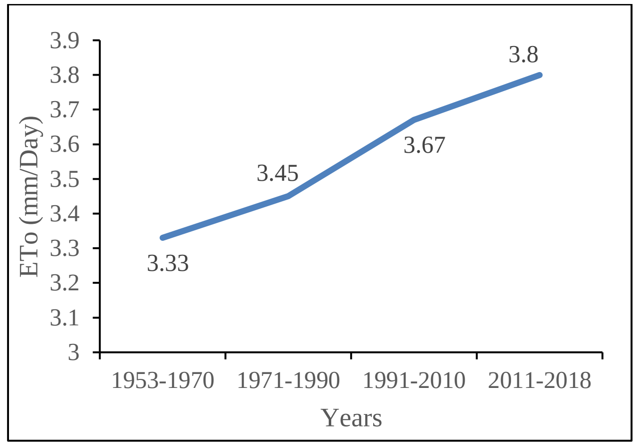

Figure 4: Decade wise trend of Reference Crop Evapotranspiration during Monsoon season in Dhaka city

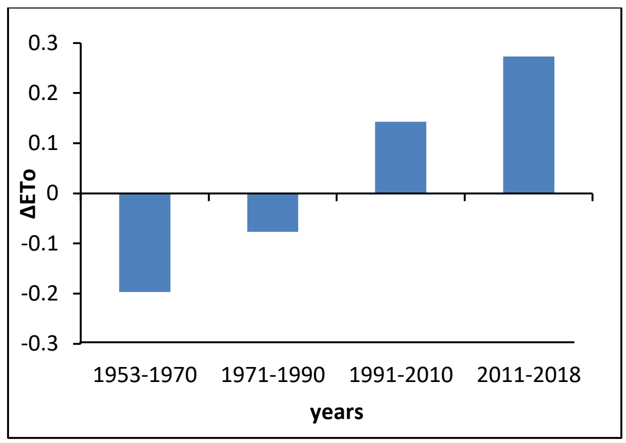

Figure 5: Deviation of Reference Crop Evapotranspiration from baseline during Monsoon season

Figure 6 represents the trend of ETo for the monsoon period. It shows that there is a positive trend over the period from 1953 to 2018. The increasing rate is 0.9 mm per 100 years. The P-value is <0.0001, which affirms that this analysis is statistically significant, and the average value of reference evapotranspiration of each year is gradually increasing. Kendall's tau value is 0.617, which also reveals the positive characteristic in the trend of the value of Reference crop evaporation during the monsoon period.

4.1.3 Post Monsoon

Figure 7 shows that the average values of Reference crop evaporation (ETo) during the post-monsoon period in every period under consideration have increased gradually. The least value has been found during 1953-1970, which was 3.11mm/Day. Then a sharp rise occurred up to 3.18 mm and 3.26 mm during 1971-1990 and 1991-2010 accordingly. The next period (2011-2018) shows a slow pace in the increase of the average value which was 3.28 mm. According to Figure 8, from 1953 to 1970, the highest deviation from the baseline value can be noted toward the negative direction. It signifies that the Reference crop evaporation was considerably lower than the baseline figure.

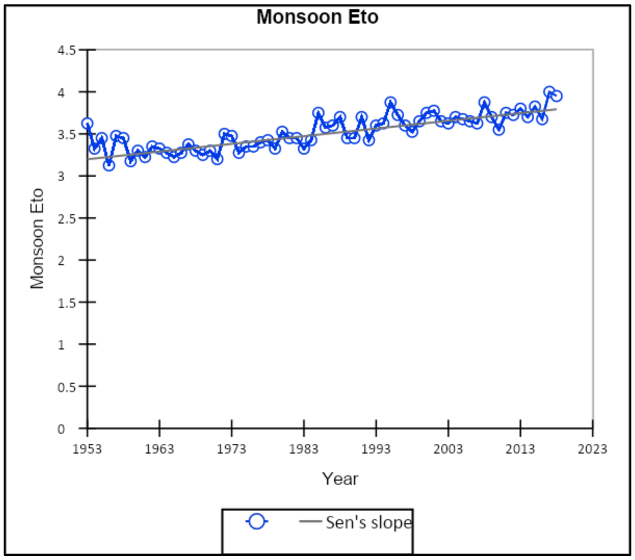

Figure 6: Trend of change of Reference Crop Evapotranspiration during Monsoon season

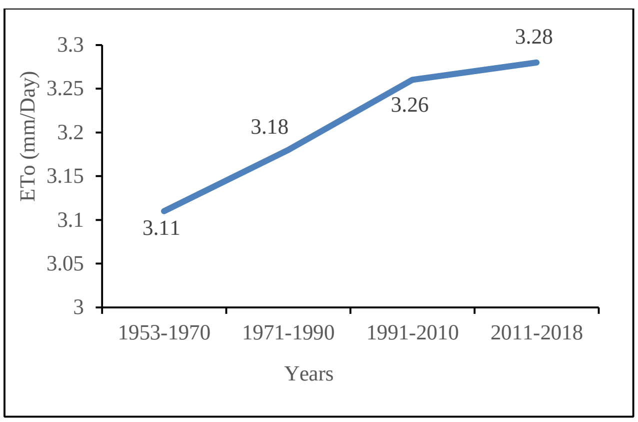

Figure 7: Decade wise trend of Reference Crop Evapotranspiration during Post-monsoon season in Dhaka city

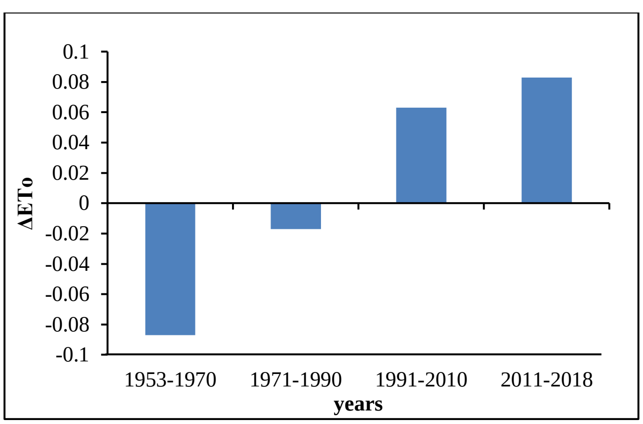

Figure 8: Deviation of Reference Crop Evapotranspiration from baseline during Post-monsoon season

In the next period (1971-1990), a prominent change can be noticed. The deviation from the baseline reduced enough but it was still also in the downward direction. After 1990, however, there occurred a significant shift in the upward direction. The average ETo increased from the baseline value up to 0.06 mm and it continued to rise towards the ascending direction in the subsequent years. Thus, 2011-2018 shows relatively higher average Eto than the baseline, whereas the other periods show lower average ETo than the baseline value. However, the overall scenario confirms that the highest deviation from the baseline value happened during 1953-1970.

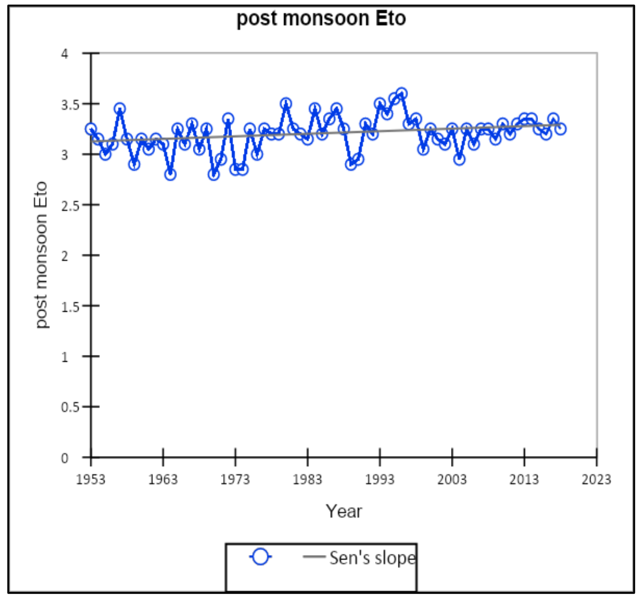

Figure 9: Trend of change of Reference Crop Evapotranspiration during Post monsoon season

Figure 9 represents the trend of ETo for the post-monsoon period during the overall time period from 1953 to 2018. It shows that there is an increasing trend over this period but the trend line is not enough inclined and the increasing rate is 0.3 mm per 100 years. This means that the value of Reference crop evaporation is rising at a rate of 0.003 mm per year. Again, the P-value is 0.008 which is lower than 0.05, which means this analysis is statistically significant. Kendall's tau value is 0.231 which is positive and thus indicates the positive trending of the value of Reference crop evaporation during the post-monsoon season.

4.1.4 Winter

Figure 10 shows a sharp decline in the Reference crop evaporation value in the four-time periods considered in this study from 1953 to 2018 during the winter season. The highest average value was found during 1953-1970 which was 3.28 mm/Day. After that, the average values for the subsequent periods have continually decreased sharply. In 1971-1990, the mean value was 3.16 mm/Day, which gradually decreased to 3.06 mm/Day during 1991-2010. The least value has been found during 2011-2018 which was 2.96 mm/Day. So, this trend shows a gradual declining characteristic of ETo during this season.

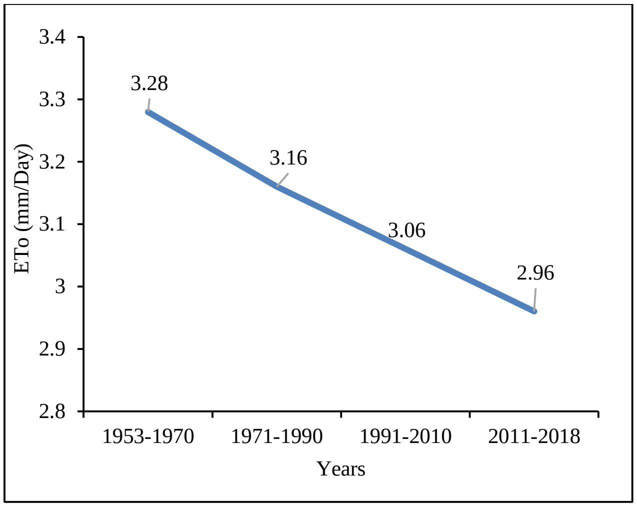

Figure 10: Decade wise trend of Reference Crop Evapotranspiration during winter season in Dhaka city

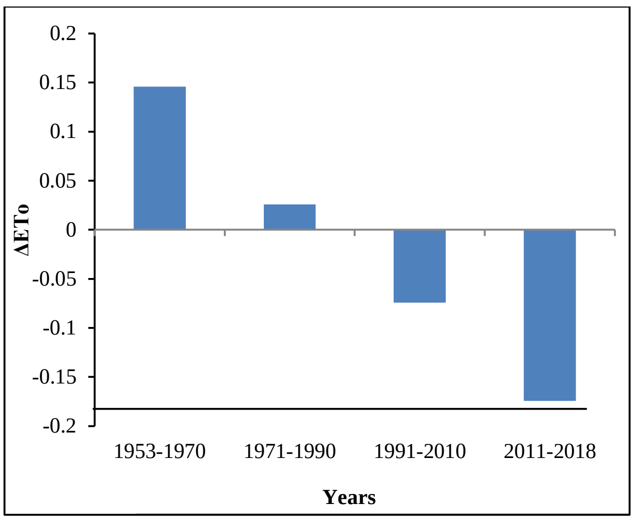

Figure 11: Deviation of Reference Crop Evapotranspiration from baseline during winter season

According to Figure 11, the period 1953-1970 shows relatively higher average ETo than the baseline for the winter season, whereas the other periods show lower average ETo than the baseline values. The variation from the baseline value was too small during 1971-1990. After that, it continued to decrease to a relatively higher extent. The deviation was the highest during 2011-2018 in the negative direction which means that the average value of Reference crop evaporation throughout the winter season in this period has lowered much more than the average value of ETo above the baseline value from 1953-2018.

Figure 12 represents the trend of ETo for the winter season through Sen's slope. It shows that there is a negative trend over the period from 1953 to 2018. The decreasing rate is 0.6 mm per 100 years. The P-value is <0.0001which indicates that the analysis is statistically significant and the trending behavior of ETo is on downward during this season. Kendall's tau value is -0.428 and this negative indicates the decreasing trending of the value of Reference crop evaporation during the winter season.

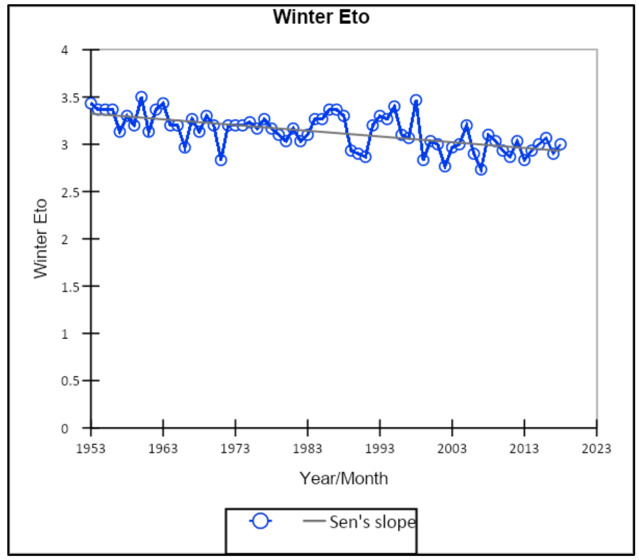

Figure 12: Trend of change of Reference Crop Evapotranspiration during winter season

5 Conclusions

Climate change influences various meteorological factors so it is necessary to simulate the trend of these factors. Dhaka city has currently experienced the influence of urbanization on various climatic disasters and so it has been an obvious necessity to observe the trend of change of the meteorological parameters to develop a robust adaptation mechanism. The overall trend of Reference crop evaporation for 1953-2018 shows two different scenarios where during pre-monsoon and winter seasons, there are declining trends, and Monsoon and Post monsoon seasons show a rising trend. The deviations from the baseline value also imply that the present state of ETo during pre-monsoon and winter season is on the negative dimension, whereas during monsoon season and post-monsoon season, the recent deviations are in the positive direction. Sen's slopes for all four seasons show statistically significant trends at a 95% significance level. In the Pre-monsoon period and winter season, Reference crop evaporations are decreasing at a rate of 0.3mm and 0.6 mm per 100 years respectively. ETo in Monsoon and Post monsoon seasons is rising at a rate of 0.9 mm and 0.3 mm per 100 years respectively. This study provides the nature of the season-wise trends of Reference crop evaporation which can be used for adopting the appropriate adaptation practices. For this, the study can further be integrated with the assessment of other influencing factors for the changing trends in Reference crop evapotranspiration.

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Ethical issue

Authors are aware of and comply with, best practices in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, and manipulation of figures, competing interests, and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language. Also, all procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. All procedures performed in this study involving animals were following the ethical standards of the institution or practice at which the studies were conducted.

Competing interests

According to the declaration of the authors, there is no conflicting interest that would jeopardize the objectivity of this scientific effort.

Authors' contribution

All authors of this study have a complete contribution for data collection, data analyses, and manuscript writing.

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