CLIMATE CHANGE TRENDS OVER CONIFEROUS FORESTS OF PAKISTAN

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ABSTRACT

Climate change trends were assessed over coniferous forests of Pakistan for the period 1961-2000. The trends were calculated using Climate Research Unit (CRU)-UK data at a scale of 50x50 km^2. The temperature regime was ranged between –12.44°C and 22.54°C over coniferous forests with the lowest temperature over Alpine pasture (AP) and the highest over Sub-Tropical Pine (STP). Monsoon was the warmest followed by summer. Precipitation regime was between 266.8 mm and 1071.6 mm. The highest precipitation was recorded over STP, while the lowest precipitation was over AP. The highest increase in maximum temperature (T_{max}) was 2.03°C over AP during winter, while the lowest increase in T_{max} was 0.08°C over AP during monsoon. The highest increase in minimum temperature (T_{min}) was 2.61°C over AP during winter and the lowest increase in T_{min} was 0.36°C over STP during monsoon. Temperature increases was relatively greater over AP as compared to other forests types. Temperature increase during winter was 1-2°C greater as compared to other seasons. The precipitation decreased by 9.6%, 5.8% and 0.3% over AP, Sub-Alpine (SA) and Dry Temperate Zone-2 (DT-2), respectively, while the precipitation increased by 16.7% and 12.3% over Moist Temperate (MT) and Sub-Tropical Pine (STP), respectively. The highest precipitation increase was 71.5% over MT during monsoon while the highest precipitation decrease was 30% over AP during summer. Precipitation increase over Dry Temperate Zone-1 (DT-1) during all seasons except summer indicated elevatio-latitudinal movement of precipitation. The increased temperature and precipitation over MT and DT-2 will enhance plant growth, while greater temperature increase and precipitation decrease over AP and SA will have negative effects on plant growth. These findings emphasize early initiation of adaptation and mitigation action plans to combat impacts of climate change on coniferous forests.

Key words: Climate change, Temperature, Precipitation, Alpine, Sub-Alpine, Dry Temperate, Moist Temperate, Sub-Tropical Pine

INTRODUCTION

Climate change is the most important multidimensional global environmental issue of today. The scientific evidences show that earth's climate is changing even faster than previously assumed. With present physical changes occurring in the nature and anthropogenic activities, the mean global temperature on the earth can rise by seven degrees Celsius by the end of 21^{st} century as compared to the pre-industrial era, 1750. This temperature increase would be greater and faster as compared to 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). The rising temperature is not an isolated phenomenon, but is closely related with changes in magnitude and spatio-temporal distribution of precipitation, incidence and pattern of winds and storms and other weather parameters.

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The climate change will likely have adverse effects on forest ecosystems, biodiversity, biomass production and ultimately the livelihoods of forest dependent communities and economies. Temperature and precipitation, two of the climatic factors are primary determinants having significant effects on forest ecology (including biodiversity), plant distribution and productivity, and health (Spurr and Barnes, 1980; Smith and Tirpak, 1989; Krischbaum, *et al*., 1996). The climate change will not necessarily have simple linear impact on growth of trees species growing in different habitats (Carter, 1996). Local, regional and global climate changes can influence the occurrence, timing, frequency, duration, extent and intensity of climatic disturbances or vulnerabilities (Baker, 1995; Turner, *et al*., 1998).

The multiple linkages between causes and impacts of climate change are, in many cases, not completely understood. Climate change will affect different regions and ecosystems differently, depending on how much temperature increases locally and how much precipitation and other weather parameters change. Hence, understanding the spatio-temporal variability and changes in temperature, precipitation and other weather parameters are of significant importance for any study on impact analysis of climate change on any ecosystem.

In Pakistan, coniferous forests have different biomes: i) Sub-Alpine (SA), ii) Dry Temperate (DT), iii) Moist Temperate (MT), iv) Sub-Tropical Pine (STP), depending upon their locations on latitudinal basis. Alpine pastures are located from about 3,600 m above sea level to perpetual snow fields at around 4,000 m in the northern and north-western parts of the country. SA and (DT) are located above 35.25°N, having winter with snowfall. DT is further subdivided in two geographical zones: DT-1 located in Greater Himalaya (Northern Pakistan), while DT-2 in Western mountainous region (Quetta, Ziarat). Because of their different geo-locations, they were dealt with separately. The MT and STP are present between 33.75°N and 35.25°N in the sub-montane regions of Himalaya, the monsoon precipitation dominated region. The coniferous forests spread over about 1930k ha, including Azad Jammu and Kashmir and Northern Area (Wani, *et al*., 2004). Besides, timber production and summer grazing pastures, coniferous forests serve as catchments areas of the Indus River System. The areas are also important for eco-tourism due to their spectacular landforms and greenery. Any climate change over these forests will affect timber production and environmental services derived from it, and consequently, the local livelihood opportunities and the local, provincial and national economy.

Keeping in view the importance of coniferous forests and impacts of climate change over these forests; the present study was conducted for assessing: (i) temperature and precipitation regimes and (ii) temperature and precipitation changes over different coniferous forests.

MATERIAL AND METHODS

A grided Forest Map of Pakistan, compatible with the grids of Climate Research Unit (CRU) data, having a grid size of 0.5 X 0.5 degree (50 km x 50 km), was used (Figure 1). Different coniferous forest types were masked using these grids. In case of a forest type covering two or more grid boxes, the mean values of temperature and precipitation were computed. The climate parameters assessed were: mean temperature, maximum temperature and minimum temperature over time scale of annual, winter, spring, summer, monsoon and autumn. The seasons defined as: winter, December to February (DJF), spring, March to April, (MA), summer, May to June (MJ), monsoon, July to September, (JAS) and autumn, October to November, (ON).

The data used were derived from observed climate data from CRU over base period of 1961-2000, the baseline used by World Meteorological Organization. The data was extracted for Pakistan as a whole and subsequently for its sub-coniferous forests. The time series data for the period 1961-2000 was then developed, and temperature and precipitation regimes and changing trends were assessed over each coniferous-forest type using simple linear regression. Student's t-test was used to check the significance of change in temperature. In the case of precipitation, monthly total precipitation was averaged for the grids. The temperature and precipitation data were validated by comparing with available climate data of Pakistan Meteorological Department.

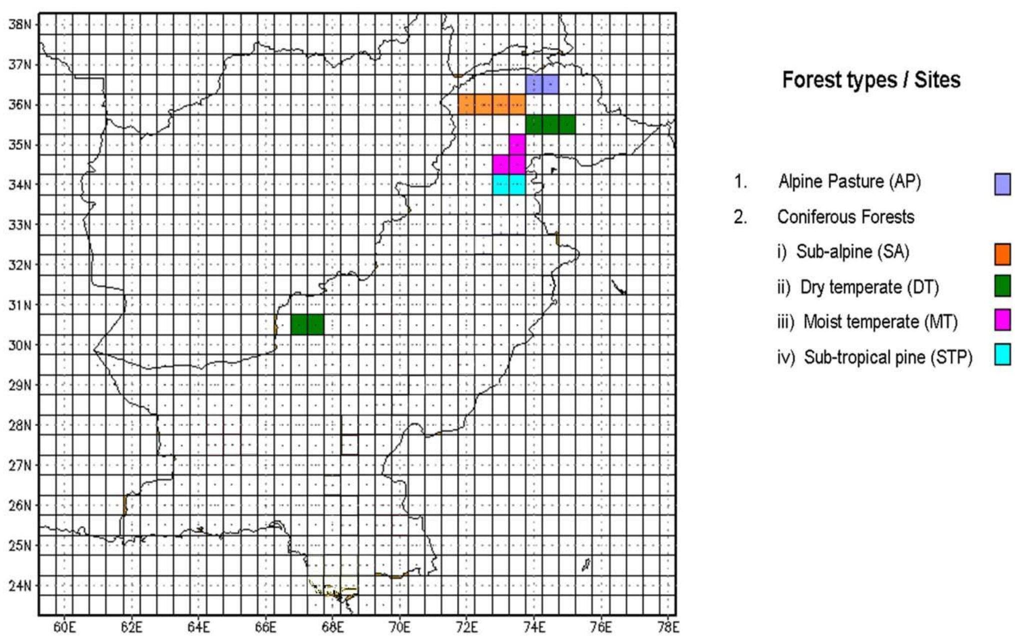

Figure 1. Sites selected for climate observation over coniferous forest

RESULTS

Temperature

The results showed considerable variation in temperature regime and temperature changes over different coniferous forest of Pakistan during 1961-2000. The lowest annual maximum temperature (T_{amax}) was over AP (4.32°C) and the highest T_{amax} was over DT-2 (21.28°C). AP was the coldest while the STP was the warmest except summer and monsoon. The least difference in T_{max} was between summer and monsoon (Table 1). Spring was relatively cooler as compared to autumn. T_{max} was of almost same magnitude over SA and DT-1, while T_{max} over MT was slightly greater as compared to SA and DT-1. The highest variability in T_{max} across the forest types was during summer and the lowest variability was during autumn. The highest variability in T_{max} across the seasons was over AP followed by DT-1. The lowest variability in T_{max} was over SA.

Table 1. Maximum temperature (°C) regime over coniferous forest in Pakistan (1961-2000)

Season	Forest type						Range ±SE
	AP	SA	DT-1	DT-2	MT	STP	
Winter	–7.75	–3.91	–3.78	10.17	1.58	10.48	-7.75-10.48±3.22
Spring	0.86	3.90	4.55	18.38	8.44	17.24	0.86-18.38±3.05
Summer	10.38	13.82	13.77	29.02	17.80	27.05	10.38-29.02±3.20
Monsoon	15.53	13.38	18.18	30.50	20.01	26.30	13.38-30.50±2.73
Autumn	3.09	6.88	6.86	19.40	11.44	19.75	3.09-19.75±2.91
Annual	4.32	7.70	7.78	21.28	11.66	19.85	4.32-21.28±2.91

The lowest annual minimum temperature (T_{amin}) was -7.09°C over AP, while the highest T_{amin} was 8.96°C over STP. The lowest T_{min} was -17.17°C over AP during winter and the highest T_{min} was 16.19°C over STP during monsoon. T_{min} remained below freezing point over all forest types except STP during winter. AP was the coldest during all seasons, whereas, STP was the warmest. Monsoon season was the warmest followed by the summer. The least difference in T_{min} was between spring and autumn over all forest types except DT-2 (Table 2). The pattern of T_{min} regime over SA and DT-1 was similar to that of maximum temperature. The highest variability in T_{min} across the forest types was during summer, while the lowest variability in T_{min} was during monsoon. On the other hand, the highest variability in T_{min} across the seasons was over AP and the lowest variability over STP.

Table 2. Minimum temperature (°C) regime over coniferous forest in Pakistan (1961-2000)

Season	Forest type						Range ±SE
	AP	SA	DT-1	DT-2	MT	STP	
Winter	-17.17	-12.58	-12.96	-3.57	-6.87	0.51	-17.17-0.51±2.76
Spring	-9.17	-5.44	-5.59	4.23	-0.72	6.90	-9.17-6.90±2.60
Summer	-1.69	2.26	1.74	12.37	6.73	15.04	-1.69-15.04±2.73
Monsoon	2.07	5.69	5.32	14.61	9.21	16.19	2.07-16.19±2.32
Autumn	-8.87	-4.59	-5.39	1.42	0.08	6.86	-8.87-6.86±2.35
Annual	-7.09	-3.04	-3.47	5.76	1.59	8.96	-7.09-8.96±2.54

The mean temperature regime ranged between -12.44°C and 22.54°C over coniferous forests. The lowest mean annual temperature was -1.38°C over AP and the highest mean annual temperature was 14.39°C over STP. Winter was the coldest followed by spring, while monsoon was the warmest followed by summer. The temperature regime over SA and DT-1 was almost of similar level. DT-2 and STP have similar mean temperature regimes (Figure 2). The highest variability in mean temperature across the forest types was during winter, while the lowest variability in mean temperature was during monsoon. The highest seasonal mean temperature variability was over AP and the lowest seasonal mean variability was over STP.

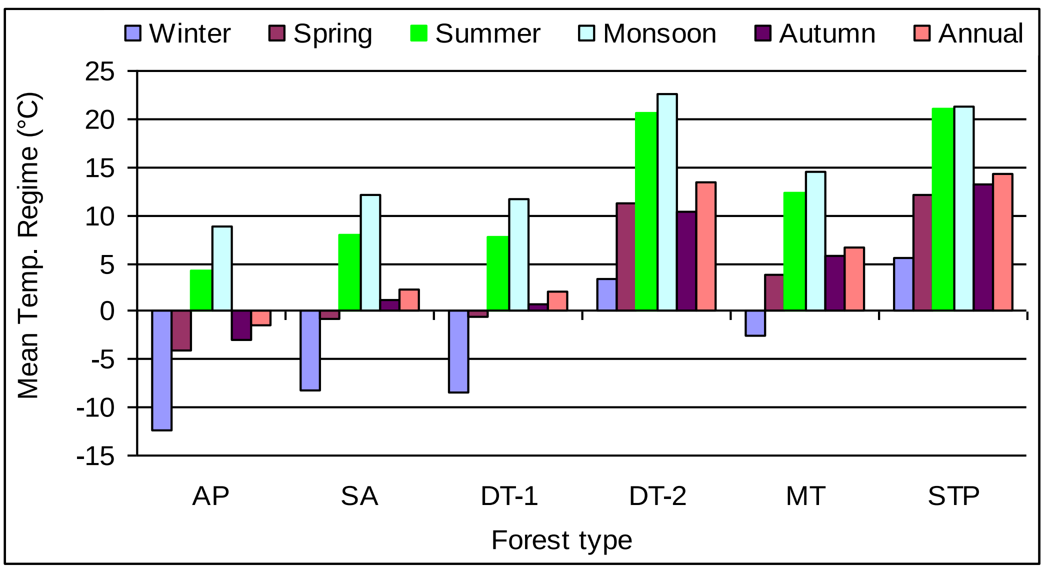

Figure 2. Mean temperature (°C) regime over coniferous forest in Pakistan (1961-2000)

Both spatio-seasonal, increases in T_{max} were recorded during 1961-2000. The highest increase in T_{max} was 2.03°C over AP during winter, while the lowest increase in T_{max} was 0.08°C also over AP during monsoon (Table 3). Increase in T_{max} was significant ($p<0.05$) over AP, DT-1, MT, STP during winter. This increase was also significant over DT-2 during autumn and monsoon. The lowest increase in T_{max} among the forest types was over STP. Conversely, T_{max} decreased during spring and summer over AP, DT-1. T_{max} decreased also over SA and MT, and DT-2 during summer and spring, respectively. The highest increase in T_{max} was during winter followed by autumn over the forest types. The highest spatial variability in T_{max} increase was during summer closely followed by winter. The lowest variability in T_{max} increase was during spring. The highest seasonal variability in T_{max} was over AP and the lowest variability was over DT-2.

Table 3. Change in maximum temperature (∆T°C) over coniferous forest in Pakistan

Season	Forest type						Range ±SE
	AP	SA	DT-1	DT-2	MT	STP	
Winter	2.03**	1.38	1.85**	0.84	1.43**	1.17**	0.84-2.03±0.19
Spring	-0.26	0.02	-0.16	-0.18	0.11	0.09	(-) 0.26-0.11±0.07
Summer	-0.46	-0.18	-0.34	0.74	-0.07	0.06	(-) 0.46-0.74±0.19
Monsoon	0.08	0.42	0.09	0.65*	0.18	0.07	0.08-0.65±0.11
Autumn	0.49	0.45	0.48	0.64**	0.44	0.39	0.39-0.64±0.04
Annual	0.45	0.45	0.44	0.67**	0.43	0.35	0.35-0.67±0.05

* Significant at 90% confidence level; ** Significant at 95% confidence level

In general, greater increase in T_{min} was observed, both in context of forest types and seasons as compared to T_{max}. The highest increase in T_{min} was 2.61°C over AP during winter and the lowest increase was 0.36°C over STP during monsoon (Table 4). Increase in T_{min} was significant ($p<0.05$) over all forest types except SA during winter and autumn. The increase was also significant over DT-2 during monsoon. The highest annual increase in T_{min} was over AP followed by SA and the lowest was over STP. Among the seasons, the highest increase in T_{min} was during winter (1.09°C to 2.61°C). The next warmest season was autumn (0.86°C and 1.98°C). Contrarily to increasing trends of T_{min}, there was decreasing trend in T_{min} over DT-2 during spring. The highest variability in T_{min} in across the forest types was during winter followed by autumn. The lowest variability was during summer. The highest seasonal T_{min} variability was over AP followed by DT-1 and the lowest variability was over STP.

Table 4. Change in minimum temperature (ΔT°C) over coniferous forest in Pakistan

Season	Forest type						Range ±SE
	AP	SA	DT-1	DT-2	MT	STP	
Winter	2.61**	1.93	2.41**	1.09**	1.92**	1.56**	1.09-2.61±0.25
Spring	0.64	0.62	0.55	(-)0.26	0.59	0.47	(-)0.26-0.64±0.15
Summer	0.56	0.66	0.63	0.86	0.69	0.76	0.56-0.86±0.05
Monsoon	0.42	0.82	0.40	0.84**	0.52	0.36	0.36-0.84±0.10
Autumn	1.27**	1.25	1.00**	1.98**	1.00**	0.86*	0.86-1.98±0.18
Annual	1.10**	1.04	0.99**	0.88**	0.92**	0.78**	0.78-1.10±0.05

* Significant at 90% confidence level; ** Significant at 95% confidence level

Mean temperature increase was observed over all forest types as well as during seasons. However, the mean temperature decreased over DT-2 during spring. The highest increase in T_{mn} was 2.32°C over AP during winter, while the lowest increase in T_{mn} was 0.07°C over AP during summer (Figure 3). The increase in T_{mn} over all forest types during winter and autumn was significant ($p<0.05/0.1$). This increase was significant also over SA and DT-2 during monsoon. The highest annual increase in T_{mn} was observed over AP followed in sequence by DT-2, SA, DT-1, MT and STP. The seasonal increase in T_{mn} was highest during winter and the lowest during spring. The variability in mean temperature increase, across the forest types, was highest during winter and the lowest variability was during spring. Variability in T_{mn} increase, across the seasons, was the highest over AP followed in sequence by DT-1, SA, MT, DT-2 and STP. The temperature changing trends of T_{mn} over the forest types as well as seasons were closer to that of the T_{min} than the T_{max}.

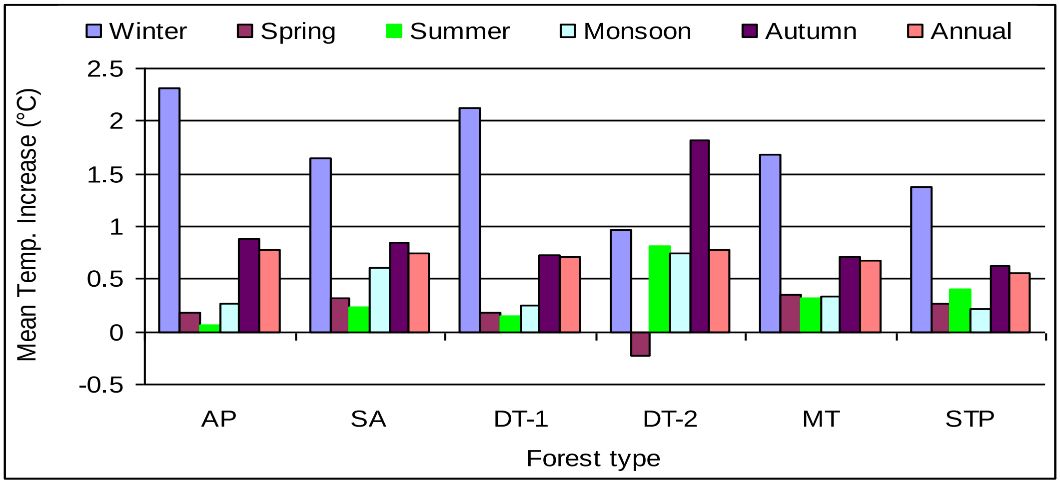

Figure 3. Change in mean temperature (ΔT°C) over coniferous forest in Pakistan

The results revealed that increase in minimum temperature was relatively greater as compared to maximum temperature. Moreover, increase in temperature during winter was the highest than the other seasons. After winter, next highest increase in temperature was during autumn. Minimum temperature increases were significant during winter and autumn, whereas, increase in maximum temperature was significant during winter only. Significant increase in temperature during autumn and then in sequence during winter was clearly indicative of early start of spring. However, temperature decreased, especially T_{max} during spring and summer and T_{min} during spring.

Precipitation

The precipitation analysis showed variable precipitation regimes over the forest types. The precipitation regimes were ranged between 266.8 mm and 1071.6 mm. The highest precipitation was observed over STP followed by MT. The lowest precipitation was recorded over AP (Figure 4). The precipitation regimes of AP and DT-2 were almost same. The precipitation regime of DT-1 was higher as compared to AP and DT-2 but lower than SA.

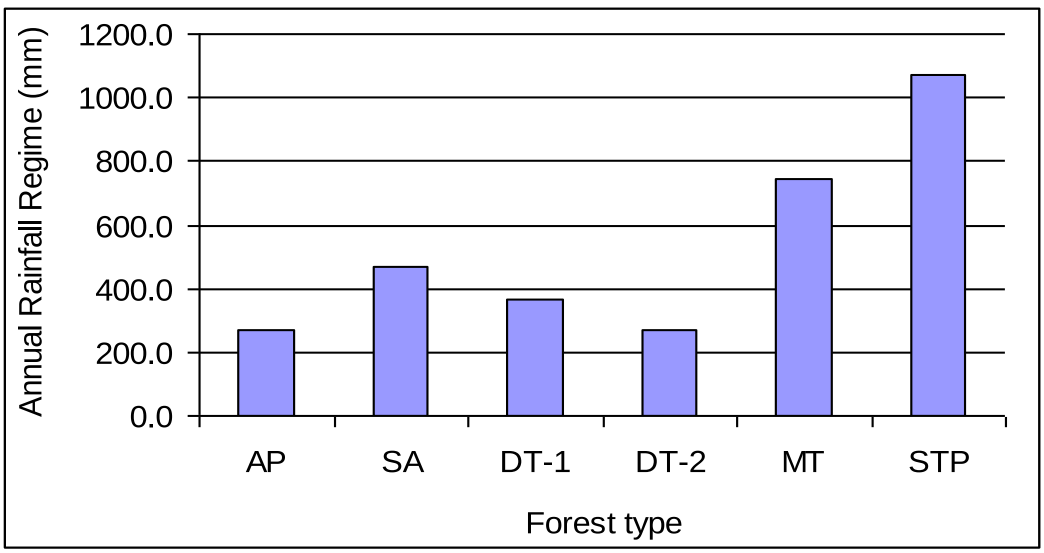

Figure 4. Mean precipitation (mm) regime over coniferous forest in Pakistan (1961–2000)

The precipitation regimes varied across the seasons. The highest precipitation was 445.7 mm during monsoon over STP, while the lowest precipitation was 14.3 mm during autumn over DT-2 (Figure 5). STP received relatively greater precipitation as compared to other forest types in all corresponding seasons. AP and DT-2 received relatively lesser precipitation. AP, SA, and DT-1 received the highest precipitation during spring. Over DT-2, the wettest season was winter. MT and STP received the highest precipitation during monsoon. Over SA, DT-1, DT-2, MT, and STP, autumn was the driest, while over AP monsoon was the driest.

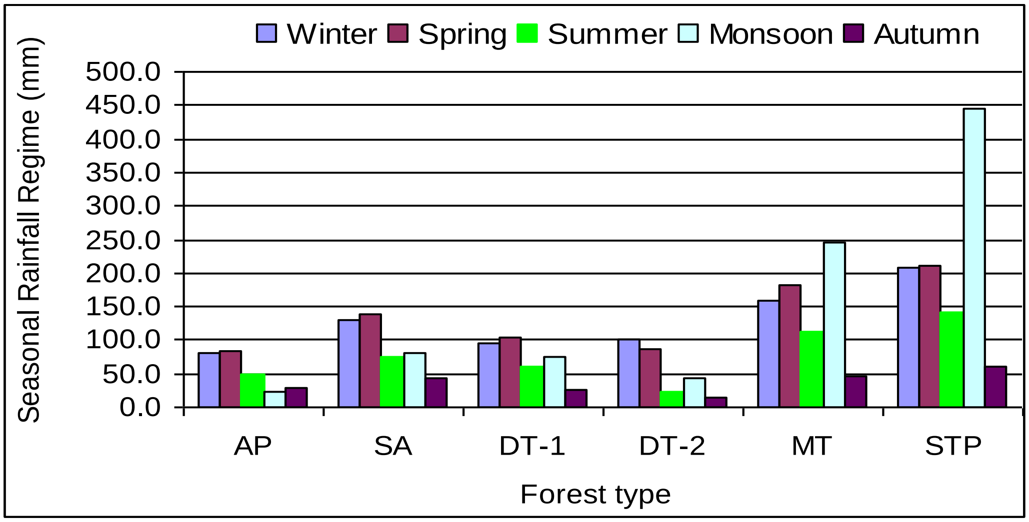

Figure 5. Seasonal precipitation (mm) regime over coniferous forest in Pakistan

The precipitation trends showed considerable changes in precipitation distribution, both in over forest types and during seasons. The annual precipitation decreased by 9.6%, 5.8% and 0.3% over AP, SA and DT-2, respectively, while precipitation increased by 11.2%, 16.7% and 12.3% over DT-1, MT and STP, respectively (Figure 6). The highest increase in precipitation was recorded over MT, while the highest decrease was over AP.

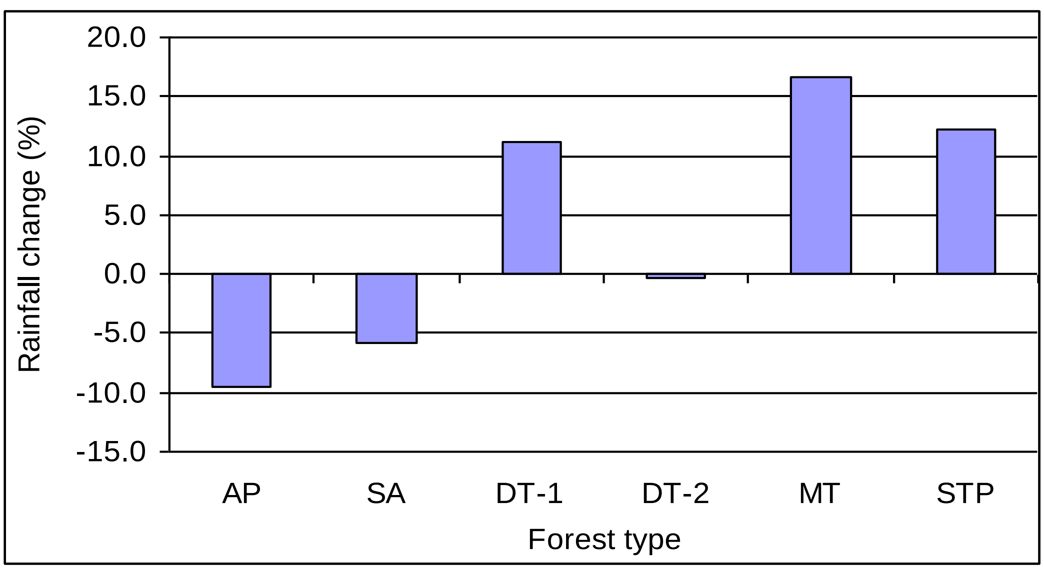

Figure 6. Mean precipitation changes (%) over coniferous forest in Pakistan

The results showed considerable seasonal precipitation variations over different coniferous forest types. The highest precipitation decrease was 30% over AP during summer and the lowest decrease was 0.3% over DT-1 during summer (Figure 7). The precipitation, however, increased maximum by 71.5% over MT during monsoon and minimum by 0.3% over STP during spring. The precipitation decreased over all forest types during winter except DT-1. Similarly, precipitation decreased over AP and SA, during all seasons, except monsoon over SA. Conversely, precipitation increased over DT-1 during all seasons apart from summer. Over DT-2, precipitation decreased during winter and spring. Similar precipitation changes trends were observed over MT and STP, i.e., precipitation decrease during winter and autumn and increase during spring, summer and monsoon. The precipitation increase was relatively greater over MT and STP as compared to other forest types. Between MT and STP, precipitation increase was greater over MT, especially, during summer and monsoon.

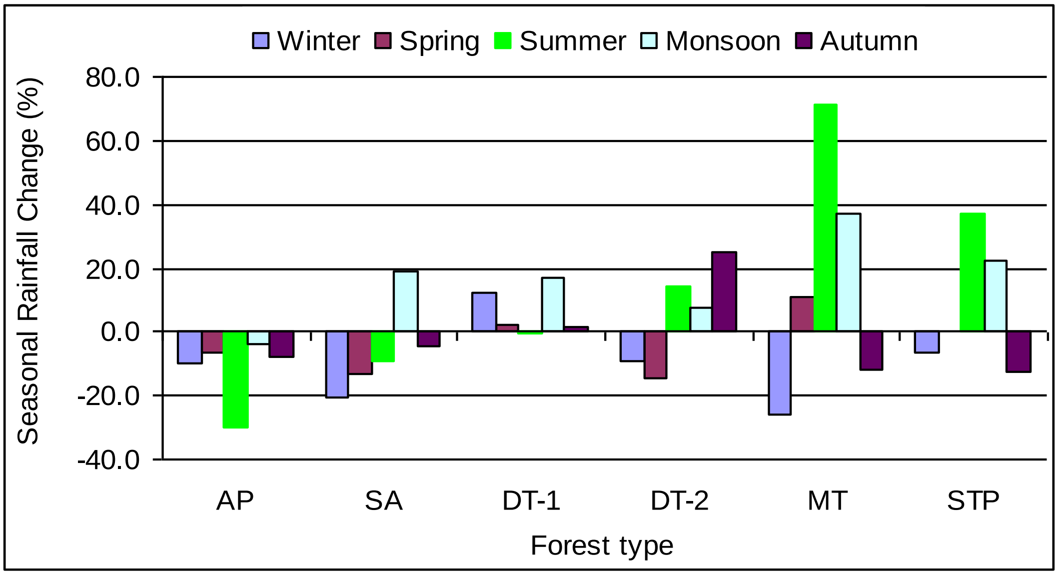

Figure 7. Seasonal precipitation change (%) over coniferous forest in Pakistan

DISCUSSION

The findings show STP is the warmest forest type. Among the seasons, monsoon is the warmest followed by summer, both in terms of maximum and minimum temperatures. Mean temperature is the lowest during winter with below freezing point over AP, SA and DT-1.

The results show an increase of 0.56°C to 0.78°C in mean temperature over different forest types. These findings are in corroboration with global mean range of 0.56°C to 0.92°C reported for period of 1906-2005 (IPCC, 2007). The results further indicate significant variation in temperature increase over different forest types. This spatial variation in temperature increase has been reported earlier by Trenberth, *et al*. (2007); Wu, *et al*., (2010). In Pakistan, spatial effects on temperature have been documented by Sajjad, *et al*., (2009a & b) and Bukhari and Bajwa (2009). The variations in temperature increase over different coniferous forests may be explained in terms of different degrees of albedo, physical nature of soil surface and anthropogenic activities. There are several physical (IPCC, 2007; Grunewald, *et al*., 2009) and anthropogenic activities (Foley, *et al*., 2005; Falcucci, *et al*., 2007; Vorholz, 2009) which influence the spatio-temporal changes in climate processes at local and regional levels. Among all these external forcings, anthropogenic activities have been considered dominant cause of temperature increase (Knutson, *et al*., 2006).

The findings indicate a greater increase in minimum temperature as compared to maximum temperature over all coniferous forests. Thus, indicates that nights are becoming warmer than the days. Moreover, temperature increases with increasing elevation. The highest increase in temperature is during winter and in sequence autumn is the next warmest. Greater increase in minimum temperature and warming of autumn and in sequence the winter is an indicative of early start of spring.

The spring is an important 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 and subsequently to complete a normal annual cycle of vegetative and reproductive growth. Earlier onset of the spring as well as shifting of seasons is in conformity with findings reported by Bukhari and Bajwa (2009); Liu, *et al.* (2010). The early start of spring and subsequently summer indicates changes in forest ecosystems. The early sprouting of plants will result in shorter over-wintering periods of associated biota especially, insects. The early start of summer will reduce 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 of summer. This will put plants under stress. The poor vegetative growth causes inferior reproductive growth (flowering, quantity and quality of seed). On the other hand, increased atmospheric CO_2 concentration coupled with higher temperature and precipitation, and longer growth season over MT and DT will enhance growth rate and biomass accumulation. Such findings have also been projected by IPCC (2007).

A mean variation of ±20% in precipitation is seen in AP, SA, DT-1, DT-2 and MT. These forest types have highest precipitation during winter and spring, however, compared to other seasons, precipitation drops over these forests during these seasons. MT and STP show different precipitation behaviour. Over MT, precipitation decreases during autumn and winter, whereas, increases during spring, monsoon and summer. Over STP, precipitation decreases during autumn, winter and spring but increases during monsoon and summer. These increasing trends are, however, lower as compared to MT.

The spatio-seasonal variation in precipitation indicates movement of precipitation towards north into upper terminus of MT and DT-1. This increase in precipitation over DT-1, especially during monsoon will be benign for this forest type. The increase in precipitation during spring, monsoon and summer over MT will also be beneficial for plant growth. Similar positive precipitation trends over STP during summer and monsoon will enhance plant growth in this forest type.

The past analysis of climate change over coniferous forests indicates changes in vegetation composition. A change in mean annual temperature, as small as 1°C over a sustained period is sufficient to bring about changes in species compositions and distribution of many tree species (IPCC, 1996). The differential temperature and precipitation changes over different forest types indicate a change, both in altitudinal and latitudinal boundaries of different coniferous forests, along with vegetation composition and species migration. A number of climate-vegetation models have also shown that certain climatic regimes are associated with particular plant communities or groups (Holdrige, 1947; Thornthwaite, 1948; Walter, 1985; Whittaker, 1975), and change in the climatic regimes may induce changes in vegetation composition. Change in species composition and upward movement of tree species have been recorded in STP and MT (pers. commu.).

CONCLUSION

Trends of past climate changes showed the highest increase in temperature over AP followed by SA. The warmest season was monsoon followed by summer. Increase in minimum temperature was relatively greater as compared to maximum temperature for all seasons. Winter was becoming relatively warmer followed by autumn as compared to other seasons. Precipitation decreased over AP and SA while increased over DT-1, MT and STP. A fluctuation in precipitation was observed over all forest types. The precipitation increase was relatively greater over MT as compared STP. A northern movement, as well as, seasonal shift in precipitation was recorded. A considerable variability in temperature over AP and SA, and during summer indicates high vulnerability. Similarly, decrease in precipitation over AP and SA indicates vulnerability of these forests, which specifically warrants adaptation and mitigation action plans.

REFERENCES

Baker, W., 1995. Long-term response of disturbance landscapes to human intervention and global change. *Landscape Ecol*. 10:143-159.

Bukhari, S. S. B. and G. A. Bajwa, 2009. Temporal Temperature Rise and its Effects on other Climatic Factors in Peshawar-Pakistan. *Pak. J. Forestry*, 58: 1-18.

Carter, K. K., 1996. Provenance tests as indicators of growth responses to climate change in 10 north temperate tree species. *Can J. For. Res*. 26: 1089-1095.

Falcucci, A., Maiorano, L. and L. Boitani, 2007. Changes in land-use/land-cover patterns in Italy and their implications for biodiversity conservation. *Landscape Ecol*. 22: 617-631.

Foley, J. A., DeFries, R., Asner, G. P., Bar Ford C., and G. Bonan, 2005. Global consequences of land use. *Science* 309: 570-574.

Grunewald, K., Scheithauer, J., Monget, J. M. and D. Brown, 2009. Characterization of contemporary local climate change in the mountains of southwest Bulgaria. *Clim. Change* 95: 535-549.

Holdridge, L. R., 1947. Determination of world plant formations from simple climatic data. *Science* 105: 367-368.

IPCC, 1996. Climate Change 1995. *Impacts, Adaptations and Mitigation of Climate*: Scientific Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, UK: Cambridge.

IPCC, 2007. Climate Change 2007: *Synthesis Report*. Contribution of Working Group I, II, III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Pachauri, R.K. and Reisinger, A. (Eds.). Geneva: IPCC, Pp: 104.

Knutson, T. R., Delworth, T. L., Dixon, K. W., Held, I. M., Lu, J., Ramaswamy, V. and M. D. Schwarzkopf, 2006.Assessment of twentieth-century regional surface temperature trends using the GFDL CM2 coupled models. *J. Clim*. 19:1624-1651.

Krischbaum, M.U.F., Cannell, M.G.R., Cruz, R.V.O., Galinski, W. and W. P. Cramer, 1996. Climate change impacts of forests. In: *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate*: Scientific-Technical Analyses. Contribution of working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Watson, R.T., Zinyowera, M.C. and Moss, R.H., (Eds.). Cambridge University Press, UK: Cambridge.

Liu, B., Henderson, H., Zhang, Y. and M. Xu, 2010. Spatio-temporal change in China's climatic growing season: 1955-2000. *Clim. Change* 99: 93-118.

Sajjad, S.H., Hussain, B., Khan, M. A., Raza, A., Zaman, B. and I. Ahmed, 2009a. On rising temperature trends of Karachi in Pakistan. *Clim. Change* 96: 539-547.

Sajjad, S.H., Shirazi, S.A., Hussain, B., Khan, M. A. and A. Raza, 2009b. Urbanization effects on temperature trends of Lahore during 1950-2007. *International J. Clim. Change Strategies & Management* 1(3): 274-281.

Smith, J.B. and D. A. Tirpak, 1989. *The potential Effects of Global Climate Change on the United States*. EPA-230-05-89-054.U.S. Environmental Protection Agency, Washington, DC.

Spurr, S.H. and B. V. Barnes, 1980. *Forest Ecology*, 3rd Ed. New York: John Wiley & Sons.

Thornthwaite, C. W., 1948. An approach toward a rational classification of climate. *Geographical Review* 38: 55-94.

Trenberth, K. E., Jones, P. D., Ambenje, P. G., R. Roxana Bojariu, 2007. Observations: Surface and Atmospheric Climate Change.

Turner, M. G., Baker, W. L., Peterson, C. J. and R. K. Peet, 1998. Factors influencing succession: Lessons from large, infrequent natural disturbances. *Ecosystems* 1: 511-523.

Vorholz, F., 2009. Global Climate Protection. Deutschland 5/2009: 8-13.

Walter, H., 1985. *Vegetation Systems of the Earth and Ecological Systems of the Geo-Biosphere*. Berlin: Springer-Verlag.

Wani, B. A., Shah, H. and S. Khan, 2004. *Forestry Statistics of Pakistan*. Pakistan Forest Institute.

Whittaker, R. H., 1975. *Communities and Ecosystem*. New York: Macmillan.

Wu, Z., Zhang, H. Krause, C. M. and N. S. Cobb, 2010. Climate change and human activities: a case study in Xinjiang, China. *Clim. Change* 99:457-472.