Climate Change Indicators of Pakistan

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1 Introduction

The world has been warming at the rate of 0.128 ± 0.026 °C per year since last 59 years (IPCC, 2007a). In response to global warming, Pakistan is also facing Change in its climate, especially, in the temperature which seems to be risen considerably. Twelve of the warmest years on record occurred in the last decade. These alarming statistics carry a clear message that warming is due. Climate has intrinsic variability and has been changing in past decades, even, before we started measuring the climate parameters. But the uniqueness of this issue in modern world is that human activities are now playing significant role in causing the climate to change. This is evident from the recent rise in carbon dioxide (CO_2) concentration in the atmosphere and in response the rise of global temperatures on land and oceans surface.

The threat of climate change can be coped with by identifying its effects on different socio-economic stores of a country. Pakistan Meteorological Department carried out an analysis on past hundred year's data to detect the changes in different climatic parameters happened in last century and trends of recent climate events. The analysis presented in this report clearly illustrate that the climate in Pakistan is also changing. Over the last 100 years and especially the last 30 years, the climate change indictors show warming trends in the region. This is now well known fact that this warning is human induced. This warming is consistent with global warming and global warming is caused by increasing green house gases (GHG).

Pakistan, being a developing country, is not contributing much in increasing the atmospheric greenhouses gases (GHG). This contribution is almost 135th part of that other nations are producing. The country is on number 12 in the list of most vulnerable nations in the world (R. K. Pachauri, 2009). The good news is that we can do something about it by changing specific policies and behaviors.

The threat of climate change can be coped with by identifying its effects on different socio-economic sectors of the country. Substantial efforts have been made to establish reliable and accurate records of surface air temperatures of the region (Singh N. and Sontakke N.A, 1996). A study on climatic normal of Pakistan, 1931 – 1960 and 1961 – 1990, revealed that there was cooling over Northern Pakistan and southeastern Pakistan due to the increase in monsoon cloudiness and rainfall (Kruss, P. O et al., 1992). Analysis of reconstructed long term temperature time series from 1876 – 1993 yielded the presence of large variability in temperature of the country and warming since the beginning of last century with total change of 0.2°C (Singh N. and Sontakke N.A, 1996).

Pakistan Meteorological Department presented this report with the hope that more people will understand nature and scope of the problem and in response will be willing to make the changes necessary.

1.1. Pakistan

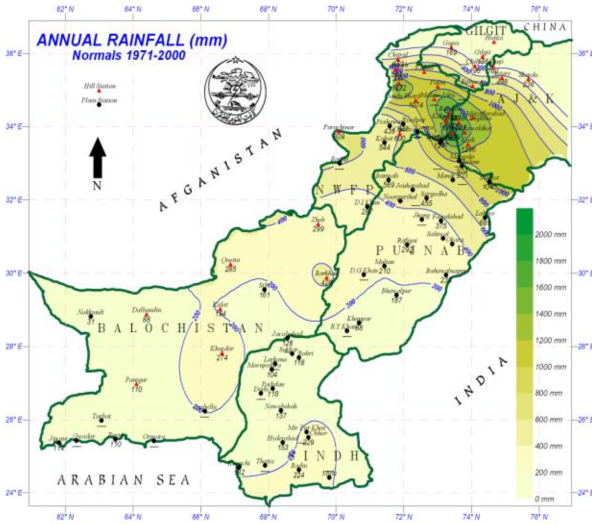
1.1.1. Geography

Pakistan contains Asia's most spectacular landscapes as it stretches from Arabian Sea, its southern border, to the world's magnificent mountain ranges in the north. There are also some ancient sites rivaling to those of Egypt and Mesopotamia. Pakistan is part of south Asia bordering the Arabian Sea, between India in the east, Iran and Afghanistan on the west and China in the north. Pakistan stretches from 61 - 78^{o}N and 23.6 - 38^{o}E, like a rectangular mass extending northeast to southeast over an area of 796,096 sq. kms. Pakistan has varied terrain with flat Indus plains, containing Deserts in the east; mountains in the north and northwest; Balochistan Plateau in the west. The surface elevation ranges from 0m, the Arabian Sea, to 8,611m, the world's second highest mountain K2 (Mount Godwin-Austin). The total arable land is estimated to be approximately 27.87% with permanent crop cover of 0.87% and others at 71.26%. Of country's total area 24% is cultivated, of which 80% is irrigated. Forests and grazing land cover is 4%, about 31% is not fit for agriculture use and about 2% is under cover.

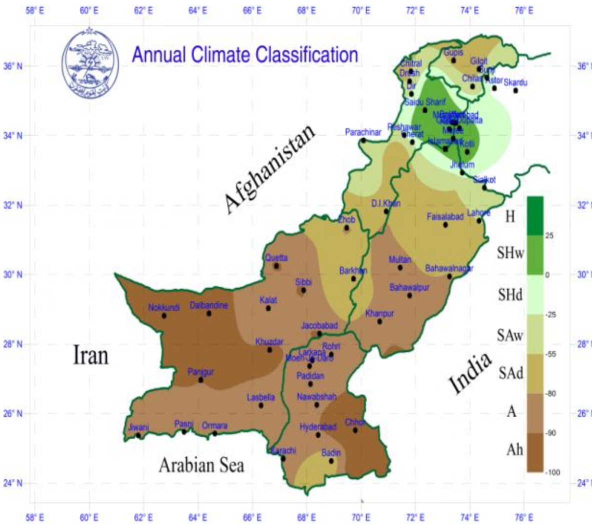
1.1.2. Meteorology

Pakistan receives monsoon rainfall in summer and in winter receives rainfall due to western systems. Most of the country is arid to semi-arid except southern slopes of Himalayas and Sub Mountain region where the annual rainfall ranges from 760mm to 2000mm. The Balochistan province is the driest part which receives 210mm on the average. Three-fourth part of the country receives rainfall less than 250mm and 20% of it receives 125mm. Normal annual rainfall is displayed in Fig. 1 (A).

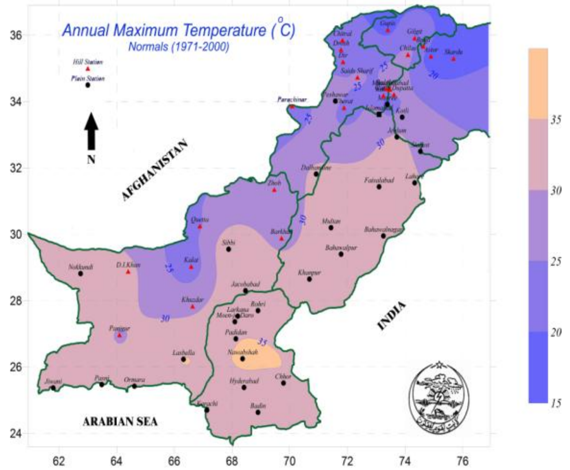
Pakistan has four well marked seasons: Cold, from November to February; Pre-monsoon (Hot), from March to mid of June; Monsoon, from mid of June to mid of September; Post-monsoon, from mid of September to October. Summer season is extremely hot and the relative humidity ranges from 25% to 50%. Day-time temperature in this season remains 40^{o}C and beyond in plain areas. The average temperatures in winter range from 4^{o}C to 20^{o}C. Mercury sometimes falls well below freezing point in Northern parts of the country. Normal Annual Maximum and Minimum Temperatures are shown in Figs.1 (C & D), respectively. Fig. 1(B) shows the annual climate classifications on the basis of evapotranspiration. The major part of Pakistan is arid to semi arid with large spatial variability in the temperature (Chaudhry, Q. Z. and G. Rasul, 2004).The data and plots in Fig. 1 have been provided by Pakistan Meteorological Department.



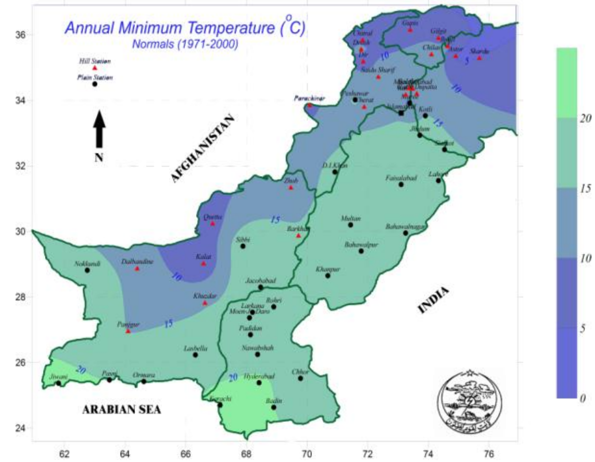
A: Annual Precipitation



B: Annual Climate Classes



C: Annual Maximum Temperature



D: Annual Minimum Temperature

Figure 1: Climatic Normals of Pakistan

1.1.3. Population

Population of Pakistan, according to year 2004 estimate is about 149 million. It was only 32.5 million at the time of independence i.e. 1947. Population growth in the country now is decelerating. Population growth now is decelerated from 3.06% to 1.9%. It is estimated that population of Pakistan will become 200 million by 2010 and 222.6 million in 2015, according to Population Census Organization of Pakistan.

2 Data and Methodology

Long term temperature and precipitation records of Pakistan are available for 20th century. The real time data generated by Pakistan Meteorological Department (PMD) along with the Climate Research Unit (CRU) data, named as CRU TS 2.0, are used. The CRU data-set comprises 1200 monthly grids of observed climate, for the period 1901-2000, and covering the global land surface at 0.5 degree resolution. A good coherence in temperature time series of PMD and CRU datasets exists. The linear correlation between the two datasets for the period 1960 - 2000 is ≈ 0.9, which shows a strong agreement between two datasets (M. Afzaal, et al. 2009).

Fourty-Three synoptic stations of PMD, in total, for which temperature data is available, are used in this study. These stations are mentioned in Table-1, alongwith start and end years of the record. For eighteen, out of forty-three, stations the daily records are available from 1960 to 2006. These stations are used to calculate climate change indices using RClimDex (1.0). There are eleven stations for which data is available from 1931 to 2007. Out of these eleven stations three lie in Punjab, four in Sindh and four in NWFP. The spatial distribution of the stations is displayed in Fig. 1. Area-weighted temperatures have been calculated for each station by the following equation (Grotch, S.L 1987)

$$T_{awy} = \frac{\sum T_{iy} \cos\Phi_i}{\sum \cos\Phi_i} \qquad \textbf{(1)}$$

Where T_{awy} is the area-weighted temperature for the year ‘y’, T_{iy} is the temperature of station/grid-point ‘i’ for the year ‘y’ and Φ_i is the latitude of station/ grid-point ‘i’. The area-weighted temperatures of all stations/grid-points have been averaged to have area-weighted temperature of Pakistan. Then annual anomaly has been calculated.

Indices are calculated for each station using RClimDex (1.0) for the year 1960 - 2006. The data quality is assured before calculating the indices. The magnitude of the trend is estimated using linear regression method, while the statistical significance is evaluated using F-Test for 95% confidence interval. There are a few significant trends for temperature and precipitation records over the time span mentioned above. Anomalies are from the baseline period 1961 – 1990, which is the baseline used by World Meteorological Organization (WMO).

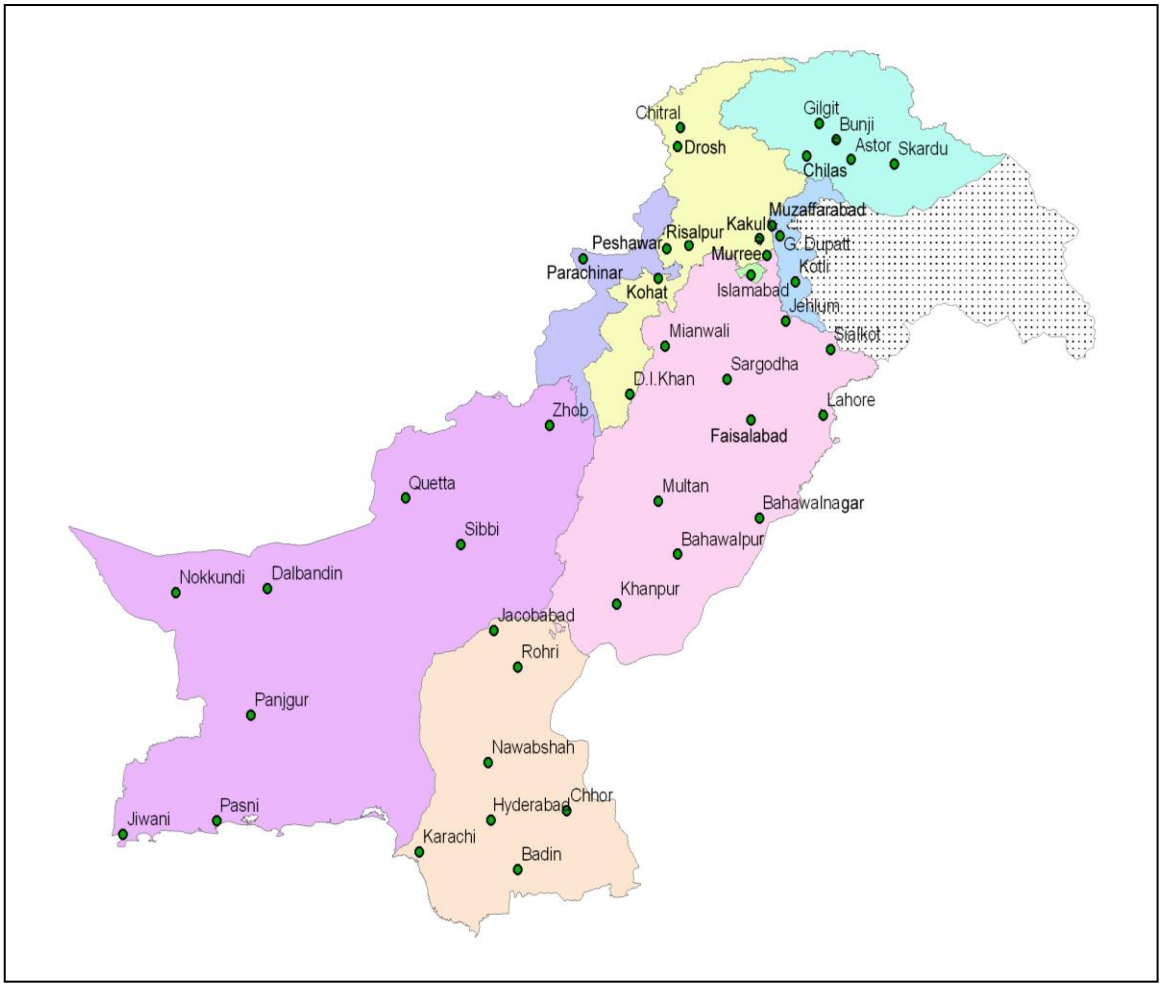


Figure 2: Spatial Distribution of Synoptic Stations of PMD used in the Report

Table 1: Start and End Date of the Data for Temperature and Precipitation

	Station	Start Date	End Date		Station	Start Date	End Date
	AZAD KASHMIR				**SINDH**		
1	Garhi Dupatta	1955	2007	21	Badin	1931	2007
2	Kotli	1952	2007	22	Chhore	1932	2007
3	Muzaffarabad	1955	2007	23	Hyderabad	1931	2007
	NORTHERN AREAS			24	Jacobabad	1931	2007
4	Astore	1954	2007	25	Karachi	1931	2007
5	Bunji	1953	2007	26	Nawabshah	1955	2007
6	Chilas	1953	2007	27	Rohri	1931	2007
7	Gilgit	1945	2007		**N.W.F.P**		
8	Skardu	1952	2007	28	Chitral	1964	2007
	PUNJAB			29	Dera Imail Khan	1931	2007
9	Bahawalnagar	1963	2007	30	Drosh	1931	2007
10	Bahawalpur	1931	2007	31	Kakul	1952	2007
11	Faisalabad	1931	2007	32	Kohat	1954	2007
12	Islamabad	1954	2007	33	Parachinar	1931	2007
13	Jhelum	1960	2007	34	Peshawar	1931	2007
14	Khanpur	1952	2007	35	Risalpur	1954	2007
15	Lahore	1931	2007		**BALOCHISTAN**		
16	Mianwali	1959	2007	36	Dalbadine	1931	2007
17	Multan	1950	2007	37	Jiwani	1938	2007
18	Murree	1936	2007	38	Nokkundi	1941	2007
19	Sargodha	1947	2007	39	panjgur	1931	2007
20	Sialkot	1931	2007	40	Pasni	1931	2007
				41	Quetta	1946	2007
				42	Sibbi	1931	2007
				43	Zhob	1961	2007

3 Air Temperature Indicators in Pakistan

3.1. Long-Term Mean Annual Temperature Anomaly

Fig. 2 shows the air temperature anomaly for Pakistan, based on the calculation of annual anomaly for each grid point. The data is plotted alongside the 10 years moving average of Global temperature anomaly calculated from the CRU data.

The global trend shows the warming of 0.6°C in the 20th century. This warming is not linear, with greatest warming being observed since mid 1970s. The global data shows warming from 1910 to 1945, slight cooling upto mid 1970s and again warming, more than previous episode continued upto the end of data series.

Pakistan temperature anomalies show greater interannual variability, but it follows the trend in-step with global temperature anomalies. Pakistan's warmest year occurred was 1941 in the 20th century, according to CRU data, while 1998 was the warmest year in the global record.

The record of Pakistan shows warming trend from 1901 to 1937. This warming is non-significant. From 1938 to 1948, there is a sharp increase, thereafter a cooling trend upto 1970. After that the temperatures remained normal with small cycles of warming upto 1998. From 1998 the temperatures again began to raise continuously upto the latest records available with Pakistan Meteorological Department (PMD).

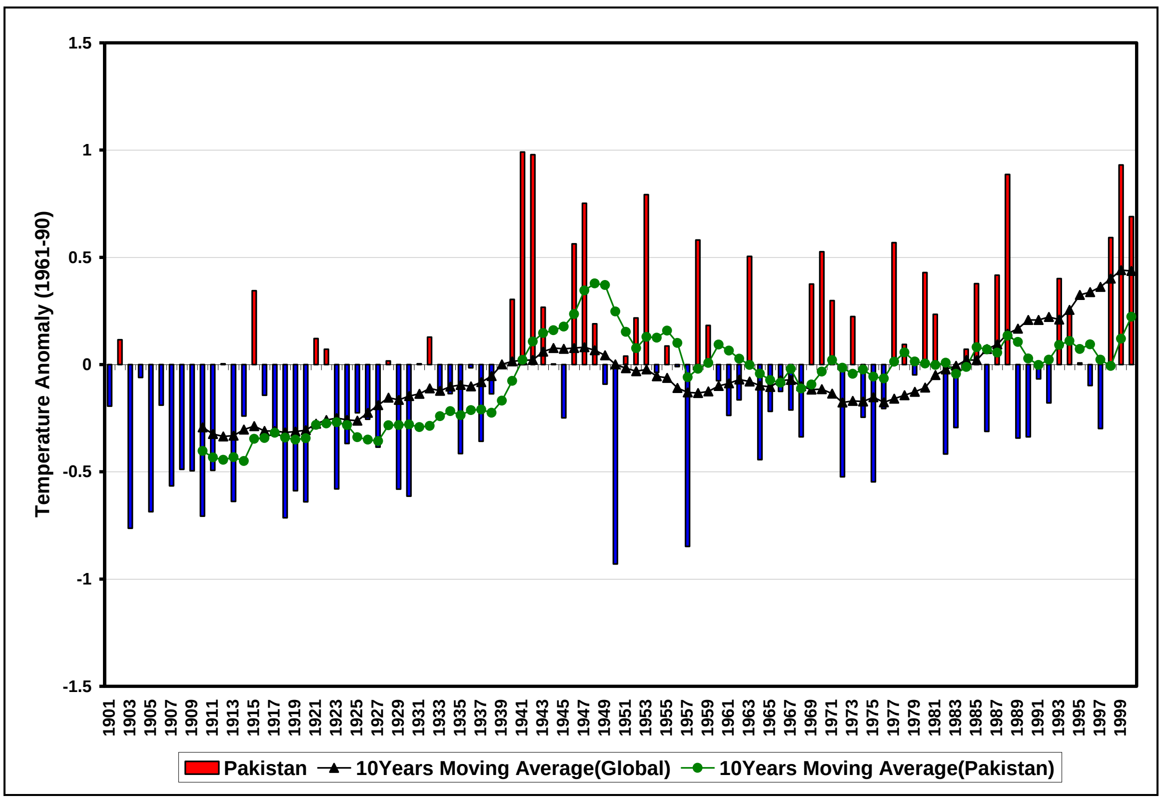


Figure 3: Global and Pakistan Air Temperatures Anomaly obtained from CRU data

Temperature increased in the last century at the rate 0.057°C per decade in Pakistan. The total change in air temperature is 0.57°C from 1901 to 2000. The warming signal is significant at 99% level. The rate of warming from 1938 to 1948 was 0.2°C per decade, while the recent rate of warming since 1998 is higher than 0.2°C per decade which is evident from the in-situ data records of PMD. There was a cooling trend from 1949 to 1970 which is non-significant; thereafter the warming shoots up.

3.1.1. Mean Temperature, Mean Maximum and Mean Minimum

Mean Annual Temperature

Fig. 3 depicts the area-weighted mean annual temperatures of Pakistan from 1960 – 2007, calculated from 38 synoptic stations of PMD across the country. The anomaly is plotted along with 10 years moving average of anomalies obtained from CRU data, which has been discussed in previous section. The time series from both observed datasets have correlation of ~0.8 for the period 1960 – 2000. It can also be seen that decadal averages of both the datasets follow the cycles of warming and cooling in the same years.

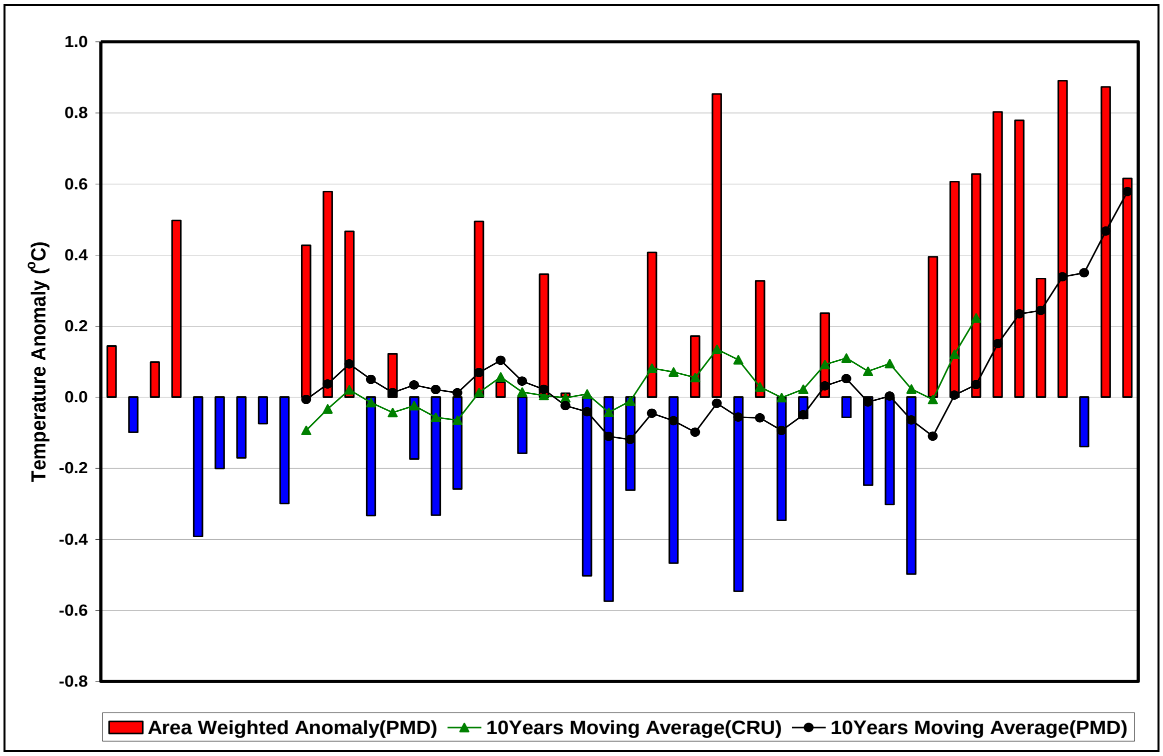


Figure 4: Area-Weighted Annual Mean Temperature Anomaly obtained from PMD Data

However, according to PMD observed data the mean annual temperatures over Pakistan are lesser than that of CRU observed data. PMD observed data shows significant rise in mean temperature from 1998. The mean temperatures have risen at the rate 0.099°C per decade form 1960 to 2007 resulting in total change of 0.47°C, which is significant at 95% level. Warmest year in Pakistan, recorded by PMD is 1988 and second warmest is 2002 in the period aforementioned. There is a drastic rise in temperatures in the last decade. Mean temperature anomaly rose to 0.8°C and then it started dropping down in last five years. The average anomaly from (1961 – 1990) normal in last decade remained 0.4°C.

There is a warming trend in mean temperatures of Balochistan, Punjab and Sindh provinces in the period 1960 – 2007, significant at 95% level. The total change in the period is 1.15°C, 0.56°C and 0.09°C, respectively. A non-significant change, though trend is rising, has been observed in Azad Kashmir, FANA and NWFP. The total change was observed to be 0.3°C, 0.16°C and 0.15°C, respectively.

Table 2: Change in Annual Mean Temperature

Change in Area-Weighted Annual Mean Temperature (°C)		
		1960 - 2007
1	Balochistan	1.15 ± 0.25
2	NWFP	*0.15 ± 0.24
3	Punjab	0.56 ± 0.25
4	Sindh	0.44 ± 0.20
5	Azad Kashmir	*0.30 ± 0.27
6	FANA	*0.16 ± 0.27
7	PAKISTAN	0.47 ± 0.21
	** Non-Significant*	

Mean Maximum Temperature

Fig. 4 displays the area-weighted annual mean maximum temperature anomaly of Pakistan calculated from the observed data of 40 stations across the country. The data period is from 1960 to 2007. Ten years moving average is plotted alongwith the anomaly.

The rise in maximum temperature can clearly be seen. The air has been warming at the rate of 0.18°C per decade and the total change is 0.85°C over the period mentioned above. This change is significant at 99% level. There is no significant change from start of the series upto 1997, but after that the warming increased very rapidly at the rate 0.36°C per decade and so was the rise in maximum temperature in the last decade.

All the provinces of Pakistan display rise in mean maximum temperature for the period, aforementioned, which is significant at 99% level except Sindh and Punjab. The linear trend ranges from 0 – 0.23°C per decade. The largest change occurred in NWFP and smallest in Punjab. It has been observed that increase in annual maximum temperature is higher in Balochistan, NWFP, Federally Administered Northern Areas (FANA) and Azad Kashmir. This increase is 1.10°C, 0.96°C, 0.91°C and 0.82°C, respectively, for the period mentioned in Fig. 3. There is statistically non-significant rise of 0.35°C in maximum temperature in Sindh and slightly decreasing (almost zero) change in annual maximum temperature in Punjab during 1960 – 2007.

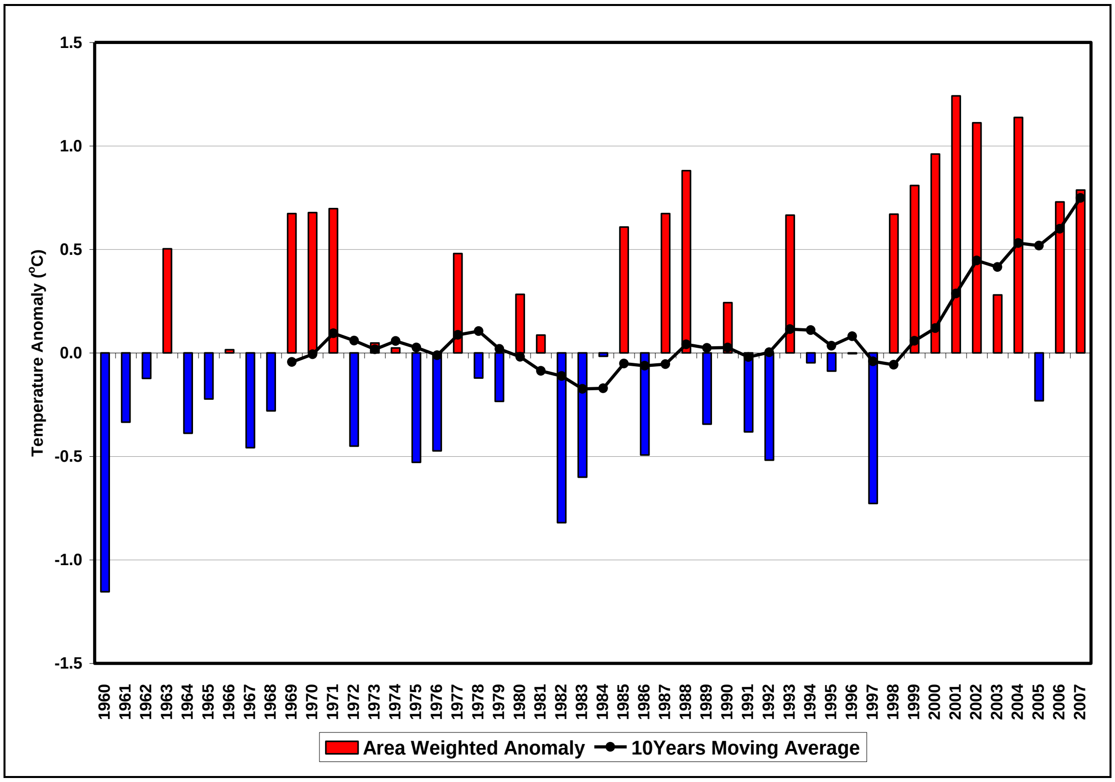


Figure 5: Area-Weighted Annual Maximum Temperatures Anomaly over Pakistan

Area-weighted annual maximum temperature have been calculated for four stations, Bahawalpur, Faisalabad, Lahore and Sialkot, of the Punjab for which data is available since 1931 to analyze the long term change in maximum temperature of the province. The analysis revealed that there is decreasing trend on all four stations. The stations may be placed, in such an order that station with highest decrease at first and with lowest decrease at last, as Sialkot, Lahore, Faisalabad and Bahawalpur. A decreasing trend has been observed in the province for the period 1931 – 2007, which is significant at 99% level. Total decrease in this period is 0.9°C.

Maximum Temperature records since 1931 are also available for six stations of Sindh. On the basis data of these six stations, the maximum temperatures trend for Sindh is decreasing for the period 1931 – 2007. This trend is non-significant, as is for the period 1960 – 2007. Total decrease in this period is 0.16°C. It is observed that three stations have decreasing trends of maximum temperature. The largest decreasing trend is of Badin, then Jacobabad and then Hyderabad. Coastal station Karachi has increasing maximum temperature trends. Rohri and Chhore have slightly increasing non-significant trends for the period 1931 – 2007.

Trends of annual maximum temperatures of NWFP are increasing with significance at 99% level for the period 1931 – 2007. Total increase is 0.6°C in this period. This analysis is based on the data of four stations, Drosh, Peshawar, Parachinar and Dera Ismail Khan. The largest increase has been observed at Drosh, then Peshawar.

D. I. Khan has decreasing trend; while Parachinar also has decreasing trend but non-significant, for the period mentioned before.

Long-term mean maximum temperature series of Balsochistan revealed that there has been significant warming in the province at the rate 0.2°C per decade. Total increase in the period is 1.2°C. Data records of four stations; Dalbandine, Panjgur, Pasni and Sibbi are available with PMD. Increasing trends of maximum temperatures has been observed on all four stations. The stations may be placed, in such an order that station with highest increase at first and with lowest increase at last, as Dalbandine, Pasni (Coastal Station), Sibbi and Panjgur.

Table 3: Change in Annual Maximum Temperature

Change in Area-Weighted Annual Maximum Temperature (°C)			
		1931 - 2007	1960 - 2007
1	Balochistan	1.22 ± 0.28	1.10 ± 0.29
2	NWFP	0.61 ± 0.30	0.96 ± 0.31
3	Punjab	-0.95 ± 0.28	*-0.02 ± 0.27
4	Sindh	*-0.16 ± 0.23	*0.35 ± 0.25
5	Azad Kashmir	N.A	0.82 ± 0.30
6	FANA	N.A	0.91 ± 0.33
7	PAKISTAN	*0.12 ± 0.24	0.87 ± 0.26
	* Non-Significant		

From the above discussion it is clear that some significant changes in area-weighted maximum temperatures have been observed. The analysis of both, long and short term datasets revealed a decreasing trend of maximum temperature in Punjab, increasing trends in NWFP and Balochistan. A non-significant increasing trend in Sindh from 1960 – 2007 and non-significant decreasing trend from 1931 – 2007. FANA and Azad Kashmir have significantly increasing trends of maximum temperatures.

Frequency of extreme maximum temperature events have also been calculated, For this purpose the eighteen stations have been used for which daily time series of Maximum Temperature was available since 1960. For these stations, TX90P i. e. Percentage of days in a year when Maximum Temperature was more than 90th percentile, have been calculated. It revealed that the frequency of warm days has been increased significantly in North Pakistan. Three stations of Balochistan have shown the increase of 4 – 16 days per decade. Hyderabad, Sindh in showing the decrease of 4 days in the frequency of warm days, while most of the stations of Punjab are showing non-significant change in the warm days.

Mean Minimum Temperature

The general pattern of area-weighted mean minimum temperature is similar to the maximum temperature with rapid increase since 1998. Rate of rise in annual minimum temperatures during 1960 – 2007 is 0.10°C per decade resulting in total rise of 0.5°C over the country. This rise is significant at 95% level. Fig. 6 shows that there are small episodes of warming and cooling since the start of the series uptill 1998. After that there is sharp increase in annual minimum temperatures and decadal average of annual minimum temperature rose to 0.75°C. It is observed from Fig. 4 that the annual maximum temperatures increased in first five years and then started to drop in last five years of the last decade, while the annual minimum temperatures are rising throughout the last decade.

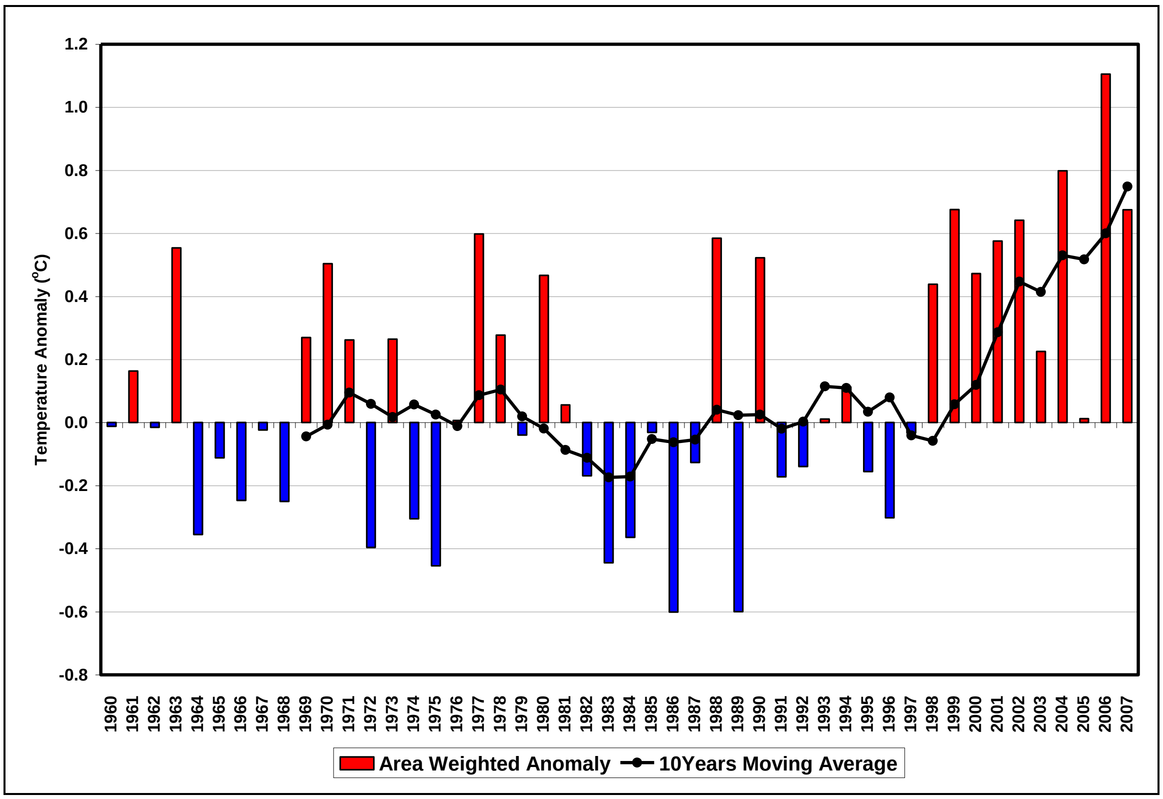


Figure 6: Area-Weighted Annual Minimum Temperature Anomaly over Pakistan

Area-weighted annual minimum temperatures trends have also been calculated for the period 1960 – 2007 for all regions of Pakistan. The analysis revealed that there is increasing trend in Punjab, Balochistan, significant at 99% level and in Sindh, significant at 95% level. Total rise in the annual minimum temperatures of the three provinces is 1.16°C, 0.99°C and 0.54°C, respectively. There is a non-significant decreasing trend in FANA, NWFP and Azad Kashmir with total change of 0.45°C, 0.35°C and 0.24°C in the period mentioned above. Decrease in FANA is near to be significant and it becomes significant at 99% level if the data of Chilas, which has significant rising trend of annual minimum temperatures in the period, are excluded. It is clear from the above discussion that there is decrease, though non-significant, in annual minimum temperatures of

Pakistan in North and North-West while there is a significant increase in South and South-West Pakistan. There is a significant rise in annual minimum temperatures across Pakistan.

Table 4: Change in Annual Minimum Temperatures

	Change in Area-Weighted Annual Minimum Temperature (°C)	
		1960 - 2007
1	Balochistan	0.99 ± 0.22
2	NWFP	*-0.35 ± 0.24
3	Punjab	1.16 ± 0.22
4	Sindh	0.54 ± 0.24
5	Azad Kashmir	*-0.35 ± 0.24
6	FANA	*-0.45 ± 0.23
7	PAKISTAN	0.48 ± 0.20
	** Non-Significant*	

The minimum temperature index TN10P i.e. percentage of days when minimum temperature is less than 10th percentile. This index has been calculated from the daily data of eighteen synoptic stations since 1960. It revealed that in north Pakistan the number of days with minimum temperature less than 10th percentile are increasing and in Central and South Pakistan the situation is opposite with some stations showing non-significant change. This is also in accordance with the above discussion of annual minimum temperatures trend in Pakistan. There is 4 – 16 days rise in the index which means more cool nights in the north while there is decrease of the same magnitude which means less cool nights in the central and south Pakistan.

3.2. Diurnal Temperature Range

Diurnal Temperature Range, DTR, is defined as the difference of daytime maximum temperature and night time minimum temperature. The change in DTR is regional rather than to be global. Many studies have revealed that there is a decrease in DTR since the mid 20th century (Easterling et al. 1997). The effect of reduced DTR is more pronounced in northern hemisphere than southern hemisphere. This may be attributed to the increase in cloud cover (Brunetti et al. 2000).

In Pakistan, there is mix trend of increasing and decreasing DTR in different regions. Gilgit, a synoptic station in FANA, there is a significant increase in DTR. This is obvious from the trend of maximum and minimum temperatures in that region i.e significant increasing and non-significant decreasing, respectively.

The data of three stations of NWFP; Chitral, Parachinar, Saidu Sharif, are showing significant increasing trend in the DTR. There is a significant decrease in Peshawar and non-significant change in D.I.Khan. The data of five stations; Islamabad, Jhelum, Lahore, Faisalabad, Multan of Punjab province show significantly decreasing trend of DTR, since 1960. Another station; Murree, is the only stations where the DTR trend is significantly rising. Murree, because of being a Hill station, is having this difference and showing the trend which is similar to the northern areas of Pakistan. All the plain stations of Punjab displaying decrease in DTR. This decreasing trend is due to the rapidly rising trend of minimum temperatures in the province, since we have seen in previous sections of maximum and minimum temperature. This may further be linked to the increase in cloud cover, especially during the night time. The data of three stations; Jacobabad, Hyderabad and Karachi of Sindh also display the decreasing trend of DTR but the significant decrease is observed only in Hyderabad. This is also due to the rapid rise in minimum temperature in the province. In Balochistan province there are significant rising trends of DTR in Zhob and Jiwani and non-significant decreasing trend in Dalbandine and Quetta.

It is observed that trends of DTR are consistent among stations lying in plain regions of Pakistan i.e. decreasing, while the trends of high elevations stations (elevation > 800m) are also fairly consistent having increasing trends of DTR.

3.3. Seasonal Mean Temperature

Fig. 7 shows the seasonal and annual mean temperature changes in different regions of the country for the period 1960 – 2007. As can be seen, that greatest increase on seasonal basis in all the regions is in winter.

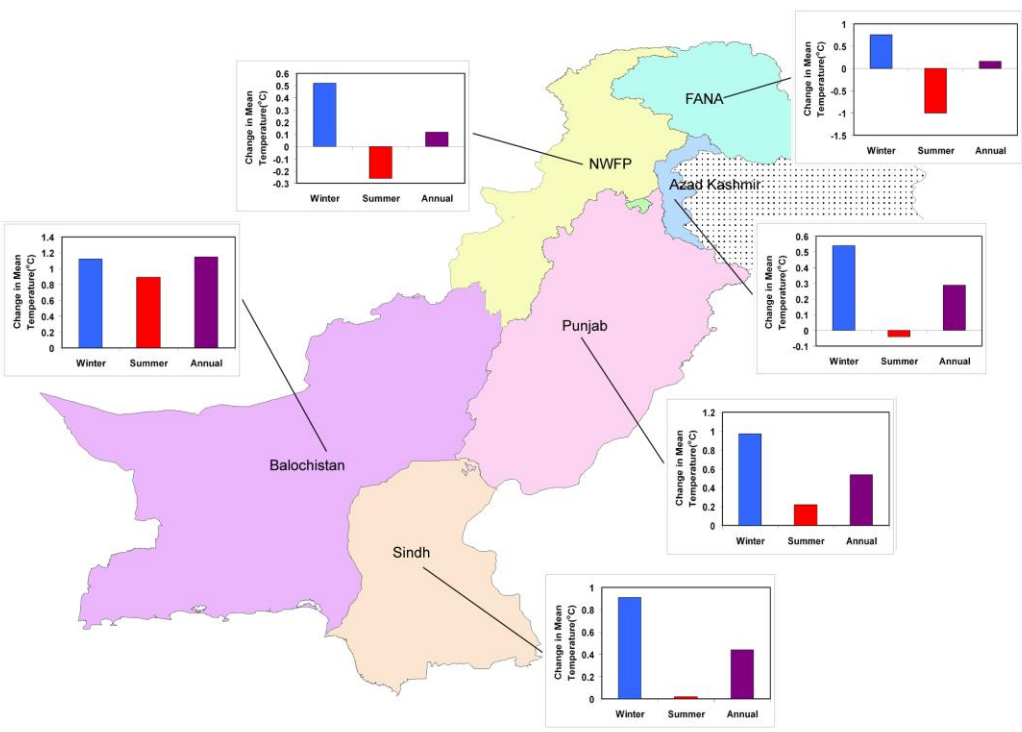


Figure 7: Change in Seasonal and Annual Mean Temperatures

Winter season is taken from December to February (DJF). Pakistan has long duration of summer season so the summer season is taken from May to September (MJJAS). In central and southern parts of the country the increase in mean temperature can be seen and in northern parts of the country there is decrease in summer mean temperatures. This decrease is even more pronounced in extreme north of the country.

3.4. Heat Wave and Cold Wave Duration

3.4.1. Heat Wave Duration

Heat wave conditions are the major cause of weather related causalities in Pakistan. In response to global warming heat waves in the country are expected to rise in future. *Heat wave is defined as the number of days when, for some consecutive days, the temperature is greater than a certain threshold, keeping in view the climatology of the station. In this report the number of days has been counted as heat wave days when, for at least 6 consecutive days, the Tmax ≥ 90th percentile of the temperature records in a year*. For this purpose the daily maximum temperature data of 35 stations have been used for the period from 1980 – 2007. Number of heat wave days has been calculated for each station. Location of these stations is can be seen in Fig. 9. In this report, number of heat wave days has been calculated instead of heat wave events because looking at the number of heat wave events, only, may be misleading in assessing the change in heat waves of a region. Since all the days (more than 6 consecutive days) with temperature higher than threshold value would be considered as one heat wave event according to the definition aforementioned.

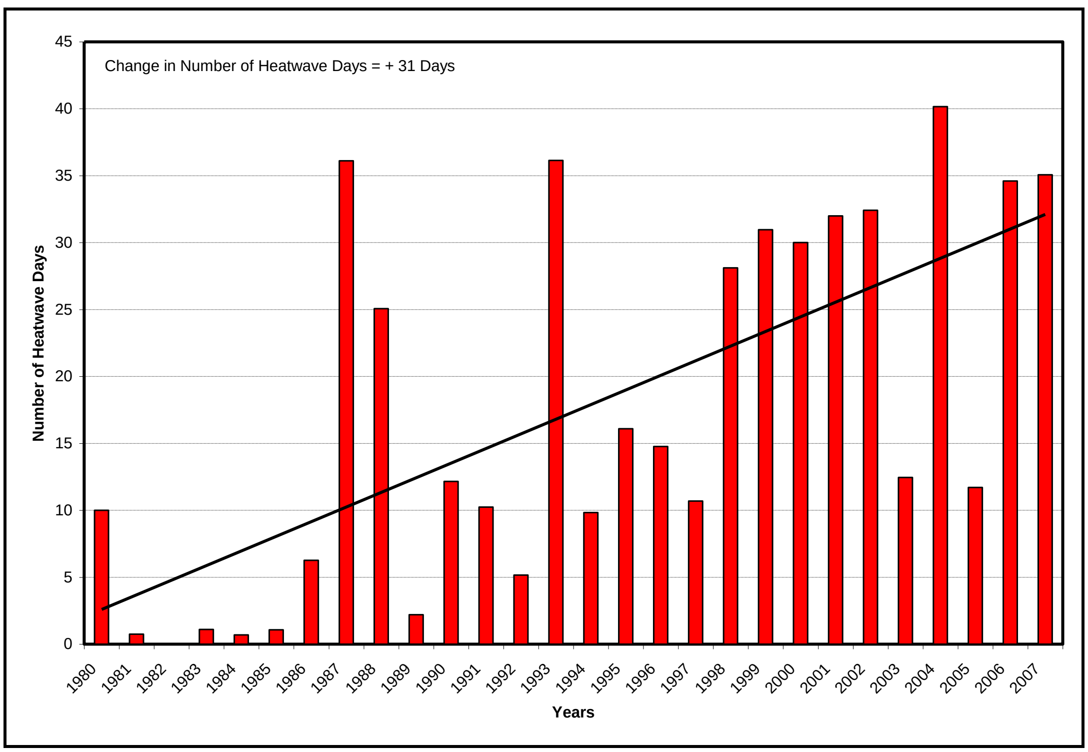


Figure 8: Change in Heat Wave Days when Tmax ≥ 90th Percentile of the Data

For example, if temperature of a station remained higher than the threshold value for a complete month in a year then the heat wave event = 1 in year 1. In another year in the same month the temperature remained higher than threshold value for first 7days then for 7 days in the mid and then for last 7 days. The heat wave events in this case = 3 in year 2. This example shows that heat wave events in year 2 are more than that in year 1, so year 2 was warmer than year 1 which is a wrong result because the number of heat wave days were more in year 1 than in year 2. Therefore, number of heat wave days is the true representative of the heat wave trends of a station. Fig. 8 displays the change in number of heat wave days in all over Pakistan. It can be seen that there is a significant rise in number of heat wave days at the rate of 11 days per decade. The total rise in the number of heat wave days is 31, over the period. This means at presents we are having a warm month more than in past in a year.

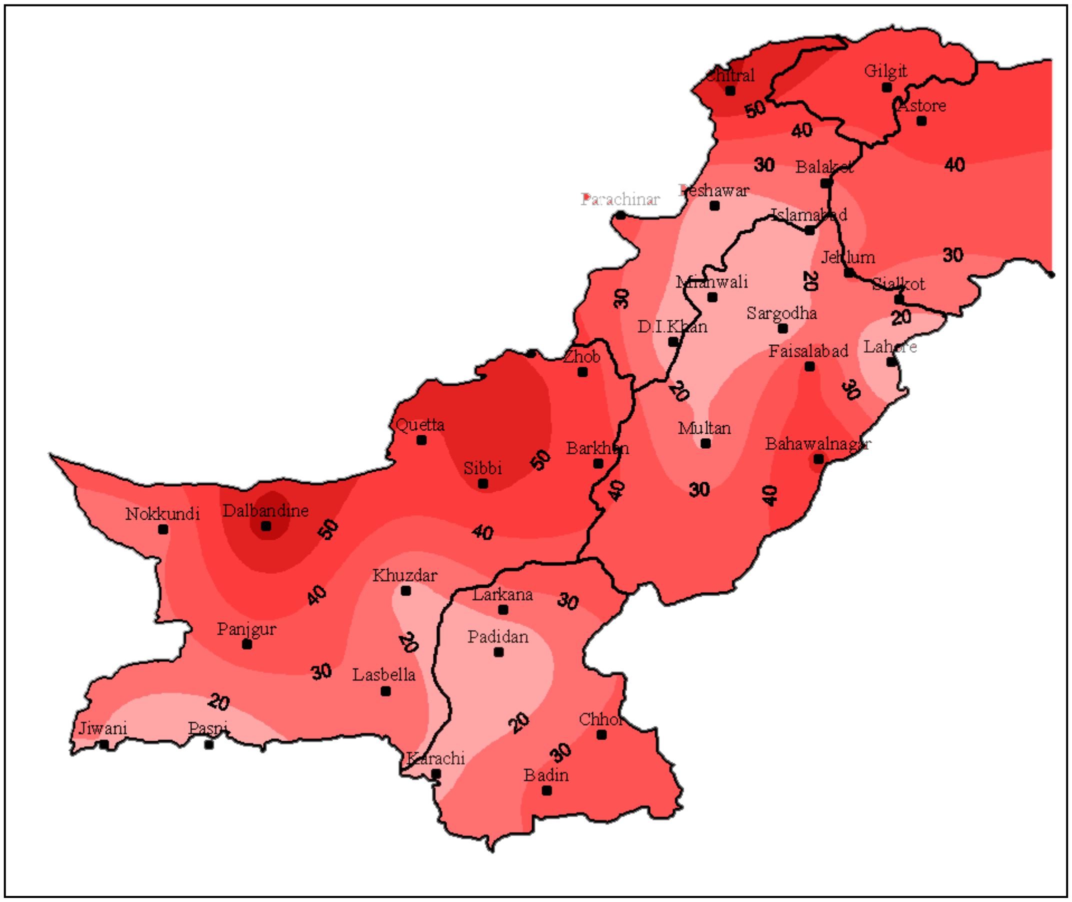


Figure 9: Total Change in Heat Wave measured in Days

Fig. 9 depicts the spatial variation of change in heat waves in Pakistan. It is clear from the figure that the number of heat wave days has increased in all regions of the country. Maximum rise has been observed in FANA, Northern NWFP, North and North-Eastern Balochistan, South-Eastern Punjab and Eastern Sindh. Rise in these regions is 30 – 60 days.

3.4.2. Isothermic Dynamics

Daily maximum temperatures from 1981-2008 for generally dry summer period from April to June over northern areas of Pakistan, were analyzed on pentad basis. Movement of isotherms with time along the elevation revealed the fact that heat is rushing towards the peaks of this elevated complex and highly irregular terrain. To know how fast it is moving upward, the dynamics of 30°C was considered the reference indicator. Figure 10 shows that in 1980s the changes in isothermic pattern were very slow and hardly a 35m upward shift of reference isotherm was seen from 1981 to 1990. Warming trend increased in 1990s. By the end of this decade, the 30°C isoline existed at about 300m higher than its position in 1981-85. The ever hottest year recorded over the globe was1998 which co-occurred with the strongest El~Nino event 1997-98 of the recorded history. The ENSO event associated with severe hygrothermal stress conditions contributed a lot to carry the heat to new heights. Overall the decade of 1990s was believed to be the warmest one (Rasul G, et al. 2008)

The first eight years of 21 century are seen surpassing all trends in the past among them 2005 seemed to be the hottest for Pakistan when a historic snowmelt flood in June created a havoc downstream Indus. Last pentad has completed 3 years so far (i.e. 2006, 2007, 2008 April-June period) and is showing moderate advance of warmth in the upward direction. The dynamics of 30°C isotherm along southern slopes of HKH ranges is shown in Fig 10. Temporal isotherm's spread show that flux of upward creeping heat is more over the eastern part (Himalaya and Karakorum) of the southern slopes than western part comprising Hindukush range. Isothermic advance is not uniform rather skewed due to the complexities of terrain and environmental degradation. On the average, the 30°C isotherm has now moved at 580m above its location in early 1980s (Rasul G, et al. 2008).

3.4.3. Heat Waves in Northern Areas of Pakistan:

Heat waves are a continuous stretch of persisting maximum temperatures above certain threshold for a specified time period. Rising temperatures are embedded with thermal extremes which were rare occurrence in the past but now becoming more common year by year. They are grouped into three categories by (Rasul G, et al. 2008) as below:

Severe Heat Wave=Five consecutive Days with Daily Maximum Temperature ≥ 40°C
Moderate Heat Wave= Five consecutive Days with Daily Maximum Temperature ≥ 35°C and <40°C
Mild Heat Wave= Five consecutive Days with Daily Maximum Temperature ≥ 30°C and <35°C

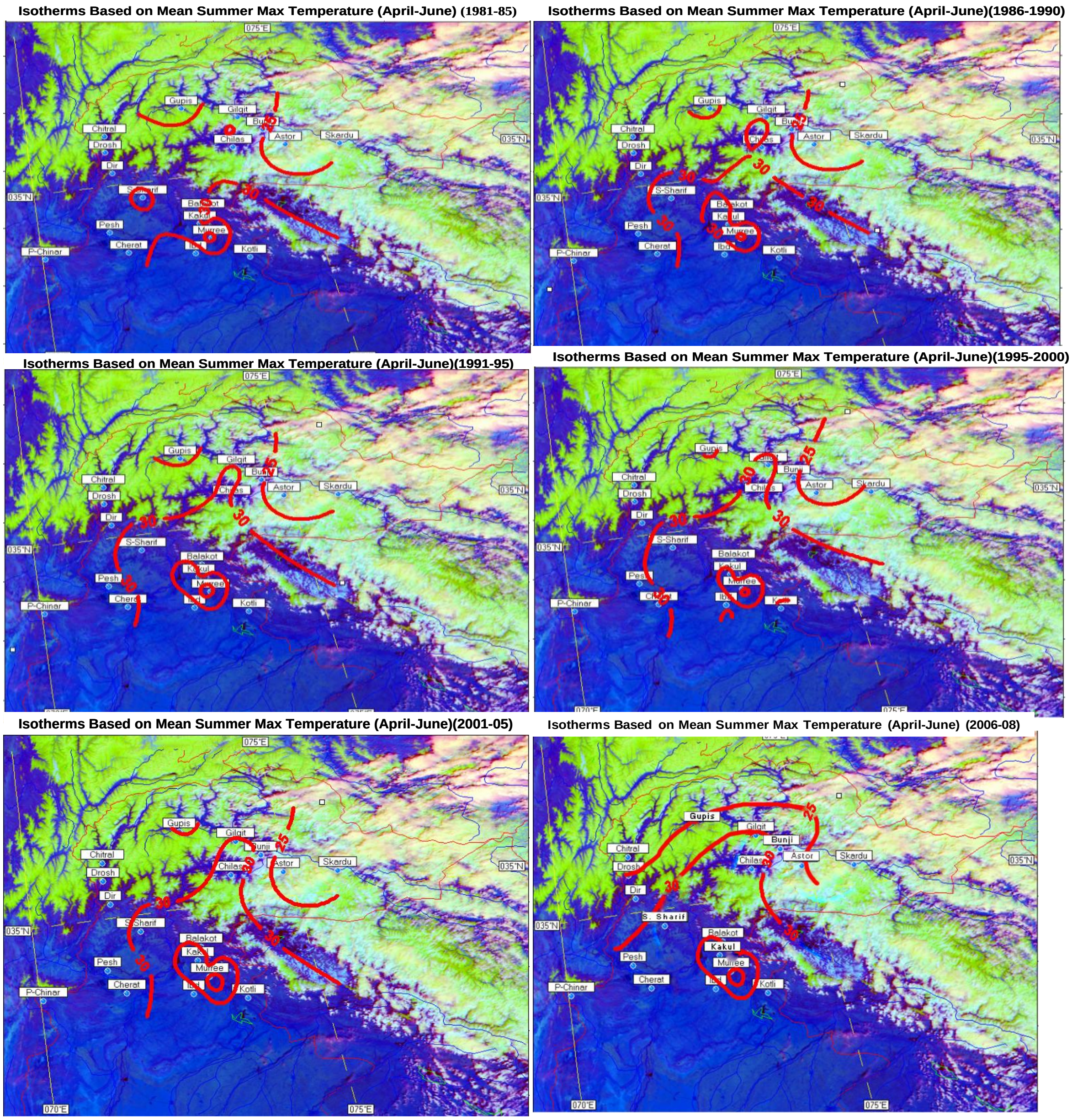


Figure 10: Heat shifting isothermic dynamics along southern slopes of HKH ranges

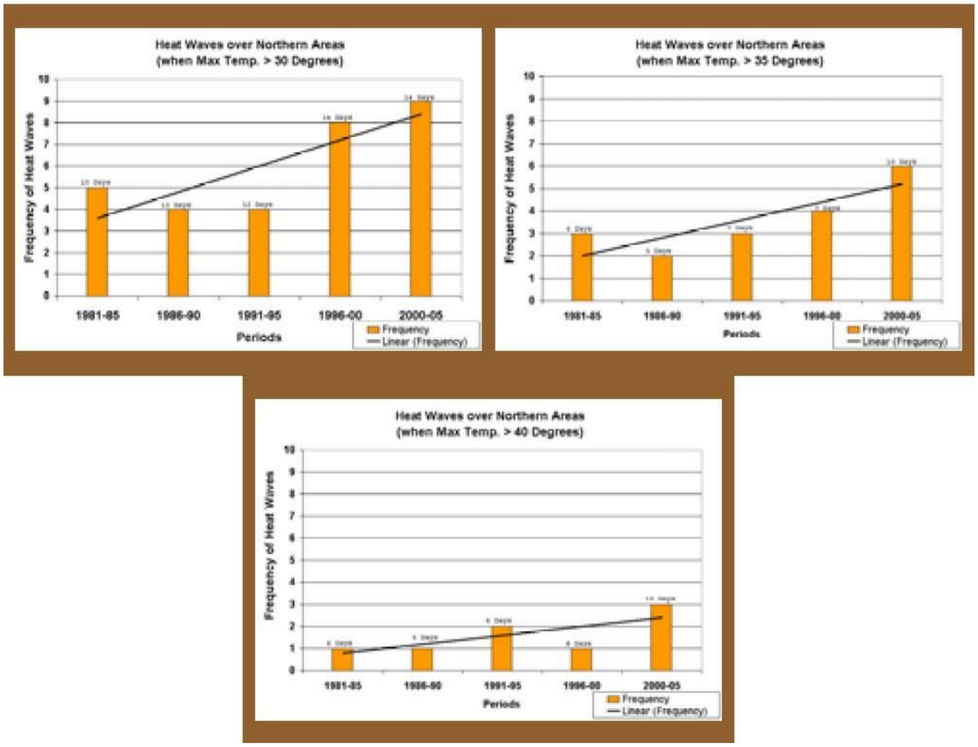


Figure 11: Frequency of moderate, mild and severe heat waves of 5-days duration (bars) and their linear trend. The numbers on the top of the bars indicate the longest

Frequency analysis carried out over all the above thresholds is presented in figure 11 from 1981 to 2008 using combined data set from all sources. The height of the bar represents the number of events when temperatures reached the mild, moderate and severe stress level in a particular pentad. Frequency of mild stress was quite common even in 1980s during May and June but moderate and severe stress conditions rarely occurred. Not only a significant increase had been noticed in occurrence of mild stress days but a sharp rise in moderate and severe stress events was also registered during the recent decade. It can be observed that the persistence of heat waves has become longer over the temporal scale on one hand while their intensity has increased on the other hand during the recent years. Similarly their areal extent has also increased significantly. The valley areas or shadow zones appearing unaffected by increasing heat in the earlier period are dominated by the heat sweep. However, they are following certain lag period than the exposed elevations (Rasul G. et al. 2008).

3.4.4. Snowmelt Flood:

Snow and ice are the most sensitive entities of the natural ecosystem to any change in thermodynamic regime directly or indirectly taking place. Due to a general trend of increasing warming, these frozen water reserves have also started melting at an accelerated rate giving rise to the formation of new glacial lakes and producing local flooding due to their outburst phenomenon. In addition to Glacial Lake Outburst Floods (GLOFs), ice and snowmelt water runs through the streams and converge into the major rivers. The convergence of stream flow peaks, sometimes, generates high river floods downstream.

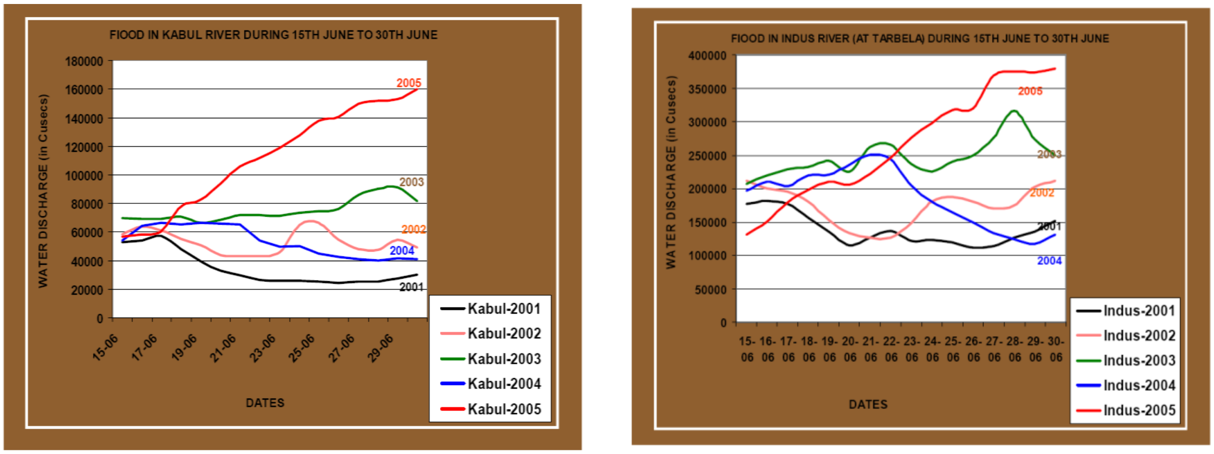


Figure 12: Comparison of 5-year river discharge (in cusecs) for river Kabul and Indus

The most devastating flood of pre-monsoon season in the rivers Indus and Kabul during 2005 was the worst example in recent era. During the last fortnight of June, the high pressure ridge of westerly waves prevailed over the northern mountainous regions of Pakistan and Afghanistan. Temperatures plunged quickly above 40°C at most of the meteorological stations up to 2500m as and such conditions persisted until the end of June. Not only this stretch of hot spell was recorded as the longest heat wave ever occurred in these areas but also established new records of the maximum temperatures reaching 43.6 °C at Gilgit (Rasul G, et al. 2008).

The large amounts of melt water rushed through the streams and flooded the main rivers. The river discharge of the Indus at Tarbela and the Kabul at Naushera are compared for the last 5-years during the last fortnight of June (Figure 12). The curves show an increasing trend of river discharge reflecting warming trend but an abrupt increase in flow of both the rivers during 2005 represent the extreme heat wave conditions discussed above. The river Indus and the Kabul join together off Naushera and known as the Indus. This historic and untimely flood took hundreds of lives, damaged thousands of hectares of standing crops and incurred huge loss to infrastructure downstream from NWFP to Sindh. The main flooding season generally coincides with the monsoon season which extends from July to September (Rasul G, et al. 2008).

3.5. Cold Wave Duration

Cold Wave Duration is defined as the number of days when, for at least 6 days, the minimum temperature remains less than a threshold value. In this report the number of days has been counted as cold wave days when, for at least 6 days, the Tmin $\leq 10^{th}$ percentile of the temperature records in a year. Fig. 13 displays the temporal variation in number of cold wave days in Pakistan over the period. It can be seen that there is not significant change in the cold waves. The cold wave duration has changed at the rate of 1.4 days per decade and the total change in number of cold wave days is 4 which is not significant at 95% confidence level.

Fig. 14 shows the spatial variation of the change in cold waves measured in days. It can be seen that cold waves have been increased in North-Western parts of the country. Maximum increase has been observed in the North of FANA, North and Western NWFP, North-Eastern Balochistan i.e. all mountainous regions. Rise in cold wave in these regions is 30 – 60 days. However, cold waves have increased in whole Balochistan, FANA and NWFP except parts of the province adjoining north Punjab. There are parts of the country where cold waves have decreased. These include North and Eastern Punjab and adjoining AJK areas and Southern parts of Sindh. Maximum decrease has been observed in North-Eastern Punjab. There is an increased cold wave regime between Sargodha and Jehlum. This may be due to the presence of hills of Salt Range. The analysis of heat wave and cold wave showed at present we are having one month warmer in a year than before. This, in turn, means that span of summer season in the country has increased significantly since 1980.

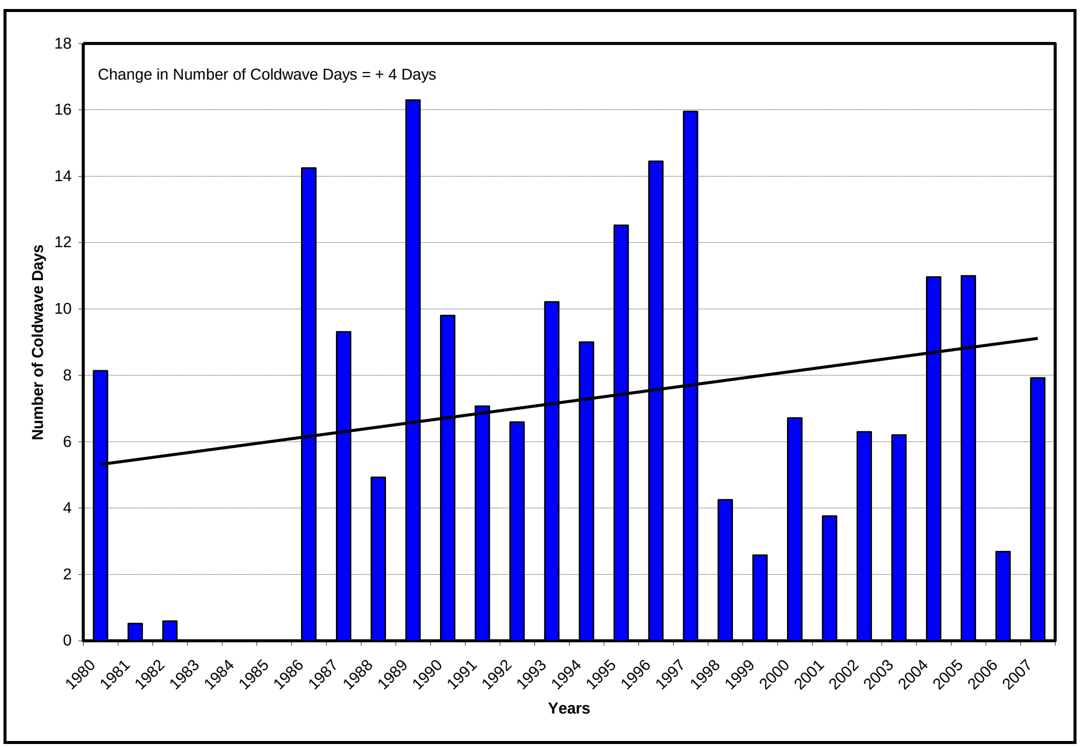


Figure 13: Change in Cold Wave Days when Tmin ≤ 10th Percentile of the Data

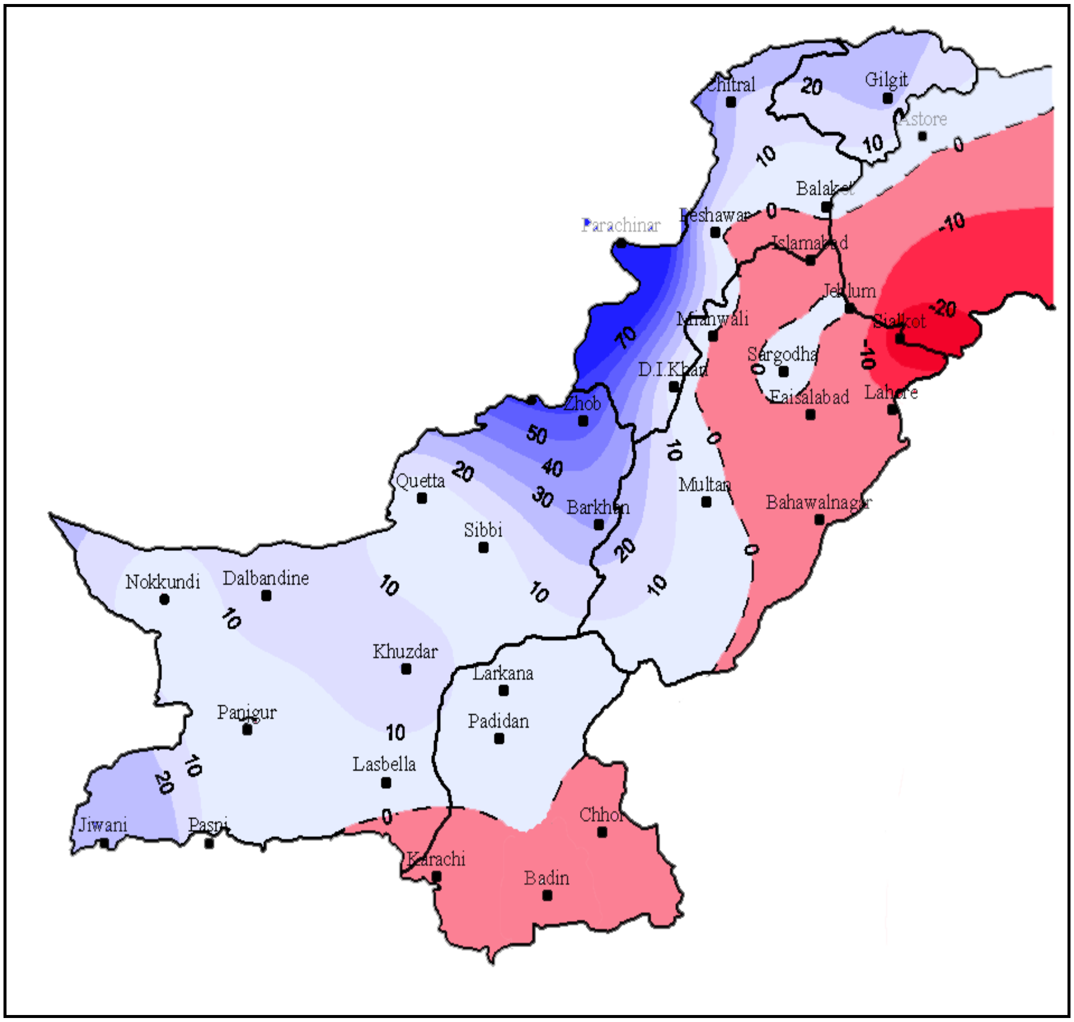


Figure 14: Total Change in Cold Wave measured in Days

4 Precipitation Indicators in Pakistan

4.1. Long – Term Precipitation Series

4.1.1. Annual Rainfall

18 stations with available long term data from 1901-2007 and 5 stations having data range from 1914-2007 were used to study all Pakistan rainfall. A study on the precipitation of Pakistan from 1901 – 2008 has been made by (Chaudhry, Q. Z, 2009). An increasing trend was observed for the annual average rainfall over Pakistan as shown in figure 15, for the period used in this report i.e. 1901 - 2007. A total change of about 61 mm was observed for the analysis period. The 10 years moving average showed that rainfall decreased from early 1900s till 1940, the rainfall gradually decreased from 600 mm average to less than 400 mm a year. Since the 1940s the net trend of precipitation is

increasing to a total change of 133 mm. The analysis of precipitation was further resolved to provincial basis.

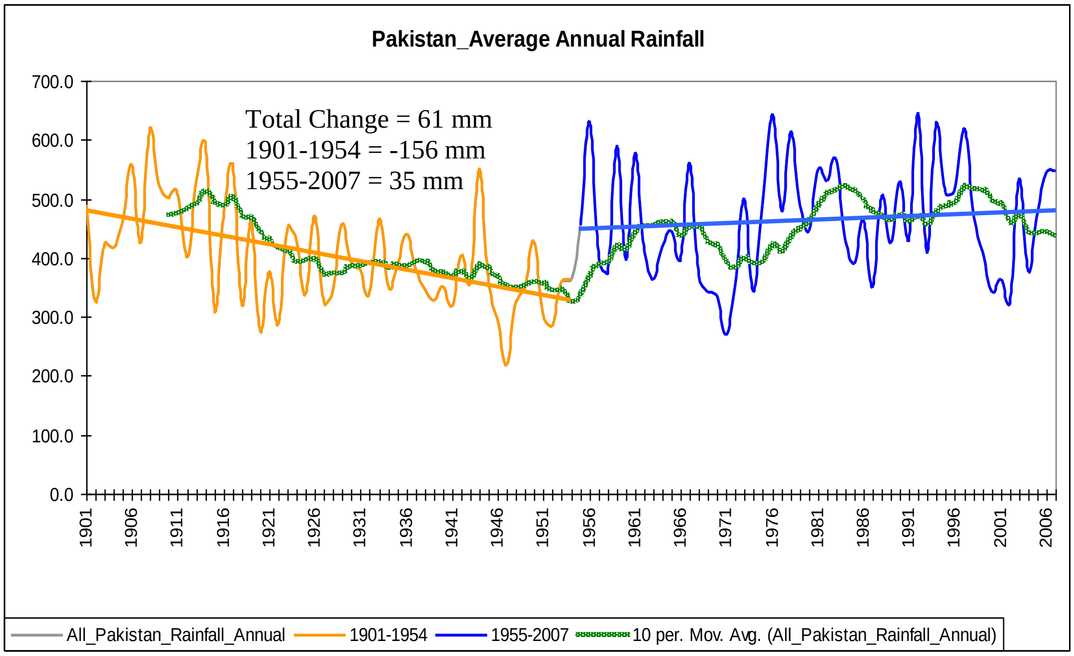


Figure 15: Time series of Annual Average Rainfall over Pakistan (1901-2007)

Punjab

For the province of Punjab, data of 6 meteorological stations were chosen each having data length from 1901-2007. A total change of 228 mm was observed for the analysis period. The time series along with the 10-years moving average is shown in figure 16.

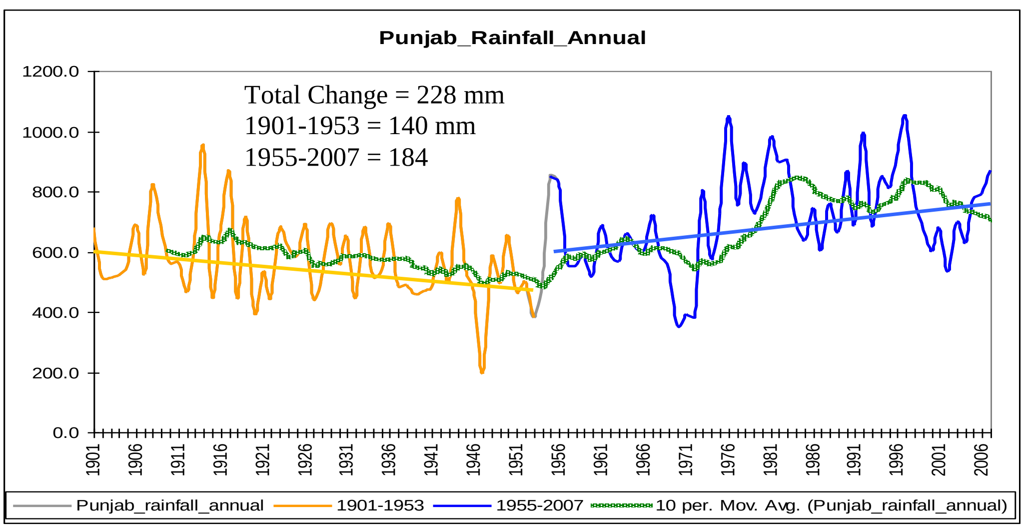


Figure 16: Annual Average Rainfall of Punjab (1901-2007)

Another interesting feature was the decrease of trend from 1901-1953 which gave a net decline of 140 mm in rainfall. The last 53 years (1955-2007) exhibited an increase in trend with a total change of 228 mm.

All the stations of Punjab are showing increasing trend in the precipitation. On the basis of annual rainfall maximum increase has been observed at Rawalpindi while the minimum was observed at Faisalabad and no station is showing the negative trend. In the monsoon however, the maximum and minimum trends were found at Mianwali and Murree respectively while the Murree showing negative trend.

Sindh

For the Sindh province, the data was available from 1914-2007 of 5 stations. There is not much change observed in the precipitation of Sindh for the study period, the total change was 15 mm. However the first 47 years were observed to show a slighter increasing trend with total change of about 13.6 mm. On the other hand a decreasing change was observed for the period of 1961-2007 with a net decrease of 10.2 mm as shown in figure 17.

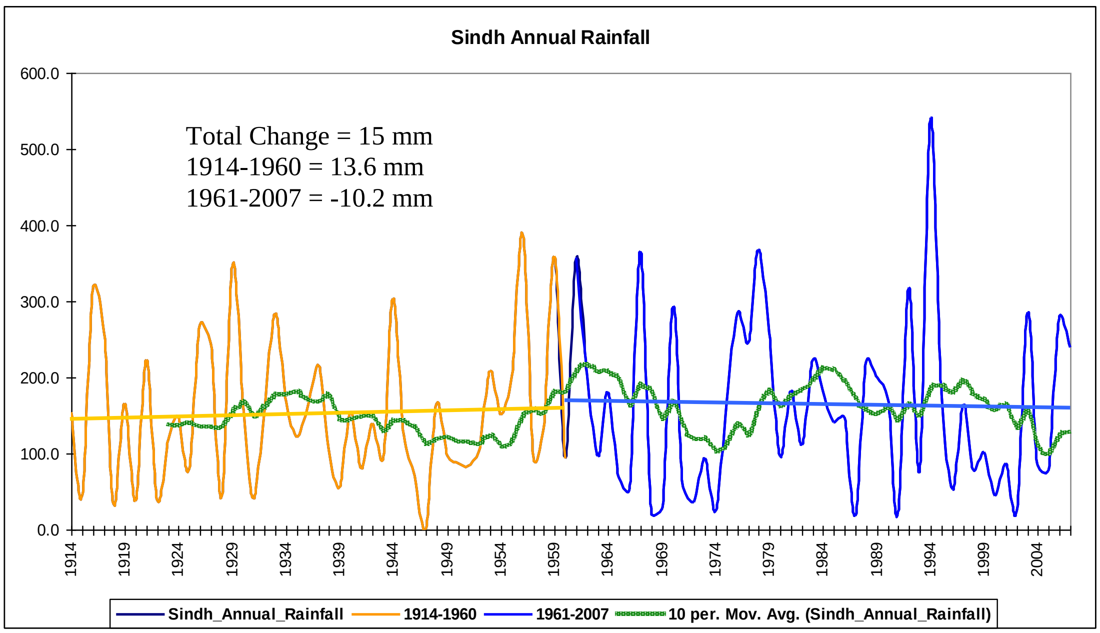


Figure 17: Sindh Annual Rainfall (1914-2007)

Balochistan

For province of Balochistan, 4 stations with long term precipitation data (1901-2007) were used. Net change of all the analyzed period was 8.45 mm. However, the major change in precipitation trend was observed in last 53 years i.e., 1955-2007 which exhibited a net change of 56.4 mm which is quite significant compared to the first 53 years (1901-1953) with only 2.2 mm of change.

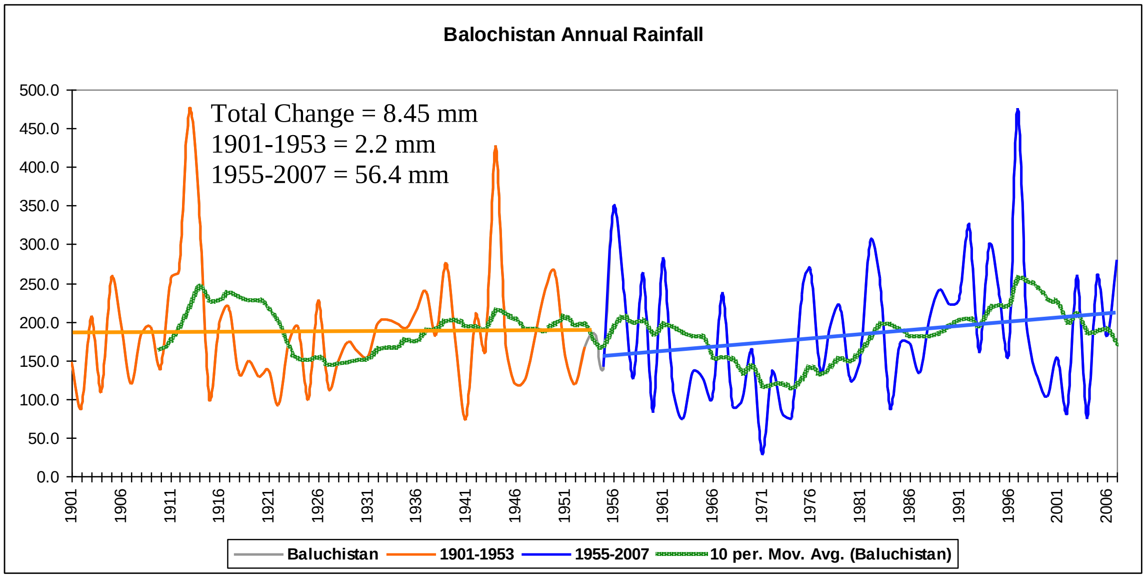


Figure 18: Annual Average Rainfall of Balochistan (1901-2007)

North-Western Frontier Province (NWFP)

Figure 19 is showing the time series of Annual Average Rainfall for NWF province. The total change for the analysis period was 73.5 mm. Calculations of 10-years moving average indicated a jump in normal value of precipitation during the 1954-1966 period. Whole analysis can be described in three parts. The period from 1901-1953 showed a slight increasing trend with total change of only 1.3 mm. During the period of 1954-1966, there were some years with relatively higher precipitation amounts. The third section i.e., from 1966-2007 showed an increasing trend of 75 mm.

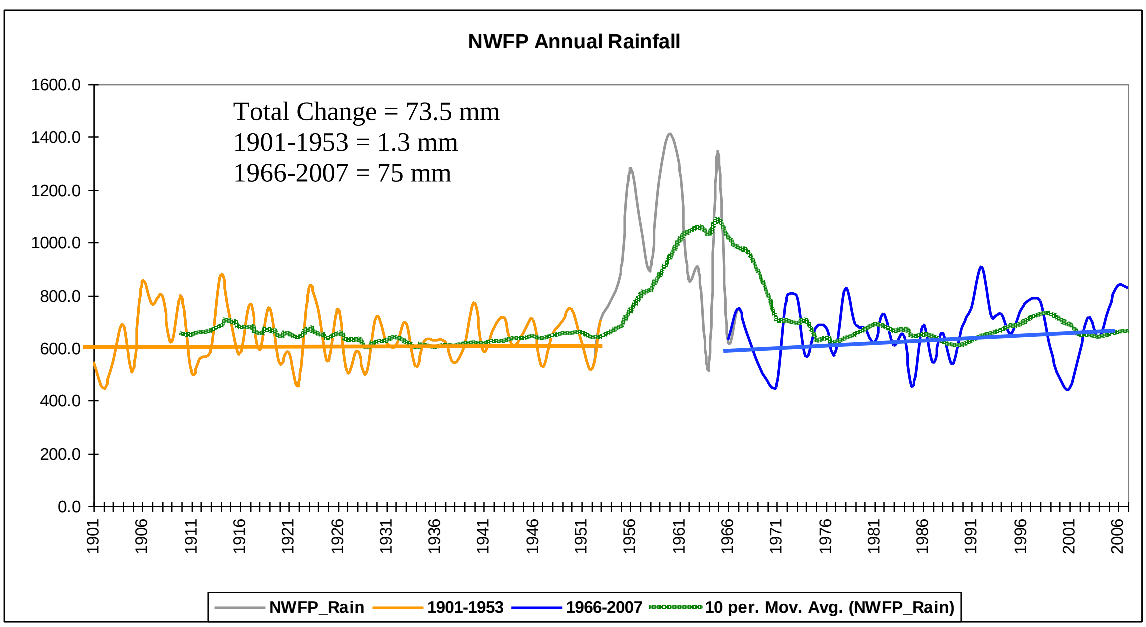


Figure 19: Annual Average Rainfall NWFP (1901-2007)

4.1.2. Seasonal Rainfall

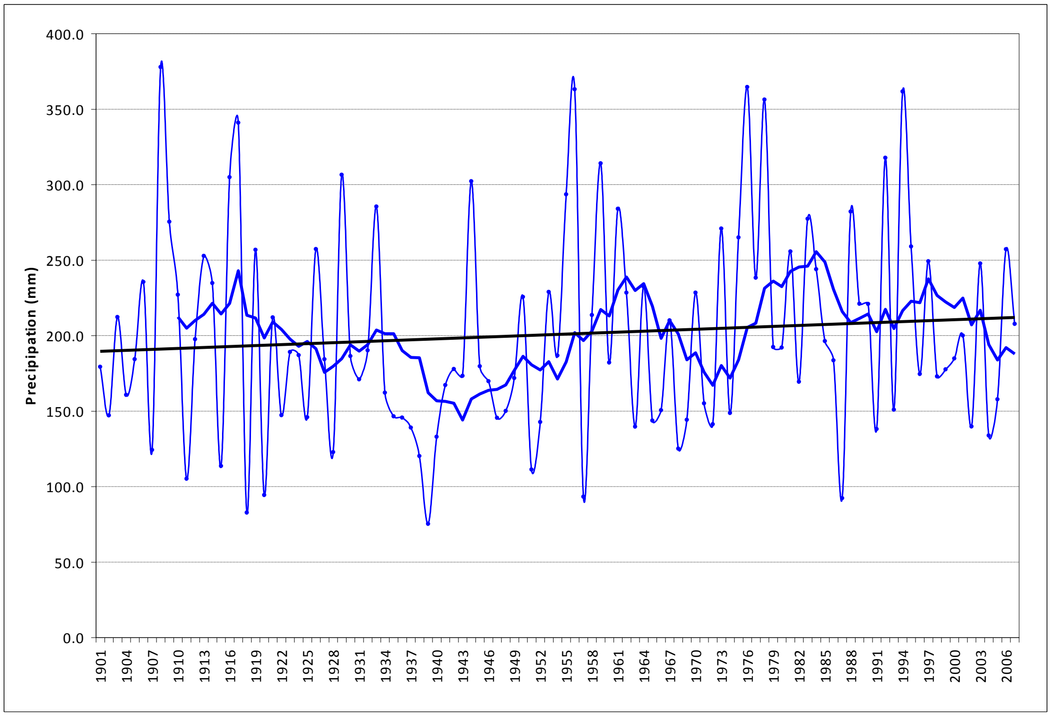


Figure 20: Summer Monsoon Rainfall all over Pakistan

The above figure depicts the time series of summer monsoon rainfall. There is an increase of 22.6 mm over the data period (1901 – 2007), which is not very significant. Moving average of 10 years period has also been displayed. It can be seen that there is very clear inter decadal variability of 20 – 30 years cycles. The decadal analysis revealed that the rainfall started decreasing from the second decade of the 20th century. This trend lasted up to the fifth decade. Then there is an increasing trend up to the 1962. Then there is a decrease of rainfall for next ten years. After that there is small variation. There is decreasing after 1997.

There is also an increasing trend in winter precipitation of Pakistan from 1901 to 2007. Winter rainfall is shown in Fig. 21. The rainfall increased at the rate 1.95mm per decade with the total increase of 20.8mm over the period. The change is not significant statistically. Moving average of ten years period does shows random variation in the time series. Figure 18 displays the winter rainfall all over Pakistan. Non significance may arise because of taking average for all over the country. Some stations have increasing trend the other stations have decreasing trend. Therefore over all trends is increasing with low statistical significance. The analysis on provincial basis is made to see the regional changes in the country.

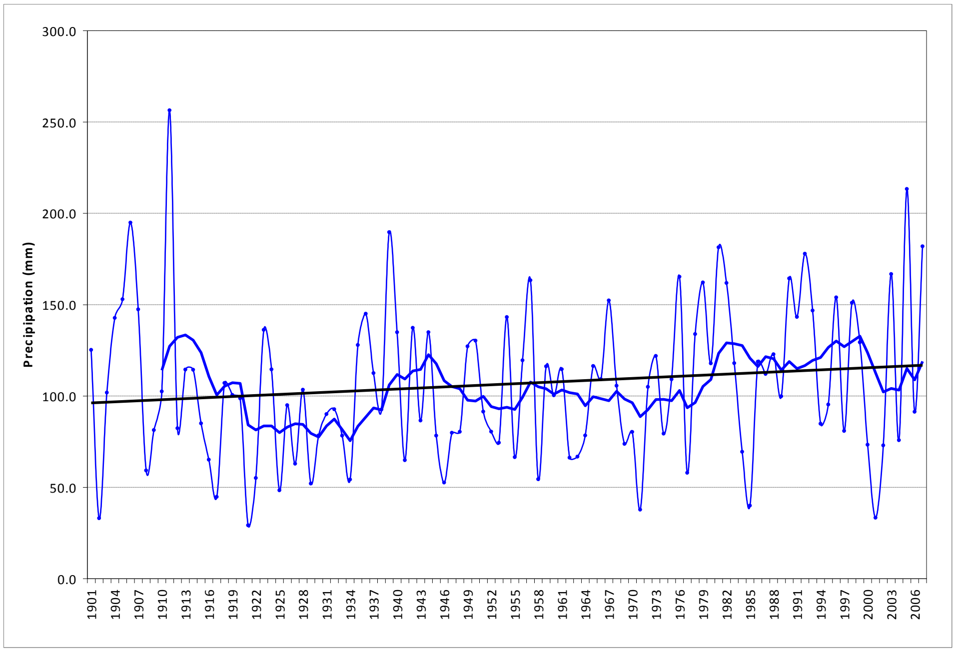


Figure 21: Winter Rainfall all over Pakistan

Punjab

Figure 22 displays the annual and seasonal rainfall over Punjab province of Pakistan for the period 1901 to 2007. Seven Met stations of the province, Faisalabad, Multan, Lahore, Murree, Sargodha, Rawalpindi, Mianwali, has been used. It can be seen that the response of annual precipitation is coherent with the monsoon rainfall. The major contribution of rainfall in a year is mostly from monsoon rains in the Punjab. The change in annual rainfall has been discussed in previous section. The rate of change of monsoon rainfall is +10.4 mm per decade and the total increase in the monsoon rainfall is 111.23 mm over the period mentioned. Decadal analysis revealed clear cycles of increase and decrease in the rainfall in last century. Major shift in the decadal average can be seen after 1970's. However, the increase in the rainfall starts from 1950's. After 1997 there is a sharp decrease in the monsoon rainfall.

Winter rainfall has lesser inter decadal variability as compared to monsoon rains. There is a major increase in the decadal average after 1977. This shift is again coherent with the monsoon rains. The rate of change of winter rains is +5.6 mm per decade and the total rise in the amount of precipitation is 59.6 mm over the data period, which is statistically non significant.

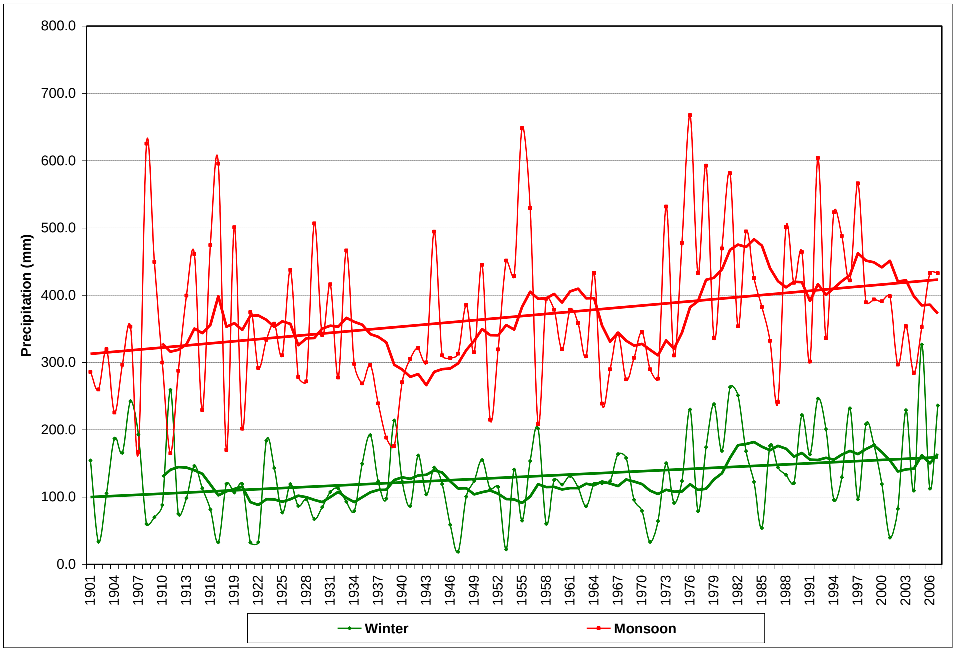


Figure 22: Seasonal Rainfall all over Punjab

Sindh

Figure 23 represents the seasonal and annual rainfall over sindh province. The data of five met stations, having the data record from 1914 to 2007, of the province has been used in this analysis. These are Badin, Hyderabad, Karachi, Jacobabad and Rohri. It can be seen that the annual rainfall of sindh depends mostly on monsoon rainfall. There is a strong coherence in annual and monsoon rainfall in the province. The annual trend follows the monsoon rains trends over the data period. There is non significant decrease in monsoon rains over the data period. The decadal analysis show cyclic variability of the monsoon rainfall. There is significant decrease after 1998.

A small portion of the annual rainfall is contributed by the winter rains over the province. There is a small non significant increase in the winter rainfall. The decadal analysis also shows a very small variability in the rainfall over the province.

Balochistan

Four met stations, Kalat, Lasbella, Quetta and Sibbi with data record from 1901 to 2007, have been used. The data have been interpolated for missing values of some year's records. Figure 24 shows the plot of annual, summer and winter rainfall over the province. Monsoon does not reach into the province generally. There have been some summer seasons when monsoon depressions reached into the province and then 3die out after giving heavy rainfall. The province most of the rain in winter season from western disturbances which enter the province form west and give significant amount of precipitation. It can be seen from the above figure that there is high interannual variability of rainfall, may be the highest among all provinces of Pakistan. Summer and winter rainfall equally contributes in the annual amount of rains. However, the part of winter rains is little higher than that of summer. There is very small, non significant increase in summer rainfall in the province i.e. 3.6 mm over the data period. The rise in winter rains is also negligible, which is 2.2 mm from 1901 to 2007 and so does the annual precipitation.

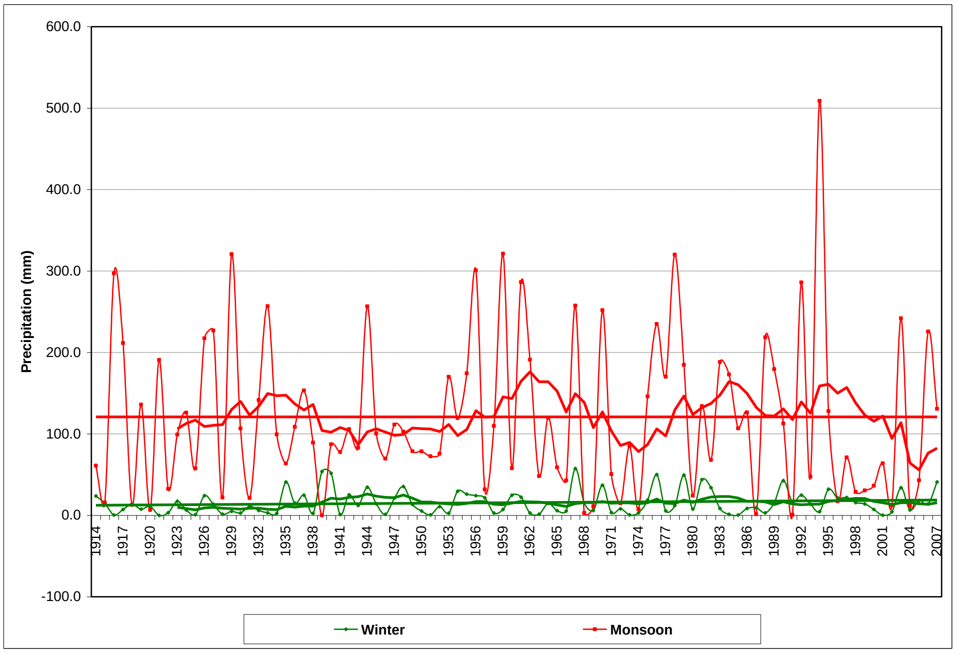


Figure 23: Seasonal Rainfall all over Sindh

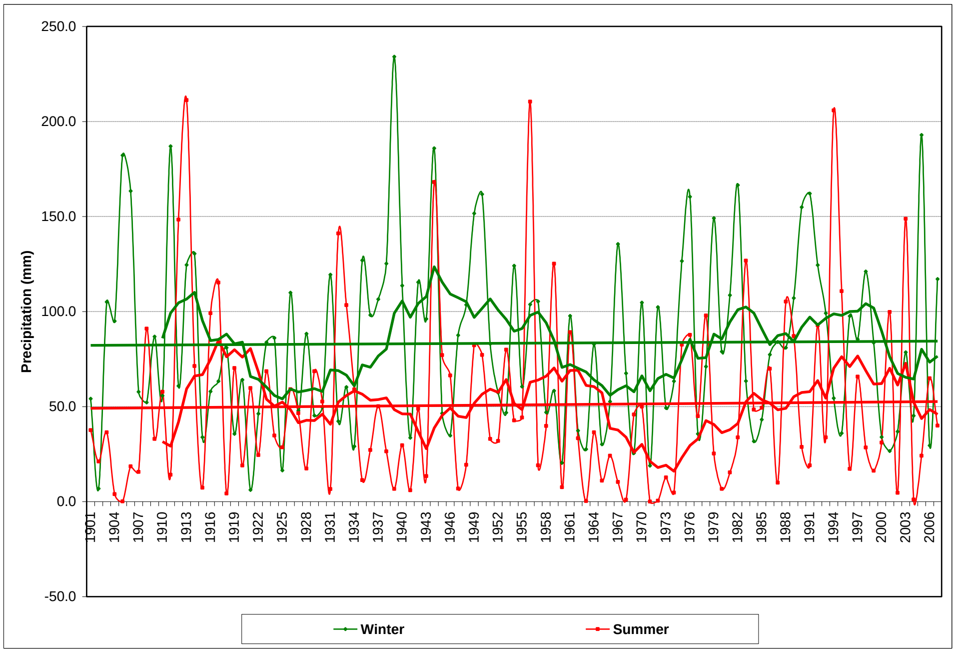


Figure 24: Seasonal Rainfall over Balochistan

North-Western Frontier Province (NWFP)

The province receives rainfall in summer due to easterly currents and in winter from westerly systems. Its geographical location is such that it receives good amount of precipitation both in summer and winter. Both the seasons contribute equally in the annual amount of precipitation. It is also obvious from the figure 25. The annual rainfall trend has been discussed in previous section. There is no significant change in the summer season rainfall in the province. Total change is -0.2 mm over the data period, which is non significant. The amount of winter rain has increased. The increasing trend is 6.6 mm per decade and the total change is 70 mm over the period.

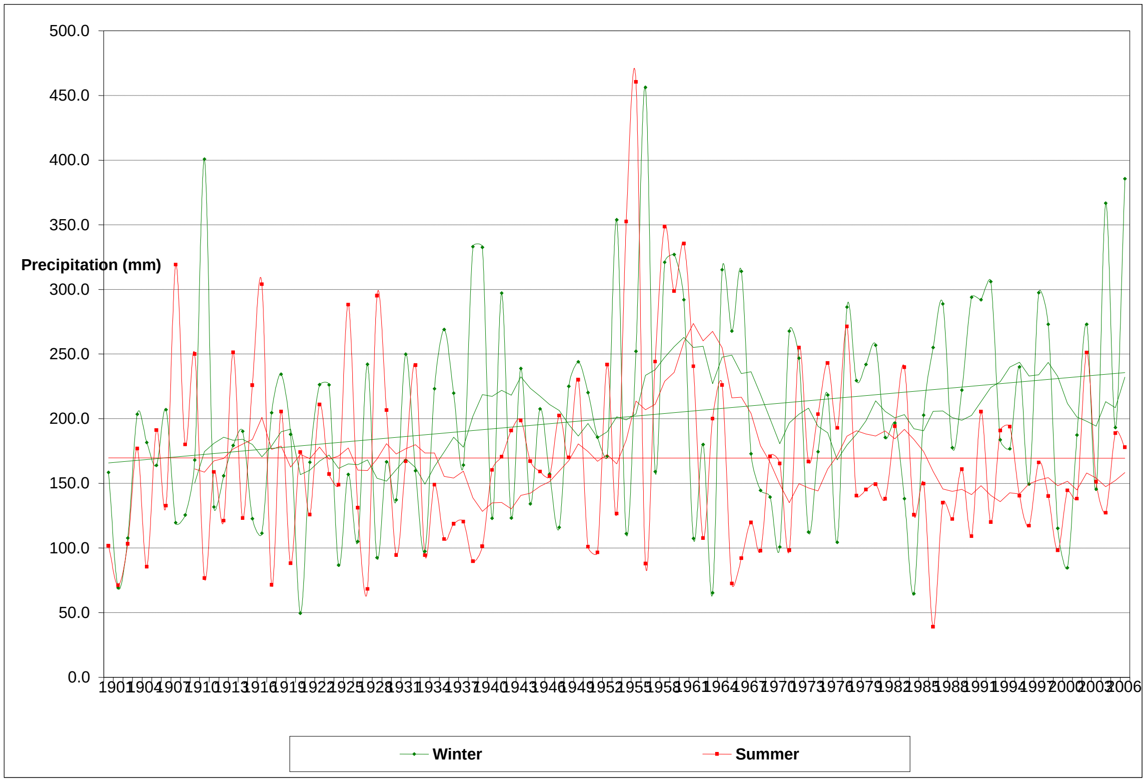


Figure 25: Seasonal Rainfall over NWFP

4.2. Frequency of Consecutive Wet Days (CWD)

Number of consecutive wet days has been calculated from the daily data of 19 meteorological stations of Pakistan for the period 1960 – 2007. CWD is defined as the total number of days when precipitation was greater than or equal to 1 mm. Table 5 shows the change in total number of these days. It can be seen from the table that there is non significant change in wet days at all stations of Punjab and Sindh. The change at Quetta and Peshawar, having total change of 1.79 and 2.16 is significant with 95% confidence.

Table 5: Change in Consecutive Wet Days (CWD)

	Station		CWD
1	Chitral	*	0.47
2	D.I.Khan	*	-0.24
3	Dalbandin	*	0.05
4	Faisalabad	*	0.05
5	Gilgit	*	0.38
6	Hyderabad	*	-0.19
7	Islamabad	*	0.00
8	Jacobabad	*	-0.09
9	Jehlum	*	0.71
10	Jiwani	*	-0.66
11	Karachi	*	0.56
12	Lahore	*	0.00
13	Multan	*	0.14
14	Murree	*	-1.93
15	Parachinar	*	-1.13
16	Peshawar		**2.16**
17	Quetta		**1.79**
18	SaiduSharif	*	0.42
19	Zhob	*	-0.24
	** Non Significant*		

4.3. Frequency of Consecutive Dry Days (CDD)

Consecutive Dry Days are defined as the total number of days when precipitation was less than 1 mm. Table 6 shows the change in total number of these days at different stations of Pakistan, the digitized daily data of which is available from 1960 to 2007. It can be seen that the data of all 19 stations is showing non significant change. Over all there is mix trend of decreasing and increasing dry days. The change in number of consecutive dry days is greater than that of wet days as discussed in previous section.

Table 6: Change in Consecutive Dry Days (CDD)

	Station		CDD
1	Chitral	*	-8.08
2	D.I.Khan	*	-22.18
3	Dalbandin	*	63.40
4	Faisalabad	*	-4.98
5	Gilgit	*	-3.62
6	Hyderabad	*	15.89
7	Islamabad	*	4.28
8	Jacobabad	*	-36.43
9	Jehlum	*	7.38
10	Jiwani	*	53.39
11	Karachi	*	34.97
12	Lahore	*	-14.99
13	Multan	*	-7.00
14	Murree	*	-18.61
15	Parachinar	*	7.76
16	Peshawar	*	1.74
17	Quetta	*	27.21
18	SaiduSharif	*	6.91
19	Zhob	*	-14.71
	** Non Significant*		

4.4. Frequency of Very Heavy Precipitation Days

RClimDex defines the day with precipitation equal to or greater than 20 mm as the heavy precipitation day. Total number of these days has been analyzed for different stations of Pakistan to assess the change in rainfall intensity. Changes in precipitation can be caused by the change in frequency or intensity of the event. It has been shown that with the change in total precipitation a disproportionate change occur in the precipitation frequency distribution (Karl and Knight, 1998; Groisman et al., 1999, 2001; Easterling et al., 2000; IPCC, 2007a; in Groisman et al., 2004). Table 7 displays the total change in heavy precipitation days over the data period for 19 stations. There is mix trend of increase and decrease in heavy precipitation days in Pakistan. Islamabad is the only station with significant rise in heavy precipitation days. There is also an increase at Lahore and Peshawar but the statistical significance is little lower than the threshold for 95% confidence level.

Table 7: Change in Heavy Precipitation Days (R20mm)

	Station		R20mm
1	Chitral	*	-0.66
2	D.I.Khan	*	1.32
3	Dalbandin	*	0.05
4	Faisalabad	*	0.28
5	Gilgit	*	0.28
6	Hyderabad	*	-1.03
7	Islamabad		**5.41**
8	Jacobabad	*	0.61
9	Jehlum	*	2.44
10	Jiwani	*	-0.61
11	Karachi	*	-2.12
12	Lahore	*	3.43
13	Multan	*	0.19
14	Murree	*	4.14
15	Parachinar	*	-1.36
16	Peshawar	*	4.65
17	Quetta	*	0.66
18	SaiduSharif	*	1.65
19	Zhob	*	1.08
	** Non Significant*		

4.5. Extreme Precipitation Events

Analysis of extreme events has been carried out by the daily data of 19 stations, aforementioned. Method of this analysis is to consider only those events which pass certain threshold. In this study, number of events when precipitation was greater than or equal to long term 95th percentile are examined. Percentiles, having the property of being station specific, represent the anomalies with respect to local climate. That is why use of percentile is very important for analyzing the extreme events. Table 8 represents the change in extreme precipitation events. It can be seen that all the stations are showing non significant increase/decrease in terms of millimeters, except Parachinar. There is also a considerable increase at Islamabad and Murree, but the statistical significance is little lower than the threshold for 95% confidence level.

Table 8: Change in Extreme Precipitation (R95P)

	Station		R95P(mm)
1	Chitral	*	-16.50
2	D.I.Khan	*	22.75
3	Dalbandin	*	-52.26
4	Faisalabad	*	23.74
5	Gilgit	*	0.19
6	Hyderabad	*	-16.73
7	Islamabad	*	165.77
8	Jacobabad	*	30.93
9	Jehlum	*	-52.92
10	Jiwani	*	-17.67
11	Karachi	*	-82.91
12	Lahore	*	82.63
13	Multan	*	-19.74
14	Murree	*	217.19
15	Parachinar		**-423.09**
16	Peshawar	*	86.25
17	Quetta	*	17.67
18	SaiduSharif	*	-54.00
19	Zhob	*	13.82
	** Non Significant*		

5 Future Projections of Climate

5.1. Summary characteristics of four IPCC-2007 Emission Scenarios

Future greenhouse gas emissions are the result of very complex dynamics govern by socio-economic, technological change and demographic developments. There is a lot of uncertainty about the future of these factors. Scenarios provide an alternate picture how the future will unfold and what will be the impact of these factors on our climate. Following is the summary of IPCC Special Report on Emission Scenarios storyline;

A1 (Low – High Emission)

World: market-oriented

Economy: fastest per capita growth

Population: 2050 peak, then decline

Governance: strong regional interactions; income convergence

Technology: three scenario groups:

- A1FI: fossil-intensive
- A1T: non-fossil energy sources
- A1B: balanced across all sources

A2 (Medium – High Emissions)

World: differentiated

Economy: regionally oriented; lowest per capita growth

Population: continuously increasing

Governance: self-reliance with preservation of local identities

Technology: slowest and most fragmented development

B1 (Low - Medium Emissions)

World: convergent

Economy: service and information-based; lowest growth than A1

Population: same as A1

Governance: global solutions to economic, social and environmental sustainability

Technology: clean and resource-efficient

B2 (Medium – High Emissions)

World: local solutions

Economy: intermediate growth

Population: continuously increasing at lower rate than A2

Governance: local and regional solutions to environmental protection and social equity

Technology: more rapid than A2; less rapid, more diverse from A1/B1

5.2. Global climate Projections

Future projections of global climate, given by Intergovernmental Panel on Climate Change (IPCC 2007a) suggest that:

- From the mid of the current century the precipitation is likely to increase in mid to high latitudes in winter with large spatial variations.
- More intense and extreme precipitation events are likely to occur.
- Global temperature is likely to increase by between 1.8°C (Low emission scenario) to 4°C (High emission scenario) up to the end of this century.

- Maximum temperature is likely to increase and more heat waves are expected.
- Present retreat of Glaciers is likely to continue during the century which will result in the shortage of water availability. It is expected that after 2035 there will be a clearly visible shortage of water in the rivers.
- The best estimates of the sea level rise are 18 – 36 cm for low emission scenario and 26 – 59 cm for high emission scenario.

5.3. Future Climate Projections of Pakistan

A project on future climate change was carried out jointly by Pakistan Meteorological Department and Global Change Impact Studies Center. The study revealed that almost all the temperature indices show significant changes over the region. Trend in temperature indices reflect an increase in both maximum and minimum temperature. There is a much larger percentage of land area showing significant change in minimum temperature (5^{o} C) than maximum temperature. Percentile based spatial change shows that the daily minimum temperature will become warmer as compared to the increase of daily maximum temperature in summer whereas in winter the change in maximum threshold temperature is high (PMD & GCISC joint Report on climate change 2007).

The climate change scenarios are based on SRES-IPCC 2007. Among them A2, A1B and B1, were chosen for interpolation on 1°X1° grid resolution using multi-model ensemble output. Monthly datasets were used by 17-model ensemble to construct A2 and A1B scenario but daily data were used for ECHAM-5 output to produce B1 scenario. Final scenarios were produced by statistical downscaling of multi-model GCMs output by using NCC regional model NCC-RCM. Future climate projections of Pakistan have been calculated keeping in view the above mentioned scenarios. The rate of change of precipitation and temperature in different future scenarios has been displayed in Table 9 &10.

Table 9: All Pakistan Climate Projections (2011-2050)

Pakistan	Precipitation (mm/Decade)			Temperature (°C /Decade)		
	A2	**A1B**	**B1**	**A2**	**A1B**	**B1**
	+1.73	+1.26	-0.89	+0.51	+0.41	+0.24

Table 10: Region-wise Climate Projections for Pakistan (2011-2050)

Region	Precipitation (mm/Decade)			Temperature (°C/Decade)		
	A2	A1B	B1	A2	A1B	B1
Northern Areas	+4.6	+2.9	-1.3	+0.76	+0.63	+0.39
Potohar & Upper NWFP	+6.1	+3.8	-0.5	+0.01	-0.34	-0.01
Central / Southern Punjab & Lower NWFP	-2.98	-1.78	-3.5	+0.63	+0.71	+0.05
High Balochistan	+1.48	+0.92	-0.57	+0.15	+0.26	+0.03
South-Eastern Sindh	+5.1	+3.0	-0.1	0.00	-0.1	+0.01
Sindh & Lower Balochistan	-1.8	-0.98	-0.05	+0.5	+0.27	+0.01

It can be seen in the above table that most of the regions in Pakistan are showing positive trend in temperature for the period mentioned. Maximum rise is expected in Northern Areas of the country and Central-Southern Punjab and Lower NWFP. However, there are mix trends of increase and decrease of precipitation in different regions.

6 Conclusion

Climate indicators and signals of climate change in Pakistan have been analyzed in this report. Temperature and Precipitation have been the key parameters for climate analysis. Long term data and daily data has been the main focus to calculate the indicators. Signals of climate change in the country are consistent with the global warming. The main findings are:

- Mean Annual Temperature of Pakistan has increased by 0.57°C from 1901 to 2000 and it has risen by 0.47°C in the period from 1960 to 2007. Rise in temperature is even faster in the last decade of the data period i.e. 1901 – 2007
- The rate of increase has been 0.057°C per decade in 20th century; it has been 0.099°C per decade from 1960 to 2007. There is high variability of climate in Pakistan, so the change is not linear. The highest rate of increase occurred in the last decade. The average annual temperature of the last decade remained 0.6°C above normal.
- The warmest year on record was 2004. The second warmest year was 1988. The other warmest years (with anomaly ≥ +0.4°C) in the order of anomaly were 2006, 2001, 2002, 2000, 2007, 1999, 1970, 1963, 1977, 1971, 1969, 1985, 1998.

- The Summer mean temperature has increased by 0.89°C, 0.22°C and 0.02°C in Balochistan, Punjab and Sindh, respectively. The same has decreased by 1°C, 0.26°C, 0.04°C in FANA, NWFP and AJK, respectively.
- There is significant increase in winter mean temperatures at all the regions of the country, mentioned above. The increase is in the range 1.12°C – 0.52°C.
- The annual maximum temperature of the country has increased by 0.87°C in the period from 1960 – 2007.
- The annual minimum temperature of the country has increased by 0.48°C in the period from 1960 – 2007.
- There has been increase of 31 days in Heat Wave duration for the data period. Heat waves have increased in all parts of the country.
- There has been non significant increase of 4 days in Cold Wave, with spatial variability across the country. The cold waves have increased significantly in western and north-western parts of the country, and decreased in north-eastern and south-eastern parts.
- The annual precipitation of Pakistan has increase, significantly, by 61 mm from 1901 to 2007. The monsoon precipitation has increase by 22.6 mm and winter precipitation has increased by 20.8 mm, both are non significant.
- The annual precipitation of Punjab province of Pakistan has increased by 228 mm over the data period mentioned. The summer monsoon precipitation has increased by 111.2mm and winter precipitation has increased by 59.6mm.
- The annual precipitation of Balochistan has increased 8.5mm which is non significant. There is also non significant increase in summer monsoon, 3.6mm, and winter 2.2mm from 1901 to 2007.
- The annual precipitation of Sindh also has non significant increase i.e. 15mm for the data period from 1914 to 2007. The summer monsoon has almost no change and winter precipitation also has non significant increase of 7.5mm over the period mentioned.
- The annual precipitation of NWFP has significantly increased by 73.5mm from 1901 to 2007. There is almost no change in summer monsoon precipitation and significant increase of 70.6mm in winter precipitation.
- There is non significant increase in the heavy precipitation events at most of the stations used in this report. Significant increase has been observed at Islamabad. There have been non significant mixed signals of increase and decrease in the extreme precipitation.
- Most of the regions in Pakistan are showing positive trend in temperature for the period 2011 - 2050. Maximum rise is expected in Northern Areas of the country and Central-Southern Punjab and Lower NWFP. However, there are mix trends of increase and decrease of precipitation are likely in different regions.

The precipitation data requires further analysis as there is a large spatial and temporal variability across the country. Emphasis may be given on daily precipitation data analysis as they have greater impact on the environment, society and economy. The analysis presented in this report will support policy decisions on climate change adaptation and mitigation in Pakistan.

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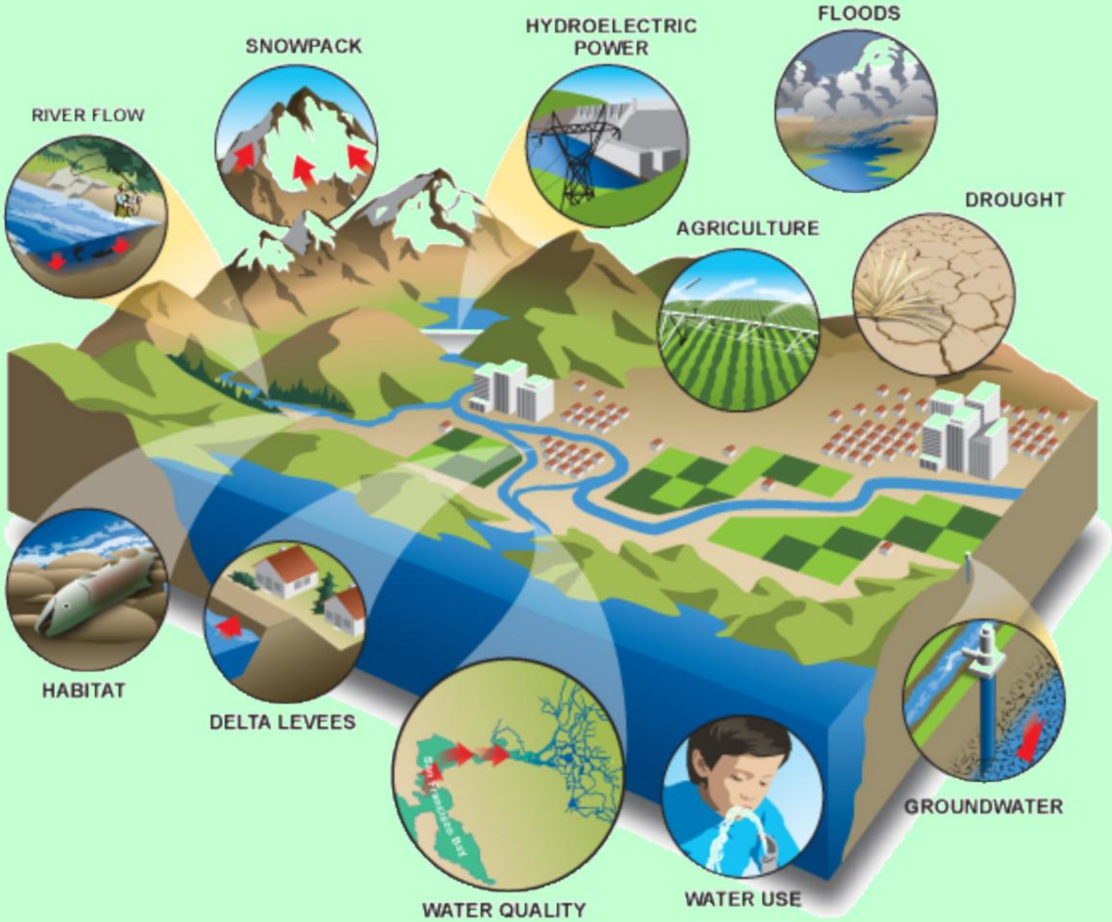

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