Article

Climate change in northern Pakistan: insights from extreme temperature indices

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Abstract: To investigate the temporal variations in temperature extremes across Northern Pakistan during the period 1990-2020, we applied the modified Mann-Kendall (MMK) test and utilized Sen's slope estimator. Analyzing the linear trends in the annual average time series, we observed a marginal upward trend in the annual maximum temperature and a slight downward trend in the annual minimum temperature. However, it is important to note that these observed patterns did not attain statistical significance at the 5% level of significance. By evaluating data from twenty-three weather stations, six distinct extreme temperature indices were examined. The study reveals a general escalation in the frequency of highly hot days, accompanied by a reduction in the occurrence of warm nights. The implications of these shifting patterns could be far-reaching, encompassing aspects such as water availability and resource management in Pakistan. These research outcomes underscore the criticality of continuous monitoring of extreme temperature indices to comprehensively grasp the implications of climate change in the region, and subsequently, to devise and implement sustainable developmental strategies.

Keywords: Climate change; Temperature extremes; MMK Test; Pakistan

1. Introduction

Changes in the global climate have been occurring for decades due to the worldwide phenomena known as climate change. Greenhouse gases are released into the atmosphere as a result of human activities including the combustion of fossil fuels, deforestation, and various industrial processes. These gases act as a blanket, absorbing radiant energy from the sun and raising global temperatures. Climate change has far-reaching consequences, including but not limited to higher sea levels, more frequent and severe weather events like heatwaves, droughts, and floods, and a shift in the normal distribution of precipitation.

The impact of global warming has been felt most acutely in the northern region of Pakistan. The World Bank predicts that Pakistan would warm at rates far higher than the world average, with temperatures increasing by 1.3°C to 4.9°C by the 2090s compared to the 1986–2005 baseline [1].

Pakistan's water supply, crop production, and biological systems would all be severely impacted by the climate change. Glaciers and snowpacks, two major sources of freshwater for the region, are melting at an accelerated rate as a result of the current warming trend [2]. This thawing is expected to reduce the supply of water during the dry season and increase the frequency and severity of disasters such glacial lake outburst floods (GLOFs) and landslides [3]. Climate change is a growing threat to the region's environment and biodiversity. Changes in species distribution and altitude resulting from climate change may have an effect on the ecosystem [4].

The purpose of this study work is to provide an understanding of the climate change and temperature extremes that occur in northern Pakistan. We conducted a comprehensive investigation of the impact of climate change on temperature extremes in the region by analyzing data collected over the previous three decades.

2. Materials and Methods

There are many different types of topographical features in northern Pakistan, including deep valleys, flat-topped plateaus, and hilly regions. There is a wide variety of climates and weather patterns in this region, each of which has a substantial effect on the local ecosystem and natural resources. Many snow-capped mountains and glaciers in this area contribute significantly to the local water cycle. This area is particularly susceptible to natural disasters like flash floods and glacial lake outburst floods (GLOFs) as a result of ongoing global warming. It is anticipated that the risks of such disasters will be amplified by the climatic extremes, particularly the temperature extremes.

Northern Pakistan has a very diverse local climate due to its elevation and topography. The average annual temperature ranges from 10 degrees Celsius to 26 degrees Celsius, and the total annual precipitation ranges from 100 millimeters to 1700 millimeters. During the monsoon season, the region receives the major portion of its annual precipitation. Snow and glacier melt are the most important factors in the region's water cycle.

This study utilized daily maximum and minimum temperature data of 23 gauging stations installed in the northern Pakistan (Figure 1) for the period of 30 years (1990 to 2020). In this investigation, six extreme temperature indices were assessed. The details of indices are provided in Table 1. The modified Mann-Kendal test was used to check the significance of trends, while Sen's Slope estimator was considered to check the rate of change in the temperature extremes.

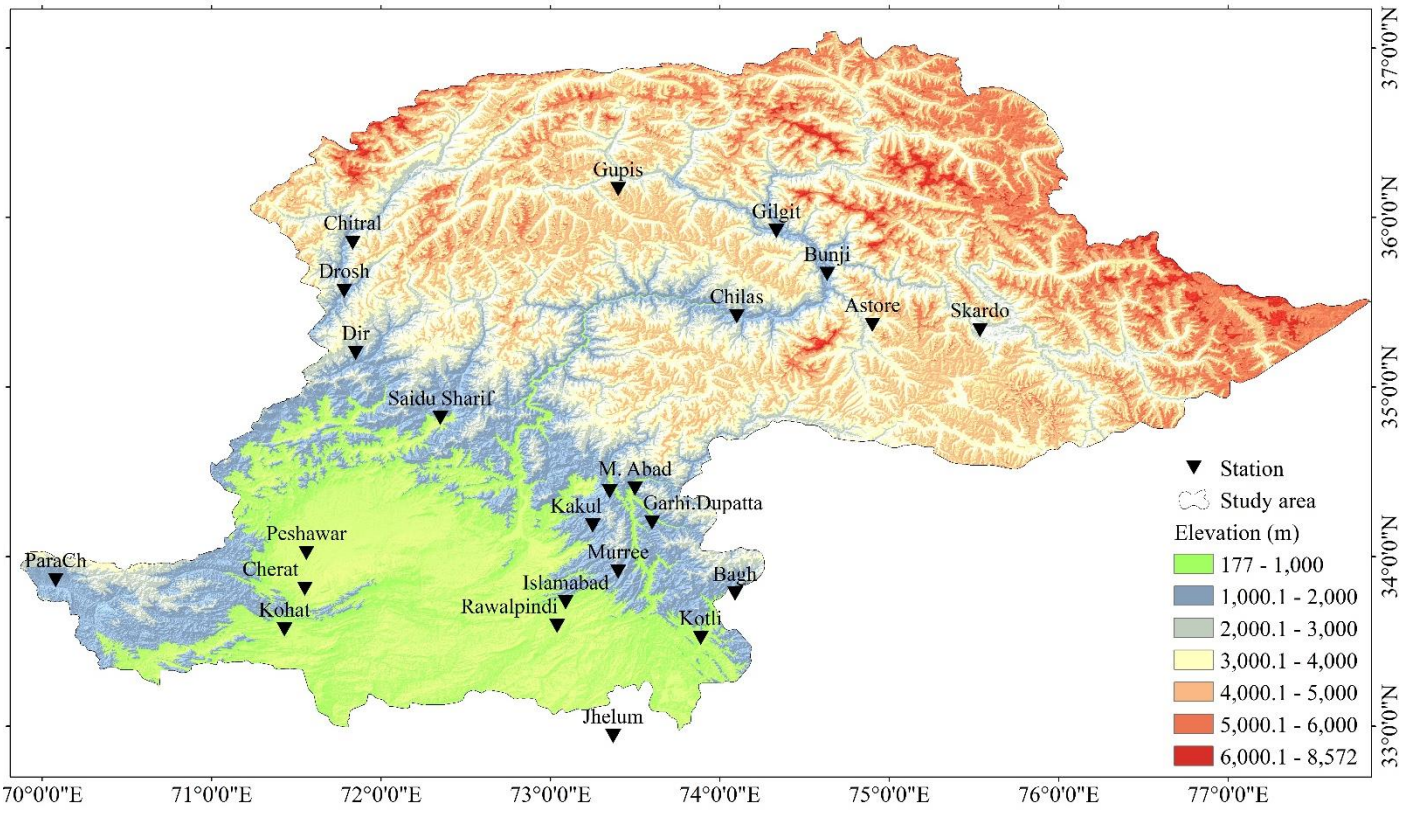

Figure 1. Location of northern Pakistan and rain gauges.

Table 1. Details of indices assessed in this study.

Sr. No.	Index	Description	Symbol	Unit

1	Cold night	Annual percentage of days when TN <10th percentile	TN10p	day
2	Hot night	Annual percentage of days when TN >90 percentile	TN90p	day
3	Cold days	Annual percentage of days when Tx <10th percentile	TX10p	day
4	Hot days	Annual percentage of days when Tx >90th percentile	TX90p	day
5	Annual average of maximum temperature	Annual mean daily maximum air temperature	AATMAX	°C
6	Annual average of minimum temperature	Annual mean daily minimum air temperature	AATMIN	°C

3. Results and Discussion

A linear trend analysis was conducted on the annual average time series of maximum and minimum temperatures to investigate their long-term variations. The analysis revealed a discernible increase in the annual average maximum temperature and a slight decrease in the annual average minimum temperature over the study period. However, statistical analysis indicated that these observed patterns did not attain statistical significance at the conventional 5% level of significance.

Table 2 shows the trends analysis results obtained from the MMK test.

Table 2. Results of MMK trends analysis.

Sr. No.	Station	AAT_{MAX}	AAT_{MIN}	TX90p	TN90P	TX10p	TN10P
1	Astore	1.84	1.09	1.5	-0.07	-1.38	-0.65
2	Bala Kot	***3.64***	***-2.76***	***3.37***	***-2.87***	***-3.2***	0.83
3	Bunji	1.26	***3.65***	1.17	***2.84***	-0.87	***-4.08***
4	Cherat	***4.66***	-0.85	***4.05***	-1.74	***-4.39***	0.29
5	Chilas	***2.04***	-0.85	0.97	***-2.14***	***-2.63***	1.24
6	Chitral	0.83	***2.07***	0.54	0.56	-0.88	***-2.62***
7	Dir	1.8	-0.26	***2.01***	***-2.12***	***-2.21***	-0.85
8	Drosh	0.54	***-3.71***	-1.17	***-4.3***	-1.9	***3.5***
9	Garhi Dupatta	***2.67***	-1.14	***3.38***	***-2.55***	***-2.26***	0.08
10	Gilgit	-0.51	***3.49***	-0.99	1.43	-0.22	***-4.08***
11	Gupis	1.43	0.24	0.31	-1.72	***-1.97***	***-1.99***
12	Islamabad	0.27	-0.78	-0.68	-0.68	-0.61	1.33
13	Jhelum	1.07	0.46	1.63	0.17	-0.68	-1.56
14	Kakul	***2.41***	-1.11	***2.92***	***-2.45***	***-2.21***	-1.36
15	Kohat	-0.43	-1.09	-0.99	***-2.4***	-0.85	-1.36
16	Kotli	***2.33***	1.95	0.78	1.77	***-2.53***	***-3.43***
17	Muzaffarabad	-0.46	1.24	-0.48	***-2.53***	-0.99	1.63
18	Murree	1	***-1.99***	1.31	-0.08	-1.19	***-3.5***
19	Para Chinar	1	***-2.16***	***-1.97***	-1.9	0.54	0.58
20	Peshawar	***-2.19***	1	0.99	0.99	0.03	-1.22
21	Rawalpindi	-0.25	-0.73	-0.07	-1.09	-0.12	0.07
22	Saidu Sharif	0	1.46	0.14	0.27	***-2.11***	***-2.55***
23	Skardu	1.39	***-2.4***	***-2.62***	***-3.13***	-0.73	0.73

For sites like Cherat and Balakot, high AAT_{MAX} values suggest that the average maximum temperature has been rising. In general, AAT_{MIN} has been on the decline throughout the past three decades. There has been an increase in the frequency of extremely hot days at five stations (Balakot, Cherat, Dir, Garhi Dupatta, and Kakul), as indicated by their significantly high TX90p values. TX90p decreased at most sites, but it was significantly decreasing at two stations (Para Chinar and Skardu). Extremely warm nights have become less common at most sites, as indicated by TN90p values trending downward. There was an increase in the frequency of extremely warm nights at Kotli, but decreases at several stations. Findings show that the TX10p index was negative at most sites, suggesting an increasing frequency of cold days. Some areas, however, have a positive TX10p index, which indicates that cold weather is occurring less frequently. Most stations recorded negative values for TX10p and TN10p, indicating a downward trend.

4. Conclusions

These findings provide strong evidence for the following main conclusions about the trends in extreme temperatures in the study area. As a first indicator of a steady increase in maximum temperatures over the past three decades, stations like Cherat and Balakot have seen a considerable increase in the average maximum temperature (AATMAX). The average annual minimum temperature (AATMIN) was found, on the other hand, to fall over the course of the study.

The data also shows that the frequency of extremely hot days (as measured by high TX90p values) has increased significantly at five stations: Balakot, Cherat, Dir, Garhi Dupatta, and Kakul. Para Chinar and Skardu, on the other hand, saw a notable decline in TX90p prices. Furthermore, most locations have seen a decrease in the frequency of extremely warm nights, as measured by the TN90p value. The frequency of exceptionally warm nights increased in Kotli whereas it decreased in many other locations.

Negative values for the TX10p index have been recorded at the majority of monitoring stations, suggesting an increase in the frequency of extremely cold days. The TX10p index exhibited positive readings in several locations, indicating warmer temperatures. TX10p and TN10p both showed a declining trend, with most stations recording negative values, indicating fewer cold days and nights.

In conclusion, the results shed light on the fact that temperature extremes vary from one region to the next, with some regions showing large increases in extreme heat events and others showing variations in cold extremes. These findings highlight the need to keep a close eye on temperature indicators in order to fully grasp the effects of climate change in the region and create effective plans for sustainable adaptation.

Author Contributions: Conceptualization, M.N.A., M.A., F.H., and G.R.; methodology, M.N.A. and G.R.; software, M.N.A., M.A., F.H. and S.; validation, S. and W.I.; formal analysis, M.N.A.; investigation, M.N.A., and G.R; resources, M.A. and F.H.; data curation S. and W.I.; writing—original draft, M.N.A., writing—review and editing, M.A. and F.H.; visualization, S.; supervision, M.N.A., and F.H. All authors have read and agreed to the submit the manuscript.

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