TEMPORAL TEMPERATURE RISE AND ITS EFFECTS ON OTHER CLIMATIC FACTORS IN PESHAWAR-PAKISTAN

Syed Said Badshah Bukhari[1] and Ghulam Ali Bajwa[2]

ABSTRACT

Change in temperature, rainfall, evaporation and wind was assessed based on instrumental meteorological observations during 1985-09 in Peshawar. The results showed 0.85°C (0.77°C – 0.92°C) increase in temperature. The spring season started 15.6 days earlier as well as spring season period was shortened by 17.8 days. The summer season was extended and spread over seven months (April-October) having mean maximum temperature >30°C. There was 30% decrease in rainfall during the study period. The climate was shifted towards dry tropical with eight months receiving <25 mm rainfall. The rainfall was reduced drastically in spring and late summer seasons. Evaporation and wind increased 1.59 times and 1.40 times, respectively. The results indicated a significant feedback mechanism among temperature, rainfall and evaporation. The temperature showed negative correlation with rainfall (r^2 = 0.49) while positive correlation with evaporation (r^2 = 0.78). The range of variation and coefficient of variation of temperature, rainfall, evaporation and wind showed a great volatility especially in the spring and autumn seasons. Present findings forecast a likely increase of 4.13°C in maximum temperature by the end of 21st century vis-à-vis extended drought conditions thus calls the principle of intergenerational justice into question. The newly emerging climate scenario predicts multifaceted effects on vegetative and reproductive growth of plants, and depending habitat characteristics. In addition to biologists and ecologists, this study provides guidelines to policy makers for adaptation of mitigation measures.

Key words: Climate change, temperature, rainfall, evaporation, wind

INTRODUCTION

The scientific findings show that earth's climate is changing even faster than previously assumed. With present anthropogenic activities and physical changes occurring in nature the mean global temperature on the earth could rise by seven degrees Celsius as compared to the pre-industrial era. Such a temperature increase would be faster and greater than the one the earth experienced at the end of last Ice Age about 15,000 years ago; rising of five degrees Celsius over a period of 5000 years (Vorholz, 2009).

Climate change is beginning to threaten lifestyle and livelihoods in several ways. Effects of rising temperature, *inter alia*, include health problems (Gosling, *et al*., 2009), increase in intense tropical cyclones and rise in sea levels (IPCC, 2007), changes in agricultural yields and depletion of ocean oxygen (Shaffer, *et al*., 2009), changes in forest types and composition (Ravindranath, *et al*., 2006), and extinction of animal and plant species (Thomas, *et al*., 2004). Due to rising temperatures many natural habitats are shifting towards the poles or into higher latitudes. One of the earliest and most powerful effects of this warming is the melting of snow packs and mountain glaciers which store precipitation as snow and ice in the winter for release during summer (Svendsen and Künkel, 2009). For example, the Himalaya snow-packed water reservoirs are melting at a rate of 15.0 m per year, the highest rate in the world, due to rising temperature (Hasnain, 2009).

[1] Director General, Pakistan Forest Institute, Peshawar
[2] Coordinator Sericulture, Pakistan Forest Institute, Peshawar

There are several physical (IPCC, 2007; Grunewald, *et al*., 2009) and anthropogenic activities (Foley, *et al*., 2005; Falcucci, *et al*., 2007; IPCC, 2007; Vorholz, 2009) which influence the spatial and temporal changes in climate processes at local and regional levels. Among all these external forcings, anthropogenic activities are dominant cause of recent global warming (Knutson, *et al*., 2006). Climate change will affect different regions differently, depending on how much temperature increases locally and how much precipitation changes. Hence understanding the spatio-temporal evolution of temperature is of significant importance for many applications including numerical weather prediction, climate and environmental studies, determining growth period and estimating evapo-transpiration.

Within regions urban conglomerations behave differently and act as heat islands. These heat islands disturb natural equilibrium and affect local as well as regional climatic conditions. It is imperative to analyse urban climate changes to plan and manage strategic resources like water and urban plantation on medium and long bases. The present study, therefore, was conducted to assess (i) climate changes in Peshawar, (ii) effect of temperature rise on rainfall, evaporation and wind, and (iii) seasonal variability and volatility.

MATERIALS AND METHODS

Study Area

Peshawar is located between 71°30´ and 71°40´E, and 33°50´ and 34°10´N in the northwest of Pakistan. It is situated at an altitude of 347 m above sea level. The north and northeast of Peshawar valley is bounded by outskirts of Hindo-kush mountain ranges; northwest by rugged Khyber mountains; south by the spurs branched off from Safed-Koh. The principal land use of district Peshawar is agriculture (53.5%) followed by rangeland (18.1%). A considerable part of land (11.3%) is barren while a small part (4.0%) bears shrubs and bushes (Anonymous, 2007) (Figure 1).

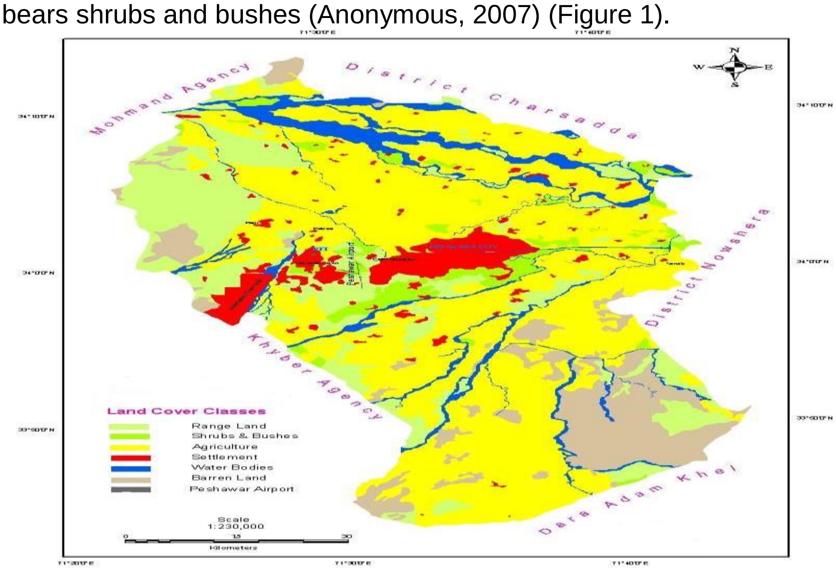

Fig.1. Land use map of district Peshawar (Source: GIS/RS Centre, FSR&DP, Pakistan Forest Institute, Peshawar)

Meteorological Observations

To assess changes in climate, instrumental meteorological data of 25 years *viz*., 1985 to 2009 were obtained from Meteorological Observatory of Pakistan Forest Institute, Peshawar. Daily weather data of maximum air temperature (°C), minimum air temperature (°C), rainfall (mm), evaporation (mm per 24 h) and wind speed at eight feet height (km per 24 h) were refined for missing or incorrect observations and 1291 records of each variable were created. The heterogeneity of the data was checked through run test.

To estimate severity of fluctuation in the climatic factors, range of variation and coefficient of variation were calculated as follow:

$$\text{Range of Variation (RV)} = \text{Maximum} - \text{Minimum}$$

Where:

Maximum = Mean maximum value of respective climate parameter
Minimum = Mean minimum value of respective climate parameter

$$\text{Coefficient of Variation (CV) \%} = \frac{\text{Range of Variation}}{\text{Mean Value of Respective Climate Parameter}} \times 100$$

Degree days were estimated to determine the onset as well as length of spring season. The cut-off date for onset of spring season was fixed first of March.

Statistical Designs and Analyses

Means of five years meteorological data of each variable was calculated for analysis of variance test. Variation, range of variation and coefficient of variation of maximum temperature (MxT), minimum temperature (MiT), rainfall, evaporation and wind across the years and months during the study period were analyzed applying 1-Way Analysis of Variance test using Minitab 15.1 statistical software. The difference among means was tested using Tukey's honestly significance difference (HSD) test at p=0.05. The change in MxT, MiT, rainfall, evaporation and wind was also analyzed using regression analysis. The regression model was subjected to χ^2 for goodness of fit. Based on regression analysis calculated values of MxT and MiT were estimated. The difference between observed and calculated values of MxT and MiT was analyzed using independent two tail student's t-test. The relationship (feedback) among the test factors was estimated using Pearson Correlation matrix.

RESULTS

Maximum Temperature

Maximum temperature increased highly significantly ($F_{4, 44}$= 5.46; p<0.01) between 1985 and 2009. There was a significant (CV= 0.65, p<0.05) difference between 1985-89 and 2005-09, however, the difference was not significant among 1985-89, 1990-

94, 1995-99 and 2000-04. Similarly the difference during 2000-04 and 2005-09 was not significant (Figure 2). There was an increase of 0.92°C in MxT during 2005-09 as compared to 1985-89. This temperature rising trend indicates resilient climate change phenomenon resulting in compounded effect on temperature rise in coming generations.

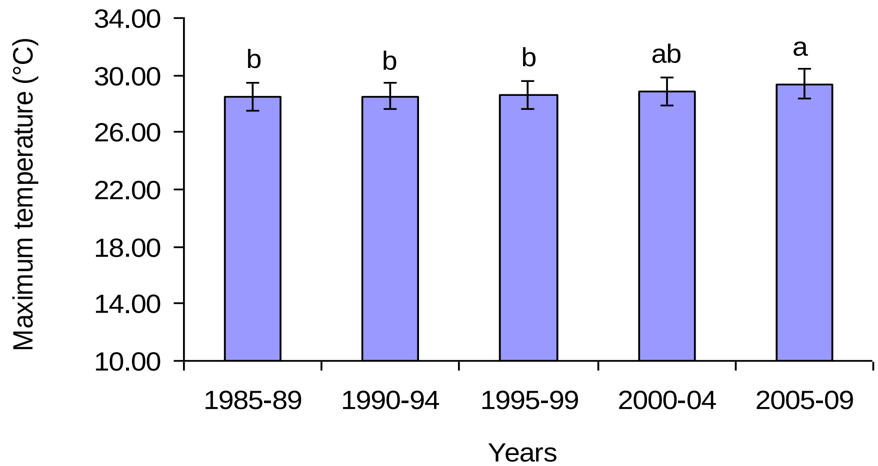

Fig. 2. Mean Maximum temperature (±SE) during 1985-2009

There was a highly significant ($F_{11, 44}$= 895.12; p<0.01) month-wise difference in MxT. The highest MxT was 39.22±0.45°C in June while the lowest was 17.19±0.43°C in January. The difference was not significant (CV= 1.22; p>0.05) between May and August; August and September; April and October; March and November; and December and February (Table 1). These results showed changing effect of temperature rise with seasons. The temperature rise was greater in the summer and spring months as compared to winter and autumn months.

The range of variation of MxT was significant ($F_{11, 48}$= 2.29; p<0.05) within months while this was not significant ($F_{4, 55}$= 1.57; p>0.05) within years. The highest range of variation was 4.46±0.58°C in April while the lowest was 2.09±0.32°C in June. The results showed less range of variation in MxT during the summer and winter months while range of variation was greater in the months of spring and autumn seasons. There were three groups of months in which means of range of variation of MxT were not significantly different from one another (CV= 1.53; p>0.05).

The coefficient of variation of MxT was highly significant ($F_{11, 48}$= 2.29; p<0.01) within months while this was not significant ($F_{4, 55}$= 1.08; p>0.05) within years. The results indicated great volatility in MxT change in the months of winter and spring while MxT remained consistently high in the summer. The highest coefficient of variation was 20.12±4.92% in February followed by 18.15±1.92% in December. On the other hand, the lowest coefficient of variation was 5.33±0.79% in June. The difference in coefficient of variation among May, June and July was marginal (5.33±0.79% to 6.87±0.93%). The coefficient of variation did not differ significantly (CV= 10.37; p<0.05) among January, February, March, April, October, November and December (Table 1). Results indicated three groups of months, i.e., months with higher coefficient of variation (winter and spring seasons), (ii) intermediate (autumn season), and (iii) lower coefficient of variation (summer season).

Table 1. Month-wise MxT, range of variation (RV) and coefficient of variation (CV±SE) during 1985-09

Month	Temp.± SE (°C)	RV±SE (°C)	CV ±SE (%)
January	17.19±0.43h	2.47± 0.22bc	14.36±1.24abc
February	19.69±0.74g	3.94±0.94ab	20.12±4.92a
March	23.80±0.62f	3.20±0.48abc	13.41±1.98abc
April	29.83±0.81e	4.46±0.58a	14.89±1.76abc
May	35.30±0.52c	2.43±0.32bc	6.87±0.93c
June	39.22±0.45a	2.09±0.32c	5.33±0.79c
July	37.13±0.42b	2.20±0.54c	5.92±1.44c
August	34.17±0.58cd	2.64±0.52bc	7.73±1.52bc
September	33.54±0.65d	2.97±0.24abc	8.83±0.63bc
October	30.85±0.77e	4.28±0.61a	13.89±2.01abc
November	24.92±0.67f	3.51±0.79abc	14.07±3.19abc
December	19.83±0.64g	3.60±0.40abc	18.15±1.92ab
Critical value	1.22	1.53	10.57

Means within column with the same letter are not significantly different (p>0.05 Tukey's HSD)

$$RV = Highest\ \ Mean\ \ Max.Temp. - Lowest\ \ Mean\ \ Max.Temp.$$

$$CV = \frac{Range\ \ of\ \ Variation}{Mean\ \ Max.Temp.} x100$$

The results showed considerable variability in four seasons. Apart from increase in MxT, duration of summer season was extended. There were six months with >30°C MxT during 1985-89 while that number of months was seven during 2005-09 (Figure 3). Furthermore, difference in MxT during four hottest months (May, June, July and August) was narrowed down from 19.09% (1985-89) to 12.68% (2005-09). In April 2005-09, MxT jumped over 30°C thus shifting this month from spring to summer season. Similarly, proximal end of the summer season was extended as MxT rose to 32°C in October. This MxT was one degree Celsius greater and 1.4°C lower as compared to that of April and August in 1989-89, respectively.

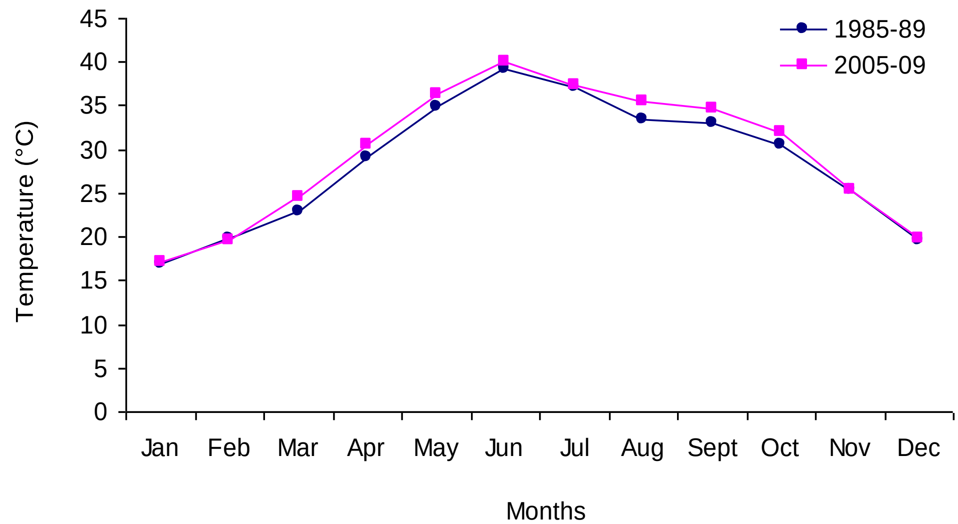

Fig. 3. Month-wise pattern of temperature change during 1985-2009

The results of degree-days accumulated in February revealed 15.6 days earlier onset of spring season during 2005-09 as compared to 1985-89. Similarly, the spring season was shortened by 17.8 days during this period. The regression analysis showed a highly significant ($F_{1, 23}$= 20.48; p<0.01) linear trend in MxT (Table 2). The calculated mean MxT was 28.86±0.07°C while the observed mean MxT was 28.79±0.10°C. The difference (0.07°C) between observed and calculated MxT was not significant (t-test; p>0.05). This forecast model projected mean MxT of 31.27°C and 33.54°C by 2050 and 2100, respectively. Thus likely increase of 1.86°C and 4.13°C in MxT by 2050 and 2100, respectively as compared to 2005-09.

Table 2. Mathematical expression of change in climatic factors during 1985-09

Climate factor	Regression equation	R^2	F (p) (d.f. 1,23)
Maximum Temp.	y =-61.79+0.04536x	0.47	20.48 (<0.01)
Minimum Temp.	y =-47.38+0.03093x	0.47	20.50 (<0.01)
Mean Temp.	y=-54.58+0.03814x	0.59	33.42 (<0.01)
Rainfall	y =120 -0.5837x	0.13	3.50 (<0.07)
Evaporation	y =-284.3+0.1450x	0.58	31.10 (<0.01)
Wind	y =-357260+357.3x-0.0894x^2	0.13	1.70 (>0.05) (d.f. 2,22)

Minimum Temperature

Minimum temperature increased significantly ($F_{4, 44}$= 2.50; p<0.05) during 1989-09. The highest MiT was 14.09±1.03°C in 1985-89 while the lowest MiT was 14.86±1.01°C in 2005-09. The MiT did not differ significantly (CV= 0.75, p>0.05) among

1985-89, 1990-94, 1995-99 and 2000-04 (Figure 4). The results showed 0.77°C rise in MiT during 2005-09 as compared to 1985-89.

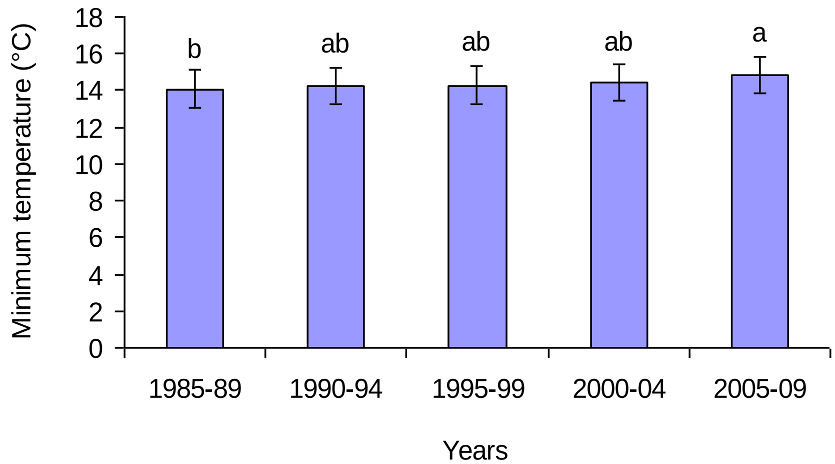

Fig. 4. Mean minimum temperature (±SE) during 1985-2009

There was a highly significant ($F_{11, 44}$= 799.75; p<0.01) variation in MiT across months. The lowest MiT was 3.41±0.43°C in January while the highest was 25.44±0.44°C in July. The difference in MiT was not significant (CV= 1.40; p>0.05) between January and December; April and October; June and October; July and August (Table 3).

Table 3. Month-wise MiT, range of variation (RV) and coefficient of variation (CV±SE) during 1985-2009

Month	Temp.± SE (°C)	RV ±SE (°C)	CV ±SE (%)
January	3.14±0.19h	2.28±0.36cd	73.48±12.86ab
February	5.74±0.32g	3.48±0.52abc	60.93±8.63abc
March	10.59±0.34e	3.42±0.74abc	32.81±4.17bcd
April	13.95±0.39d	4.94±0.42a	35.74±7.66bcd
May	19.07±0.30c	3.66±1.27abc	19.15±0.97cd
June	22.10±0.31b	4.01±0.20ab	18.22±2.94cd
July	25.44±0.15a	1.50±0.62d	5.92±0.84d
August	24.29±0.24a	3.05±0.66bcd	12.57±2.75d
September	21.78±0.29b	2.62±0.51bcd	12.07±2.42d
October	14.66±0.29d	3.10±0.65bcd	20.80±3.90cd
November	8.13±0.23f	2.22±0.58cd	27.90±8.07bcd
December	3.75±0.27h	2.91±0.51bcd	87.37±12.26a
Critical value	1.40	1.61	47.13

Means within column with the same letter (s) are not significantly different (p>0.05 Tukey's HSD);

$$RV = Highest\ Mean\ Min.Temp. - Lowest\ Mean\ Min.Temp.$$

$$CV = \frac{Range\ of\ Variation}{Mean\ Min.Temp.} x100$$

The range of variation was significant ($F_{11, 48} = 2.59$; $p<0.05$) within months while this was not significant ($F_{4, 55} = 2.27$; $p>0.05$) within years. The highest range of variation was 4.94±0.42°C in April while the lowest was 1.50±0.62°C in July. The results showed less variation in MiT in hot and cold months with exception of June where the range of variation was 0.93°C less as compared to April. The difference in range of variation was not significant (CV=1.6; $p>0.05$) among February, March, April, May and June (Table 3). Range of variation of MiT was nearly replica of MxT.

The coefficient of variation of MiT was highly significant ($F_{11, 48}$= 7.28; $p<0.01$) within months while it was not significant ($F_{4, 55}$= 1.51; $p>0.05$) within years. The highest coefficient of variation was 87.37±12.26% in December followed by 73.48±12.86% and 60.93±8.63% in January and February, respectively. The lowest coefficient of variation was 5.92±0.84% in July. The difference between May and June (19.15±0.97%, 18.22±2.94%); and August and September (12.57±2.75%, 12.07±2.42%) was marginal. The coefficient of variation did not differ significantly (CV= 47.13; $p<0.05$) among March, April, May, June, July, August, September, October and November (Table 3). There was more consistency in MiT during hot months while MiT was highly inconsistent during cold months.

The regression analysis showed a highly significant ($F_{1, 23}$= 20.50; $p<0.01$) linear trend in MiT (Table 2). The calculated mean MiT was 14.387±0.07°C while the observed mean MiT was 14.386±0.10°C. The difference (0.001°C) between observed and calculated MiT was not significant (t-test; $p>0.05$). The forecast model indicated likely increase of 1.17°C and 2.27°C in MiT by 2050 and 2100, respectively as compared to 2005-09.

Rainfall

The results showed downward trend in rainfall during the study period. There was 30.0% decrease in rainfall during 2005-09 as compared to 1985-89. The highest mean rainfall was 39.56±5.26 mm in 1985-89 while the lowest rainfall was 27.71±4.75 mm in 2005-09. Results showed a considerable erratic behaviour in rainfall. The range of variation in rainfall was not significant ($F_{4, 55}$= 0.37; $p>0.05$) while coefficient of variation was significant ($F_{4, 55}$= 2.16; $p<0.05$). The greatest range of variation was 83.90±16.38 mm in 1995-99 while the lowest range of variation was 61.26±14.24 mm in 2000-04 (Table 4). The highest coefficient of variation was 274.83±7.24% in 2005-09 and was significantly (CV= 65.35; $p<0.05$) greater as compared to 1985-89 (195.84±4.56%).

Table 4. Year-wise mean rainfall, range of variation (RV) and coefficient of variation (CV±SE) during 1985-09

Year	Rainfall ±SE (mm)	RV ±SE (mm)	CV ±SE (%)
1985-89	39.56±5.26 n.s	76.79±13.57 n.s	195.84±4.56b
1990-94	38.08±4.91	73.00±12.65	215.67±6.85ab
1995-99	35.42±5.50	83.90±16.38	238.39±8.70ab
2000-04	34.11±5.50	61.26±14.24	193.33±5.07b
2005-09	27.71±4.75	68.61±12.82	274.83±7.24a
Critical value	23.78	55.84	65.35

Means within column with the same letter are not significantly different (p>0.05 Tukey's HSD); n.s. = non-significant

$$RV = Highest\ Mean\ Rainfall - Lowest\ Mean\ Rainfall$$

$$CV = \frac{Range\ of\ Variation}{Mean\ Rainfall} x100$$

The horizontal (across the months) change in rainfall pattern during the study period is presented in Figure 5. Results indicated that apart from considerable decrease in rainfall, distribution of rainfall became more uneven. During 1985-89, one month received >100 mm rainfall; two months between 50 mm and 75 mm; five months between 25 mm and 50 mm; and four months <25 mm. Contrarily, during 2005-09, one month received rainfall between 75 mm and 100 mm; one month between 50 mm and 75 mm; and two months between 25 mm and 50 mm, whereas, eight months received <25 mm rainfall.

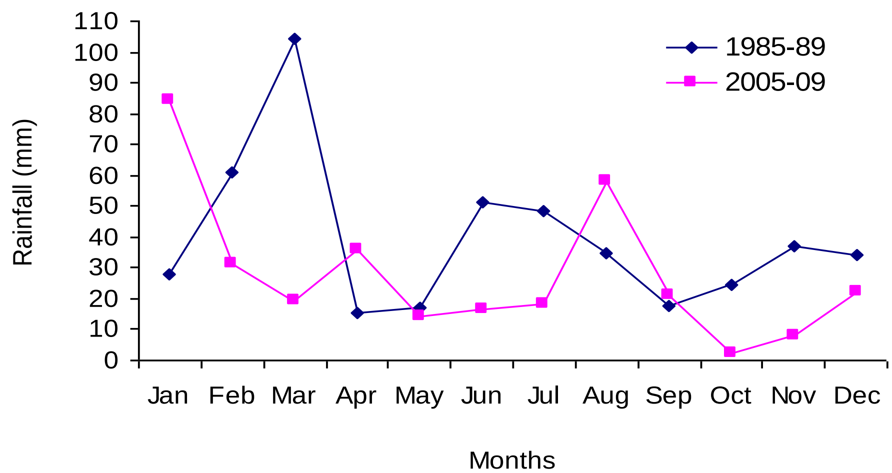

Fig. 5. Month-wise pattern of rainfall during 1985-2009

There was a highly significant ($F_{11,\ 44}$= 2.91; p<0.01) variation in rainfall within months during 1985-09. The highest mean rainfall was 63.37±10.78 mm in March while the lowest rainfall was 17.50±4.34 mm in October (Figure 6). Measurement of central dispersion tendency in terms of standard error of means indicated also erratic rainfall behaviour. The variation was greater in rainy months as compared to dry months. The rain was >50 mm in three months (January, February and March) while the rain was <25 mm during five months (May, June, September, October and November).

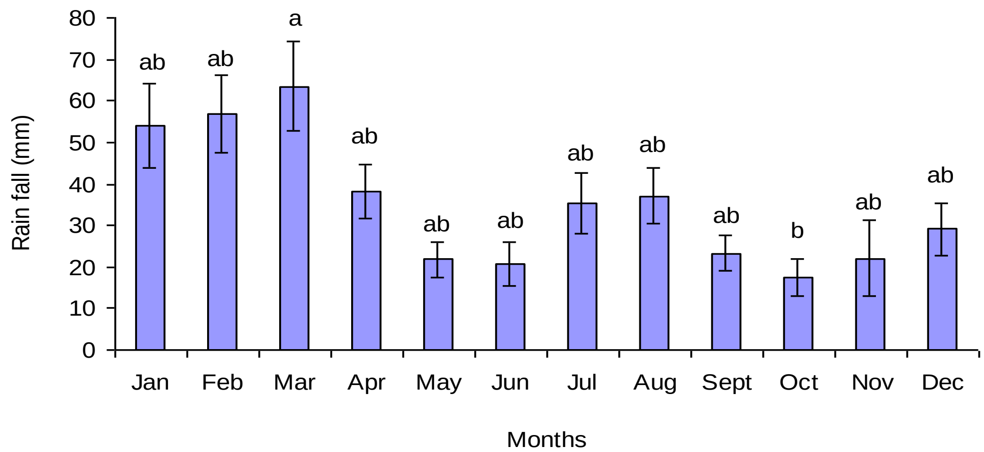

Fig. 6. Month-wise mean rainfall (±SE) during 1985-09

The results showed an inverse correlation between temperature and rainfall, i.e., increase in temperature resulted in decrease in rainfall (Figure 7).

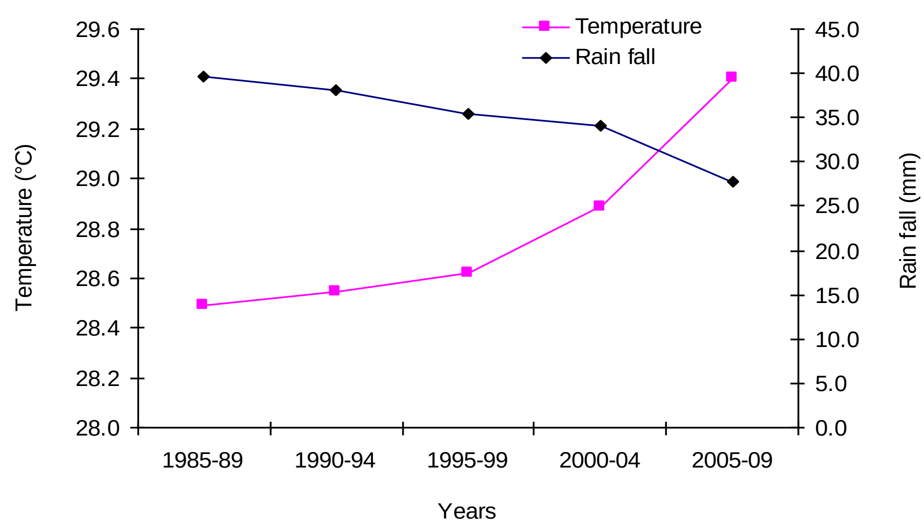

Fig. 7. Correlation between temperature and rainfall during 1985-09

The Pearson correlation matrix analysis showed highly significant (r^2= 0.49, p<0.01) negative effect of MxT on rainfall (Table 5) while the effect of MiT rainfall was negative but was not significant (r^2=0.235; p>0.05).

Table 5. Correlation matrix among climatic factors during 1985-09

Climate factors	Climate factors			
	MxT	MiT	Rainfall	Evaporation
MiT	0.58**			
Rainfall	-0.49**	-0.24 n.s		
Evaporation	0.78**	0.49**	-0.41*	
Wind	0.01 n.s	0.54**	0.16 n.s	-0.15 n.s

* p<0.05; ** p<0.01; n.s non-significant

Evaporation

The evaporation increased highly significantly ($F_{4, 44}$= 10.79; p<0.01) during 1985-09. The highest evaporation was 7.06±0.61 mm/24 h during 2005-09 while the lowest evaporation was 4.42±0.96 mm/24 h during 1985-89. The variation in evaporation was not significant among 1985-89, 1990-94 and 1995-99; 2000-04 and 2005-09 (CV= 1.48; p<0.05). The range of variation was highly significant ($F_{4, 55}$= 4.78; p<0.05) while the coefficient of variation was not significant ($F_{4, 55}$= 0.33; p>0.0) across the years. The highest range of variation was 8.93±1.75 mm/24 h during 2005-09 which was approximately three times greater as compared to 1985-89 (Table 6). The highest coefficient of variation was 124.28±17.81 mm/24 h during 2005-09 and was almost double than that of 1985-89. The Pearson correlation analysis showed a positive relationship between temperature and evaporation. The maximum temperature showed greater influence on evaporation as compared to MiT (r^2= 0.78; r^2= 0.49). Similarly the effect of rainfall on evaporation was highly significant (r^2= 0.41; p<0.01) but negative (Table 5).

Table 6. Year-wise mean evaporation, range of variation (RV) and coefficient of variation (CV±SE) during 1985-09

Year	Evaporation ±SE (mm/24 h)	RV±SE (mm/24 h)	CV ±SE (%)
1985-89	4.42±0.96b	3.02±0.66b	66.29±9.89 n.s
1990-94	4.45±0.35b	3.59±1.01b	91.43±14.37
1995-99	4.59±0.35b	3.46±0.73b	87.32±22.73
2000-04	6.16±0.38a	5.19±1.07ab	89.36±16.70
2005-09	7.06±0.61a	8.93±1.75a	124.28±17.81
Critical value	1.48	4.43	75.79

Means within column with the same letter are not significantly different (p>0.05 Tukey's HSD); n.s.: non-significant

$$RV = Highest\ Mean\ Evaporation - Lowest\ Mean\ Evaporation$$

$$CV = \frac{Range\ of\ Variation}{Mean\ Evaporation} x100$$

The evaporation varied significantly ($F_{11, 44}$= 9.19; p<0.01) across the months. The highest evaporation was 8.56±0.49 mm/24 h in June while the lowest evaporation was 2.97±0.69 mm/24 h in December. The higher evaporation rate in June is due to hot season with low rainfall. The higher evaporation rate in hot months as compared to cold months indicates positive correlation between temperature and evaporation. Contrarily decrease in evaporation rate with increasing rainfall shows inverse correlation between rainfall and evaporation. The evaporation increased gradually between January and April, remained at peak from May to July and decreased between August and December (Figure 8). The range of variation and coefficient of variation of evaporation within months were not significant ($F_{11, 44}$= 0.33 & 1.85, p>0.05).

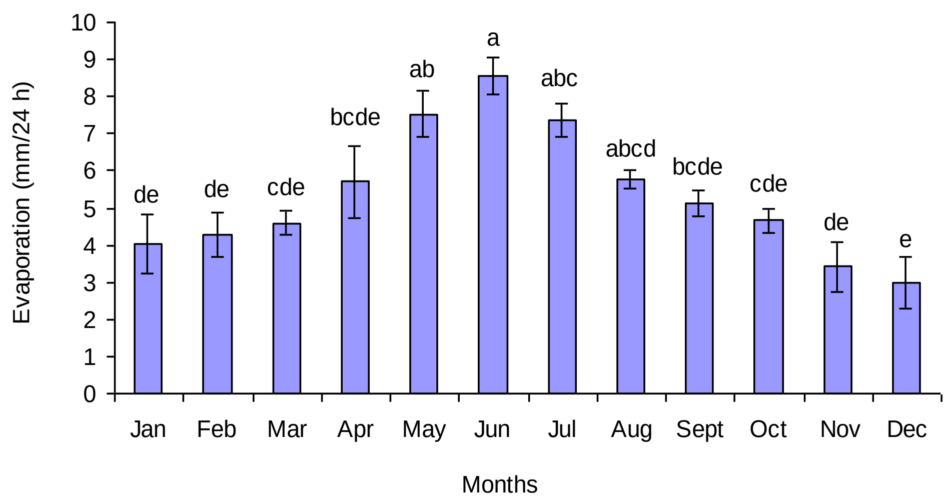

Fig. 8. Month-wise mean evaporation (±SE) during 1985-09

Wind

The wind showed a non-linear trend during 1985-09. The wind was slowest (21.82±1.76 km per 24 h) during 1990-94 while increased gradually to reach 33.81±3.22 km per 24 h during 2005-09 (Table 7). The range of variation in wind was highly significant ($F_{4, 55}$= 11.82; p<0.01) across the years while it was not significant ($F_{4, 55}$= 1.77; p>0.05) across months. There was marginal difference in range of variation among 1985-89, 1990-94 and 1995-99; and between 2000-04 and 2005-09. Overall the range of variation increased 2.8 times between 1985-89 and 2005-09. The coefficient of variation of wind was highly significant ($F_{4, 55}$= 8.81; p<0.01) across the years while this was not significant ($F_{4, 55}$= 0.88; p>0.05) within months. The highest coefficient of variation of wind was 155.29±11.99% during 2005-09 while the lowest was 67.02±9.33% during 1985-89. The coefficient of variation of wind during 2005-09 was two times higher as compared to 1985-89.

Table 7. Year-wise mean wind, range of variation (RV) and coefficient of variation (CV±SE) during 1985-09

Year	Wind± SE (km/24 h)	RV± SE (km/24 h)	CV± SE (%)
1985-89	24.45±1.49b	17.31±3.56b	67.02±9.33b
1990-94	21.82±1.76b	17.51±4.95b	83.93±5.91b
1995-99	22.55±1.67b	17.58±3.11b	79.72±11.93b
2000-04	31.19±2.44a	42.58±3.19a	137.21±8.50a
2005-09	33.81±3.22a	48.09±2.90a	155.29±11.99a
Critical value	4.76	17.86	52.44

Means within column with the same letter are not significantly different (p>0.05 Tukey's HSD)

$$RV = Highest\ Mean\ Wind - Lowest\ Mean\ Wind$$

$$CV = \frac{Range\ of\ Variation}{Mean\ Wind} x100$$

The wind varied significantly $F_{11,\ 44}$= 28.90; p<0.01) across months. The mean highest wind speed was 39.56±4.12 km/24 h in July while the lowest wind speed was 12.05±1.79 km/24 h in December (Figure 9). There were three groups of months according to wind speed; (i) months with wind speed of >30 km/24 h (April, May, June, July and August), (ii) months with wind speed of >20 km/24 h (February, March, September), and (iii) months with wind speed of <20 km/24 h (January, October, November, December). There was no relationship between coefficient of variation of temperature and that of wind.

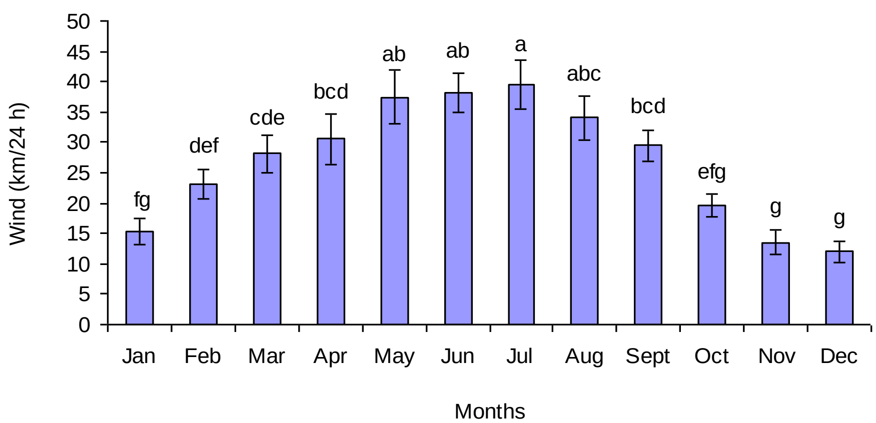

Fig. 9. Month-wise mean wind (±SE) during 1985-09

The results showed a positive correlation between temperature and wind. Similarly there was a positive correlation between rainfall and wind. On the other hand, there was a negative correlation between evaporation and wind. The Pearson correlation analysis indicated a non-significant correlation of wind with all under study climatic factors except MiT (Table 6).

DISCUSSION

The results show a mean increase of 0.92°C and 0.77°C (mean 0.85°C) in maximum and minimum temperature, respectively during 1985-09 in Peshawar. The temperature increased both vertically (across the years) and horizontal (across the months). The summer season was extended while spring season was shortened. There is likely an increase of 3.2°C (2.27°C to 4.13°C) in temperature by the end of 21st century if recent trends continue. This forecast is tilting towards higher sides of future prediction of 1.1°C to 6°C globally (IPCC, 2007). The temperature increase shows a feedback mechanism with other climatic factors. There was a negative correlation with rainfall while a positive one with evaporation and wind. The range of variation and coefficient of variation indicate a great volatility in climatic factors especially in spring and autumn seasons.

The present increase in temperature is slightly higher as compared to global average increase of 0.74°C during 1906-2005 (IPCC, 2007), however, this is within the reported range of 0.56°C to 0.92°C. The greater increase in temperature at local level may be explained in terms of urban heat island effect as has previously been reported (Trenberth, *et al*. 2007; Wu, *et al*., 2010). Higher rate of temperature increase under urban conditions have also been reported in Karachi-Pakistan during 1976-05 period (Sajjad, *et al*., 2009a); where they recorded increase of 2.7°C, 1.2°C and 1.95°C in maximum temperature, minimum temperature and mean annual temperature, respectively. Present increase of 0.92°C in maximum temperature is, nevertheless, in corroboration with 0.94°C recorded in Lahore-Pakistan during 1975-07 (Sajjad, *et al*., 2009b).

The spring is a crucial season for blossom time and, therefore, reflects biological responses of vegetation towards temperature. Each plant species requires a specific amount of heat to break winter dormancy as well as to complete a normal annual cycle of vegetative and reproductive growth. The results indicate 15.6 days early onset of spring season. Moreover, the spring season has reduced by 17.8 days. The shortening of the spring season is further substantiated by raised temperature (>30°C) in April and subsequently shifting this month into summer season. Earlier onset of the spring as well as shifting of seasons is in conformity with Liu, *et al.* (2010); where they reported an early onset of the spring season by 4.6 to 5.5 days in China. The early start of spring season indicates early sprouting of plants but shortening of this season reduces flowering period. Apart from this, day length in March and April is still short which limits the photosynthetic process and subsequently plants are still in tender stage when exposed to higher temperatures. This will put plants under further stress. The poor vegetative growth causes inferior reproductive growth (flowering, quantity and quality of seed). In addition to plant growth, the short spring would provide less period for floricultural attractions.

The long summer season may also change the basic composition of seasonal rhythms and subsequently flora and fauna of this region. These seasonal variations might cause extinction of some animal and plant species. Apart from disturbance of biological processes, the seasonal variations hamper greatly physical processes. The newly emerging climate scenario, i.e., long summer season combined with droughts would demand more water for irrigation, livestock and civic utilities. This would certainly put pressure on critically scarce water resources.

Many parts of the world have experienced changes in global water cycle such as the magnitude and timing of runoff, the frequency and intensity of floods and droughts, rainfall patterns, etc. (Jiang, *et al*., 2007). Temperature is a key parameter of the energy which affects water cycles of the earth-atmosphere system (Behbahani, *et al*., 2009). Present findings show significant impact of temperature on water cycle, *viz*., rainfall and evaporation. There is 30% overall decrease in rainfall during 25 years. The drought period also increases with eight months receiving <25 mm rainfall. These findings are broadly in line with that of Grunewald, *et al*. (2009); Liu, *et al*. (2009).

The recent climate changes in Peshawar may be explained in terms of increased human population, livestock and urban sprawl as well as increase in greenhouse gases (GHGs). The population was doubled from 1.10 million to 2.24 million during 1981-02 (Anonymous, 1998). Moreover, Peshawar has still the higher population growth rate of 3.56% as compared to average of many other cities in Pakistan. In addition to unabated increase in local population, about three million Afghan refugees mobbed Peshawar and surroundings during 1980s. With escalated population mushroomed anthropogenic activities started and subsequently resulted in immense urbanization. The city area of Peshawar and its suburbs were hit severely by these activities. The combination of increased population and anthropogenic activities influences the biogeochemical processes which might change climate in Peshawar, because these factors are dominant reasons of climate changes globally (Brovkin, *et al*., 2004; Motha and Baier, 2005; Grunewald, *et al*., 2009; Houghton, 2008; Wu, *et at*., 2010).

Land cover and land use are very important factors which interact with atmospheric conditions to determine the overall climate. These interactions have great impacts on various ecosystems from regional to global scales (Pyke and Andelman 2007). Land cover change and land degradation either due to anthropogenic activities, deforestation or livestock can directly increase temperatures (Briggs, *et al*., 2005; Balling, *et al*., 1998). The increased livestock changed the land cover and land use pattern. Livestock, besides, directly responsible for green house gases (18% of all human-induced green gases globally) cause deforestation as well as deteriorate rangelands (Van de Steeg, *et al*., 2009). In Peshawar over-grazing and deforestation for timber and fuelwood turned meagre shrub and bush land area (4.0%) into barren. This, in addition to urban sprawl, changed land cover and land use pattern and subsequently resulted in climate changes.

Present increase in temperature, evaporation and wind, and decrease in rainfall both vertical and horizontal would have multiple affects specifically in terms of (i) altering planting seasons due to early start of spring as well as extended summer seasons, (ii) poor plant growth, (iii) low survival of newly planted trees in spring and monsoon seasons, (iv) increased competition for water among different stakeholders (agricultural, forestry, civic utilities) and may lead to social conflicts, (v) change in forest types, species composition, geographical relocation of plant and animal species, (vi) increased and frequent insect pests and diseases outbreaks, (vii) escalated wind damage of forests as reported by Blennow, *et al*. (2010), and (viii) increased cost of management.

Overall these projected climate change scenarios presents a great threat to the present and, to a much greater extent, to coming generations. To mitigate adverse climate change effects on future generations requires advance planning because GHGs especially carbon dioxide (CO_2) is a long-lived atmospheric gas which makes the climate change a resilient phenomenon. Moreover, the climate change that we are currently experiencing is primarily the result of emissions from some time in the past, rather than current emissions (backloaded effect of climate change) and the full cumulative effects of our current emissions will be realized for some time in the future (delayed/deferred effect of climate change). The resilient and delayed phenomena of climate change have serious implications for future generations which call the principle of intergenerational justice into question.

CONCLUSION

Based on present findings it is concluded that climate is changing in Peshawar with increased temperature and decreased rainfall. Apart from vertical increase in temperature, there are horizontal changes in temperature causing considerable shifting in seasons. The increased temperature is affecting rainfall quantity and pattern, evaporation and wind. The long drought and hot season would have significant impacts on plant growth as well as on medium and long term planning of water resources. This study can be further worked out by using different meteorological models to study the effects of urbanization and land use patterns on climate changes. The projected climate change scenarios in Peshawar urge to undertake mitigation and adaptation measures, such as, planting trees on urban and surrounding areas for carbon sequestration, reduce livestock pressure to restore land cover, introduce adaptive agricultural practices, economical use of water and reduce vehicular emissions to mitigate adverse effects of climate change.

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