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Research Article

Impact of urban evolution on local temperature trends of Rawalpindi and Islamabad

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Abstract

Rawalpindi and Islamabad commonly known as twin cities of Pakistan have 3.2 million population. Twin cities have rapidly urbanized in the last three decades. The objective of the present study is to compute the urban growth and its effect on evolution of local temperature trends of twin cities. To compute the land-cover change such as built-up area, vegetation cover, water and barren land, Landsat images of 1980, 1992, 2000 and 2013 are classified by using the supervised image classification with maximum likelihood rule and probability surface method. To evaluate the change in temperature trends, homogenized time series data of daily averaged monthly minimum (T_{min}) and maximum (T_{max}) temperatures for the period of 1983 to 2013 is analyzed by using the linear regression. The results show that built-up area of twin cities increased from 66 km^2 in 1983 to 148 km^2 in 2013 with an increase of 120 per cent within 31 years. Due to resulted urbanization, T_{min} and T_{max} of twin cities have been increasing. T_{min} is increased more in Rawalpindi than Islamabad and T_{max} is increased more in Islamabad than Rawalpindi. The highest increase in T_{min} and T_{max} at both stations is observed during spring season.

Keywords: Urban climate, landuse change, temperature trends, built-up area.

1. Introduction

In 1950, 30 per cent of the world's population was urban. Currently, 54 per cent of the world's population is residing in urban areas in 2014 which is projected to reach at 66 per cent in 2050 (UNDESA, 2014). Given the large and ever-increasing fraction of the world's population living in cities, and the disproportionate share of resources used by these urban residents, especially in the global North, cities and their inhabitants are key drivers of global environmental change (Grimmond, 2006). However, in big cities, the urbanization creates significance changes in the atmospheric and surface properties that can result in alter the local weather and climate (Changnon, 1981, Cotton & Pielke, 1995). In this context, the environment of the cities is being affected in two ways: by global climate change and

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by local urban areas effects. Although the cities are not influencing global temperature trends (Founda et al. 2004; Parker, 2004) the impacts of global warming may be exacerbated in urban areas (Alcoforado & Andrade, 2008). The local effect is mainly associated with urban characteristics such as abundance of paved surfaces, scarceness of vegetation cover, excessive use of energy for the functioning of the cities, decreasing the affective albedo at local level due to surface canyon, increased long wave radiation from the sky due to higher pollution at top of an urban area, less long wave radiation lose due to reduction of sky view factor, human heat sources, decreased evapotranspiration and reduced wind speed due to building geometry (Ok, 1982).

The scientific findings about local effect of several cities of the world exhibit the higher temperature in cities than their surrounding non-urban areas (Sajjad et al., 2015), the phenomenon known as urban heat island (UHI) (Oke, 1973). The alteration of natural surfaces with concrete and asphalt materials leads to reduce the available surface moisture reduction, through evapotranspiration. In urban areas, anthropogenic heat, street structure and higher buildings participate to change the heat fluxes near surface flow. The association among surface temperature increase with land-cover change and changing physical properties of surfaces reveal the impact of local urban surfaces on local temperature trends (Dousset & Gourmelon, 2003).

Pakistan is one of the important countries of South Asia in which the urban population is growing rapidly. Pakistan has the highest urban proportion in South Asian region (UNDESA 2014). This study is focusing on twin cities of Pakistan: Rawalpindi and Islamabad. Rapid urbanization in both cities caused merging of these cities into one. Administratively, they are divided by one major road known as Grand Trunk Road (connecting Peshawar to Lahore). Rawalpindi is an older and larger city and is a center of industrial, commercial and the hub of military activities. Rawalpindi lies along the ancient trade route from Persia and Europe across the Khyber Pass to India. Islamabad is comparatively new planned cities built after 1960s as the capital of Pakistan. All of major offices of federal government are located in Islamabad. It is a planned city in a beautiful setting at the foot of the mountains immediately north of Rawalpindi, constructed to serve as capital of the newly independent country of Pakistan. Construction began in the early 1960's, following extensive surveys and planning. The combined estimated population of twin cities in 2014 is 3,225,000 (Demographia, 2013) making them 4th largest city cluster of Pakistan.

The objective of the present work is to study the evolution of urbanization in Rawalpindi and Islamabad since 1983 and its effect on evolution of local temperature trends. The study also elaborates the relationship between growth in built-up area and change in minimum and maximum temperature of twin cities. Part 2 describes the data and methodology, part 3 provides the results about urban growth and change in temperature, and part 4 concludes the whole study.

2. Data and Methodology

Landsat is a series of US satellites having most accurate historic images to study land use. It is commonly used for research and study purposes (Foody, 2002, Bay, 2011). For this study, Landsat images for the years of 1980, 1992, 2000 and 2013 were acquired to identify the built-up area of Islamabad and Rawalpindi. The reason for the selection of these years is the unavailability of images in regular intervals. Erdas Imagine was used for the image processing and classification purposes. Before classification process, image enhancement techniques were used as noise reduction and histogram match to identify the radiometric and visual properties of images (Foody, 2002). Four classes (built-up area, vegetation, water and barren land) in each image were identified through supervised image classification with maximum likelihood rule and probability surface method (Bhatta, 2009). Supervised classification method is commonly used on the basis of known land features and clusters of same feature are separated by statistical or radiometric, spectral and spatial properties that are adopted here too.

Classification has some drawbacks because of sensor's low efficiency and selecting large area where feature identification becomes difficult. Sometimes it creates salt and pepper effect that makes problem by mixing of similar features. For this kind of study, 100% accuracy is not possible through classification method however it is still considered as best way to study land-use changes and is applied in urbanization and land change studies (Bay, 2011). For accuracy assessment Kappa Coefficient was used through error matrix in which actual and predicted classes were arranged to observe how much percent predict classes are accurate according to actual class.

Time series data of annual minimum (T_{min}) and maximum (T_{max}) temperatures of Rawalpindi and Islamabad cities were collected from Pakistan Meteorological Department (PMD). The data was analysed by using linear regression and the trends of change in T_{min} and T_{max} were obtained to see the effect of urbanization/built-up area on local temperature trends of twin cities.

3. Results and Discussion

3.1 Landuse/Land covers change

To examine the extension of built up area due to urbanization in twin cities, four satellite images of the years 1980, 1992, 2000 and 2013 were acquired and then classified to take out the desired results. Figure 1, Figure 2, Figure 3 and Figure 4 show the classified images of Landsat for the year 1980, 1992, 2000 and 2013, respectively. They show the greater evolution in land-use change and spatial trends of urbanization. The results of figure 1 to 4 are summarized in table 1 which shows here the total built-up area of study years. Jointly twin cities covered 67.55 km^2 concrete areas in 1980 and this was measured 87.45 km^2 in 1992. During 1980 to 1992, total concrete area grew 19.9 km^2 in 12 years. The major expansion of built up area during this period is observed to south-west and eastern side. In 1992, the built-up area of the city was 87.5 km^2 which increased to 103 km^2 in 2000. In this time period the built up area of the twin cities grew 17 per cent. Further the figure 1 highlights that during1992 to 2000 the major construction of the study area took place towards south and south-eastward direction near and along Soan river region and further extension observed to south and south-westward route. The eastern side of the twin cities experienced practically no expansion. Up to 2013, almost 45 km^2 more built-up area added into existing built-up area. Between 2000 and 2013 the expansion was mostly towards the south, west and eastern sides of the cities. By summarizing the result of Landsat images classification, overall 120 per cent increase in urban built-up area is measured.

Table 1: Built-up area and its cumulative average growth rate in percentage.

Year	Built up Area (km^2)	Cumulative average growth rate (%)
1980	67.55	-
1992	87.45	29
2000	102.6	17
2013	148.4	45

The cumulative average growth rate (CAGR) of built-up area shows that the highest growth in built-up area took place from 2000 to 2013 (45 %) whereas it was calculated 29 per cent during 1980 to 1992 and only 17 per cent during 1992 to 2000 (Table 1). The recent growth in built-up area shows that the natural surface is removed for the construction of buildings, roads and other infrastructure. Figure 5 highlights the growth in built-up area in 1980, 1992, 2000 and 2013 by combining them in one map. It is created by using ArcGIS Desktop which is useful software for mapping and analysis. This map helps to analyse the change pattern in a visual way to find the built-up area in different time periods.

3.2 Error Matrix and Kappa Coefficient

Table 2 shows the Error matrix for land classes of image 2000 to observe Kappa Coefficient. The same procedure is adopted for all other Landsat images. Error matrix compares on category by category basis the relationship between known reference data (ground truth) and corresponding results of automated classification. This error matrix show the number of samples used for classification of image. Here we have measured two types of accuracies 1), User accuracy and 2) producer's accuracy. User accuracy is the probability that a spatial data unit classified on the map or image actually represents that particular category on the ground. In user's accuracy we divide the number of samples of each class to row total of that class. Whereas the Producer's accuracy is the probability of a sample spatial data unit being correctly classified for the particular category to which the sample data belong. The producer's accuracy is so-called because it indicates how accurate the classification is at the time when the data are produced. In producer's accuracy we divide the number of samples of each class to column total of that class.

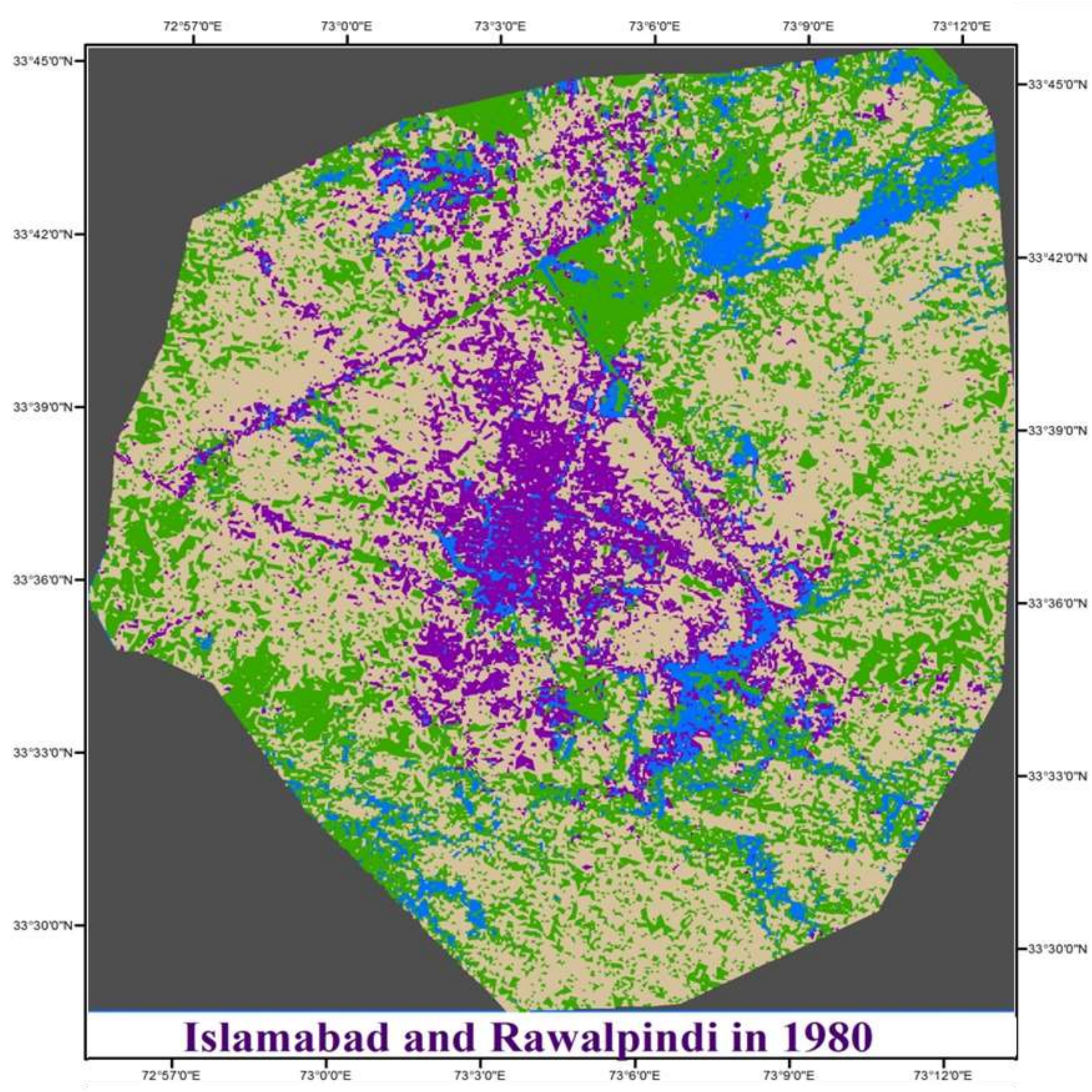

Figure 1: Classified Landsat images of twin cities for the year 1980.

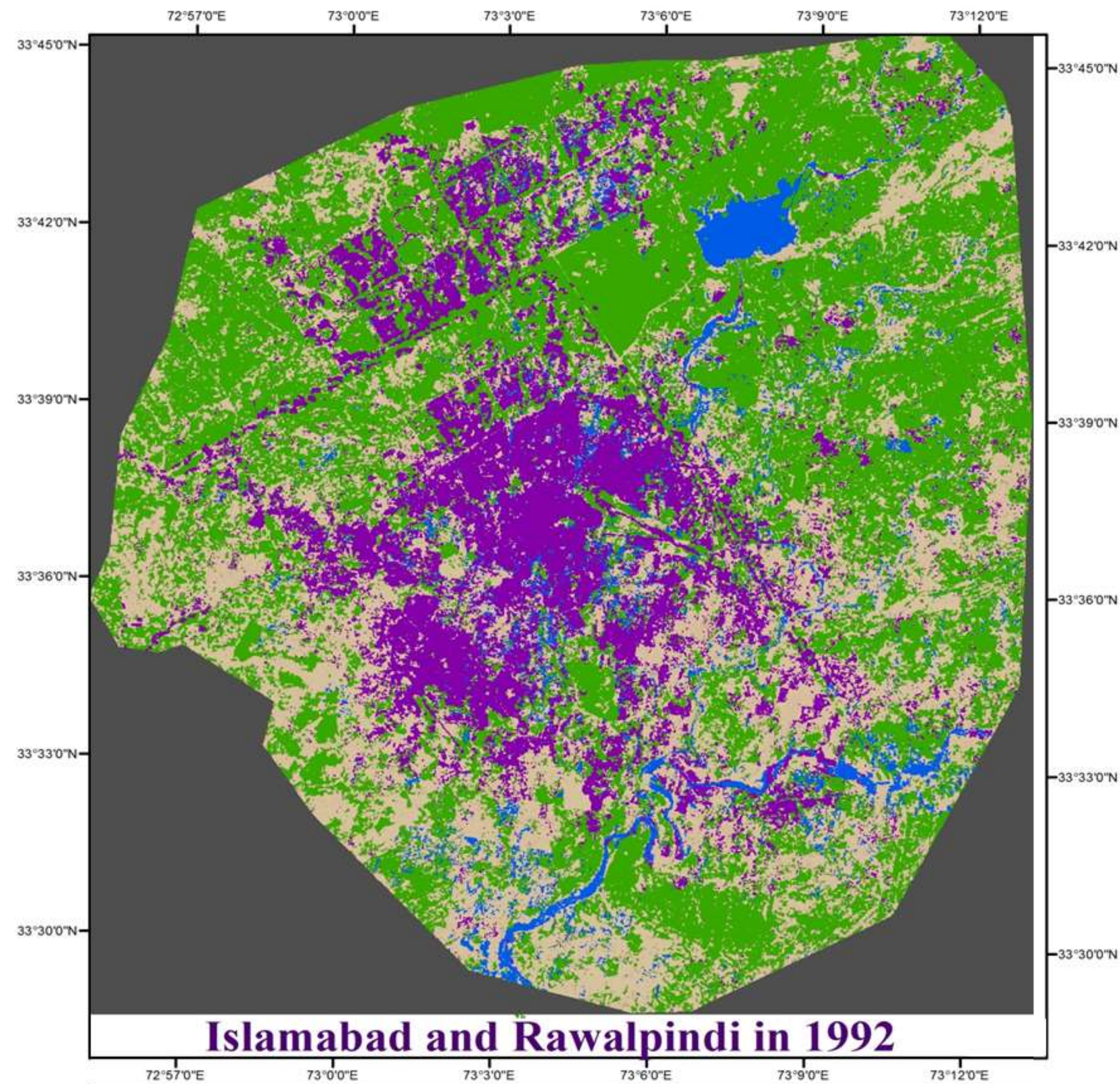

Figure 2: Classified Landsat images of twin cities for the year 1992.

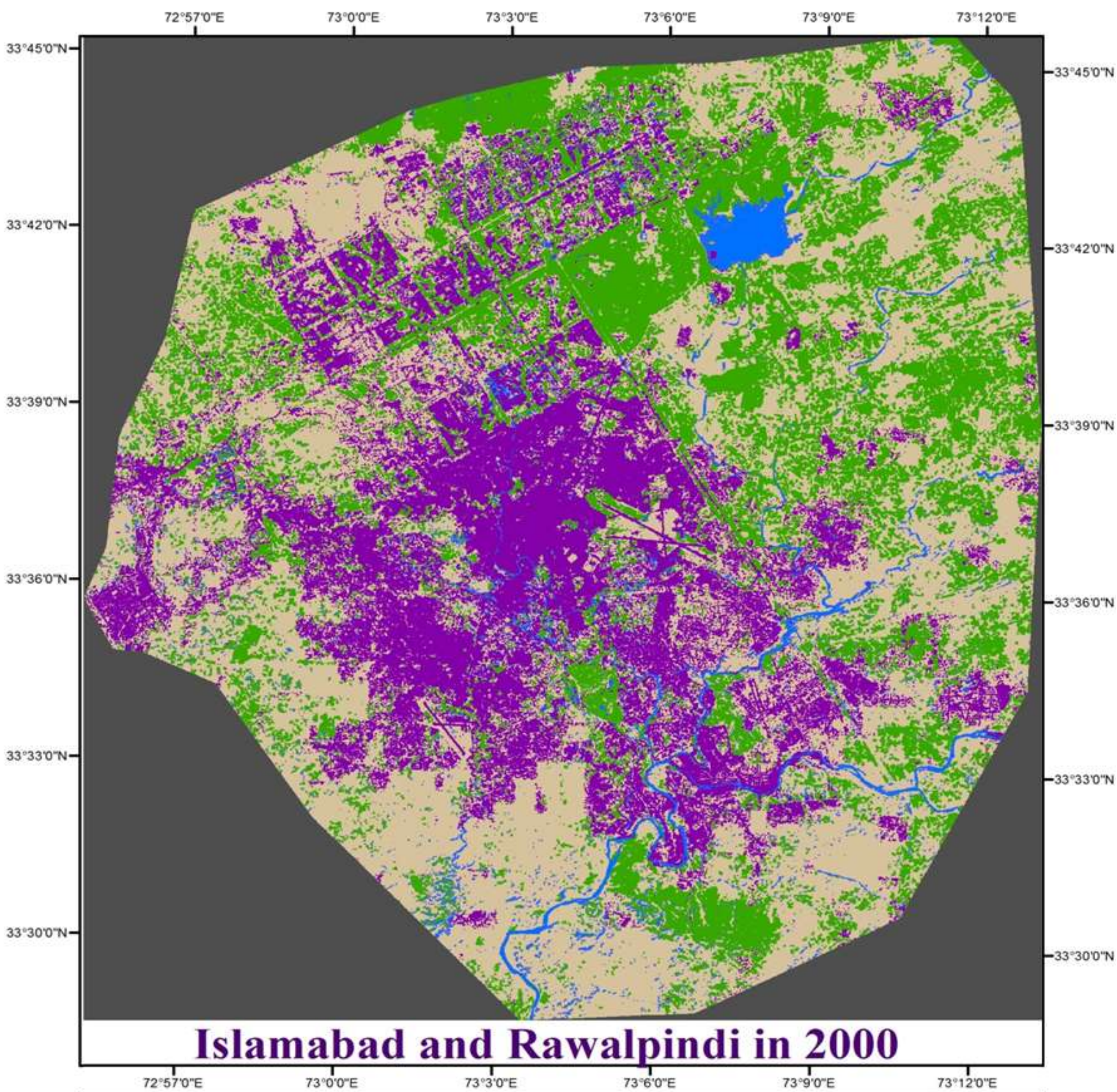

Figure 3: Classified Landsat images of twin cities for the year 2000.

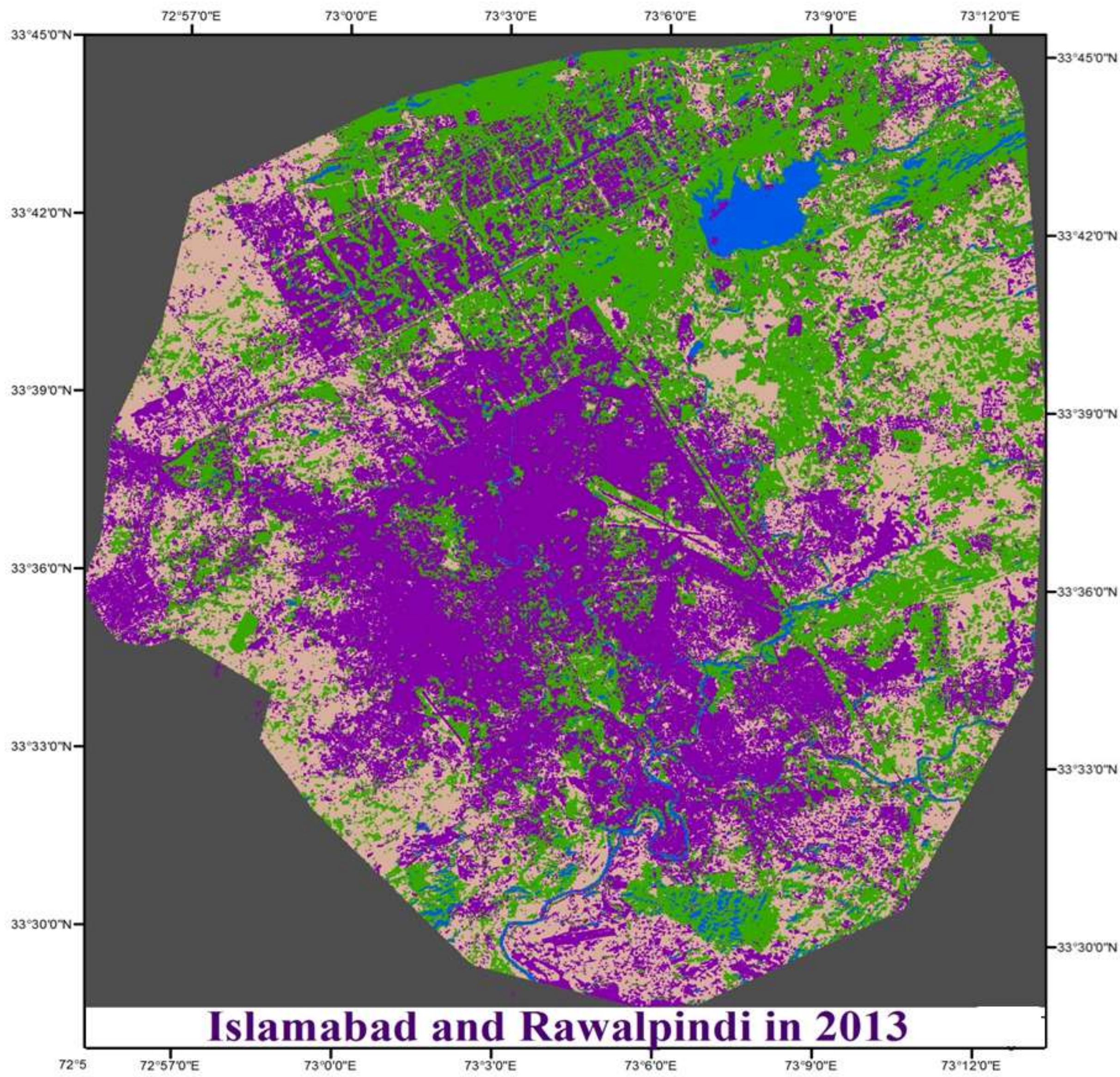

Figure 4: Classified Landsat images of twin cities for the year 2013.

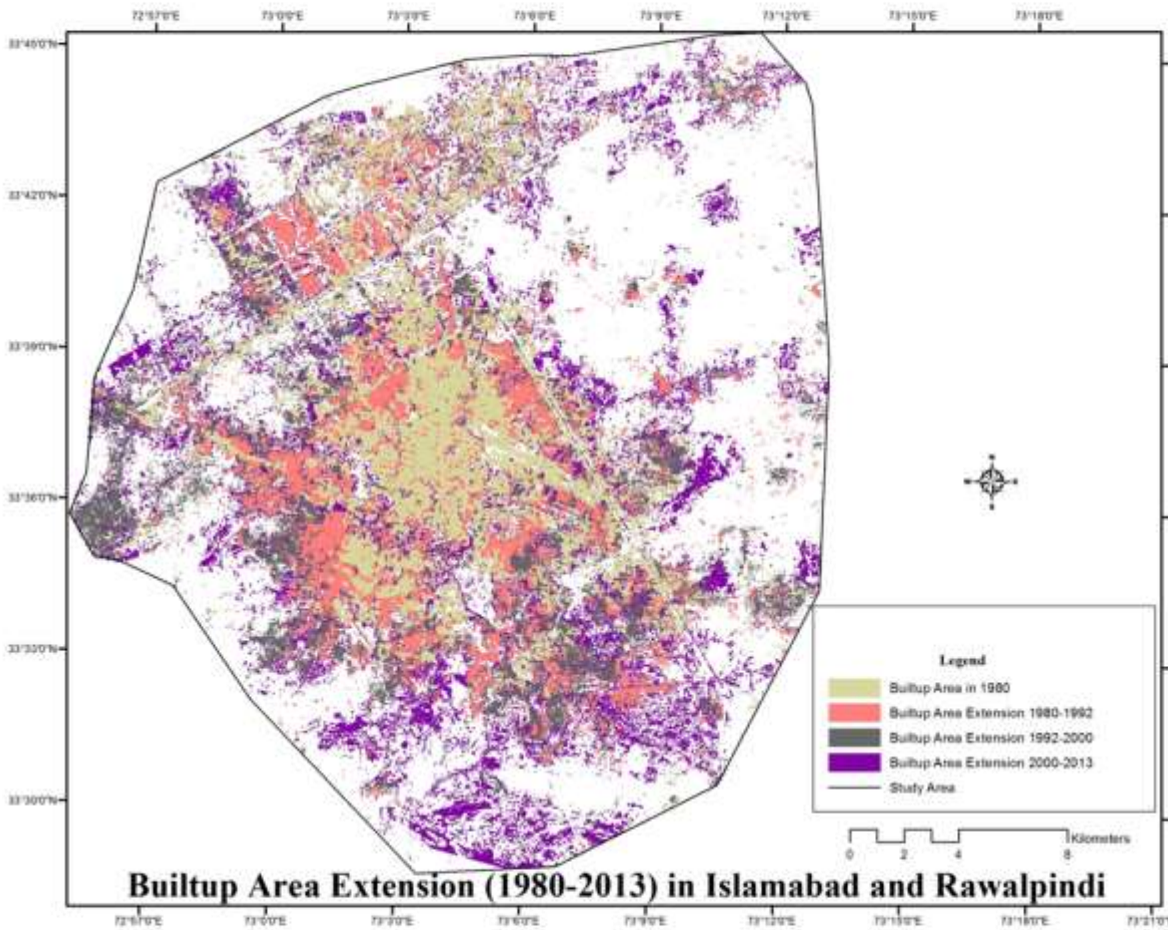

Figure 5: Classified Landsat image of twin cities showing the expansion of built-up area from 1980 to 2013.

Table 2: Error matrix for land classes of image 2000 to observe Kappa Coefficient.

	Actual Class					
	Landuse classes	Built up area	Vegetation	Water	Barren land	Total
Predicted Class	Built up area	27	1	0	2	30
	Vegetation	0	28	1	1	30
	Water	1	0	29	0	30
	Barren land	3	0	1	26	30
	Total	31	29	31	29	120

The value of Kappa Coefficient was measured from the following formula,

$$\text{Kappa coefficient} = \frac{n\sum_{k=1}^{q} n_{kk} - \sum_{k=1}^{q} n_{k+}n_{+k}}{n^2 - \sum_{k=1}^{q} n_{k+}n_{+k}}$$

where

n = number of observed points

k = number of cells in matrix diagonal

q = last cell in the diagonal

Another useful analytical technique is the computation of the kappa coefficient or Kappa Index of Agreement (KIA). It is capable of controlling the tendency of the PCC index to overestimate by incorporating all the off-diagonal values in its computation. The use of the off-diagonal values in the computation of the kappa coefficients also makes them useful for testing the statistical significance of the differences in different error matrices (given in table 3). The value of Kappa Coefficient was measured from the following formula:

K = Po – Pc / 1 – Pc

Where Po is the proportion of agreement between the reference and sample data i.e (PCC). Kappa coefficient varies from a minimum of 1 to a maximum of 0.

Pc = (row sum / N) x (Column sum / N) = Sum (row sum * column sum) / N*N

For our example built-up area = 30*31= 930; vegetation = 30*29= 870; water = 30*31= 930; barren land = 30*29= 870. Based on it Pc can be calculated as under:

Pc= 930+870+930+870 / 120*120= 3600/14400= 0.25.

Now we have Po= 0.917 and Pc=0.25 so

K= Po – Pc / 1 – Pc = 0.917-0.25/1-0.25= 0.667/0.75= 0.889.

Table 3: Kappa Coefficient and image accuracy.

Image	Kappa Coefficient	Accuracy
1980	0.72	77 %
1992	0.76	83%
2000	0.82	90%
2013	0.80	89%

3.3 Evolution in local temperature trends

3.3.1 Seasonal changes

Figure 6 highlights the dT_{min} and dT_{max} of four prominent seasons of Rawalpindi and Islamabad during 1983-2013. The minimum temperature in all seasons at Rawalpindi has been increasing more than the maximum temperature during last 31 years. In Rawalpindi too, the rapid dT_{min} and dT_{max} is computed during spring season where minimum and maximum temperatures increase to 3.2 °C and 2.6 °C, respectively. At this station, in winter there is less increase in minimum and maximum temperatures as compare to other seasons. On other hand, the figure shows that in Islamabad, both minimum and maximum temperatures are increasing in all seasons. But minimum temperature is increasing more than maximum temperature in all seasons. Further, minimum and maximum temperatures in Islamabad are increasing faster in spring season than other seasons. During spring, minimum and maximum temperatures increase to 2.5°C and 2.0°C, respectively, over 31 years. However, the increase in minimum and maximum temperatures is less in winter and autumn, respectively. It is noticed that comparatively during cold seasons (winter and autumn) maximum temperature has decreasing trends where it computed -0.1 °C for winter and -0.2 °C for autumn. The higher increase of T_{min} and T_{max} at both stations during spring may prolong or cause early summer in this region that may cause to modify the regional climate pattern.

3.3.2 Annual changes

Figure 7 represents annual dT_{min} and dT_{max} of Rawalpindi and Islamabad during 1983-2013. The figure shows that over the period of last 31 years, minimum and maximum temperature of both cities has been increasing. At both cities, annual minimum temperature increases more than the maximum temperature. But the increase in minimum temperature at Rawalpindi is higher than Islamabad and the increase in maximum temperature at Islamabad is higher than Rawalpindi. The higher increase of minimum temperature at Rawalpindi may be due to its bigger size and less vegetation cover as compare to Islamabad. However, it is the future motive to study it to find the reason of higher increase of T_{min} at Rawalpindi. Table 4 summarises the whole seasonal and annual results of dT_{min} and dT_{max} of twin cities.

3.3.3 Relationship between Built-up area and dT_{min} and dT_{max}

Figure 8 presents the effect of urban expansion since 1983 to 2013 on dT_{min} and dT_{max}. The average of minimum and maximum temperatures of Rawalpindi and Islamabad is computed and is then compared with built-up area. The study reveals that increasing built-up area caused to increase both T_{min} and T_{max} however; it is vibrant fact derived from results of figure 8 that growing built-up area has greater impact on minimum temperature and less impact on maximum temperature.

Table 4: Annual and seasonal changes in minimum and maximum temperatures since 1983 to 2013 of Rawalpindi and Islamabad.

		Winter	Spring	Summer	Autumn	Annual
Rawalpindi	dT_{min}	1.2	3.2	1.5	2.3	2.0
	dT_{max}	-0.1	2.6	0.4	-0.2	0.6

		Winter	Spring	Summer	Autumn	Annual
Islamabad	dT_{min}	1.3	2.5	1.4	2.1	1.8
	dT_{max}	1.2	2.0	0.9	0.8	1.2

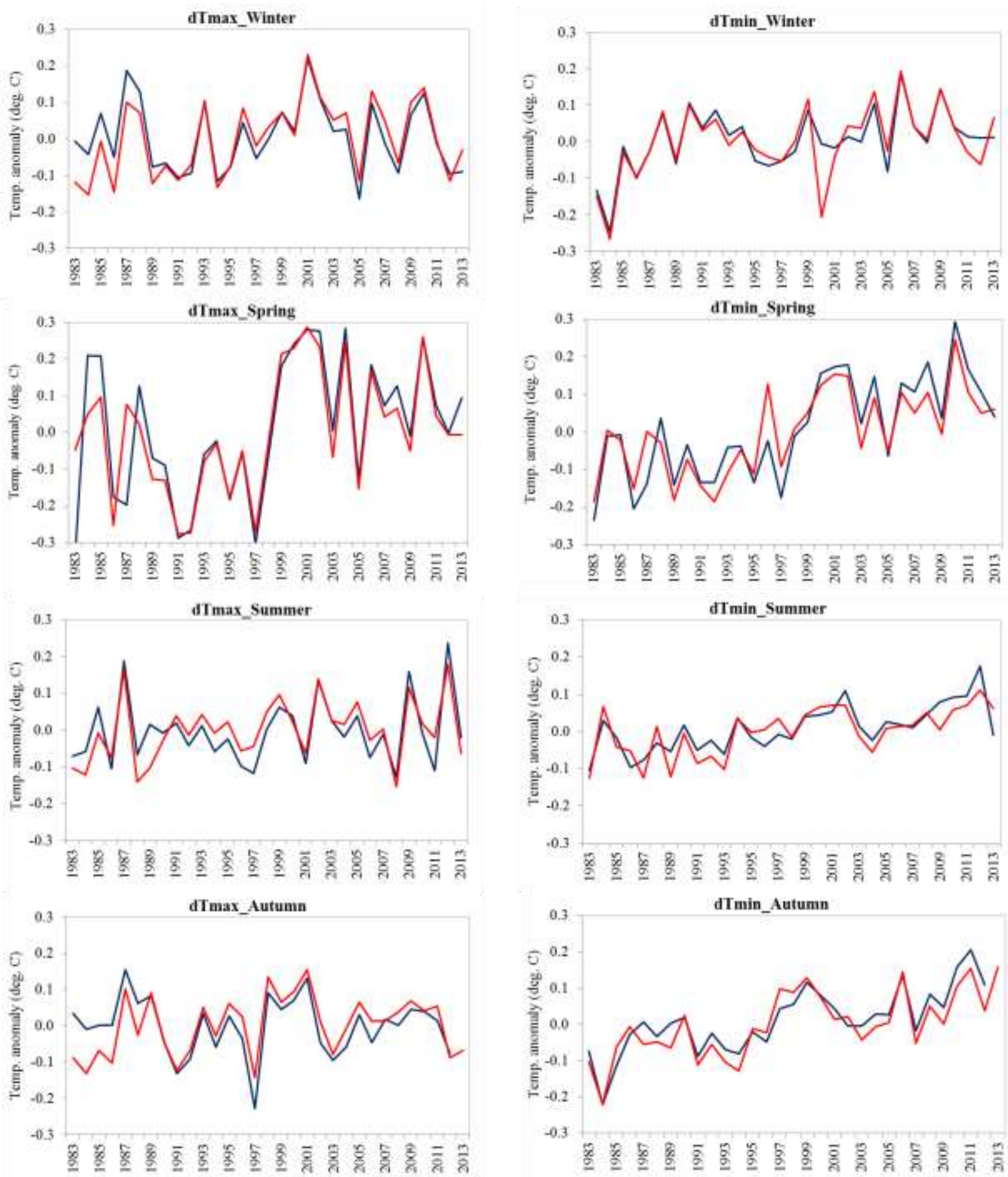

Figure 6: Seasonal daily average's monthly minimum and maximum temperature trends of Rawalpindi (blue solid line) and Islamabad (red solid line) for the period of 1983 to 2013.

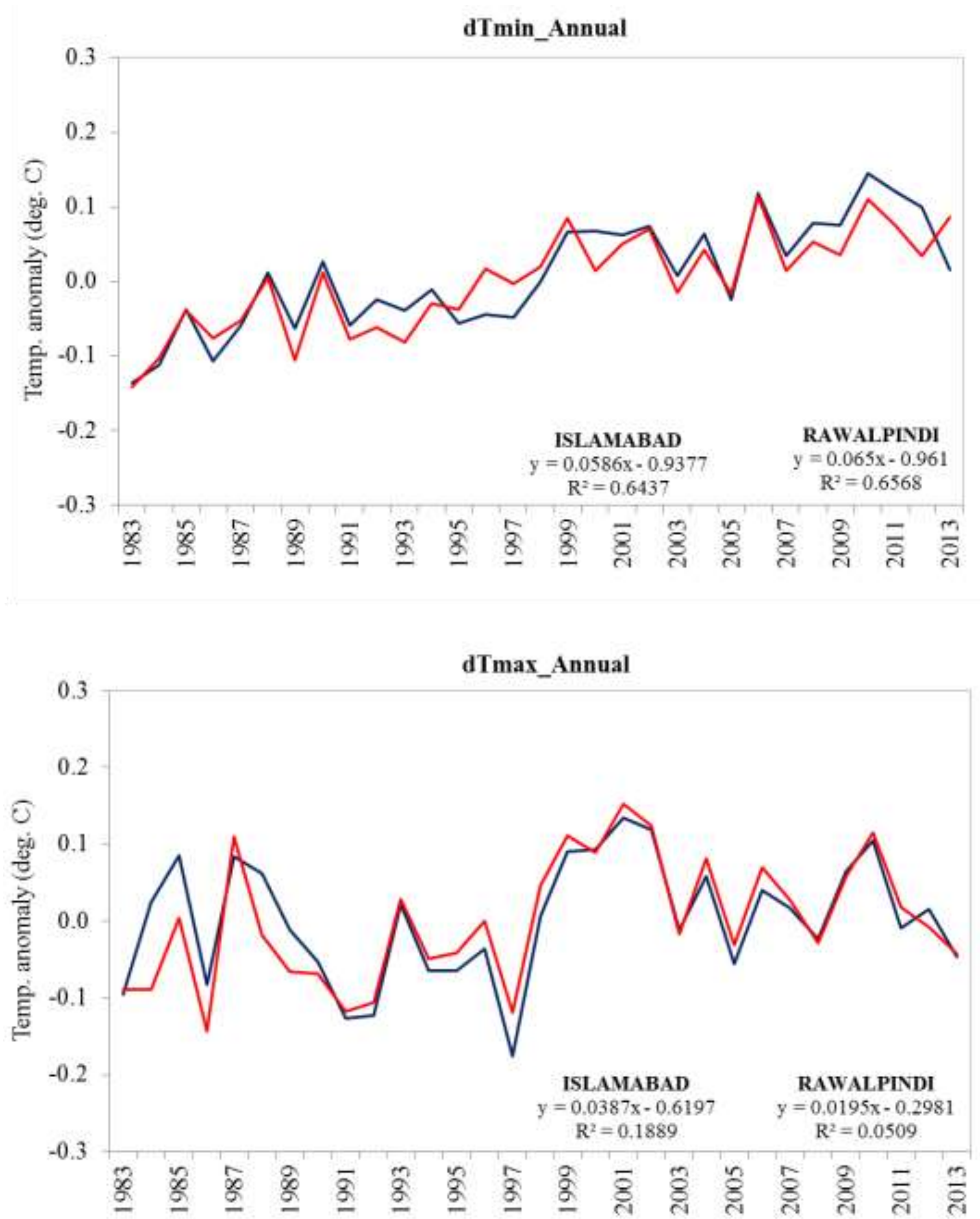

Figure 7: The variability in annual dT_{min} and dT_{max} of Rawalpindi (blue solid line) and Islamabad (red solid line) from 1983 to 2013.

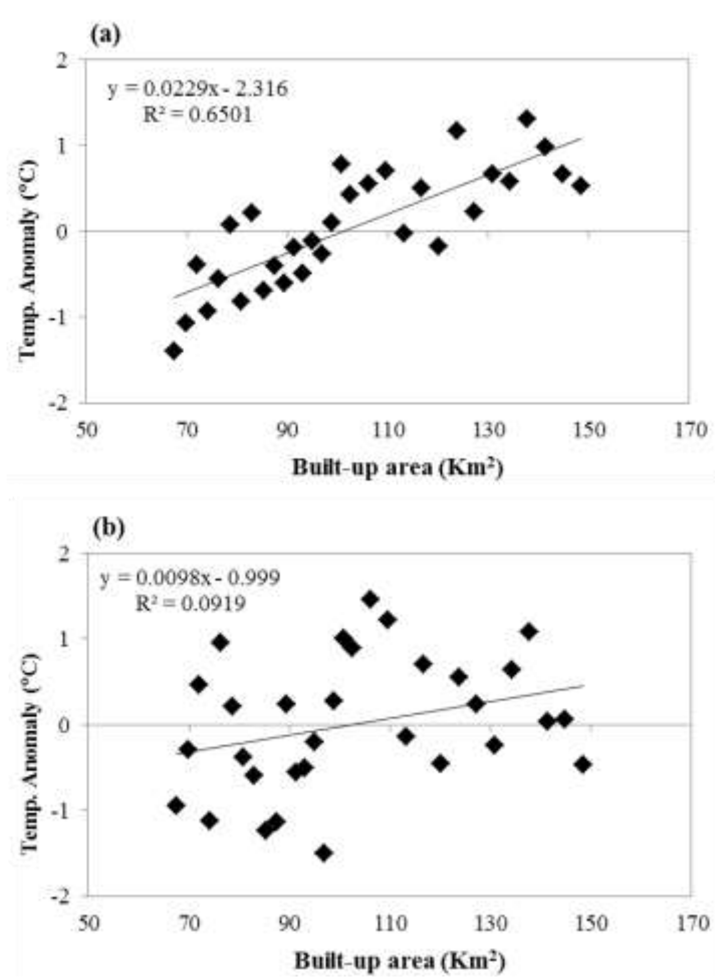

Figure 8: Built-up area of twin cities as a function of dT_{min} (a) and dT_{max} (b).

4. Conclusion

This study was accomplished to study the evolution of urbanization and potential effect of it on variability of minimum and maximum temperature of twin cities (Rawalpindi-Islamabad) during the period of 1983 to 2013. The analysis of data highlighted that both temperature of twin cities and built-up area increased with time. However it is found that minimum temperature of both cities increased faster than the maximum temperature. We can say that these results of higher growth in T_{min} than T_{max} are in coherent with other studies such as the studies of Chung et al. (2004); Sajjad et al. (2009); Wibig and Glowicki, (2002) where they found that the minimum temperature of urban areas is increasing more than the maximum temperature. The highest increase of T_{min} and T_{max} in spring season in this study is in agreement of the findings of Englehart and Douglas (2003). The relationship between change in minimum and maximum temperature and urban expansion revealed that urban expansion has significant effect of temperature trends (Yin et al., 2007). Yen et al. (2007) found that urban expansion has more effect on minimum and less effect on maximum temperature, similar to the above mentioned studies.

Generally, in most of the studies about urban areas climate, daily minimum temperature increased at faster rate as compare to daily maximum temperature resulting in decline in daily temperature range (DTR). But in some areas maximum temperature decreased as minimum temperature increased (Plantico et al., 1990; Karl et al., 1993; Kukla and Karl, 1993). The higher increase in minimum temperature at urban areas may be the result of increasing intensity of urban heat island. As the urban area has the significant effect on development of UHI due to its urban structure, the urban structure (paved surfaces, buildings, roads) absorb the solar energy during day times and re-emit it at night when there is no sun. This emission of heat from urban structure into atmosphere causes to modify the urban energy balance where urban areas experience higher temperature than the surrounding non-urban areas causing to develop urban heat island phenomenon.

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