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DAILY CLIMATE EXTREMES OF TEMPERATURE AND PRECIPITATION OVER QUETTA VALLEY, PAKISTAN DURING 1961-2019

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Abstract

Climate extremes are imperative to study the impacts of climate change that is significantly observed for the management of scarce water resources of the Quetta Valley. The daily data of temperature and precipitation are used to model the climate extreme indices for Quetta Meteorological Station from1961 to 2019. The statistical tests were performed by using Mann Kendal and Sen's Slope method at the 95% confidence level. The overall change in minimum to maximum temperatures and precipitation-based climate extreme indices specify the frequencies of extreme events are increasing. That would cause heatwaves, gradual warming, steady dryness, and extreme precipitation events in the long term over the Quetta Valley. The minimum and maximum temperature-based indices inclusively indicate positive trends. That ultimately leads to a warming climate with a significant increase in summer as 5 days/decade, tropical nights as 5.3 days/decade, daily maximum as 0.28°C/decade, warm nights as 1.7 days/decade and warm days as 1.9days/decade. For precipitation, all the indices show positive trends with a significant increase in consecutive wet days for 0.1 days/decade and an annual contribution of very wet days 0.8% per decade. The monthly increase in temperature and decrease in precipitation would increase the evaporative demands which may arise the water stress conditions over the valley and may put pressure over groundwater reservoirs.

Keywords: Climate Extremes; Climatic Indices; Quetta Valley; Pakistan.

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1. Introduction

The impacts of climate extremes are observed and gain attention throughout the world (Alexander *et al.*, 2006). It was projected that average global temperature would increase 1.4 to 5.8°C during the 21st century and the frequency of extremes events, i.e., floods, droughts, and heatwave would also be increased (IPCC, 2007). Several researchers conducted work over the world regarding the changes in extreme temperature and precipitation based on observation data sets (Frich *et al*., 2002; Meehl *et al*., 2004; Griffith *et al*., 2005; and Tebaldi *et al*., 2006). The future projected study also shows the frequency of climate extreme increases over Pakistan (Sajjad and Ghaffar, 2018). These studies identified the changes in climate extreme of precipitation and temperature and its related indices over the Quetta valley of Pakistan.

The world consensus shows that the environment is highly sensitive to shifts in frequency and intensity of extreme events (Boccolari & Malmusi, 2013). The indices based on percentile, threshold, duration and other statistical tools may be utilized to represent extreme events (Grigges and Noguer, 2002). The Expert Team on Climate Change Detection and Indices (ETCCDI) has proposed a set of climate indices that are used globally to investigate the extremes in observed data as well as for future projections of climatic extremes over a region (Zhang *et al*., 2011). Numerous researchers (Frich *et al*., 2002; Klein Tank *et al*., 2003; Meehl *et al*., 2004 and Tebaldi *et al*., 2006 etc.) concentrated on data collection from ground weather stations to study the climate extreme indices.

In many countries around the world, hot days and warm nights have been increased, whereas cold days and cold nights have been decreased and precipitation significance varies from region to region (Manton *et al*., 2001). The gradual reduction in cold days and increase in warm days is identified since 1961 over China (Yan *et al*., 2002). Similarly, trends of precipitation extreme indices have increased during 1910-2000 in 70% of the studies conducted in most areas of the world (Sen Roy and Balling, 2004). The change (direction and magnitude) in extreme climate does not necessarily remain the same to climate means (IPCC, 2007). Earlier studies conducted on the mean climate and climate extremes over south Asia (Choi *et al*., 2009; Ahmad *et al*., 2015; Sajjad and Ghaffar, 2018).

Climate change invariably affects the global hydrological cycle as well as air temperature (Hunt, 2020; Zhao, 2015). The global land surface temperature has risen at the rate of 0.175°C to 0.197°C per decade during 1951-2012 (Stocker *et al.*, 2013). Extreme weather events have increased worldwide in terms of frequency and intensity (Huber and Gulledge, 2011). Several studies suggest that climate change may widen the production and consumption gap between the nations as the agriculture productivity in developed countries will increase while it will decrease in developing countries (Rosenzweig and Parry, 1994; Fischer *et al.*, 2005). It is expected that millions of more people will face hunger by 2050 (Parry *et al.*, 2004).

A previous study on extreme temperature identified that it falls to -26°C in the northern area and reaches 52°C in the central as well as southern parts of Pakistan (Srinivas and Kumar, 2006). Also, the air temperature has shown a rising trend of 0.06°C per decade from 1901 to 2007 (Afzaal *et al.*, 2009). To investigate the climate variations and trends over Pakistan, many studies have been conducted in recent years (e.g., Treydte *et al.*, 2006; Del Rio *et al.*, 2012; Hanif *et al.*, 2013). Mean annual temperature has increased at 0.36°C/decade in Pakistan during 1952-2009 (Del Rio *et al.*, 2012). The annual precipitation has gradually increased over southwestern parts and the Cholistan desert of the country during 1951-2010 (Hussain and Lee, 2014). The studies of Kazmi *et al.* (2015) and Ikram *et al.* (2016) indicated that the past trends of increasing temperature in Pakistan may continue during the current century. The southern parts of Pakistan are arid and most vulnerable to drought as indicated by Haider and Adnan (2014). Also, the frequency and intensity of drought in the southern parts of Pakistan are high, especially in the Sindh province (Adnan *et al.*, 2015).

Diagnosis of extreme events in terms of intensity, duration and frequency is crucial to frame mitigation and adaptation strategies to counter the impacts due to climate change (Choi *et al.*, 2009). Previously, several studies were conducted based on mean climate over different South Asian domains (Ahmad *et al*., 2015; 2018 etc.). However, the present study is conducted only for Quetta Valley by using observational data of precipitation and temperature to identify the climate extreme indices and their trends. The main objective of the study is to identify the climate extremes events that may create disaster regarding heat/cold wave, droughts, flood, and, most importantly, the agricultural water demands over the region. The findings of this study will help the water resource managers, climate research scientists, agriculturist, agronomists and disaster risk management agencies to develop a contingency plan for sustainable environment and climate-smart agriculture to cope with the future challenge of climate change and its extremes.

2. Study area

Most parts of the Balochistan province including Quetta lie in an arid climate with significant variation between summer and winter temperature (Adnan and Ullah, 2020). The Quetta Valley lies at 30.18 latitudes and 66.99 longitudes with an elevation of 1680m. The Quetta Valley is one among nine sub-basins of the Pishin river basin with a total *watershed* area of 1757 km^2; the geographical location is shown in Figure1.

The only source for recharging the groundwater of the Quetta valley is precipitation. The mean annual rainfall in the valley is about 210 mm, over 80% of which falls during the winter months from November to April. The rise in water levels was also observed from January to mid of April, and this recharge is due to the seasonal precipitation (Gazdar *et al.*, 2010). Western depressions bring precipitation over this region during winter, the temperature drops down to freezing level (Durrani *et al*., 2018). At the valley, the monthly mean minimum temperature ranges from -2.73 to 20.51°C with the lowest in January and highest in July respectively. Similarly, the monthly mean maximum temperature varies from 11.06°C to 36.28 °C during January (lowest) and July (highest). Furthermore, the mean precipitation range varies from 2.29 to 51.52 mm with the lowest in June and highest in January respectively.

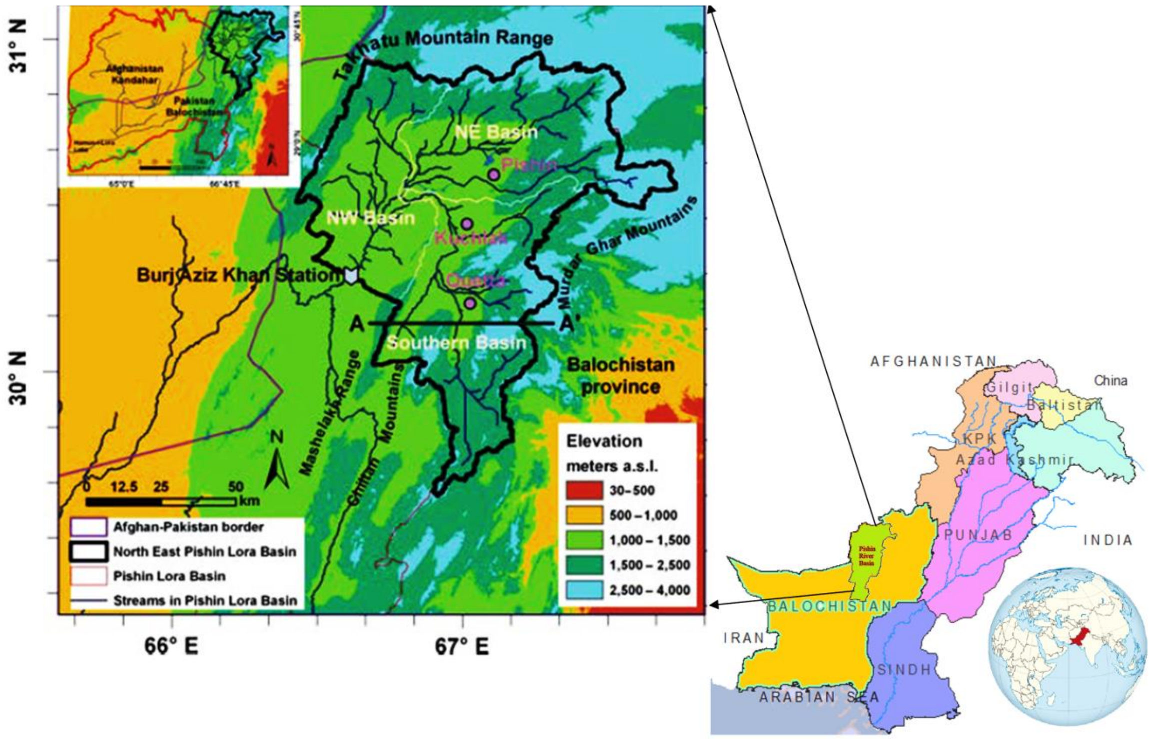

Figure 1: Geographical location of Quetta Valley, Sub-basin of Pishin River Basin (Source Sagintayev *et al*., 2012).

At the present concept of water availability from karezes, and dug wells are almost eliminated few dug wells are still being used in the west of Quetta valley and about 95% of water availability is dependent on water supplied through tubewells from alluvium and hard rock aquifers the remaining 5% is through springs active in Urak and 3126 m^3/day is collected in the reservoirs and 2748 m^3 /day is being supplied to the Cant area while 378 m^3 is supplied as support to the city water supply. According to the Quetta action plan, 2010, the water points in Quetta sub-basin are shown in Table A1 (see Appendix).

According to Ashraf and Hassan, (2020) report revealed that the assessed availability of sustainable groundwater in alluvium and hard rock aquifers from the year 2000 to 2042 as shown in Table A2 (see Appendix). To avoid water mining, the supplementary water requirements were recommended to be arranged from surface water availability in and around the Quetta valley. The groundwater in Quetta Valley generally occurs under water table conditions, but artesian conditions do exist in some parts of the valley.

The district of Quetta has two cropping seasons: 1. Rabi Crops: Rabi crops include wheat, barley, cumin, vegetables and fodder. These crops are sown in winter or during the early summer and harvested in the late summer. 2. Kharif Crops: melons, fruits, vegetables, potato, fodder and onion come under cash crops; they are sown in the summer and harvested in the late summer or early winter.

Fruit production is very important and dominant in district Quetta as 48.7% of the irrigated area was under fruit production. Apple, apricot, grapes, peach, plum, pear and cherry are the leading fruits of district Quetta. Among the cereal crops grown in the Quetta district, wheat and barley are the leading cereal crops. The average yield of 2,060 kg/ha was recorded in wheat followed by barley having 1,510 kg/ha yield during the year 2017-18. Data from the list of major crops revealed that the contribution of fruits for the year 2017-18 remained topmost covering 48.7% area followed by wheat with 28.6% area. Vegetables stood 3rd, thereby occupying 6.1% of the total area under major crops. However, the lowest area of only 0.6% was recorded in potatoes, followed by melons having 0.9% contribution in the cultivable soils of district Quetta.

3. Methodology

3.1 Climate Indices

The daily observational data of rainfall and minimum and maximum temperature for the Quetta station was used. The core 27 climate indices were used to monitor the trends during 1961-2019 by adopting the criteria to select the parameters whose missing values are less than 20% of the daily values as suggested by Manton *et al*., 2001. These 27 climate extreme indices are recommended by the Expert Team on Climate Change Detection and Monitoring Indices (ETCCDMI), the World Meteorological Organization, Table A3 (see Appendix). Out of 27 climate extreme indices, 16 are related to temperature and 11 to precipitation (Alexander *et al*., 2006) and also present at the CLIMDEX project website http://www.climdex.org. The remaining four indices mean maximum and minimum temperature is directly calculated whereas two indices, i.e., extreme temperature range (ETR) and an annual contribution of very wet days (R95PT)) are calculated by using the equation mentioned in Table 1. Indices are related to 9 warm and 7 cold temperatures, the categorization based on methods of calculations. Accordingly, these indices are categorized in 4 percentile, 4 thresholds, 5 absolute, 3 duration indices and 3 others. The precipitation indices comprised of 11 wet and 1 dry index that is categorized into 2 percentiles, 3 thresholds, 2 absolute, 2 durations, and 3 others.

Based on the relative threshold for the temperature indices, the 10^{th} percentile of the 53-year average of daily temperature at Quetta Meteorological Station is calculated for each of the 365 days of the year. These percentile-based indices include lower and higher extremes for cool and warm days along with nights respectively. The cold spell duration index (CSDI) and warm spell duration index (WSDI) are also calculated based on the percentile values of cool and warm days. The monthly extreme temperature indices, i.e., the lowest and highest daily minimum and maximum temperatures TXx, TXn, TNx and TNn, and diurnal temperature range (DTR) based on percentiles. The indices using the fixed thresholds includes frost days (FD0), summer days (SU25), ice days (ID0), tropical nights (TR20) and growing season length (GSL).

The relative threshold for precipitation-based indices on first (R99p) and upper fifth (R95p) percentile values is used to calculate the extreme or very wet day precipitation. Single-day total precipitation (RX1day) is used to determine the monthly maximum five-day precipitation (RX5day) for consecutive days at Quetta. The consecutive dry days (CDD) and consecutive wet days (CWD) are used to determine the characteristic of extreme precipitation. Whereas; the annual average precipitation is represented by annual total wet days precipitation (PRCPTOT) and trends in simple daily intensity index (SDII). Extreme precipitation events are also calculated for a threshold of 10mm (R10) and 20mm (R20). Additionally, extreme temperature range and an annual contribution of very wet days are also considered.

3.2 Data Homogenizing

R-ClimDex (1.0) climate model is used for calculating indices of climate extreme for Quetta Valley and 3 (sigma) standard deviation levels was used to identify the outlier data. The selected station’s data was formatted for further quality check and control with R-ClimDex and linear regression for trend calculations. The model is developed by Xuebin and Yang (2004) at the climate research branch of the meteorological service of Canada. The R-ClimDex computed threshold indices for 52 years from 1961–2019. The temperature thresholds include summer days, tropical nights, frost days and icy days. The precipitation indices use thresholds for heavy rainfall events, seasonal trends, extremes etc.

The homogeneity and quality control of all the outliers was checked like the repeated values, sudden jumps in the series and maximum temperature less than the minimum temperature. The obvious data was sorted out and replaced by -99.9. The major gaps were removed and rectified by the available documented data of the Pakistan Meteorological Department for Quetta Station. Gap filling was performed by using criteria of a fixed number of days with missing data. If the number of consecutive days with missing data was less than or equal to five, the gap-filling was done by using interpolation among these values and keeping in view not to miss a heatwave, a cold wave, or an extreme precipitation event. For missing data greater than five, the whole month was excluded from the analysis so that it may not render a false contribution in the trend analysis.

Several checks were considered while performing the quality control for the data. The outliers were identified and set to missing values for maximum and minimum temperature, using 3 × standard deviation criteria. For precipitation, corresponding daily values of monthly maxima were searched in the monthly climatic normal of Pakistan and set as upper limit thresholds for the identification of precipitation outliers. Quality checks were performed for values showing minimum temperature ≥ maximum temperature. To calculate R_{nn} index, the threshold of 23mm for the region was utilized. Two thresholds were taken to consider for Ice days index (ID0) i.e. 0°C and 11°C. Two new indices namely extreme temperature range (ETR) and an annual contribution of very wet days (R95PT) were identified.

3.3 Mann-Kendall and Sen's Estimator

The temporal trends and magnitude of trends for each of the indices are determined by using Mann Kendall and Sen’s Slope (non-parametric) methods at 95% confidence level (Mann 1945, Sen 1968). The linear trend of monthly, seasonal and annual precipitation and temperature are calculated using Mann Kendal Test, which has been broadly used to analyze the long term climatological and hydrological time series (Zhang *et al.*, 2010; Tabari *et al*., 2011; Tabari *et al*., 2012; Du *et al.*, 2013; Gocic and Trajkovic, 2014, Zhang *et al.*, 2015, Adnan *et al*., 2016,17,18). The following equation is used to calculate the variance of the equation:

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p (t_p - 1)(2t_p + 5) \right] \quad (1)$$

Where q number has the same value of sample data and t_p is the data values of the p^{th} group.

The statics S is:

$$S = \sum_{j=1}^{n-1} \sum_{k=j+1}^{n} \operatorname{sgn}(x_k - x_j) \quad (2)$$

Where j and k are the data values, n represents the data length and sgn (θ) is a significant function that varies from -1 to 1.

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if\ S < 0 \end{cases} \quad (3)$$

The value of Z is approximately normal distributed and the positive value of Z greater than 1.96 represents the significant increasing trend, whereas a negative value lower than -1.96 donates a significant decreasing trend.

The true slope (change per unit time) of linear time series trend is determined by *Sen* (1968).

$$f(t) = Mt + C \quad (4)$$

Where f(t) is the function of a linear trend, M and C are the slopes and constant of the equation respectively.

This method estimates the magnitude of trend as follows:

$$Q = \text{median} \frac{x_i - x_j}{t_i - t_j} \quad (5)$$

Where x_i and x_j are the data values at times t_i and $t_j (i > j)$, respectively.

The trend and magnitude of the trend were calculated for Quetta valley using Mann Kendal and Sen's Slope method at the 95% significance level during 1961-2019 Table-3. The values of man Kendal on one-tailed test are ±1.645 to identify the trend significance at the 95% level as described by Adnan *et al.*, 2017. The significant values are highlighted in bold representing the Mann Kendal, whereas the values are representing the magnitude of the trend (change per decade) using Sen's slope.

4. Results and discussion

4.1 Climate Extreme Indices Analysis

The statistical significance of climate-based indices analyzed by Mann Kendal and Sen's Slope method for Quetta valley are presented in Table 4. The results of the indices analysis represent those frost days decreased significantly by -6.38 days/decade when the minimum temperature fell below 0°C over the Quetta valley (Table 2). A significant increase in summer days by 5.0days/decade and tropical nights by 5.27days/decade was observed when the daily maximum temperature exceeds 25°C and 20°C respectively. The monthly maximum value of daily maximum temperature has increased significantly at 0.28°C/decade. The percentage of cool nights and days has significantly decreased by -3.75days/decade and -1.34days/decade at the tenth percentile. Whereas, warm nights and warm days have significantly increased by 1.70days/decade and 1.92days/decade at the 90th percentile respectively. These results show significant warming trends over Quetta valley. The cold spell duration has been decreased significantly by -1.12days/decade when the minimum temperature is less than the tenth percentile for consecutive six days. The diurnal temperature range has decreased significantly by -0.25 days/decade, represents the difference between the maximum and minimum temperatures have become lessen. The consecutive wet days have increased by 0.10 days/decade, which represents rainy days have increased significantly. The significant increase in mean maximum 0.61°C/decade and mean minimum temperature by 0.37°C/decade is a positive indication of temperature rise and warming trends over Quetta Valley. The extreme temperature range of 0.28°C/decade and annual total precipitation of wet days by 13.8mm/decade has increased, but it is insignificant. However, the annual contribution of very wet days has increased by 0.80%/decade significantly.

The results indicate a significant increase in minimum and maximum temperature-based indices. That shows a warming trend, whereas the precipitation base indices represent an increase, but it is statistically insignificant at the 95% confidence level. The increase in temperature-based indices may put pressure on to trigger evapotranspiration, soil moisture, groundwater and, most importantly, the excessive crop water demand for the Quetta valley (Durrani *et al*., 2018).

Table 4: Statistical significance of climate-based indices analyzed by Mann Kendal and Sen's Slope method for Quetta valley.

Category	Index name Temperature	Sen'Slope	Category	Index name Precipitation	Sen'Slope
Percentile	TN10p	**-3.75**	**Percentile**	R95p	3.74
	TX10p	**-1.34**		R99p	2.52
	TN90p	**1.70**	**Threshold**	R10	0.00
	TX90p	**1.92**		R20	0.29
Threshold	FD0	**-6.38**		Rnn	0.00
	SU25	**5.00**	**Absolute**	RX1day	1.75
	ID0	-0.09		RX5day	2.29
	TR20	**5.27**	**Duration**	CDD	4.29
Absolute	TXx	**0.28**		CWD	**0.10**
	TNx	0.13	**Other**	PRCPTOT	13.80
	TXn	0.01		SDII	0.02
	TNn	0.18	TMAXmean		**0.61**
	DTR	**-0.25**	TMINmean		**0.37**
Duration	GSL	3.43	R95PT		**0.80**
	WSDI	1.48			
	CSDI	**-1.12**			
ETR		**0.28**			

**Bold values represent statistical significance at 95% confidence level using Mann Kendal test.*

The monthly temperature (maximum, minimum) and precipitation data (1961-2019) of Quetta valley is used to identify the trends at the 95% significance level (Table 5). The highest significant change in mean monthly minimum temperature (0.10°C/year) was observed during May and October, whereas the mean monthly maximum temperature change was highest (0.05°C/year) during April at the 95% confidence level. However, no significant change in precipitation was observed over the valley. The study provides scientific evidence of climate extreme events that may help the climate change managers and policymakers to develop the contingency plan towards the sustainable surface and groundwater development for Quetta valley.

Table 5: Monthly mean minimum and maximum temperature and precipitation at Quetta Valley along with change per year from 1961-2019.

Months	Temperature (ºC)				Precipitation (mm)	
	Minimum		Maximum			
	Mean	Change per year	Mean	Change per year	Mean	Change per year
January	-2.73	**0.05**	11.06	**0.04**	51.52	-0.29
February	-0.46	0.03	13.37	0.01	51.11	0.49
March	4.04	**0.05**	19.13	0.04	48.21	-0.10
April	8.87	**0.05**	25.30	**0.05**	28.32	-0.10
May	12.73	**0.10**	30.92	**0.05**	6.34	0.00
June	17.05	**0.10**	35.34	0.01	2.29	**0.00**
July	20.51	**0.06**	36.28	**0.03**	11.99	-0.00
August	18.57	**0.06**	35.13	**0.02**	9.23	0.00
September	11.89	**0.09**	31.62	**0.03**	2.55	**0.00**
October	5.01	**0.10**	25.59	0.02	4.51	0.00
November	0.23	**0.10**	19.54	**0.04**	7.01	0.00
December	-2.41	**0.06**	14.19	**0.05**	30.48	-0.11
Annual	7.77	**0.07**	24.79	**0.03**	253.57	0.97

Note: Bold value represents the magnitude of the trend at 95% significance level

4.2 Trends in Temperature Indices

The frequency distribution analysis for temperature indices over Quetta valley during the two different periods, i.e., 1961-1990 and 1991-2019, were conducted. The analysis was based on daily maximum temperature, daily minimum temperature, and both because the temporal variations of the daytime temperature can be different from those of the nighttime temperature (Vincent *et al.* 2005). The maximum change between the two means was observed on warm spell duration (WSDI) and cold spell duration (CSDI) as it has increased by 174.56% and decreased by -83.20% over Quetta at the 95% significance level respectively. A Similar increase change has been observed for TX90P, TN90P, TR20, TMINmean, SU25, TMAXmean and TXx, whereas it has decreased for TN10P, TX10P, FD2 and FD0 at the 95% significance level. The temperature increase has significantly increased the warm days and night along with the extreme maximum temperature and summer days over the valley (Folland *et al.*, 2002). Moreover, cool days, frost days have also decreased significantly. These results indicate the warming trend that may enhance the crop water requirement and evapotranspiration rate over Quetta. The same results have been obtained for major cities of Punjab province as determined by Abbas, 2013. The majority of the temperature indices have increased (TXn, GSL, ETR and TNx) except (DTR, TNn, ID0) during 1991-2019 in comparison to 1961-1985, but they are not statistically significant at the 95% level.

The time series characterize for the indices of summer days (SU25), ice days (ID0), monthly maximum of daily maximum temperature (TXx), the monthly minimum value of daily maximum temp (TXn), cool days (TX10P), warm days (TX90P), warm spell duration indicator (WSDI), and the mean monthly maximum temperature (TMAXmean). The said time-series indices are shown in Figure 2, the black solid line represents the trend of an individual index at Quetta valley. Time series demonstrate an overall increasing trend between extreme climatic indices for SU25, TXx, TX90P, WSDI, and TMAXmean. Similarly, the time series graphs represent a declining trend for the individual index of IDO and TX10P, while a consistent trend is observed for the TXn. These trends show more heatwaves are expected in the future over Quetta. The frequency distribution analysis for temperature indices over Quetta Valley from 1961-1990 and 1991-2019 are as shown in Table 6.

Table 6: Frequency distribution analysis for 20 temperature indices for two periods: 1961-1990 and 1991-2019 for Quetta Valley.

Category	**Index**	**Mean**		**Change between two means**	**P Value**
		(1961-1990)	**(1991-2019)**		
Percentile	TN10p	18.99	6.49	-65.82	**0.00**
	TX10p	13.3	8.41	-36.77	**0.00**
	TN90p	6.45	11.81	83.00	**0.00**
	TX90p	5.78	11.68	102.27	**0.00**
Threshold	FD0	81.67	68.52	-16.10	**0.02**
	SU25	180.95	192.43	6.34	**0.01**
	ID0	0.73	0.61	-16.30	0.34
	TR20	31.9	46.26	45.00	**0.00**
Absolute	TXx	39.28	40.1	2.09	**0.00**
	TNx	24.29	24.72	1.76	0.14
	TXn	1.72	1.84	6.89	0.35
	TNn	-10.3	-9.85	-4.37	0.18
	DTR	16.87	16.43	-2.64	0.15
Duration	GSL	322.48	332.91	3.24	0.06
	WSDI	2.45	6.74	174.56	**0.02**
	CSDI	21.48	3.61	-83.20	**0.00**
Others	TMINmean	7.29	8.8	20.71	**0.00**
	TMAXmean	24.23	25.26	4.27	**0.00**
ETR		37.56	38.27	1.87	0.31

Bold p-values for shift in mean represent significance at 95% level.

A significant change between the two means of all percentile indices has been observed at the 95% confidence level. Similarly, all indices of threshold values except ice days have also been changed significantly. Moreover, the warmest days, wet spells and cold spells duration and mean of maximum and minimum temperature has significantly changed for a period of 1961-1990 and 1991-2019. The time-series data analyzed for extreme changes in temperatures in 1961-2019 at Quetta valley. The minimum temperature-based indices are presented in Figure 2. The trends of frost days, cool days and cool spell duration are sharply decreasing, whereas the mean minimum temperature, tropical nights, warm nights and an annual minimum of daily maximum, as well as annual minimum of the daily minimum, are increasing, which represents the warming trends over Quetta valley. Rare climate trends show an overall decrease (increase) in the number of cool nights and cool days (hot nights and hot days) may be due to real but local urban heat island effects (You *et al*., 2008).

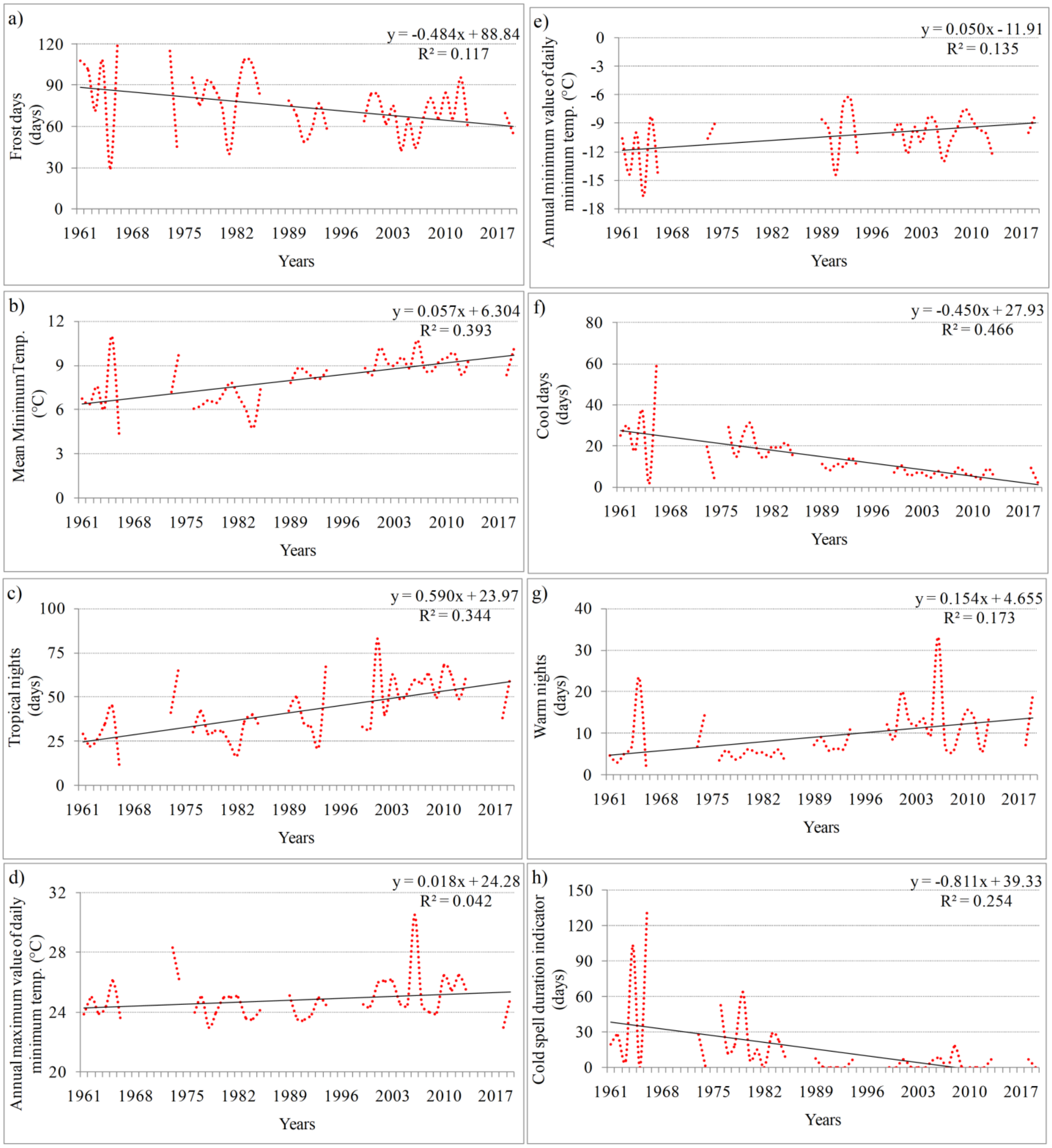

Figure 2 (a-h): Climate extremes indices based on the daily minimum temperature of Quetta Valley.

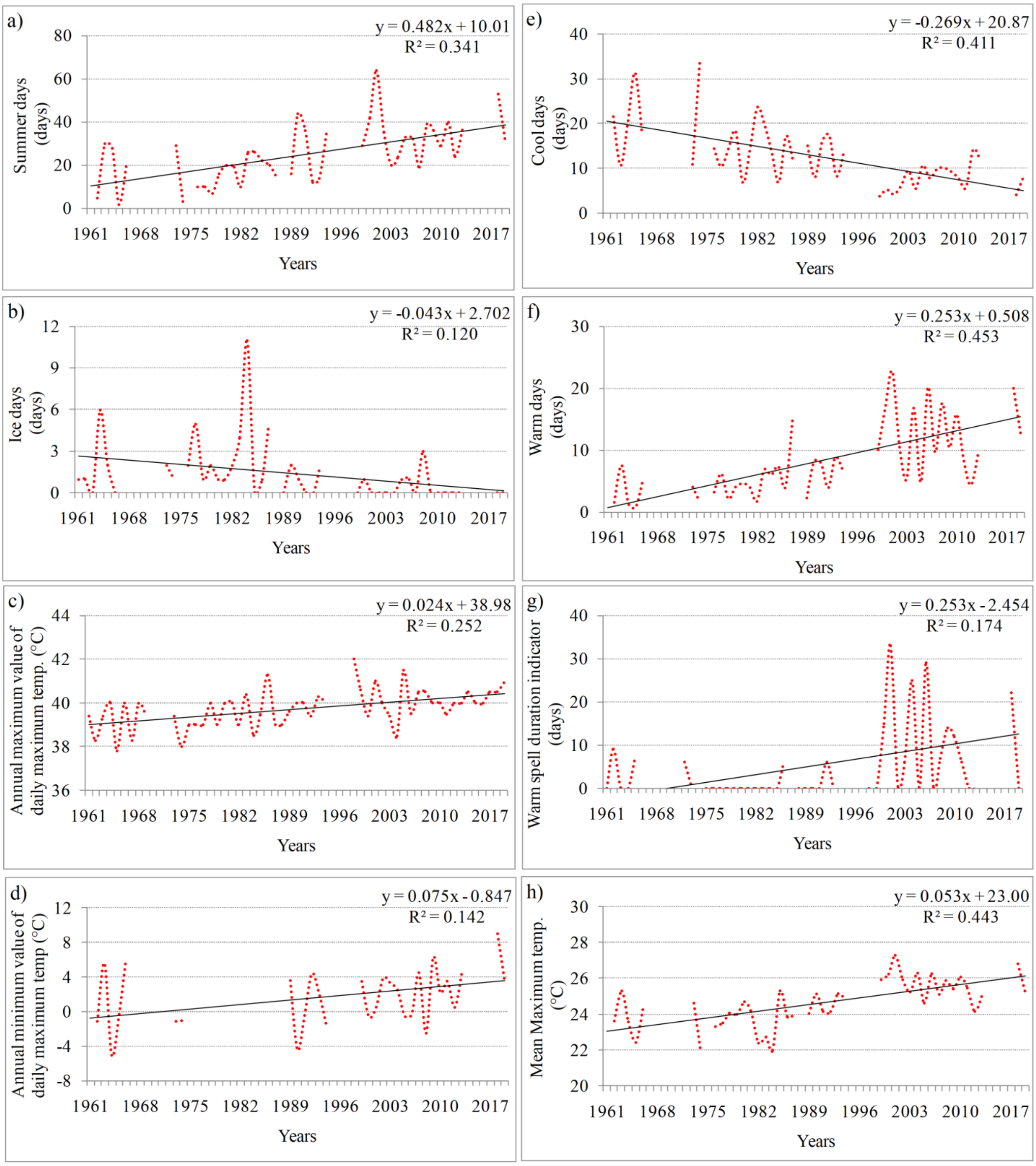

Figure 3 (a-h): Climate extremes indices based on the daily maximum temperature of Quetta Valley.

The temperature threshold for ice days and cool days is decreasing, whereas the summer days are increasing. Similarly, the ice days are decreasing, whereas the summer days, warm days, warm spell duration, mean maximum temperature, as well as an annual maximum of daily maximum and an annual minimum of daily maximum, are increasing. These results show a clear indication of warming over the days and nights as shown in Figure 3. The absolute temperature for warmest days to warmest nights and coldest day to coldest nights along with the diurnal temperature range is shown in Figure 2. These results indicate a positive increase for warmest days to warmest nights and coldest days to coldest nights. The annual value of the daily maximum and minimum temperature are increasing, showing an increase in the warmest days and nights along with coldest days and nights over the Quetta valley. The negative trend in the diurnal temperature range indicates that the temperature range between maximum and minimum temperature is decreasing. The results depict that the diurnal temperature range lies between 11.0 to 20.5°C with a maximum (20.5°C and 45°C) during 1966. Urbanization and land-use change play a significant role in surface warming at the local scale (Kalnay and Cai 2003; Safeeq *et al*., 2013), though these human-induced changes do not bias surface warming at a global scale. The significant impact of human-induced land-use changes has been reported on Tibetan Plateau through a modelling approach (Li and Xue, 2010). The impacts of increased irrigation have been determined on long-term temperature trends (Roy *et al*., 2007). An increase of maximum temperature to higher limits (i.e., 40°–50°C) can adversely affect wheat, cotton, or vegetable yield because a failure of only one critical enzyme system, in above temperature limits, can cause the death of an organism (Abrol and Ingram, 1996).

4.3 Trends in Precipitation Indices

The daily precipitation data (1961-2019) has been used to calculate the climate extreme indices of Quetta valley as shown in Figure 4. Time series for the indices of Max 1-day precipitation amount (RX1day), Max 5-day precipitation amount (RX5day), Simple daily intensity index (SDII), Number of heavy precipitation days (R10mm), Number of very heavy precipitation days (R20mm), Consecutive dry days (CDD), Number of days above (nn mm Rnn), Very wet days (R95p), Extremely wet days (R99p), Annual total wet-day precipitation (PRCPTOTAL), and Consecutive wet days (CWD). The increasing or decreasing trends are shown with a black solid line.

The precipitation over Quetta valley shows a slightly increasing trend for the entire precipitation-related variable. The precipitation percentile for very wet to extremely wet days has shown a positive increasing trend as shown in Figure 4. The precipitation threshold for an annual count of days for precipitation greater than equal to 10, 20 and 23mm was calculated as shown in Figure 4. All the three variables show a positive increasing trend with the highest in 1982. The

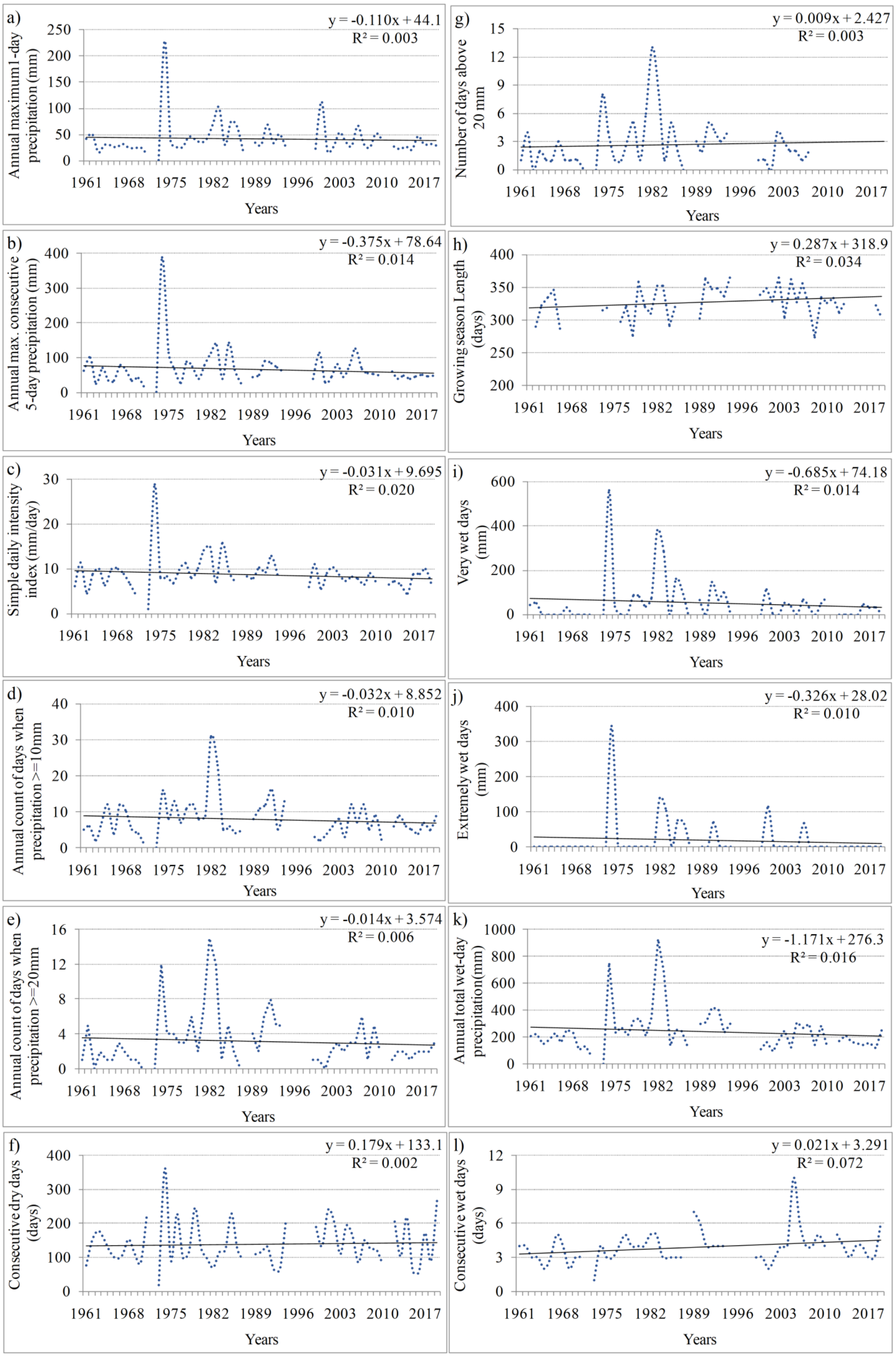

Figure 4 (a-l): Climate extremes indices based on daily rainfall of Quetta Valley.

absolute precipitation for 1-day and 5 consecutive days as well as the precipitation duration for consecutive dry and wet days are calculated as shown in Figure 4. These two indices show a positive increasing trend and the highest values of consecutive rainfall were experienced in 1974. These results show a positive increase in consecutive dry and wet days. The highest consecutive dry days are experienced in 1974, whereas the highest wet days were observed in 2005.

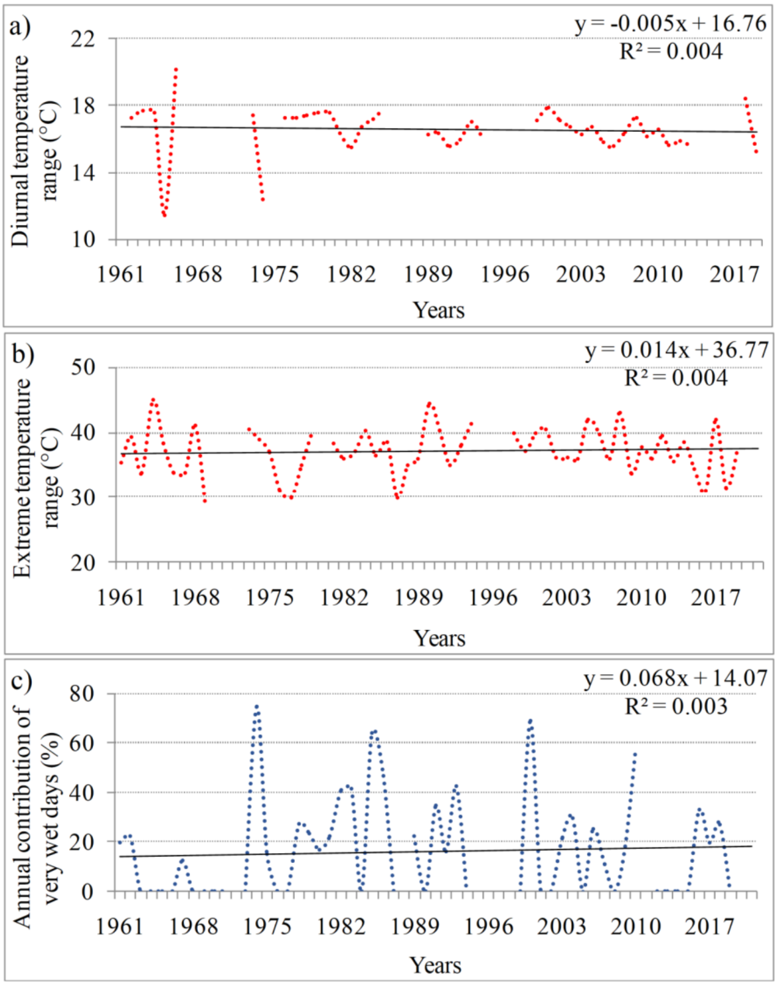

Figure 5: Climate extremes indices based on the daily temperature and rainfall of Quetta Valley.

The growing season length and warm spell duration are increasing sharply, whereas the cold spell shows decreasing trends. These results indicate that the temperature rise has significantly impacted the growing seasonal length as well as the warm and cold spell duration. The total precipitation to daily rainfall intensity and an annual contribution of very wet day precipitation was also calculated. These results show a positive increasing trend for all three indices. The highest annual rainfall was 928.9mm during 1982 while the maximum intensity of precipitation was observed during 1974 over Quetta. These results indicate the precipitation-based climate extremes, especially consecutive wet days, are slightly increasing as compared to the rest of the indices. The indices represent an ultimate slight increase in total precipitation over Quetta valley. The time series graphs show a sharp increase in R95PT has been observed. The annual contribution of very wet days was maximum (74.5%) during 1974. The same results have been identified over Pakistan by Ahmed *et al*., 2015.

The Diurnal temperature range (DTR), extreme temperature range and an annual contribution of very wet days are shown in Figure 5. The entire three variables show a positive increasing trend, which indicates warming over the Quetta valley. These results also determine the frequency of climate extreme indices, which may also change due to change in the minimum and maximum temperature. Urban growth, deforestation, and variations in local land use can all affect the DTR; in particular, urbanized areas often show a narrower DTR than nearby rural areas. Moreover, the extreme temperature range (ETR) of both temperatures (max, min) would also increase. The ETR lies between 30°C to 45°C with a maximum (20.5°C and 45°C) during 1964. The analysis shows that the extreme temperature range is increasing along with an annual contribution of very wet days.

The time series for the indices of frost days (FD0), mean monthly minimum temperature (TMINmean), tropical nights (TR20), the monthly maximum value of daily minimum temp (TNx), the monthly minimum value of daily minimum temp (TNn), cool nights (TN10P), warm nights (TN90P), and cold spell duration indicator (CSDI) were prepared to analyze. The time-series graphs of said indices are represented (Figure 2 and Figure 3). The prominent increased trends of the TMINmean, TR20, TNx, TNn, and TN90P were observed. These trends represent an increase in the minimum temperature, increase in tropical and warm nights. You *et al*., 2008 reported a more rapid change in temperature at some high mountains in the Tibetan Plateau than that at low elevations.Due to the increase of said indices, the associated observed parameters considerably decreased for frost days, cool nights and cold spell durations. An increase in the minimum temperature along with its associated indices favours the heatwave increase.

The icy and frost days are decreasing due to the increase in the minimum temperature, which reduces the cold night days and their spell duration. Although, Quetta valley lies in western barren mountains covered with snow during the winter, this overall annual decrease would significantly impact the livelihood of the people living in that area. The warm spell duration has increased, whereas the cold spell duration has decreased. Both figures indicate that the majority of changes in maximum and minimum temperature were experienced during the 1980s. The Sharp increase in the frequency of tropical nights has been observed. The maximum variation in all the indices has been observed after 1990.

The frequency distribution analysis for the precipitation indices over Quetta valley during the two different periods from 1961-1990 and 1991-2019 was conducted. The maximum increase of 32.50% in consecutive wet days (CWD) has been observed over Quetta Valley at the 95% significance level. It has been identified that most of the precipitation indices except R95PT and CDD have decreased in the second half from 1991-2019 as compared to 1961-1990. But, it is not statistically significant, Table 7. The results of these rainfall indices indicate that the reduction of total rainfall along with the cold spell rainfall associated with winter rainfall has decreased over the Quetta valley. Although, the consecutive wet days have increased significantly, it has not enhanced the total rainfall over the valley. The changes in annual rainfall from very wet days (R95PT) contribute significant social impacts (Alexander *et al.*, 2006).

Table 7: Frequency distribution analyses for 12 precipitation indices for two periods; 1961-1990 and 1991-2019 of Quetta valley.

Category	Index name	Mean		Change between two means	P Value
		(1961-1990)	(1991-2019)		
Percentile	R95p	76.42	52.04	-31.90	0.2
	R99p	26.36	21.44	-18.66	0.37
Threshold	R10	8.84	7.83	-11.39	0.26
	R20	3.72	3.39	-8.90	0.31
	Rnn	2.92	2.44	-16.29	0.22
Absolute	RX1day	45.39	41.2	-9.24	0.31
	RX5day	78.15	66.13	-15.38	0.21
Duration	CDD	139.12	141.5	1.71	0.49
	CWD	3.48	4.61	32.50	**0.01***
Other	PRCPTOT	274.48	253.96	-7.48	0.3
	SDII	9.61	8.82	-8.24	0.25
	R95PT	16.98	20.26	19.36	0.36

**Bold p-value for shift in mean represent significance at 95% level.*

Quetta is the capital city of the Balochistan province and considered one of the atmospherically polluted cities region-wide. Snowfall was a common feature in January till the late eighties, but thereafter, the snowfall has become rare in winters; especially owing to the significant changes in temperature-related indices of the Quetta city. Significant increase in temperature-related indices in Balochistan, with no change in rainfall, may curtail the net irrigation water supply of this already water-scarce region of the country. Temperature indices of desert air over Balochistan have shown a wide diurnal temperature difference. Strong radiative cooling may lead to rapid heat loss after sunset. This may rapidly cool the immediate atmosphere, resulting in a surface-based inversion that may have a strong increasing impact on inversion downburst dust storm frequencies over the region. The inversion downburst dust storms have the potential to decrease air visibility to as low as 1 km and sometimes even lesser.

The variability in meteorological parameters, i.e., increase in temperature and decrease in precipitation will enhance the water loss in the form of evapotranspiration that would ultimately impact the crop water demands in the region. Moreover, the precipitation deficiency will increase the drought frequency and severity that would impact the groundwater recharge and put pressure on the water resources of the region. Increased temperature in urban areas causes a change in the energy balance of Quetta city, often leading to higher temperatures than surrounding rural areas under the phenomenon of the urban heat island effect.

During the quality control, the missing data of both precipitation and temperature have remained a challenge. More importantly, there was only one meteorological station in the Quetta valley which has long term data (1961-2019). So, the number of stations could improve the result and give more confidence to the findings.

5. Conclusions

The climate extreme provides a better understanding of observed data changes in temperature and precipitation-based indices for Quetta valley at the 95% confidence level. The significant increasing trends in temperature based indices show warming over the Quetta valley for the period 1961-2019However, no significant change was observed in precipitation-based indices except for consecutive wet days and an annual contribution of a very wet day, which has significantly increased at the 95% confidence level. Most importantly, the significant increase in temperature and precipitation based extreme indices shows a clear indication that the frequency of climate extremes has increased over the Quetta valley and more intense rainfall along with a warming trend may be observed in future due to convective rainfall. In light of the above findings, it is concluded that the Quetta valley will face both climate extremes, i.e., droughts and floods (in the form of torrential rainfall) in future. The policymakers should develop a contingency plan keeping in view the current climate extremes (droughts, floods) results to avoid the future calamity over the Quetta valley.

Conflict of interest statement

The authors have shown no conflict of interest for this publication.

Author contribution statements

Imran Hameed Durrani: Conceptualization, Formal analysis, Investigation, review & editing Shahzada Adnan: Conceptualization, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. Syed Mobasher Aftab: Supervision, Conceptualization, review and editing.

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Appendix

Table A1 Types of water-points in Quetta Sub-basin

Type /Use	Irrigation	Domestic	Water Supply	Dried	Total
Kareze	3	0	0	4	7
Springs	10	2	1	23	36
Dug Wells	0	1048	0	81	1129
Tube-wells	1310	76	672	386	2444
Total	1323	1126	673	494	3616

Table A2 Water Balance for Quetta Water Supply,

Period (Year)	Water Demand (m^3/day)	Sustainable Water Available (m^3/day)	Supplementary water required from different sources (m^3/day)
2000	103050.26	59654.30	43395.96
2009	139605.98	59654.30	79951.68
2010	143989.49	59654.30	84335.18
2020	218634.02	59654.30	155194.31
2030	300145.30	59654.30	240490.99
2040	375308.43	59654.30	316676.19
2042	393959.16	59654.30	334304.85

Table A3 Explanation of core extreme temperature and precipitation indices.

Category	Index name	ID	Definition	Units
		Temperature		
Percentile	Cool nights	TN10p	Percentage of days when TN<10th percentile	Days
	Cool days	TX10p	Percentage of days when TX<10th percentile	Days
	Warm nights	TN90p	Percentage of days when TN>90th percentile	Days
	Warm days	TX90p	Percentage of days when TX>90th percentile	Days
Threshold	Frost days	FD0	Annual count when TN (daily minimum) <0ºC	Days
	Summer days	SU25	Annual count when TX (daily maximum) >25ºC	Days
	Ice days	ID0	Annual count when TX (daily maximum) <0ºC	Days
	Tropical nights	TR20	Annual count when TN (daily minimum) >20ºC	Days
Absolute	Warmest day	TXx	Annual maximum value of daily maximum temp	ºC
	Warmest night	TNx	Annual maximum value of daily minimum temp	ºC
	Coldest day	TXn	Annual minimum value of daily maximum temp	ºC
	Coldest night	TNn	Annual minimum value of daily minimum temp	ºC
	Diurnal temp range	DTR	Annual mean difference between TX and TN	ºC
Duration	Growing season length	GSL	Annual (1st Jan to 31st Dec in Northern Hemisphere, 1st July to 30th June in Southern Hemisphere) count between first span of at least 6 days with TG>5ºC and first span after July 1 (January 1st in SH) of 6 days with TG<5ºC	Days
	Warm spell duration indicator	WSDI	Annual count of days with at least 6 consecutive days when TX>90th percentile	Days

	Cold spell duration indicator	CSDI	Annual count of days with at least 6 consecutive days when TN<10th percentile	Days
Others	Mean Min. Temp.	TMINmean	Mean of daily minimum temperature	ºC
	Mean Max. Temp.	TMAXmean	Mean of daily maximum temperature	ºC
Extreme temperature range		ETR	$ETR = TX_X - TN_n$	ºC
		Precipitation		
Percentile	Very wet days	R95p	Annual total PRCP when RR>95th percentile	mm
	Extremely wet days	R99p	Annual total PRCP when RR>99th percentile	mm
Threshold	Heavy precipitation days	R10	Annual count of days when PRCP>=10mm	Days
	Very heavy precipitation days	R20	Annual count of days when PRCP>=20mm	Days
	Days above nn mm	Rnn	Annual count of days when PRCP>=23 mm	Days
Absolute	Max 1-day precipitation	RX1day	Annual maximum 1-day precipitation	mm
	Max 5-day precipitation	RX5day	Annual maximum consecutive 5-day precipitation	mm
Duration	Consecutive dry days	CDD	Maximum number of consecutive days with RR<1mm	Days
	Consecutive wet days	CWD	Max. No. of consecutive days with RR>=1mm	Days
Other	Annual total wet-day precipitation	PRCPTOT	Annual total PRCP in wet days (RR>=1mm)	mm
	Simple daily intensity index	SDII	Annual total precipitation divided by the number of wet days (defined as PRCP>=1.0mm) in a year	mm/day
Annual contribution of very wet days		R95PT	$R95PT = \left(\frac{R95P}{PRCPTOT}\right) \times 100$	%