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On rising temperature trends of Karachi in Pakistan

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Abstract Karachi is the largest city of Pakistan. The temperature change in Karachi is studied in this research by analyzing the time series data of mean maximum temperature (MMxT), mean minimum temperature (MMiT) and mean annual temperature (MAT) from 1947 to 2005 (59 years). Data is analyzed in three parts by running linear regression and by taking anomalies of all time periods: (a) whole period from 1947–2005; (b) phase one 1947–1975 and (c) phase two 1976–2005. During 1947 to 2005 MMxT has increased about 4.6°C, MMiT has no change and MAT has increased 2.25°C. During 1947–1975, MMxT increased 1.9°C, in this period there is −1.3°C decrease in MMiT and MAT has raised upto 0.3°C. During 1976–2005, the MMxT, MMiT and MAT increased 2.7°C, 1.2°C and 1.95°C, respectively. The analysis shows significantly the role of extreme vulnerability of MMxT in rising the temperature of Karachi than the MMiT.

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1 Introduction

Today, the world's population is approximately 6.5 billion and grows by nearly 80 million people each year (Economic Survey of Pakistan 2006). The urban population of the developing countries increased from 286 to 1,515 million during 1950 and 1990. This figure is expected to reach four billion by 2025 (Gupta 2004). During the course of the twenty-first century, scientific evidence points to global-average surface temperatures that are likely increasing by 2°C∼4.5°C. The current rate of global warming is 2°C per century (Salinger 2005). The global mean temperature will rise by at least 1.5°C by 2050. It is unlikely to rise by less, but it could rise by much more (Tickell 1990). Most of the urban growth in the developing world is concentrated in 'mega cities' (Mills 2006). The annual temperature increase in large urban areas is higher than the rural and marine stations (Chung et al. 2004).

Located on the Arabian Sea coast, Karachi is the largest city of Pakistan. It is the financial and commercial capital of Pakistan which generates 60% of the total national revenue. It has 18 million population with density of 4,115 persons/km^2. The city is divided into 18 major administrative towns (CDGK 2008). There is 5% annual increase in population that had lion jumps during 1975 to 2008. The urban area increased from 233 km^2 in 1947 to 3,566 km^2 in 2004 and population in 1947 was just 0.4 million but it reached up to 140 million in 2004 (Fig. 1) (Qureshi et al. 2008). So ever multiplying population and several unplanned development projects in the city have greatly affected the urban climate on alarming scales.

2 Environmental problems of study area

Pakistan is 6th largest country of the world on the basis of population. The urban share in total population of Pakistan was about 17% at the time of independence which has been raised up to 40% in 2006 (AUICK 2006). Since the emergence of Pakistan in 1947, the population of Karachi has seen 35-fold increases in its population and almost 16-fold increases in the spatial expansion (Qureshi and Lu 2007). Eleven of the world's 'global cities' are responsible for some 70% of CO_2

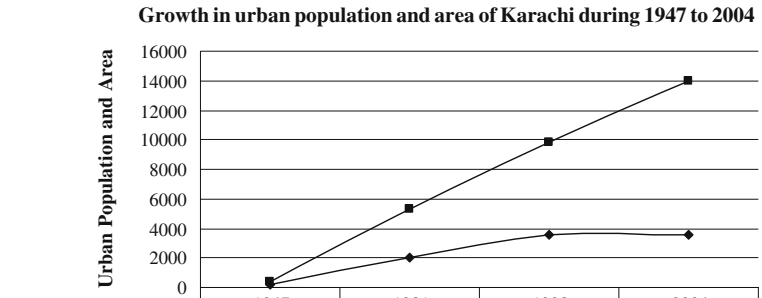

Fig. 1 Growth in urban population and occupied land area of Karachi during 1947 to 2004

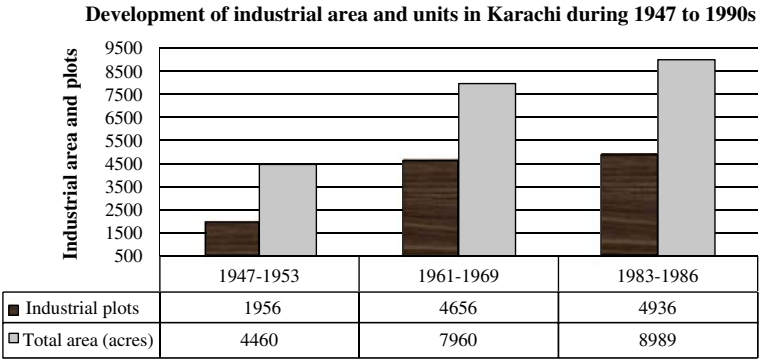

Fig. 2 Industrial development in Karachi. Numbers given under the time periods are indicating the total number of industrial plots and area under the industrial units

emissions and the same cities equally fundamental to global GDP (UCL Workshop 2005) and during the last ten years (1995–96 to 2004–05), the consumption of petroleum products, natural gas, electricity and coal in Karachi has increased at an average rate of 0.9%, 7.9%, 4.6% and 9.1% per annum, respectively. The number of vehicles has jumped from 0.8 million to about 4.0 million within last 20 years showing an overall increase of more than 400% (Economic Survey of Pakistan 2006). Total per-capita energy consumption in Pakistan is 12.4 million Btus (1 Btus = 1,055.05585 joules) that contribute 0.7 metric tons per-capita, energy related CO_2 emission (EIA, US 2008) and being as the largest city of Pakistan, Karachi is the major consumer of energy and contributor of CO_2. It has three major industrial zones in West Karachi, North Karachi and Southeast Karachi. In addition, it has a vibrant cottage industry in all areas of the city and there is a rapidly flourishing Free Industrial Zone with an annual growth rate of nearly 6.5%. Industrial area and industrial units during 1947 to 1986 increased 50% and 60%, respectively (Fig. 2; FPCCI Pakistan 2008).

3 Data and methodology

The time series data of mean minimum temperature (MMiT), mean maximum temperature (MMxT) and mean annual temperature (MAT) from 1947 to 2005 is used to find out the possible changes in temperature of the mega city of Pakistan. Temperature data is collected from Computerize Data Processing Center (CDPC), Pakistan Meteorological Department (PMD) Government of Pakistan. PMD is only reliable, competent and official source in Pakistan for meteorological data. The linear regression method is used to analyze the behavior of MMiT, MMxT and MAT for the last 59 years. It is analyzed in three ways: First the whole study period 1947–2005, then dividing the whole period into two phases i.e. 1947–1975 and 1976–2005. Trend lines on each graph are used to get the clear picture of the results. Furthermore, in this study the anomalies of MMxT, MMiT and MAT are also observed. Temperature is used as dependent variable while the time period is used as the independent variable which is specified as: Temperature $= f(\text{time})$ and $Y = \alpha +$

$\beta X + \mu$. Where, Y = mean temperature (minimum, maximum), X = time period and μ = error/random term. The t-value of each parameter is calculated to check the statistical significance that null hypothesis Ho: $\beta = 0$. The student's t statistic is calculated as

$$t_{\text{cal}} = \frac{\hat{\beta}}{\text{S.E}\left(\hat{\beta}\right)}$$

where $\hat{\beta}$ is the coefficient (i.e. slope) and S.E is standard error of $\hat{\beta}$ which shows the rate of change in temperature per unit time. It is calculated as

$$S_{yx} = \sqrt{\frac{\sum (y - \bar{y})^2 \frac{\left[\sum (x-\bar{x})(y-\bar{y})\right]^2}{\sum (x-\bar{x})^2}}{n-2}}$$

where n is the sample size. Data of urban area, population, industrial area and industrial plots/units is also analyzed in graphical format to identify the problems of expansion of city, its area and industrialization.

4 Results and discussions

The interannual variation and change in temperature of Karachi by analyzing through linear trends has shown significant results. The observed change in temperature is positive which has clear increasing trends in MMxT and MAT but MMiT has constant but little bit decreasing trends over the last 59 years. The urban temperature of Karachi has the greatest variation but it has a regular increase after 1975 to 2005. The linear trend lines along with anomalies of time series of mean MMxT, MMiT and MAT are presented in Fig. 3a–c and in Fig. 5 while time series of MMxT, MMiT and MAT are presented in Fig. 4a, b which are showing the temperature change in two different phases i.e. 1947–1975 and 1976–2005.

In Fig. 3a, the anomaly of time series data of MMxT has the most significant increase than any other time period or temperature parameter. There is an alarming increase in MMxT of Karachi since 1947 with out any significant decrease in temperature. During 1947 to 2005, the observed increase in MMxT is about 4.6°C that is 0.78°C increase per decade. This change in temperature is not uniform during the whole study period. MMxT in first phase (1947–1975) increased 1.9°C (Fig. 4a) while in later phase (1976–2005), it maximized up to 2.7°C (Fig. 4b).

The anomaly data of MMiT in Fig. 3b is showing the constant trend. From 1947–1974, there is a regular swift downfall in temperature. 1962 has the lowest record of MMiT throughout the observed data that was just 14.4°C but opposite of it, MMxT in this year is 31.7°C. Other meteorological observatories near or far of Karachi also observed the low minimum temperature during this year as Dalbandin 12.7°C, Khuzdar 14.9°C, Panjgur 14.1°C and Zhob 11.7°C. So this uncertain change in minimum temperature greatly affected the mean annual temperature of Karachi that is shown in Figs. 3c and 4a. The observed data also make it clear that the MMiT of Karachi shows an increase of 1.2°C during 1975–2005 and overall from 1947–2005, it is reduced −0.1°C.

Figure 3c is showing the regular increase in MAT with some significant decreasing fluctuations in 1962 and 1976. Overall results show that MAT increased about 2.25°C

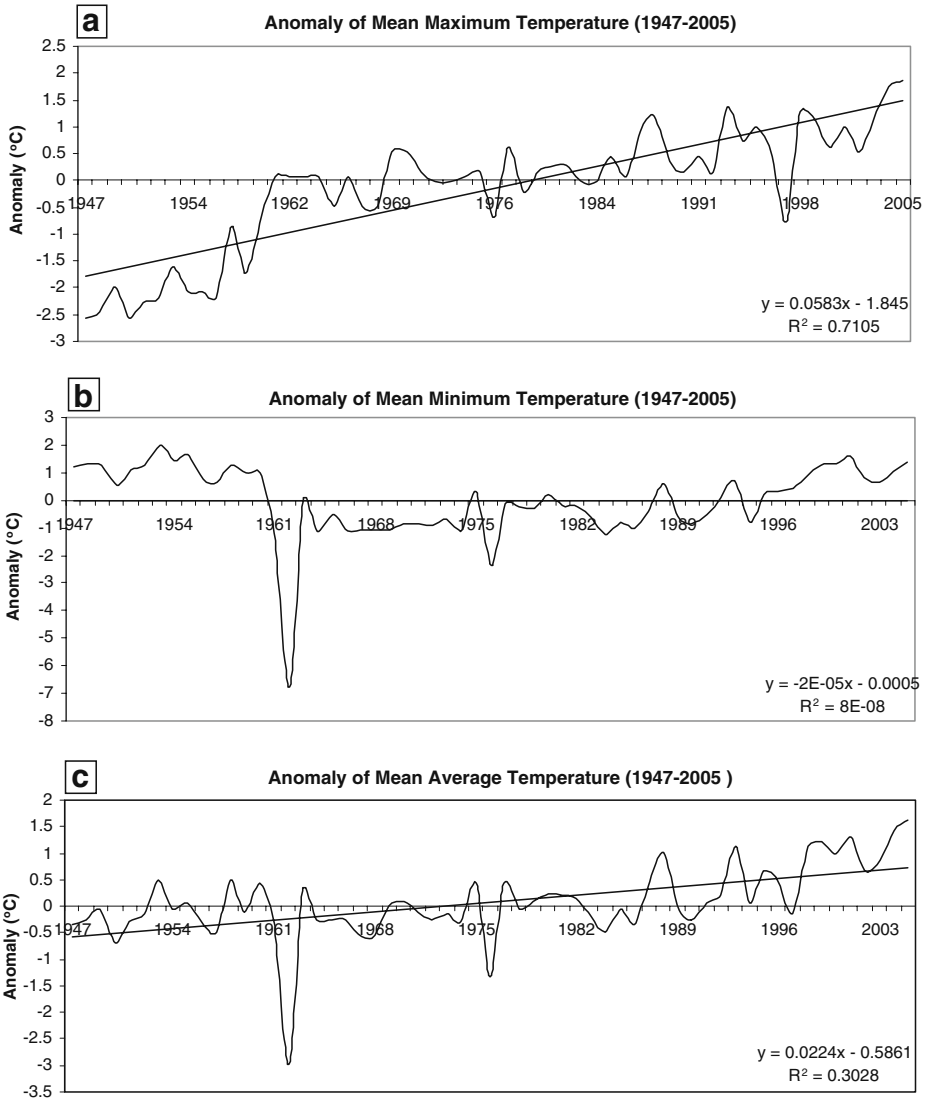

Fig. 3 **a–c** Annual surface temperature anomalies of Karachi during 1947 to 2005. **a** Maximum temperature; **b** minimum temperature and; **c** mean temperature

during the whole study period but this change in phase one is not more significant than the phase two. During 1947–1975, MAT increased only 0.3°C that is only 13.3% of total change. While during 1976–2005, it increased up to 1.95°C that is about 86.7 % of total change during last 59 years.

In Fig. 5, the anomalies of second phase are showing that there is almost no change during 1976–1987 but after 1987, the analysis are showing significant increasing trends in MMiT, MMxT and MAT. The increasing intensity of MMxT is higher than the MMiT which is greatly affecting the MAT during last 59 years.

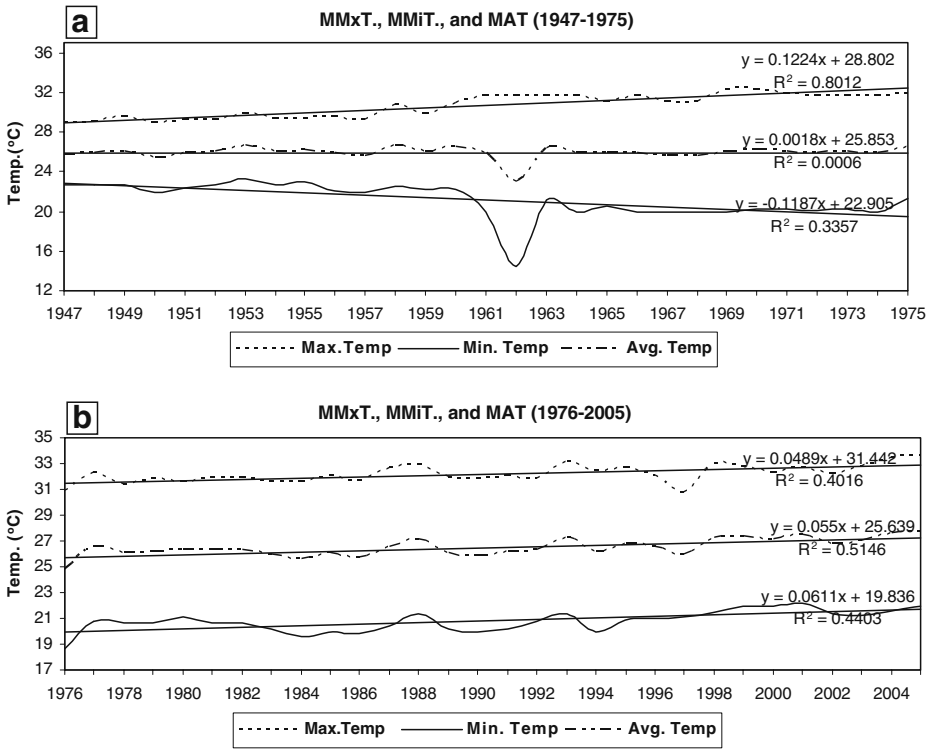

Fig. 4 **a** Annual surface maximum, minimum and mean annual temperature trends of Karachi during 1947 to 1975. **b** Annual surface maximum, minimum and mean annual temperature trends of Karachi during 1976 to 2005

The value of *t*-statistic is also calculated to check the significance of the parameters. All the parameters are found statistically significant at 5%. The regression of MMxT and MAT showed positive trends and are significant while that of MMiT showed negative trends during the study period i.e. 1947–2005. The coefficient of

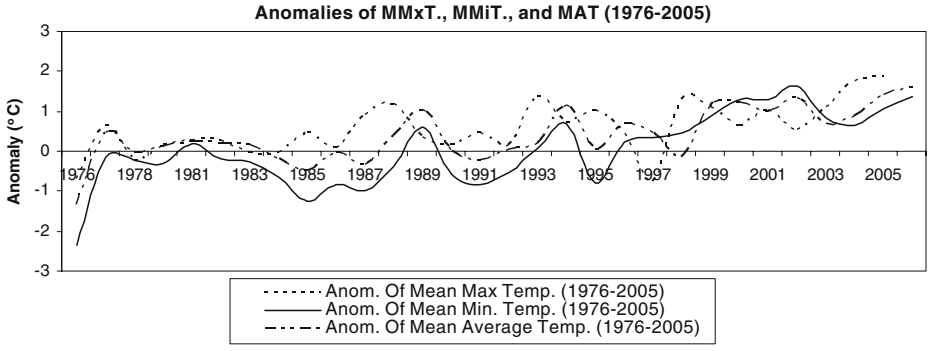

Fig. 5 Annual surface temperature anomalies of Karachi during 1976 to 2005

Table 1 Regression results by using temperature as dependent and time as an independent variable

Temperature	Time period	Regression results	
Mean maximum	1947–2005	$Y = 31.31636 + 0.0611X$	S.E (0.08946) (0.005635)
		t-statistics 350.02	10.8495
Mean minimum	1947–2005	$Y = 20.909 - 0.0119X$	S.E (0.18222) (0.005899)
		t-statistics 114.74	−2.0302
Mean annual	1947–2005	$Y = 26.112 + 0.00977X$	S.E (0.081) (0.0026)
		t-statistics 322.0669	3.7238
Mean maximum	1947–1975	$Y = 28.802 + 0.1224X$	S.E (0.2015) (0.01173)
	(phase-I)	*t*-statistics 142.89	10.4311
	1976–2005	$Y = 31.442 + 0.0489X$	S.E (0.2002) (0.0112)
	(phase-II)	*t*-statistics 157.022	4.335
Mean minimum	1947–1975	$Y = 22.905 - 0.1187X$	S.E (0.552) (0.03214)
	(phase-I)	*t*-statistics 41.49	−3.6936
	1976–2005	$Y = 19.836 + 0.0611X$	S.E (0.2311) (0.01302)
	(phase-II)	*t*-statistics 85.817	4.6937
Mean annual	1947–1975	$Y = 25.853 + 0.0018X$	S.E (0.2443) (0.1422)
	(phase-I)	*t*-statistics 105.79	0.1298
	1976–2005	$Y = 25.639 + 0.055X$	S.E (0.1792) (0.010)
	(phase-II)	*t*-statistics 143.037	5.447

The values in parenthesis show standard error and significance of *t*-statistics

time period is found significant positive in both first and second phases. However, the coefficient is negative and significant in first phase while it is positive and significant in second phase. Moreover, the average of mean minimum and mean maximum temperature showed positive and significant effect over both phases (Table 1).

5 Conclusion

The decade of 1990s is observed the warmest decade of the last century (WMO 2004). All over the world urban areas are being affected by urban climate change. Increasing temperatures of Dhaka, (Alam and Golam Rabbani 2007), increase of 2°C temperature of Saö Paolo since 1993 (Edmilson et al. 2007), increasing tendencies of Beijing temperatures from 1977–2000 (Liu et al. 2007), 0.28–0.44°C/10a increase rate of annual mean air temperature in city-belt of Yangtze River Delta in China (Yin et al. 2007) and 1.5°C increase in annual mean temperature of Seoul during last 29 years (Chung et al. 2004) are the global examples of urban climate change. Karachi is the rapidly growing city not only in Pakistan but also in South Asian region in respect of population, area and economic activities. It is the shelter to 11% population of Pakistan. About 55% growth in urban population and urban area is observed after 1990s. Until 1990s, the establishment of thousand heavy and small scale industries on vast area all around the city caused mass scale rural–urban migration throughout the country. This growth in population, urban and industrial area and economic activities forced to develop the infrastructure in the city but unfortunately during all these developments, climate friendly policies were not adopted to protect the urban climate to change on local level. Now Karachi is included in the list of those mega cities of the world which are highly vulnerable to the urban climate change mostly due to human activities.

The MMxT, MMiT and MAT of Karachi have significant positive trends of change. Overall there is 2.25°C increase in mean temperature since last 59 years. Per decade increase in mean temperature is 0.38°C which is ten times more than the global increase of temperature. The time period during 1947 to 1975 has less intensity of temperature growth than the time period 1976–2005. The contribution of first phase in increasing the mean temperature is only 13.3% (0.3°C) while the second study period has contributed 84.7% (1.95°C). If the temperature of Karachi continued increasing at the same rate, then it is possible that it will rise up to 3.9°C till the end of this century

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References

Alam M, Golam Rabbani MD (2007) Vulnerabilities and responses to climate change for Dhaka. Environ Urban 19(1):81–97

Asian Urban Information Centre of Kobe (AUICK) (2006) Workshop on population and sustainable development addressed by United Nation Fund for Population Activities (UNFPA), June 19–29, 2006, Kobe, Japan

Chung Y-S, Yoon M-B, Kim H-S (2004) On climate variations and changes observed in South Korea. Clim Change 66:151–161

City District Government Karachi (CDGK) Pakistan (2008) Karachi city geography and demography. http://www.karachicity.gov.pk/ URL accessed on November 22, 2008 at 10:27

Economic Survey of Pakistan (2006) Population, labour force & employment, Pakistan Federal Bureau of Statistics, part 13, pp 187–199

Edmilson FD, Rozoff Christopher M, Cotton William R, Silva Dias Pedro L (2007) Interactions of an urban heat island and sea-breeze circulations during winter over the metropolitan area of São Paulo, Brazil. Boundary-Layer Meteorol 122(1):43–65

Energy Information Administration (EAI) (2008) Official energy statistics from the US Government. http://tonto.eia.doe.gov/country/country_energy_data.cfm?fips=PK. URL accessed on November 23, 2008 at 23:47

Federation of Pakistan Chambers of Commerce & Industry (FPCCI) (2008) Industrial zones in Pakistan. http://www.fpcci.com.pk/industrialzone.asp. URL accessed on November 20, 2008 at 21:18

Gupta A (2004) Geoindicators for tropical urbanization. Environ Geol 42:736–742

Liu W, Ji C, Zhong J, Jiang X, Zheng Z (2007) Temporal characteristics of the Beijing urban heat island. Theor Appl Climatol 87:213–221

Mills G (2006) Progress toward sustainable settlements: a role for urban climatology. Theor Appl Climatol 84:69–76

Qureshi IA, Lu H (2007) Urban transport and sustainable transportation strategies: a case study of Karachi, Pakistan. Tsinghua Sci Technol 12:309–317

Qureshi IA, Lu H, Ye S (2008) Urban transportation and equity: a case study of Beijing and Karachi. Trans Res Part A 42:125–139

Salinger MJ (2005) Guest editorial, increasing climate variability and change: reducing the vulnerability. Clim Change 70:1–3

Tickell C (1990) Human effects of climate change: excerpts from a lecture given to the society on 26 March 1990. Geogr J 156:325–329

University College London Workshop (2005) Climate change and urban areas: 11–12 April 2005. University College London Environment Institute Report, pp 1–28

World Meteorological Organization (WMO) (2004) Press release no. 718. Geneva. www.wmo.ch/web/Press/Press718_E.doc. Accessed on November 15, 2008, at 14:53

Yin D, Zhiqing X, Yan Z, Yafeng S, Jingang W (2007) Impact of urban expansion on regional temperature change in the Yangtze River Delta. J Geogr Sci 17(4):387–398