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INTER-ANNUAL AND SEASONAL VARIATIONS OF SURFACE AIR TEMPERATURE OF MAJOR CITIES IN BANGLADESH

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ABSTRACT

The present study investigated recent trends in the mean annual maximum and minimum surface air temperature at selected six major cities over Bangladesh by using statistical techniques. Annual and seasonal records of maximum and minimum surface air temperature of major cities for the period 1971-2011 were used in this analysis. The cities are Rajshahi, Sylhet, Dhaka, Khulna, Barisal and Chittagong. The trend of mean annual maximum and minimum surface air temperature has been analyzed using linear regression technique, which showed that the warming trend is dominant over the city areas in Bangladesh. It has been found that at Sylhet, Barisal, Chittagong and Dhaka the temperature shows very strong warming trends of maximum temperature with high values of 0.048^o, 0.026^o, 0.024^o and 0.022^{o}C/year. These cities also show strong warming trends of minimum temperature.

The values of seasonal mean maximum and minimum surface air temperatures in the cities were computed for winter (December–February), pre-monsoon (March-May), monsoon (June-September) and post-monsoon (October-November) seasons. The seasonal mean maximum and minimum surface air temperature show increasing trends except Rajshahi (-0.015^{o}C/year) for minimum temperature in postmonsoon. Rajshahi also shows decreasing (cooling) trend in the winter season of -0.011^{o}C.

Keywords: *Inter-annual variation, Linear trend, Statistical techniques and Surface Air Temperature.*

1. INTRODUCTION

As per IPCC report (IPCC, 2001a, b) the global surface air temperature has increased by 0.6^o C in the past century. This warming trend has been accelerated during the last 3 decades and has been found to be 0.15^{o}C per decade. This warming has been attributed mainly due to the enhanced greenhouse gases in the atmosphere. The projection made by various models depicts that the global temperature will increase by 1.4-5.8^{o}C by the end of this century with 1990 as the base year. According to the observations and also from the model results the warming is not spatially or regionally uniform. Though the increasing concentration of greenhouse gas plays the major role for enhanced radiative forcing causing global warming, it has been found that the higher concentration of the atmospheric aerosols especially the sulfate particulates strongly scatter the solar radiation causing the negative radiative forcing, which may cause cooling instead of warming. The higher concentration of aerosols thus retards the warming due to greenhouse gas or even causes the net cooling, depending on the level of aerosol loading. Thus, the global warming and associated climate change are related to various anthropogenic forcing such as greenhouse gas and industrial aerosols, land use change, natural forcing etc. This warming would be different for different regions and resulting climate at various parts of the world would also vary. The global sea levels have also been reported to rise due to warming of the seawater and melting of the glaciers (IPCC, 2001a,b). Some studies have shown that the sea level is rising in the Bangladesh coast at an alarming rate (4.0-7.8 mm/year) of which around 2.0 mm/year is due to warming of the sea and the rest might be due to geological subsidence (Khan *et al*., 1999 and 2002).

The trends and variations of temperature for Bangladesh, India and surrounding regions have been studied by many authors. Some studies have reported that the temperature and rainfall of Bangladesh have been increasing during the recent decades (Choudhury *et al.,* 1997; Karmakar and Shrestha, 2000). However, these studies are not detail and up-to-date. Hingane *et al.* (1985) reported a linear warming trend of about 0.5-0.9 ^{o}C/100 years in the mean annual temperature in the northeast India. Srivastova *et al.* (1992) observed an increasing trend of surface air temperature over south of 22^o N and a decreasing trend over the north of 23^o N. Choudhury *et al.* (1997) and Karmakar *et al.* (2000) found that the maximum, minimum and mean surface air temperature and rainfall over Bangladesh have increasing trends. The study of the trends of temperature and rainfall by Shrestha (2000) shows that the seasonal and annual maximum, minimum and mean temperatures over Sri Lanka have an increasing trend and the rainfall has the decreasing trend. Shrestha *et al.* (1999) have studied the trends of temperature over Nepal and have found an increasing trend of maximum temperature since mid 1970s. Quadir *et al*. (2004) have shown that the temperature of Bangladesh and its surrounding areas have increasing trends. The correlation temperature with SOI shows negative correlation of most of the stations.

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Considering the above, in the present paper, the study has been carried out on the recent annual and seasonal climate variability and its trends using the data of maximum and minimum surface air temperatures in Bangladesh.

2. DATA USED AND METHODOLOGY

The maximum and minimum surface air temperatures for individual years and seasons (winter, pre-monsoon, monsoon and post-monsoon) have been estimated from the monthly data. The data period of temperature was used from 1971 to 2011 but for Khulna city minimum temperature was used from 1981 to 2011. The inter-annual variability and linear trends have been analyzed using the temporal plots of these parameters and least square regression analysis. The significance levels of the slopes of the linear trends have been calculated using the student t-test.

The significance test is carried out by using Student's t-distribution:

$$t_{cal} = r\sqrt{\frac{n-2}{1-r^2}}$$

Where r is the correlation coefficient, n is the number of data and (n-2) is the degree of freedom. If $t_{cal} > t_{0.05}$ or $t_{0.01}$, the correlation coefficient is significant on the basis of a one-tailed test of Student's distribution.

3. RESULTS AND DISCUSSION

The inter-annual and seasonal variations of mean maximum and minimum surface air temperatures have been studied using the yearly time series and least square regression analysis. The characteristics of trends of mean maximum and minimum and seasonal surface air temperatures are described below.

3.1 Trends of annual mean maximum surface air temperature

The selected major cities for this present study are Rajshahi, Sylhet, Dhaka, Khulna, Barisal and Chittagong. The temporal plots of the time series of annual mean maximum temperature of the major cities in Bangladesh show that the temperature has the dominant increasing trends (Figure 1). The causes of the warming are attributed mainly to the radiative forcing due to the increased greenhouse gases. Besides, the local changes such as urbanization, land-use changes and industrialization have impacts on the local changes of the thermal regime. The slopes of the linear trends of the regression analysis of the mean maximum temperature have been shown in Table 1. Strong warming is observed at Sylhet city at the rate of 0.048°C/year, which is highly statistically significant at 1% level. Shrestha *et al*. (1999) also reported that the maximum temperature over Nepal increasing trend. Such strong warming trend over Sylhet city/region may affect the ecology and tea plantation growth. Moderate warming is found at Barisal, Chittagong, Rajshahi and Dhaka cities at the rate of 0.026°, 0.024°, 0.019° and 0.022°C/year, respectively, which are statistically significant at 1% level (Table 1). Khulna city also shows warming trend at the rate of 0.015°C/year, which is also statistically significant at 5% level, but not stronger than the other major cities as shown in Table 1.

Table 1: Trend values of mean maximum surface air temperature of selected 6 major cities in Bangladesh (°C/year) during the period 1971-2011.

Name of Cities	Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual
Rajshahi	-0.012	0.032**	0.036*	0.006	0.019*
Sylhet	0.045*	0.046*	0.055*	0.043*	0.048*
Dhaka	-0.0002	0.023**	0.036*	0.027**	0.022*
Khulna	0.009	0.010	0.035*	0.012	0.015**
Barisal	0.019**	0.024**	0.034*	0.026*	0.026*
Chittagong	0.038*	0.023**	0.018**	0.033*	0.024*

* Represents significant at 1% level; ** Represents significant at 5% level

It can further be seen in Table 1, mean maximum surface air temperature of Sylhet city shows strong warming trend. It is located in the northeastern part of Bangladesh and its elevation is about 33 meters. Barisal, Chittagong and Dhaka are located in the southern, southeastern and central part of Bangladesh. These cities show warming trend but not highly strong warming trend like Sylhet (Table 1). Rajshahi and Khulna are located in the northwestern and southwestern part of Bangladesh. These two cities have increasing trend of mean maximum surface air temperature which are rather weaker than that of other major cities of Bangladesh.

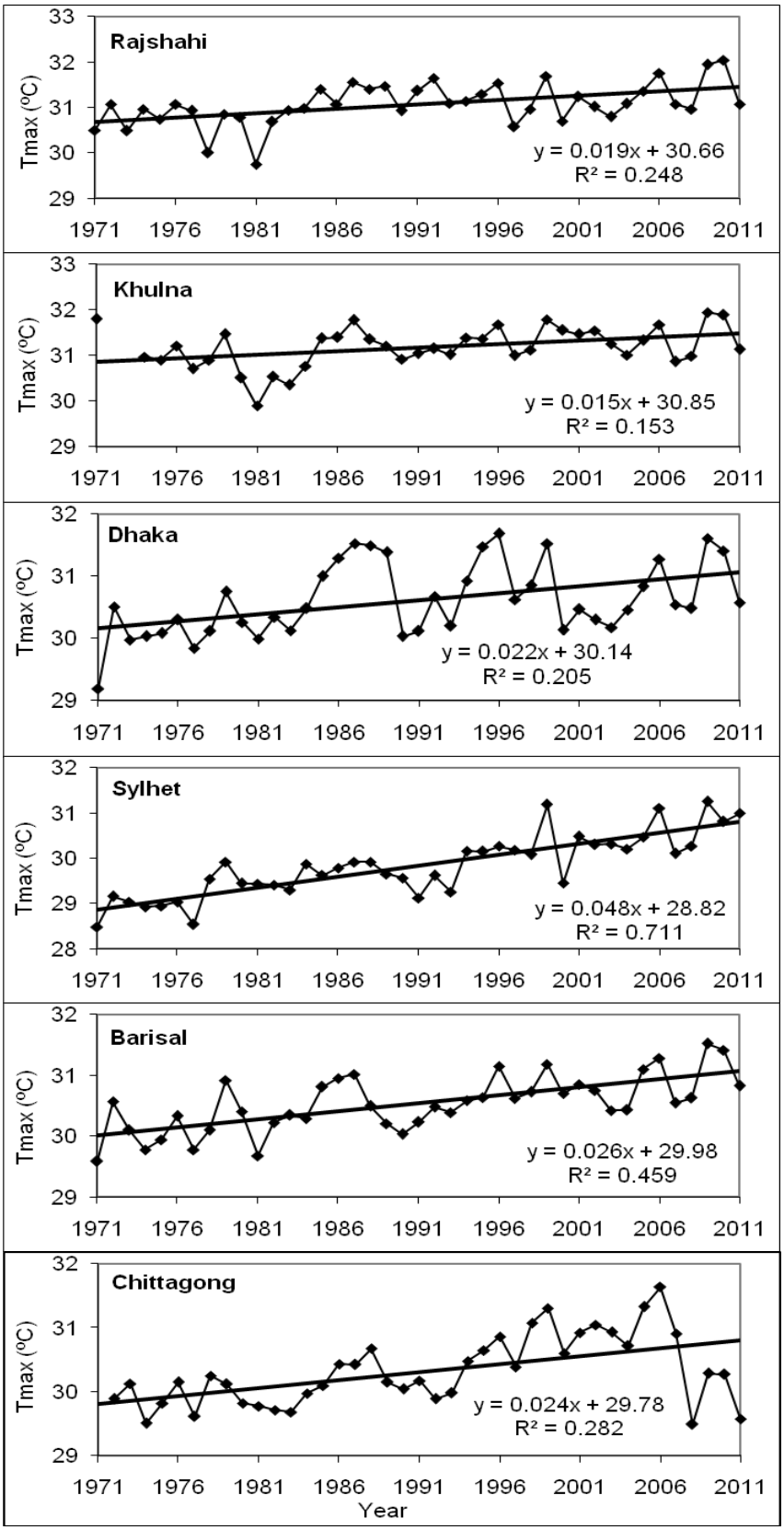

Figure 1: Inter-annual variation of annual mean maximum surface air temperature of six major cities in Bangladesh.

3.2 Trends of seasonal mean maximum surface air temperature

Winter

The winter mean maximum surface air temperature has a strong increasing trend over major cities of Bangladesh without a few exceptions (figure not shown here). The increasing trend at Sylhet is 0.045°C/year which is statistically significant at 1% level. Except Rajshahi and Dhaka of the selected major cities of Bangladesh show warming trend with relatively high values at Sylhet (0.045°C/year) and Chittagong (0.038°C/year) which are both statistically significant at 1% level (Table 1). Rajshahi and Dhaka are located in the northwestern and central part of Bangladesh show the decreasing trends at the rate of -0.012°C/year and -0.0002°C/year respectively which are not statistically significant at all. Khulna and Barisal cities represent the southwestern and mid-southern parts of Bangladesh and show the increasing trend values of 0.009°C/year and 0.019°C/year respectively. The increasing trend at Khulna is 0.009°C/year which is not statistically significant but the increasing trend of Barisal is 0.019°C/year is statistically significant at 5% level. The above results show that the winter is growing milder over most of the major city areas except the northwestern and central part of Bangladesh, where winter is expected to be cooler.

Pre-monsoon

The selected six major cities of Bangladesh have shown warming trends for pre-monsoon season during the period 1971-2011. Sylhet and Rajshahi have shown strong warming trends with slope values of 0.046°C/year and 0.032°C/year respectively (Table 1) which are statistically significant at 1% level. Strong warming is observed at Dhaka, Barisal and Chittagong cities of Bangladesh at the rate of 0.023°C/year 0.024°C/year and 0.023°C/year respectively, which are statistically significant at 5% level. Khulna also shows warming trend at the rate of 0.010°C/year which is not statistically significant. Considering the above discussion, it is found that the changing pattern of mean maximum surface air temperature over the major cities of Bangladesh has an extremely homogeneous character for the pre-monsoon season. The warming is more prevalent over the major cities of Bangladesh.

Monsoon

The selected major cities of Bangladesh have shown strong warming trends of maximum temperature in the monsoon season during the period 1971-2011. The major cities of Bangladesh namely Rajshahi, Sylhet, Dhaka, Khulna and Barisal exhibit strong warming trends during monsoon season with high values at the rate of 0.036°C/year, 0.055°C/year, 0.036°C/year, 0.035°C/year and 0.034°C/year respectively (Table 1). These are statistically significant at 1% level. Chittagong has also shown warming trend during the same season for the same period at the rate of 0.018°C/year which is statistically significant at 5% level. Trend values of mean maximum temperature are mostly within the range between 0.018°C/year and 0.055°C/year, which indicate dominating warming tendency in these main cities of Bangladesh. From the above discussion, it appears that the more rapid warming occurs over the major cities of Bangladesh.

Post-monsoon

Strong warming trend is found in the post-monsoon season in Bangladesh of Sylhet, Dhaka, Barisal and Chittagong at the rate of 0.043°C/year, 0.027°C/year, 0.026°C/year and 0.033°C/year respectively which are statistically significant at 1% level (Table 1). Rajshahi and Khulna have also shown warming trends with the values of 0.006°C/year and 0.012°C/year respectively, which are not statistically significant.

Table 2: Trend values of mean minimum surface air temperature of selected 6 major cities in Bangladesh (°C/year) during the period 1971-2011.

Name of Cities	Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual
Rajshahi	-0.011	0.012	0.009**	-0.015	0.001
Sylhet	0.054*	0.036*	0.027*	0.035**	0.037*
Dhaka	0.055*	0.033*	0.013**	0.020**	0.029*
Khulna	0.058*	0.053*	0.015**	0.042*	0.040*
Barisal	0.022**	0.021*	0.014**	0.011	0.017*
Chittagong	0.031*	0.033*	0.025*	0.005	0.025*

* Represents significant at 1% level; ** Represents significant at 5% level

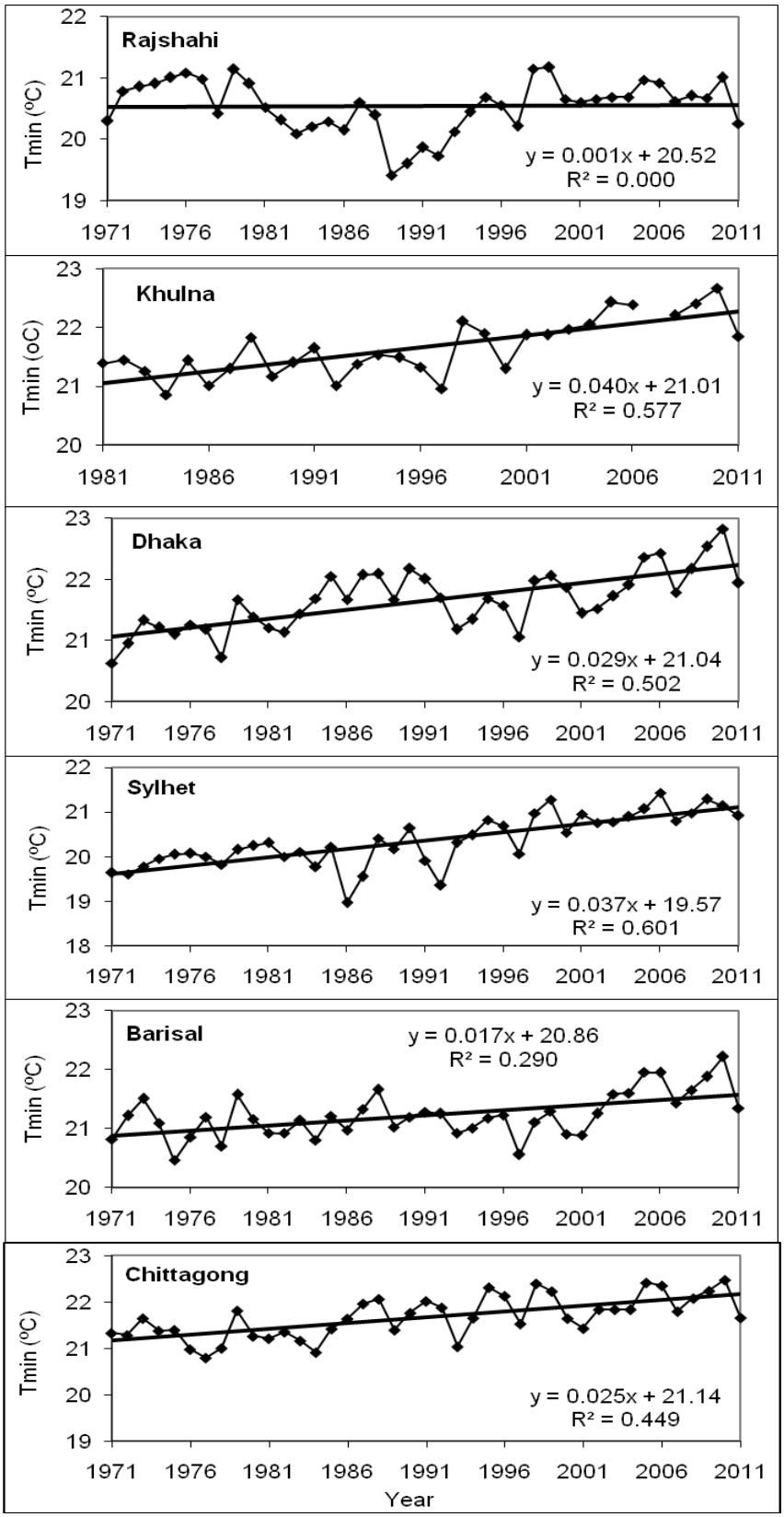

Figure 2: Inter-annual variation of annual mean minimum surface air temperature of six major cities in Bangladesh.

3.3 Trends of annual mean minimum surface air temperature

The temporal plots of mean minimum surface air temperature have been prepared for selected six major cities in Bangladesh. The yearly variation of annual mean minimum surface air temperature for six major cities are shown in Figure 2 for the period 1971-2011, (for Khulna city: 1981 to 2011). The results of the trend analysis for mean minimum and seasonal surface air temperature have been presented in Table 2.

From the table 2, it can be seen that the annual mean minimum surface air temperature shows strong warming trends for all selected major cities in Bangladesh except Rajshahi city. Strong warming is found at Khulna, Sylhet, Dhaka, Barisal and Chittagong at the rate of 0.040^{o}C/year, 0.037^{o}C/year, 0.029^{o}C/year, 0.017^{o}C/year and 0.025^{o}C/year respectively which is statistically significant at 1% level. Rajshahi shows warming trend at the rate of 0.001^{o}C/year which is not statistically significant.

3.4 Trends of seasonal mean minimum surface air temperature

Winter

According to the trend analysis, it is found that the warming is dominant over the northeastern, central, southwestern, southern and southeastern parts of Bangladesh because Sylhet, Dhaka, Khulna, Barisal and Chittagong cities are located in these regions. Sylhet, Dhaka, Khulna, Barisal and Chittagong are observed strong warming trend at the rate of 0.054^{o}C/year, 0.055^{o}C/year, 0.058^{o}C/year, 0.022^{o}C/year and 0.031^{o}C/year respectively which are statistically significant at 1% level (Table 2). The cooling is observed at Rajshahi city with trend value of -0.011^{o}C/year which is not statistically significant. It may happen due to climate change. In addition, it may also happen due to deforestation and dryness of river over this region.

Pre-monsoon

Pre-monsoon seasonal mean minimum surface air temperature shows increasing trends all over the selected major cities in Bangladesh. Sylhet, Dhaka, Khulna and Chittagong show strong warming trend at the rate of 0.036^{o}C/year, 0.033^{o}C/year, 0.053^{o}C/year and 0.033^{o}C/year respectively which are statistically significant at 1% level (Table 2). Barisal also shows warming trend with trend value of 0.021^{o}C/year which is statistically significant at 1% level. Rajshahi is also observed warming trend at the rate of 0.012^{o}C/year which are not statistically significant.

Monsoon

Sylhet and Chittagong have the strong warming trend with the value of 0.027^{o}C/year and 0.025^{o}C/year respectively which is statistically significant at 1% level. The moderate warming trend is observed at Rajshai, Dhaka, Khulna and Barisal at the rate of 0.009^{o}C/year, 0.013^{o}C/year,0.015^{o}C/year and 0.014^{o}C/year respectively, which are statistically significant at 5% level (Table 2).

Post-monsoon

Khulna shows strong warming trend at the rate of 0.042^{o}C/year for the post-monsoon season, which is statistically significant at 1% level. Sylhet and Dhaka also exhibit warming trend at the rate of 0.035^{o}C/year and 0.020^{o}C/year respectively which are statistically significant at 5% level (Table 2). Barisal and Chittagong shows mild warming trend with the values of 0.011^{o}C/year and 0.005^{o}C/year respectively which are not statistically significant. The minimum cooling is found over Rajshahi city at the rate of -0.015^{o}C/year, which is not statistically significant.

4. CONCLUSIONS

On the basis of the present study, the following conclusion can be drawn:

i. The mean maximum surface air temperature shows strong warming trend over all selected major cities in Bangladesh for the period 1971-2011. Among the major cities temperature shows a higher warming trend at Sylhet and lower warming temperature at Khulna with the values of 0.048^{o}C/year and 0.015^{o}C/year respectively which are statistically significant at 1% and 5% level respectively. The causes of the warming are attributed mainly to the radiative forcing due to the increased greenhouse gases. Besides, the local changes such as urbanization, land-use changes and industrialization have impacts on the local changes of the thermal regime. Very strong warming in the cities at Sylhet, Barisal, Chittagong, Dhaka and Rajshahi at the rate of 0.049^{o}C/year, 0.026^{o}C/year, 0.025^{o}C/year, 0.022^{o}C/year and 0.019^{o}C/year respectively is due to the rapidly expanding urbanization in these cities areas.

ii. Strong warming trends of mean maximum surface air temperature is observed in all the seasons except the winter seasons where the increasing trend is very week except at Sylhet and Chittagong. Sylhet and Chittagong shows warming trend at the rate of 0.045°C/year and 0.038°C/year respectively which are statistically significant at 1% level and decreasing trend is also observed at Dhaka and Rajshahi cities at the rate of -0.0002°C/year and -0.012°C/year respectively, which are not statically significant.

iii. The mean minimum surface air temperature during the study period 1971-2011 shows the strong(highest) warming trends of 0.040°C/year and 0.037°C/year at Khulna (data was used from 1981-2011) and Sylhet respectively, which is statistically significant at 1% level and lowest of 0.001°C/year at Rajshahi which is not statistically significant.

iv. The seasonal mean minimum surface air temperature of major cities for all four seasons shows increasing trends except Rajshahi and Chittagong. Rajshahi city has been found decreasing trends at the rate of -0.011°C/year and -0.015°C/year for winter and post-monsoon seasons and Chittagong city has also been found almost neutral trend (0.005°C/year) for post-monsoon season. These are not statistically significant. Very strong warming trends are exhibited at Khulna and Dhaka with high values of 0.058°C/year and 0.055°C/year for winter season, which are statistically significant.

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