A Comparison of Present and Future Climate Anomalies over Pakistan

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Abstract

This study investigates present and future climate anomalies over Pakistan. The variation in the present climatic period and future (2021-2050) has compared. For past and present climate anomalies, real-time data after a quality check by using RClimDex (1.0) was utilized. The 3 × Standard Deviation criteria for maximum and minimum temperatures were used to correct identified outliers. Annual mean and thirty years average for both temperature and rainfall for the period (1931-1960,1971-2000, 1981-2010, 2021-2050) was calculated. EC-Earth downscaled data was used for future projection of Representative Concentration Pathway 4.5 (RCP4.5) and RCP8.5 respectively after downscaling through the quantile mappings technique. Based on the analyses, it is found that maximum and minimum temperature has risen throughout the country. This increasing trend of maximum temperature is more significant in future (2021-2050) as compared to the present climate (1981-2010). The mean annual temperature rise over Pakistan during the current century is 1.6°C. The rainfall departure and extreme rainfall events have been increased for present as well as for future climate. Both scenarios (4.5 and 8.5) show a rise in temperature about 1.5°C over the upper half of the country with major change over GB according to RCP 8.5. Rainfall anomalies in the first period evidenced drought-like conditions in southern parts of the country. In addition, 2000 and 2010 were recorded as first and second wettest years for study period 1931-2010. Future rainfall anomalies represent 5-10% deficient rainfall in the subtropical arid zone. It is strongly recommended that agriculture experts must consider these changes in policy-making.

Keywords: EC-Earth, projections, quantile mappings.

Introduction

Climate change is evident from rising sea levels, temperature, retreating/depleting glaciers, and increasing downpours (IPCC 2014). Rainfall and temperatures are the most important measures of climate change and their trend can influence water, health, biodiversity, glacier, forests and socio-economic sectors. An increase in temperature can cause heat exhaustion that caused death and illness in susceptible people. Similarly, change in rainfall patterns and frequency affects water availability and the energy sector. Heavy rainfall episodes may cause flash flood as well as urban flooding which affect the water quality and cause airborne diseases. On the other hand a deficiency in rainfall rate could involve an increase in drought events. Rainfall and temperature are two interconnected variables. An increase in temperature leads to more evaporation which in turn increases rainfall (Tabari et al. 2011).

It is a fact that developing countries will suffer more due to climate change as compared to developed ones (Barker 2007). According to Global Climate Index Report (2017), Pakistan ranked 7th out of the ten most vulnerable countries to the consequences of climatic change (Kreft et al. 2016). During the current century, Pakistan in general and River Indus, in particular, will experience a 4°C to 6 °C rise in temperature with an average of 0.5°C per decade (Rasul et al. 2012). This changing climate can cause the potential threat of rapid recession of glaciers, and increase the intensity of rainfall in monsoon season that can enhance the risk of flood in Indus and eastern rivers. Many studies conclude that the changing climate system has been affected by the intensity, frequency, and duration of extreme weather events due to a warm climate (IPCC 2007). In Pakistan, during the last few years, there has been exceptional flooding in Northern areas along the Indus bank, and extreme heat wave events have been observed in Southern Pakistan. Flood has been occurring every year since 2010. The other dangerous and hazardous effect of climate change over Pakistan

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weather is a seasonal disorder. One of such disorder is the seasonal onset and offset caused shortening of spring season.

For the study of future climate changes, the Global Climate Model (GCM) data scenario has been used in many studies (Sachindra et al. 2014; Sachindra and Perera 2016; Division et al. 2018). However, GCM data is available at coarse resolution. The GCM data was utilized after downscaling for the region. There are normally two modes of downscaling; dynamical and statistical. Statistical downscaling has proved to be a better option over dynamic downscaling in climate impact studies as well as for the prediction of regional climate (Trzaska and Schnarr 2014). Different bias adjustment techniques are used to improve the quality of a GCM data, and a large number of statistical bias correction methods have been developed and some inter-comparisons have been carried out between these methods under various scopes (Teutschbein and Seibert 2012; Lafon et al. 2013). The linear correction method (LCM) approach corrects the average value of rainfall and temperature on the difference between real-time data and model-simulated data. However, the LCM method is unable to correct the variance between two climate data sets (Vila et al. 2009; Ghajarnia et al. 2015; Ajaaj et al. 2016).

Different studies applied different approaches to find out climate change facts over different regions of the world. Ikram et al., (2016) calculated past and future trends in the frequency of heavy rainfall events over Pakistan by using linear interpolation and bias correction techniques for Coupled Model Inter-comparison Project Phase5 (CMIP5). The analysis was carried out for two future time periods: mid-century (2040-2069) and end of the century (Ikram et al. 2016). Using different GCMs and three emission scenario is known as A1B, B1, and A2, Sharif predicted a rise in future temperature over Saudi Arabia (Sharif 2015). Yan et al., (2016) used the annual temperature data to examine the climate change detection over Amur River Basin. The author used Mann-Kendall test is used for the calculation of extreme temperature and annual temperature change in Amur-River Basin. This study found that, for the Northwest and central regions in the basin, the probability of episodes of hot extremes increased, while the event probability of cold extremes were decreased in the central basin under climate change (Yan et al. 2016).

Mean surface air temperature would be increased from 2.5°C to 5°C with maximum increased in north-western parts of selected domain and rainfall would likely to increase 30% over Bangladesh, Myanmar and North-eastern India.

The main research question for this study is as:

"Is the future climate change unusual compared to current/past changes over Pakistan"? The first section represents spatial variation in annual rainfall, maximum and minimum temperature for present climate periods; the second part entails future variation in rainfall and temperatures. The average annual rainfall, maximum and minimum temperature departures were examined for the whole country. The thirty years average values of the statistically downscaled Community Climate System Model Version 4 (CCSM4) have been calculated (RCP4.5 and RCP8.5) for the period 2021-2050. The aim of this paper is to compare the change for the present and the future. The present study deals with synergistic analyses in the change between two different climate periods before 2010 and after 2020.

Data and Methodology

The term "climatic anomaly" as used in this study is the absolute difference of the changes in the present climate with respect to past climate, similarly projected for the future climate relative to its current climate. Initially daily data for the period 1930-2010 of rainfall and temperature (maximum and minimum) has been used after the quality check by using RClimDex (1.0) (Zhang et al. 2004). The 3 × Standard Deviation criteria for maximum and minimum temperature was used to correct identified outliers. All those values which were ±3SD were recognized for Quality checks; similarly for temperature all those values of temperature for which minimum temperature ≥ maximum temperature corrected (Ahmad 2018).

The daily data was compiled into monthly by Pakistan Meteorological Department (PMD). We compute annual mean for forty eight stations and then calculate thirty years average for both temperature and rainfall for the period (1931-1960 and 1981-2010) as discussed in equation 1. The details of all stations is presented in Figure 8.

$$T_{ij} = \frac{1}{30}\sum_{n=1}^{n=30} T_{ij}^{n} \qquad (1)$$

Where T ij and T^n ij represents thirty years annual mean and annual mean for the i[th] station in the j[th] year respectively, n € (1,30), i € (1,48) and j € (1930-1960, 1981-2010). Next we compute the anomalies as shown in equation 2.

$$Anomalies(Present) = Average_{(1981-2010)} - Average_{(1931-1960)} \qquad (2)$$

Similarly anomalies were computed for future period as mentioned in equation 2. Then climatic anomalies associated with precipitation and temperature were analysed for both present and future period The EC-Earth data with a resolution of 0.25° was employed for generation of future scenario.

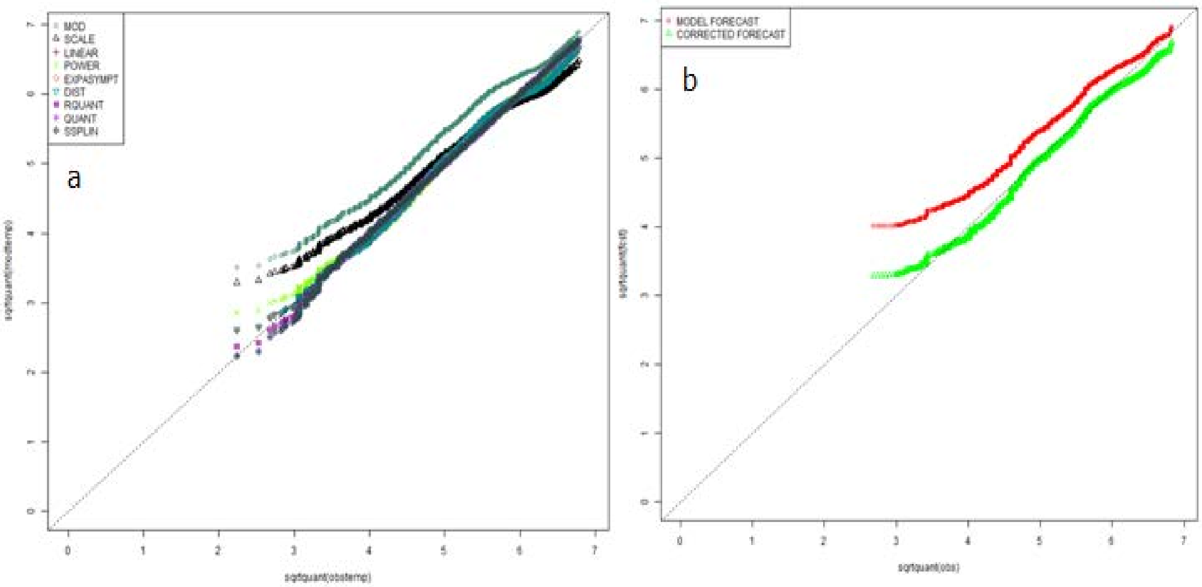

Figure 1: (a) Comparison of Quantile plots for different transformations, SqrtQuant(obs) on the X-axis and SqrtQuant(mod) on the Y-axis ,(b) Comparison of Quantile for model forecast and corrected forecast for the validated period, SqrtQuant(obs) on X-axis and SqrtQuant(mod) on Y-axis . The red line represent model forecast before bias correction and the green one after bias correction

This data has become a prominent state-of-the-art model as shown by the involvement in many projects with a significant contribution to CMIP5 and CMIP6. From the statistical perspective, bias is corrected by a "transfer function" between the GCM and observed rainfall series. This is known as "quantile mapping"(Ines and Hansen, 2006; Li et al., 2010; Maurer et al., 2013; Piani et al., 2010; Wood et al., 2004). A simple empirical Quantile mapping technique has been used after applying different transformation techniques for calibration period (1971-2000) as shown in Figure 1 (a). In Figure 1 (a and b) square root of quantile for observed and forecast have been plotted, observed is as independent (x-axis) while forecast is dependent variable on (Y-Axis). The mapping was carried out separately for each station. In cases where the real-time data had missing values, the corresponding simulated values were omitted to obtain time series of equal length (Sillmann et al. 2013). For future forecast, an empirical technique was selected and validated for the period 2001-2005. Figure 1 (b) depicts the comparison of GCM raw data and corrected data of above-said stations. In addition to observing climate behaviour in future 1SD+Mean was used to investigate whether there is a climate change or variability in Pakistan and which areas would be more effective in near future from 2021-2050. If future rainfall value exit in this range, it recommends variability rather than change.

Result and Discussion

A long term change in rainfall and temperature of a region is important for decision making in agriculture field, water management department etc.

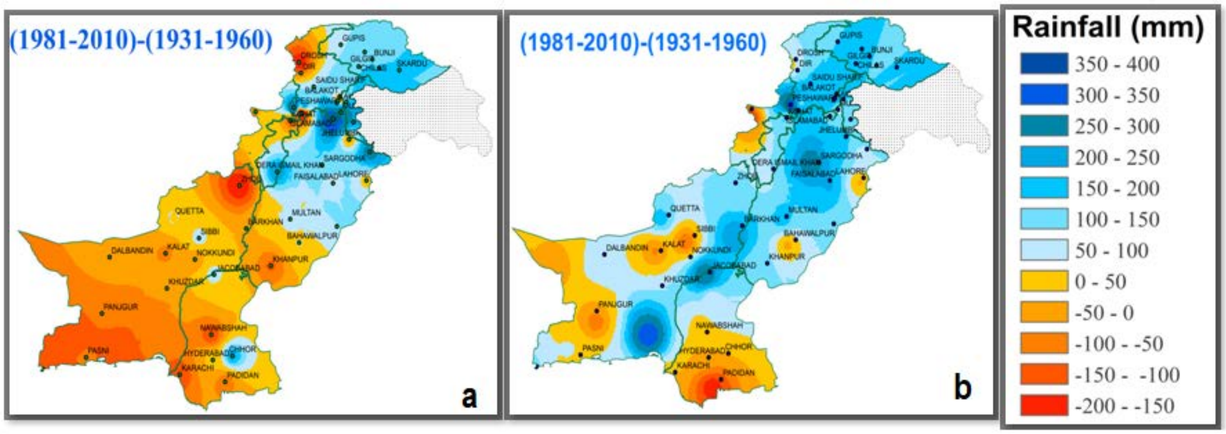

Figure 2: (a) Departure between normal (1981-2010) and normal (1931-1960) of total annual rainfall (mm) (b) Change in daily extreme rainfall (mm) normal (1981-2010)-(1931-1960).

Present climate anomalies are shown in figure 2 for annual rainfall and daily normal values of extreme rainfall (mm) obtained from PMD. An increasements in annual range is noted from 50 mm in the central parts to 350 mm in the upper parts of the country. While a negative departure occurs in a major chunk of the southern parts of the country. The maximum increase in mean annual rainfall was observed in the monsoon region including Sialkot, Rawalpindi and Jhelum districts. The Northwestern Ghats of Balochistan received less annual rainfall; in this rain-fed area less than normal rainfall is not good for crops and caused agro meteorological drought conditions in the region. The 1998-2002 drought period reflects this negative anomaly in Pakistan. The drought was at its peak in Balochistan and Sindh, 26 districts of Balochistan were suffering from severe famine as a result of the drought. 1.2 million People in the province were affected by the great drought. A prominent change observed for extreme rainfall in the map of Figure 2 (b). In southern parts total annual rainfall is observed below than total annual rainfall (1931-1960) ranging from 0- 100 mm. The daily extreme rainfall frequency has been enhanced in all over Pakistan. However maximum departure was observed along the Indus basin. This departure also depicts the 2010 heavy flood along the Indus floodplain areas. The monsoon rainfall of 2010 was recorded as the highest rainfall since 1994 and the second highest during last the 50 years. Pakistan Meteorological Department recorded above-average rainfall in the months of July and August 2010 and monitored the flood wave progression, similar floods had been observed in 1988, 1995, and 1997. During the period spatial variability in rainfall was observed throughout the country.

Figures 3(a) and 3(b) depict minimum temperature anomalies of (1981-2010) from the climate period (1931-1960) with negative change for upper areas including Giligt Baltistan and AJK as compared to low elevation regions. Extreme night temperatures have also been decreased in the current climatic period over elevated region including some upper parts and coastal region of Balochistan. The cold wave episodes encourage these negative anomalies of extreme minimum temperature in the upper parts of the country. However, in Balochistan and upper Sindh areas, there was a positive change during 1981-2010.

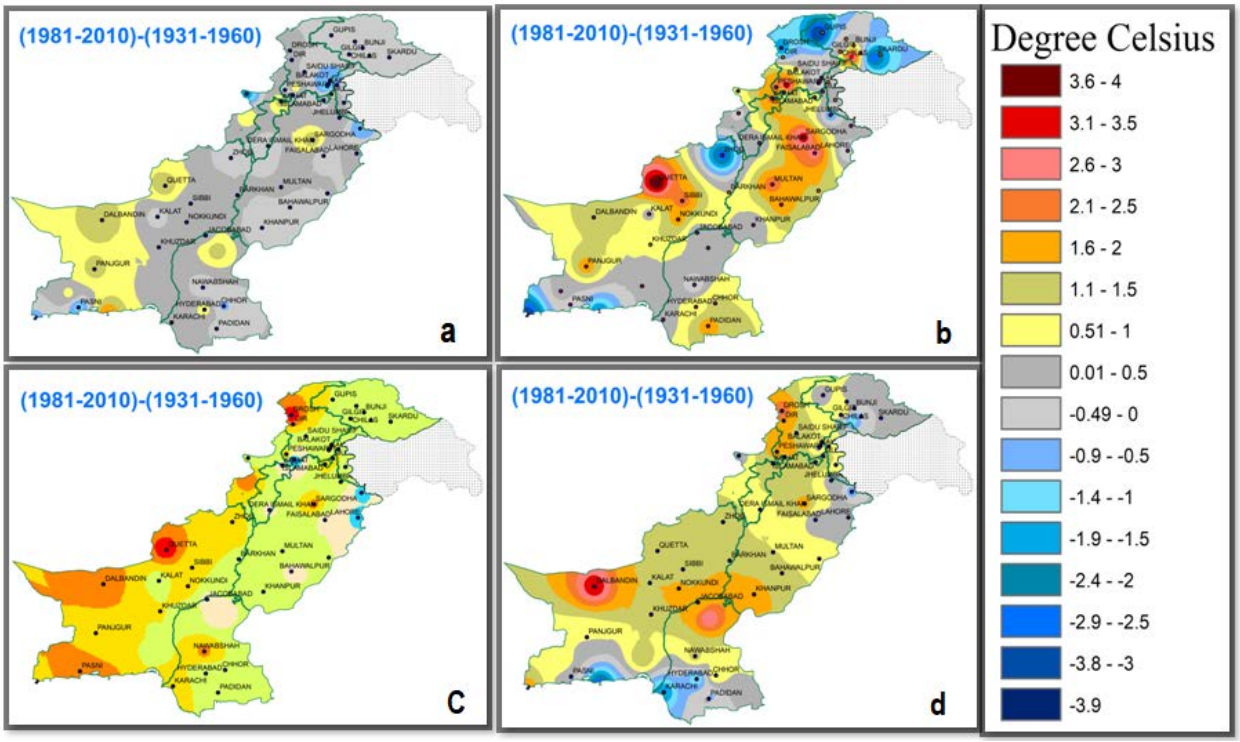

Figure 3: Change in temperature (a) Annual mean minimum °C (b) Extreme minimum temperature °C (C) Annual mean maximum °C (d) Extreme maximum temperature °C

Due to the rapid addition of greenhouse gases to the atmosphere, especially since the Industrial Revolution, it is observed greater changes in the Earth's temperature over the current century than have been recorded over the last thirty years. The main impression is that significant warming is common in most parts of the country, especially in the southern region. It was found that the largest warming trends (≥1 ◦C) predominantly occur in the southern parts. In the twentieth century, the global temperature averaged over land and ocean areas warmed by 1.28°C (34.4°F) (Fig, 3a). However, the mean annual temperature raised 1.6 °C over Pakistan during the current century. The rise was not uniform in time or space. For example, temperatures of the first decade of the 21^{st} century were warmest as compared to the 1981-2000 period. Also, temperature rise has been greater in the north-western high-latitudes.

There is a hot dry condition prevailed in Balochistan over the present thirty years, from 1981-2010. The spatial distribution of extreme maximum temperature change is shown in Figure 3(d). The episodes of hot and dry days have increased from 1981-2010.Southern Punjab, Balochistan, and Sindh are the core region for agricultural products in Pakistan. Southern Punjab is most dominant in terms of the Cotton crop. This crop required specific climate conditions for its proper growth. An increase in maximum temperature events had bad impacts on its yield. The frequency and intensity of 2007 heat waves support our results for Sindh and Southern Punjab. Above discussion on weather extremes (floods and heat-waves) has depicted both agricultural and economic losses associated with these events.

Mean Annual Departure of Future Rainfall and Temperature from Normal (1981-2010)

Before discussion about the departure of rainfall and temperature here, a gist of climate for 1981-2010 is captured in Figure 4. Figure 4(a) represents the annual mean of maximum temperature, 4(b) is an annual mean of minimum temperature and 4(C) is the total annual rainfall for Pakistan. Annual maximum temperature range from 15-36°C, whereas Annual maximum temperature range from 02-22°C having a maximum in the southern region and the minimum value in upper parts. Figure 4(c) represents annual mean rainfall for Pakistan. There is much variability in annual rainfall over Pakistan.

A small amount of rainfall received in Baluchistan, Sindh and South East Punjab around the year. However, more than 1000(mm) rainfall occurred in Northern Punjab, KPK, AJK and some parts of Gilgit Baltistan. Annual mean rainfall map shows that Central Punjab and upper parts of the country received the almost same amount of rainfall.

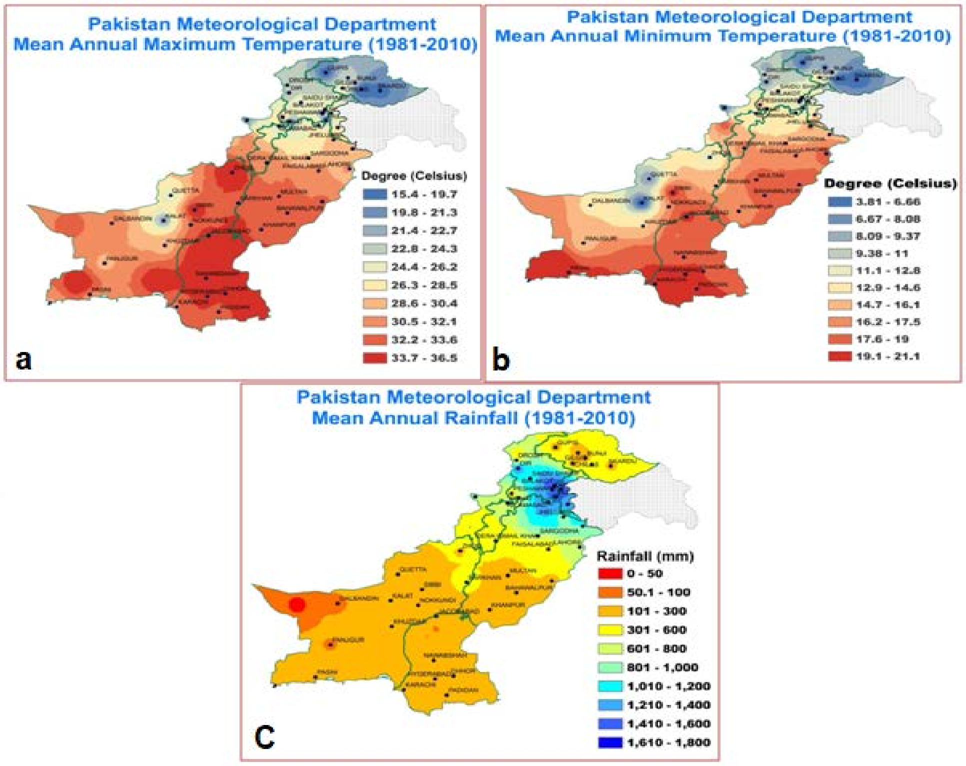

Figure 4: Pakistan mean annual of Temperature and rainfall (1981-2010)

Future anomalies of Minimum Temperature:

Projected spatial distributions of annual average minimum temperature anomaly considering the RCP 4.5 and RCP 8.5 scenario derived from the GCMs over Pakistan for the time period (2021-2050) are presented in Figures 5(a) and 5(b) respectively.

Both projections showed a warmer temperature pattern over the country except Kohat district, ranging between 0.5°C to ~2.0°C in comparison with the recent (1981-2010) climatic period. The Kohat district depicts a negative trend which may be a reflection of a human error during recording observed temperature. As compared to past climate anomalies it is expected in future cold regions will face a rise in minimum temperature during the aforesaid period. The projected changes are positive for the near future; because the scenario with a large concentration of greenhouse gases (RCP8.5) is used.

Future anomalies of Maximum Temperature:

Figure 6(a) and 6(b) represents the spatial distribution of future anomalies in the annual mean of maximum temperature for the period 2021-2050. The RCP 8.5 scenarios predict warmer over GB and KPK mountains as of RCP 4.5. Snow covered areas of Pakistan in the north are likely to observe more increase in maximum temperature (1.5°C to 2°C) as compared to central and southern regions. The warmth of the period is accompanied by the melting of ice over mountains, glaciers, and thawing of permafrost. These temperature projections show that glaciers will lose more mass in future, snow cover decline rate is also expected to enhance in this period (2021-50).

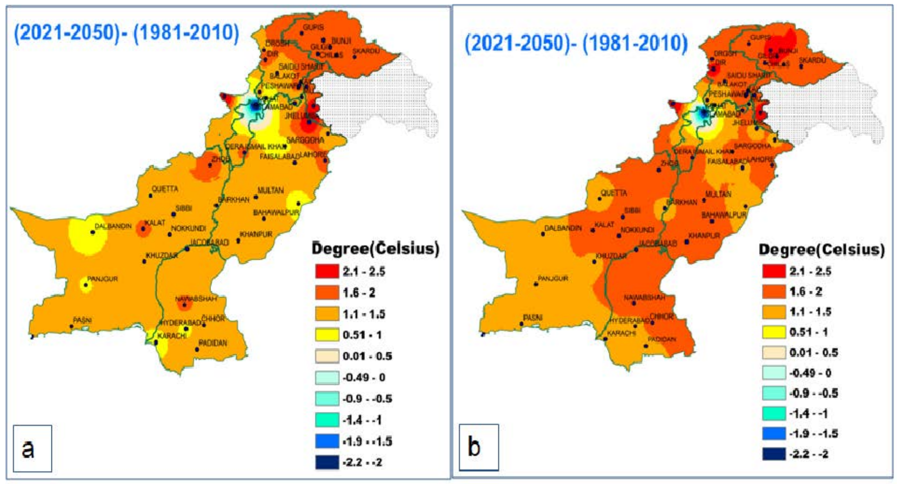

Figure 5: Future anomalies of TMin (a) RCP4.5,(b) RCP 8.5.

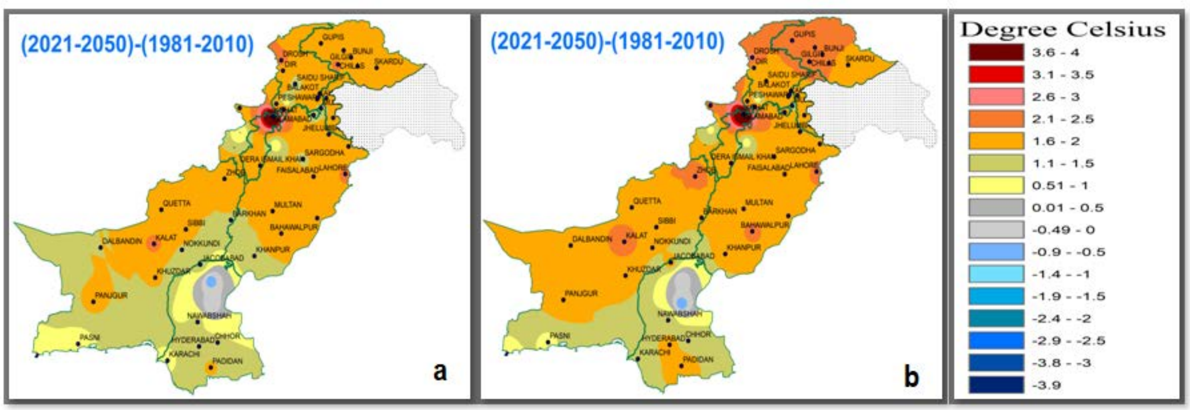

Figure 6: Future anomalies of TMax (a) RCP4.5,(b) RCP 8.5.

The maximum temperature anomalies are higher than the minimum temperature anomalies show in Figure 6 (a and b). Generally, there will be of higher Diurnal Temperature Range (DTR) over Pakistan and small over northern regions. Higher DTR effect lower-level cumulus clouds in the early afternoon, when the planetary boundary layer is best mixed, and convective thermals reach the highest. The DTR also enable storm to generate more rainfall in the plain areas of Punjab and Sindh. A small region of Sindh will be observed the minor negative change in maximum temperature. Again Kohat district scenarios show an abnormal behaviour in maximum temperature.

Future anomalies of Rainfall (RCP4.5 and RCP8.5):

Future scenario of rainfall showed much variation for both selected scenarios during the study, so anomalies were calculated in percentage instead of absolute change. Future rainfall projections are much important regarding adaptation and action plan in Pakistan. Seasonal rainfall also plays a vital role in agriculture productivity; the scenario was generated on annual as well as on seasonal basis. For the percentage rainfall change, no significant change is observed in southern and central parts of the country in future. However, there is some rainfall increase in upper parts of Punjab and KPK. During monsoon season July- September (JJAS), the GCM outputs predict a maximum rise in rainfall in the monsoon belt over North Punjab and lower parts of Khyber Pakhtunkhwa.

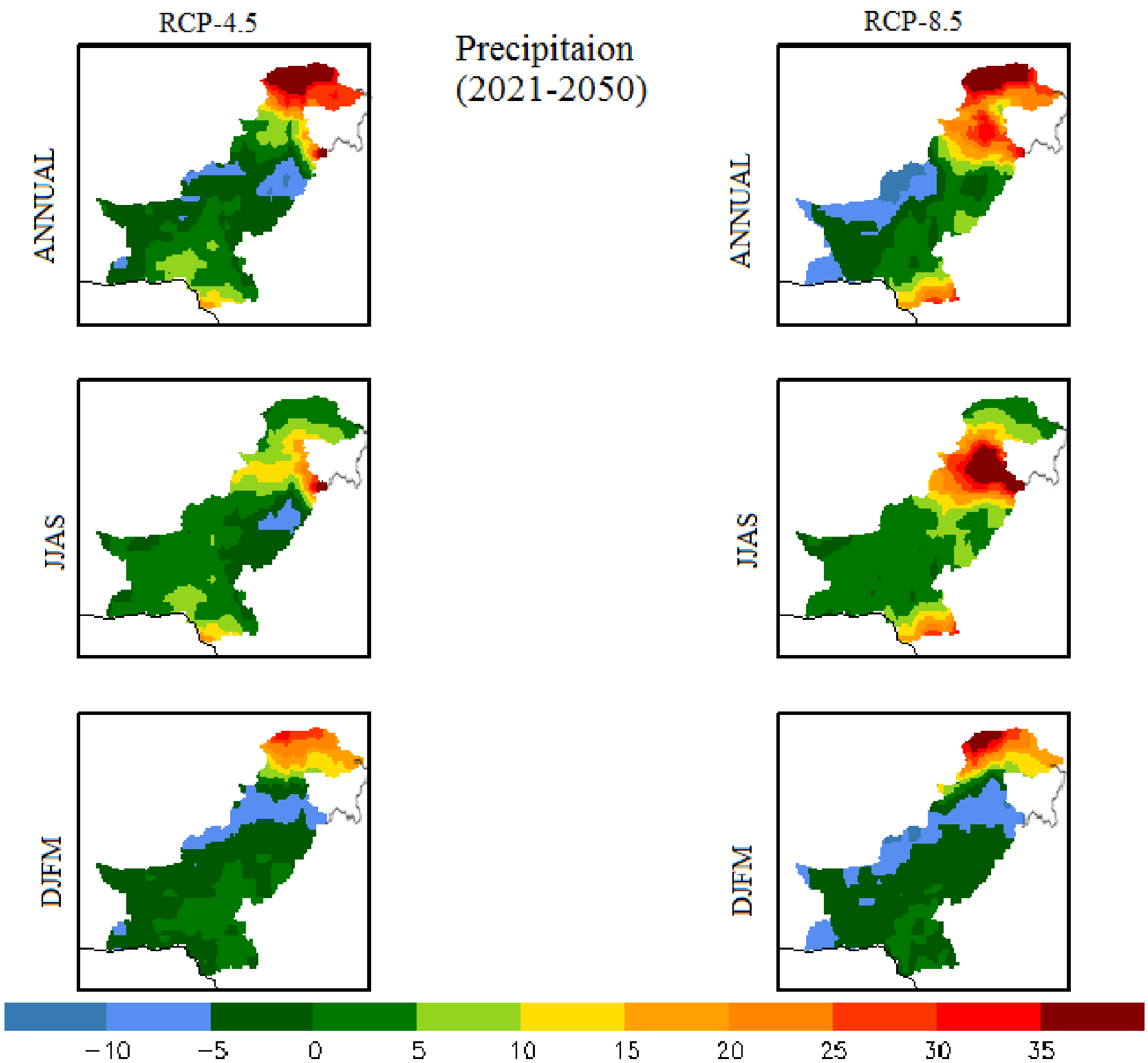

Figure 7: Rainfall percentage anomalies for annual, summer and monsoon rainfall.

The RCP8.5 predicts a significant change in the south-eastern tips of Sindh province. However, mixed trends are projected for rainfall over different regions of Pakistan. Similarly, in winter season rainfall, there may be 25-35% above than normal rainfall in snow-covered areas of KPK and GB. On the other hands, rainfall is below than normal in upper Punjab and adjoining areas of KPK and Baluchistan. These areas are rain-fed areas for the wheat crop; declining rainfall affects the agriculture of this sector. The long-term annual rainfall average over 2021-2050 is above than 1981-2010 average. It may be possible country will receive more flooding due to urban heating and more rainfall over 2021-2050.

Conclusions

This study finds the departure in mean annual rainfall, maximum temperature and minimum temperature for the present (1981-2010) and future (2021-2050) era for 48 climatic stations of Pakistan covering all provinces. EC-Earth model output was analysed for two future scenarios, RCP 4.5 and RCP8.5. The predicted temperature rise throughout Pakistan in near future may be attributed to global warming, local land use, and regional climate change.

The following conclusions are derived from the study:

- The maximum positive change in maximum and minimum temperature for the first period (1981_2010 - 1931_1960) was observed in the hyper-arid zone of Balochistan. However, there was a slight change (±0.5°C) in both temperature examined over snow-covered areas and Punjab Province along with adjoining areas of Sindh and Balochistan.
- In the case of extreme minimum temperature, the maximum positive change > 3°C occurred in Kalat and Awaran districts, upper and southern Punjab districts also observed positive change, again over mountains extremes night temperatures have decreased.
- The daytime temperature has increased throughout the country except for coastal arid zone.
- For a future change (2021_2050), both scenarios predict a rise in temperature > 1.5°C over the upper half of the country. However, RCP 8.5 predicts anomalies more than 02°C over GB making human survival difficult. As compared to the departure of the first period, in future temperature rise pattern will be shifted over the snow-covered and glaciated regions of Pakistan, which is an alarming situation for planning and action plans, especially in the water sector. This trend shows there may be the high tendency of snow and glacier melting in future, this melting will also cause a rise in sea level.
- Rainfall anomalies in the first period showed drought-like conditions in southern parts of the country, land-surface rainfall averaged over 1981-2010 was above the 1931–1960 average. In addition, 2000 and 2010 were the first and second wettest years ever recorded during 1931-2010.

Future rainfall anomalies represent a 5-10% decrease in rainfall in the subtropical arid zone. It is strongly recommended that agriculture experts must consider these changes in policy-making.

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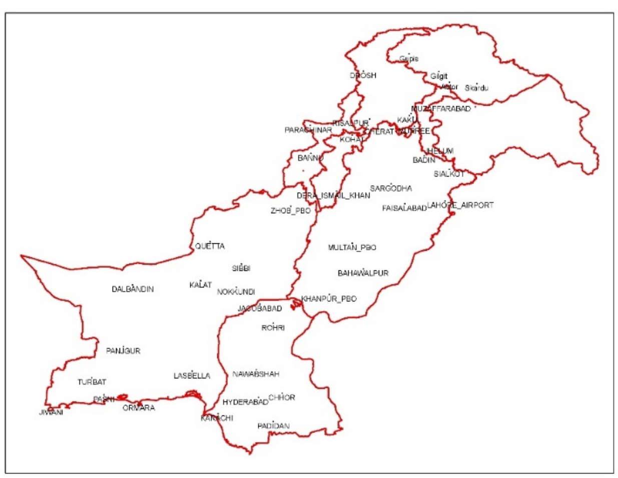

Figure 8: Station names and location of study area.