Temporal Climate Change and Climate, Vegetation Productivity Index in Galies Forest Division, Abbottabad-Pakistan

Syed Said Badshah Bukhari
University of Peshawar, Peshawar

Syed Shafiq-ur-Rehmanand Ghulam Ali Bajwa
Pakistan Forest Institute, Peshawar

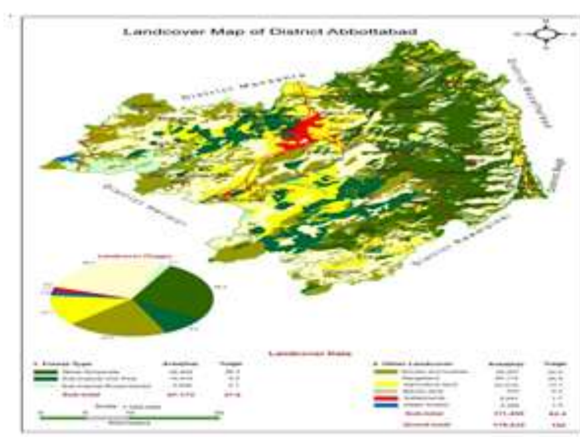
The present study was conducted to assess temporal climate changes and climate, vegetation productivity potential of Galies Forest Division-Abbottabad (GFD) over time span of 1962-2011. The climate parameters, including: temperature (maximum, minimum, mean) and precipitation were used, both on annual and seasonal basis, to assess climate regimes and climate changes. The results showed temperature regime of 16.36±0.08°C, 6.08±0.08°C and 11.21±0.07°C for maximum temperature, minimum temperature and mean temperature, respectively. Monsoon was the warmest season, while winter was the coldest season. The mean precipitation regime was 889.48±19.43 mm/annum. Monsoon was the wettest season and autumn was the driest season. A highly significant increase in mean temperature, maximum temperature and minimum temperature was observed. The winter got the highest increase in minimum temperature. The lowest increase was estimated in minimum temperature during monsoon. The increase in minimum temperature was relatively greater compared to maximum temperature. An overall increase of 1.39% in precipitation was recorded. The precipitation increased during monsoon, autumn and winter. Conversely, the precipitation decreased during spring and summer. Climate, Vegetation Productivity Index (CVPI) ranged between 4,362 and 9,091 with an increasing trend. The highest Climate Vegetation Productivity Index was recorded during 2003, while the lowest during 1971. Based on these results, it is concluded that climate has changed significantly, both vertically and horizontally over GFD. This changing climate has considerable effects on vegetation productivity in the Forest Division. The increase in vegetation productivity within certain temperature ranges is an encouraging sign for management of the forests in the GFD.

Key words: Climate change, Climate regimes, Climate, Vegetation Productivity Index, Galies Forest Division,

Climate change is the most striking contemporary global multidimensional environmental issue which is noticeable in various forms. Increase in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level are some of the indicators that show the warming of climate system. The 100-year temperature increasing trend (1906-2005) is 0.74˚C. However, warming trend over the last 50 years has nearly doubled over the last 100 years (IPCC, 2007).

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). The global warming has also triggered changes in forest types and composition (Ravindranath et al., 2006), and extinction of animal and plant species (Thomas et al., 2004). The impact of the rising temperature might be seen in reallocation of many natural habitats towards the poles or into higher latitudes. Moreover, one of the earliest and most significant effect of this warming is evident from the melting of snow packs and mountain glaciers (Svendsen and Künkel, 2009).

Figure 1: Land use map of GFD-Abbottabad



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; Bukhari and Bajwa, 2009) which influence the spatio-temporal changes in climate processes. Each of these forces have significant role in increasing global warming, however, anthropogenic activities still remains the most dominant one (Knutson et al., 2006).

Correspondence concerning this article should be addressed to Syed Said Badshah Bukhari, Department of Environmental Sciences, University of Peshawar, Peshawar, Email: secretaryfinancekp@gmail.com

Climate change will affect different regions differently, depending on how much temperature increases locally and how much precipitation changes. Hence, understanding spatio-temporal variability of temperature is of significant importance for many applications, including numerical weather prediction, climate and environmental studies, determining growth period and estimating evapo-transpiration.

The emerging climate change scenarios, particularly down scaled to local forest types, will likely have adverse effects on biomass production, biodiversity and forest ecosystem dynamics. These changes will, in turn, reduce economic and ecological services from these forests with dampening effects on livelihood of forest dependent communities. Thus, present study was conducted to assess: (i) climate change on time scale of annual and five seasons (spring, summer, monsoon, autumn, winter), and (ii) climate related potential vegetation productivity in Galies Forest Division-Abbottabad.

Methods

The study was conducted in Galies Forest Division-Abbottabad, located between 33°50´ and 34°23´ N, 73°35´ and 73°31´ E, in northern Pakistan (Figure 1).

Climate Change

A grid based forest map compatible with the grids of Climate Research Unit (CRU) data, having a grid size of 0.5 X 0.5 degree (50x50) km² was used for scaling down study area. The climate parameters, including temperature (maximum, minimum mean) and precipitation were used to assess climate regimes and climate changes. The climatic parameters were analyzed, both on horizontal (seasonal) and vertical (annual) basis. Five seasons were marked as spring (March-April), summer (May-June), monsoon (July-September), autumn (October-November) and winter (December to February). Time series data for the time period of 1962 - 2011 was used to calculate temperature and precipitation regimes and changing trends thereof.

Climate, Vegetation Productivity Index

The potential vegetation productivity of the Forest Division was estimated using Climate, Vegetation and Productivity Index (CVP), following the method as described by Paterson (1956):

$$CVP\ Index = \frac{Tv \times P \times G \times E}{Ta \times 12 \times 100}$$

Where:

Tv = Mean maximum temperature (°C) during the year

Ta = Range between mean maximum temperature (°C) and mean minimum temperature (°C)

P = Annual precipitation (mm)

G = Growing months, number of months during which the mean monthly temperature exceeds 3°C

E = Radiation received at the pole expressed as a percentage of the radiation received at the latitude in question

Parameters of climate were analyzed using best fit regression. The significance of change in the parameters was assessed applying Student t-test at p=0.05.

Results

Climate Regimes

The mean temperature regime was 11.21±0.07°C with the maximum temperature regime of 16.36±0.08°C and minimum temperature regime of 6.08±0.08°C. The highest seasonal maximum and minimum temperature regimes were estimated during monsoon. The lowest seasonal maximum temperature regime was estimated during winter. The highest seasonal minimum temperature regime was estimated during monsoon, while the lowest seasonal minimum temperature regime was found during winter. The seasonal minimum temperature regimes of spring and autumn were nearly equal. The mean seasonal maximum temperature regime was the highest during monsoon and the mean seasonal minimum temperature regime was the lowest during winter (Table 1). The temperature regime (maximum, minimum, mean) during summer were slightly lower compared to monsoon.

The mean annual precipitation regime over GFD, during 1962-2011 was 889.48±19.43 mm. The wettest season was monsoon, while the driest season was autumn. The spring and winter were moderately wet (Table 1).

Table 1
Temperature and precipitation regimes over GFD (1962 to 2011)

Seasons/ Periods	Climate parameters			
	Max. Temp. (°C)	Min. Temp. (°C)	Mean Temp. (°C)	Precipitation (mm)
Spring	13.70±0.17	4.19±0.15	8.93±0.15	198.50±9.68
Summer	23.09±0.15	11.58±0.14	17.32±0.14	116.63±4.59
Monsoon	23.46±0.08	13.12±0.07	18.27±0.07	345.06±13.50
Autumn	16.01±0.11	4.12±0.11	10.05±0.09	46.67±3.01
Winter	6.78±0.12	-2.01±0.14	2.39±0.12	180.53±8.14
Annual	16.36±0.08	6.08±0.08	11.21±0.07	889.48±19.43

Climate Trends

There was an overall increasing trend in mean annual maximum temperature. The highest mean annual maximum temperature was 17.40°C during 1999, while the lowest mean annual maximum temperature was 15.20°C during 1965. Overall, the mean annual maximum temperature remained higher during 1998-2011, except 2005, compared to the mean annual maximum temperature during 1972-1994. There were 20 years having mean annual maximum temperature higher than 16.50°C, while there were three years having mean annual maximum temperature lower than 15.50°C (Figure 2). The highest variability in mean annual maximum temperature within a year was recorded during 1968, followed by 1982 and the lowest variability was recorded during 2011.

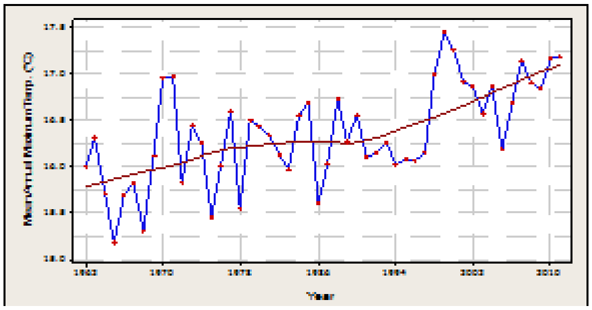


Figure 2: Changing trend of Mean Annual Maximum Temp. (°C) over GFD (1962 to 2011)

An overall increasing trend was observed in mean annual minimum temperature. The highest mean annual minimum temperature observed was 7.61°C during 2001, and the lowest mean annual minimum temperature was 4.96°C during 1975. There were four years, near the turn of the century, having mean annual minimum temperature higher than 7.00°C. Similarly, the mean annual minimum temperature remained above 6.00°C during 1998 to 2011 (Figure 3). The increasing trend of the mean annual minimum temperature followed almost the same pattern as that of the mean annual maximum temperature. The highest variability in the mean annual minimum temperature within a year was during 1968, followed by 1975, while the lowest variability in the mean annual minimum temperature within a year was recorded during 2004, followed by 1989.

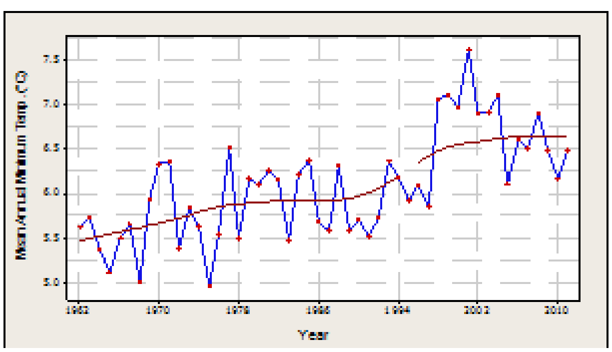


Figure 3: Changing trend of Mean Annual Minimum Temp. (°C) over GFD (1962 to 2011)

An overall increasing trend was observed in mean annual temperature. The highest mean annual temperature observed was 12.26°C during 1999 and 2001. The lowest mean annual temperature observed was 10.13°C during 1965, followed by 10.14°C during 1968. The mean annual temperature increased steadily, except 1986 to 1992, and remained above 11.50°C during 1995-2011, except 2005 (Figure 4). The increasing trend of mean annual temperature followed more closely that of the annual maximum temperature than the annual minimum temperature. The highest variability in mean annual temperature within a year was during 1968, while the lowest variability was recorded during 2004.

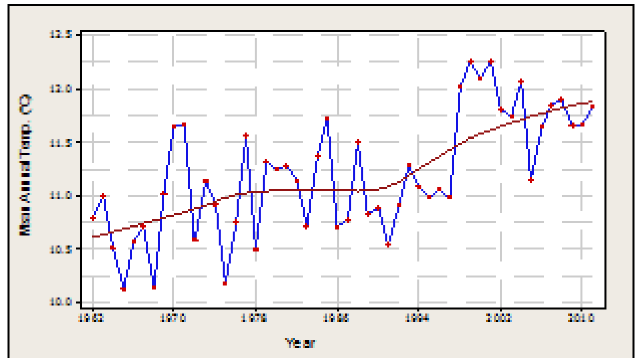


Figure 4: Changing trend of Mean Annual Temp. (°C) over GFD (1962 to 2011)

The analysis showed a flattened normal distribution of annual precipitation during 1962-2011, with peak values around 1986. The wettest year was 1983, with annual precipitation of 1146.2±25.01 mm/annum, followed by 1975. The driest year was 1971, with annual precipitation of 561.2±11.60 mm, followed by 2000 (Figure 5). Overall, the annual precipitation remained around 950 mm/annum during late 1970s to mid-1990s, with sharp declines on both sides. The annual precipitation was more unevenly distributed during 2006, followed by 1978. In contrast, the annual precipitation was more evenly distributed during 2000, followed by 1974.

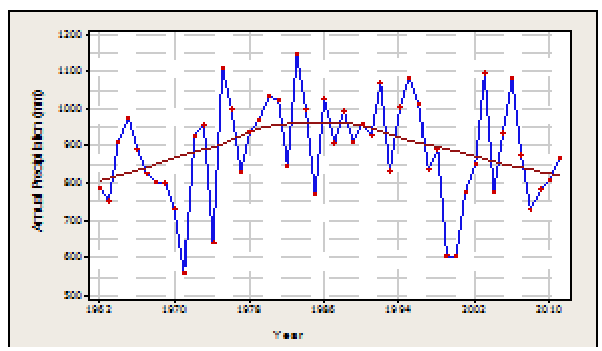


Figure 5: Changing trend of Annual Precipitation over GFD (1962 to 2011)

Climate Changes

The climate data showed considerable variations in temperature and precipitation, both in horizontal (within year) and vertical (between years) patterns, during 1962-2011. A highly significant ($p<0.01$) increase in maximum, minimum and mean temperatures was observed (Table 2). Amongst the seasons, the highest increase in maximum temperature was recorded during winter and the lowest increase during autumn. The highest increase in minimum temperature was recorded during winter and the lowest increase during monsoon. The highest increase in mean temperature was recorded during winter, followed by spring and summer. The lowest increase in mean temperature was recorded during monsoon, followed by autumn. The increase in maximum temperature and minimum temperature during spring and autumn indicated shortening of winter period and lengthening of summer period.

Table 2

Temperature and precipitation changes over GFD (1962 to 2011)

Seasons/ Periods	Climate parameters and precipitation changes			
	Max. Temp. (Δ°C)	Min. Temp. (Δ°C)	Mean Temp. (Δ°C)	Precipitation (Δ %)
Spring	1.47*	1.78**	1.64**	-14.90*
Summer	1.04*	1.16**	1.12*	-9.85^{ns}
Monsoon	0.68*	0.35^{ns}	0.54*	8.94*
Autumn	0.50^{ns}	0.92*	0.73*	11.81^{ns}
Winter	1.73**	2.37**	2.08**	12.04^{ns}
Annual	1.10**	1.32**	1.22**	1.39^{ns}

* Significant ($p<0.05$); ** Highly significant ($p<0.01$); ns= Not significant ($p>0.05$)

The analysis showed an overall 1.39% increase in precipitation during 1962-2011. Likewise, the magnitude of precipitation increased during monsoon and autumn and winter. Conversely, the magnitude of precipitation decreased during spring and summer. The analysis of temperature data indicated relatively higher increase in the minimum temperature compared to the maximum temperature (Figure 6). The slope gradient of the minimum temperature was higher compared to the mean and the maximum temperatures on annual, as well as, seasonal basis, thus indicating warming of night temperature and narrowing down diurnal temperature gap. The narrowing down of the gap between maximum and minimum temperatures was more pronounced in monsoon. The results also showed higher variability in the minimum temperature compared to the mean and the maximum temperatures. Least fluctuations were recorded in the maximum temperature, thus indicating a uniform increase which was also supported by the linear model fit for the change in the maximum temperature.

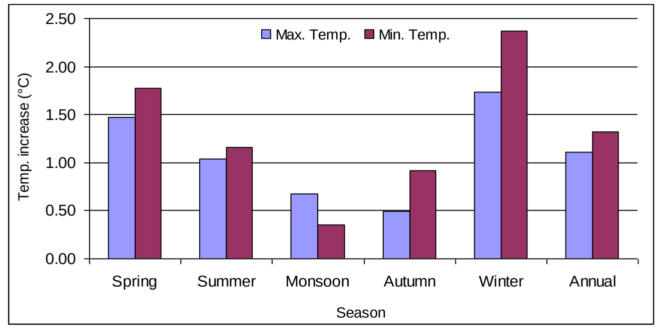


Figure 6: Comparison between increase in maximum and minimum temperature

Mathematical expressions of temperature and precipitation changes during 1962-2011 showed both linear and quadratic behaviors. Climate parameters, such as, annual minimum temperature, summer maximum temperature, summer minimum temperature, summer mean temperature, monsoon maximum temperature, autumn maximum temperature, autumn mean temperature, winter minimum temperature, winter mean temperature and winter precipitation exhibited linear function, while the other 14 parameters followed quadratic pattern of regression response. The R^2 indicated the best fit model for some climate parameters and poorly fit model for others, especially precipitation (Table 3).

Table 3

Mathematical expressions of climate change trends over GFD (1962 to 2011)

Climate Parameters	Mathematical Expressions	R^2	$F_{(1)2,(48)47}$* (p)
Annual Max. Temp.	Y=1306-.321×X+0.0003×X^2	0.39	15.11 (0.000)
Annual Min. Temp.	Y=- 47.58+0.027×X	0.44	37.01 (0.000)
Mean Annual Temp.	Y=1133-.155×X+0.0003×X^2	0.43	17.79 (0.000)
Annual Precipitation	Y=-983447+990.8×X-0.249×X^2	0.12	3.12 (0.050)
Spring Max. Temp.	Y=3821-3.863×X+0.001×X^2	0.15	4.09 (0.023)
Spring Min. Temp.	Y=2196-.243×X+0.0006×X^2	0.26	8.43 (0.001)
Spring Mean Temp.	Y=3081-3.127×X+0.001×X^2	0.22	6.55 (0.003)
Spring Precipitation	Y=-182887+185.0×X-0.047×X^2	0.04	0.87 (0.425)
Summer Max. Temp.	Y=-19.08+0.021×X	0.08	4.17 (0.047)
Summer Min. Temp.	Y=-35.43+0.0237×X	0.13	7.11 (0.010)
Summer Mean Temp.	Y=-28.02+0.0228×X	0.11	6.00 (0.018)
Summer Precipitation	Y=-53502+54.23×X-0.014×X^2	0.02	0.45 (0.643)
Monsoon Max. Temp.	Y=-3.93+0.014×X	0.12	6.21 (0.016)
Monsoon Min.	Y=613-	0.05	1.34 (0.271)

Temp.	0.611×X+0.0002×X^2		
Monsoon Mean Temp.	Y=1241-.242×X+0.0003×X^2	0.12	3.31 (0.045)
Monsoon Precipitation	Y=-695351+699.9×X-0.176×X^2	0.13	3.47 (0.039)
Autumn Max. Temp.	Y=- 4.19+0.0102×X	0.04	1.77 (0.190)
Autumn Min. Temp.	Y=1547-.572×X+0.0004×X^2	0.13	3.63 (0.034)
Autumn Mean Temp.	Y=-19.54+0.01489×X	0.11	6.03 (0.018)
Autumn Precipitation	Y=-77864+78.34×X-0.0197×X^2	0.04	0.86 (0.428)
Winter Max. Temp.	Y=1935-.976×X+0.0005×X^2	0.36	13.45 (0.000)
Winter Min. Temp.	Y=-98.24+0.0484×X	0.49	46.78 (0.000)
Winter Mean Temp.	Y=-81.97+0.0425×X	0.50	48.29 (0.000)
Winter Precipitation	Y=-649+0.4174×X	0.01	0.54 (0.465)

* Values in parenthesis in the top row are degree of freedom for linear equations

Climate, Vegetation Productivity Index

Climate, Vegetation Productivity Index (CVPI) during 1962-2011 ranged between 4,362 and 9,091 with mean of 6,815.7. The highest CVPI was estimated during 2003, while the lowest CVPI was estimated during 1971. The pattern of CVPI showed significant increase ($F_{2, 47}$= 5.34, p>0.01). The mathematical expression (CVPI = -8059491+8104xX- 2.036xX^2; R^2= 0.18) showed a quadratic function of CVPI. The maximum CVPI calculated was for the time period between 1980 and 2000. A declining trend was observed in CVPI, after 2000 (Figure 7).

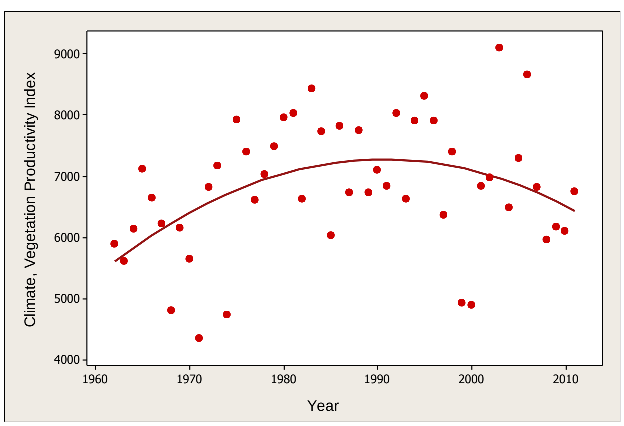


Figure 7: Trend of Climate, Vegetation Productivity Index of GFD (1962 to 2011)

Discussion

The results of this study show an increase in temperature (maximum, minimum, mean) over Galies Forest Division-Abbottabad, during 1962-2011. The temperature changes show an upward trend both horizontally (across the seasons) and vertically (across the years). The highest increase on annual basis is recorded in the minimum temperature, followed by the mean temperature and the maximum temperature. The highest increase on seasonal basis is recorded in the minimum temperature during winter and the lowest increase again in the minimum temperature during monsoon. By seasons, the highest increase in temperature (maximum, minimum and mean) is in winter, followed by spring, thus indicating extending summer time period. The climate change shows a feedback mechanism with climate parameters. For instance, the maximum temperature and the minimum temperature are positively correlated *inter se* and with the mean temperature. Conversely, precipitation is negatively correlated with temperature. The range of variation and the coefficients of variation indicate a large seasonal volatility of climate.

The present findings of increasing temperature are higher compared to global average temperature increase of 0.74°C during 1906-2005 (IPCC, 2007). However, these findings are broadly in conformity with Bukhari and Bajwa (2009); where they reported an increase of 0.92°C and 0.77°C in the maximum and the minimum temperatures, respectively, in Peshawar, during 1985-09. Similarly, Bukhari and Bajwa (2011) reported an increase of 0.56°C to 0.78°C in the mean temperature over different forest types of Pakistan. The greater increase in temperature towards the end of 20th century and beginning of 21st century is in corroboration with previous works (Esper et al., 2002; IPCC, 2007). The increasing temperature trends 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).

Furthermore, the greater increase in temperature at local level may be explained in terms of newly emerging urbanization phenomenon, with associated spree of construction, infra-structure development and deforestation in the area. The local urban areas act as heat island. Previously, heat island effects have been reported by 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 (Sajjad et al., 2009). Present increase in temperature is lower compared to that reported by Sajjad and his colleagues (2009), except the minimum temperature. The differences in reported increase in temperature may be, besides other factors, due to time period analyzed, as Sajjad et al., (2009) included time period between 1976-05, while the present study covers time period of 1962-2011. Similarly, the increase in the maximum temperature is, nevertheless, higher compared to previous reports in Lahore-Pakistan during 1975-07.

The present findings also indicate a greater increase in the minimum temperature compared to the maximum temperature. Thus, indicating that nights are becoming warmer at higher rates compared to days. The highest increase in temperature is during winter, followed by spring. Greater increase in the minimum temperature during winter is bringing early start of spring. These findings are in corroboration with Bukhari and Bajwa (2009, 2011 & 2012).

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 and rainfall patterns (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). The resent findings show significant changes in precipitation. There is an overall increase of 1.39% precipitation over GFD, however, a significant decrease is observed during spring and summer. The decrease in precipitation and increase in temperature during spring and summer, signify inverse relationship between temperature increase and magnitude of precipitation during these seasons. The drought periods also increase with a number of years receiving scanty or moderate precipitation. These results are broadly in line with findings reported previously by Grunewald et al., (2009); Liu et al., (2010).

The recent climate changes over GFD may further be explained in terms of increased human population, livestock and urban sprawls in the area, especially during summer and monsoon, in the recent past. These activities, subsequently, are increasing greenhouse gases (GHGs) in the area. The combination of increased population and anthropogenic activities influence the biogeochemical processes which might have changed climate in the Forest Division, 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 et al., 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 also change the land cover and land use pattern. Livestock, besides, directly responsible for GHGs (18% of all human-induced GHGs globally) cause deforestation as well as deteriorate rangelands (Van de Steeg et al., 2009). In GFD, grazing and deforestation for timber and fuel wood put pressure on forest resources. These factors, in addition to urban sprawl and road network, have changed land cover and land use pattern which subsequently may have resulted in climate changes.

The observed increase in temperature and precipitation, both horizontal and vertical, will likely have multiple effects, 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), (v) change in forest types, species composition, geographical relocation of plant and animal species, (vi) increased and frequent insect pests and diseases outbreaks, and (vii) escalated wind damage of forests, as reported by Blennow et al., (2010); Bukhari and Bajwa (2012). These effects would likely lead to increased cost of forest management and other economic activities in the area.

Overall, these climate changes present a great threat to the present and, to a much greater extent, to the coming generations. The mitigation of adverse effects of climate change 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 (back loaded 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.

The present findings show an increase in mean annual and seasonal Temperature Efficiency Indices and decrease in mean annual Aridity Index (AI). Similarly, changes have occurred in Dryness Index, Rain Factor, Dryness Factor, Humidity Coefficient and Precipitation Efficiency Index. The Climate, Vegetation Productivity Index (CVPI) of GFD has an observed range of 4,362 to 9,091. The results indicate an overall increase in CVPI and a close relationship between climate change and changing CVPI. The increasing temperature shows a negative impact on CVPI, especially after 2000. Bioclimatic indices are tools to explain the spatio-temporal distribution of vegetation by the combination of different climatic factors (Baltas, 2007). These findings are increasingly important for future planning and management of the GFD. Previously, these indices were used to transfer the results from climate modeling to land use and vegetation science, to predict long-term trends in desertification (Gavilán, 2005), and in the methodology of pollen forecasting (Valencia-Barrera, et al., 2002). The mean CVPI placed GFD in ideal site class estimated as per methodology described by Paterson, 1956, Champion et al., 1965. The increasing trend of CVPI within certain temperature ranges, however, indicates increasing CVPI. This is an encouraging finding for management of the GFD.

Changes in bioclimatic indices, both horizontally and vertically, indicate changes in forest growth and productivity. The climate change coupled with bioclimatic indices during spring is crucial. The spring is a 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 complete a normal annual cycle of vegetative and reproductive growth (Bukhari and Bajwa, 2009). The increasing temperature in winter and spring indicates early onset and completion of spring. Earlier onset of the spring as well as shifting of seasons is in conformity with Bukhari and Bajwa (2009); Liu et al., (2010); where they reported an early onset of the spring season. The early start of spring 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. Further, the poor vegetative growth also leads to inferior reproductive growth (flowering, quantity and quality of seed) (Bukhari and Bajwa, 2009 & 2011).

Apart from forest growth and productivity, the present findings of changing climate and bioclimatic indices over GFD indicate changes in vegetation composition. It has been reported that a change in the mean annual temperature, as small as 1°C over a sustained period is sufficient to bring about changes in species composition and distribution of many tree species (IPCC, 1996). 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. The long summer combined with long monsoon may also change the basic composition of seasonal rhythms and subsequently flora and fauna of GFD. These seasonal variations might cause extinction of some floral and faunal species by facing climatic conditions beyond their critical survival ranges. Apart from disturbance of biological processes and biodiversity, the climate change and seasonal variations also affect a number of physical processes and livelihood activities in the area, particularly in agriculture, livestock, water supply, housing, construction and tourism sectors.

Conclusion

Based on the results, it is concluded that climate over GFD has changed significantly over time span of 1962-2011. Among the climate parameters, the highest increase occurred in minimum temperature. The warmest and the wettest season was monsoon. Increase in minimum temperature was relatively greater compared to maximum temperature for all seasons. Winter was becoming relatively warmer followed by autumn compared to other seasons. An overall increase in annual precipitation was recorded, however, precipitation decreased during spring and summer. The changing climate showed considerable effect on vegetation productivity. An increase in CVPI was found within certain temperature ranges, which was an encouraging sign for management of the GFD.

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