Paper No. 287

GLOBAL WARMING IN THE CONTEXT OF PAKISTAN: MAJOR CONCERNS AND REMEDIAL STRATEGIES

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ABSTRACT

Global warming and consequently the global climate change, resulting from the increasing concentrations of Greenhouse Gases (GHGs) in the atmosphere, caused by the use of fossil fuels and other anthropogenic activities is now an established phenomenon. Its effects have been observed in most parts of the world including Pakistan. The four Assessment Reports published by the Intergovernmental Panel on Climate Change (IPCC) since 1990, attribute most of the observed increase in global average temperature since the mid-20th century to the observed increases in the GHG concentrations due to human activities. According to the IPCC Fourth Assessment Report (AR4), the average global temperature increased by 0.6°C over the period 1901-2000. It is now projected to increase further by 1.8-4.0 °C by the end of this century. Globally 11 of the last 12 years since 1995 were the warmest during the last 150 years with 1998 being the warmest in the previous century and 2005 in the current century. These temperature changes have been accompanied by large impacts on global precipitation, extreme events (floods, droughts, severe cyclonic storms etc.), melting of glaciers, sea level rise etc. These are discussed in detail in the global perspective and in the context of Pakistan. The past climate changes in temperature and precipitation using the CRU (Climate Research Unit), UK data for the period 1901-2000 and the data of these parameters at around fifty meteorological stations for the period 1951-2000 are worked out for Pakistan. Future climate change projections are assessed using the ensemble of various coarse resolution Global Circulation Models (GCMs) for Pakistan as a whole and for its northern and southern parts. The outputs of GCMs are further downscaled to regional levels by using the fine resolution Regional Climate Models namely PRECIS of Hadley Centre, UK and RegCM3 of Abdus Salam International Centre for Theoretical Physics (ICTP), Italy. The past temperature trends over Pakistan are seen very much tallying with the global trends, whereas future projections show that the rate of increase of average temperature over Pakistan is higher than the increase observed globally. Furthermore, Pakistan located in sub-tropics and in temperate region, has a warm climate and its economy being largely agrarian, is highly climate sensitive. In addition to the above, some 50-80% of the average river flows in the Indus River System (IRS) are fed by snow and glacier melt in the Hindu Kush-Karakoram part of the HKH mountain ranges. The Upper Indus Basin, mostly the Karakoram part, has more than 5,000 glaciers which cover a total glaciated area of about 15,000 sq. km. Their importance can be seen from the fact

that the stored volume of ice in these glaciers is equivalent to about 14 years of average IRS flows. Their current and future status in the context of changing climate also makes part of the paper. The paper discusses the threats to water security and food security of Pakistan arising from climate change and considers the required adaptation measures in the light of work being done at Global Change Impact Studies Centre (GCISC). The adverse effects of climate change on the coastal ecosystems of Arabian Sea mainly due to the threat of sea level rise and due to the increased variability of river flows in the Indus River System (IRS) flows under the changing climate are also discussed. This paper also covers a brief discussion of some other vulnerable ecosystems such as rangelands, mountain ecosystems and biodiversity etc.

INTRODUCTION

The concentration of CO_2, the main greenhouse gas in the atmosphere has increased from a pre-industrial (mid eighteenth century) value of about 280 ppm to 379 ppm in 2005 (IPCC AR4, 2007). According to the above report, the concentration increased by only 20 ppm over the 8000 years prior to industrialization. However, as per the above report, the CO_2 concentration has risen by nearly 100 ppm since 1750. The annual growth rate was larger during the last 10 years (1995-2005, average: 1.9 ppm / year) and came largely from fossil fuel consumption and from the effects of land use change. Since 1750, it is estimated that about 2/3rds of anthropogenic CO_2 emissions have come from fossil fuel burning and about 1/3rd from land use change. The concentrations of other greenhouse gases, including CO_2 are shown in Table 1.

Table 1: Changes in Atmospheric Concentration of GHGs

Gases	Pre-industrial level	1998 level	2005 level	Relative increase
CO_2* (ppm)	280	365	379	35 %
CH_4 (ppb)	700	1,745	1,774	153 %
N_2O (ppb)	270	314	318	18 %
CFCs (ppt)	0	268	292	-

* Current CO_2 concentration is the average of the annual values at Barrow, Alaska; Mauna Loa, Hawaii,

American Samoa, and the South Pole (one high-latitude and one low-latitude station from each hemisphere). Refer to C.D. Keeling and T. P. Whorf for records back to the late 1950s.

Continued heavy reliance of the world energy system on fossil fuels for the foreseeable future and consequently enhanced global warming, would accompany much larger climatic changes and their adverse impacts in the coming decades. The most commonly considered indicator of climate change is the surface air temperature (Tamara S. Ledley et al; 1999). An increase in temperature causes an increase in evaporation and generally higher levels of atmospheric water vapours. The positive feedback associated with this certainly leads to the expectation that an increase in surface air temperature leads to a more intense hydrological cycle, with more frequent heavy precipitation events (Houghton et al; 1992; Kattenberg et al; 1996). These will be accompanied by large variations (both, increases and decreases) of temperature and precipitation in different world regions including Pakistan. Pakistan lies in a world region where the average temperatures are expected to be higher than the global averages; its land area is mostly arid and semi-arid (about 60 percent of the area receives less than 250 mm of rainfall per year and 24 per cent receives between 250-500 mm); its rivers are predominantly fed by the Hindukush-Karakoram-Himalaya (HKH) glaciers which are reported to be receding rapidly due to global warming; its economy is largely agrarian and hence highly climate sensitive. Under the influence of all these factors, the water security and the food security of the country are under serious threat.

Past climate changes over Pakistan

The temperature and precipitation changes during the previous century (1901-2000) over Pakistan using the CRU (Climate Research Unit), UK data has shown an increase of 0.6°C in temperature and +25% in precipitation (Figs. 1 & 2). The rise in temperature over Pakistan tallies closely with the global rise in temperature over the previous century. Past climate changes for the temperature parameters (mean, max & min) and precipitation using the data of around 54 meteorological stations are also worked out for the period 1951-2000 over different regions of Pakistan (Fig. 3). The mean temperature trends and percentage precipitation trends on annual and seasonal basis are consolidated in Tables 2 & 3.

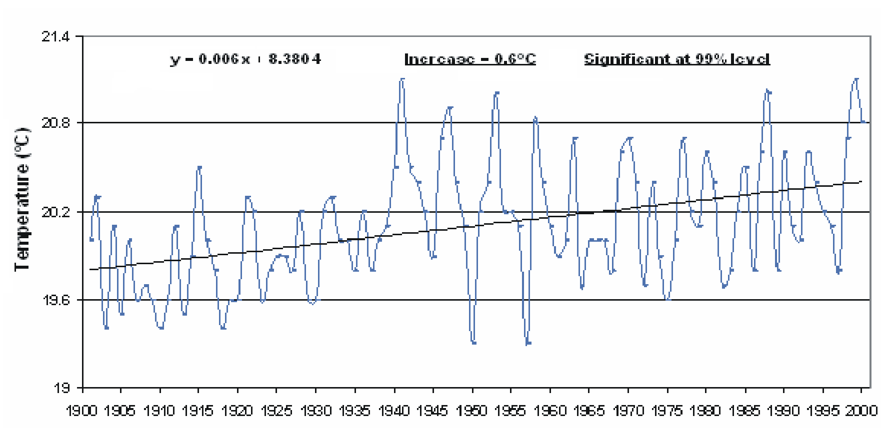


Fig. 1: Annual mean temperature trend (°C) for 1901-2000 over Pakistan

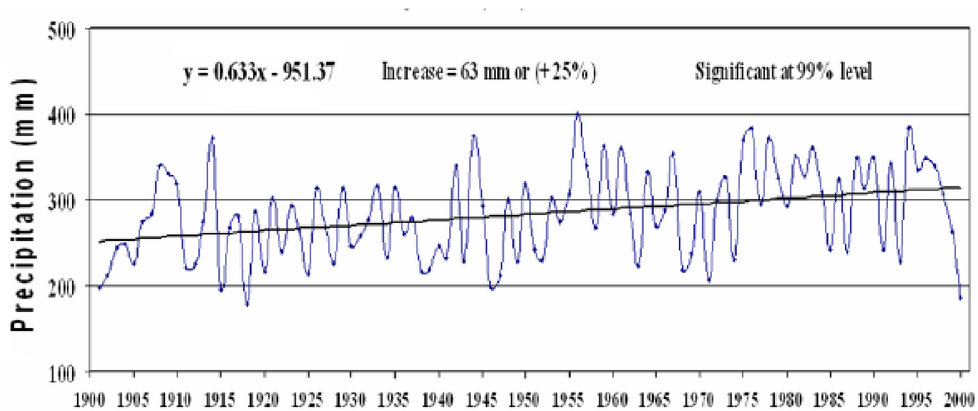


Fig. 2: Annual precipitation trend (mm) for 1901-2000 over Pakistan

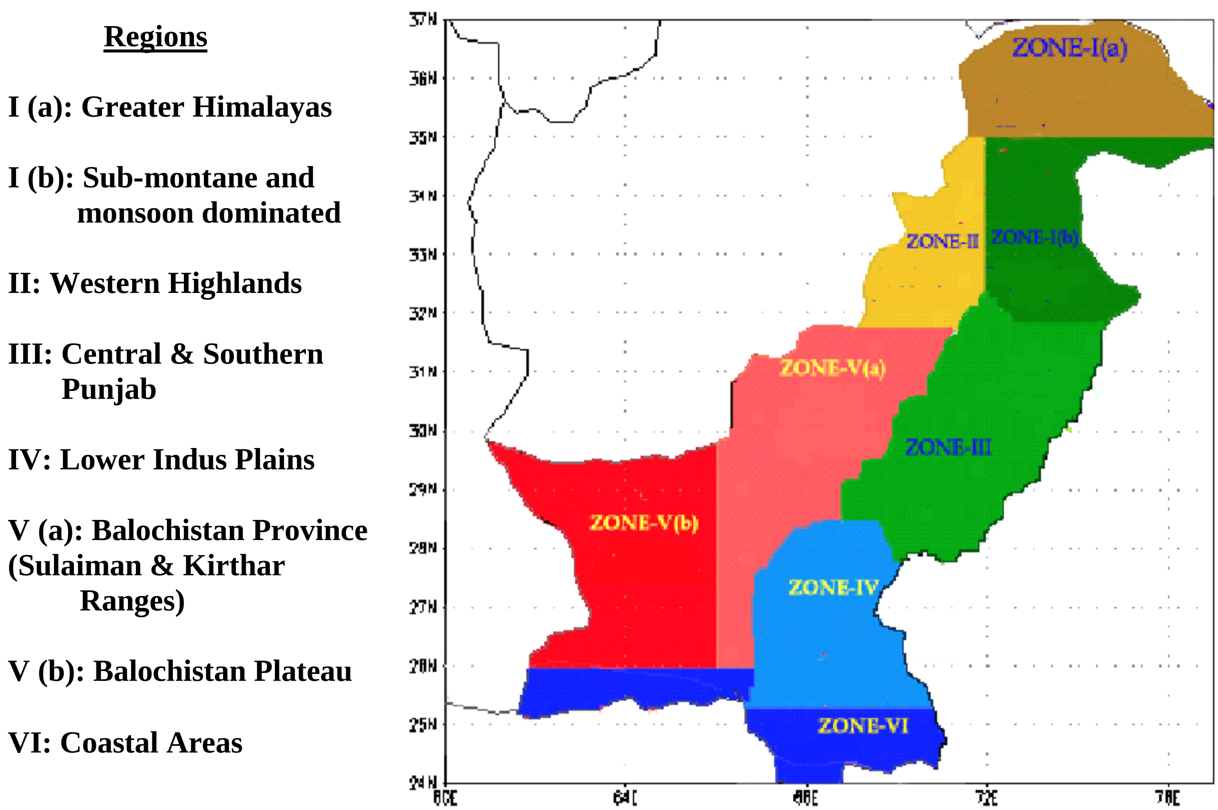


Fig. 3: Different regions of Pakistan (1951-2000). Source: GCISC (2009a)

Table 2: Mean temperature trends (ΔT °C) in different regions on annual and seasonal basis (1951-2000)

Regions/Seasons	Annual	Monsoon (Jun-Sep)	Winter (Dec-Mar)	Apr-May	Oct-Nov
I (a): Greater Himalayas	0.04	-0.80	0.32	1.09	-0.06
I (b): Sub-montane / monsoon dominated	-0.19	-0.57	0.00	0.13	0.12
II: Western Highlands	-0.72	-1.48	-0.65	0.17	-0.47
III: Central & Southern Punjab	0.11	-0.25	0.03	0.83	0.31
IV: Lower Indus Plains	-0.08	-0.55	-0.07	0.35	0.15
V (a) : Balochistan Province (Sulaiman & Kirthar Ranges)	0.11	0.46	0.63	0.79	0.50
V (b): Balochistan Plateau (Western)	1.17	1.3	0.43	2.17	1.80
VI: Coastal Areas	0.00	-0.18	0.05	0.03	0.30

Source: GCISC (2009a)

Table 3: Percentage precipitation trends (ΔP %) in different regions of Pakistan on yearly basis (1951-2000)

Regions/Seasons	Annual	Monsoon (Jun-Sep)	Winter (Dec-Mar)
I (a): Greater Himalayas	0.49	1.73	-0.04
I (b): Sub-montane / monsoon dominated	0.3	0.38	0.53
II: Western Highlands	-0.02	0.22	0.00
III: Central & Southern Punjab	0.63	0.57	0.99
IV: Lower Indus Plains	0.22	0.45	-0.27
V (a) : Balochistan Province (Sulaiman & Kirthar Ranges)	1.19	1.16	1.14
V (b): Balochistan Plateau (Western)	0.1	-0.2	-0.4
VI: Coastal Areas	-0.82	-1.34	0.00

Source: GCISC (2009a)

Temperature Trends

The area average mean annual temperature over Pakistan increased by 0.6 °C over the period 1901-2000 (in agreement with the global trend). The slope of the mean annual temperature over Pakistan during the 48-years period 1960-2007 was about 0.24 °C per decade (PC, 2010) as compared to 0.06 °C per decade during 1901-2000 (AR4, 2007), reflecting much increased rate of warming in recent years. During the period 1901-2000, the increase in mean annual temperature in the Northern half of Pakistan was seen higher than that for the country as a whole (0.8 °C versus 0.6 °C) (PMD, 2009). Summer (April-May) temperatures (both mean and maximum) increased in all parts of Pakistan during the period 1951-2000. During the same period, Balochistan Plateau became warmer in all the seasons. Temperatures (both mean and maximum) during the monsoon season dropped throughout Pakistan during 1951-2000 except in Balochistan Plateau. (The tables for maximum and minimum temperatures are not shown in this paper). During 1951-2000, Greater Himalayan region (the abode of sizeable glaciers feeding the Indus River System) had a warming trend on annual basis as well as in all seasons except the monsoon season and in the post monsoon season (Oct-Nov), where it dropped slightly.

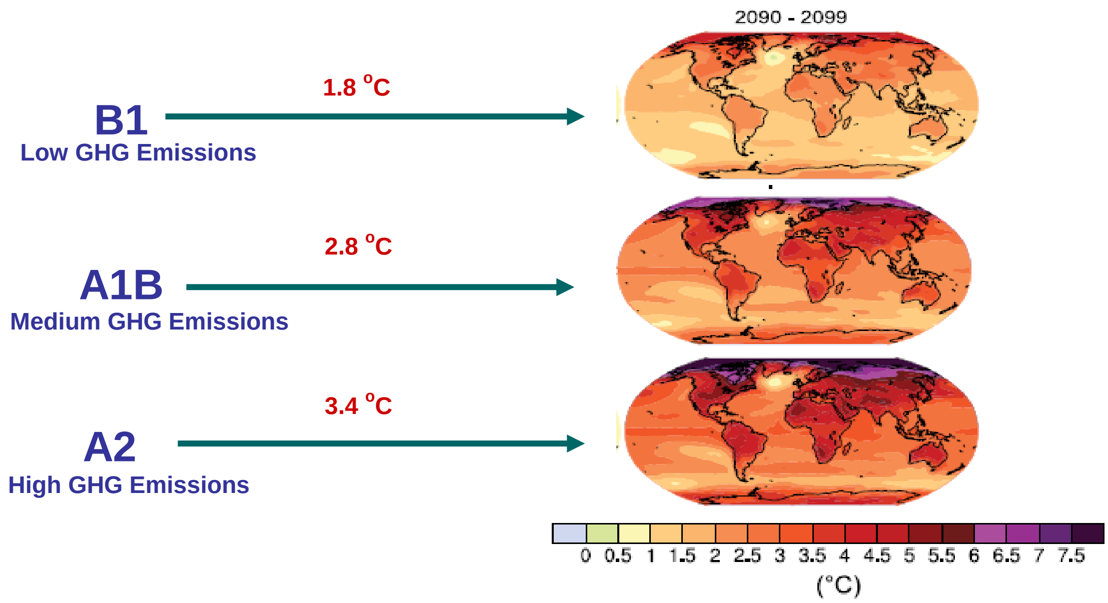
Precipitation Trends

The area averaged mean annual precipitation over Pakistan increased by 25% during the previous century (1901-2000). Monsoon precipitation increased everywhere except in coastal regions (where there was a significant drop) and the Western Balochistan Plateau during 1951-2000. During the same period, winter rains increased by 26-57% in Sub-Montane, Central & Southern Punjab, and North-Eastern Balochistan and decreased by 13-20% in Sindh and Western Balochistan. The Greater Himalayan region experienced the highest growth in monsoon precipitation (86%) and a nominal decrease (2%) in winter (December-March) precipitation during 1951-2000.

Global Projected Temperature changes

The most commonly and widely accepted method of scenario construction involves the use of the outputs of Global Climate Models (GCMs), also known as General Circulation Models (Fiona et al, 2004). These models are the most complex of climate models, since they attempt to represent the main components of the climate system in three dimensions. GCMs are the tools used to perform climate change experiments from which climate change scenarios (plausible representations of how the climate will evolve in future) can be constructed. GCMs are able to simulate fairly well the most important mean variables.

Future changes in global average temperature, according to IPCC AR4 (2007) are expected to be in the range1.8°C–3.4°Cover the 21st century for the three SRES (Special Report on Emissions Scenarios) B1, A1B & A2 scenarios (Fig.4) of IPCC. The highest projected temperature of 4°C is with the A1F1 (A1 Fossil Intensive) Scenario. The narrative description of a scenario (Story line), or family of scenarios highlighting the main scenario characteristics, relationship between key driving forces and the dynamics of their evaluation are available in the IPCC Third Assessment Report (TAR, 2001).

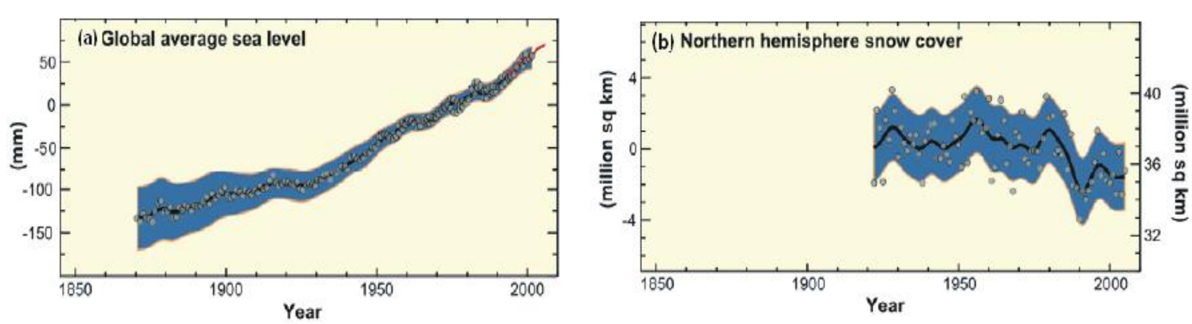


Source: IPCC 2007 WG1-AR4

Fig. 4: Projected temperature changes over the 21st Century under different IPCC, SRES scenarios

These changes are expected to be accompanied by much increased impacts on global precipitation, extreme events, melting of glaciers, sea level rise etc. 17 cm rise in the sea level was observed during the 20th Century and about (28–42 cm) rise is projected for the 21st century as shown in Fig. 5a. Similarly 10% reduction was observed in the snow cover in Northern hemisphere in the 20th century since 1920 (Fig. 5b).

According to the National Institute of Oceanography (NIO), Pakistan, the sea level along the coast of Arabian Sea has been rising approximately at 1.2 mm/year which looks in agreement with the average global rise of 1.5 mm/year since 1960.



Source: IPCC, AR4 (2007)

Fig 5: (a) Global average sea level rise (b) Northern hemisphere snow cover

Projected climate changes over Pakistan

Future climate projections over Pakistan are developed using the coarse resolution (300 km x 300 km) Global Circulation Models (GCMs) and fine resolution Regional Climate Models (RCMs) for projections at the regional level.

Ensemble projections using the outputs of various GCMs for SRES A2, B2 and A1B scenarios are developed. Fine resolution (~50 km x 50 km) projections are developed through the dynamic downscaling of GCM outputs for above scenario using the Regional Climate Models (RCMs). The base period of these projections is taken as 1961-90 whereas the time slices for future projections are for 2020s (2010 – 2039), 2050s (2040 – 2069) and for 2080s (2070 – 2099).

Projected changes in average temperature over Pakistan for A2 and A1B scenarios for its northern half (above 31° N) and southern half (above 31° N) based on the ensemble of 13 and 17 GCMs are shown in Figs. 6 & 7. Precipitation changes for the above scenarios based on the ensemble of 13 and 17 GCMs are shown in Figs. 8 & 9. Projected temperature and precipitation values for both summer and winter seasons in Northern and Southern Pakistan are consolidated in Tables 4 & 5.

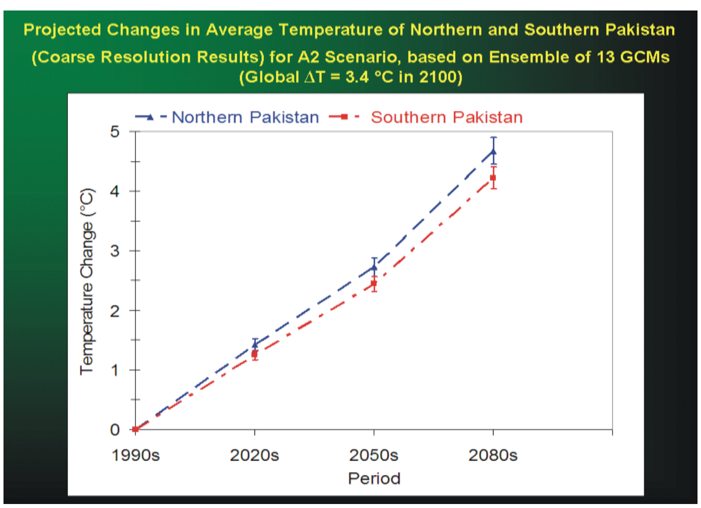


Fig. 6: Projected changes in average temperature over Pakistan for A2 scenario based on the ensemble of 13 GCMs

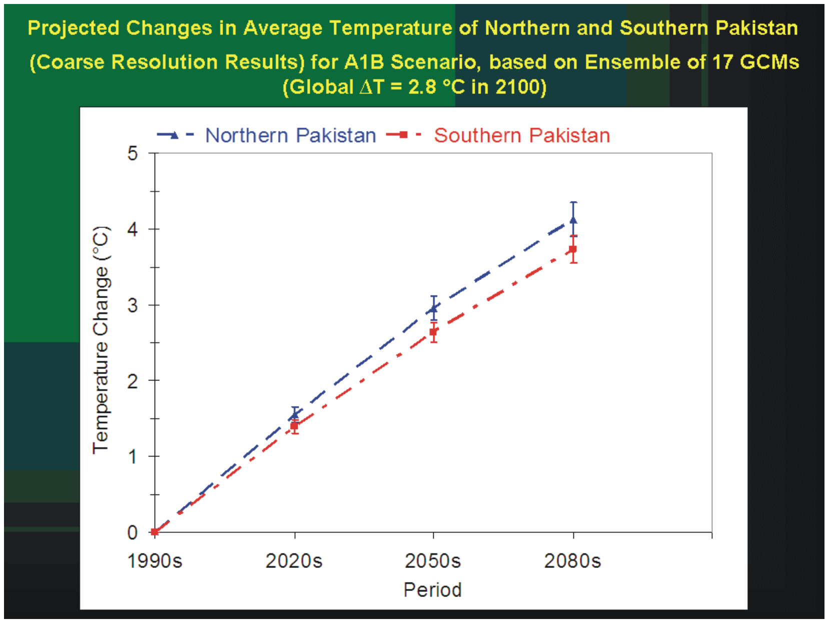


Fig. 7: Projected changes in average temperature over Pakistan for A1B scenario based on the ensemble of 17 GCMs

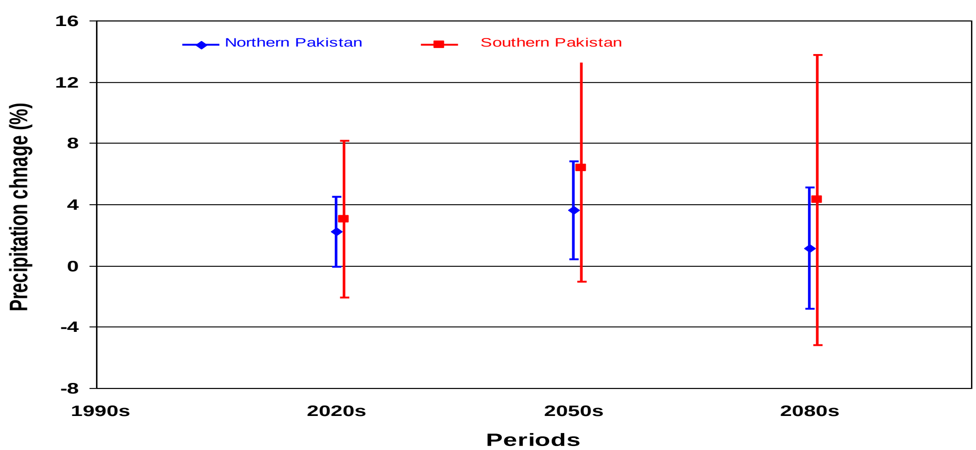


Fig. 8: Projected changes in percentage precipitation over Pakistan for A2 scenario based on the ensemble of 13 GCMs

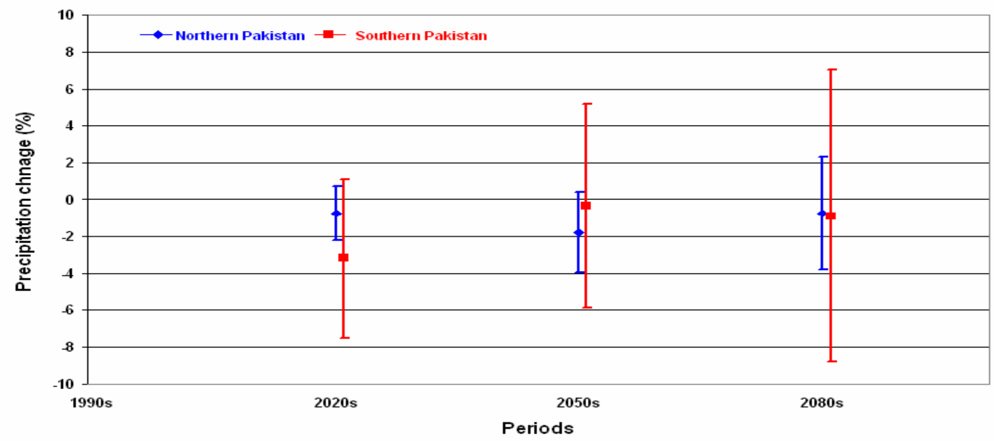


Fig. 9: Projected changes in average temperature over Pakistan for A1B scenario based on the ensemble of 17 GCMs

Table 4: Projected Temperature Changes in 2080s, ΔT (°C) by GCM Ensemble for A2 Scenario

	Pakistan	Northern Pakistan	Southern Pakistan
Annual	4.38 ± 0.44	4.67 ± 0.23	4.22 ± 0.18
Summer	4.13 ± 0.26	4.56 ± 0.28	3.90 ± 0.26
Winter	4.47 ± 0.20	4.72 ± 0.24	4.33 ± 0.18

The values indicate that the temperature increases in both summer and winter are higher in Northern Pakistan than in Southern Pakistan. However, temperature increases in Northern and Southern parts of Pakistan are higher in winter than in summer.

Table 5: Projected Precipitation Changes in 2080s, ΔP (%) by GCM Ensemble for A2 Scenario

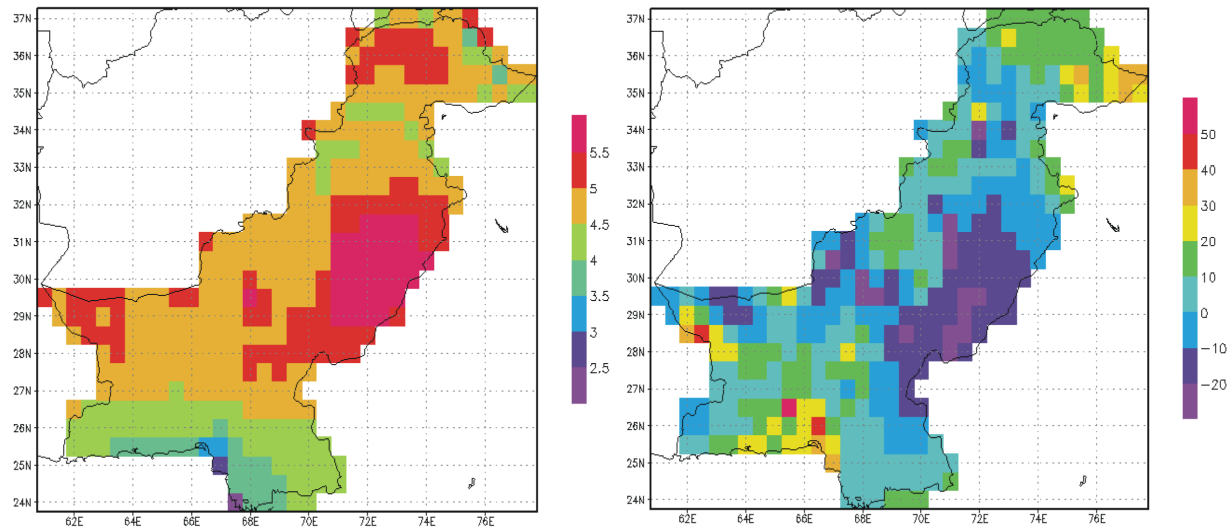
	Pakistan	Northern Pakistan	Southern Pakistan
Annual	3.48 ± 5.78	1.13 ± 3.95	4.28 ± 9.46
Summer	12.16 ± 8.91	1.08 ± 8.35	51.07 ± 39.78
Winter	-5.12 ± 4.78	-2.24 ± 4.10	-20.51 ± 9.05

The rather large errors make it difficult to draw any definite conclusions about change in precipitation with time. There is, however, some indication of precipitation increase in summer and precipitation decrease in winter in the Southern parts of Pakistan.

Projected Climate Changes using Regional Climate Model PRECIS (Providing Regional Climates for Impacts Studies) of Hadley Centre, UK for A2

Scenario for the period 2080s are shown in Fig. 10 (a & b) and corresponding values are shown in Table 6. (Values with the other time slices i.e. 2020s & 2050s are also worked out but are not shown here).

(a) (b)



Source: GCISC

Fig. 10: **(a):** Projected Temperature Change (°C) and (b) Projected Precipitation Change (%) for 2080s by PRECIS (A2 Scenario).

Table 6: Projected Temperature and Precipitation changes for 2080s by PRECIS (A2 Scenario) over Pakistan.

Pakistan	**Annual**	**Summer (JJAS)**	**Winter (DJFM)**
Temperature change ΔT (°C)	4.77	4.68	4.88
Precipitation change ΔP (%)	3.99	-1.48	24.95

The projected temperature changes are higher in winter compared to summer months. Precipitation changes show an increasing trend on annual basis but the increase in the winter period is much higher than summer monsoon rains which show a slight negative trend.

Water Resources of Pakistan: Current Status and Vulnerability to climate Change

Pakistan is extremely short of fresh water resources. Under the pressure of increasing population, it became a water-stressed country (i.e. having overall per capita water availability less than 1800 cubic meters per year (m^3/y) at the turn of the century and is now heading towards a water-scarce country, per capita availability less than 1000 m^3/y by 2035 (WB 2006). Pakistan's primary sources of water are rainfall and glacier melt. About 50 Million acre feet (maf) (60 Billion cubic meters (bcm) of water is brought down by monsoonal and westerly wind systems. River flows (about 141 maf or 174 bcm) in the Indus River System (IRS) (Fig. 11) are fed largely by glacier and snow melt from the Hindukush-Karakoram-Himalayas (HKH) mountain ranges. The shares of main contributing rivers to the IRS in Pakistan are: Indus: 44%, Chenab: 19%, Jhelum: 16%, Kabul: 16% and Others: 5%. The per capita availability of river water, which was 5,650 m^3/y in 1951 and 1200 m^3/y in 2003, declined to 1100 m^3/y in 2008 and is projected to be around 855 m^3/y in 2020 under the pressure of increasing population (GoP-PC 2007). The water security of the country is therefore a very critical issue for Pakistan (PC, 2010)

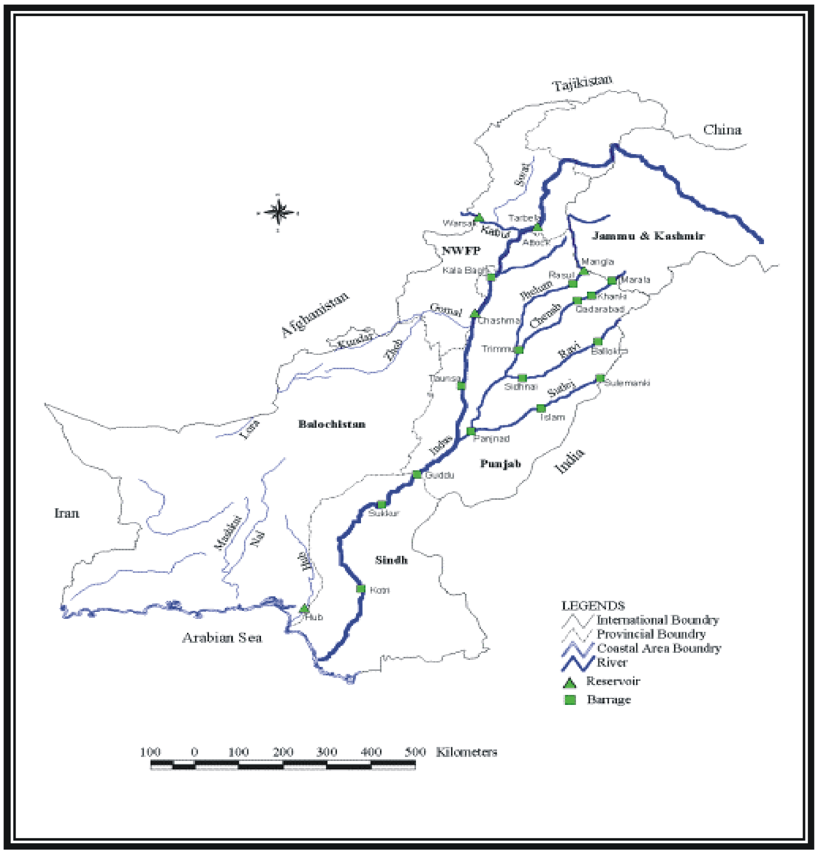


Fig. 11: The Indus River System (IRS). The water from the tributaries Ravi and Sutlej is not received by Pakistan under the Indus Water Treaty, 1960

The annual rainfall in the country is low and irregular, with the national average being about 278 mm, varying from around 160 mm during a dry year (e.g. 2002) to over 440 mm in a wet year (e.g. 1994), thereby contributing an average of 180 maf of rainwater over the country's total land area (PC, 2010). According to this Planning Commission's Final Report on Climate Change, the spatial variation of rainfall is also huge; it varies between 1500 mm in the northern mountainous areas and northern Punjab to less than 100 mm in the south with southern Punjab and upper Sindh getting about 150 mm per annum. About 80% of the annual rainfall occurs during July to September (the monsoon period). As Pakistan is located at the western edge of the monsoon system, heavy summer rains occur only in the northern part of the Punjab province, while the rest of the country is in a permanent state of water shortage**.** The monsoon in the Punjab is also highly variable from year to year. It is expected that climate change will enhance the variability of monsoon and winter rains.

The average annual river flows (PC, 2010) are about 141 maf or 174 bcm at RIM (River Inflow Monitoring) stations, varying from 97 maf in a low-flow year (2002) to 172 maf in a high flow year (1992) during the period 1977-2003. Some 82% of the water inflows are during the Kharif period (i.e. the summer months: April – September) and about 18% in the Rabi period (i.e. the winter months: October – March). The summer flows in Indus and Kabul rivers are dominated by snow and glacier melt, while those in Chenab by snow and glacier melt together with monsoon rains; Jhelum is mainly fed by snowmelt and rains from summer monsoon. The source of winter flows in all the IRS rivers is winter rainfall combined with the base flow from snow and glacier melt (Table 7).

It is expected that due to increased variability of monsoon and winter rains and the loss of natural reservoirs caused by glacier melting as a result of climate change, the inter-annual and intra-annual variability of river flows will increase and also there will be more frequent and intense occurrences of floods and droughts (PC, 2010).

Table 7: Distribution of Water in Main Rivers of Pakistan

	% of IRS Inflows	% Seasonal Distribution		Dominant Source in Summer	Dominant Source in Winter
		Summer (Apr-Sep)	Winter (Oct-Mar)		
Indus	44	86	14	Snow/Glacial melt	Winter Rainfall + Baseflow
Chenab	19	83	17	Snow/Glacial melt + Monsoon	Winter Rainfall + Baseflow
Jhelum	16	78	22	Mainly Snow melt + Monsoon	Winter Rainfall + Baseflow
Kabul	16	82	18	Snow/Glacial melt	Winter Rainfall + Baseflow
Others	5				

Source: GCISC-RR-13

The average outflow to the sea (i.e. the flow below Kotri) is about 35 maf (average for 1976-77 to 2002-03 period) with the minimum flow being as low as 0.8 maf (in 2000-01) and the maximum flow as high as 92 maf in 1994-95 (GoP-MoW&P 2005). In the low-flow years, water going to the sea is less than that necessary to prevent intrusion of sea water into the Indus deltaic region (IPOE 2005). With the rise in sea level caused by climate change, the minimum flow requirements will also go up in future.

Pakistan's water storage capacity comprises three large reservoirs Mangla, Chashma and Tarbela built in the years 1967, 1971 and 1974 with original capacities of 5.88 maf, 0.87 maf and 11.63 maf respectively (total original capacity: 18.37 maf (PC, 2010). Due to silting, the capacities of all the three reservoirs have been decreasing with time. The total capacity decreased to 13.68 maf in 2003 and was projected to decrease to 12.34 maf by 2010 (GoP-PC 2005). The present reservoir capacity (live storage) corresponds to only 9 percent of the IRS average annual flow and is low when compared with the corresponding figures for the world average (40 percent), India (33 percent), Nile river basin (347 percent) and Colorado river basin (497 percent) (GoP-PC 2005). Furthermore, the water storage capacity per inhabitant in Pakistan is also very low: only 150 cubic meters as compared to 2,200 cubic meters in China and 5,000 cubic meters in the U.S. and Australia (WB 2006). At present on the average 35 maf of water flows to the sea annually during flood season, while there is a need to conserve every drop for optimal ecological flow into the sea (GoP-PC 2007). With the frequency and intensity of floods and droughts increasing as a result of climate change, there will be even greater need to store the surplus water during high river flow periods.

About 50-80% of the 141 maf average river inflow in the IRS is fed by snow and glacier melt in the Hindu Kush-Karakoram part of the HKH mountain ranges. The HKH glaciers represent the third largest ice mass on earth, after the Arctic/Greenland and Antarctic. The Hindu Kush-Karakoram mountains receive most of their precipitation during winter under westerly winds and act as a reservoir, capturing snow and rains, holding the water and releasing it in summer into the IRS, which feeds the irrigation system of the country. The Upper Indus Basin has more than 5,000 glaciers which cover a total glaciated area of about 15,000 sq. km. These glaciers correspond to about 2,700 cubic km of stored volume of ice (Roohi / ICIMOD 2005), equivalent to about 14 years of average IRS inflows.

Although the glaciers all over the world are found to be receding over the past century, those in the HKH region are reported to be receding faster than in any other part of the world. Notwithstanding the above, there is some uncertainty about the temporal behavior of Karakoram glaciers which have not been studied in detail because of their difficult terrain and steep slopes (PC, 2010). Hewitt (2005) reports that some of the Karakoram glaciers are surging rather than receding. Hewitt's findings may possibly not be true for a vast majority of HKH glaciers as, according to PMD (2009), the thermal regime of HKH glaciated region has in general warmed up and the frequency of occurrence of moderate as well as severe heat waves has also increased significantly. Preliminary analysis of the time series data on flows of the Indus and its tributary rivers did not indicate any large melting of glaciers so far (GCISC 2009c). More detailed analysis needs to be done but it requires appropriate modeling tools together with reliable information on exact contributions of snow melt, glacier melt and monsoon components, water balance of selected catchments, disintegrating glaciers, and contributions and impacts of other hydrological variables like evapotranspiration and sub-surface flows. For the present, on the basis of bulk of the evidence, it looks most likely that the HKH glaciers are also receding under the influence of the global warming and that the melting will increase with increase in the summer temperature. This will have very serious implications for the water supply in the IRS flows (PC, 2010).

Climate Change and Glacier Retreat in Upper Indus Region (UIB)

The glacier melting in the Himalayas is expected to increase flooding of Indus and its tributaries for the next two to three decades which will be followed by decreased river flows as the glaciers recede (IPCC 2007). The increased flow in combination with the predicted more flashy rainfall will result in frequent floods unless the reservoir capacity is increased (PC,2010). The river flows are expected to decrease after a few decades due to reduced glacier mass to a level that would be determined by the precipitation input at that time. According to the World Bank report (2006): "Pakistan's Water Economy: Running Dry", the western Himalayan glaciers will retreat for next 50 years causing increase in Indus River flows. Then the glacier reservoirs will be empty, resulting in decreases of 30% to 40% in river flows in the Indus Basin. Similarly, a three-year modelling study by the Centre for Ecology and Hydrology, Wallingford, UK and Alpine Glacier Project, University of Salford, UK covering the 100-year time horizon starting from 1991 reports that in the Upper Indus, the mean river flow will increase between 14% and 90% followed by flow decreasing to between 30% and 90% of baseline by the last decade of the 21st century (Rees and Collins 2004). A simulation modelling study by GCISC shows that if the average temperature in the Indus watershed were to rise by 3 °C and the HKH glaciers to shrink to half their present size, not only the overall annual flow would reduce by about 15%, the monthly flow pattern would also change considerably, with more water coming in spring and early summer and less water in the later part of summer (GCISC 2009c) (Fig.12).

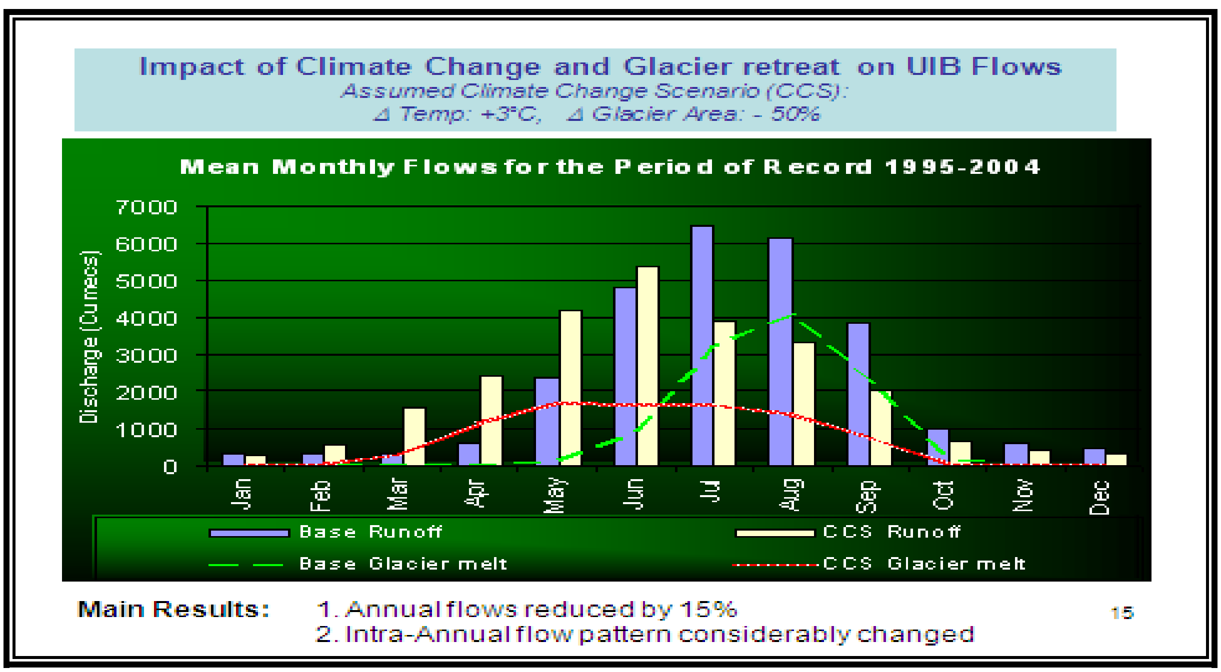


Fig. 12: Impact of Climate Change and Glacier retreat on UIB flows

Major Concerns

The major climate change related threats to water security (PC, 2010) are identified as:

Increased variability of river flows due to increase in the variability of monsoon and winter rains and loss of natural reservoirs in the form of glaciers; Likelihood of increased frequency and severity of extreme events such as floods and droughts; Increased demand of irrigation water because of higher evaporation rates at elevated temperatures in the wake of reducing per capita availability of water resources and increasing overall water demand; Increase in sediment flow due to increased incidences of high intensity rains resulting in more rapid loss of reservoir capacity; Changes in the seasonal pattern of river flows due to early start of snow and glacier melting at elevated temperatures and the shrinkage of glacier volumes. Possible drastic shift in weather patterns, both on temporal and spatial scales; Increased incidences of high altitude snow avalanches and Glacial Lake Outburst Floods (GLOFs) generated by surging tributary glaciers blocking main un-glaciated valleys.

Adaptation Strategies

Considerable expansion in reservoir capacity is required (a) to take care of the increasing frequency and intensity of floods and droughts, (b) to take advantage of the greater water flows over the next two to three decades due to glacier melting as well as to address the expected decreases of flows in the subsequent years after the glaciers have largely melted, (c) to provide regulated minimum environmental flows to the sea to prevent excessive intrusion of sea water into Indus deltaic region, (d) to take care of the loss in reservoir capacity due to silting, and (e) to meet future increases in water demand. Even without specific consideration of the climate change related impacts, the Planning Commission envisages that without additional storage the water shortfall will increase by 12 percent over the next decade alone (GoP-PC 2007). There is also a lack of current knowledge and monitoring effort on climate change impacts in the HKH region and a lack of understanding and modelling capability about the patterns of glacier melt and rainfall feeding the IRS and the corresponding impacts on IRS flows. All these need to be adequately addressed.

Agriculture of Pakistan and its vulnerability to Climate Change

The crop sector contributes 10.5% to the National Gross Domestic Product (GDP) against a 22% GDP for both agriculture and livestock. (GoP-MoF, 2010). The main food crops are wheat and rice with respective shares of 60% and 25% in the food crop part of GDP. Crops are particularly sensitive to changes in temperature, ambient CO2 concentrations, precipitation and availability of irrigation water. (GoP-MoF, 2010). Given that Pakistan has a varied type of climate ranging from sub-zero temperatures in the north to above 50 °C in the south, the impact of climate change on crops can be wide ranging.

A widely accepted approach to analyze the possible effects of climate change parameters on crop yield is to determine the effect of incremental changes in temperature, precipitation, Carbon Dioxide (CO_2) etc on a baseline climate e.g., the daily climatic records at a weather station (Rosenzweig and Iglesias, 1994). Simulation studies, using crop growth simulation models CERES-WHEAT and CERES- RICE, have been conducted at Global Change Impact Studies Centre (GCISC), Islamabad to study the impact of climate change on crop life cycle or Growing Season Length (GSL), and yield of wheat and Basmati rice (Iqbal *et al.* 2009a and 2009b).

Initially the impact of climate change on wheat and rice was studied using hypothetical scenarios of increase in CO_2 concentrations and rise in temperature in the four agro-climatic zones of Pakistan (Fig.13). The zones are: Northern Mountainous region, Northern sub-mountainous region, Southern semi-arid plains and Southern arid plains. Then, the GCM-based climate change scenarios (A2 and B2) were used for climate change impact assessment on these crops.

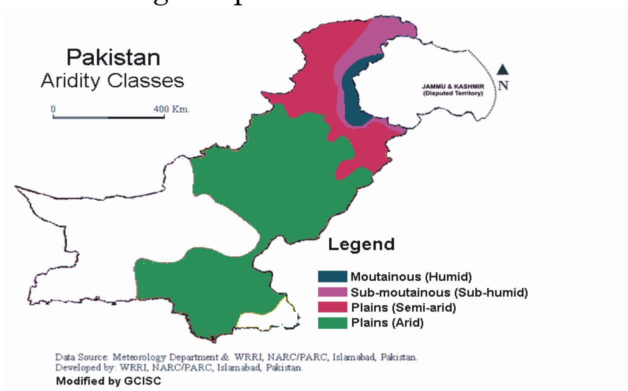


Fig. 13: Agro-climatic zones of Pakistan based on aridity classes

Wheat Yield in the Context of various Climate Change related parameters:

Keeping the other climatic parameters constant, the wheat yield was seen gradually increasing with increasing levels of CO_2 from 360 to 1050 ppm in the four agro-climatic zones of Pakistan (Fig 14). It is seen that the yield in the northern mountainous zone is lower than all the other agro-ecozones whereas the yield increases in all the other three eco-zones are more or less similar. Wittwer (1995) reported that with a higher level of CO_2 in the air, plants can grow faster with a higher temperature.

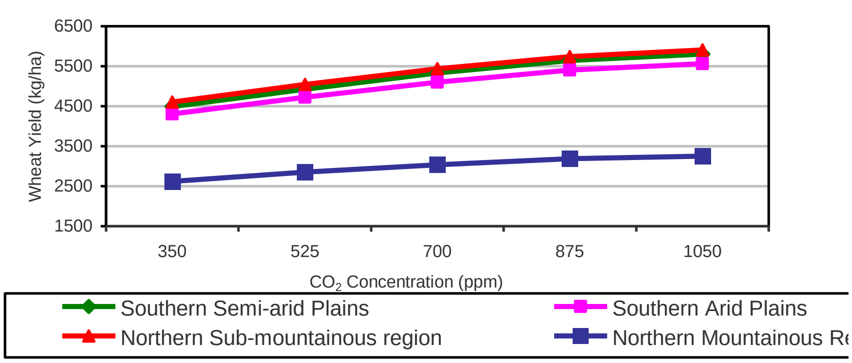


Fig. 14: Effect of increase in CO_2 concentration on wheat yield in the four agro- climatic zones of Pakistan

The impact of increasing temperature (keeping other factors constant) on yield is shown in Fig. 15. The increase in temperature was studied up to 5°C in consonance with the IPCC, AR4 (2007), which says that the projected temperatures are likely to increase by 1.8 to 4 °C by the end of this century. The projected temperature increases in Pakistan are seen higher compared to global average increase in temperature (GCISC, 2009b). The yield will increase in the northern mountainous region with each degree rise in temperature until 4°C and thereafter, the yield will level off. The yield in the other three zones (northern sub-mountainous, southern semi-arid plains and southern arid plains) will gradually decrease with each degree rise in temperature.

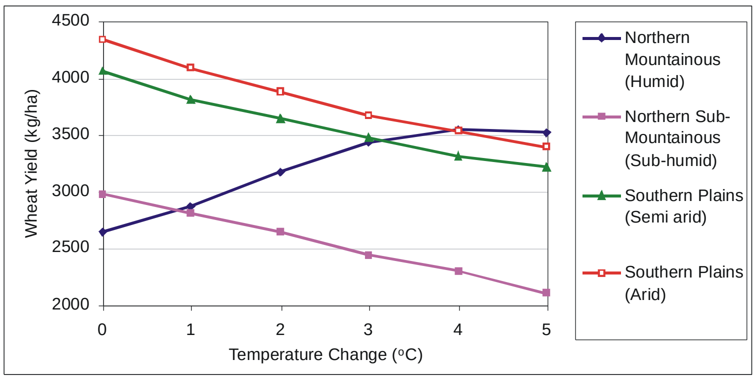


Fig. 15: Effect of increase in temperature (keeping other factors constant) on wheat yield in different agro-climatic zones of Pakistan.

The impact of temperature increase from baseline to 5°C, in increments of 1°C on GSL of wheat is shown in Table 8. It can be seen that GSL decreased in all the agro-climatic zones even with 1°C increase in temperature but the magnitude of decrease is different.

Table 8: Impact of rise in temperature on Growing Season Length of wheat in Northern and Southern parts of Pakistan.

Temperature °C (increase over baseline)	**Growing Season Length (Days)**			
	Northern Pakistan		**Southern Pakistan**	
	Mountainous (Humid)	**Sub-Mountainous (sub-humid)**	**Plains (Semi-arid)**	**Plains (Arid)**
Baseline	246	161	146	137
1	232	155	140	132
2	221	149	135	127
3	211	144	130	123
4	202	138	125	118
5	194	133	121	113

The highest decrease occurred in the northern mountainous region where GSL decreased by 14 days (from 246 to 232 days) for 1°C increase in temperature and 52 days (from 246 to 194 days) for 5°C increase in temperature. The corresponding decreases in other zones were relatively less.

The projected impact of climate change on wheat yield in Pakistan, under IPCC SRES scenario A2, developed by GCISC from the outputs of six Global Circulation Models for the four agro-climatic zones is presented in Fig. 16. The IPCC A2 scenario family describes a very heterogeneous world. The underlying theme is self reliance and preservation of local identities. Economic development is primarily regionally oriented and per capita economic growth and technological change is more fragmented and slower than other storylines. The B2 scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change. (IPCC TAR, 2001).

It is seen that the yield will increase in the northern mountainous region whereas it is likely to decrease in the remaining three zones by 2080s.

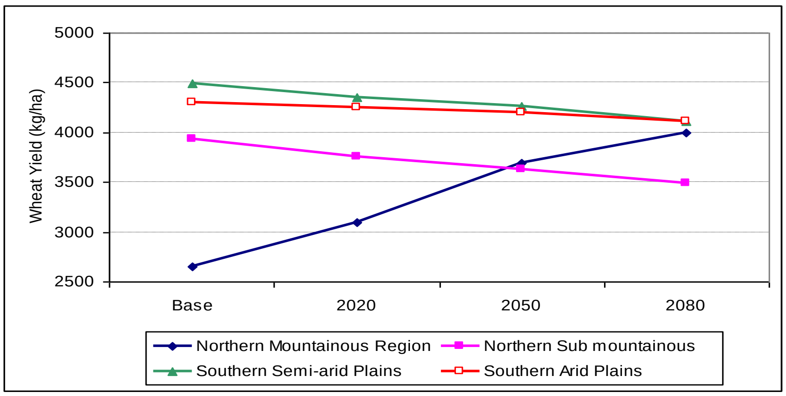


Fig.16: Wheat yield in different agro-climatic zones of Pakistan, at different time slabs towards end of this century, under IPCC Scenario A2.

The wheat production situation in these agro-climatic zones towards the end of this century (Table 9) shows that by 2085, there will be about 6% reduction in wheat production in Pakistan although there will be an increase in production in the northern mountainous region by 50% under A2 and 40% under B2 scenario. But given a meager (2%) share of this area in gross national production, it will not make any significant impact on wheat production in Pakistan. The increase, however, will be beneficial locally from the view point of food self sufficiency and livelihood of the dependant communities (Iqbal *et. al.* 2009a).

Table 9: Climate change impact on wheat production in Pakistan by 2085 under IPCC A2 and B2 Scenarios.

Region	**% Share in National Production**	**Baseline Yield ($kg\ ha^{-1}$)**	**% Change in yield in 2085**	
			A2 Scenario	**B2 Scenario**
Northern Mountainous	2	2658	+50	+40
Northern Sub-mountainous	9	3933	-11	-11
Southern Semi arid Plains	42	4306	-8	-8
Southern Arid Plains	47	4490	-5	-6
Pakistan	100	4326	-5.7	-6.4

Rice Production in the context of various Climate Change related parameters

In case of rice, only the fine-grain aromatic Basmati rice was studied. The Basmati rice is grown chiefly in the central Punjab in semi-arid plains of the country. Firstly, the impact of increase in CO2 concentration and rise in temperature were studied under hypothetical scenarios (Fig. 17). The yield increased with increase in CO_2 concentrations.

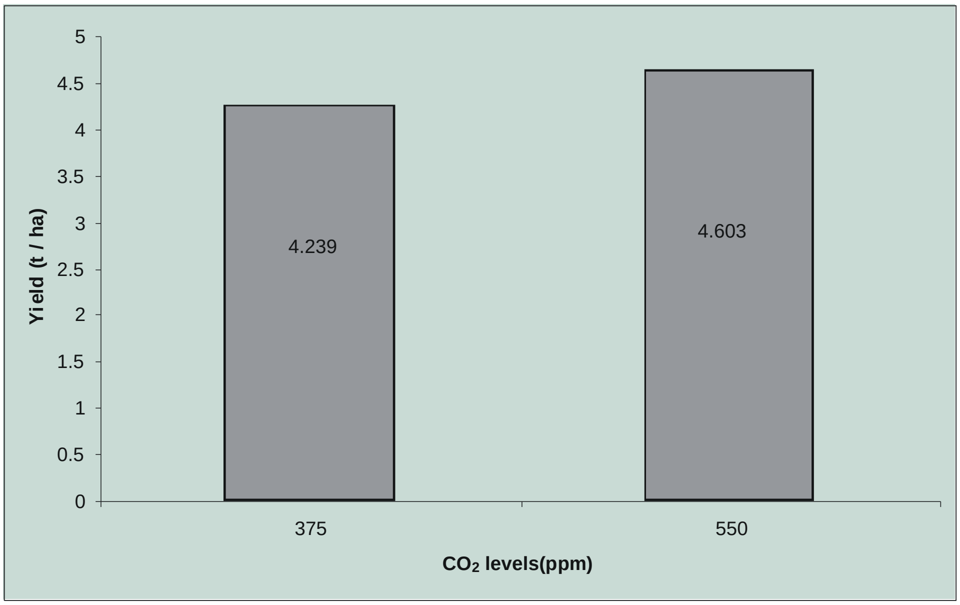


Fig.17: Impact of rise in CO_2 levels on Basmati rice yield under changing concentration of CO_2

Higher temperature shortens the rice growth period, consequently reducing the period available to the plant for photosynthetic accumulation. The data (Table 10) showed that the growing season length of rice was shortened by 6 days, from 108 days at the baseline temperature to 102 days at 1°C increase in temperature over baseline, and by 19 days (from 108 to 89 days) at 5°C rise in temperature over baseline. This reduced growing season length leads to reduced yields.

Table 10: Impact of rise in temperature on Growing Season Length (GSL) of Basmati Rice

Temperature (°C)	Growing Season Length (Days)
(Increase over baseline)	108
1	102
2	100
3	98
4	92
5	89

The reduced growing cycle of a crop as a result of increasing temperature can affect the yield adversely with an increase in temperature upto 5°C (Fig. 18), there was a continuous decline in the yield of Basmati rice in the semi-arid plains of Punjab province. For one degree increment, there was about 6% decline in the simulated yield; a 2°C increase resulted in 12% decrease in grain yield but beyond that the decrease rate was higher. Such reductions are, however, offset to a certain extent by increase in CO_2 concentration because of fertilizing effect of CO_2.

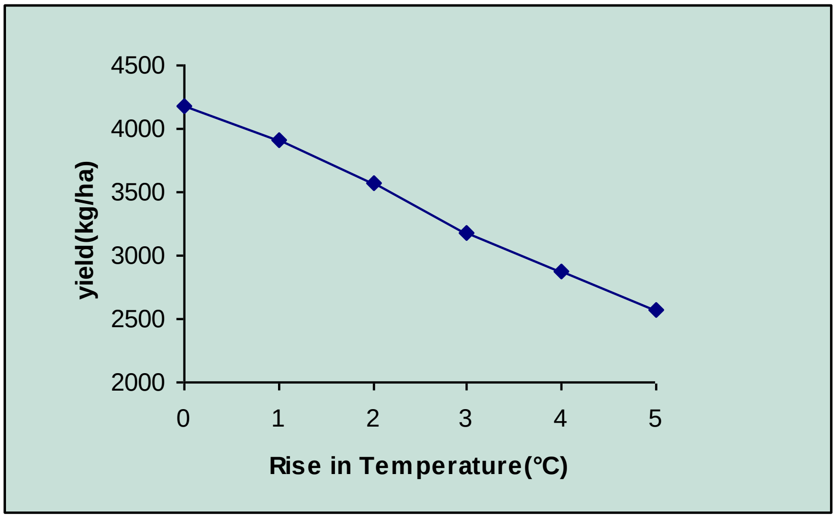


Fig. 18: Effect of increase in temperature on Basmati rice yield in Central Punjab province of Pakistan.

The combined effect of rise in temperature (from 1 - 5^{0}C) and CO_2 level (at 375 and 550 ppm levels) on Basmati rice is shown in Fig. 19. The yield is likely to decrease even at 1°C rise in temperature at the ambient CO_2 level (375 ppm) but at the elevated CO_2 concentration (550 ppm), the baseline yield would sustain only up to 1°C. This shows higher sensitivity of Basmati rice to increase in temperature.

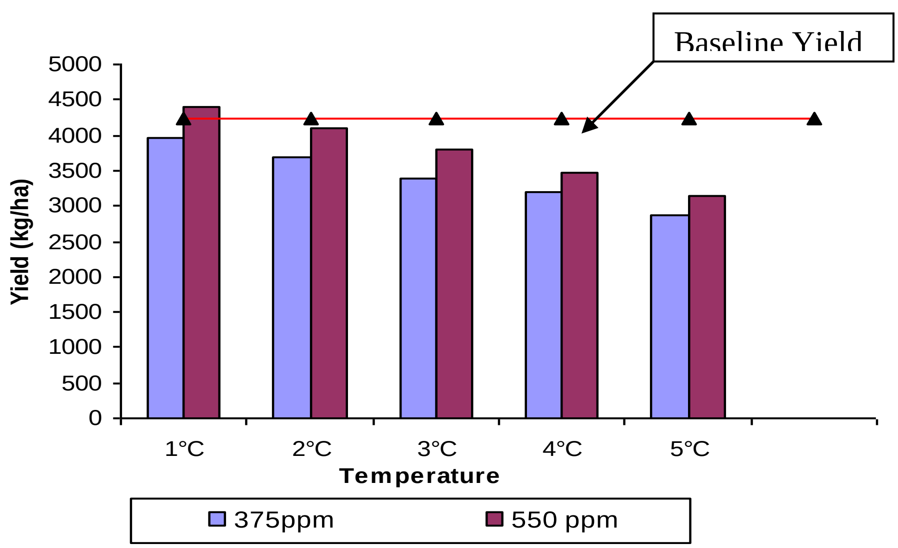


Fig.19: Combined effect of increase in CO_2 concentration and temperature on Basmati rice yield in Central Punjab province of Pakistan.

The impact of climate change on Basmati rice was later studied under IPCC A2 and B2 scenarios, using crop growth simulation model CERES-RICE. The results (Fig. 20) show that rice will suffer reduction in yield, and the reduction will be greater than that in wheat (Table 9). There will be an expected shortfall of 18% under A2 and 15% under B2 scenario in rice production by 2080s.

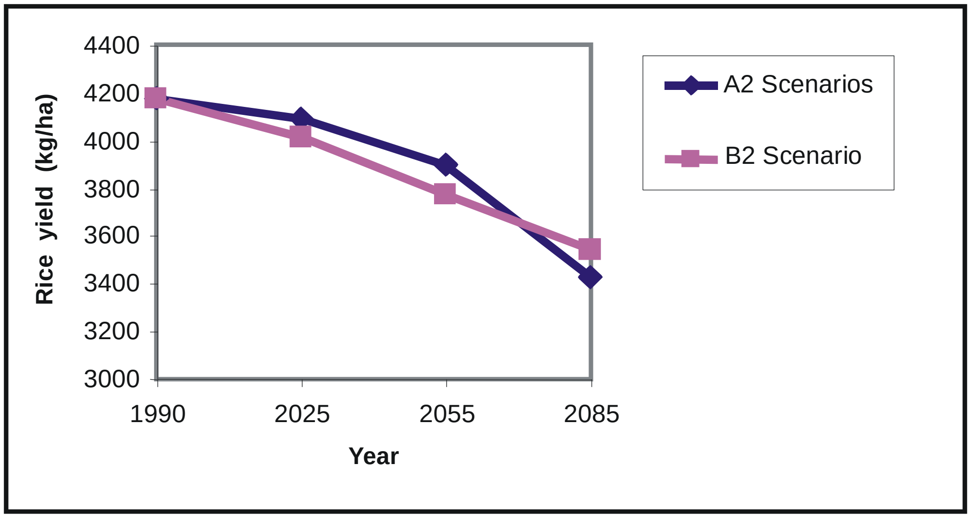


Fig. 20: Basmati rice production in Central Punjab in semi-arid plains, by 2085 under IPCC A2 and B2 scenarios.

The rising temperature and carbon dioxide levels, and changes in rainfall are of direct physiological consequence to plant growth and development. Their interactive effect was studied, under the A2 and B2 scenarios through the use of CERES-Rice simulation model. On an average, under A2 scenarios, the maturity period will be shortened by 5, 11 and 15 days (5%, 10% & 14%) from the baseline growing season length (GSL) of 107 days, by 2020s, 2050s and 2080s, respectively. Under B2 scenario, the crop duration period is likely to shrink by 6, 10 and 13 days (6%, 10% & 12%) from the baseline GSL of 107 days, by 2020s, 2050s, 2080s, respectively (Table 11).

Table 11: Impact of climatic parameters on growing season length of Basmati rice in northern semi-arid plains of Pakistan under A2 and B2 scenarios

Time Horizon	Growing Season Length (Days)	Difference		Growing Season Length (Days)	Difference	
		Days	(%)		Days	(%)
	A2 Scenario			B2 Scenario		
Baseline	107	-	-	107	-	-
2020s	102	5	5	101	6	6
2050s	96	11	10	97	10	10
2080s	92	15	14	94	13	12

The impact of changes in temperature, CO_2 concentration and rainfall, embedded in A2 and B2 scenarios, on paddy yield of Basmati rice in the northern semi-arid plains is given in Table 12. The simulated yield would decrease gradually from the baseline yield computed from 1960 to 1990 to the year 2080. Under A2 scenarios, the yield would decrease from 4175 kg/ha in 1990 to 4094 kg/ha by 2020 (2% reduction), to 3900 kg/ha by 2050 (7% reduction) and to 3427 kg/ha by 2080 (18% reduction). Under B2 scenario, the decrease would be from 4175 kg/ha in 1990 to 4012 kg/ha by 2020 (4% reduction), to 3773 kg/ha by 2050(10% reduction) and to 3541 kg/ha by 2080 (15% reduction).

Table 12: Impact of climatic parameters on paddy yield of Basmati rice in northern semi-arid plains of Pakistan under A2 and B2 scenarios.

Years	**Yield(kg/ha)**	**Percent decrease**	**Yield(kg/ha)**	**Percent decrease**
	A2 scenario		**B2 scenario**	
Baseline	4175	-	4175	-
2020s	4094	2	4012	4
2050s	3900	7	3773	10
2080s	3427	18	3541	15

The simulated rice production data (Table 13) revealed that there is likely to be a decrease in production in the northern semi-arid plains to the extent of 18 and 15%, under A2 and B2 scenarios respectively. This points out to the need for resorting to immediate adaptive measures to forestall such decreases in rice production being the second staple food of Pakistan.

Table 13: Climate change impact on the yield of Basmati rice in northern semi-arid plains of Pakistan by 2080s under A2 and B2 Scenarios.

Region	**% Share in Total Rice Production**	**Baseline Yield (kg/ha)**	**% Change in Yield in 2080s**	
			A2	**B2**
Northern Semi-arid Plain	52*	4175	- 18	- 15

Major Agriculture related concerns and remedial strategies:

The major climate change related threats to food security of Pakistan (PC, 2010) are identified as reduced productivity of crops and livestock due to heat stress and other adverse impacts of changes in climatic parameters; increased requirements of irrigation water due to higher evapotranspiration at elevated temperatures; uncertainty in timely availability of irrigation water caused by changes in river flows due to glacier melting and altered precipitation patterns; shortage of irrigation water due to inadequate storage capacity; erratic and uncertain rainfall patterns affecting particularly the rain-fed agriculture; increased frequency and intensity of extreme climate events of floods, drought and cyclones etc. resulting in heavy damages to both crops and livestock; abundance of insects, pests and pathogens in warmer and more humid environment, particularly after heavy rains and floods; degradation of rangeland and further deterioration of the already degraded cultivated land due to water erosion, wind erosion, water-logging, salinity etc. These include further the intrusion of sea water into deltaic region affecting coastal agriculture; lack of technical capacity to predict with reasonable certainty the expected changes in climatic parameters (temperature, precipitation, extreme events etc.) in different parts of the country, and in river flow patterns at seasonal, inter-annual and inter-decadal levels; also lack of technical capacity to fully assess, in quantitative terms, the corresponding impacts on the agriculture and livestock sector; and low adaptive capacity to adverse climate change impacts due to lack of technical know-how and low financial resources.

The remedial strategies include development of new breeds of crops of high yield, resistant to heat stress, drought tolerant, less vulnerable to heavy spells of rain, and less prone to insects and pests: Crop productivity per unit of land and per unit of water needs to be improved by increasing the efficiency of various agricultural inputs, in particular the input of irrigation water; improvement of farm practices by adopting modern techniques such as laser land leveling, and crop diversification and optimized planting dates etc.

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