The Nucleus 47, No. 4 (2010) : 301-311

The Nucleus
A Quarterly Scientific Journal of Pakistan Atomic Energy Commission
NCLEAM, ISSN 0029-5698

FORECAST MODELS FOR URBAN EXTREME TEMPERATURES : KARACHI REGION AS A CASE STUDY

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(Received June 07, 2010 and accepted in revised form November 03, 2010)

The climatic signature of global warming is both local and global. The forcing by increasing greenhouse gases is global, so there is clearly a global component to the climatic signature. Moreover, the damaging impacts of global warming are manifesting themselves around the world in the form of extreme weather events like storms, tornadoes, floods and droughts, all of which have been escalating in frequency and intensity. Furthermore, it is a well-known fact that there is high degree of uncertainty surrounding projections of basic climate variables, such as temperature and precipitation. However, numerous authors have explored many of these effects individually and have begun exploring the interactions between climate change-induced impacts in different sectors of urban activities. Therefore, it is safe to say that an attempt to conduct a definitive, comprehensive analysis of all the potential impacts of climate change on the urban structure is premature at present. This communication attempts to examine the trends in maximum monthly urban temperature fluctuations. Analysis reveals increasing trends in urban temperature fluctuations showing effect of Karachi industrializations. Forecast models also suggest future scenario with respect to occurrence of extreme temperature. The analysis carried out in this work would be useful for urban planners for sustainable future development, economists and environmentalists etc.

Keywords : Global warming, Temperature fluctuations, Greenhouse gases, Climate, ACF and PACF

1. Introduction

Global warming (GW) is now an accepted fact that is influencing the lower atmosphere as well as the oceans of the globe [1] and that the climate parameters remain in dynamic equilibrium [2]. In addition, the dynamics of the climate system is chaotic [3-4]. Thus for a better planning, urban planners need to have a clear insight of the situation in future. This requires plausible forecasts of future population and other urban parameters. Fortunately, over the years, researchers have successfully developed sophisticated tools for obtaining better forecasts to support urban planning and management. In recent years, increasing number of studies has appeared dealing with the impact of intense heat on health of urban dwellers [5].

Here, we are not attempting to make a comprehensive assessment of the scientific literature corresponding to climate change. However, to mention some, are the significant correlation between eleven years sun sunspots cycles and ozone layer depletion over arctic region determined by [6-7], the determination of the presence of positive trend in global warming making the quantity of seawater increase due to increasing input from the lakes, underground water, and polar region glaciers and the acceleration in its fluctuations of the GW [8]. Situation in different regions can differ because of different structure, climatic conditions and different conditions of the oceans but the basic facts remain the same. However, the consequences can differ [9]. Urban structures parameters, for example, thermal and radioactive properties of the artificial surfaces modify the climate at both city scale and local scale. The main influence of the cities on microclimate is the heat island caused by radioactive trapping in urban materials. To predict overheating periods within the urban region, this communication attempts to give short- and long-

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term forecasts of urban extreme temperatures. Long-term forecasts are specially used by urban planners in designing of urban reserve areas and are more importantly, for sustainable urban development.

The use of time series provided by modern remote sensing platforms, in particular improves the quality of derived ecological indicators. These indicators can be generated on a global scale from optical/thermal remote sensing data. The quality of ecological indicators, especially in complex terrain, is determined by thorough pre- and post-processing of the data in order to minimize artifacts in the resulting maps. The MODIS sensor is currently the optimal match between temporal and spatial resolution and is an excellent data source for both local and global change research.

The paper is organized as follows. Section 2 reviews ARIMA modeling theory briefly. In Section 3, urban monthly maximum temperature fluctuations are modeled. Section 4 gives a comparison of trends of 47 years mean monthly maximum temperature fluctuations of the mega city of Karachi with Hyderabad, a much smaller city. Finally, Section 5 concludes this work.

2. Time Series Analysis

In general, the primary goals of conducting a time series analysis are:

a. Characterizing the nature of the phenomenon represented by the sequence of observations, and

b. Forecasting or predicting future values of the time series variable. The focus of this study is on the forecasting capabilities of the models.

Hydrologic processes usually exhibit time dependence, known as autocorrelation, between a given observation at some time t denoted by z_t and some previous observations, z_{t-1}, z_{t-2} etc. and with those occurring at the same time during the previous season(s), denoted by z_{t-s}. The autoregressive, integrated, moving-average (ARIMA) model developed by Box and Jenkins (1976), is denoted as ARIMA $(p, d, q) \times (P, D, Q)_s$, where

p = order of the non-seasonal autoregressive process,

d = number of consecutive differencing,

q = order of the non-seasonal moving average process,

P = order of the seasonal autoregressive process,

D = number of seasonal differencing,

Q = order of the seasonal moving average process, and

s = the span of the seasonality.

Box (1994), developed a systematic class of models called autoregressive integrated moving average (ARIMA) models to handle time-correlated modeling and forecasting [10-11]. The ARIMA methodology has gained enormous popularity in many areas, and research practice confirms its power and flexibility, especially when patterns of the data were unclear and individual observations involved considerable error [12]. In this study, their application to seasonal data is particularly important. The Box-Jenkins approach consists of extracting the predictable movements from the observed data. It primarily makes use of three linear filters known as the autoregressive, the integration and the moving average filter. The objective in applying these filters is to end up with a white noise process which is unpredictable. Once this is done successfully, we have a model that has properties similar to the process itself. This model can then provide a basis for accurate and reliable forecasts. By combining differencing, autoregressive and moving-average representations in one model, Box and Jenkins were able to propose a parsimonious class of models called the ARIMA models [13]. They are applied in some cases where data show evidence of non-stationarity, where an initial differencing step (corresponding to the "integrated" part of the model) can be applied to remove the non-stationarity. The Box –Jenkins procedure has been found useful by many researchers but extremely complex, requiring quite a bit of experience to use effectively. Next, we apply this modeling technique to the Arabian Sea monthly averaged seawater temperature data to obtain reliable forecast models [14].

3. Time Series Models for Maximum Temperature Fluctuations

This section reports the ARIMA forecast models using mean monthly maximum temperatures (1961-2007) of Karachi region. The forecasts are made for 2008-2012 Computer software MINITAB version 14 was used for the estimation of statistically significant model parameters. Appropriated models were selected for which values of modified Box-Pierce Q-statistic and Auto Integrated Correlation AIC = $\sigma_k^2 + \frac{\eta + 2k}{\eta}$ showed minimum. In AIC, $\sigma_k^2 = \frac{RSS_k}{\eta}$ and k is the number of parameters in the model. The value of k yielding the minimum AIC specifies the best model [21]. On the basis of Autocorrelation Function (ACF) and Partial Autocorrelation Function(PACF) structure it is possible to create parametric mathematical models that are able to simulate a data generating process and extrapolate the time series to the future periods (Figs.1-12).

Models for January to December(1961-2007) appear in Table1. Forecasts (2008 -2012), with 95% Confidence Intervals (CI)) based on these models appear in Table 2. Note that the breadth of CI increases as we go far into the future (Figs. 1-12).

4. Comparison of Karachi Urban Extreme Temperatures with Hyderabad Urban Extreme Temperatures

To show that global warming is affecting the mega cities more than the smaller cities, we compare the extreme temperatures of the coastal mega city of Karachi and the comparatively smaller city of Hyderabad. In the ranking of mega cities, Karachi appears at 8^{th} position. Its estimated population (2009) are between 12 and 18 million. Located in the south of Pakistan on the coast of the Arabian Sea (geographic coordinates 24°51′ N 67°02′ E [15] Karachi has a relatively mild, arid climate with low average precipitation levels (approximately 250 mm per annum), the bulk of which occurs during the July-August moonsoon season. Karachi's highest recorded temperature is 48 °C (118°F) and its lowest is 0.0 °C (32 °F) [16]. Winters are mild and the summers are hot; the proximity to the sea maintains humidity levels at a near-constant high and cool sea breezes relieve the heat of the summer months.

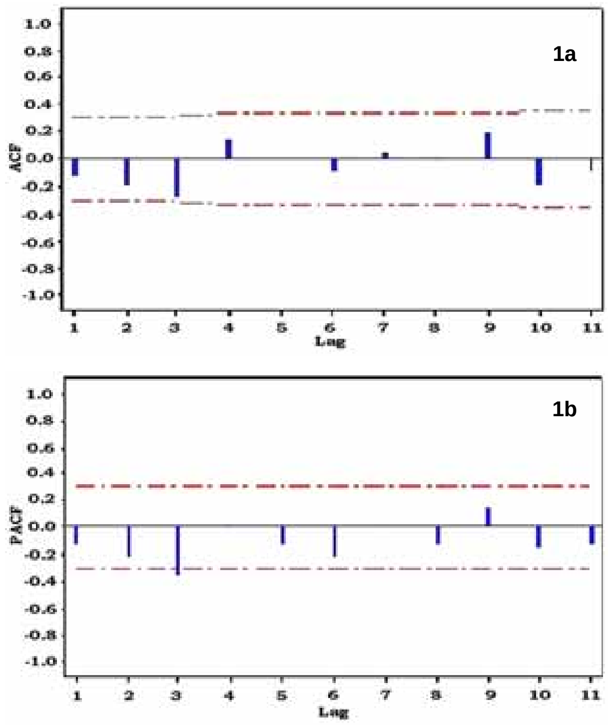

Figure 1. (a, b) Estimated ACF and PACF of residuals from the fitted model showing a weak correlation χ^2 value of most appropriate model is = 12.9.

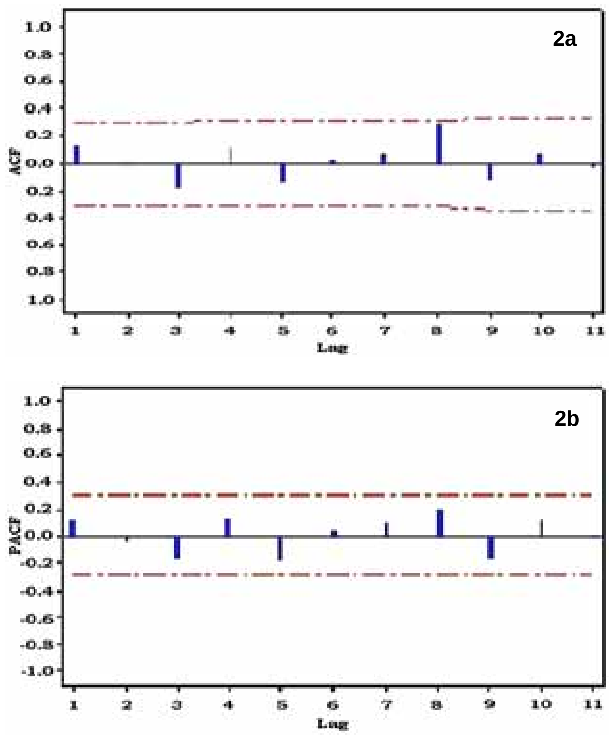

Figure 2. (a, b) Estimated ACF and PACF of residuals from the fitted model showing a weak correlation χ^2 value of most appropriate model is = 9.0.

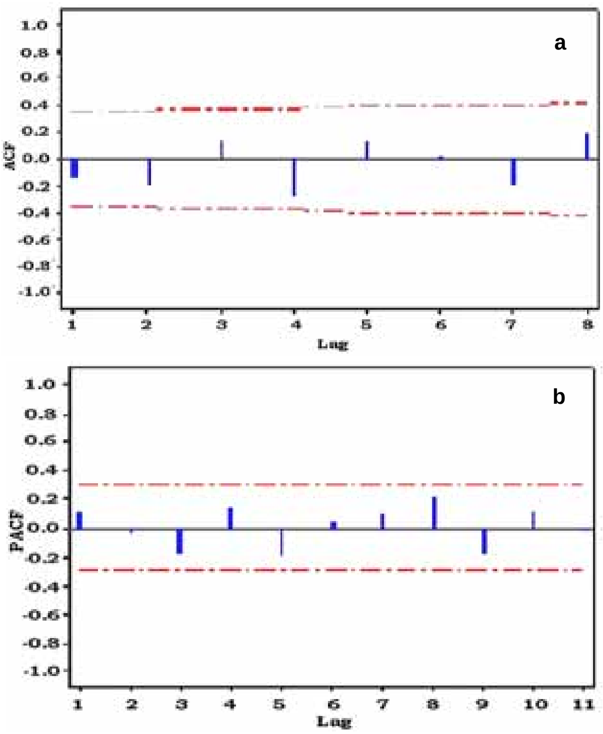

Figure 3. (a, b) Estimated ACF and PACF of residuals from the fitted model showing a weak correlation χ^2 value of most appropriate model is = 17.4.

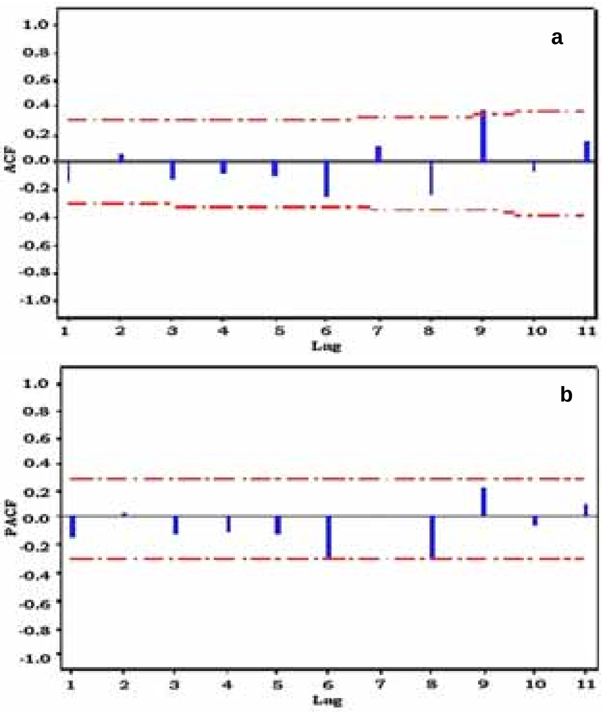

Figure 4. (a, b) Estimated ACF and PACF of residuals from the fitted model showing a weak correlation χ^2 value of most appropriate model is = 19.3.

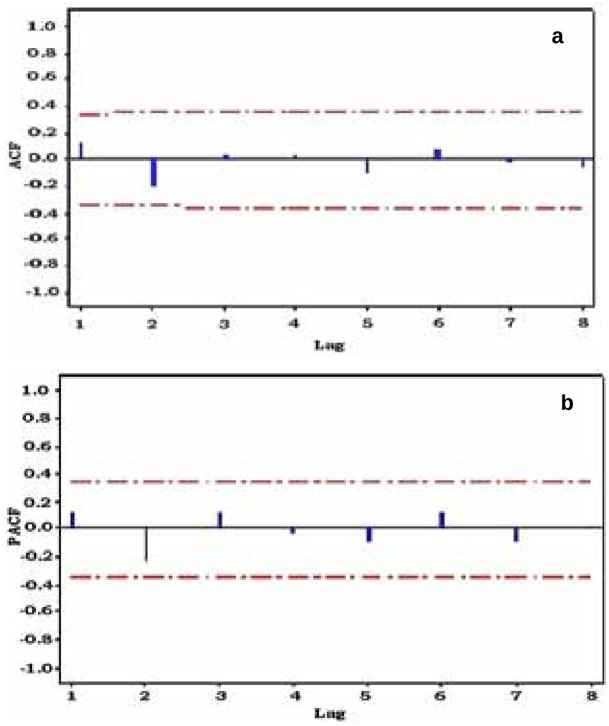

Figure 5. (a, b) Estimated ACF and PACF of residuals from the fitted model showing a weak correlation χ^2 value of most appropriate model is = 7.8.

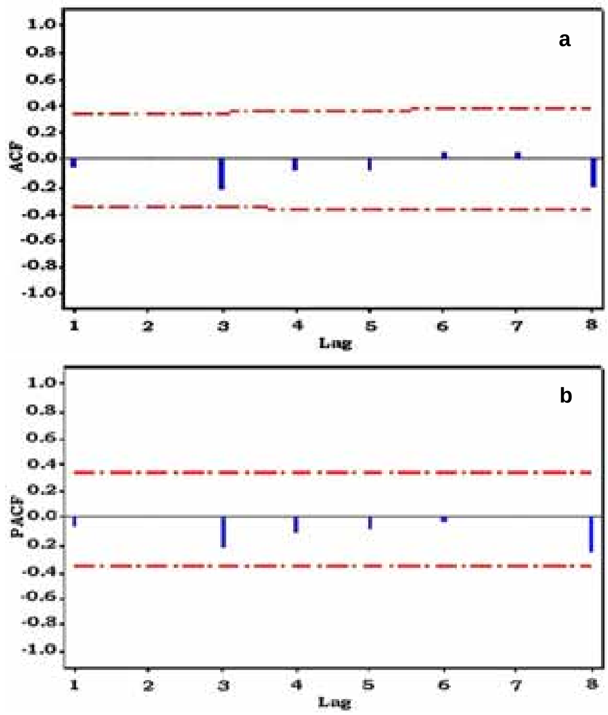

Figure 6. (a, b) Estimated ACF and PACF of residuals from the fitted model showing a weak correlation χ^2 value of most appropriate model is = 6.3.

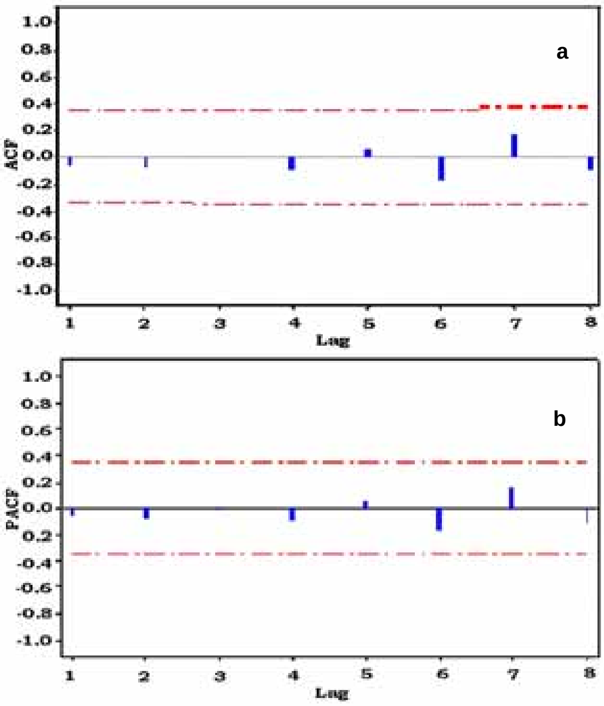

Figure 7. (a, b) Estimated ACF and PACF of residuals from the fitted model showing a weak correlation χ^2 value of most appropriate model is = 7.6.

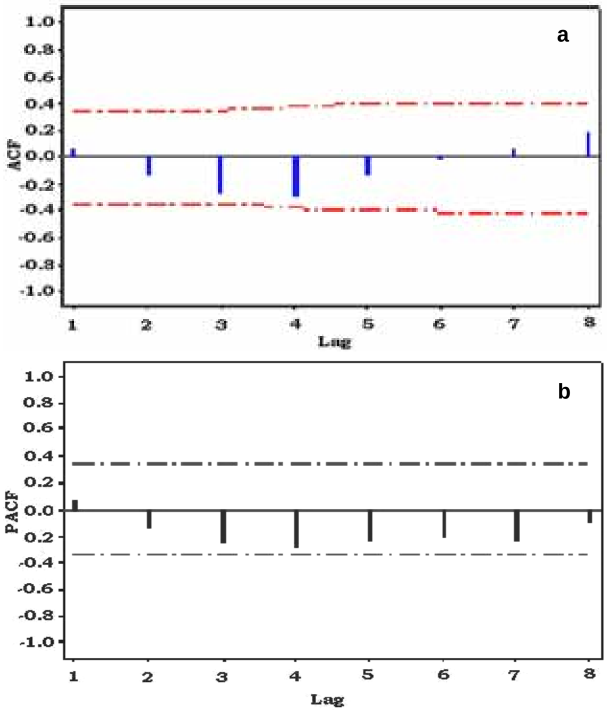

Figure 9. (a, b) Estimated ACF and PACF of residuals from the fitted model showing a weak correlation χ^2 value of most appropriate model is = 27.0

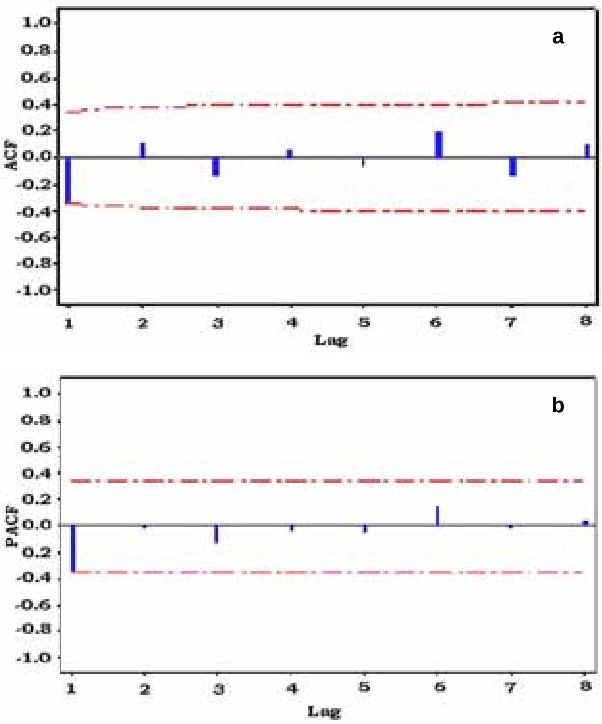

Figure 8. (a, b) Estimated ACF and PACF of residuals from the fitted model showing a weak correlation χ^2 value of most appropriate model is = 21.0.

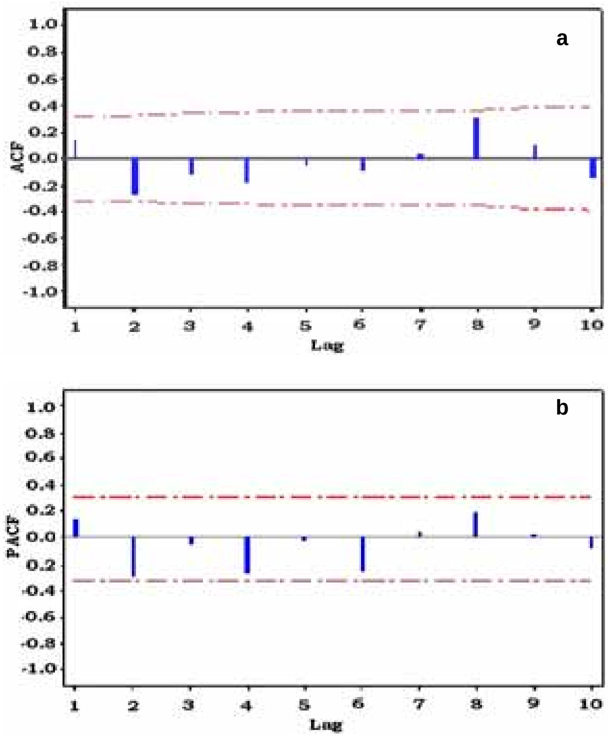

Figure 10. (a, b) Estimated ACF and PACF of residuals from the fitted model showing a weak correlation χ^2 value of most appropriate model is = 14.8.

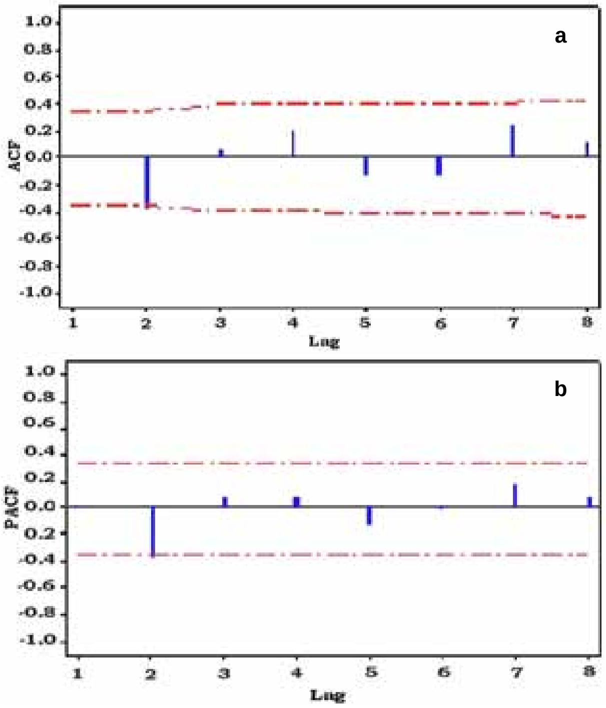

Figure 11. (a, b) Estimated ACF and PACF of residuals from the fitted model showing a weak correlation χ^2 value of most appropriate model is = 22.3.

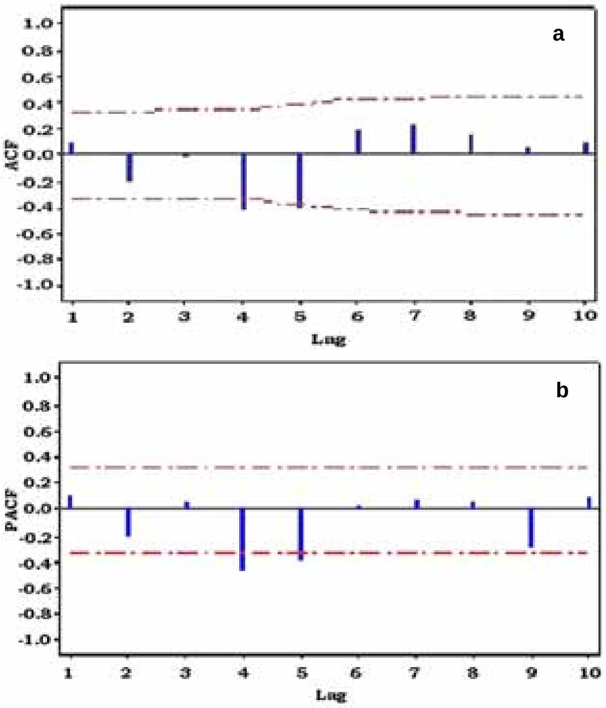

Figure 12. (a, b) Estimated ACF and PACF of residuals from the fitted model showing a weak correlation χ^2 value of most appropriate model is = 30.2

High temperatures ranging from 30 to 44 degrees Celsius occur from April to August while low temperature occur from November to February. December and January have pleasant and cloudy weather. In 2003, 2006, 2007 and 2009, Karachi was affected by heavy to extremely heavy rainfall. On June 23, 2007, heavy downpours and strong windstorms took place. The city's highest monthly rainfall - 711.5 mm (28.0) inches - occurred in July 1869 [17].

The city of Hyderabad is the second largest city in Sindh, eighth largest in Pakistan and 209th largest city of the world with respect to population. Its estimated population is close to 1,348,288. Hyderabad city is located on the east bank of the Indus River and is roughly 150 km away from Karachi. Hyderabad is located at 25.367°N latitude and 68.367°E longitude with an elevation of 13 m (43 ft) [18]. The city features a hot arid climate with extremely hot summers and mild winters. Hyderabad has an extreme climate. The days are hot and dry usually going up to extreme height of 40°C, whilst the nights are cool and breezy. Winds that blow usually bring along clouds of dust and people prefer staying indoors in the daytime while the breeze at night is pleasant and clean. In recent years, Hyderabad has seen spills of heavy downpour [19]. Hyderabad received 105 millimetres of rain in 12 hours contributing towards a sudden climate change in Feb. 2003. Years 2006 and 2007 saw close contenders to this record rain with death toll estimated in hundreds all together. Although on July 18, 2009 a total of 110mm rain lashed the city, setting a new record.

Table 3 gives a comparison of the annual linear trends of Karachi and Hyderabad (in °C/decade temperature series (1961 – 2007). It can be easily observed that the trend for Karachi is positively increasing in contrast to Hyderabad which is more or less steady (in some cases it is clearly negative). One reason may be the impact of global warming affecting via the Arabian Sea. In Ref. [20] observations of Khan supports this point of view.

Coming back to Table 1 once again, it can be observed that the forecasted values of maximum temperature from January to May and from October to December show a clear increase in the initial years and a slight decrease in the ending years. From June to September the temperature values increased continuously.

Table 1. Models estimates for the month of January to December (1961-2007).

Months	Model	Type	Coefficient	SE of coefficient	T-statistic	P-value
January	ARIMA(3,1,1)	AR 1	-1.6067	0.2173	-7.39	0.000
		AR 2	-1.0879	0.2708	-4.02	0.000
		AR 3	-0.3954	0.1860	-2.13	0.039
		MA 1	-0.3954	0.1591	-6.07	0.000
February	ARIMA(1,1,1) × $(0\ 0,\ 1)_{12}$	AR 1	-0.2849	0.1565	-1.82	0.076
		MA 1	1.0080	0.1022	9.86	0.000
		SMA 12	0.7329	0.1640	4.47	0.000
		Const	0.0348	0.0056	6.25	0.000
March	ARIMA(0,1,1) × $(0,\ 1,0)_{12}$	MA 1	0.9362	0.0858	0.91	0.000
April	ARIMA(0,1,1) × $(0\ 0,\ 1)_{12}$	MA 1	0.8703	0.1175	7.41	0.000
		SMA 12	0.8351	0.1744	4.79	0.000
		Const	0.02987	0.0124	2.40	0.021
May	ARIMA(0,1,2) × $(1\ 1,\ 1)_{12}$	SAR 12	-0.5296	0.2005	-2.64	0.013
		MA 1	1.2916	0.1453	8.89	0.000
		MA 2	-0.3802	0.1521	-2.50	0.018
June	ARIMA(0,1,1) × $(1\ 1,\ 0)_{12}$	SAR 12	-0.9529	0.1482	-6.43	0.000
		MA 1	0.9394	0.1288	7.30	0.000
		Const	-0.0572	0.0081	-7.06	0.000
July	ARIMA(0,1,1) × $(1\ 1,\ 1)_{12}$	SAR 12	-0.9691	0.2904	-3.34	0.002
		MA 1	0.8919	0.1187	7.52	0.000
		SMA12	0.6654	0.2807	2.37	0.024
		Const	0.0179	0.0088	2.04	0.050
August	ARIMA(0,1,1) × $(1\ 1,1)_{12}$	SAR 12	-0.9898	0.0942	-10.50	0.000
		MA 1	0.9192	0.0698	13.17	0.000
		SMA12	-0.5533	0.2772	-2.00	0.055
September	ARIMA(0,1,1) × $(0\ 1,\ 1)_{12}$	MA 1	0.8421	0.1086	7.75	0.000
		SMA 12	0.6183	0.2422	2.55	0.016
October	ARIMA(0,1,1) × $(1\ 1,1)_{6}$	SAR 6	-0.4416	0.2035	-2.17	0.037
		MA 1	0.9034	0.1053	8.58	0.000
		SMA 6	0.7779	0.2049	7.75	0.001
		Const	0.0192	0.0057	2.55	0.002
November	ARIMA(1,1,1) × $(1\ 1,\ 0)_{12}$	AR 1	0.4674	0.1880	2.49	0.019
		SAR 12	-0.9941	0.0564	-17.62	0.000
		MA 1	0.9576	0.0564	14.18	0.000
		SMA 12	-0.6708	0.2404	-2.79	0.009
December	ARIMA(1,1,1) × $(1\ 1,\ 0)_{12}$	SAR 6	-0.4380	0.2258	-1.94	0.060
		MA 1	1.0310	0.0899	11.47	0.000
		SMA 1	0.8296	0.1559	5.32	0.000
		Const	-0.0134	0.0017	-7.98	0.000

Table 2. Mean monthly maximum temperature forecast values for the month of January to December.

Months	Year	Forecast temperature (°C)	Lower 95% C.I.	Upper 95% C.I.
January	2008	25.61	23.32	27.89
	2009	26.22	23.79	28.64
	2010	26.22	23.70	28.74
	2011	26.03	23.04	29.01
	2012	26.09	22.99	29.20
February	2008	28.65	26.50	30.80
	2009	31.19	26.70	35.68
	2010	32.89	28.39	37.39
	2011	35.39	30.88	39.90
	2012	33.19	28.67	37.71
March	2008	28.65	26.50	30.80
	2009	27.88	25.64	30.13
	2011	35.39	30.88	39.90
	2012	33.19	28.67	37.71
April	2008	34.72	32.66	35.77
	2009	37.58	35.50	39.65
	2010	35.27	33.18	37.36
	2011	33.54	31.44	35.65
	2012	34.54	32.42	36.67
May	2008	35.17	32.97	37.36
	2009	35.45	33.16	37.73
	2010	36.59	34.30	38.89
	2011	34.97	32.67	37.27
	2012	34.89	32.58	37.19
June	2008	35.25	33.91	36.58
	2009	34.27	32.93	35.61
	2010	35.52	34.18	36.86
	2011	35.77	34.43	37.12

	2012	35.82	34.48	37.17
July	2008	32.23	29.81	34.65
	2009	31.55	29.11	33.98
	2010	32.72	30.27	35.17
	2011	36.36	33.90	38.83
	2012	33.61	31.13	36.08
August	2008	30.32	28.71	31.94
	2009	31.97	30.35	33.60
	2010	31.28	29.65	32.91
	2011	32.53	30.90	34.17
	2012	32.85	31.21	34.49
September	2008	32.77	30.37	35.18
	2009	32.71	30.27	35.15
	2010	33.99	31.52	36.46
	2011	33.25	30.75	35.74
	2012	33.94	31.42	36.47
October	2008	34.95	32.59	37.30
	2009	33.94	31.58	36.31
	2010	36.04	33.66	38.42
	2011	36.09	33.71	38.48
	2012	34.97	32.57	37.36
November	2008	32.11	30.38	33.84
	2009	33.15	31.20	35.09
	2010	34.28	32.27	36.28
	2011	35.04	33.01	37.07
	2012	33.05	31.01	35.09
December	2008	28.57	26.32	30.82
	2009	27.71	25.45	29.96
	2010	28.08	25.82	30.33
	2011	29.82	27.57	32.08
	2012	29.21	26.95	31.46

Table 3. Annual linear trend in °C/decade performed on the Karachi and Hyderabad urban maximum temperature series (1961 – 2007).

Months	Linear Trend (Karachi)	Linear Trend (Hyderabad)
January	0.22	−0.09
February	0.30	−0.06
March	0.27	−0.20
April	0.31	0.11
May	0.13	−0.15
June	0.31	0.0027
July	−0.0029	−0.13
August	0.12	−0.30
September	0.29	−0.21
October	0.37	−0.22
November	0.37	0.10
December	0.39	0.06

The average of all decadal monthly maximum temperature trend values (Table 3) 0.27 very close to the decadal temperature increasing trend of Karachi coast water 0.28. This is in confirmation to the results of [20] with reference to local and global climatic parameters interactions. Moreover, heat waves occurrence frequency might increase due to high maximum monthly temperature trend in Karachi region.

It strengthens the result found in with reference to local and global climatic parameters interactions [9]. In view of the high maximum monthly temperature trend in Karachi region it is expected that in future the frequency of heat waves occurrence frequency will increase.

5. Conclusion

Urban mean monthly maximum temperature data sets have been examined to see the rate of increase in six decades due to urban activities. It has been observed that almost every month has increasing trend except for the month of July, which has, more or less, steady trend. It has also been observed that the second summer season in Karachi region has higher trend values as compared to the first summer season. This reflects the fact that the urban activities in any mega-city greatly affect the local temperature fluctuations. The situation in Hyderabad also reflects this fact as there is no appreciable change in the trends of local extreme temperature. Forecast models of local temperature variations would be useful for urban planners and for environmental control strategies. It is imperative to find modern methods of adaptation to the climate impacts focusing on urban, rural and coastal categories. The working with seasonal temperature variations, sea surface temperatures fluctuations and the role of urban population would be important to clarify the linkage among these urban parameters. This could also enhance the understanding of daily or weekly temperature variability. Further studies are needed to be undertaken to explore the sensitivity of these results with respect to other parameters. For this purpose the extreme value theory seems more promising.

Acknowledgement

We thank the management of Pakistan Meteorological Department, Karachi, for providing the used in this work. Some results of this paper are part of Ph. D. thesis of the second author to be submitted at the Mathematical Sciences Research Centre Federal Urdu University Arts, Sciences & Technology, Karachi.

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