Spatial and Temporal Analysis of Temperature Time Series over Gilgit-Baltistan (GB), Pakistan

Muhammad Raza*[1] and Fazal Wahab[1]

[1] Department of Physics, Karakorum International University (KIU) Gilgit-Baltistan.

**Corresponding author's email address: raza.physics@kiu.edu.pk*

Abstract

Global warming is one of the burning issue of this era, its impact and intensity is changing with space and time. As temperature is one of the major thermodynamic parameter which mainly derive the whole climate system. Analysis of spatial and temporal variation in temperature any region is much more needed to understand the physical behavior of that specific region. To examine seasonal as well as annual trends of temperature over Gilgit-Baltistan (GB), the fifth province of Pakistan, non-parametric Mann-Kendall (MK) and Sen's tests were employed in this research. This study particularly aims to reveal the spatial and temporal trends in temperature over GB, during 1955-2018. This study identified an increasing trend in annual mean temperature. At Astor and Skardu the annual temperature have increased with a significant rate of 0.02 ^{o}C/y. Trend analysis showed increasing trends in winter temperature at five stations (Astor, Bunji, Chilas, Gilgit and Skardu) but it slightly decreased with a rate of -0.01 ^{o}C/y at Gupis. The summer temperature has decreasing trends at all stations except for Astor, where it increased with a rate of 0.01 ^{o}C/y. In GB summer temperatures changes from 16.8^{o}C to 31.5 ^{o}C. Annual mean temperatures over south-east parts of GB remained below the base period (1981-2010) temperature during all seasons, except in winter in which the temperature remained the same.

Keywords: Temperature, Global Warming, Annual, Summer, Spring.

I. INTRODUCTION

The IPCC (Inter-Governmental Panel on Climate Change) defines Climate Change (CC) as climatic condition identified by applying statistical test, which changes in the mean of its properties and persist for a normal period of 30 years [1]. Changes in extreme weather and climate condition have important impacts on different sectors of society. The variability in temperature is one of the more triggering factor of climate changes [2]. The world population can become rather more sufferer because of the continuing warming as a result of climate changes [3]. Gilgit-Baltistan (GB) at the extreme north of Pakistan bordering with China and India is high ranked within the list of most climate-vulnerable regions on the globe. GB covered by Himalaya, Karakoram and Hindukush which host the world's third largest ice reserves. These mountain host the water towers of Pakistan, which fed water to the world's largest contiguous irrigation system and the water reservoirs down the country. The environment has given the operational control of this water towers in terms of temperature after the strong buildup of greenhouse gases [4]. The economy of Pakistan is based on agriculture that is highly dependent on Indus Basin Irrigation System (IBIS). This irrigation system serves an area of 22 million hectares and irrigated land accounts for 85% of all production in the country [5].

Different climate related hazards occur in GB such as Glacial Lake Outburst Flooding (GLOF), river bank erosion, heavy floods, land sliding, and rock falling which have been contributing to increase the vulnerability of many regions. However, many region of GB remained outside the field of climate change related actions. Change in climate will revise the hydrological cycle and water balance of GB. The process of runoff generation will directly influence the changes in temperature and precipitation [6]. Thus, any change in the spatial and temporal availability of water upsets agriculture, industry and urban development. In context of climate change and disaster management, it is therefore important to understand the varying trends of temperatures in GB [7, 8].

From the point of environmental condition and meteorological condition, four distinct seasons can be acknowledged in GB: i) spring (March-May), ii) summer (June-August), iii) autumn (September-October) and winter (November-February)[9]. Solid precipitation over the northern mountains melts in early summer and maintains sustainable river flow for power generation and irrigation before the onset of summer monsoon. In addition to this precipitation, winter rain bearing systems yield substantial rainfall in sub-mountainous and low elevation plains [10]. The northern part, especially Gilgit-Baltistan (GB) is host to the world's largest glaciers and is the major water resource the River Indus, the leading river of the country [5, 9]. Changing trends of precipitation, temperature and extreme events in GB bring floods in the Indus on large scale and damage the population living down the country [11]. According to Latif, the warming trend of annual temperature up to 5 % (1 ^{o}C) has increased the runoff of rivers Shoyk (at Yogu), Shigar (at shigar) and Indus (at Kachura) has increased up to 9 %, 7 % and 5 % respectively [12]. So it is dire need to assess the annual and seasonal trends of temperature to trace out its impacts on water and energy sectors of the country. The specific aim of this study is to analyze the recent trends of annual and seasonal temperatures over GB, so the policy makers can make batter policies while using these results.

II. DATA AND STUDY AREA

In Pakistan the Pakistan Meteorological Department (PMD) carried out collection of metrological data. PMD is a member of World Meteorological Organization (WMO) and strictly follow all the Standard Operating Procedures (SOPs) regarding setting up gadgets, acquisition and propagation of data to researchers and academia [13].

To carry out temperature assessments, daily data over the period 1955 - 2018 from the six weather stations situated in GB were obtained from PMD. Table 1 shows the specific locations of the six stations, and data period of temperatures used in this study. Using these datasets monthly, seasonal and annual temperatures were calculated and trend analysis were performed.

GB is located between three mighty mountain Himalaya-Karakoram and Hindukush (HKH) ranges. After the polar region, the world third largest mass in form of largest glaciers and the world second highest peak K-2 also increases the importance of this fragile region [14]. The Indus revere and its tributaries play the vital rule in the economic agricultural and energy sector of Pakistan. The ganging behaviors of it glaciers, biodiversity and climate are attracting the national and international well known researchers toward this regions. Many researcher has been carried out research on climate change and its impacts on its glaciers and other sectors of life. After the China Pakistan Economic Corridor (CPEC) project, this region become the backbone for the economic development of the whole Asia. The rapid development in the region also changing environmental conditions of GB. These changings are highly effecting the every sector of life. So, it is dire need to assess these environmental changes spatially and temporally.

III. METHODOLOGY

For all the six stations homogeneity analysis of the datasets were performed on monthly average temperature. Graphical analysis were carried out to check the homogeneity of the datasets. The monthly data of all the six stations have been used to calculate seasonal, annual, regional averages and the regional temperature series for GB. Temperature anomalies were calculated from the mean of baseline period (1981-2010). The purpose of trend testing is to determine whether the values of a random variable changes (increases/decreases) over a given period of time in statistical term [15]. Parametric or Non-parametric tests can be used to decide whether the trend is statistically significant or not [16, 17]. For detecting and estimating trends in the time series Mann-Kendall and Sen's tests were performed, using Microsoft Excel template MAKESENS, which was developed by the Finnish Meteorological Department.

MAKESENS is a widely used software for detecting and researching temperature and precipitation trends [18, 19].

IV. RESULTS

A. Annual Temperature Trends

Table 02 shows that in the region of GB the annual mean temperature varies by location. During the period 1955-2018 the annual mean temperature varied from 9.77 ^oC to 20.24 ^oC. Gilgit and Astor simultaneously remained warmest and coldest region of GB. To give quantitative description of main features of individual region, descriptive statistics has been applied. The highest annual mean temperature has recorded (20.24 ^oC) at Chilas, and that of lowest recorded (9.77 ^oC) at Astor. The temperature data of Gupis has highest value of standard deviation (0.89), but the data recorded at Gilgit station has lowest value of standard deviation (0.56).

MK test results revealed upward trends in annual temperature at five weather stations i.e. Astor, Chilas, Gilgit, Gupis and Skardu, and a downward trend of annual temperature at Bunji. Annual temperature of Astor and Skardu were significantly increased, while it has significantly decreased at Bunji. It is also identified that the annual precipitation has increasing trends at all stations excluding Astor and Chilas, where it has decreased not significantly.

B. Seasonal Temperature Trends

The summary of seasonal trends of mean temperatures over GB for the last 64 years given in Fig. 01. This figure show that during all seasons Chilas and Astor were simultaneously the warmest and coldest areas of the region.

Table 03 shown that winter temperatures have upward trends at all stations except at Gupis, where winter temperature has a nonsignificant decreasing trend. This clearly revealed that in GB winter season got warm during the study period. While summer temperature showed downward trends at all stations except Astor, where summer mean temperature increased non-significantly. Autumn temperature of Astor, Bunji and Gilgit has increased significantly.

C. Regional Temperature Trends

Table 04 shows the seasonal means, respective standard deviations, and the mean minimum and maximum temperatures over the whole GB between the bracketed periods (1955 – 2018). Which shows that during winter the mean temperature falls below freezing point and during summer it rises above 30^oC. Spring temperature has maximum deviation.

Fig. 02 depicts the seasonal temperature anomalies over GB from the baseline period (1981-2010), during 1955 - 2018. During summer the mean temperatures remained below normal in south-east and above normal in north-west parts of GB. The highest summer mean temperature departure (0.36^{o}C to 0.42^{o}C) occurred in Gilgit and its northern parts. Winter mean temperatures remained above normal in the most part of GB, only in the small portion of Ghizer and Diamir where winter temperature remained below normal. Mean temperature of spring season remained below normal in Baltistan region, district Astore and small portion of Diamir, but it was above normal in north -east parts of GB. The spring mean temperature remained significantly above normal in Ghizer during study period. Autumn mean temperature during the aforementioned study period remained below normal over Baltistan and Astore regions, while over the most part of Gilgit region it remained above normal.

V. DISCUSSIONS

This study carried out to assess the spatial and temporal climatic variability and trend in Gilgit-Baltistan (GB) based on appropriate statistical analysis of temperature data during 1955-2018. This 64 years investigation of monthly, seasonal and annual temperatures revealed that the mean annual temperature changed considerably at different stations. Annual mean temperature at Astore and Skardu significantly increased at a same rate of 0.02 ^{o}C/year with Z values of 3.84 and 2.66. Though the Gupis has highest annual warming rate of 0.03 ^{o}C/year, but it is not significant. Summer mean temperature decreased in all region of GB except in Astore, where it increased non-significantly. Skardu has highest falling rate (-0.04oC/year) in summer temperature with Z value of -2.0. These falling trends in summer temperatures decreased the flow of waters in Indus River and its tributaries, which seriously disturb the water supply in upper valleys and lower plane areas for agricultural purposes. Except at Gupis, winters warmed over all regions of GB. The warming trend of winter season over the whole GB may affect the solid precipitation trend, which seriously decrease the snow and ice areas in the region [13]. Astore has highest raise 0.05 ^{o}C/year in winter temperature with Z value of 2.82. Gilgit and Bunji have same rate of raise (0.04 ^{o}C/year) in winter temperature with same Z value. Only winter season has warmed non-significantly at Chilas, all other seasons have falling rate of seasonal temperature and summer has significant falling rate of -0.04 ^{o}C/year with Z = -2.03. Autumn season has significant increasing rate in mean temperature in all regions, except in Chilas and Skardu where temperature slightly fall with non-significant rate. These changes ultimately disturbed the upstream water supply, which is crucial to sustain upstream water reservoir system, and used to store and release water to downstream area when most needed. Indus Basin Irrigation System is the world largest irrigation network, which regulated through two major storage dams (Tarbela dam on Indus River and Mangla dam on the Jhelum River). Both are located in the upper Indus basin and are fed predominantly by melt water. The snow and ice area in the form of glaciers is the major source of water for the Indus River, any change in this area will change the water supply to down the stream [10, 20]. Summer is the warmest season in GB with mean value of 24.15 ^{o}C, with minimum mean temperature of 16.84 ^{o}C and maximum mean temperature of 31.49 ^{o}C. Winter remained the coolest season with mean value of 5.81 ^{o}C, by varying temperature from a minimum value -0.13 ^{o}C to 11.75 ^{o}C. Spring season remained warm comparative to autumn with mean value of 17.23 ^{o}C but have maximum value of standard deviation 1.34. Astore and Chilas remained the coolest and hottest regions during all seasons from 1955-2018. Gupis and Skardu have same pattern of seasonal temperature by having same seasonal mean temperatures. Same seasonal and annual trends of temperatures also identified by Raza et al. in 2016 with linear trend models [21].

VI. CONCLUSIONS

Following conclusions deduced from the study:

- Annual mean temperatures at Astore, Chilas, Gilgit and Skardu warmed with significant rates.
- A Bunji annual temperature has a decreased with a non-significant rate.
- Winter season has highest warming rate over the whole GB.
- Spring season has highest deviation of 0.6 ^{o}C over north-west part of GB.
- Summers got cool over whole GB.
- Annual mean temperatures over south-east parts of GB remained below the base period (1981-2010) temperature during all seasons, except in winter in which the temperature remained the same.

ACKNOWLEDGEMENT

We would like to express our sincere gratitude and appreciation to the Pakistan Meteorological Department (PMD) for providing data and valuable information.

REFERENCES

1. STOCKER, T. F., QIN, D., PLATTNER, G-K. TIGNOR, M. M. B. ALLEN, S. K. BOSCHUNG, JUDITH, NAUELS, ALEXANDER, XIA, YU, BEX, VINCENT, MIDGLEY, PAULINE M, Climate Change 2013: The physical science basis. contribution of working group I to the fifth assessment report of IPCC the intergovernmental panel on climate change. **2014**.
2. FAHAD, M., ISLAM, A.K.M.S., ISLAM, G., BALA, S.K., The Projection of Temperature and Precipitation over Bangladesh under RCP Scenarios using CMIP5 Multi-Model Ensemble. in Proceedings of the International Conference on Recent Innovation in Civil Engineering for Sustainable Development, Gazipur. **2015**.

3. SOLOMON, S., S. MANNING, M. MARQUIS, M. QIN, DAHE, Climate change 2007-the physical science basis: Working group I contribution to the fourth assessment report of the IPCC. Vol. 4. **2007**: Cambridge university press.
4. CHAUDHRY, Q. and G. RASUL. Global warming and expected snowline shift along northern mountains of Pakistan. in Proceedings of 1st Asiaclic symposium, Yokohama, Japan. **2007**.
5. KHAN, A.R., K. ULLAH, and S. MUHAMMAD, Water availability and some macro level issues related to water resources planning and management in the Indus Basin Irrigation System in Pakistan. **2002**.
6. SALMA, K., Q. MUHAMMAD, and F. DILAWAR, Hydro-meteorological characteristics of Indus River basin at extreme North of Pakistan. Journal of Earth Science & Climatic Change, **5**(1). **2014**.
7. RASUL, G. and B. AHMAD, Climate change in Pakistan. Pakistan Meteorological Department, **2012**.
8. RASUL, G., Climate data and modelling analysis of the Indus region. Pakistan Meteorological Department (PMD), **2012**.
9. RAZA, M., H. DOSTDAR, R. GHULAM, A. MUHAMMAD, and R. GHULAM, Variations of surface temperature and precipitation in Gilgit-Baltistan (GB), Pakistan from 1955 to 2010. Journal of Biodiversity and Environmental Sciences, **6**(2): p. 67-73. **2015**.
10. NAHEED, G., D. KAZMI, and G. RASUL, Seasonal variation of rainy days in Pakistan. Pakistan Journal of Meteorology, **9**(18): **2013**.
11. HARTMANN, H. and L. ANDRESKY, Flooding in the Indus River basin—a spatiotemporal analysis of precipitation records. Global and planetary change, **107**: p. 25-35, **2013**.
12. LATIF, Y., Climate change impact on hydrologic parameters and river flows of Indus basin., M. Sc Thesis, Centre of Excellence in Water Resources Engineering, UET, **2012**.
13. LATIF, Y., M. YAOMING, and M. YASEEN, Spatial analysis of precipitation time series over the Upper Indus Basin. Theoretical and applied climatology, **131**(1): p. 761-775, **2018.**
14. IMMERZEEL, W.W., L.P. VAN BEEK, and M.F. BIERKENS, Climate change will affect the Asian water towers. science, **328**(5984): p. 1382-1385, **2010**.
15. Sen, P.K., Estimates of the regression coefficient based on Kendall's tau. Journal of the American statistical association, **63**(324): p. 1379-1389, **1968**.
16. Begum, M.A.R.M., Application Of Non Parametrictest For Trend Detection of Rainfall In The Largest Island of Bangladesh. ARPN J. Earth Sci., 2006. **2**: p. 40-44.
17. MANN, H.B., Nonparametric tests against trend. Econometrica: Journal of the econometric society, 1945: p. 245-259.
18. AHMAD, I., T. DESHAN, W. TIAN, F. WANG, M. WAGAN, AND BAKHTAWAR, Precipitation trends over time using Mann-Kendall and spearman's rho tests in swat river basin, Pakistan. Advances in Meteorology, **2015**.
19. KENDALL, M., Rank correlation methods. 2nd impression. Charles Griffin and Company Ltd. London and High Wycombe, **1975**.
20. RAZA, M., Analysis OF precipitation trends IN gilgit-baltistan (gb), Pakistan. Journal of Mountain Area Research, **4**: p. 16-23, **2019**.

21. RAZA, M., D. HUSSAIN, AND G. RASUL, Climatic Variability and Linear Trend Models for the Six Major Regions of Gilgit-Baltistan, Pakistan: Climatic Variability and Linear Trend Models. Proceedings of the Pakistan Academy of Sciences: B. Life and Environmental Sciences, **53**(2): p. 129-136, **2016**.

LIST OF TABLES AND FIGURES

Table 01: Details of Observatories in GB.

General Location	Station Name	Latitude	Longitude	Average Altitude a.s.l. (meters)
GB Pakistan	Astor	35°20′	74° 54′	2168
	Bunji	35°40′	74° 38′	1372
	Chilas	35°25′	74° 06′	1251
	Gilgit	35°55′	74° 20′	1460
	Gupis	36°10′	73° 24′	2155
	Skardu	35°18′	75° 41′	2210

Table 02: MK Test and Sen's Slop Estimator Results of Annual Temperature.

Stations	MK Test (Test Z)	Trends	Results	Sen's Slope Estimate (°C/y)	Mean Temp. (°C)	Std. Dev.	Range of Temp. (°C)	
							Min	Max
Astore	3.84	↑	Sig.	0.02	9.8	0.69	3.97	15.60
Bunji	-1.44	↓	NS	-0.01	17.8	0.77	12.26	23.84
Chilas	2.03	↑	Sig.	0.01	20.3	0.65	14.90	26.38
Gilgit	1.72	↑	Sig.	0.01	15.94	0.56	7.82	23.85
Gupis	1.48	↑	NS	0.03	12.40	0.89	6.10	18.80
Skardu	2.66	↑	Sig.	0.02	11.66	0.73	4.89	18.46

°C= Degree Celsius; MK: Mann-Kendall; NS: Not Significant; Sig: Significant; ↑: Upward; ↓: Downward.

Table 03: Mean, Standard Deviation and Trends of Seasonal Temperature of all Six Stations.

Stations	Seasons	Mean Temp. (oC)	Std. Dev. Temp. (oC)	Mean Min. Temp. (oC)	Mean Max. Temp. (oC)	MK Test (Test Z)	Trends	Results	Sen's Slope Estimate Change in Temperature (oC/y)
Astor	Winter	1.63	0.94	-3.49	6.75	2.82	↑	Sig.	0.05
	Spring	11.83	1.40	5.94	17.71	1.19	↑	NS	0.03
	Summer	18.88	0.69	12.41	25.35	0.14	↑	NS	0.01
	Autumn	8.41	0.92	2.11	14.71	2.12	↑	Sig.	0.034
Bunji	Winter	8.83	0.66	3.17	14.49	3.72	↑	Sig.	0.04
	Spring	20.07	1.39	13.59	26.55	0.51	↑	NS	0.02
	Summer	26.49	0.96	19.53	33.46	-0.29	↓	NS	-0.01
	Autumn	14.61	0.79	7.15	22.07	2.05	↑	Sig	0.03
Chilas	Winter	10.63	0.63	4.96	16.29	1.43	↑	NS	0.02
	Spring	22.62	1.73	16.46	28.78	-0.09	↓	NS	-0.01
	Summer	30.92	1.01	24.71	37.12	-2.03	↓	Sig.	-0.04
	Autumn	17.93	0.76	11.15	24.72	-0.08	↓	NS	0.00
Gilgit	Winter	7.43	0.66	0.29	14.56	3.83	↑	Sig.	0.04
	Spring	18.75	1.21	10.43	27.07	0.79	↑	NS	0.02
	Summer	24.78	0.71	15.35	34.21	-0.91	↓	NS	0.02
	Autumn	12.80	0.72	3.19	22.41	2.31	↑	Sig.	0.03
Gupis	Winter	3.72	1.41	-2.06	9.50	-0.23	↓	NS	-0.01
	Spring	15.14	1.65	8.80	21.48	0.43	↑	NS	0.01
	Summer	21.96	1.38	14.99	28.93	-1.57	↓	NS	-0.03
	Autumn	10.22	1.51	3.39	17.04	1.29	↑	NS	0.03
Skardu	Winter	2.62	1.09	-3.66	8.91	0.91	↑	NS	0.02
	Spring	14.94	1.12	8.05	21.85	0.11	↑	NS	0.01
	Summer	21.85	0.89	13.81	29.89	-2.00	↓	Sig.	-0.04
	Autumn	9.14	0.85	0.79	17.48	-0.29	↓	NS	-0.01

Table 04: Seasonal Mean Temperature over whole Gilgit-Baltistan (GB)

Region	Seasons	Mean Temp. (ºC)	Std.Dev. Temp. (ºC)	Mean Min Temp. (ºC)	Mean Max Temp. (ºC)
GB	Winter	5.81	0.69	-0.13	11.75
	Spring	17.23	1.34	10.54	23.91
	Summer	24.15	0.75	16.84	31.49
	Autumn	12.18	0.68	4.63	19.73

Fig. 01: Seasonal mean Temperature.

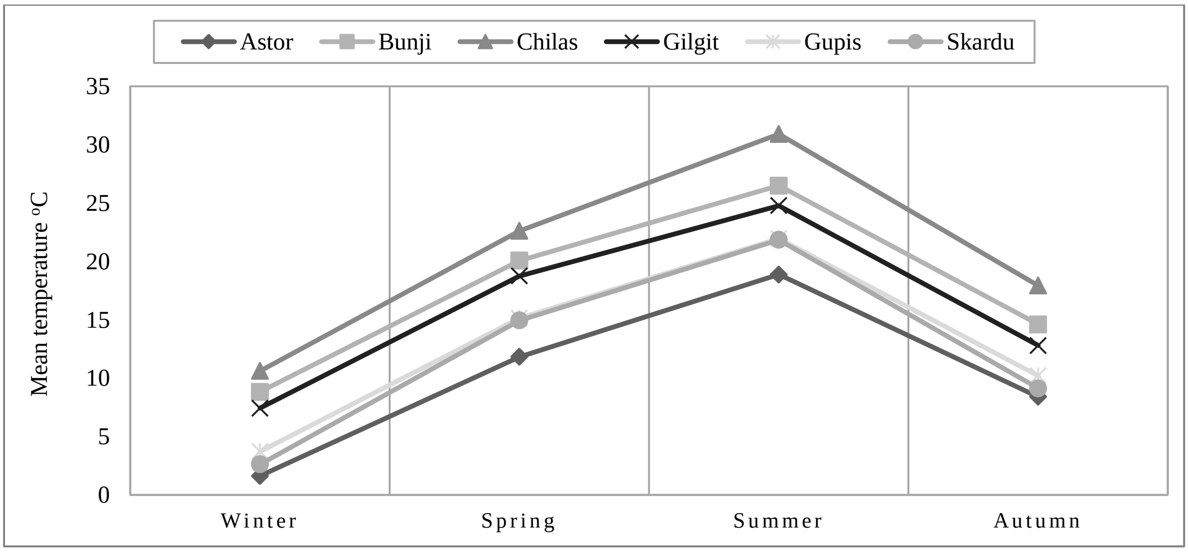

Fig. 02. Seasonal Temperatures anomalies from 1981-2010.