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Research Article

Climatic Variability and Linear Trend Models for the Six Major Regions of Gilgit-Baltistan, Pakistan

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Abstract: Global warming is one of the main cause of climatic variability along with the increased frequency and intensity of extreme events in Pakistan. Northern Pakistan is composed of the greatest mountain complex having the junction of three mountain ranges Himalaya, Karakoram and Hindukush (HKH), which is reservoir of world third largest ice mass after the polar region. Snow and glaciers, the most sensitive indicators of warming, have been giving the negative signals at large. To quantify the impact of the climate change in Central Karakoram National Park (CKNP) region, the temperature and precipitation data gathered from different sources have been analyzed. Those include in-situ daily observations of mean maximum, mean minimum and mean temperatures extracted from the data archives of Pakistan Meteorological Department (PMD) at six stations for the period 1981 to 2012.No significant change in the total amount of precipitation has been found for the area of study which is quite consistent with the entire Gilgit-Baltistan (GB). However, the rise of varying magnitude has been noticed in day and night temperatures which resulted in a positive change in the mean daily temperatures. The most increase is found to be 0.04^0C/year in Bunji with both day and night rising temperatures. The least increased of mean day temperature is 0.006^0C/year in Chilas. While, in Gupis, the most increase in mean day temperature was observed as 0.065^oC/year. Moreover, precipitation in Astore and Skarduhas exhibited a decreasing trend merits further studies.

Keywords: Climate, temperature, precipitation, glaciers, Gilgit-Baltistan (GB)

1. INTRODUCTION

Climate Change (CC) is one of the serious environmental issue of recent century that we are expected to face under most likely scenarios. Climate Change has become a convincing truth on the basis of data collected by the world meteorological community around the globe. The positive and negative impacts of Climate Change are observable according to the vulnerability of the areas. Negative impacts resulting into disasters at different scales such as land erosion of HottoValley of Skarduin July2013 or Ataabad lake formation in January 2010 due to a massive land slide and devastating floods of summer. Although, extreme weather anomalies have been occurring everywhere due to climate change but the mountainous areas are more vulnerable to random ice melting and catastrophic flood downstream.

Upper Indus Basin (UIB) is located in rugged mountainous topography, therefore population density at such elevations is low. However, the population increases with the decrease in elevation in the UIB region. The population live down the stream depends on the water resources of the UIB and its tributaries, such as Astore River, Ghizer River, Hunza River, Shigar River and Shyoke River, for the purpose drinking, irrigation and hydro-power generations.

Unexpected changes in rainfall in terms of intensity, time and space as well as variable snowfall pattern are prime cause of decreasing water quantity in Indus River and its major tributaries. This water scarcity is affecting

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agriculture as well as agro-based industry of our country.

The system which regulated the temperature on earth is known as the “greenhouse effect”, a phenomena through which the greenhouse gases primarily CO_2, CH_4, and N_2O together with water vapor trap radiation from the sun preventing it from dispersing back into the space. As without these greenhouse gases in atmosphere the average temperature on the earth would be -18^oC instead of the current average of 15^oC and life on earth would be impossible [1].Since the Industrial Revolution the concentration of greenhouse gases increasing rapidly. The increasing amount of these heat–trapping gases enhanced the effect of natural greenhouse gases to a point that it has the potential to worm the glob at a rate that has never been experience in our history. The Intergovernmental Panel on Climate Changes (IPCC), working over the last twenty years on climate change assessment. According to their recent reports the average temperature of our glob has increased by 0.85^oC since the industrial revolution, and projection of global surface temperature is likely to exceed 1.5^oC for RCP4.5, RCP6.0 and RCP8.5. It is likely to exceed 2^oC for RCP6.0 and RCP8.5 and more likely than not to exceed 2^oC for RCP4.5, relative to the average of 1850 to 1900 [2]. These increases in temperature will have considerable both positive and negative impact on our socio-economic sectors such as health, water, agriculture, forestry and biodiversity.

The changing trends of temperature effect the seasons causing variation in their duration. The seasonal changes like shorter winter can lead to mismatches between the key elements in ecosystems, such as feeding periods of young birds and variability of worm/insects for their food. This changes also affect the growing seasons of forming [3].

All over the globe several attempts have been made for determining the temperature and precipitation trends of different parts of the world. In case Pakistan trend analyses of the historical data for the period 1971-2000 show that winter season temperatures have increased in both sub-mountain and high mountain region during the past 30 years and rainfall has also increased in both regions[2]. The HKH region, the world third largest ice mass has warmed up approximately 1.5^oC almost double than the remaining regions of Pakistan (0.76^oC) during the previous three decades [4]. Rapid melting of glaciers in GB is not only contributing to floods downstream but also to rise of sea level. Consequently, sea water intrusion into the land has been abolishing the fertility of agricultural land.

The aim of this study is the trend analysis of two climatic factors focusing on GB, viz. (a) Temperature and (b) Precipitation over six major regions, i.e., Astore, Bunji, Chilas, Gilgit, Gupis and Skardu. To explore these trends we assess the maximum, minimum and mean temperature trends. Annual precipitations are also studied by linear and quadratic models.

2. MATERIALS AND METHODS

The Pakistan Meteorological Department (PMD) is the national organization responsible for operation of meteorological network in Pakistan and to maintain the data records according to the laid down standards of World Meteorological Organization (WMO). The primary data (daily records) was collected from the data archives of PMD, at different meteorological observatories located in GB.

The data under this study consist of different time series of precipitation and temperature over the period of 1981 to 2012. The study of precipitation encompasses the total annual precipitation trends. However, the trends of temperature over the whole period include three time series of maximum temperature (T_{max}), minimum temperature (T_{min}) and mean temperature (T_{mean}). There are six meteorological measurement stations providing long time series for temperature and precipitation in GB. Stations are situated at Astor (2167 m a.s.l.), Bunji (1372 m a.s.l.), Chilas (1250 m a.s.l.), Gilgit (1459 m a.s.l.), Gupis (2155 m a.s.l.) and Skardu (2209 m a.s.l.).

Linear regression analysis is a statistical technique of taking one or more variable called independent variable (predictor) and developing a mathematical equation that show how they relate to the value of an another variable (called independent variable). While quadratic regression is prepared by adding the square value of the time periods. The coefficients in the quadratic formula are calculated again using regression, where time periods and the squared time periods are the independent variables [5, 6].

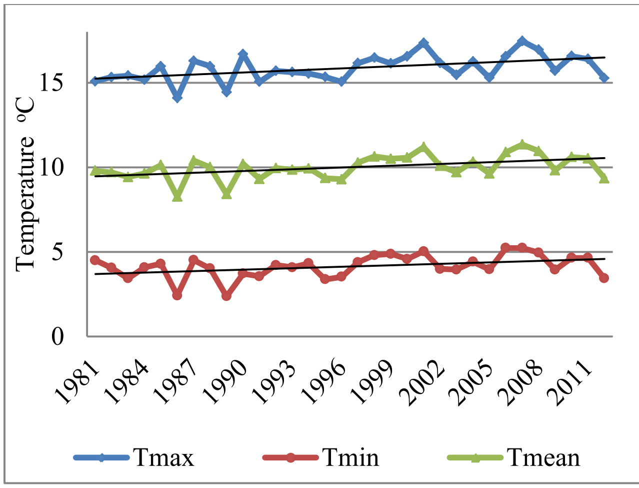


Fig. 1.T_{max}, T_{mean}, T_{min} of Astor (1981-2012).

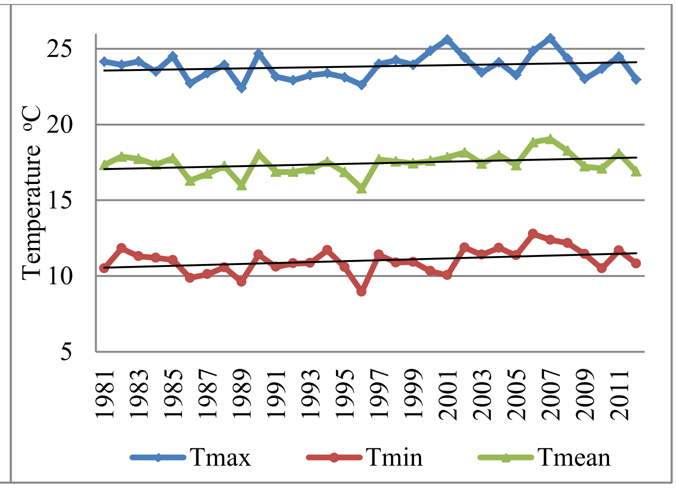


Fig. 2.T_{max}, T_{mean}, T_{min} of Bunji (1981-2012).

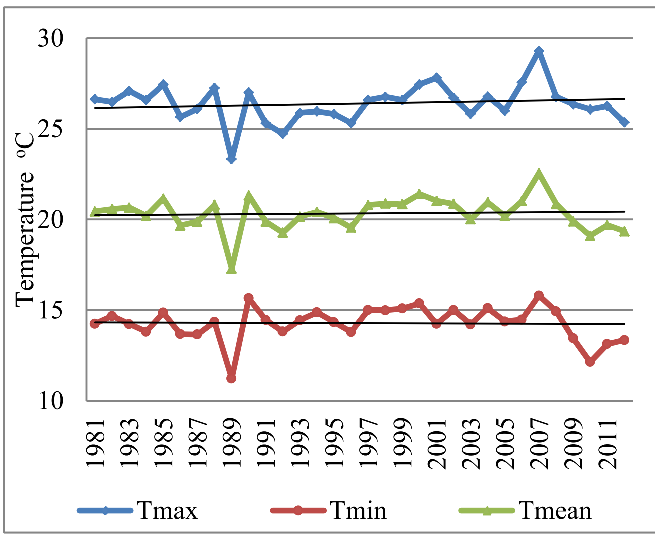


Fig. 3. T_{max}, T_{mean}, T_{min} of Chilas (1981-2012).

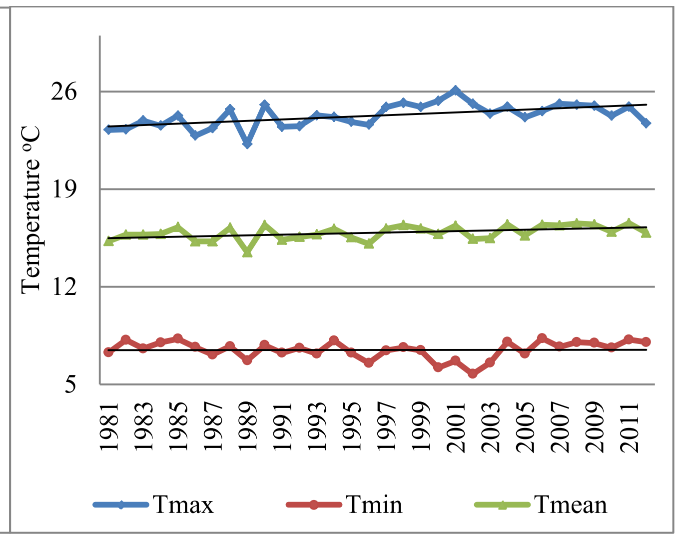


Fig. 4. T_{max}, T_{mean}, T_{min} of Gilgit (1981-2012).

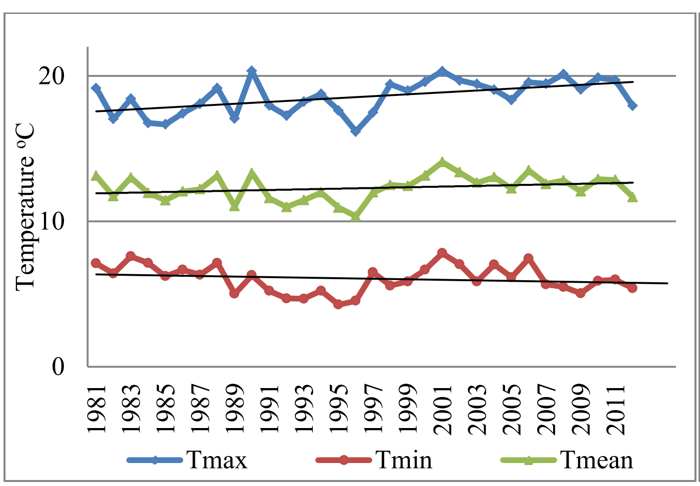


Fig. 5. T_{max}, T_{mean}, T_{min} of Gupis (1981-2012).

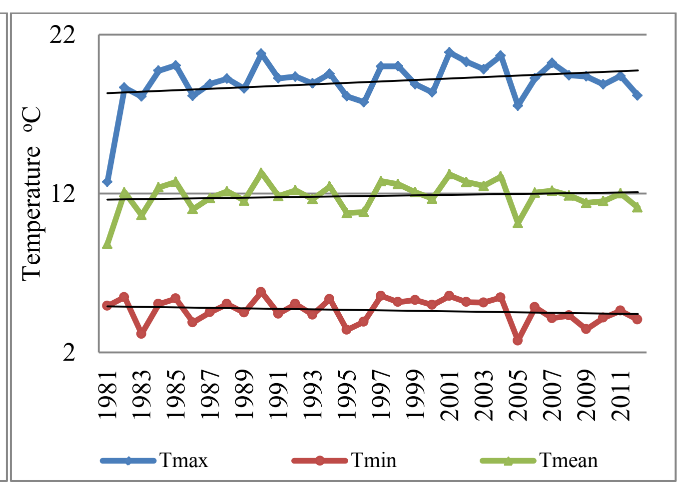


Fig. 6. T_{max}, T_{mean}, T_{min} of Skardu (1981-2012).

The linear (2.1) and quadratic (2.4) trend models were investigated by using least square assessment.

$$y = ax + b \quad 2.1$$

Where

$$a = \frac{\sum y_i . \sum x_i^2 - \sum x_i . \sum x_i y_i}{n . \sum x_i^2 - (\sum x_i)^2} \quad 2.2$$

$$b = \frac{n \sum y_i x_i - \sum x_i - \sum x_i . \sum y_i}{n . \sum x_i^2 - (\sum x_i)^2} \quad 2.3$$

x_i is the years in the time series such as $x_o = 1981$ (the first year in the time series), whereas y_i is the weather parameters (mean, maximum, minimum temperature and annual precipitation). All summations run through i = 0, 1, 2, 3,…..32, i.e., a total of 32 years. Equations 2.2 and 2.3 are the solution of the normal equations related to the scheme.

and

$$y = ax^2 + bx + c \quad (2.4)$$

In this equation, a, b and c are again the solution of normal equations related to the scheme. The obtained linear fit for the given period determine the concern climatic dynamics. The quality of these fittings are further assessed by using some statistical parameters in time series for each case. Which include; Mean Absolute Percentage Error (MAPE), is the measures of accuracy of fitted time series values. Which expresses accuracy in percentage. Its mathematical expression is given by:

$$MAPE = \frac{\sum_{i=1}^{n} |(y_t - y_t^{/})/y_t|}{n} \quad (2.5)$$

Where y_t is the actual values, $y^{/}_t$ is the values forecast by the models and n is the number of data values. The second parameter is Mean Absolute Deviation (MAD), measure the accuracy of fitted time series. It expresses accuracy in the same units as data, and helps to conceptualize the error. It is computed by using;

$$MAD = \frac{\sum_{i=1}^{n} |(y_t - y_t^{/})|}{n} \quad (2.6)$$

The parameter is Root Mean Square Deviation (RMSD), is the measure of accuracy of fitted time series values. RMSD is compute by using the same denominator 'n' irrespective of model, we can compare RMSD values across models. It is computed by using:

$$RMSD = \sqrt{\frac{\sum_{i=1}^{n} (y_t - y_t^{/})^2}{n}} \quad (2.7)$$

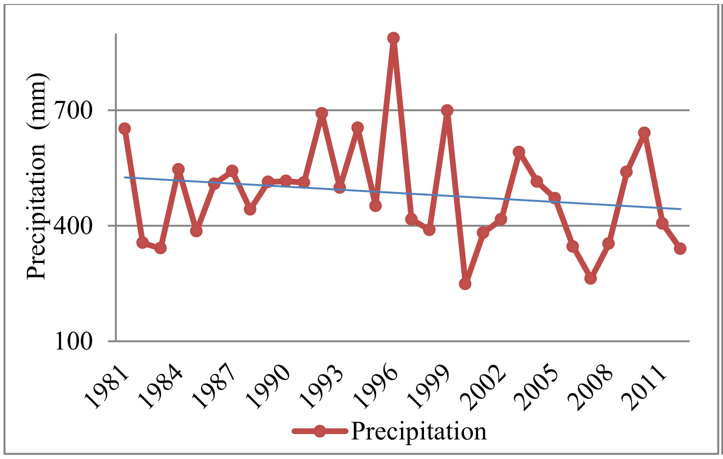
The temperature is analyzed by linear least square estimation, however the precipitation was analyzed through both linear and quadratic models.

3. RESULTS

This study reveals that the temperature is increasing, as shown in Table 1. The mean (T_{mean}), mean minimum (T_{min}) and maximum (T_{max}) temperature follows an increasing trend that signifies the impact of global warming over GB. Results of linear trends are summarized in Table 1 and main features are conferred below:

The increasing rate of maximum temperature of Gup is more than the rest, i.e., 0.065°C/year (Fig. 13a). But the minimum temperature of Gup is, Skardu and Chilas are showing decreasing trend, having values -0.018°C, -0.016°C and -0.002°C/year, respectively. The mean temperature of the most region have an increasing rates that lies within 0.01°C to 0.04°C/year. The minimum temperature of Gilgit has not changed significantly but maximum temperature has been increasing at the rate of 0.05°C/year, as it is evident from Table 1.

An in depth trend analysis of precipitation specifies that Gup is received heavy precipitation during number of years under the study period, showing increasing trend significantly. The rate of increase leads the rest with a value 7.001mm/year. This may be one of the possible reasons for decrease in the mean minimum temperature. However quadratic trend analysis shows no significant improvement in the results so linear trend analysis is adequate to extract tendency of temperature. That is why the result are not reported. Generally it is an anticipation that the consequence of global warming is an increase in precipitation in South Asia. This concept also confirm by the result obtain in this study, and all the regions an increase in annual precipitation except Astor and Skardu. The decrease of precipitation 2.655 mm/year and 1.605 mm/year (Fig. 13b) simultaneously in Astor and Skardu. It is a notable feature that may be caused by other latent factors that needs to further explored. Along



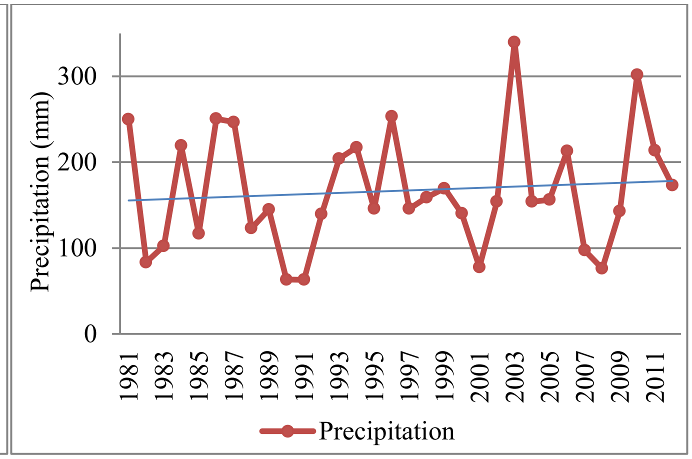
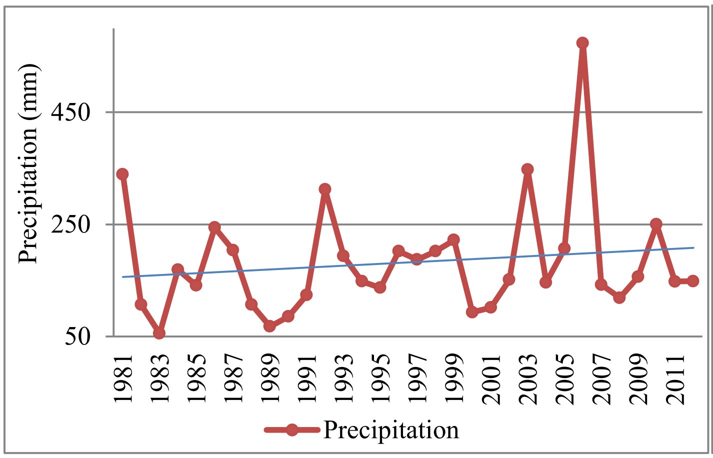


Fig. 7. Linear trend model for annual precipitation of Astor.

Fig. 8. Linear trend model for annual precipitation of Bunji.



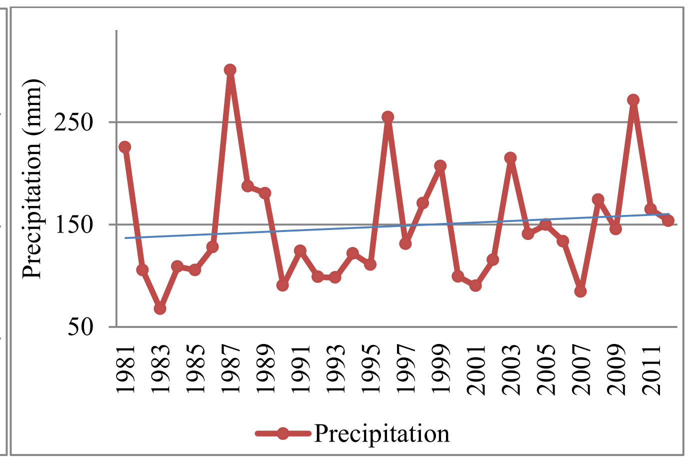
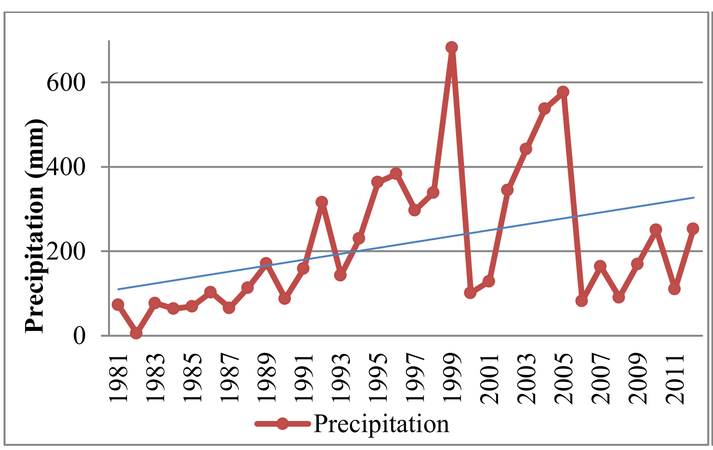


Fig. 9. Linear trend model for annual precipitation of Chilas.

Fig.10. Linear trend model for annual precipitation of Gilgit.



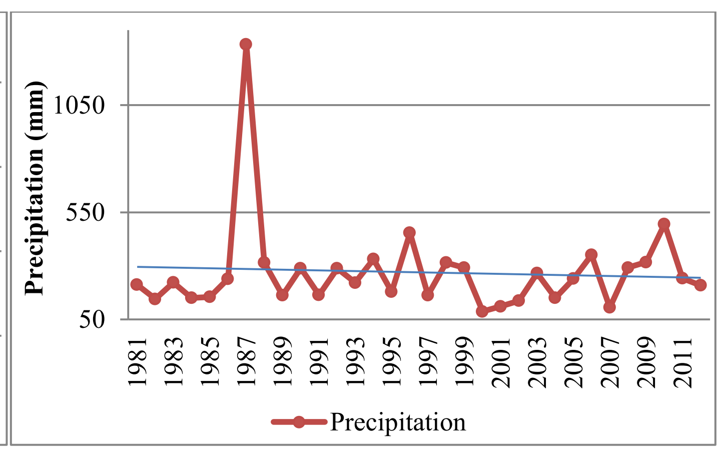


Fig. 11. Linear trend model for annual precipitation of Gupis.

Fig. 12. Linear trend model for annual precipitation of Skardu.

Table 1. Linear Trend equations for mean, maximum & minimum temperature along with MAPE, MAD and RMSD values for major regions of GB.

Region	Temp	Linear Trend	MAPE	MAD	RMSD
Astor	Mean	y_t=0.036t+9.444	0.054	0.541	0.693
	Max	y_t=0.034t+15.27	0.038	0.613	0.738
	Min	y_t=0.028t+3.668	0.154	0.624	0.751
Bunji	Mean	y_t=0.04t+16.86	0.030	0.521	0.683
	Max	y_t=0.017t+23.53	0.027	0.654	0.801
	Min	y_t=0.03t+10.51	0.057	0.639	0.808
Chilas	Mean	y_t=0.006t+20.22	0.033	0.672	0.896
	Max	y_t=0.015t+26.13	0.028	0.736	1.024
	Min	y_t= -0.002t+14.31	0.049	0.679	0.934
Gilgit	Mean	y_t=0.025t+15.45	0.026	0.419	0.497
	Max	y_t=0.050t+23.44	0.029	0.698	0.874
	Min	y_t=0.00t+7.472	0.069	0.500	0.625
Gupis	Mean	y_t=0.023t+11.93	0.056	0.695	0.837
	Max	y_t=0.065t+11.49	0.051	0.930	1.080
	Min	y_t=-0.018t+6.362	0.143	0.806	0.970
Skardu	Mean	y_t=0.010t+11.68	0.061	0.698	0.917
	Max	y_t=0.046t+18.27	0.049	0.864	1.363
	Min	y_t=-0.016t+4.927	0.155	0.628	0.789

Table 2. Linear and quadratic trend equations of annual precipitation along with MAPE, MAD and RMSD values for major regions of GB.

Region	Precipitation	Linear & Quadratic Trend	MAPE	MAD	RMSD
Astor	Yearly	y_t =-2.655t+528.6	2.474	1243.366	1341.103
		y_t =-0.390t^2+10.22t+455.6	178.836	94113.220	109926.397
Bunji	Yearly	y_t =0.742t+154.5	0.858	111.455	112.833
		y_t =0.091t^2 -2.288t+171.7	13.134	2578.934	3345.105
Chilas	Yearly	y_t =1.674t+154.5	1.743	277.273	285.294
		y_t =0.018t^2+1.050t+158.0	4.422	943.162	1423.615
Gilgit	Yearly	y_t =0.751t+136.1	0.792	99.104	100.101
		y_t =0.082t^2 -1.965t+151.5	10.377	1783.657	2331.241
Gupis	Yearly	y_t =7.001t+102.9	7.293	1414.126	1727.684
		y_t =-1.006t^2+40.21t-85.24	262.093	84638.94	142390.374
Skardu	Yearly	y_t =-1.605t+296.4	1.2195	412.780	688.165
		y_t =0.035t^2-2.780t+303.0	5.001	2906.547	10233.344

with the linear trend analysis the quadratic least square estimates have also been studied in order to obtain more convergent results. The quadratic fitting results found marginally better than the linear one as given in Table 2.

But in-depth analysis of precipitation show that Skardu received record heavy precipitation in 1987 (Fig.12). The rate of increment of precipitation in Bunji and Gilgit shows approximately same trend (Fig.13b).

DISCUSSION

The assessment of climate change fundamentally encompasses a good understanding of temperature and precipitation patterns. While studying climate change there are many factors to be considered.

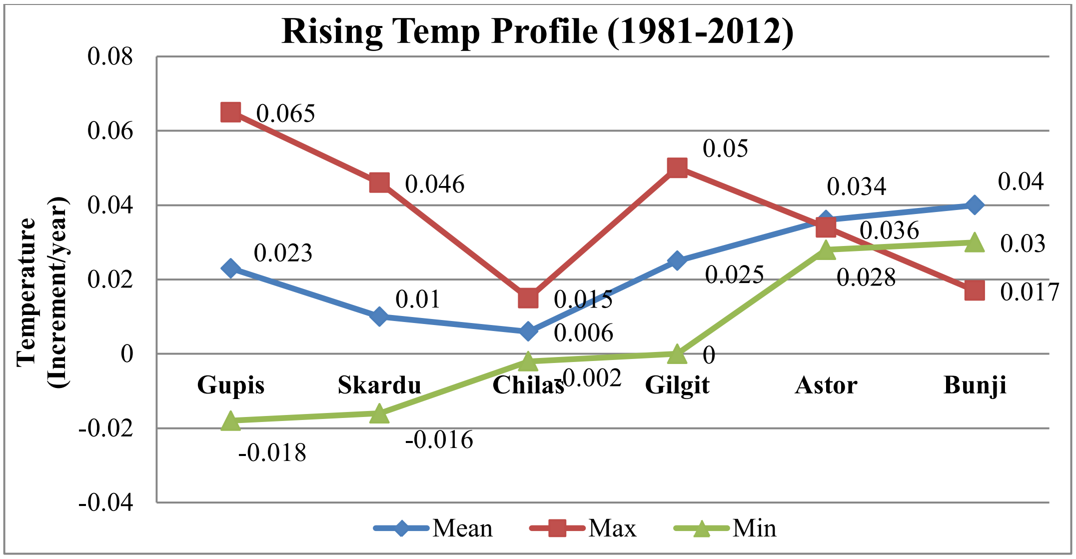


Fig. 13(a). Temperature increment per annum for considered areas.

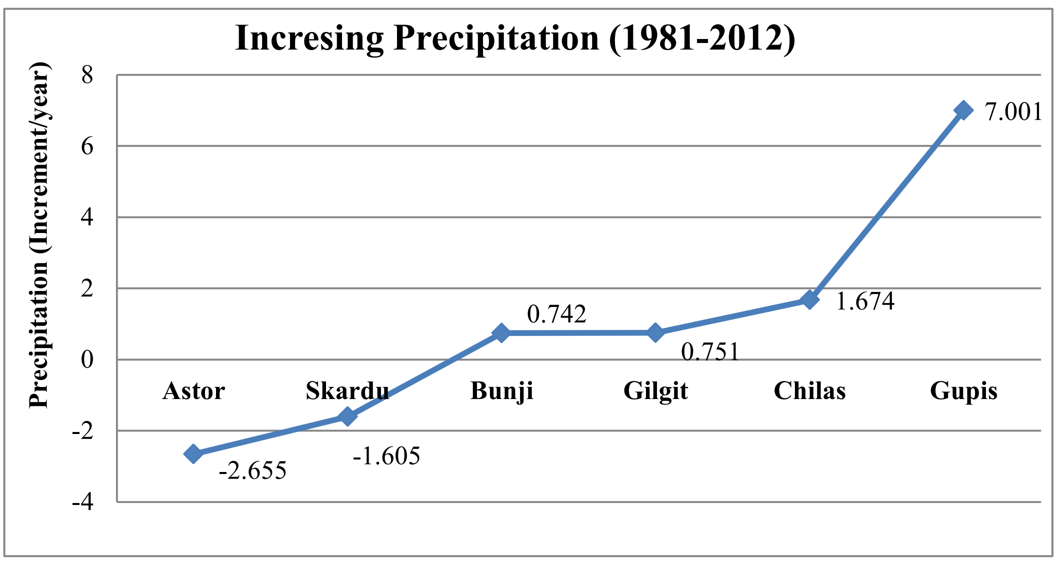


Fig. 13(b). Precipitation increment per annum for considered areas.

The linear behavior of increasing temperature in all regions except minimum temperature of Gup is and Skardu (Fig. 13b), show a clear effect of global warming in these regions (Table 1). During the study period (i.e., 1981-2012), the region of GB has warmed up by approximately 1.3°C. However, Rasul et al. [4] reported an increase of 1.5°C; similarly results were reported by Raza et al. [15]. This warming trend will greatly affect the seasonal pattern and solid water reservoirs of GB, which is alarm for the consistent flow of water in Indus River. It follows from above conclusion that GB, as the other parts of Pakistan is also facing land and atmosphere problems by global warming.

The effects of global warming on the rainfall are showing up day by day [3]. The precipitation trend of major region of GB is follow highly non-linear, so it is difficult to determine the precipitation pattern by only linear trend analysis as seen from the values of MAPE, MAD and RMSD. That is why we employed quadratic trend analysis that yields better results; their comparisons are given in Table 2. Both Fig. 7 and

12 shows a negative slope of precipitation pattern for Astor and Skardu sites.

To detect precipitation trend more accurately, more sophisticated techniques such as ARIMA modeling and Neural Network must be considered. Moreover the nonlinearities within the data can be dealt by using windowing and space-time separation plots techniques. It is dire need to identify and explain the unexpected behavior of T_{min} of Gupis, Skarduand Chilas, as well as annual precipitation pattern of Astor and Skardu.

4. ACKNOWLEDGEMENTS

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