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Variations of surface temperature and precipitation in Gilgit-Baltistan (GB), Pakistan from 1955 to 2010

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Abstract

This study characterizes precipitation and temperature variability for the whole region of Gilgit-Baltistan (GB), covering winter dominated high mountain region. Trend analyses of the historical data for the period 1955-2010 show that winter season temperatures have increased in this region during the past 55 years. Relatively higher increase in maximum winter temperatures was observed, whereas minimum temperatures during winter showed a slight decline which is negligible. These results suggest that days have become warmer whereas nights have become cooler during the winter season in the high mountain areas. Monsoon temperatures have also decreased in this region. More interestingly, average temperatures in the transitional periods "October-November" and "April-May" are at a rising trend. The results indicate that the maximum temperatures have increased all around the year last 55 years. Precipitation has also increased in GB. The paper included an annual and seasonal analysis for the periods 1955-2000 & 2001-2010 to compare variability in climate parameters in previous century (available data) to the recent decade of 21st century. This showed that recent decade is 0.33^{o}C warmer than that of previous half century, and precipitation trend is much greater, i.e. 5.013mm per year than that of previous rate 1.045mm per year. However, these rising temperature trends may increase the melting of glaciers and snow, reduce snow accumulation during winter and enhance the overall de-glaciations process and therefore could well endanger the country's sustained sources of fresh water from glaciers and snow melting.

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Introduction

Climate change is a shift in average weather of a particular region experience over a long period of time (30 years). Climate variability here refers to variations in the mean state. These days, climate change has become a growing worldwide environmental concern. One of the most remarkable features of climate change is the increase in temperature, so it has been mainly recognized as 'global warming'. As the Gilgit-Baltistan (GB) is located at the extreme north of Pakistan and host of more than 5000 glaciers, so it is a dire need to assess the temperature and precipitation pattern of the region. This study presented the past and present trend of temperature and precipitation along with a comparison of the past and present. As the seasonal analysis is also important so this study also includes an analysis of all seasons.

GB is the largest fresh water reservoir of Pakistan and this study will help to understand the snow fall and rain fall pattern, and the shifting of timing and distribution of runoff. These changes definitely affect the availability of freshwater for natural systems and human uses, such as agriculture. With rising temperatures considerably in winter, precipitation will fall more as rain than as snow, then less water is stored and available during water-deficient times later in the year. Most of this rain falls will immediately runoff during the winter and spring months, which can increase the risk of landslides and flooding (both in the mountains and downstream). Furthermore, if freshwater runoff is reduced in the summer months because of earlier snow melting, soils and vegetation may become drier, increasing the risk and intensity of wildfires. It will also affect vegetation cover, disrupt agriculture and threaten overall biodiversity. Mountainous areas may experience more intense bursts of heavy rains in the summer; any resulting runoff would carry more sedimentation and soil nutrients than snow melt.

Because of hydrological as well as geographical importance of GB, this region demands clear assessment of present and past climatic conditions. Stile no one has done a sufficient assessment to understand the temporal and spatial changing of climatic parameters, which will help to foresee the future climate pattern of the region. So this work is a small effort to find out the variability/changing of important climatic parameters, which can be use for climate projections.

Materials and methods

Study Area

This paper covers the high mountainous regions (i.e. GB) of Pakistan which covers parts of Himalayas, Karakorum and Hindukush (HKH) ranges. GB has small geographic range of an area of 72971 km², lying in the extreme north of Pakistan (75° 08/ 48.12// E & 37° 00/ 47.33// N to 77° 41/ 11.82// E & 35° 27/ 26.06// N). Nature has gifted this area with high mountainous ranges, massive glaciers, glorious rivers and splendid valleys. GB serves as a major water catchment for the Indus River Basin (IRB) upon which majority part of Pakistan depends for hydroelectrically and for irrigation purposes. The high mountain region is mostly winter rain dominated (Sheikh and Manzoor, 2004). This region is the main source for water in Pakistan. The winter precipitations are brought during December to March due to the western disturbances passing along the path between 30-60°N, whereas monsoon rains are caused by lows and depressions developing in the Arabian Sea and Bay of Bengal during July to September (Sheikh and Manzoor, 2004).

Like other mountainous regions of the world, the climate of GB is also changing. To asses and analyze the climatic condition of this region, Pakistan Meteorological Department (PMD) has established multiple stations in this region. For research and academic purposes, PMD will provide the data of all required parameters of these observatories.

Fig. 1. Map of the study area.

Data Sources and Methodology

Monthly data on temperature and precipitation covering the period from 1955-2010 was used. The data was obtained from Pakistan Meteorological Department. The study areas covered 05 meteorological stations in high mountain region of Pakistan as shown in Table 1.

Table 1. Meteorological Stations Covered in the Study Area.

S.NO	Gilgit-Baltistan (GB) regions	Latitude	Longitude	Average Altitude a.s.l. (meters)
01	Astor	35°20/	74°54/	2168
02	Bunji	35°40/	74°38/	1372
03	Chilas	35°25/	74°06/	1251
04	Gilgit	35°55/	74°20/	1460
05	Skardu	35°18/	75°41/	2210

The seasonal changes were carried by applying descriptive statistics and also trend analyses were conducted separately for temperature and precipitation using Linear Trend Model.

Result and discussions

Fifty five years average monthly temperatures covering the period 1955–2010 reveal that the first five month (Jan-May) for the resent decade (2001-2010) of the GB region obviously was hotter than the period 1955-2000 of the same regions. But during the monsoon period (July – September) where the resent decade shown decrease in mean monthly temperatures (Fig. 02), which is because of the higher monsoon rain fall in the GB in recent decade comparing the period 1955-2000 (Fig. 03).

Snow fall occur in winter season (Nov-Feb) in the whole GB. The Fig. 03 clearly shows that the snow fall increased in recent decade as compare to the period 1955-2000 except in the month of November, which is indication of shortening of snow fall season.

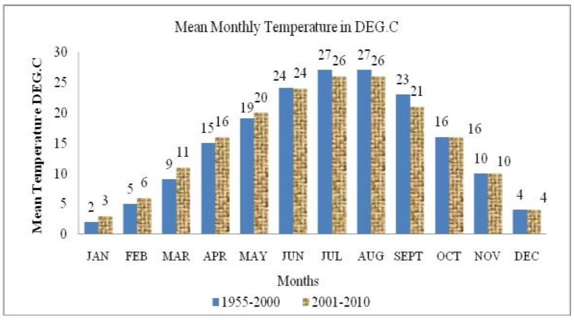

Fig. 2. Mean Monthly Temperature for the periods 1955-2000 and 2001-2010.

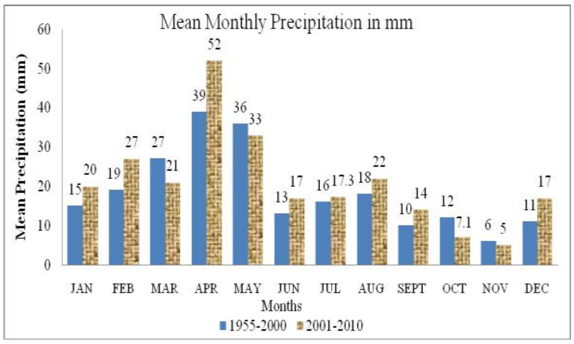

Fig. 3. Mean Monthly Precipitation for the periods 1955-2000 and 2001-2010.

Regression Results

Separate regressions were fitted for annual average, maximum and minimum temperatures as well as annual average rainfall using data for the period 1955- 2010. Similar regressions for temperature and rainfall were also fitted for the average temperatures and rainfall, each for the four different seasons of the year viz. monsoon (July – September), winter (October-March), transitional period-1 (April-May) and transitional period-2 (Oct-Nov). The results are presented in Table 3.

To study the change in temperature and precipitation in Gilgit-Baltistan during 20th century and recent decade we divide the available data i.e. 1955-2010 into two periods 1955-2000 & 2001-2010. And for the both periods separate regression were fitted for annual bases as well as seasonal bases, the results are presented in Table 4.

Temperature trends

Average annual temperature was observed to be about 0.33°C higher in the period 2001-2010 compared to 1955-2000. The regression results suggest that annual average temperatures have declined for both the periods 1955-2000 and 2001-2010 with values -0.001^{o}C & -0.056 ^{o}C per year respectively (Table 4). Average annual maximum temperatures have increased (0.012 °C) for the period of 1955-2000 but shows a decreasing trend (-0.087 °C) for 2001-2010 period. On the other hand average annual minimum temperatures have decreased in both periods.

But the regression results of the period 1955-2010 suggest that the regions of GB have got hotter during the last 55 years.

However, trend analysis for various seasons provides a different picture. The monsoon temperatures have decreased in both periods by -0.023 °C and -0.044 °C respectively. Winter temperatures have increased in 1955-2000 by 0.006 °C per year but a slight declining trend could be observed in 2001-2010. On average the winters have become hotter by 0.76 ^{o}C in the recent decade which is greater than the global average and this is alarm for this glaciated region of Pakistan.

Another interesting trend was observed for the transitional period temperatures. Temperatures in both the transitional periods (October- November) and (April-May) show increasing trends (0.005 °C and 0.013 °C respectively) during 1955-2000. On the other hand, for both the transitional period temperatures show slight decreasing trends in 2001-2010, but on the average both transitional periods become hotter in the recent decade by 0.25 ^{o}C & 1 ^{o}C respectively. As April-May proceed the summer seasons as well as maximum temperatures during October-November show an increasing trend in GB.

These results point towards an onset of early summers in GB.

Precipitation trends

Regression trends for precipitation (Table 3) suggest that in GB the precipitation has generally increasing in all the seasons except during transitional periods where a slight decreasing trend was observed. On the other hand, precipitation has increased throughout the year in GB. The increasing trend during 2001-2010 is 5.013 °C per year, which is greater than that of 1955-2000 value 1.045 °C per year.

Summary of Regression Results

In summary, the trend analyses suggest that winter temperatures both in GB have increased during the period 1955-2000 and decreased during 2001-2010 (Table 2). Monsoon temperatures have also decreased in both periods. More interestingly, maximum temperatures in the transitional periods "October-November" and "April-May" particularly during 1955-2000 is rising. All these changes and seasonal variations have important implications for water resources and agriculture in the mountain areas in particular and for Pakistan in general.

Table 2. Summary of temperature trends in Gilgit-Baltistan (GB) for periods 1955-2000 & 2001-2010.

Periods	Temperature	Oct-Nov	Winter	April-May	Monsoon	Annual
1955-2000	Average	+++++	+++++	+++++	-------	--------
2001-2010		-------	--------	-------	-------	--------
1955-2000	Maximum	+++++	+++++	+++++	-------	+++++
2001-2010		-------	-------	-------	-------	-------
1955-2000	Minimum	-------	-------	+++++	-------	-------
2001-2010		-------	-------	------	-------	-------

------- Indicates a decline in temperature; +++++ Indicates an increase in temperature.

Table 3. Regression Results Regarding Temperature and Precipitation in GB.

Dependent Variable	Intercept	Time(Trend)	R^2
Average Annual Temp	14.94	0.004	0.014
Average Annual Max Temp	21.09	0.018	0.159
Average Annual Min Temp	8.74	-0.008	0.086
Average monsoon Temp	24.49	-0.023	0.29
Average max monsoon Temp	29.88	-0.008	0.035
Average min monsoon Temp	19.11	0.386	0.386
Average winter Temp	8.07	0.015	0.25
Average max winter Temp	14.58	0.03	0.43
Average min winter Temp	1.56	$-4e^{-05}$	$1e^{-06}$
Average April-May Temp	18.73	0.021	0.13
Average max April-May Temp	26.94	0.032	0.16
Average min April-May Temp	10.53	0.01	0.03
Average Oct-Nov Temp	9.56	0.006	0.04
Average Max Oct-Nov Temp	13.42	0.031	0.33
Average Min Oct-Nov Temp	5.69	-0.018	0.15
Annual Precipitation	193.2	1.066	0.06
Monsoon Precipitation	35.04	0.33	0.05
Winter Precipitation	89.01	0.207	0.01
April-May Precipitation	79.32	-0.042	0.00
Oct-Nov Precipitation	21.93	-0.145	0.01

Table 4. Percent Change in Temperature in ºC and Precipitation in mm during 1955-2000 & 2001-2010 for GB.

	1955-2000	2001-2010
Temperature	ºC	ºC
Average Annual Temp	-0.001	-0.056
Average Annual Max Temp	0.012	-0.087
Average Annual Min Temp	-0.013	-0.024
Average monsoon Temp	-0.023	-0.044
Average max monsoon Temp	-0.008	-0.072
Average min monsoon Temp	-0.038	-0.016
Average winter Temp	0.006	-0.042
Average max winter Temp	0.02	-0.067
Average min winter Temp	-0.007	-0.017
Average April-May Temp	0.013	-0.093
Average max April-May Temp	0.019	-0.165
Average min April-May Temp	0.007	-0.02
Average Oct-Nov Temp	0.005	-0.03
Average Max Oct-Nov Temp	0.033	-0.051
Average Min Oct-Nov Temp	-0.023	-0.008
Precipitation	mm	mm
Annual Precipitation	1.045	5.013
Monsoon Precipitation	0.472	2.95
Winter Precipitation	0.253	4.39
April-May Precipitation	-0.154	1.65
Oct-Nov Precipitation	0.00	-1.96

Conclusions and recommendations

Temperatures have increased in Gilgit-Baltistan during the last 55 years. These increases in temperature may have some positive implications for livelihood, agriculture and other sector in the GB. However, these temperature increases could well affect the Pakistan's sustained fresh water resources in the long run through accelerated melting of glaciers and snow in the high mountain areas. Detailed temporal and spatial analyses would however be required to assess the impacts of these climatic changes in the high mountain regions. An adaptation strategy needs to be developed to cope up the negative impacts of climate change.

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