Signals of Climate Change and Spatio-temporal Analysis of Climate Extremes in the Homogeneous Climatic Zones of Pakistan During 1962-2019

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Abstract

This study investigates contemporary climate change and spatio-temporal analysis of climate extremes in Pakistan (divided into five homogenous climate zones) using observed data, categorized between 1962–1990 and 1991–2019. The results show that on the average, the changes in temperature and precipitation are significant at 5 % significance level throughout Pakistan in most of the seasons. The spatio-temporal trend analysis of consecutive dry days (CDD) shows an increasing trend during 1991–2019 except in zone 4 indicating throughout decreasing trend. PRCPTOT (annual total wet-day precipitation), R10 (number of heavy precipitation days), R20 (number of very heavy precipitation days) and R25mm (extremely heavy precipitation days) are significantly decreasing (increasing) during 1962–1990 (1991–2019) in North Pakistan. Summer days (SU25) increased across the country, except in zone 4 with a decrease. TX10p (Cool days) decreased across the country except an increase in zone 1 and zone 2 during 1962–1990. TX90p (Warm days) has an increasing trend during 1991–2019 except zone 5 and decreasing trend during 1962–1990 except zone 2 and 5. The Mann-Kendal test indicates increasing precipitation (DJF) and decreasing maximum and minimum temperature (JJA) in the Karakoram region during 1962–1990. The decadal analysis suggests decreasing precipitation during 1991–2019 and increasing temperature (maximum and minimum) during 2010–2019 which is in line with the recently confirmed slight mass loss of glaciers against Karakoram Anomaly.

1. Introduction

Climate change poses variety of risks including climate extremes and associated hazards [1]. Changing climate has been linked with human-induced activities particularly increased greenhouse gases after the mid of 20th century [2–5]. Climate extremes are rare events caused by climate change [6–8]. The increased intensity and frequency of certain extreme weather and climate events, particularly daily precipitation and temperature extremes are evident [9]. These fluctuations have been linked to the increased emission of greenhouses gases, however, the quantification of climate change impacts on an individual climate extreme event is challenging [9–10].

Several global and regional studies are conducted on recent and future projection of climate extremes and their impacts [8; 11–12]. The results of [6] concluded that changes in total precipitation are amplified at the tails of the distribution, and changes in temperature extremes have been observed in many areas of the world. The projected climate extremes, increase in intense precipitation, decrease (increase) in extreme low (high) temperatures are previously reported [12–14]. The societal infrastructure is becoming more sensitive to climate extremes and would be exacerbated by the changing climate. The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) specified that global warming has increased the frequency, duration and intensity of climate extremes in space and time [15–16]. The consequences of climate extremes including droughts, floods, heatwaves and typhoons results in economic, health, social, ecological and environmental implications varying regionally [17–22].

A Study by [23] derived climate extremes in temperature (for the duration of 1971–2000) and precipitation (for the duration of 1961–2000) using ground data from Pakistan, India, Bangladesh, Nepal and Sri Lanka. The results indicate an increase in precipitation extremes in South Asia, consistent with the global average. [24] investigated climate extremes using a Regional Climate Model, PRECIS. Their study considered reference duration (1961–1990) and future duration till the end of 21st Century (2071–2100), concluding that the warm spell will increase and the cold spell will significantly decrease in future. [25] used three GCMs with emission scenarios RCP4.5 ad RCP8.5 and concluded that climate extremes, mean maximum, mean minimum temperature and summer days are increasing in the future. Recently [8] used selected GCMs and found increasing consecutive dry days and decreasing wet days. All these studies have lack of assessment of homogeneous climate regions and consider the whole country as a single zone except [8] assuming each state/province as a homogeneous climate region, which can alter the regional climate change assessment.

Glaciers play significant role in terms of water availability in the mountainous regions in the world [26–27]. Most of the mountain glaciers worldwide are losing mass [28–29]. In contrast, Glaciers in the Karakoram and adjacent Kunlun Shan seem to be stable or even growing in the recent past [30–32]. The glaciers stability is consistent with temperature trends in the Upper Indus Basin (UIB) between 1961 and 2000, investigated by [33], indicating decreasing summer temperatures and runoff. These studies used somehow outdated climate data till 2000 and call for updated investigation. With the recently recorded climate data, it can update the recent trends and potentially explain the Karakoram anomaly. In addition, spatio-temporal trend analysis of precipitation and temperature extremes can provide information of extremes events.

The present study analyzed the climate change signals in observed data in homogeneous climate zones of Pakistan for the duration of 1962–2019. The criterion for the homogeneity of climate zone is reconnaissance drought index which uses the information from precipitation and temperature [34]. Initially, the change between two-time slices was tested for possible significance for precipitation and temperature and then spatio-temporal trend analysis was performed zone wise for each duration. A comparison was made between the two time periods (1962–1990 and 1991–2019) to see the possible changes in climate change and climate extremes. The assessment was drawn by using various statistical techniques e.g., probability density functions, spatio-temporal trend analysis and testing the statistical significance of climate extremes. For analysis and visualization of the results, R statistical software with packages RClimdex [35] and ArcGIS® were used.

The major aims of this study are: (1) to test the significance of changing climate in two-time durations for each climate zone in Pakistan and each station in the Karakoram region; (2) spatio-temporal trend and statistical significance analysis of climate extremes in each climate zone in Pakistan and for each station in the Karakoram region. Moreover, the findings of this study may help various stakeholders including policymakers in climate change mitigation and adaptation, urban planning, agriculture management, water management and food security. Further, the results of this study may help to address some of the Sustainable Development Goals (SDGs) of the United Nation Development Programme (UNDP) related to climate action, water, hunger and the environment.

2. Analysis And Results

The results of this study are discussed zone-wise and thereafter the new findings of the Karakoram anomaly. Considering the importance of the Karakoram region, climate extremes are also presented for each station in this region.

2.1 Zone wise results

Zone 1:

The differences between the two-time slices (1991-2019 and 1962-1990) were tested for possible significance in temperature and precipitation on a seasonal basis. A significant increase in temperature during DJF and MAM and a significant decrease during JJA and SON was observed as shown in Table 2. Precipitation increased significantly during all seasons except JJA. The Mann-Kendall tests' results for maximum, minimum temperature and precipitation are shown in Table 3. For zone 1, the MK statistic for precipitation shows significantly decreasing trend with value -0.06.18. The values of MK statistic for maximum and minimum temperature are 0.07.52 and 0.07.62, respectively, indicating increasing trends. The MK test's results support the Karakoram anomaly during the 1962-1990 given in Table 5, however, the decadal analysis during the 1990-2019 offers complex results (discussed in details under Present climatic status of Karakoram Anomaly). During the last decade, the trend analysis show that precipitation and temperature have decreasing and increasing trends, respectively, in most parts of the Karakoram.

Most of the temperature extremes are significantly increased during 1991-2019. Results related to climates' extremes are given in Figures 3-4 for all zones. The number of frost days decreased significantly while growing season length and summer days increased significantly in zone 1 (Northern Pakistan). Interestingly, TN10P shows a significantly decreasing trend in 1991-2019 while increasing in 1962-1990. TX10P and TX90P have significantly decreasing and increasing trends during 1991-2019 and increasing and decreasing trends, respectively during 1962-1990. Most of the precipitation extremes have increasing trends during 1962-1990 and decreasing trends during 1991-2019. For example, PRCPTOT, R10mm, R20mm and R25mm have significantly increasing and significantly decreasing trend during 1962-1990 and 1991-2019, respectively. R95P decreased but R99P increased in zone 1. Spatial distribution of changes in selected temperatures' extremes are presented in Figures 6-8 while changes in selected precipitations' extremes are mentioned in Figure 9 for all climate zones.

The distribution of the number of CWD is displayed in Figure 5 and Figure 11 for all zones. For zone 1, the average number of CWD increased from 16 to 19 in 1991-2019 compared to 1962-1990. A strong increase in variability was observed during 1991-2019. The maximum number of CDD was 60 and 40 during 1962-1990 and 1991-2019, respectively. The number of Frost days (FD0) has decreased from 110 to 88 during 1991-2019 compared to 1962-1990 as shown in Figure 12.

Zone 2:

The results of t-statistic (Table 2) show a significant increase in average temperature during MAM and JJA, increase during DJF, and insignificantly decrease during SON. MK results for maximum and minimum temperature indicate significantly increasing trends with values 0.0293 and 0.0938, respectively. On the other hand, average precipitation increased significantly throughout in all seasons. The MK tests' results (Table 3) show a significantly decreasing trend in precipitation with a magnitude of -0.0141.

Interestingly, this is the only region with the increasing number of frost days and decreasing GSL in both time slices. The SU25, TMAXMean, TN90p, TR20 and TX90p increased during the 1991-2019. The TMINMean increased significantly while TX10p and TN10p both decreased significantly during the 1991-2019. The CWD, WSDI, R10mm, R20mm and R25mm decreased during the 1991-2019. The CSDI, PRCPTOT, R95p and R99p decreased during the 1991-2019. The RX1day (Max 1-day precipitation amount) and Rx5day (Max 5-day precipitation amount) increased significantly and decreased during the 1962-1990 and 1991-2019, respectively.

The average number of CWD increased from 22 to 26 in the recent period. The standard deviation of CWD has increased from 8 (during 1962-1990) to 11 (during 1991-2019). The CDD (Figure 10) slightly reduced, with insignificant variability. The average FD0 recently increased from 34 to 47.

Zone 3:

The average temperature significantly increased in this region, except a significantly decreased for JJA with a value of -0.42. In contrast, the average precipitation increased significantly throughout except an insignificant increase during the DJF. The results of MK test show decreasing trends in precipitation change and minimum temperature change while an increasing trend for maximum temperature change with the values -0.0890, -0.0637 and 0.0645, respectively.

GSL and SU25 have increased in the recent period. TMAXMean has decreasing and significantly increasing trends in the first and second-time slice, respectively. The results of TMINMean are in contrast with TMAXMean. TN10P, TN90P, TNN, TNX, TR20 decreased in the recent time period. A significantly decreasing and increasing trends were found in TX10P and TX90P in the second time slice, respectively. In addition, most of the precipitation extremes indicate an increasing trend during the first time slice except CDD, CSDI and WSDI with decreasing trends. In contrast, most of these extremes are decreasing except CDD, R10mm, R25mm and WSDI which have increasing trends during the 1991-2021. R95P, R99P and PRCPTOT have decreasing trend in the second time slice.

The average CWD and standard deviation reduced from 8 and 6 during 1962-1990 to 7 and 3 during 1991-2019. The CDD (Figure 10) drastically decreased from 330 to 170 during 1962-1990 to 1991-2019 with decreased variability in the recent period. The average number of FD0 (Figure 12) reduced from 55 to 34 during 1962-1990 to 1991-2019.

Zone 4:

The average precipitation and temperature changes in zone 4 are given in table 2. The average temperature changed significantly with an increase during DJF, MAM, SON and decrease during JJA. The magnitude of change during DJF and JJA were highest with values 0.6908 and -0.1703, respectively. In addition, precipitation increased significantly only during JJA and SON. The MK test shows a decreasing trend in precipitation and maximum temperature with values -0.0986 and -0.0212, respectively. The change in minimum temperature has significantly increasing trend with value a value of 0.158.

During the second time slice, GSL and SU25 increased and decreased, respectively. TMAXMean show an increasing trend in contrast to the significant decreasing trend of TMINMean. TN10P decreased during the second period compared to the first time slice. On the other hand, TN90P significantly increased during the second time slice. TX10P and TX90P shows an insignificant decrease and increase during the second time slice, respectively. During the second time slice, all precipitation extremes have decreasing trend except an increase in CWD.

The average number of CWD (Figure 5) has increased from 7 to 8 annually. The standard deviation of CWD increased from 3 to 5 during the 1991-2019. The maximum number of CWD were 19 during 1991-2019. The maximum number of CDD reduced from 225 to 149 during 1962-1990 and 1991-2019, respectively. No significant change with the average number of zero were observed in the distribution of FD0 (Figure 12).

Zone 5:

The average temperature shows a significant increase except JJA with an insignificant change. Changes in average precipitation, except MAM are highly significant. There is a significantly decreasing trends in precipitation and maximum temperature while significantly increasing trend for minimum temperature in this zone. The values of MK test statistic for precipitation, maximum, and minimum temperature are -0.0224, -0.0157 and 0.0560, respectively.

GSL, SU25, TMINMean, and TMAXMean have increasing trends during both time slices. TN10P has decreasing trend throughout while TN90P has decreasing and significantly increasing trends in the first and second time slice, respectively. TX10P and TX90P have decreasing trends during the second time period. Most of the precipitation extremes have increasing trends during both time slices. CDD, CSDI, R99P and WSDI have decreasing trends during the first time period while CSDI, PRCPTOT, R10mm, R95P and SDII have decreasing trends during the second time period.

The average number of CWD slightly increased from 15 to 17 annually from 1962-1990 to 1991-2019 (Figure 5). In contrast, the standard deviation of CWD decreased from 8 to 6 during 1962-1989 to 1991-2019. The distribution of CDD increased from 75 to 92 during 1962-1990 to 1991-2019. The number of FD0 reduced considerably from 8 to 2 during 1962-1990 to 1991-2019 (Figure 12).

2.2 Present climatic status of Karakoram Anomaly

The widely known Karakoram anomaly is investigated to see its present status utilizing the updated observed meteorological data from the North of Pakistan as shown in Table 1. The stations are located between an altitude of 1,250 m a.s.l. at Chilas and 2,317 m a.s.l. at Skardu station. The data was analyzed seasonally to assess the contemporary climate change. The average temperature shows an interesting pattern, specifically in winter (DJF), a significant increase at high altitude station (Skardu) of 0.97 and a significant decrease at the lowest station (Chilas) of −0.56 given in Table 4. Almost similar pattern was observed during MAM with the maximum increased at Astore and decrease at Chilas station. During JJA, average temperature has been decreased at all meteorological stations. Maximum and minimum decrease in the average temperature was noted at Gopis (with the magnitude of -1.42 ^{o}C) and Darosh (with magnitude of -0.01 ^{o}C). These changes are highly significant except at Chilas meteorological station. In SON, the average temperature shows an increasing trend at all stations other than Bunji, Chilas and Gopis with decreasing trend.

Table 5 shows the seasonal trends in precipitation, maximum, and minimum temperature during 1962-1990. During DJF, precipitation has significantly increasing trend except Gopis where the trend is insignificantly decreasing. Maximum and minimum temperature results show significantly decreasing trend during JJA except Astore with insignificant decrease in maximum temperature. These results are in lines with Karakoram Anomaly during the 1962-1990. Table 6-8 show seasonal trend analysis for precipitation, maximum temperature and minimum temperature during 1990-1999, 2000-2009 and 2010-2019, respectively. Table 6 shows a comparison among three decades (1990-1999, 2000-2009, 2010-2019) using MK test for precipitation. During 1990-1999, precipitation in Gilgit and Bunji increased while in Gopis and Skardu the trends decreased in DJF. On the contrary, the trend during 2000-2009 remained increasing. The trend changed again and decreased during 2010-2019 except Gilgit with an insignificant increasing trend. The comparison of these three decades for maximum temperature is shown in Table 7. In JJA, the maximum temperature shows a decreasing trend during 1990-1999 except Gilgit and during 2000-2009 in Gopis in JJA. The trend during 2010-2019 changed and increased in most of the stations except Gilgit with insignificant decreasing trend in JJA. Minimum temperature shows increasing trend in some parts (Bunji and Gilgit) and decreasing trend in others (Gopis and Skardu) during 1990-1999 and 2000-2009 as shown in Table 8. In contrast, during 2010-2019, minimum temperature shows increasing trend. These results show conflicting signals in climate. In the most recent decade of 2010-2019, precipitation decreases in DJF and temperature (maximum and minimum) increases in JJA. It is interesting to see a consistently decreasing trend in the SON in temperature (maximum and minimum) considering the overall thirty years period (1990-2019).

The station-wise climate extremes in the northern Pakistan are shown in Figure 13. The results show that SU25 increased throughout except Skardu during 1991-2019. TN10P (cold nights) has significantly decreased at most parts of the Northern Pakistan. TN90P (warm nights), TX90P (warm days) TR20 (tropical nights) have decreasing trend during the 1991-2019 in most parts of the region. TX90P (warm days) have mixed trend, decreasing at Darosh, Gilgit and Skardu and increasing trend at the remaining station.

Figure 14 shows decreasing trend precipitation extremes except CDD and WSDI in western and eastern parts. However, CWD, R10mm, R20mm, R25mm, R95 show increasing trends while CWD and PRECPTOT show decreasing trends in the eastern-central Karakoram.

3. Discussion

Zone 1 is rich of water resources (snow and glaciers). Therefore, the changes in climate and climate extremes may have significant impacts on water availability in dry summers, the frequency of flooding, and Glacier Lake Outburst Floods (GLOFs) in the future. Zone 2 comprise of Monsoon dominated region receiving more than 60% precipitation during Monsoon season [47–49]. The seasonal changes in precipitation and temperature may affect the demand and supply of water and ultimately the crop's production. In addition, Zone 3 is the south-west part receiving low amount of rainfall round the year. Precipitation extremes may contribute less to cause flooding in the region. (This region has already facing shortage of water). In contrast, Zone 4 faces shortage of rainfall and have severe rainfall decrease, which can further exacerbate the shortage of water for drinking, agriculture and other purposes. Zone 5 is mainly comprised of Punjab province dominating the agriculture production of the country. Our results of R99P shows increasing trend in this region with the likelihood of intense rainfall and may cause flash flooding in the future.

As UIB is melt water dominated, therefore, the latest information of the cryosphere is important. In addition, changes in climate variables can significantly affect downstream availability for millions of inhabitants [33; 50]. Most of the HKHs' glaciers are retreating since the mid-19th century [30–31; 51]. In addition, some recent studies found that mass balance of the glaciers in the Karakoram are nearly in balance during 1971–2010 [30; 52–53]. [54] derived the mass balance of glaciers in the sub-basins of UIB with negative mass balance except Shigar and Hunza in the central and western Karakoram, respectively. In another study [55] investigated the mass balance of glaciers in the Astore (a sub basin of UIB) and concluded that the glaciers in the basin (western Himalaya) are nearly in balance during 2000–2016 similar to the neighboring glaciers in the adjacent Karakoram. In addition to the direct glacier observations, climate data also show interesting signals and indirectly indicate glacier's health status. For instance, [33] noted that mean temperature decreased at the stations (Bunji, Gilgit and Skardu) lying in the Karakoram region during 1961–2000. Their analysis shows that a decrease of 1 ^{o}C in mean summer temperature can cause a reduction of ~ 20% in summer runoff. The study of [33] concluded an expansion in contrast to the widespread retreat in the remaining parts of the HKH region. [56] investigated trends in maximum, minimum temperature in the northern part of Pakistan. They observed that maximum temperature has mixed (upward and downward) trend while the cooling in minimum temperature become stronger in the recent past. [57] investigated temperatures' changes in the UIB by considering meteorological data for two stations. They have noted that the mean temperature increased by 0.63°C in Skardu while decreased by – 0.137°C in Gilgit in the recent past.

The mass balance of the glacier is heavily dependent on the winter accumulation and summer ablation strongly influenced by precipitation and temperature among other factors [58]. This study provides up to date changes in precipitation and temperature in the northern Pakistan. We found significant increase in winter average precipitation and decrease in summer average temperature particularly at the meteorological stations in the Karakoram region during the 1962–1990 (Table 1). However, the MK test indicates a decreasing trend in DJF precipitation and increasing trend in temperature in the recent period of 2000–2019 in the Karakoram which is not aligned with the Karakoram Anomaly. Our findings are an indication of glaciers mass loss in future in the Karakoram region. These stations are situated in the valley below the glacier terminating zones, however, an indirect clue can be inferred based on climate change and extreme events regarding future trends. Our results suggest further investigation of glaciers mass balance in the region in future for better understanding of glaciers' health and associated impacts. The downstream water availability in UIB is dominated by snow and glacier melt water particularly in Summer, therefore, the climate change assessment can indicate indirect signals for water availability. In addition, climate extremes can provide guidelines to policy makers and relevant stakeholder for future climate trends and meltwater resources in the country.

4. Conclusions And Recommendations

During DJF and MAM, average temperature increased in all climate zones. A decreasing trend during JJA in zone 1, 3, 4 and during SON in zones 1 and 2 were found in the average temperature. Precipitation indicated mixed trend in different zones. Mann-Kendal test indicates trend in maximum and minimum temperature except zone-4 where the maximum temperature has no trend. On the average, CWDs increased in all zones except in zone 3 where it decreased. The number of SU25 increased in all climate zone except zone 4.

In the Karakoram region, temperature decreased significantly during the JJA. Also, precipitation increased significantly in the region except a significant decrease in Gilgit during DJF. MK test suggests increasing trend in precipitation and decreasing trend in maximum and minimum temperature during the 1962–1990 and closely in line with Karakoram Anomaly. However, precipitation (in DJF) and temperature (in JJA) have decreasing and increasing trend, respectively, during the most recent period of 2010–2019 which do not support the notion of Karakoram Anomaly. These findings suggest that the glacier may lose mass in future rather than gaining or stable conditions. Climate extremes have mixed trends over North Pakistan. For instance, summer days increased and Cold nights have mixed trends in the region. Warm nights decreased except in western Karakoram.

The key takeaways are:

1. Climate (maximum, minimum temperature and precipitation) is changing across the country.
2. TN10p, TX10p and TR20, CSDI and PRECPTOT have decreasing trends particularly during the 1991–2019 in most parts of the country.
3. Precipitation has increasing trend in DJF while temperature has decreasing trend in JJA during the 1962–1990 in the Karakoram.

4. During the last decade (2010–2019), precipitation and temperature have decreasing and increasing trend, respectively, in most part of the northern part of the country.
5. Based on the points in 3 and 4, the glaciers in the Karakoram may loses mass balance slightly in the near future.

The stations considered in this study have not enough high elevation and this is one of the limitations. However, a long data series was required and available at these stations. As we have updated information about the climate change in the northern Pakistan which has glaciers and snow. Therefore, a study is needed about glacier and snow melt based on the latest data sets which may be helpful to validate further the results of this study regarding impacts of climate change on glaciers and snow melt in this region. Effort can be made to do expeditions for monitoring glaciers particularly in the western and central Karakoram which may provide the evidence about the mass balance of the glaciers.

5. Data And Study Area

Pakistan lines in the northern hemisphere with latitude of 23.4-37.3N and longitude of 60.5-80.5E [36]. The country has a clear diversity in the climate as it has Arabian sea in the south and the world's highest mountains ranges (Himalaya, Hindukush and Karakoram) in the north. In a recent study by [34] developed five homogeneous climate regions on the basis of reconnaissance drought index mentioned in Fig. 1. From Fig. 1 we can see that zone 1 comprise of cold areas including northern parts and central-western part of the country. Zone 2 comprised of Islamabad Capital Territory (ICT), some parts of Azad-Jammu and Kashmir and Khyber Pakhtoonkhwa. This region is part of the monsoon dominated region and therefore receive maximum rainfall during the monsoon season. Zone 3 is the south-western part of the country and has least rainfall in a year as compared to the other region of the country. Zone 4 include the south-eastern and coastal areas in the south of the country. Zone 5 is the central-eastern part of the country and due to its fertile land and water, it is considers the food basket of the country. Observed daily climate data (maximum, minimum temperature and precipitation) for the period of 1962–2019 was acquired from Pakistan Meteorological Department (PMD). The data was divided into two independent climatic periods (1962–1990 and 1991–2019) for the assessment of potential climate change and climate extremes over Pakistan. The missing values in the data were estimated by using statistical techniques. The target location of this study is Pakistan which has 881,913 square kilometers area and approximately 222 million inhabitants [37–39]. The northern part of the country has one of the world's largest glaciers and coastal area in the south. The country has four seasons and consequently significant spatial and temporal variation in the climate.

6. Methodology

6.1. Inconsistencies in the data

There were some missing values in the maximum, minimum temperature and precipitation particularly in the remote stations. We have enough data as we are using daily climate data for 28 years for each time duration, however, the missing values are estimated. There are various statistical methods available to address the issue of missing values, for instance, multivariate regression, interpolation, imputation etc. In this study, imputation method is used at multiple stations to preserve spatial dependence structure. Multiple chains have been run and the convergence was assessed in each chain after a specified number of iterations. The method consists of the following steps:

1) Impute the missing values by the mean values from observed data
2) Consider the missing values as a variable and name it missvar
3) Regress missvar on the available observed data. This mean that missvar is response variable and the available observed data sets are predictors.
4) Predict the missing values form the regression model. Now these values can be imputed (replaced) by the newly predicted values.
5) The steps 2–4 are then repeated for each variable that has missing values. The cycling through of each variable is called iteration. The missing values are then imputed with the precited values from regression model for each variable after each iteration.
7) Steps 2–4 are repeated a number of iterations and the imputation are being updated at each iteration.
The number of iterations depend on researcher and the nature of the study [40]. However, the convergence of the process can be assessed at each iteration. The process can be stopped if there are no significant changes during the successive iterations.

6.2. Climate change

This study based on observed climate data (1962–2019) about maximum, minimum temperature and precipitation for fifty-four (54) meteorological stations across Pakistan. The spatial distribution of meteorological stations is shown in Fig. 1. Initially, the difference between average climatology the two time slices were tested for possible statistical significance at a 5% level of significance. Here the average climatology means average temperature or precipitation for the mentioned time duration. This was carried out under the hypothesis testing procedures of the student t-test. Under this procedures, the null hypothesis states that there is no difference between the average climatology of two-time slices. The hypothesis under the student t-test can be formulated as:

$$H_0: ontheaveragethereisnochangeintheclimatologyofbothtimeslices$$

Vs

$$H_A: ontheaveragethereischangeintheclimatologyofbothtimeslices$$

Alternatively, it can be written as:

$$H_o: \mu_{1991-2019} = \mu_{1962-1990}$$

Vs

$$H_o: \mu_{1991-2019} \neq \mu_{1962-1990}$$

Where H_0 and H_A represent null and alternative hypothesis, respectively. The notation $\mu_{1962\text{-}1990}$ and $\mu_{1991\text{-}2019}$ represent the average climatology during 1962–1990 and 1991–2019, respectively. The change between the two time slices is significant at 5% level of significance if the p-value of the test is less than or equal to 0.05. To assess the detailed behaviors of zone-wise climatology, this analysis was carried out on a seasonal as well as on annual basis.

6.3. Trend analysis

For trend analysis, a non-parametric test, Mann Kendall (MK) has been used proposed by [41] and widely uses in hydrology and climatology for trend analysis [42–43]. The null hypothesis (H_0) under the MK test states that the observations (x_1, x_2, …, x_n) are independently and identically distributed (no trend) and the alternative hypothesis (H_1) shows that the observation are not identical (there is a trend) for all $i \neq j$. Consequently, a positive and negative value of test statistics indicates an upward trend and downward trend, respectively. The hypothesis under the MK test can be formulated as:

$$H_0: nomonotonictrendispresent$$

Vs

$$H_A: monotonictrendispresent$$

If the p-value of the test is less than or equal to 0.05, then we reject H_0 and conclude that there is a trend in the data. For further details about the test statistic and calculation of the MK trend test, we refer to [44].

6.4. Climate extremes analysis

Climate extremes related to temperature and precipitation were calculated for both time slices. To assess the changes in climate extremes, probability density functions were drawn for both time slices and a comparison was made between them. To investigate spatial variability and changes, the changes in climate extremes were interpolated to the target location by using a geostatistical interpolation method. The analysis provides information about the changes in climate extremes during the two-time slices over the full domain. Finally, the statistical significance of the climate extremes was performed by using a 5% level of significance. A comparison was made between climate extremes in both time slices for temperature and precipitation in each climate zone in terms of statistical significance. This may clarify the changes in climate extremes and consequently help policymakers with floods, droughts, water management etc., in the future. For definition and unit of measurement of climate extremes, we refer to Annex-01.

3.5. Climate change in Zone 1 (Karakoram region)

In the Northern Pakistan, Karakoram, Himalaya and Hindukush are joining to create one of the highest and extended mountain regions of the world. These mountains play a significant role in water availability, particularly for dry summers [26–27; 45]. A study by [46] claims that the contribution is 62% of the runoff, 28% and 10% by snowmelt, glacier and rain during the melt season (summer) in the UIB. The agriculture downstream (specially in zone 5) and hydropower heavily depend on water availability. In a study by [33] investigated a decrease in summer temperature, increase in winter precipitation in the Karakoram region, and [32] observed stable glaciers mass balance on a small sample of glaciers. We investigate the long-term meteorological changes using ground observations. There are seven meteorological stations with long-term observations in this region as shown in Table 1. The significance of difference (average changes) between the two periods (1962–1990 and 1991–2019) was tested by utilizing a t-test to see whether it is significantly changing or not for each station separately on a seasonal basis. This will help to see the significance of the changes in average temperature and precipitation on a seasonal basis in different parts of the Karakoram region. In addition, the MK test was used to identify a monotonic trend in temperature and precipitation. Finally, climate extreme was calculated for each station to see whether it is behaving differently than the zone wise climate extremes. This special part will disclose the latest status of climate change in different parts of the Karakoram and update the present status of Karakoram anomaly which was first investigated by [32]. The details of meteorological station in Northern Pakistan are given in Table 1, with four stations in the Karakoram and the remaining in the Himalaya and Hindukush region. The schematic presentation of the methodology is given in Fig. 2.

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Tables

Table 1

Brief information about meteorological stations situated in Northern Pakistan and used for Karakoram Anomalies investigation.

S. No	Station	Latitude	Longitude	Mountain range	Altitude
1	Astore	35 20	74 54	Himalaya	2,168.0 meters
2	Bunji	35.75	74.75	**Karakoram**	1,372.0 meters
3	Chilas	35.75	74.00	Hindukush	1,250.0 meters
4	Darosh	35.50	71.75	Hindukush	1,464.0 meters
5	Gilgit	36.00	74.50	**Karakoram**	1,460.0 meters
6	Gupis	36.25	73.50	**Karakoram**	2,156.0 meters
7	Skardu	35.25	75.75	**Karakoram**	2,317.0 meters

Table 2

Test of significance of the difference between 1990–2017 and 1962–1989 about average temperature and precipitation for all seasons and climate zones.

Variable	Season	Zone-1	Zone-2	Zone-3	Zone-4	Zone-5
Average Temperature	DJF	1.8174***	0.0358	0.3453***	0.6908***	0.5422***
	MAM	1.2477***	0.3193***	0.1619**	0.3604***	0.9524***
	JJA	-1.2613***	0.0654**	-0.4206***	-0.1703***	0.0501
	SON	-0.5780***	-0.0100	0.3273***	0.3578***	0.4525***
	Overall	**0.3016****	**0.1033**	**0.1017**	**0.3077*****	**0.4992*****
Precipitation	DJF	2.4593***	4.8609***	0.1886	0.2085	2.2729****
	MAM	0.7455**	2.0928**	0.7138***	0.1233	0.7285
	JJA	0.0995	5.5510***	1.9361***	1.1500**	4.9269***
	SON	0.9809***	3.4153***	0.5277***	1.5977***	3.7380***
	Overall	**1.0649****	**3.9773*****	**0.8455*****	**0.7703****	**2.9174*****

*Note: Where "***" and "**" indicate significance of the test at 1% and 5% level of significance. DJF = December, January, February; MAM = March, April, May; JJA = June, July, August; SON = September, October, November.*

Table 3

Man-Kendall test for testing trend in each duration (1962–1989, 1990–2017, Change = difference between 1990–2017 and 1962–1989). Each series has t

S. No	Zones	Precipitation						Max. TMP			
		1962–1989		1990–2017		Changes (1990-2017-1962-1989)		1962–1989		1990–2017	
		Kendall τ	P-Value	Kendall τ	P-Value	Kendall τ	P-Value	Kendall τ	P-Value	Kendall τ	P-Value
1	Z-1	0.0453698	5.476e-11	-4.554031e-02	3.078e-11	-6.181994e-02	2.2e-16	-2.941424e-03	0.6556	2.879244e-02	1.266e-05
2	Z-2	-8.099797e-03	0.2362	-1.955711e-02	0.004891	-1.409285e-02	0.03446	3.382319e-03	0.608	2.200206e-02	0.00084
3	Z-3	1.265816e-01	< 2.2e-16	-1.866923e-02	0.01437	-8.902188e-02	< 2.2e-16	-1.167005e-02	0.07684	2.368513e-02	0.0003292
4	Z-4	2.655612e-02	0.0005049	7.844310e-03	0.3084	-9.856097e-03	0.1802	1.122931e-02	0.08862	1.109748e-02	0.09244
5	Z-5	1.998956e-02	0.005168	-2.121013e-02	0.002958	-2.239363e-02	0.001017	1.140568e-02	0.08369	9.684728e-03	0.1419

Table 4

Test of significance of the changes between 1990-2017 and 1962-1989 about average temperature and precipitation for all seasons and meteorological stations situated in the Karakoram regions.

Variable	Season	Stations						
		Astore	Bunji	Chilas	Darosh	Gilgit	Gupis	Skardu
Difference of Average Temperature between 1990-2017 and 1961-1989	DJF	0.5082***	0.5404***	-0.5618***	0.7148***	0.8567***	-0.1942***	0.9677***
	MAM	0.6780***	0.5298***	-0.1238	0.6121***	0.7384***	-0.0823	0.7679***
	JJA	-0.2891***	-0.9248***	-0.1220**	-0.0137	-0.4890***	-1.4199***	-0.2753***
	SON	0.3906***	-0.3328***	-0.2666**	0.5326***	0.1510	-0.0157	0.0041
	Overall	**0.3208****	**-0.0489**	**-0.2671****	**0.4600*****	**0.3121****	**-0.4303*****	**0.3642****
Precipitation	DJF	0.2720***	0.1299***	0.1980***	0.1877**	-0.2388***	0.1456***	0.2984***
	MAM	-0.1176	-0.0347	0.0705	-0.3605***	-0.1836***	0.5083***	0.0513
	JJA	0.1502***	0.1719***	-0.2282**	0.03797	-0.3112**	0.3367***	0.0850***
	SON	-0.0786	0.0604***	0.0024	0.1001	-0.0727*	0.1046**	-0.3861**
	Overall	**0.0558**	**0.0817****	**0.0098**	**-0.0099**	**-0.2017****	**0.2749*****	**0.0119**

*Note: Where "***", "**" and "*" indicate significance of the test at 1%, 5% and 10% level of significance. DJF = December, January, February; MAM = March, April, May; JJA = June, July, August; SON = September, October, November*

Table 5
Station and seasonal wise results of MK test and their statistical significance for precipitation, maximum and minimum temperature during the 1962–1990.

Station	**DJF**		**MAM**		**JJA**		**SON**	
	Kendall τ	P-Value	Kendall τ	P-Value	Kendall τ	P-Value	Kendall τ	P-Value
Precipitation (1962–1990)								
Astore	3.87e-02	0.011	1.63e-02	0.270			3.64e-02	0.020
Bunji	1.18e-02	0.461	5.91e-02	0.000	7.03e-02	6.82e-06	1.72e-02	0.280
Chilas	8.60e-02	5.44e-08	5.68e-02	0.000	8.49e-02	4.58e-08	5.79e-02	0.000
Darosh	1.54e-02	0.308	-5.37e-02	0.000	2.28e-02	0.136	-1.95e-02	0.204
Gilgit	4.34e-02	0.007	3.67e-02	0.017			7.05e-02	8.89e-06
Gopis	-6.32e-02	7.60e-05	-1.14e-01	1.95e-13	-8.49e-02	6.16e-08	-1.19e-01	8.97e-14
Skardu	5.05e-02	0.001	2.67e-02	0.083	9.11e-02	5.33e-09	2.02e-02	0.205
Maximum Temperature (1962–1990)								
Astore	-4.38e-02	0.001	3.42e-02	0.009	-6.06e-03	0.648	2.72e-03	0.838
Bunji	1.98e-02	0.140	2.75e-02	0.036	-8.89e-02	1.88e-11	-1.74e-02	0.188
Chilas	9.25e-03	0.490	3.76e-02	0.004	-3.13e-02	0.02	-6.33e-03	0.634
Darosh	-4.00e-02	0.003	6.11e-02	3.72e-06	-1.81e-02	0.173	-4.18e-02	0.002
Gilgit	6.74e-03	0.616	4.05e-02	0.002	-3.68e-02	0.005	-4.51e-03	0.734
Gopis	3.04e-02	0.023	5.77e-02	1.25e-05	-3.99e-02	0.002	-4.11e-02	0.002
Skardu	7.84e-02	4.73e-09	8.59e-02	7.90e-11	3.49e-02	0.008	3.49e-02	0.008
Minimum Temperature (1962–1990)								
Astore	1.23e-02	0.357	7.00e-02	1.28e-07	-2.93e-02	0.027	-3.48e-02	0.009
Bunji	-1.43e-01	2.2e-16	-5.93e-02	7.69e-06	-1.70e-01	2.2e-16	-1.57e-01	2.2e-16
Chilas	-5.26e-02	8.52e-05	4.24e-02	0.001	-4.98e-02	0.000	-4.22e-02	0.001
Darosh	-1.06e-01	2.68e-15	-3.04e-03	0.818	-1.11e-01	2.2e-16	-8.56e-02	1.20e-10
Gilgit			5.03e-03	0.704	-3.74e-02	0.005	-4.54e-02	0.000
Gopis	1.68e-02	0.21	5.08e-02	0.000	-6.19e-02	3.08e-06	-8.87e-02	2.53e-11
Skardu	6.14e-02	4.46e-06	-6.95e-03	0.600	-7.90e-02	2.78e-09	-5.60e-02	2.45e-05

Table 6
Seasonal MK test results in the Karakoram region for precipitation. The table shows the Kendall τ and their significance for the 1990–1999, 2000–2009 and 2010–2019.

Station	**DJF**		**MAM**		**JJA**		**SON**	
Station	Kendall τ	P-Value	Kendall τ	P-Value	Kendall τ	P-Value	Kendall τ	P-Value
Precipitation (1990–1999)								
Astore	-6.75e-02	0.007	-1.06e-02	0.663	-2.46e-02	0.327	-2.40e-02	0.357
Bunji	4.34e-02	0.104	8.94e-02	0.000	4.04e-02	0.121	4.50e-02	0.091
Chilas	4.21e-02	0.114	4.48e-03	0.862	1.66e-02	0.524	1.16e-03	0.965
Darosh	-9.16e-0	0.000	-3.57e-02	0.140	2.14e-03	0.934	9.95e-03	0.702
Gilgit	2.46e-02	0.351	2.67e-02	0.289	6.03e-02	0.018	-1.62e-02	0.539
Gopis	-1.62e-03	0.951	4.77e-02	0.069	6.50e-02	0.014	-6.71e-02	0.012
Skardu	-3.37e-02	0.190	3.81e-02	0.133	7.15e-02	0.006	6.41e-02	0.016
Precipitation (2000–2009)								
Astore	-5.21e-02	0.044	-1.02e-01	5.227e-05	-4.62e-02	0.068	-3.80e-02	0.146
Bunji	3.58e-02	0.180	-1.20e-02	0.645	2.65e-02	0.307	-3.15e-02	0.236
Chilas	1.22e-01	4.14e-06	4.03e-02	0.118	1.13e-01	1.52e-05	5.52e-02	0.038
Darosh	6.47e-02	0.011	2.31e-02	0.355	-5.41e-02	0.038	-3.77e-02	0.147
Gilgit	6.84e-02	0.009	1.31e-02	0.608	-3.86e-02	0.127	-2.61e-03	0.921
Gopis	5.69e-02	0.033	-3.12e-02	0.234	-8.10e-02	0.002	-6.50e-02	0.015
Skardu	5.38e-02	0.037	-1.41e-02	0.584	-2.92e-02	0.254	8.34e-04	0.975
Precipitation (2010–2019)								
Astore	-1.30e-01	7.53e-06	1.34e-03	0.961	-6.15e-03	0.828	-3.59e-02	0.219
Bunji	-3.37e-03	0.910	-7.70e-03	0.787	-1.60e-02	0.574	-2.59e-02	0.379
Chilas	1.57e-01	9.5e-08	-3.05e-02	0.286	-1.18e-02	0.683	-9.35e-02	0.001
Darosh	6.88e-03	0.812	-1.27e-02	0.646	-1.95e-02	0.502	-4.89e-02	0.095
Gilgit	-1.03e-02	0.728	-3.62e-03	0.898	-2.35e-02	0.401	-6.59e-02	0.023
Gopis	4.52e-03	0.881	7.16e-02	0.014	6.73e-03	0.818	-7.48e-03	0.802
Skardu	-1.54e-01	1.98e-07	1.26e-02	0.66	4.69e-02	0.102	-2.52e-02	0.395

Table 7
Seasonal MK test results in the Karakoram region for maximum temperature. The table shows the Kendall τ and their significance for the 1990–1999, 2000–2009 and 2010–2019.

Station	**DJF**		**MAM**		**JJA**		**SON**	
Station	Kendall τ	P-Value	Kendall τ	P-Value	Kendall τ	P-Value	Kendall τ	P-Value
Maximum Temperature (1990–1999)								
Astore	5.18e-02	0.021	9.51e-02	1.68e-05	9.22e-02	3.24e-05	-3.05e-02	0.169
Bunji	8.52e-02	0.000	6.23e-02	0.005	-1.41e-02	0.525	-4.92e-02	0.027
Chilas	1.32e-01	3.35e-09	7.49e-02	0.001	9.76e-03	0.659	-2.66e-02	0.232
Darosh	2.28e-01	2.2e-16	8.28e-02	0.000	-6.26e-02	0.005	-1.44e-02	0.515
Gilgit	1.40e-01	3.23e-10	8.06e-02	0.000	3.32e-03	0.881	-2.45e-02	0.27
Gopis	1.81e-01	1.90e-15	7.74e-02	0.000	-1.13e-01	4.14e-07	-5.00e-02	0.025
Skardu	3.85e-02	0.084	7.03e-02	0.001	-7.74e-02	0.000	-7.57e-02	0.001
Maximum Temperature (2000–2009)								
Astore	-5.60e-02	0.012	9.88e-02	8.00e-06	6.90e-02	0.002	-6.35e-02	0.004
Bunji	-8.24e-02	0.000	3.46e-02	0.119	-3.17e-02	0.156	-8.61e-02	0.000
Chilas	-1.08e-01	1.53e-06	4.33e-02	0.050	-7.52e-03	0.735	-6.58e-02	0.003
Darosh	-9.40e-02	2.54e-05	-1.08e-02	0.626	-3.63e-02	0.101	-8.58e-02	0.000
Gilgit	-1.15e-01	3.1e-07	3.03e-02	0.171	-2.59e-02	0.244	-1.06e-01	2.01e-06
Gopis	-1.17e-01	2.08e-07	5.18e-02	0.019	2.27e-03	0.919	-7.33e-02	0.001
Skardu	-1.13e-02	0.614	3.27e-02	0.139	-1.47e-02	0.508	-1.18e-01	1.11e-07
Maximum Temperature (2010–2019)								
Astore	9.78e-02	0.000	9.92e-02	6.24e-05	9.77e-02	8.57e-05	-3.85e-02	0.122
Bunji	1.33e-01	1.54e-07	6.51e-02	0.008	1.90e-02	0.446	-8.71e-02	0.000
Chilas	1.01e-01	6.28e-05	8.18e-02	0.001	1.14e-01	4.30e-06	-7.29e-02	0.003
Darosh	1.00e-01	5.67e-05	8.03e-02	0.001	6.04e-02	0.014	-5.94e-02	0.016
Gilgit	3.87e-02	0.127	5.08e-02	0.041	-1.30e-02	0.602	-9.77e-02	9.50e-05
Gopis	9.21e-02	0.000	5.88e-02	0.018	1.17e-02	0.640	-8.01e-02	0.001
Skardu	7.72e-02	0.002	8.19e-02	0.001	1.79e-02	0.4704	-1.50e-01	1.58e-09

Table 8

Seasonal MK test results in the Karakoram region for minimum temperature. The table shows the Kendall τ and their significance for the 1990–1999, 2000–2009 and 2010–2019.

Station	**DJF**		**MAM**		**JJA**		**SON**	
Station	Kendall τ	P-Value	Kendall τ	P-Value	Kendall τ	P-Value	Kendall τ	P-Value
Minimum Temperature (1990–1999)								
Astore	3.60e-02	0.11	1.51e-01	8.73e-12	1.61e-01	4.38e-13	-3.14e-04	0.989
Bunji	-4.88e-02	0.030	7.85e-02	0.000	1.10e-03	0.960	-4.94e-02	0.026
Chilas			1.12e-01	5.79e-07	1.41e-01	3.23e-10	-7.65e-02	0.001
Darosh	1.13e-01	4.54e-07	1.03e-01	3.33e-06	6.64e-03	0.764	-5.04e-02	0.023
Gilgit	-1.56e-01	2.88e-12	9.95e-02	7.01e-06	4.19e-02	0.058	-3.51e-02	0.114
Gopis	3.91e-02	0.086	1.05e-01	2.72e-06	-3.01e-02	0.178	-2.01e-02	0.368
Skardu	-6.44e-02	0.004	9.08e-02	4.04e-05	-1.24e-02	0.575	-3.72e-02	0.094
Minimum Temperature (2000–2009)								
Astore	2.76e-03	0.902	1.07e-01	1.56e-06	7.35e-02	0.001	-7.00e-02	0.001
Bunji	7.40e-02	0.001	7.49e-02	0.001	1.13e-01	3.77e-07	5.98e-02	0.007
Chilas	1.59e-01	3.66e-12	8.46e-02	0.000	3.84e-02	0.089	-3.69e-02	0.100
Darosh	-1.91e-01	2.2e-16	-5.36e-02	0.015	-2.88e-01	2.2e-16	-2.30e-01	2.2e-16
Gilgit	1.31e-01	5.39e-09	1.24e-01	2.61e-08	1.84e-01	2.2e-16	3.98e-02	0.074
Gopis	-1.94e-01	2.2e-16	2.56e-02	0.250	-6.04e-02	0.007	-1.43e-01	1.46e-10
Skardu	1.05e-02	0.635	-3.29e-03	0.882	-1.48e-01	2.18e-11	-1.51e-01	9.57e-12
Minimum Temperature (2010–2019)								
Astore	-9.41e-03	0.709	5.45e-02	0.028	1.23e-01	9.29e-07	-1.08e-01	1.55e-05
Bunji	2.65e-01	< 2.2e-16	1.41e-01	1.30e-08	1.62e-01	9.06e-11	-7.09e-03	0.777
Chilas	1.18e-01	2.90e-06	9.01e-03	0.716	-1.40e-01	1.66e-08	-1.11e-01	8.16e-06
Darosh	1.31e-03	0.958	-5.57e-03	0.822	1.57e-02	0.527	-7.7e-02	0.001
Gilgit	8.88e-02	0.000	4.42e-02	0.078	1.23e-01	1.16e-06	-9.07e-02	0.000
Gopis	2.13e-01	< 2.2e-16	6.32e-02	0.012	2.14e-02	0.397	-1.11e-01	1.05e-05
Skardu	1.08e-01	1.70e-05	4.59e-02	0.063	2.01e-02	0.418	-4.81e-02	0.053

Figures

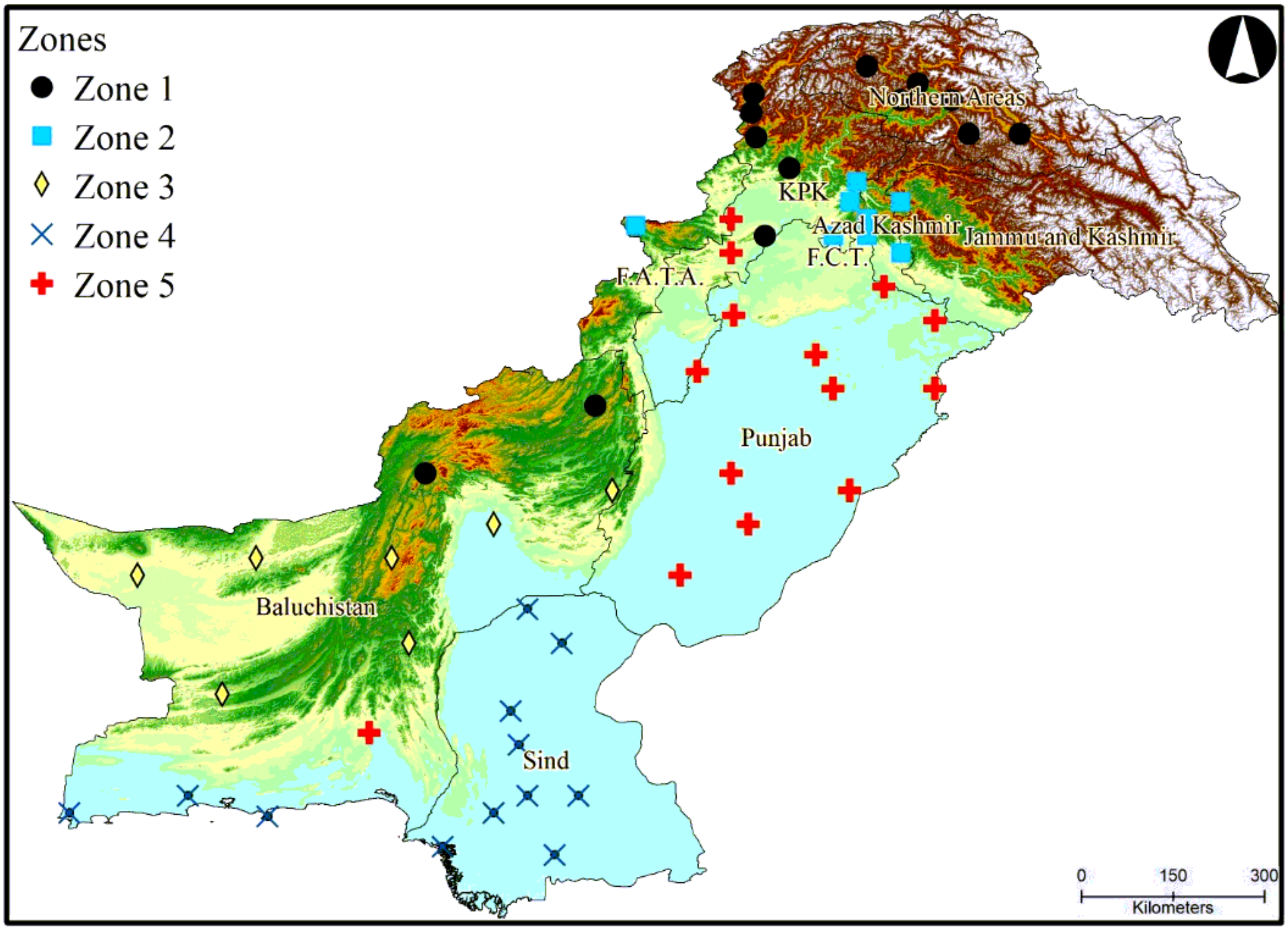

Figure 1

Five homogeneous climate zones. The figure is reused with the permission Ullah et al., 2019 after making some changes.

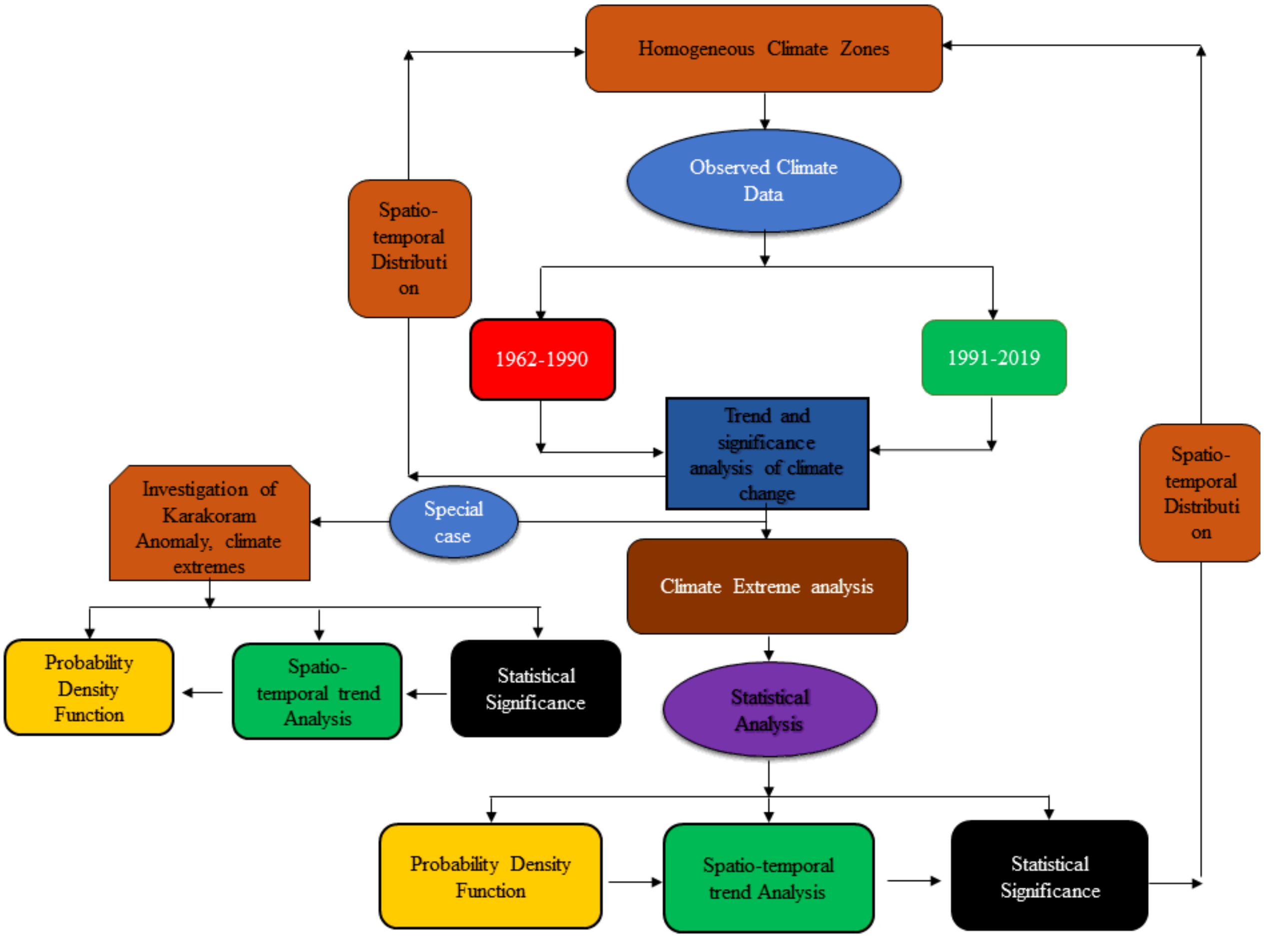

Figure 2

Schematic presentation of the methodology of the study.

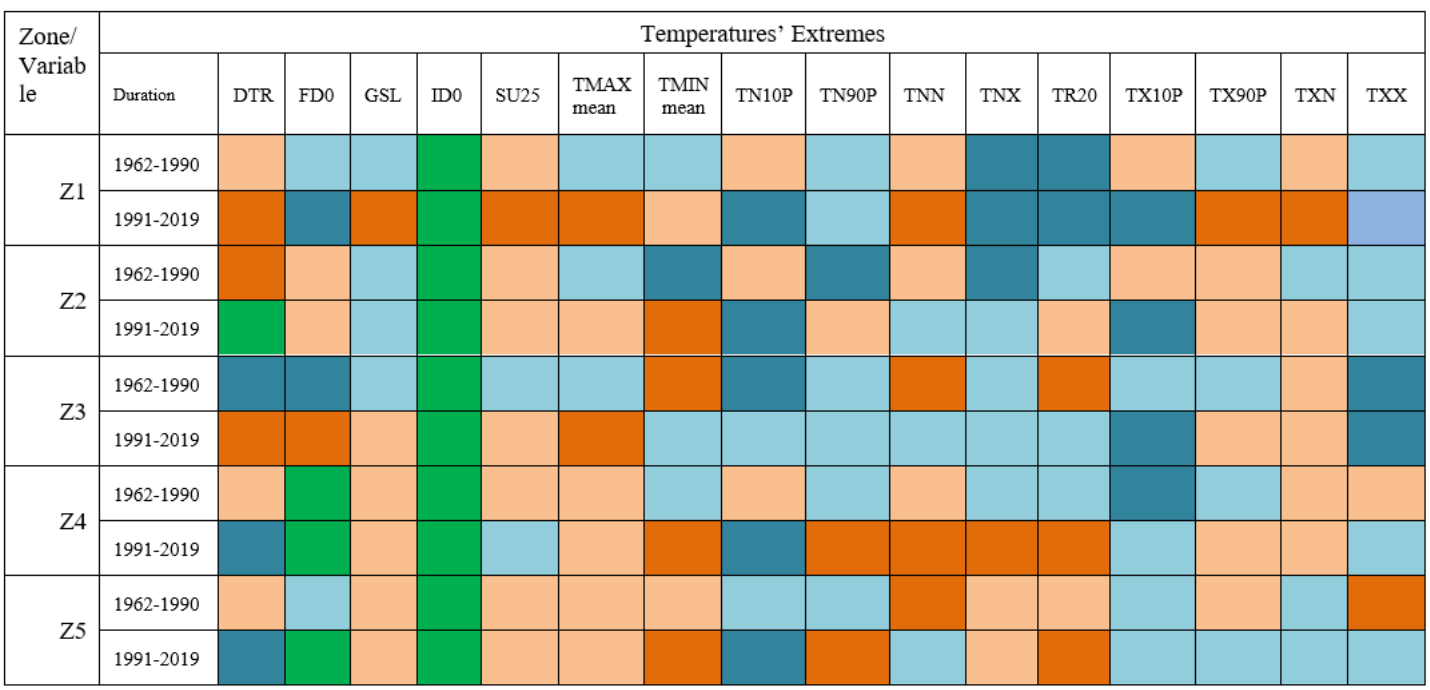

Figure 3

Climate extremes related to temperature for each climatic zone and two independent time duration. Each color has specific meaning and given in note mention with figure 4.

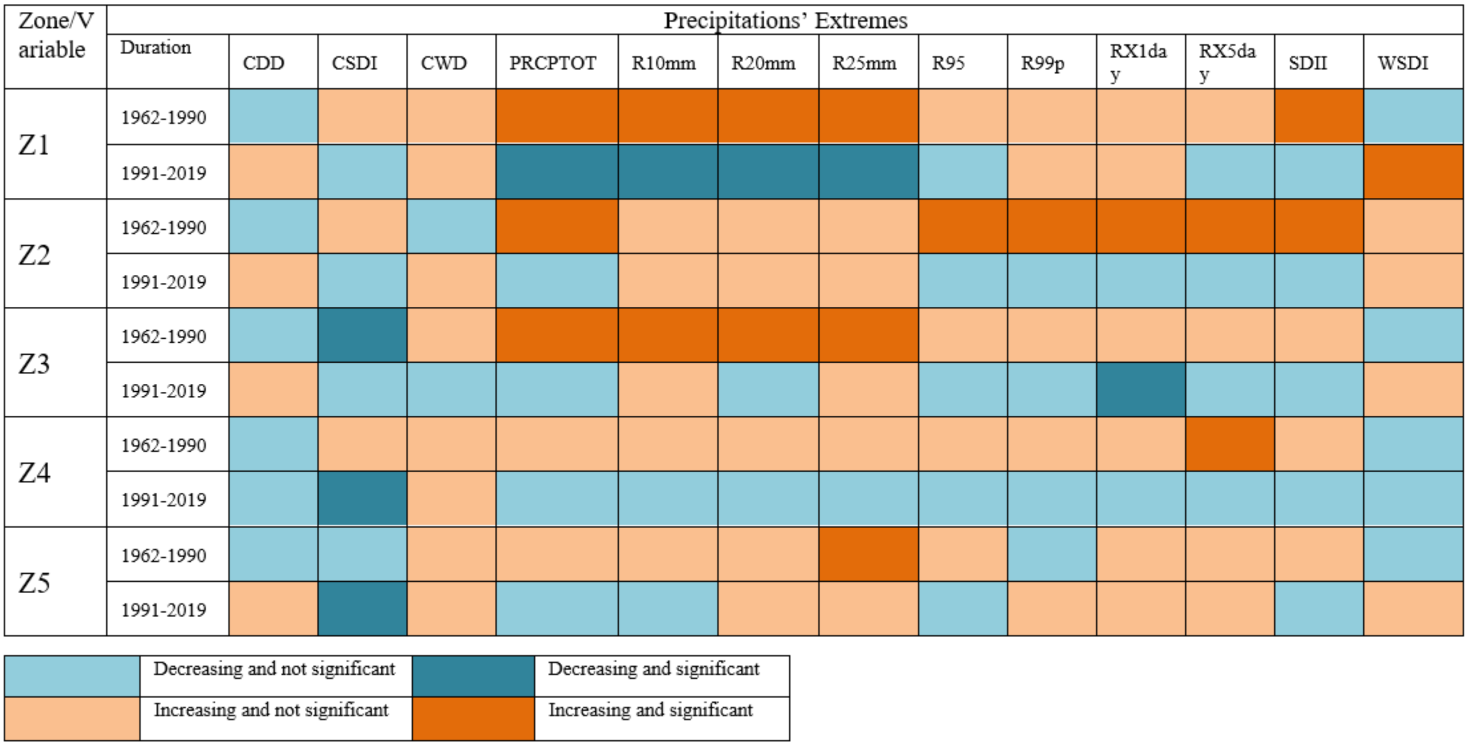

Figure 4

Climate extremes related to precipitation for each climatic zone and two independent time duration. Each color has specific meaning and given below: Note (Figures 3-4): The colors represent different status for different extremes' events and the corresponding duration is mentioned in the colored boxes. Green color shows no changes.

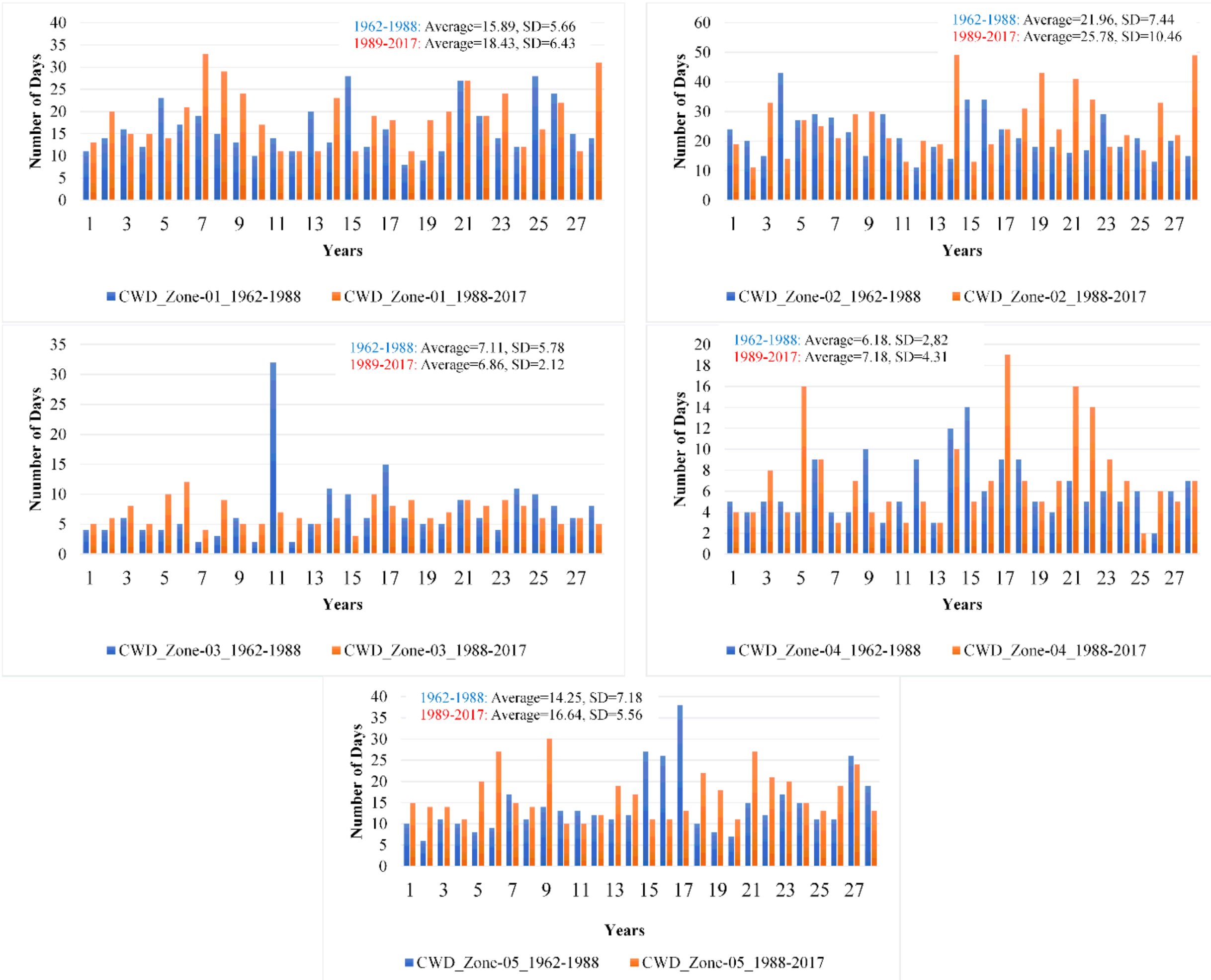

Figure 5

Number of consecutive wet days (CWD) for each climate zone and two independent durations. In each part of the figure, on x-axis and y-axis, years and number of days are mentioned.

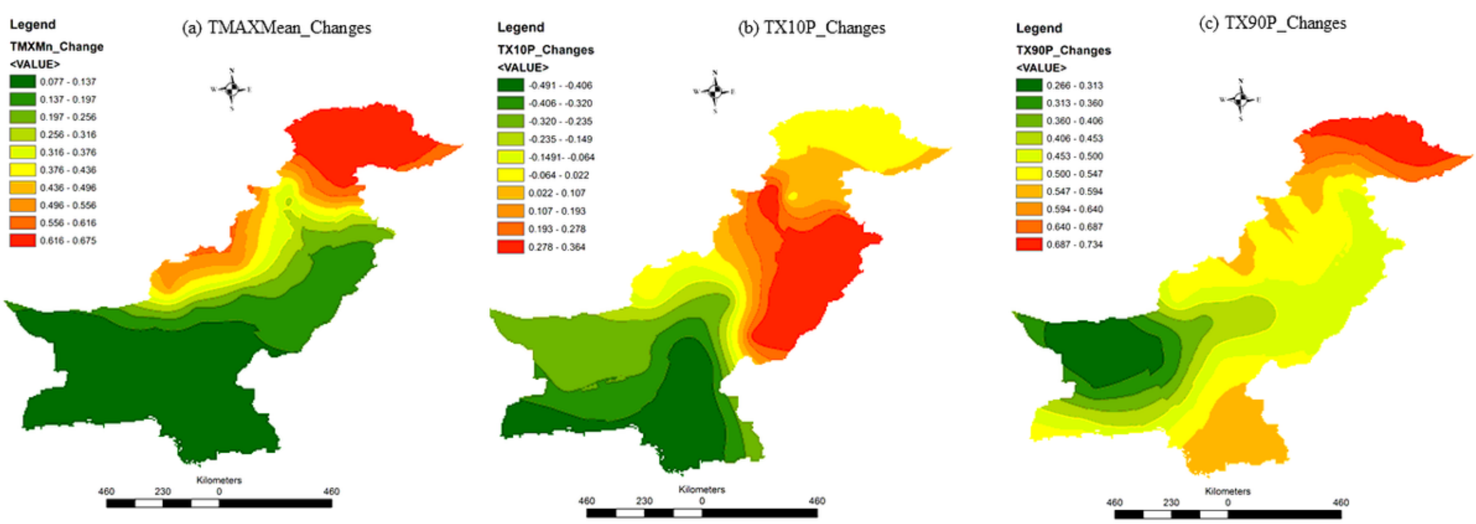

Figure 6

Spatial distribution of changes during 1991-2019 with respect to 1962-1990 of different climate extremes across Pakistan. (a) TMAXMean, (b) TX10P, (d) TX90P.

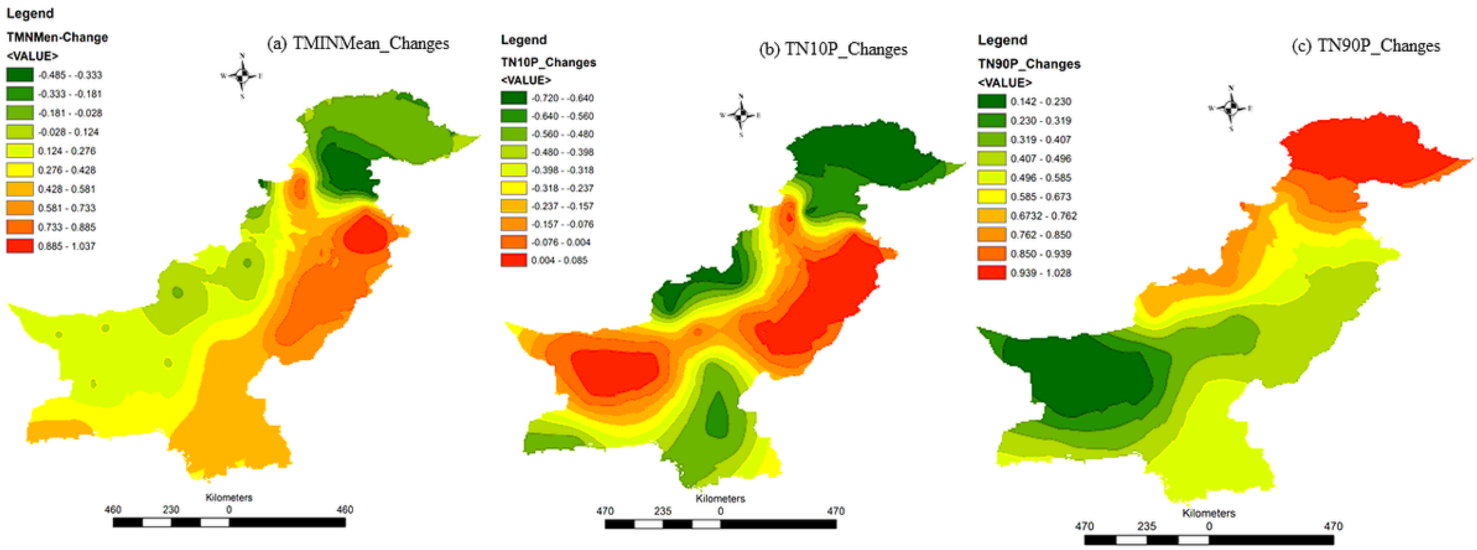

Figure 7

Spatial distribution of changes during 1991-2019 with respect to 1962-1990 of different climate extremes across Pakistan. (a) TMINMean, (b) TN10P, (c) TN90P.

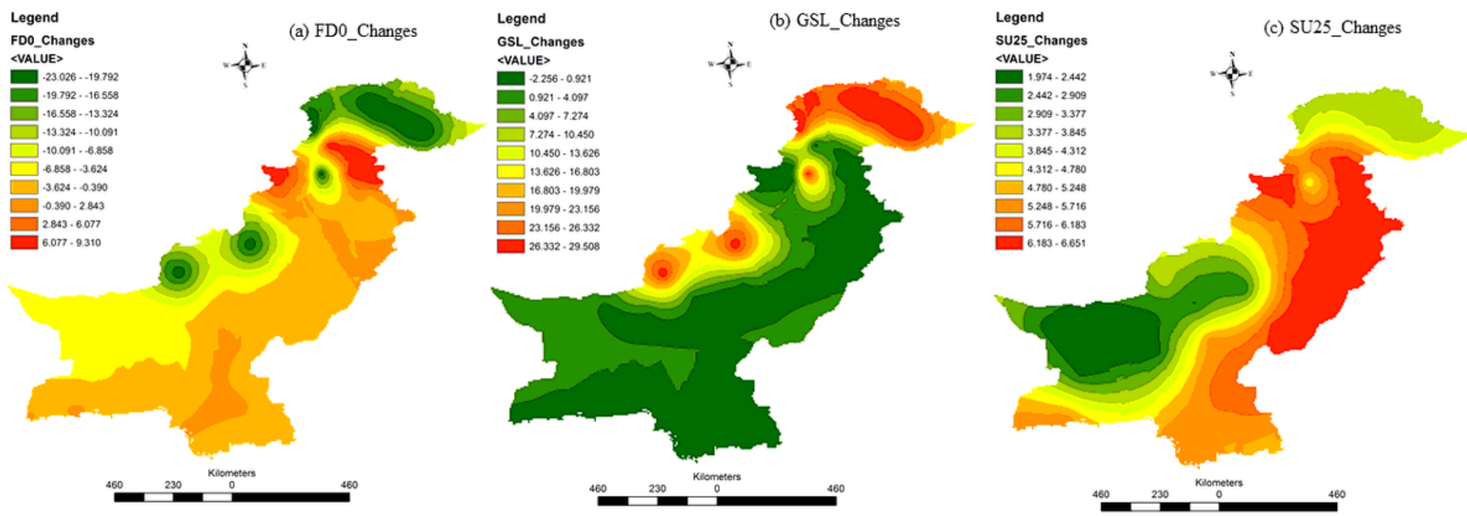

Figure 8

Spatial distribution of changes during 1991-2019 with respect to 1962-1990 of different climate extremes across Pakistan. (a) FD0, (b) GSL, (c) SU25.

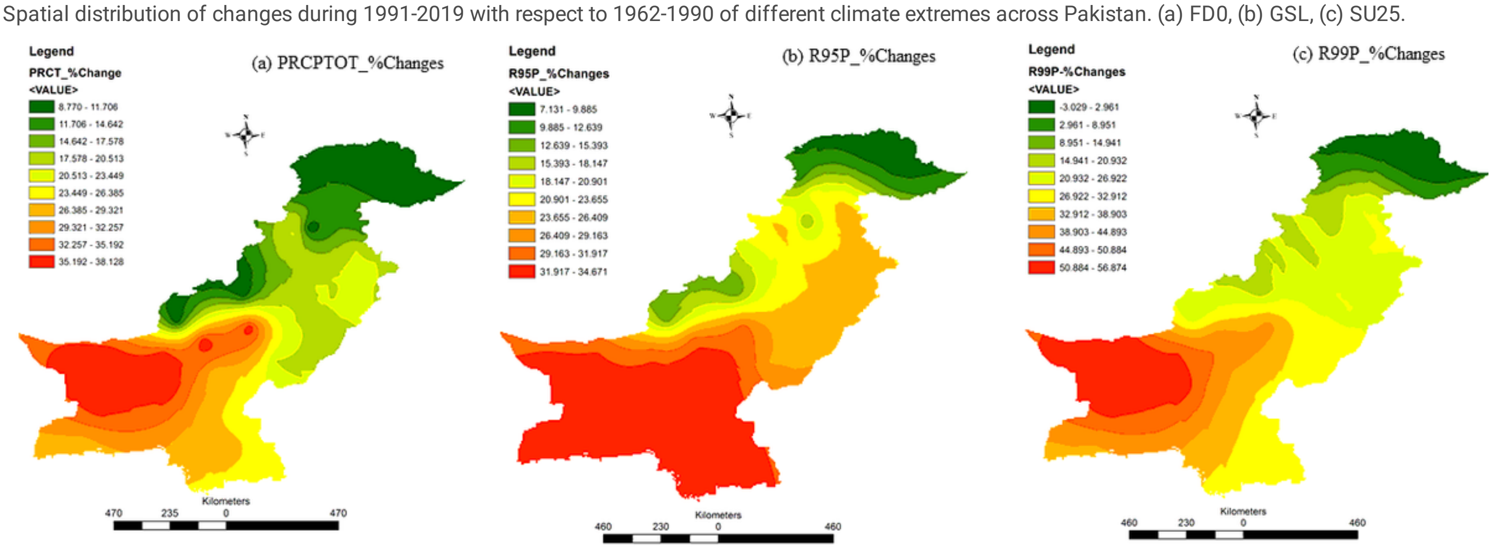

Figure 9

Spatial distribution of changes during 1991-2019 with respect to 1962-1990 of different climate extremes across Pakistan. (a) PRCPTOT, (b) R95P, (c) R99P.

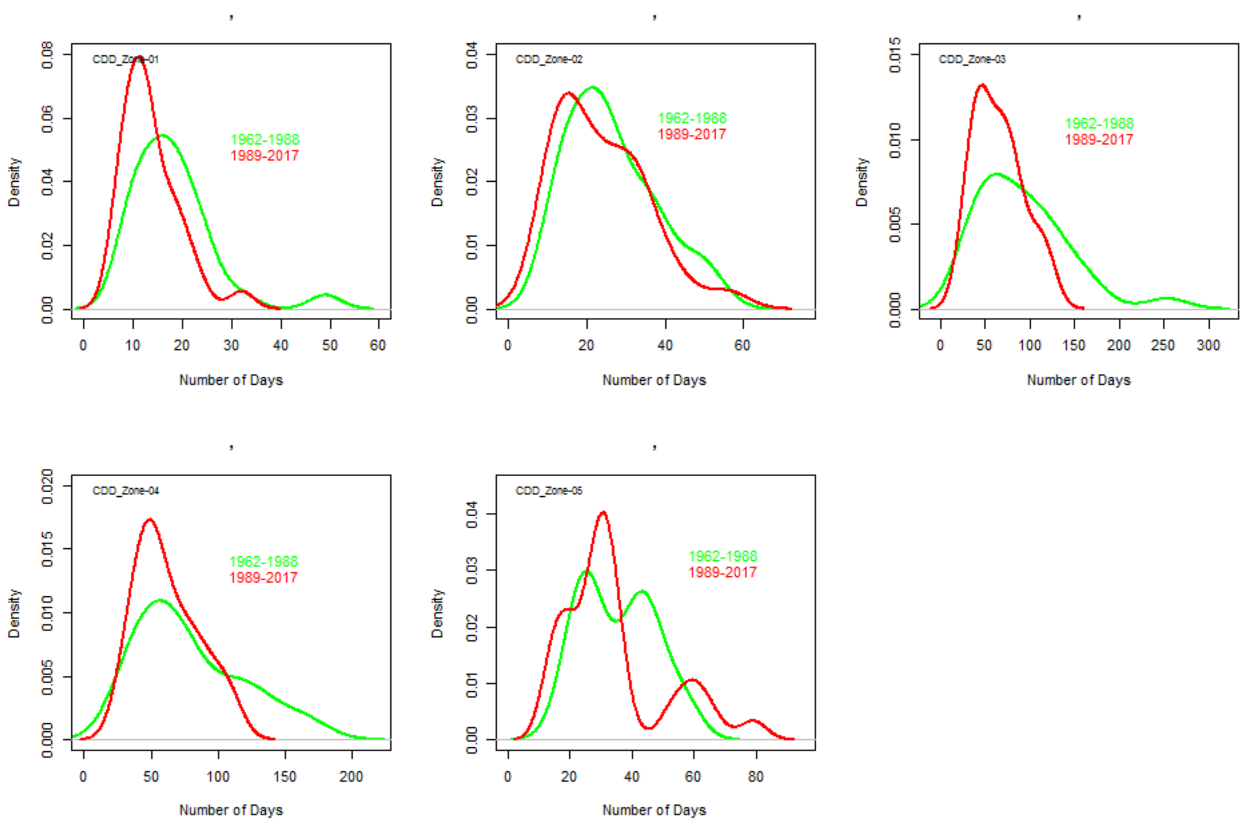

Figure 10

Probability density function of Consecutive dry days (CDD) for the duration of 1991-2019 and 1962-1990 in each climate zone. Green and red color represent 1962-1990 and 1991-2019, respectively. On x-axis the number of days and on y-axis the density of CDD is given.

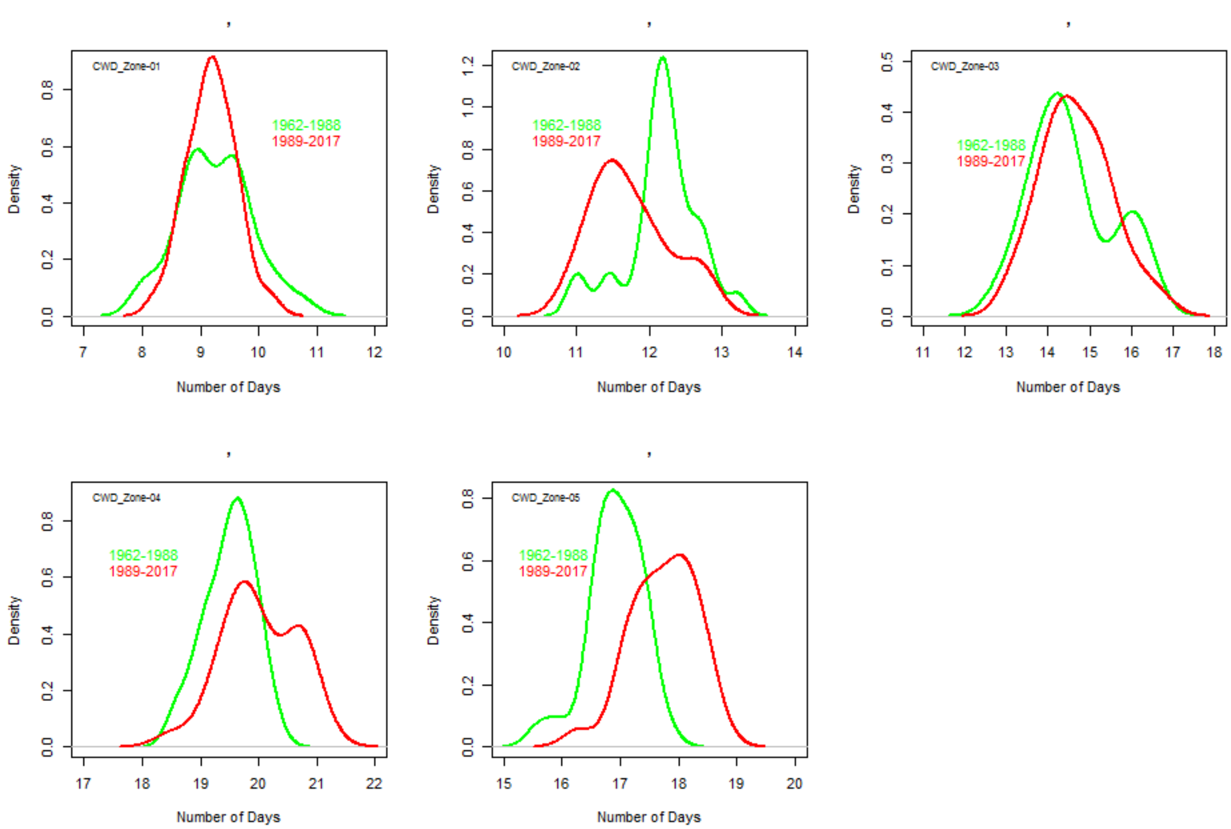

Figure 11

Probability density function of Consecutive wet days (CWD) for the duration of 1991-2019 and 1962-1990 in each climate zone. Green and red color represent 1962-1990 and 1991-2019, respectively. On x-axis the number of days and on y-axis the density of CWD is given.

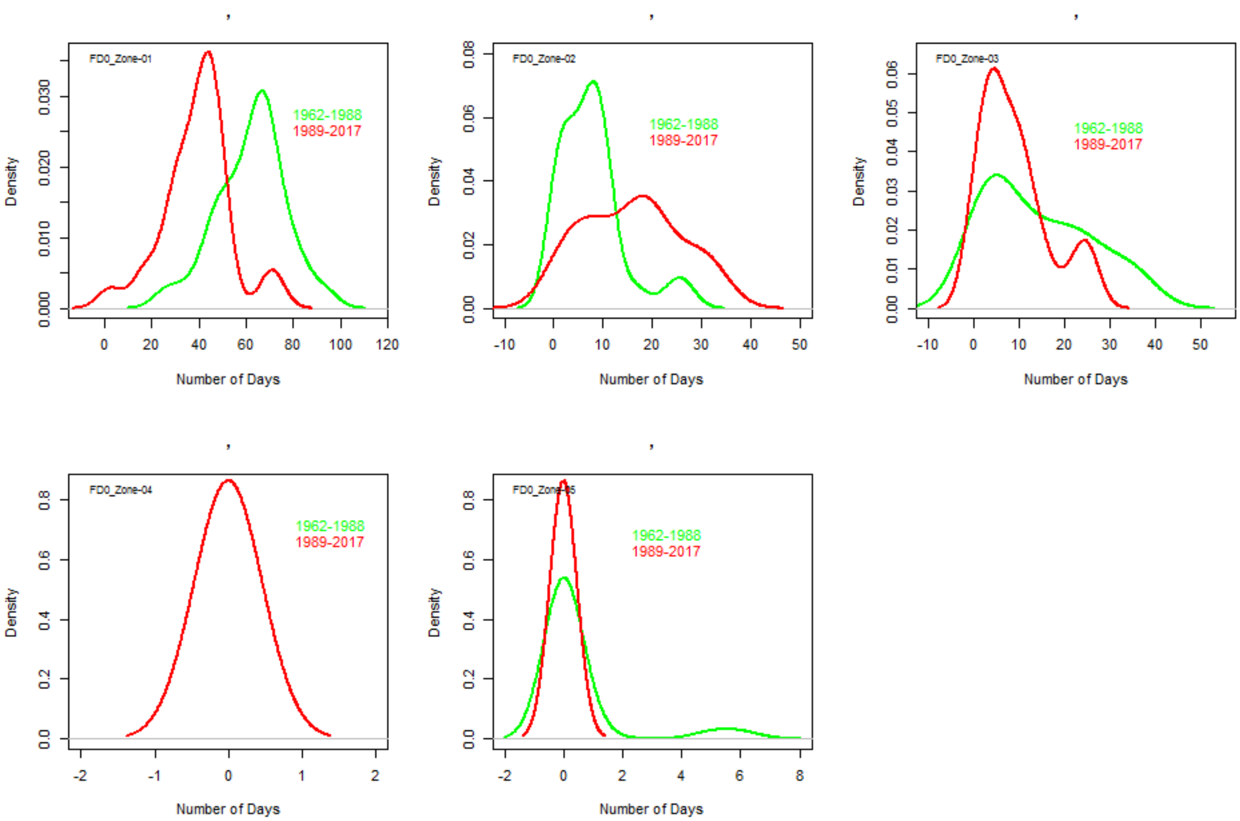

Figure 12

Probability density function of number of frost days (FD0) for the duration of 1991-2019 and 1962-1990 in each climate zone. Green and red color represent 1962-1990 and 1991-2019, respectively. On x-axis the number of days and on y-axis the density of FD0 is given.

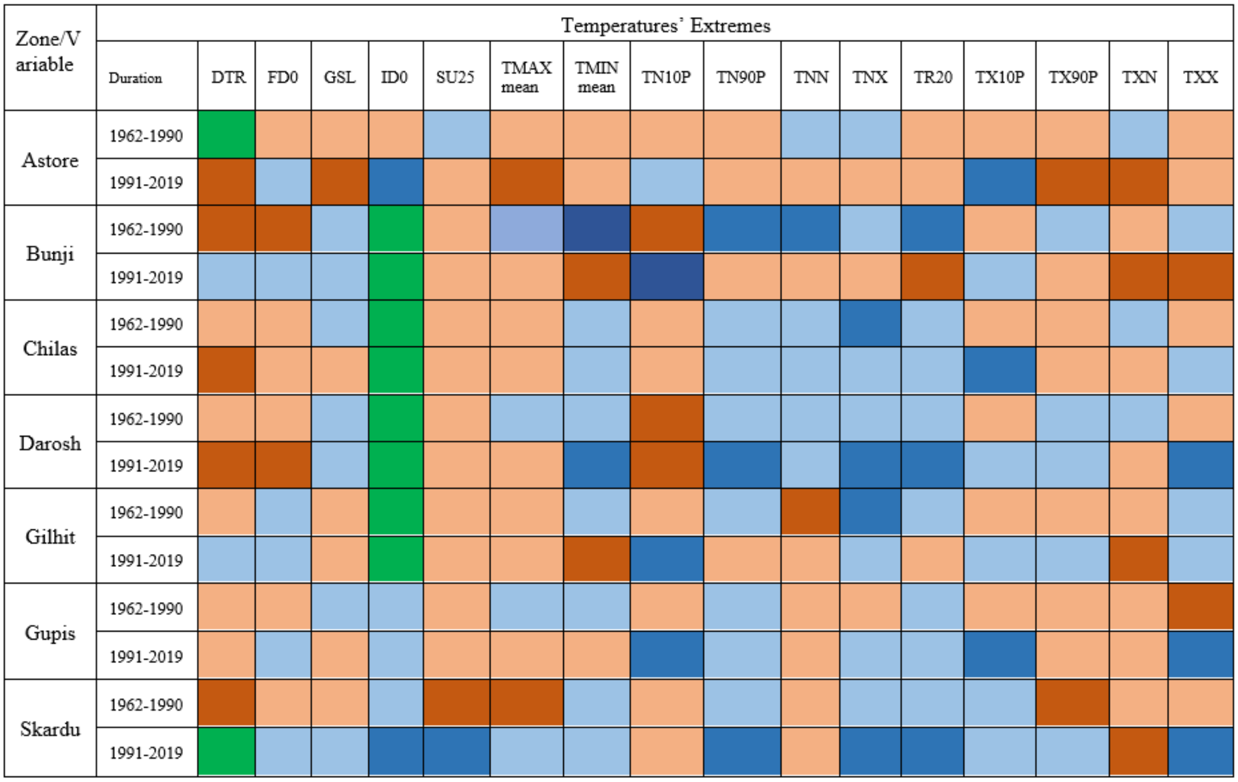

Figure 13

Station-wise climate extremes related to temperature for each climatic zone and two independent time duration in Karakoram region. Each color has specific meaning and given with Figure 12.

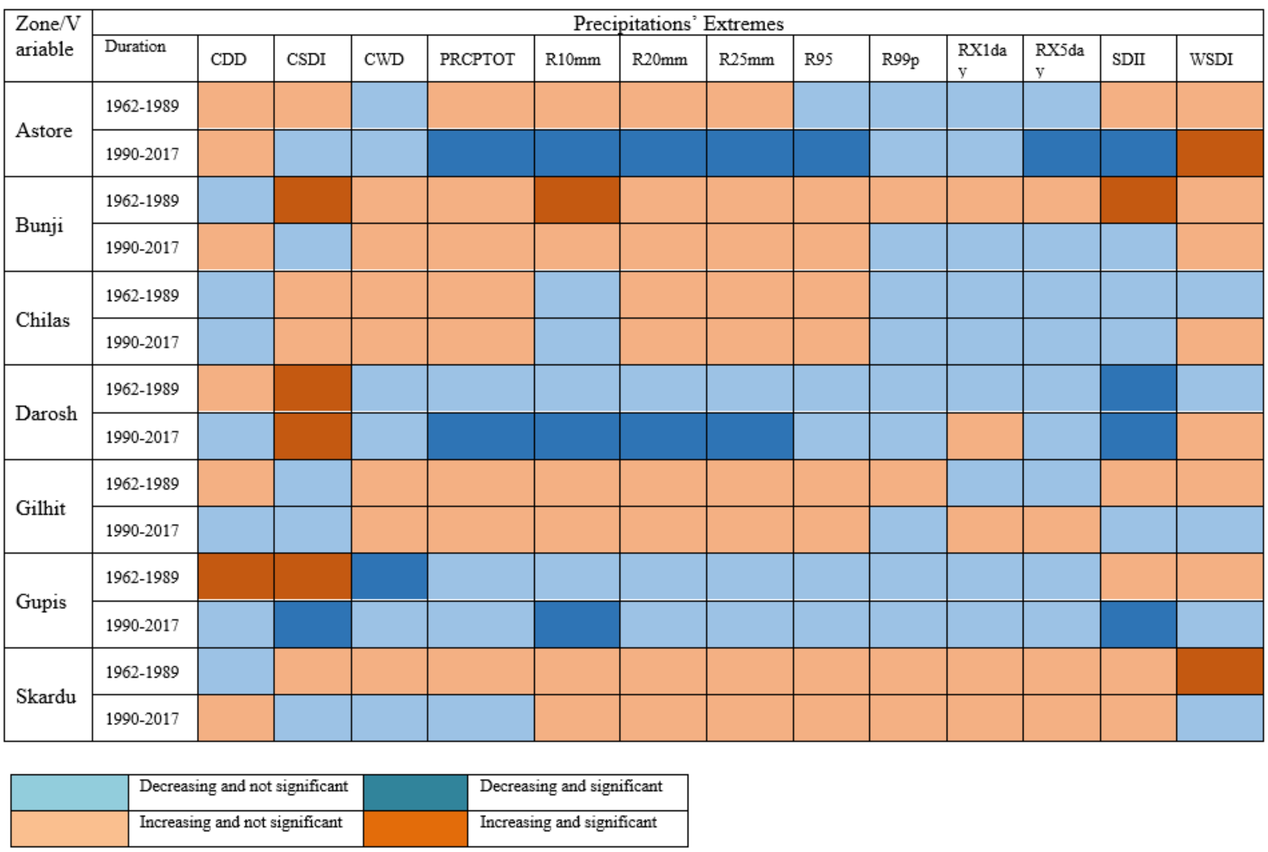

Figure 14

Station-wise climate extremes related to precipitation for each climatic zone and two independent time duration In Karakoram region. Each color has specific meaning and given below: Note: The colors represent different status for different extremes' events and the corresponding duration is mentioned in the colored boxes. Green color shows no changes.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Annex01.docx