CHAPTER 6

CLIMATE CHANGE: PAST AND FUTURE TRENDS

Climate Change:
Past and Future Trends

6.1 Introduction

This chapter discusses the climate change trends in Pakistan. It is divided into four sections. The first section pictures the climate trends in the past including observed temperatures and precipitation patterns. The second section highlights the magnitude and frequency of extreme events, which have increased considerably in the recent past. The next section deals with climate projections and the most likely future scenarios in Pakistan and its climatic regions. The final section concludes the findings.

6.2 Climate Trends

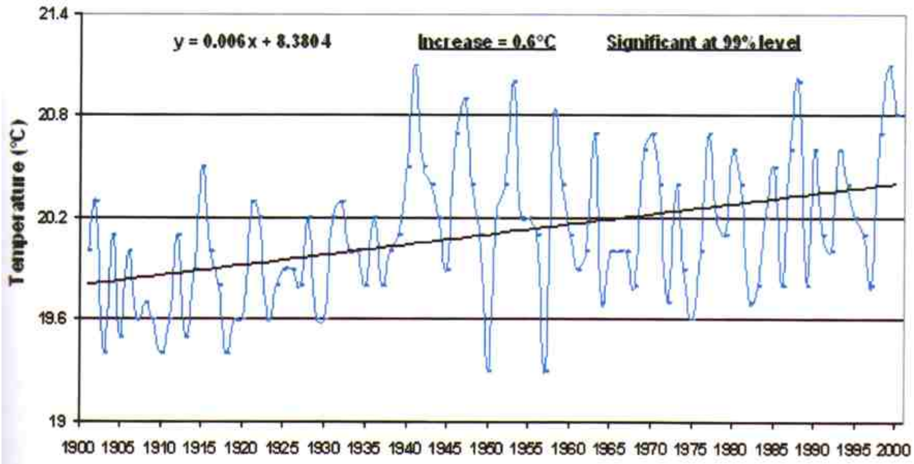
6.2.1 Observed

The Global Change Impact Studies Centre (GCSIC, 2009a, 2009b, 2009c) and Pakistan Meteorological Department (Farooqi, Khan and Mir, 2005; Husain et al., 2005; Gadiwala and Sadiq, 2008; Zahid and Rasul, 2009; Ahmad et al., 2010) have conducted substantial studies on climate trends in Pakistan. According to these studies and analysis, the climate of Pakistan is changing.

6.2.1.1 Temperature

During the last century, average annual temperature over Pakistan increased by 0.6 °C, which is in agreement with the global trend (Fig. 6.1).

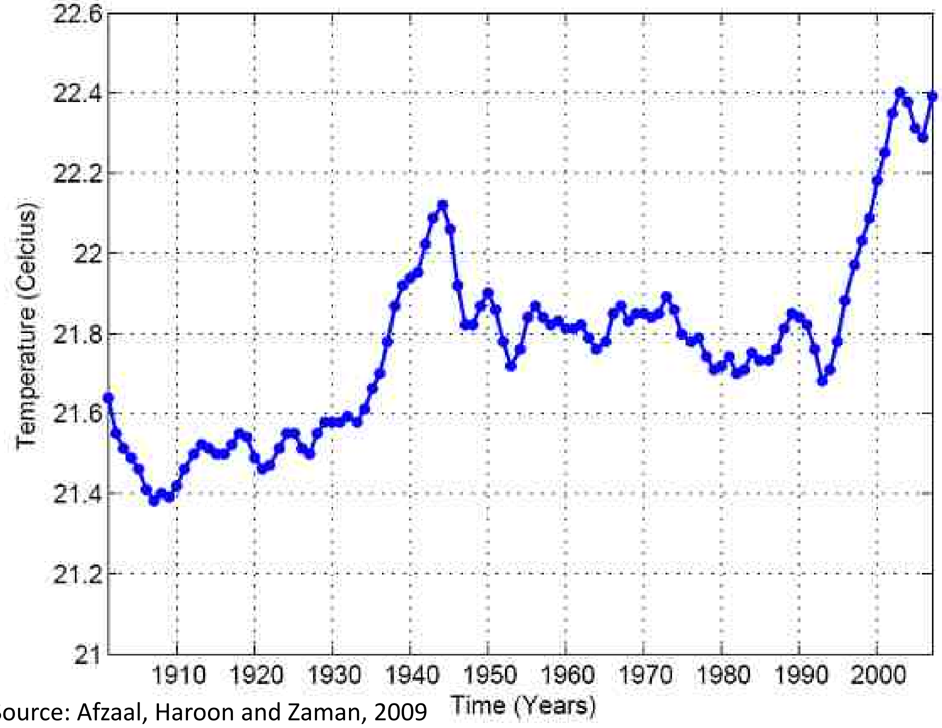
Fig. 6.1 Pakistan: Mean Annual Temperature Trend 1901-2000



Source: GCSIC 2009a

The time series of area-weighted annual mean temperatures of Pakistan for the period from 1901 to 2007, analyzed by the Meteorological Department (Afzaal, Haroon and Zaman, 2008) also showed a warming trend (Fig. 6.2), with the temperature rising at the rate of 0.06°C per decade. The total change in temperature was 0.64°C, which is significant at 95 percent confidence level with cycles of increase and decrease over the period.

Fig 6.2 Pakistan: Area Weighted Mean Annual Temperature Trend 1900-2007



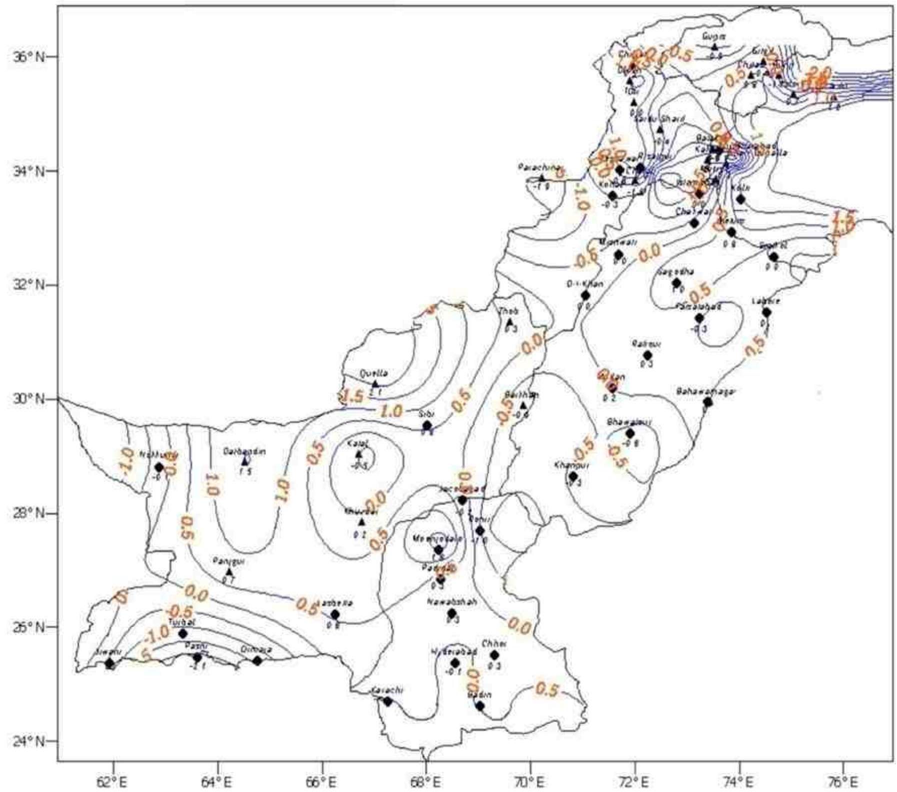
Source: Afzaal, Haroon and Zaman, 2009

The temperature shows a steep rise from 1933 to 1945 at the rate of 0.6°C in 12 years. Then it began to fall at the rate of 0.03°C per decade up to 1993. However the average temperature in the later period was 21.8°C while in the former period it was 21.6°C, which indicates a warming by 0.2°C. There is a sharp increase in temperature after 1993, which continued to the end of the time series. The temperature rose at the rate of 0.53°C per decade in this period. The average temperature in the last decade was 22.3°C.

A spectral analysis of the time series revealed that there are inter-annual to inter-decadal frequencies in the temperature. The inter-annual oscillations of 5-6 years might be related to the impacts of the El-Nino Southern Oscillation. The inter-decadal oscillations with periods of 50, 33 and 14 years may be associated with other global processes such as ocean circulation. This needs further investigation (Afzaal, Haroon and Zaman, 2008).

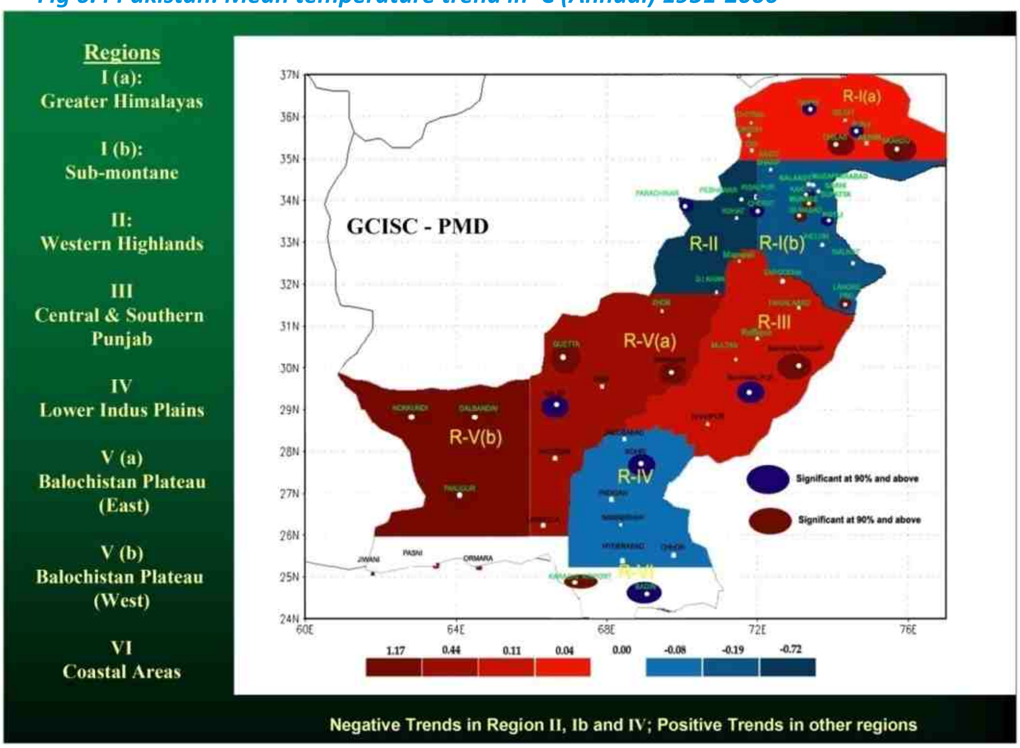
The above analysis of the temperature time-series clearly indicates warming in the country. The rate and nature of change has not only varied over time but also across the country spatially. For example the temperature increase over northern Pakistan was higher than over southern Pakistan (0.8 °C versus 0.6 °C) over 1900-2000 period. Further, it was higher in the second half compared to the first half of the last century. The spatial distribution of annual mean temperature trend for the country is shown in fig. 6.3 by isotherms and in fig. 6.4 by shade for regions. Both figures are for 1951-2000.

Fig 6.3 Pakistan: Spatial Change in Mean Annual temperature 1951-2000



Source: Source: Farooqi, Khan and Mir, 2005

Fig 6.4 Pakistan: Mean temperature trend in ˚C (Annual) 1951-2000



Source: Source: Farooqi, Khan and Mir, 2005

Regional variations of temperature data during 50 years (1951-2000) for 60 stations in table 6.1 reveals that the annual mean temperature rose by 0.6-1.0°C in arid coastal areas, arid mountains and hyper arid plains. Summer (April-May) temperatures increased in all parts of Pakistan. The Balochistan Plateau became warmer in all the seasons over the same period. In all other regions, the monsoon (July-September) temperatures dropped.

Table 6.1 Pakistan: Region-wise Mean Temperature Trends (°C) 1951-2000

Region/Seasons	Annual	Monsoon (Jun-Sep)	Winter (Dec-Mar)	Apr-May	Oct-Nov
Zone I(a): Greater Himalayas (Winter dominated)	0.04	-0.80	0.32	1.09	-0.06
Zone I(b): Sub-montane Region and Monsoon dominated	-0.19	-0.57	0.00	0.13	0.12
Zone II: Western Highlands	-0.72	-1.48	-0.65	0.17	-0.47
Zone III: Central and southern Punjab	0.11	-0.25	0.03	0.83	0.31
Zone IV: Lower Indus Plain	-0.08	-0.55	-0.07	0.35	0.15
Zone V(a): Balochistan Province (Sulaiman & Kirther Ranges)	0.44	0.11	0.36	0.63	0.86
Zone V(b): Balochistan Plateau (Western)	1.17	1.30	0.43	2.17	1.80
Zone VI: Coastal Belt	0.00	-0.18	0.05	0.03	0.30

Source: GCSIC, 2009a

Winter temperatures showed higher trends in the desert region and coastal region except around Pasni and Ormara. However, winter temperatures fell over Western Highland and the Lower Indus Plains. Over two-third of the stations showed an increasing trend during April-May. Likewise temperatures showed an increasing trend in all regions except in the Western Highlands and Greater Himalayas during October-November. The analyses of the historical data for the Greater Himalayan region (the abode of sizeable glaciers feeding the Indus River System) showed a warming trend on an annual basis as well in all seasons except the monsoon season (GCSIC, 2009). All these changes and seasonal variations have important implications for water resources and agriculture of Pakistan in general and its mountainous areas in particular.

Table 6.2 Pakistan: Region-wise Distribution of Monthly Mean Maximum Temperature Trends (°C) 1951-2000

Region/Seasons	Annual	Monsoon (Jun-Sep)	Winter (Dec-Mar)	Apr-May	Oct-Nov
Zone I(a): Greater Himalayas (Winter dominated)	0.63	-0.16	0.73	1.91	0.98
Zone I(b): Sub-montane Region and Monsoon dominated	0.04	-0.46	0.08	0.55	0.29
Zone II: Western Highlands	-0.42	-1.10	-0.55	0.78	-0.25
Zone III: Central and southern Punjab	0.14	-0.20	0.54	0.78	-0.06
Zone IV: Lower Indus Plain	-0.02	-0.17	-0.33	0.63	0.08
Zone V(a): Balochistan Province (Sulaiman & Kirther Ranges)	0.54	0.36	0.53	0.86	0.59
Zone V(b): Balochistan Plateau (Western)	0.83	1.23	0.10	1.97	1.17
Zone VI: Coastal Belt	0.08	-0.08	-0.20	-0.25	0.43

Source: GCSIC, 2009a

Temperature Extremes

Widespread changes in extreme temperatures have been observed over the 1951-2000 period. Cold days, cold nights and frost have become less frequent, while hot days, hot nights, and heat waves have become more frequent. Trends in monthly mean maximum and minimum temperatures for 1951-2000 have been given in tables 6.2 and 6.3. It is important to point out that more than 75 percent of the stations in the Greater Himalayan Region recorded an increase in the extreme temperatures, which indicates a higher likely rate of snow and glacier melt. Balochistan Plateau also experienced similar higher temperature extremes.

Table 6.3 Pakistan: Region-wise Distribution of Monthly Mean Minimum Temperature Trends (°C) 1951- 2000

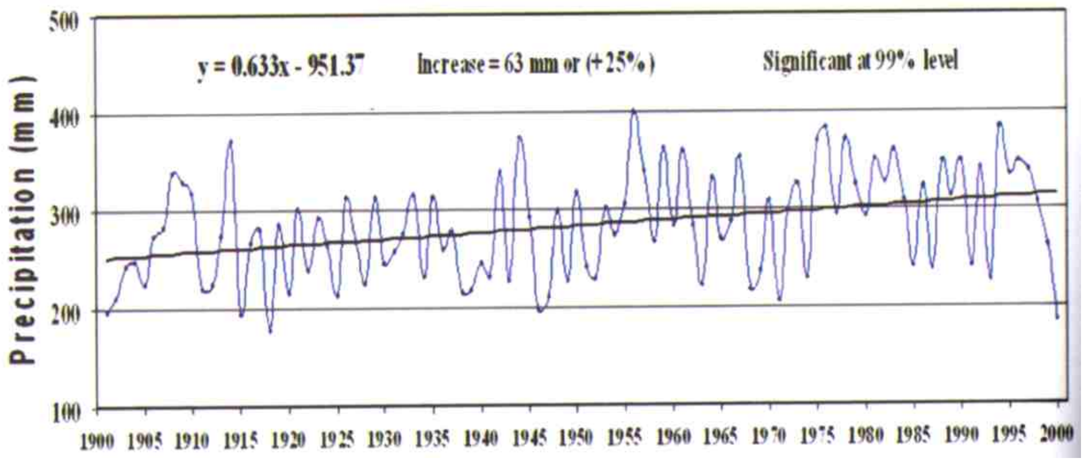
Region/Seasons	Annual	Monsoon (Jun-Sep)	Winter (Dec-Mar)	Apr-May	Oct-Nov
Zone I(a): Greater Himalayas (Winter dominated)	-0.80	-1.58	-0.23	-0.10	-1.23
Zone I(b): Sub-montane Region and Monsoon dominated	-0.32	-0.14	-0.14	-0.19	-0.08
Zone II: Western Highlands	-0.45	-1.10	-1.10	-0.03	-0.78
Zone III: Central and southern Punjab	0.41	-0.36	0.77	0.76	0.99
Zone IV: Lower Indus Plain	-0.20	-1.18	-0.12	-0.02	0.00
Zone V(a): Balochistan Province (Sulaiman & Kirther Ranges)	0.36	0.10	0.27	0.53	0.96
Zone V(b): Balochistan Plateau (Western)	1.33	1.40	0.67	2.20	2.50
Zone VI: Coastal Belt	0.13	-0.23	0.25	0.43	0.23

Source: GCISC 2009a

6.2.1.2 Precipitation

During the last century, average annual precipitation increased in Pakistan (Fig. 6.5) by 25 percent (GCSIC 2009a). However, the downward trend from 1994-2000, plus the lowest value for 2000 in the 100-year period indicates that the 25% increase need to be taken with some reservations. Nevertheless, there is an overall increase in the wet events in the country: 41 out of 54 meteorological stations recorded an increasing trend in precipitation.

Fig 6.5 Pakistan: Mean Annual Precipitation Trend



Source: GCSIC 2009a

Table 6.4 Pakistan: Region-wise Precipitation Trends (changes in mm /year) 1951-2000

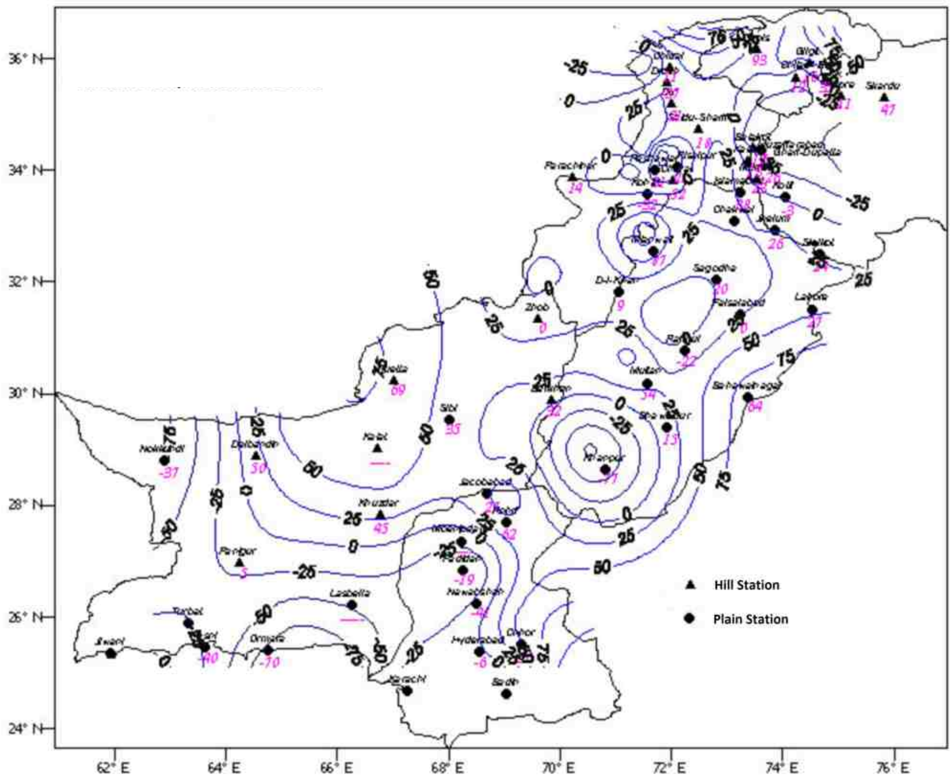
Region/Seasons	Annual	Monsoon (Jun-Sep)	Winter (Dec-Mar)
Zone I(a): Greater Himalayas (Winter dominated)	0.49	1.73	-0.04
Zone I(b): Sub-montane Region and Monsoon dominated	0.30	0.38	0.53
Zone II: Western Highlands	-0.02	0.22	0.00
Zone III: Central and southern Punjab	0.63	0.57	0.99
Zone IV: Lower Indus Plain	0.22	0.45	-0.27
Zone V(a): Balochistan Province (Sulaiman & Kirther Ranges)	1.19	1.16	1.14
Zone V(b): Balochistan Plateau (Western)	0.10	-0.20	-0.40
Zone VI: Coastal Belt	-0.83	-1.34	0.00

Source: GCSIC 2009a

The rate and nature of change, however varied. Precipitation trends for 1951-2000 over Pakistan are shown in table 6.4 and figures 6.6 and 6.7. It can be seen that monsoon precipitation increased in the country with a few exception. The Greater Himalayan region experienced the highest increase in Monsoon precipitation (86 percent), while the coastal region (where it dropped significantly) and the Western Balochistan saw a decrease in precipitation.

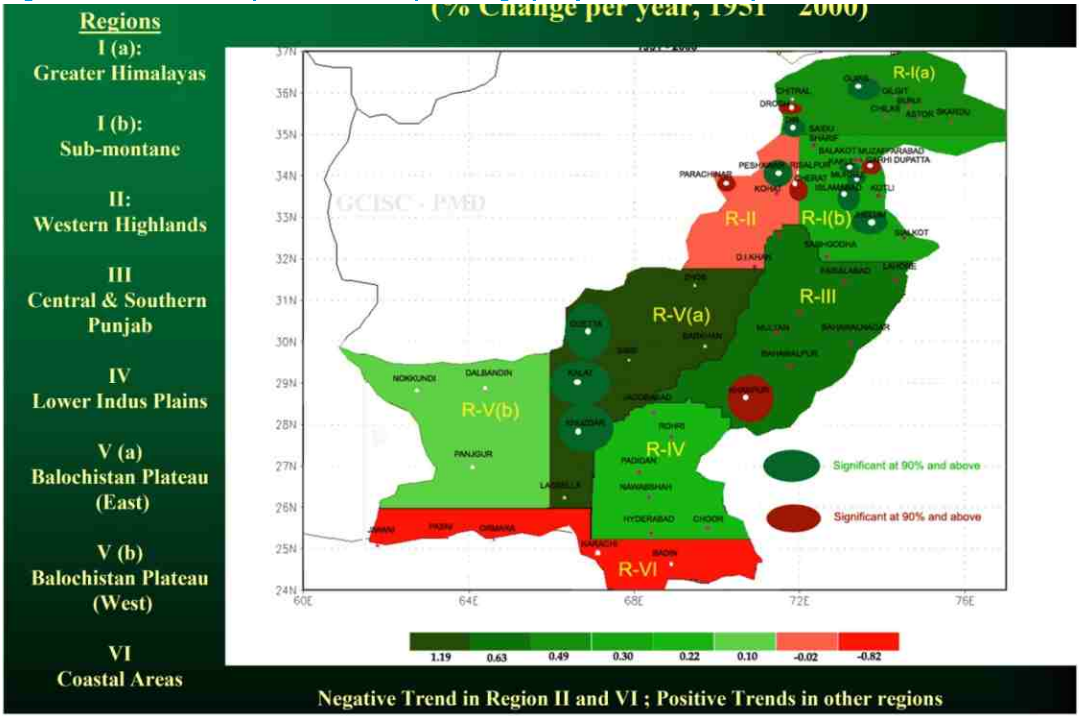
Winter rains (December-March), increased significantly in sub-montane areas, central and southern Punjab and in region V (a) of Balochistan Province (Fig 6.7). The Greater Himalayan region saw a nominal decrease (-2 percent) in precipitation during this period. The decreasing trend in precipitation was also noted in region V (b) of Balochistan Province. Mixed trends are seen in other regions (GCSIC, 2009a).

Fig. 6.6 Pakistan: Spatial Change in Mean Annual Precipitation 1951-2000



Source: Farooqi, Khan and Mir, 2005

Fig. 6.7 Pakistan: Precipitation trend (% change per year, 1951-2000)



Source: GCISC, 2009a

Precipitation Extremes

The frequency of extreme monthly precipitation events during the second half of the previous century increased substantially in the mountainous north, where seven out of nine meteorological stations of the Greater Himalayan Region and eight out of eleven in the sub-montane region recorded such events (Table 6.5). Extreme wet events also increased over the whole of Balochistan Province indicating a change in the distribution pattern of rainfall with many adverse implications not only in terms of flash floods but also for recharge of the underground aquifer because extreme rainfall disappears as run-off.

Table 6.5 Pakistan: Region-wise extreme monthly precipitation trends 1951-2000

Region/Seasons	#Stations With Increasing trend	#Stations with Decreasing trend
Zone I(a): Greater Himalayas (Winter dominated)	7	2
Zone I(b): Sub-montane Region and Monsoon dominated	8	3
Zone II: Western Highlands	3	3
Zone III: Central and southern Punjab	6	2
Zone IV: Lower Indus Plain	4	2
Zone V(a): Balochistan Province (Sulaiman & Kirther Ranges)	7	0
Zone V(b): Balochistan Plateau (Western)	3	0
Zone VI: Coastal Belt	3	1

Source: GCSIC 2009a

6.2.1.3 Other Climate Variables

Among other climate variables, relative humidity decreased by 5% in Balochistan, and solar radiation increased by 0.5 to 0.7% over the southern half of the country. Cloud cover decreased by 3-5% in central Pakistan which increased the sunshine hours, while the evapotranspiration rate enhanced by 3-5% due to a 0.9°C temperature increase. As a result, net irrigation water requirements with no change in rainfall, increased by 5%. There was an expansion of aridity in the northern parts of the country falling outside the monsoon region and areas already receiving scanty rains in winter. 7 strong, 10 moderate and 7 weak El-Nino events occurred over the 1900-2000 period with a 17-64% departure of rainfall from normal (both positive and negative) during the strong events (Farooqi, Khan and Mir, 2005)

A study on the influence of El-Nino Southern Oscillation (ENSO) and North Atlantic Oscillation (NAO) on Pakistan by GCISC (2009a) concluded that El-Nino events are associated with deficient rainfall in the monsoon region. However, the study noted that the pattern changed during the last decade of the previous century when it caused excessive rains. On the other hand La Nina years were generally associated with a rainfall departure (both positive and negative); again the exception were the 1990s.

The North Atlantic Oscillation (NAO) index values had a positive correlation with winter rains for the region extending from 31.5-35 degrees North. Correlation with the winter-dominated region above 35 degrees North was comparatively low (GCSIC, 2009a). The ENSO composite precipitation pattern over South Asia indicated a drastic drop in the rainfall over the upper part of Pakistan (GCSIC, 2009a).

6.3 Extreme Weather Events

Extreme weather events have also become worse in Pakistan. At the turn of the century, the country was experiencing the worst drought in history. The first decade of the 21st century also saw several extreme weather events including the worst floods of history in 2010 (Box 6.1). These floods resulted from a rain intensity that reached 300 mm in a 36-hour period contributing to the highest water levels in 110 years in the Indus River in the northern part of the country. The unprecedented floods affected more than 20 million people (Refugee International, 2010).

Table 6.6: Pakistan: Frequency of Occurrence of Highest Daily Temperature and Heaviest One Day Precipitation Events by Decade (1961-2000)

	1961-70	1971-80	1981-90	1991-2000
Stations that recorded highest daily temperature	4	12	16	20
Stations that recorded highest daily precipitation	6	18	11	17

Source: GCISC 2009a

An analysis of data from 52 meteorological stations in Pakistan over a 40-year period (1961-2000) shows that the frequency of occurrence of highest daily temperature and heaviest rainfall events in 24 hours (Table 6.6) have increased by passing decades (GCISC, 2009a).

Box 6.1 Pakistan: Extreme Weather Events of Twenty First Century

2011	Floods in Pakistan's southern province of Sind affected 22 out of 23 districts claiming 500 lives. Nearly 2.2million ha cropland was damaged and 72 percent of crops were lost in the worst affected areas. 1.6 million homes were destroyed
2010	Monsoon rainfall of 300 mm over a 36-hour period resulted in swelling of rivers causing the history's worst flood in Pakistan. The unprecedented flood submerged twenty percent of the country's area.
2009	Karachi received 205 mm of rain at Masroor Airbase and 143 mm at Airport on 18 and 19 July. The previous heaviest rainfall recorded at Karachi Airport was 207 mm on 1st July 1977. Normal rainfall at Karachi Airport for the periods 1961-1990 and 1971-2000 was 85.5 mm and 66.2 mm respectively.
2007	A record heat wave gripped Pakistan during June 2007. The temperature reached 48°C on 9th June at Lahore, repeating the record of 78 years earlier on 8th June 1929.
2007	Two super cyclones Gonu (02A) of Cat-5 and Yemyin (03B) of Cat-1 developed in the Arabian Sea during June 2007 and hit Makran coast of Pakistan and adjoining countries. Not ever before two such events occurred in the same month in the Arabian Sea.
2006	Monsoon-related flooding in Pakistan resulted in more than 185 deaths between late July and mid-August 2006. In neighbouring eastern Afghanistan, heavy rainfall generated flooding that claimed at least 35 lives.
2005	Heavy rain caused flooding in parts of Balochistan, Khyber Pakhtunkhwa and Afghanistan during March. There were more than 30 fatalities in south-western Pakistan.
2005	During June, unusually warm temperatures in the mountainous areas of northern Pakistan occurred, accelerating snowmelt and causing extensive flooding along the Kabul, Swat, Kunar and Chitral rivers.
2003	Heavy rain and snow produced flooding during February (around 17th) and was responsible for more than 60 deaths in Balochistan province. Flash floods washed away parts of roads and highways.
2003	Seasonal monsoon rains affected at least one million people in southern Pakistan. Heavy rains caused 162 deaths, 153 in the Sind province.
2003	During early June, a heat wave caused maximum temperatures to reach 52°C at Jacobabad on the 5th of June; normal highs in early June are around 44°C.
2001	621 mm rainfall in Islamabad during 10 hours on 23rd July; it caused flooding in Lai Nullah (rivulet).
1998-2001	History's worst drought gripped southern parts of Pakistan and parts of surrounding countries.

6.4 Future Climate Projections for Pakistan

A number of studies have developed future climate change scenarios for Pakistan (Box 6.2). The Global Change Impact Studies Centre (GCSIC) has taken the lead in this respect. It has developed high-resolution climate change scenarios for South Asia as well as Pakistan using the Regional Climate Model RegCM3, developed by the Physics of the Weather and Climate (PWC) group of the Abdus Salam International Centre for Theoretical Physics (ICTP), Italy (GCSIC, 2009b).

Box 6.2 Pakistan's Predicted Climate Change

The Intergovernmental Panel on Climatic Change (IPCC) 4^{th} assessment, based on the projection of future global climate with the help of various Global Circulation Models predict somewhat higher temperature increases in the region where Pakistan is located as compared to average global temperature increase. Research at the Global change Impact Studies Centre (GCISC) in Pakistan has shown a strong correlation between the projections of the IPCC and modelling based on historical weather in Pakistan. Studies based on ensemble outputs of several Global Circulation Models (GCMs) project that the average temperature over Pakistan will increase progressively by 2.8-3.4°C upto 2100. Precipitation is projected to increase slightly in summer and decrease in winter with no significant change in annual precipitation. It is also projected that climate change will increase the variability of monsoon rains and enhance the frequency and severity of extreme events such as floods and droughts.

Source: IPCC, 2000a and 2000b; GOP, 2010; GCISC, 2009b

SRES Scenarios for Pakistan

The model was run at 50 km horizontal resolution. It was calibrated for the period 1961-1990 and simulations for future climate were conducted for the period 2040-2069 & 2071-2100. These simulations were driven by the lateral boundary conditions from two Global Circulation Models, ECHAM5 and FVGCM. The analytical results for Pakistan show that the temperature increases in summer in the coming decades will be higher than those in winter. The model projects a decrease in summer precipitation.

Model simulated temperature and precipitation from ERA40, ECHAM5 and the Finite Volume General Circulation Model (FVGCM) averaged over Pakistan, were compared by the Climate Research Unit (CRU). ECHAM5 gave better results in summer and on annual basis whereas FVGCM showed better results in winter. The root mean square error (RMSE) in winter was less as compared to ECHAM5. Similarly the correlation was quite high for the model outputs from ERA40 and ECHAM5 as compared to FVGCM. The RMSE was less in case of ERA40 as compared to ECHAM5 and FVGCM, which showed that the model driven by re-analysis datasets gave better performance than the model driven by the GCM datasets.

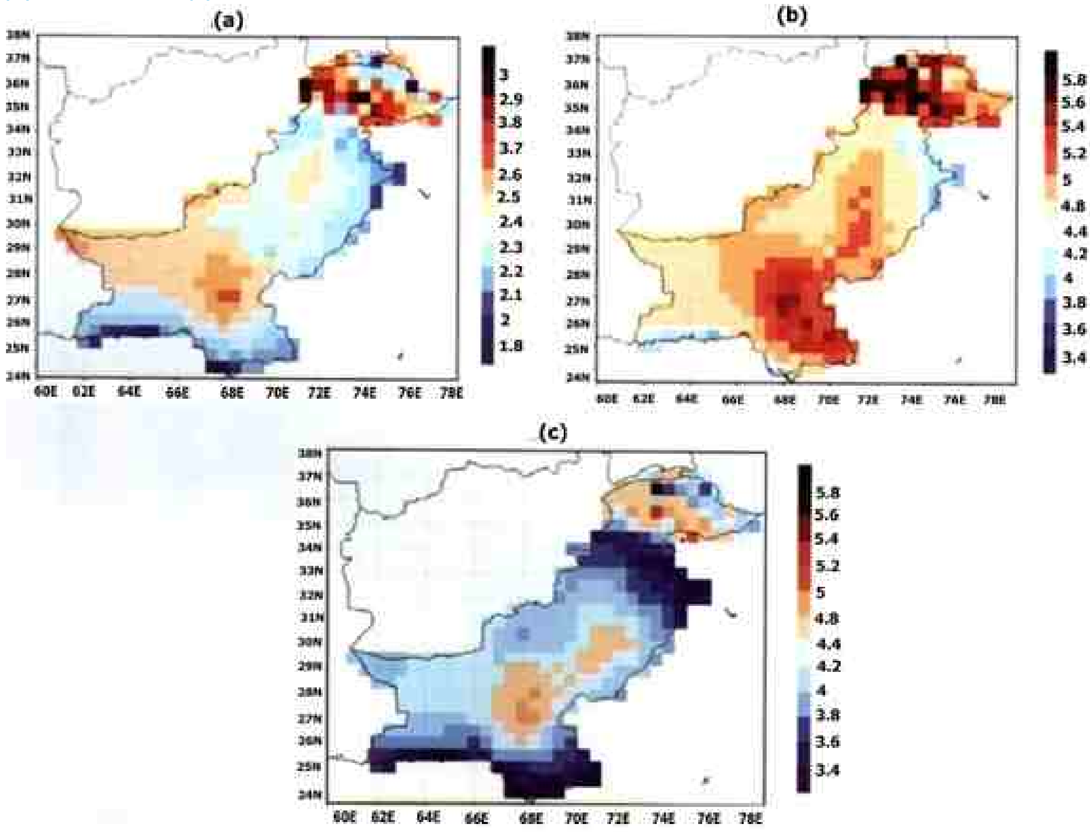
Three time slices were selected for scenario experiments, one for the base i.e. 1960-1990 and two time slices for future namely F1 (2040-2060) and F2 (2071-2100).

6.4.1 Temperature Change

6.4.1.1 Annual Temperature Change

In case of ECHAM5-F1 (Fig 6.8a), the model predicts a 2-3°C rise in temperature over Pakistan; with 2.4-2.6°C increase over Balochistan, desert areas, part of central Punjab and part of Sind province and 2.8-3°C increase over the Northern region of the country. ECHAMS-F2 (Fig 6.8b), predicts a rise of about 4.4-5.8°C over most parts of Pakistan and 5-5.8°C increase over the Northern region and South-eastern regions of the country. This value was higher than the prediction made by the IPCC for the A2 scenario. FVGCM-F2 (Fig 6.8c), predicted a lesser increase in temperature as compared to the ECHAM5-F2 projections. The spatial patterns were in close agreement for both the projections, as more warming was observed over the Northern region of Pakistan, desert areas and part of Southern Punjab as compared to the other regions of the country.

Fig. 6.8 Pakistan Annual Change in Temperature (°C) Simulated by RegCM3; (a) ECHAM5-F1 (b) ECHAM5 F2, (c) FVGCM-F2



6.4.1.2 Seasonal Temperature Change

a. Summer (JJAS)

A rise in temperature of about 1.9-3.7°C is predicted for Pakistan by ECHAM5-F1 (Fig. 6.9a) with the maximum increase in temperature over the north-western region of the country. The model predicts a rise of about 2.5-3.1°C over Balochistan, desert areas and part of Sind province.

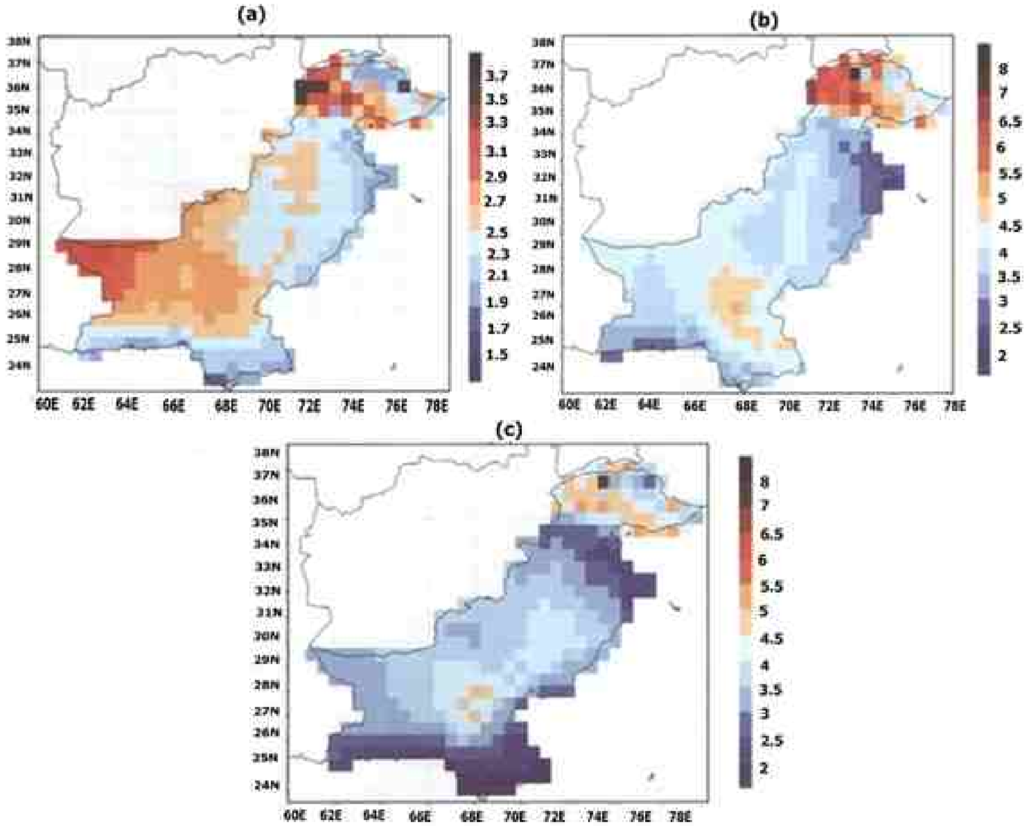
ECHAM5-F2, (Fig. 6.9b) projects a rise of about 2-8°C all over Pakistan with the greater increase predicted over northern region and desert areas of Pakistan. In north-western part, an increase of about 5- 8°C is predicted, whereas in the eastern part, the rise in temperature comes to 3.5-4°C. In Punjab, the maximum rise of temperature is about 4.5°C.

FVGCM-F2 (Fig 6.9c) projects less warming compared to the ECHAM5-F2. FVGCM also predicts a greater warming over the Northern region of Pakistan like ECHAM5. The model simulates a rise of 4.5-6°C.

b. Winter (DJFM)

The temperature changes for the winter (DJFM) over Pakistan in F1 and F2 scenarios are shown in fig 6.10. ECHAM5-F1 (Fig. 6.10a) projects a temperature rise of about 2-2.5°C for the winter season. A maximum rise of

Fig. 6.9 Pakistan Seasonal Change in Temperature (°C) for Summer Simulated by RegCM3; (a) ECHAM5-F1, (b) ECHAM5 F2, (c) FVGCM-F2



about 2.25-2.55°C is projected for Northern region, deserts, southern Punjab, Sind, and Northern part of Balochistan.

In case of ECHAM5-F2 (Fig 6.10b), a rise of about 4-5.5°C is predicted by the model with a maximum increase (above 5°C) over the Northern region, part of central Punjab, and in the south-eastern part of Sindh province. This predicted temperature is on the higher side as compared to the IPCC prediction for the region. The over predicted rise over the Northern region might be due to the complex topography, which is difficult to simulate accurately.

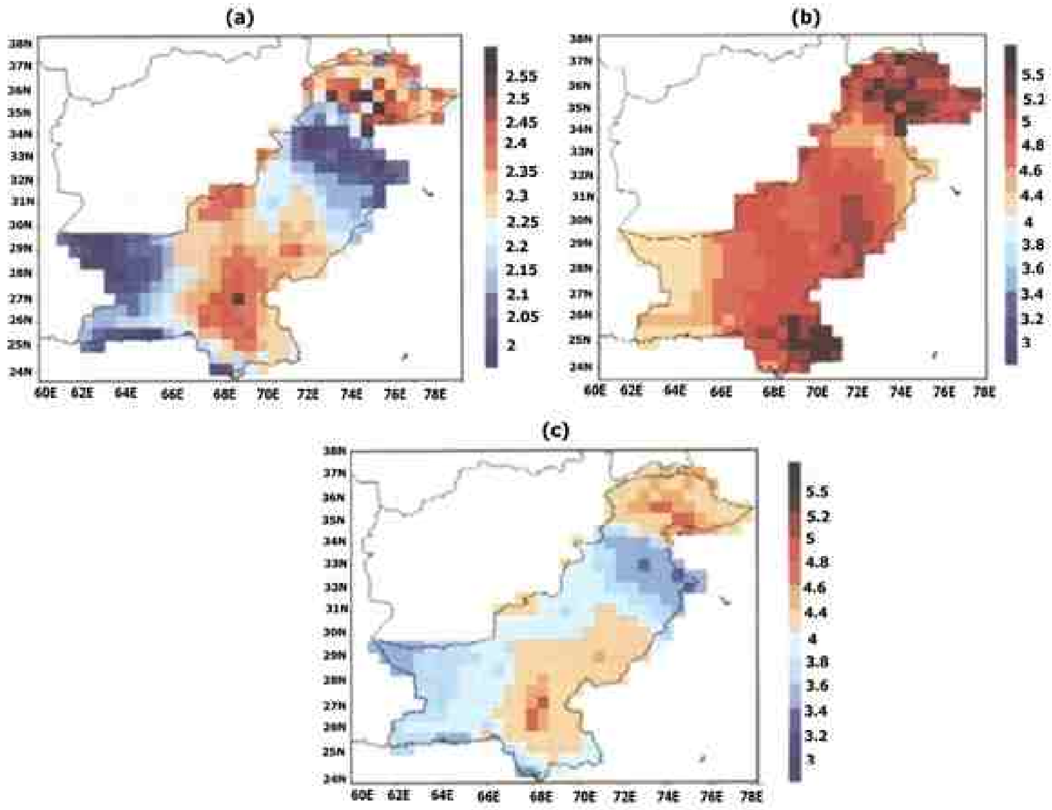
FVGCM-F2 (Fig 6.10c) projects less warming compared to ECHAM5-F2. The model for Pakistan as a whole gives a rise of 3.4-4.8°C. The maximum rise is predicted for the northern region, the central-southern Punjab region, desert areas, and part of Sindh province.

6.4.2 Precipitation Change

6.4.2.1 Annual Precipitation Change

The overall precipitation change pattern is similar from all models (Fig 6.11a, b & c). However there is a difference in the magnitude. ECHAM5-F1 (Fig 6.11a) does not show a significant change in annual precipitation for Pakistan. The spatial pattern shows a non-significant increase of precipitation over the

Fig. 6.10 Pakistan Seasonal Change in Temperature (°C) for Winter Simulated by RegCM3; (a) ECHAM5-F1, (b) ECHAM5 F2, (c) FVGCM-F2



Northern region of 5-15 percent and a 10-20 percent decrease over the Southern region of the country. ECHAM5-F2 (Fig. 6.11b) predicts an increase in precipitation by about 5-20 percent in the Northern region of Pakistan, whereas it predicts a decrease in precipitation of about 5-50 percent in the Southern region and 5-30 percent in Central Punjab & Balochistan region. In some parts of Balochistan and Khyber Pakhtunkhwa, an increase of precipitation by about 10-20 percent is predicted. In southern Punjab, the model predicts a decrease in precipitation, whereas no significant change is observed over the Monsoon belt in the Punjab.

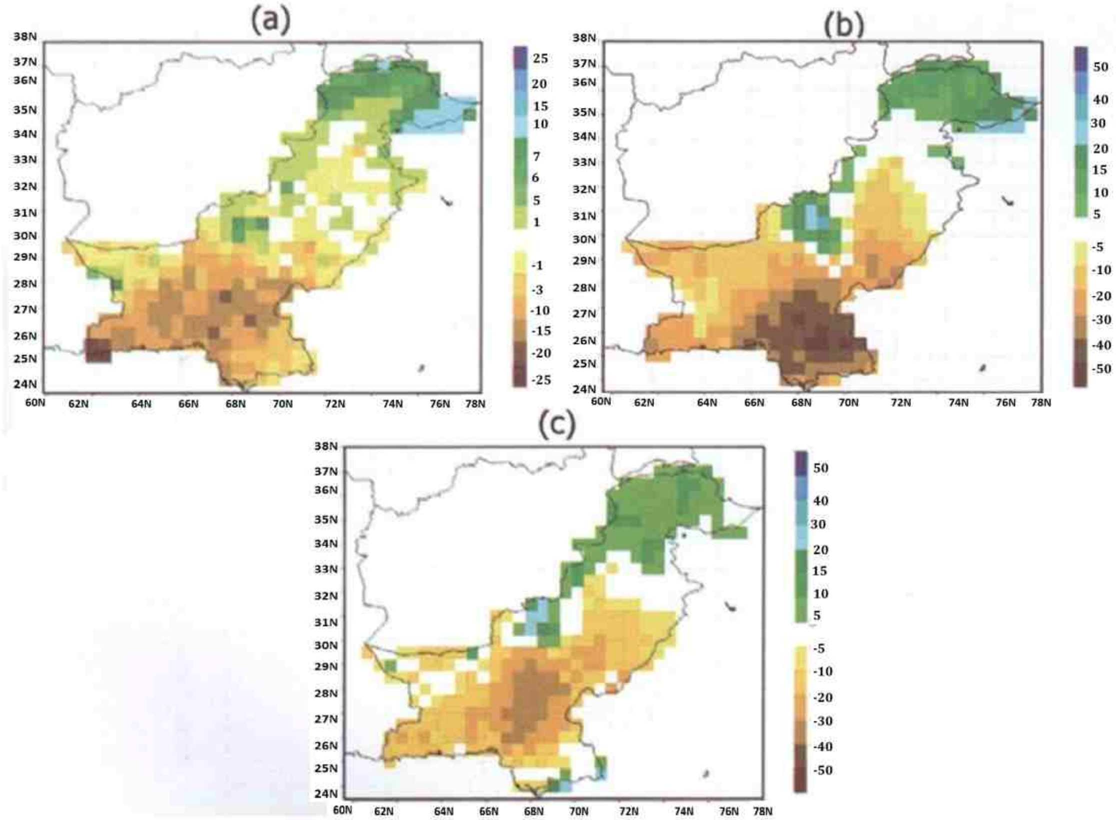
FVGCM-F2 (Fig.6.11c), projects a decrease in precipitation by about 20-30 percent over the desert areas, 5-20 percent over central and southern Punjab and about 5-10 percent over parts of Balochistan. The model predicted an increase of about 5-20 percent over the Northern region and some parts of the Khyber Pakhtunkhwa province. No significant change is observed in the Monsoon belt of the country on annual scale.

6.4.2.2 Seasonal Precipitation Change

a. Summer (JJAS)

The changes in precipitation for F1 and F2 for summer (JJAS) over Pakistan are shown in Fig. 6.12. ECHAM5-F1 (Fig. 6.12a) shows a decrease of about 5-20 percent over the southern region and parts of northern region of Pakistan, whereas an increase in precipitation of about 5-50 percent is predicted in parts of Khyber Pakhtunkhwa and Balochistan provinces and in the Monsoon belt of the country. No significant change was observed for other regions of Pakistan.

Fig.6.11. Pakistan Annual Change in Precipitation (%); (a) ECHAM5-F1, (b) ECHAM5-F2, (c) FVGCM-F2 simulated by RegCM3



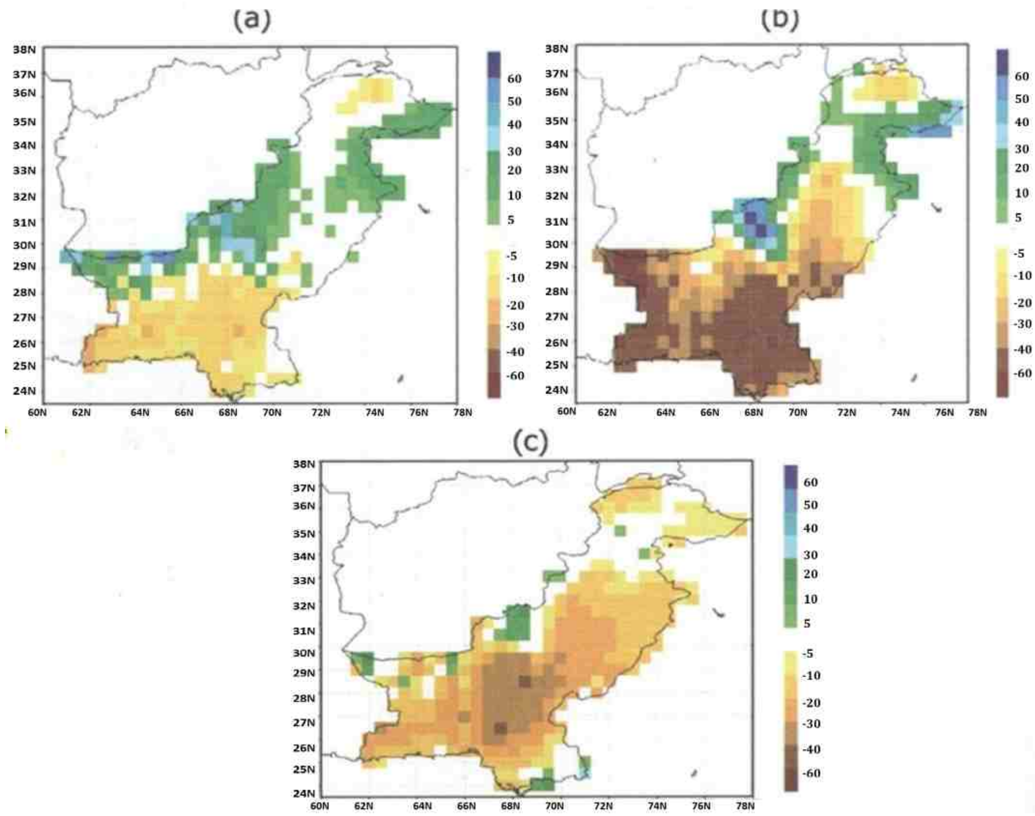
In case of ECHAM5-F2 (Fig.6.12b), the model predicts a decrease in precipitation of about 60 percent in desert areas of the Sind region, and south-western parts of Balochistan, while about 20 percent decrease in precipitation is observed in the extreme north of Pakistan. An increase of about 10-30 percent is projected for the monsoon belt and a decrease of about 10-30 percent for central Punjab. FVGCM-F2 (Fig 6.12c) overall predicts a decrease in summer precipitation over Pakistan. The decrease is more over desert areas of Pakistan, around 30 percent.

b. Winter (DJFM)

The future projections of precipitation for the winter (DJFM) season are given in fig. 6.13. ECHAM-F1, except for the northern region, predicts a decrease of about 5-35 percent. Over the northern region and some parts of southern Pakistan, the change is within 5-35 percent. ECHAM5-F2 (Fig 6.13b) predicts a decrease of 5-35 percent in winter precipitation except for the extreme north of the country. FVGCM-F2 (Fig 6.13c), predicts a different precipitation change pattern: a decrease in precipitation in the Balochistan province, and for most other parts of Pakistan an increase in precipitation. The maximum increase is in central Punjab, where it is more than 35 percent. Over the northern region, the increase is within 10-25 percent.

Overall precipitation patterns by all the models are similar. However there is a difference in magnitude. ECHAM5-F1 does not show a significant change in annual precipitation for the country. The spatial pattern

Fig.6.12. Pakistan: Seasonal Change in Precipitation for summer (%); (a) ECHAM5-F1, (b) ECHAM5-F2, (c) FVGCM-F2 simulated by RegCM3



shows an increase of precipitation over Northern Pakistan and a decrease over Southern Pakistan but the change is not significant.

6.5 Future Projections for Regions of Pakistan

6.5.1 Scenarios for Northern and Southern Pakistan

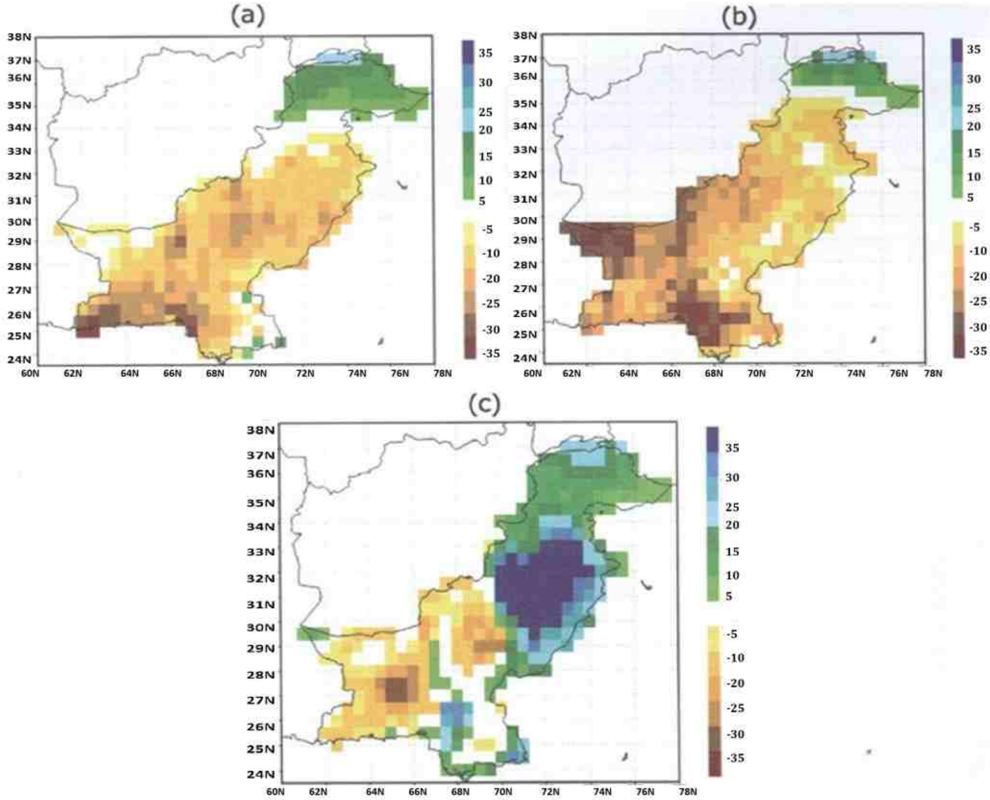
6.5.1.1 Temperature Change

The projected changes in temperature in the 2080s (representing average for 2070-2099) are compared to the base period (1960-1990) in table 6.7 for Northern and Southern Pakistan (separated at 31˚N) for the IPCC high and medium range scenarios A2 and A1B respectively (GCISC 2009b). The results are based on the outputs of ensembles of several GCMs used in the IPCC AR4 (a 13-GCM ensemble for the A2 scenario and a 17-GCM ensemble for the A1B scenario). According to AR4, the average global surface temperature is projected to increase in the A2 and A1B scenarios by 3.4°C and 2.8°C respectively during the 21st century.

The summary of the findings is as follows:

- The temperature will increase in Northern Pakistan as well as in Southern Pakistan. The increase is higher for A2 than A1B.

Fig.6.13. Pakistan: Seasonal Change in Precipitation for winter (%); (a) ECHAM5-F1, (b) ECHAM5-F2, (c) FVGCM-F2 simulated by RegCM3



- In each scenario the temperature increase in Northern Pakistan is more than that in Southern Pakistan, in line with the IPCC global scenarios, which show a higher temperature increase over Central Asia compared to South Asia.
- The temperature increase in both Northern and Southern Pakistan in each scenario is higher than the corresponding globally averaged temperature increase (for the A2 scenario, the projected temperature increases by 2080 for Northern and Southern Pakistan are 4.7°C and 4.2°C respectively compared to 3.4°C average global temperature increase; for the A1B scenario, the corresponding values are 4.1°C, 3.7°C and 2.8°C respectively). The current annual average temperatures for Northern and Southern Pakistan are about 19 °C and 24 °C respectively.

The temperature increases for Pakistan as a whole, in the 2020s, 2050s and 2080s are 1.3°C, 2.5°C and 4.4°C in A2 scenario and 1.5°C, 2.8°C and 3.9°C in the A1B scenario. Projected changes in seasonal temperature for A2 and A1B scenarios (Table 6.7) show that in each scenario a) the temperature increases in both summer and winter will be higher in Northern Pakistan than in Southern Pakistan, and (ii) the temperature increases in both Northern and Southern Pakistan will be higher in winter than in summer.

6.5.1.2 Precipitation Change

The GCM ensemble based precipitation projections are much less certain than those for temperature due to limitations of the current generation of Global Circulation Models for modelling precipitation. Although the

Table 6.7 Projected temperature (°C) changes by 2080 for A2 and A1B Scenarios

	Average Annual Temperature Change (°C) by 2080		
	A2 Scenario		
	Pakistan	Northern Pakistan	Southern Pakistan
Annual	4.4 ± 0.4	4.7 ± 0.2	4.2 ± 0.2
Summer (JJAS)	4.1 ± 0.3	4.6 ± 0.3	3.9 ± 0.3
Winter (DJFM)	4.5 ± 0.2	4.7 ± 0.2	4.3 ± 0.2
	A1B Scenario		
	Pakistan	Northern Pakistan	Southern Pakistan
Annual	3.9 ± 0.2	4.1 ± 0.2	3.7 ± 0.2
Summer (JJAS)	3.7 ± 0.2	4.1 ± 0.3	3.5 ± 0.2
Winter (DJFM)	3.9 ± 0.2	4.1 ± 0.2	3.8 ± 0.2

Source: GCSIC, 2009b

precipitation projections by various GCMs vary a great deal, the analysis conducted by GCISC (GCISC, 2009b) using the ensemble outputs of 13 GCMs for the A2 scenario and 17 GCMs for the A1B scenario (Table 6.8)

Table 6.8 Projected precipitation changes (%) by 2080 for A2 and A1B Scenarios

	Average Precipitation Change (%)		
	A2 Scenario		
	Pakistan	Northern Pakistan	Southern Pakistan
Annual	3.5 ± 5.8	1.1 ± 4.0	4.3 ± 9.5
Summer (JJAS)	12.2± 8.9	7.1 ± 8.4	51.1 ± 39.8
Winter (DJFM)	-5.1 ± 4.8	-2.2 ± 4.1	-20.5 ± 9.1
	A1B Scenario		
	Pakistan	Northern Pakistan	Southern Pakistan
Annual	-0.4 ± 4.4	-0.7 ± 3.1	-0.9 ± 7.9
Summer (JJAS)	3.9 ± 6.9	2.0 ± 5.7	37.6 ± 34.0
Winter (DJFM)	-6.3 ± 3.6	-4.1 ± 3.1	-15.1 ± 7.6

Source: GCSIC, 2009b

indicates that precipitation is likely to increase in summer and decrease in winter in both Northern and Southern Pakistan, with no significant change in the annual precipitation.

6.5.2 Scenarios for Eight Climatic Regions of Pakistan

6.5.2.1 Projected Temperature Change

a. Annual Temperature Change

Future projected annual temperatures for different regions of Pakistan are given in table 6.9. In case of ECHAM5-F1, a slightly higher rise in temperature is observed in Greater Himalayas compared to other regions. For F2 projections of ECHAM5 and FVGCM, slightly higher temperature is observed over Greater Himalayas and lower Indus Plains. Moreover, ECHAM5-F2 shows more warming as compared to FVGCM F2 projections.

Table 6.9 Projected Region-wise changes in average annual temperature

Regions	Annual		
	RegCM3 - ECHAM5		RegCM3 - FVGCM
	F1	F2	F2
	∆ T (°C)	∆ T (°C)	∆ T (°C)
I (a): Greater Himalayas	2.53	5.32	4.37
I (b): Sub-montane	2.37	4.68	3.88
II: Western Highlands	2.35	4.71	3.89
III: Central & Southern Punjab	2.34	4.80	4.20
IV: Lower Indus Plains	2.46	5.12	4.33
V (a): Balochistan Plateau (East)	2.42	4.85	4.25
V (b): Balochistan Plateau (West)	2.43	4.67	4.20
VI: Coastal Areas	2.12	4.44	3.48

b. Seasonal Temperature Change

The projected values of temperature for summer (JJAS) and winter are given in tables 6.10 and 6.11. For summer, ECHAM5-F1 projects more warming in Balochistan Plateau (west) whereas ECHAM5-F2 gives more warming in the lower Indus Plains. FVGCM-F2 shows the highest temperature rise in Balochistan Plateau (East). In winter, the highest increase is observed over Greater Himalayan Region. Moreover, ECHAM5-F2 shows more warming as compared to FVGCM-F2 for all the climatic zones.

6.5.2.2 Projected Precipitation Change

a. Annual Precipitation Change

ECHAM5 (F1 & F2) and FVGCM-F2 show a significant increase in precipitation over the Greater Himalayas

Table 6.10 Projected Region-wise Changes of Summer temperatures

Regions	Summer (JJAS)		
	RegCM3 - ECHAM5		RegCM3 - FVGCM
	F1	F2	F2
	ΔT (°C)	ΔT (°C)	ΔT (°C)
I (a): Greater Himalayas	2.60	5.50	4.46
I (b): Sub-montane	2.34	4.51	4.06
II: Western Highlands	2.47	4.85	4.29
III: Central & Southern Punjab	2.34	4.85	4.79
IV: Lower Indus Plains	2.52	5.59	4.69
V (a): Balochistan Plateau (East)	2.56	5.19	4.86
V (b): Balochistan Plateau (West)	2.85	5.14	4.53
VI: Coastal Areas	2.06	4.42	3.25

Table 6.11 Projected Region-wise Changes of Winter temperatures

Regions	Winter (DJFM)		
	RegCM3 - ECHAM5		RegCM3 - FVGCM
	F1	F2	F2
	ΔT (°C)	ΔT (°C)	ΔT (°C)
I (a): Greater Himalayas	2.27	5.07	4.35
I (b): Sub-montane	2.10	4.77	3.89
II: Western Highlands	2.06	4.74	3.85
III: Central & Southern Punjab	2.12	4.85	4.05
IV: Lower Indus Plains	2.26	4.90	4.27
V (a): Balochistan Plateau (East)	2.20	4.76	3.99
V (b): Balochistan Plateau (West)	2.00	4.30	3.72
VI: Coastal Areas	2.07	4.57	3.75

(Table 6.12). Increase in precipitation over central and southern Punjab and a decrease in precipitation over lower Indus Plains, Balochistan Plateau (west) and in coastal areas is predicted under F2 projections.

Table 6.12 Projected Region-wise Changes in Average Annual Precipitation

Regions	Annual		
	RegCM3 - ECHAM5		RegCM3 - FVGCM
	F1	F2	F2
	ΔP (%)	ΔP (%)	ΔP (%)
I (a): Greater Himalayas	7.46	12.59	7.97
I (b): Sub-montane	3.63	6.95	5.32
II: Western Highlands	1.20	-0.65	3.67
III: Central & Southern Punjab	2.15	12.62	12.79
IV: Lower Indus Plains	-14.08	-14.63	-24.99
V (a): Balochistan Plateau (East)	-4.69	7.10	-13.84
V (b): Balochistan Plateau (West)	-8.06	-12.86	-14.53
VI: Coastal Areas	-11.85	-31.62	-5.77

b. Seasonal Precipitation Change

In case of summer (Table 6.13), ECHAM5-F2 and FVGCM-F2 predict a significant decrease in precipitation over lower Indus Plains and Central and Southern Punjab.

Table 6.13 Pakistan Projected Region wise Changes in Precipitation in Summer

Regions	Summer (JJAS)		
	RegCM3 - ECHAM5		RegCM3 - FVGCM
	F1	F2	F2
	∆ P (°C)	∆P (°C)	∆P (°C)
I (a): Greater Himalayas	-0.98	0.79	-7.26
I (b): Sub-montane	9.29	13.68	-4.69
II: Western Highlands	5.98	-1.23	-5.70
III: Central & Southern Punjab	1.99	-18.07	-19.29
IV: Lower Indus Plains	-11.42	-50.22	-26.81
V (a): Balochistan Plateau (East)	5.20	-10.53	-22.23
V (b): Balochistan Plateau (West)	-6.69	-41.53	-19.47
VI: Coastal Areas	-9.35	-42.43	-7.44

In case of winter (Table 6.14), ECHAM5 (F1 & F2) gives no significant change in precipitation in all climatic regions except the Greater Himalayas. FVGCM-F2 shows a significant increase over Greater Himalayas, sub-Montane, Western Highlands and central & southern Punjab whereas there is no significant change in other zones. In case of winter precipitation: ECHAM5-F2 and FVGCM-F2 show a significant decrease in precipitation over lower Indus Plains and central & southern Punjab.

Table 6.14 Projected Region wise Changes of Precipitation in Winter

Regions	Winter (DJFM)		
	RegCM3 - ECHAM5		RegCM3 - FVGCM
	F1	F2	F2
	∆ P (°C)	∆P (°C)	∆P (°C)
I (a): Greater Himalayas	14.44	9.22	15.02
I (b): Sub-montane	0.74	-7.29	14.44
II: Western Highlands	0.05	-11.58	17.33
III: Central & Southern Punjab	-16.89	-11.48	30.38
IV: Lower Indus Plains	-17.83	-22.30	3.23
V (a): Balochistan Plateau (East)	-18.99	-25.52	-1.03
V (b): Balochistan Plateau (West)	-11.65	-28.76	-10.17
VI: Coastal Areas	-25.92	-23.94	-1.03

6.6 Conclusions

Following the global trend the average annual temperature over Pakistan has increased by 0.6°C during the last century. The rate and nature of this change not only varies over time but also across the country. The temperature increase over northern Pakistan was higher than over its southern part (0.8°C versus 0.6°C). It was also higher in the second half compared to the first half of the last century. In terms of regional variations during 1951-2000 the mean annual temperature rose by 0.6-1.0°C in arid coastal areas, arid mountains and hyper arid plains while summer temperatures (both mean and maximum) increased in all parts of Pakistan. Widespread changes in extreme temperatures were observed over the same period with more frequent occurrence of hot days, hot nights and heat waves. Average annual precipitation has increased in Pakistan in the 20th century. There has been an overall increase in wet events in the country. Precipitation trends for the 1951-2000 period indicate that monsoon precipitation increased in the country with a few exceptions. The Greater Himalayan region experienced the highest increase in Monsoon precipitation (86 percent), while the coastal regions (where it dropped significantly) and the Western Balochistan saw a decrease in precipitation.

Extreme weather events have also enhanced in Pakistan. An analysis of data from 52 meteorological stations in Pakistan over a 40-year period (1961-2000) showed that the frequency of highest daily temperature and heaviest rainfall events have increased in the passing decades. At the turn of the century, the country experienced the worst drought in its history. The first decade of the 21st century also saw several extreme weather events including the history's worst flood in 2010. This flood resulted from a rain intensity reaching 300 mm over a 36-hour period resulting in the highest water levels in 110 years in the Indus River in the northern part of the country. This unprecedented flood submerged one-fifth of the country and affected more than 20 million people.

The IPCC assessments based on the projection of future global climate with the help of various Global Circulation Models predict somewhat higher temperature increases in the region where Pakistan is located as compared to average global temperature increase. The research conducted at the Global Change Impact Studies Centre (GCISC) in Pakistan, based on historical weather data and modelling has shown a strong correlation with the IPCC's predictions and projections for Pakistan. Studies based on the ensemble outputs of several Global Circulation Models (GCMs) project that the average temperature over Pakistan will increase progressively corresponding to an increase in average global surface temperature by 2.8-3.4°C by 2100. The projected temperature increases, for Pakistan as a whole in the 2020s, 2050s and 2080s will be 1.31°C, 2.54°C and 4.38°C respectively in the A2 scenario and 1.45°C, 2.75°C and 3.87°C in the A1B scenario.

Projected changes in seasonal temperature for A2 and A1B scenarios show that in each scenario a) the temperature increases in both summer and winter will be higher in Northern Pakistan than in Southern Pakistan, and b) the temperature increases in both Northern and Southern Pakistan will be higher in winter than in summer. The GCM ensemble based precipitation projections are much less certain than those for temperature as the precipitation projections by various GCMs vary a great deal. The analysis conducted by GCISC using ensemble outputs of 13 GCMs for the A2 scenario and 17 GCMs for the A1B scenario indicate that precipitation is likely to increase in summer and decrease in winter in both Northern and Southern Pakistan, with no significant change in annual precipitation in either part.

Scenarios for eight regions under ECHAM5-F1 (2040-2060) indicate a slightly higher rise in temperature in the Greater Himalayas compared to other regions. For F2 2071-2100 projections of ECHAM5 and FVGCM, a slightly higher temperature is observed over the Greater Himalayas and lower Indus Plains as compared to other regions. Moreover, ECHAM5-F2 shows more warming as compared to FVGCM F2 projections. The projected values of temperature for summer (JJAS) under ECHAM5-F1 show more warming in Balochistan Plateau (west) whereas ECHAM5-F2 predicts a higher rise in temperature in lower Indus Plains. FVGCM-F2 shows the highest temperature rise in Balochistan Plateau (East). In winter, the highest increase is observed over Greater Himalayan Region. Moreover, ECHAM5-F2 shows more warming as compared to FVGCM-F2 for all the climatic zones.

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