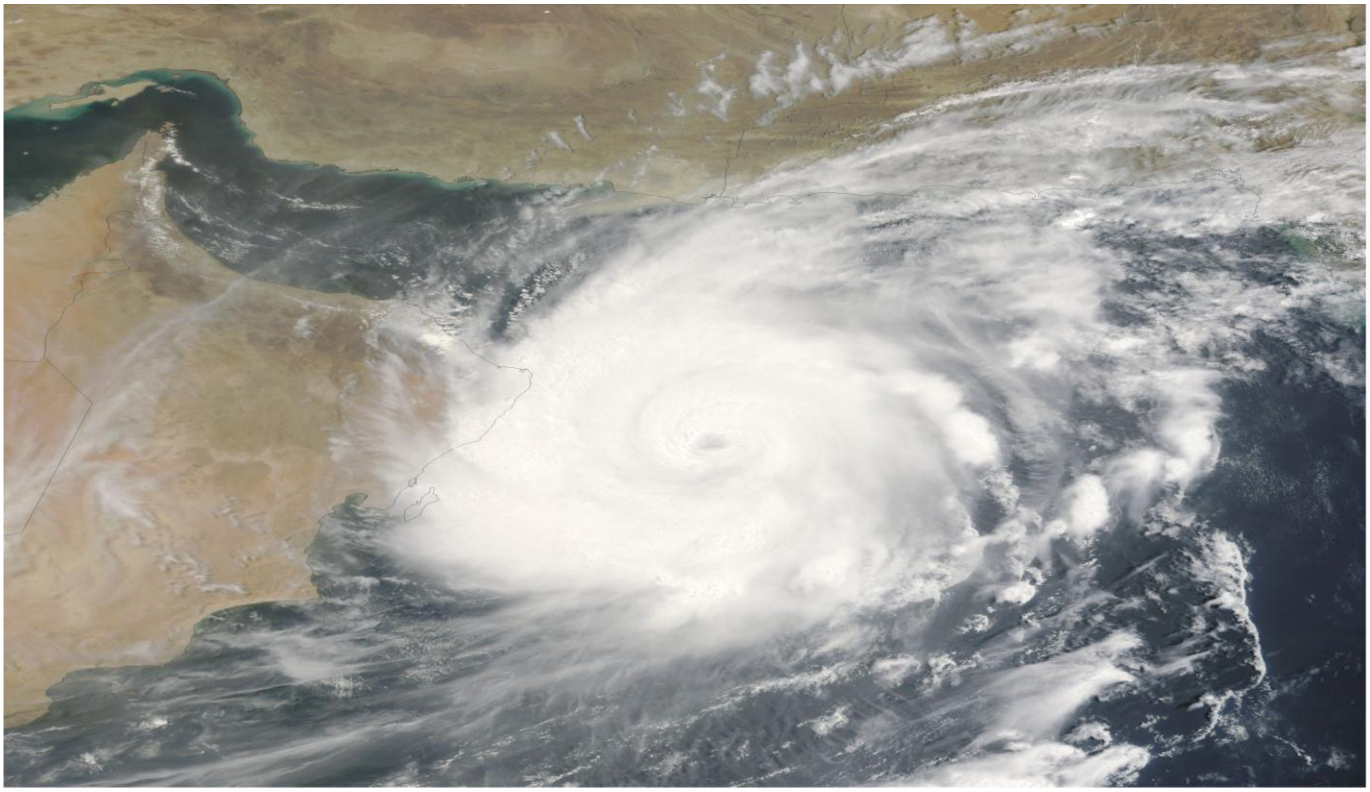
Technical Report No. PMD-25/2012

Climate Change in Pakistan

Focused on Sindh Province



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December 2012

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Foreword

In this era of rapid climate change, the importance of climate projections in policy making, resource management, economic activity and technological advancement cannot be denied. Information about changes in climate change and variability is required to better anticipate potential impacts of climate change on the water resources, agriculture, energy, economic, health, industrial and private sectors. Global warming is bringing lot of interactive changes to the physical processes responsible for the climate system dynamics. Such changes, sometimes, appear as occurrence of extreme events of unprecedented intensity casting irreversible loss to the natural resources. Pakistan is one of the most vulnerable countries to the consequences of the climatic change because of its diverse geographical and climatic features. The north of Pakistan hosts more than 5000 glaciers while the south is composed of hyper deserts despite the closet vicinity of the Arabian Sea. Precipitation and temperature gradients are converse of each other as winter and summer precipitation concentrates in the northern half. The upstream and downstream interaction, under increasing frequency and intensity of extreme hydrological events, makes the Indus Delta highly risky zone for sustainable crop production.

This is the first comprehensive report linking global changes to Pakistan's climate system dynamics including the future climate projections at the finest temporal and spatial resolutions for temperature and precipitation. Almost all climate change related risks likely for the Indus Deltaic region are discussed in detail backed by scientific evidence based on the output of Global Climate Models. I believe that the report will help the scientists, researchers, planners and policy makers to devise future strategies for climate change impact assessment and adaptation in various sectors of vital interest for the economy of Pakistan. For future climate projections, mild climate change scenarios A1B are selected because lots of efforts are underway by the global community to develop consensus on curtailing the emission levels of Green House Gases (GHGs) to optimum limits. Although, there are uncertainties in the outputs of Global Climate Models (errors much enhanced on centurion scale) yet the decadal outputs may be of great value for planning purposes.

ARIF MAHMOOD
Director General
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Executive Summary

Climate change is an established fact and its impacts on water, agriculture, health, biodiversity, forest and socio-economic sectors are quite visible around the globe. According to IPCC (2007), developing and the least developed countries are expected to suffer more due to climate change as compared to the developed countries. This is true if we scale down this fact to the community level; in case of any climatic anomaly the poor people face the consequences due to lack of resources and access to information. Anthropogenic activities are mainly blamed to be responsible for the surging trend of climate related disasters occurring in different parts of the world and marginal income people are the major sufferers. After industrial revolution, emission of Green House Gases (GHGs) to the atmosphere increased drastically from industry and vehicular fossil fuel burning. Such gases have large warming potential and long life time to sustain warming process for decades to centuries. During 20th century, the increase in the global temperature was recorded as 0.76°C but in the first decade of this century 0.6°C rise has been noticed. Among 16 warmest years recorded over the globe, 9 top most were from the first decade of 21st century with ranks in decreasing order; ***2010, 1998, 2005, 2003, 2002, 2009, 2004, 2006, 2007, 2001, 1997, 2008, 1995, 1999, 1990, 2000.***

Pakistan is particularly vulnerable to climate change because it has generally a warm climate; it lies in a geographical region where the temperature increases are expected to be higher than the global average; its land area is mostly arid and semi-arid (about 60 per cent 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 Hindu Kush-Karakoram Himalayan glaciers which are reported to be receding rapidly due to global warming; its economy is largely agrarian and hence highly climate sensitive; and because the country faces increasingly larger risks of variability in monsoon rains, hence large floods and extended droughts. Under the influence of all these factors the Water Security, the Flood Security and the Energy Security of the country are under serious threat. Compounding these problems are the expected increased risks to the coastal areas and the Indus deltaic region due to sea level rise, coastal erosion, saline sea water intrusion and increasing cyclonic activity in the Arabian Sea. The Indus Delta is already located in the intense heat zone and any rise in temperature would impact human health due to heat strokes, diarrhea, cholera, vector borne diseases; and human settlements due to frequent floods, droughts and cyclones. In this region, temperature is likely to increase by 4°C till 2100 and rainfall is going to be highly variable on temporal and spatial scale. The deltaic region would not only be affected by the local weather conditions but also weather activities upstream Indus and over the neighboring sea in the south due to climate change.

Although there are many challenges to the livelihood of the Indus Delta dwellers due to climate change but there are opportunities also. There is a large potential of wind power generation due to the vicinity of sea which can attract lot of investment building climate resilient infrastructure, generating employment for local population and hence ensuring sustainable livelihood. An organized land reclamation and water treatment will ensure the food security too.

Section 1

Introduction

By virtue of its geographical location, Pakistan is highly vulnerable to the consequent climate change because of global warming. Slightly north of the Tropic of Cancer and along the shore of the Arabian Sea, the string of deserts connecting Rajistan of India, Thar and Balochistan of Pakistan and Dasht of Iran passes through the southern half of Pakistan. North of Pakistan is the junction of three world famous mountain ranges known as Himalayas, Karakoram and Hindukush which possess third largest mass of ice after the polar regions. There are more than 5000 glaciers in Pakistan territory having Volume of water in the frozen form to sustain our water supplies through melting process. Winter snowfall tends to nourish the melt mass of ice from glaciers but the balance is disturbed due to increased heat (Krishnamurti, 1987 and Rao, 1976).

Monsoon in summer is another blessing of nature which transports water from the Bay of Bengal and the Arabian Sea to Pakistan which makes the western border for this weather system to reach. On one hand, the seasonal march of monsoon (onset, number of rainy days, offset etc.) is disturbed due to changing climate, on the other hand its inter-annual variability (repeated drought/flood events) has posed a serious challenge for the sustainable crop production. Pakistan's hydrological regime upstream and downstream is highly connected; if north gets surplus of water from heavy rainfall or snow/glacier melting, it immediately runs down to the low elevation plains of Sindh and Punjab flooding the cultivated lands and destroying standing field crops. In case of weak monsoon and less rainfall in the northern half, again the agricultural plains of south suffers a lot due to intense heat, higher water demands but less available water (Rasul, G. 1992 and Chaudhary et al., 2004).

Not only precipitation variability poses threat to the hydrological regime over the Indus plains known in the world for their crop production potential but an emerging challenge is faced from the tropical cyclones of the north Arabian Sea. The cyclogenesis potential of the Arabian Sea was less than the Bay of Bengal therefore tropical cyclones were the rare phenomenon to directly hit the Pakistan coast. Now reverse has happened since the rise of 21st century and these disasters are not only becoming frequent and intense but making landfall on the shoreline of Pakistan (Haider et al., 2008). The tropical cyclones are the storms associated with strong winds speeding up to 200 km/h and very heavy precipitation of the magnitudes of hundreds of millimeters in an hour. They make a clean sweep of infrastructure, crops and trees as well as inundating the whole area (Rasul et al., 2005).

Adaptation to climate change and building resilience among ecosystems and peoples to respond to climate variability and hazard threats are relatively new concepts. For this reason, networks for sharing experiences and ideas, especially between delta areas, will have a fundamental role in helping to address adaptation within specific ecosystems or sites. As well as regional collaboration, facilitating support from multi-lateral and bilateral donor agencies is crucial to enable on-going implementation climate change actions and improved governance, especially of water resources.

1.1 Objective

Global warming has been affecting the dynamics of climate system whose five components viz-a-viz atmosphere, cryosphere, hydrosphere, biosphere and lithosphere are interacting each other in a complex way. Mitigation and adaptation are two ways for dealing with the climate change. Mitigation works very slowly due to certain scientific reasons but adaptation is a workable option to be adopted immediately if the resources allow. To support the adaptation initiatives of different agencies, this report is prepared for vulnerability assessment to facilitate the development of climate adaptation plans. The vulnerability assessment will guess the health of ecosystems across the Indus Delta and other areas of the country. It will help to determine the likely changes to ecosystem services as a result of climate change; investigate links between ecosystems, livelihoods and climate change; and identify hotspots of vulnerability and natural resilience. For this purpose, a detailed analysis of past climatic trends and projections of future climatic conditions under most likely emission scenarios has been carried out with the state-of-art methodology using outputs of Global Climate Models (GCMs) downscaled to regional and local level by Regional Climate Models (RCMs).

1.2 Main Contents

Through the analyses of climatic data and model simulations, following targets have been set;

- Temperature variations on annual and seasonal scales in Pakistan and the Indus Delta.
- Precipitation trends, monsoon pattern, winter and annual
- Sea surface temperature variations over a long period (from 1980s to date)
- Sea Level Rise and its projections
- Temperature Projections for future on regional and Delta scale next 50 years or more
- Precipitation Projections for future on regional and Delta scale next 50 years or more
- Identification of key threats to the region and the Indus Delta due to Climate Change

1.3 Composition of Report

Section-1 includes introduction and objectives of this study. It includes the description of main contents annexing methodology followed for the analysis of past climate data of Pakistan and the development of climate change scenarios with some necessary details of global/regional models and software.

Section-2 of the report involves an overview of the global warming citing the extracts of Inter-Governmental Panel on Climate Change (IPCC 2007) updated up to 2010 and World Meteorological Organization (WMO) statements on status of Global Climate (using data from climatological stations all around the world) released at the end of each year. This section also stated the melting process of glaciers in different parts of the world over a period of time and equivalent sea level rise which impacts the riverine deltaic regions in different ways.

Section-3 deals with the assessment of climate change in Pakistan in general and over the Indus Delta in particular during the last 50 years. Discussion on recent extreme flooding is also included in this section. Vulnerabilities of the Indus Delta due to global warming and climate change are particularly focused which have been and most likely to become a serious challenge to the sustainable development efforts in future.

Section-4 involves the future projections of temperature and precipitation on national, basin, provincial, city and grid point scales for three decades of 21^{st} century in detail. Climate change scenarios on decadal scale for this century will also be given on national and provincial basis.

Section-5 has summarized the whole discussion and ended up with recommendations.

Section 2

Some Facts about Global Warming

Global warming is a widely used term which delivers a sensational message of increasing temperature of the planet earth. This claim does not base on any hypothesis rather a fact driven from thousands of meteorological measurements all around the globe covering both land and sea surfaces. These measurements follow a uniform method using universally accepted standard instruments under the supervision of the United Nation's World Meteorological Organization (WMO) since 1935. When well-marked changes in global climate were felt seriously in 1980s (e.g. strong El~Nino of 1982-83), the working group of nations decided to establish a high level forum of political decision makers for devising strategies to mitigate the effects of climate change. Global leaders appreciated this initiative of WMO and United Nations Environment Programme (UNEP) and an international forum now known as Inter-Governmental Panel on Climate Change (IPCC) was established. Its mandate includes developing consensus among developed countries to reduce Green House Gases (GHG) emission to certain levels, generate resources for adaptation, incentives to mitigation efforts and to publish climate change assessment report for the globe on 6-years term. IPCC released its Fourth Assessment Report (AR4) in 2007 which includes plausible facts on changing climate in different parts of the world. Not only the past changes in climate of different parts of the world have been included in this report but due consideration has also been given to the future climate projections and likely impacts. Recent report superceded all the previous reports in terms of science of climate change, impact assessment techniques in different sectors as well as the numerical modeling approach to project the future status of climate over the planet earth. Simultaneously some civil society groups took lead in the awareness campaign for general public about the likely impacts of climate change on the lives of present and future generations.

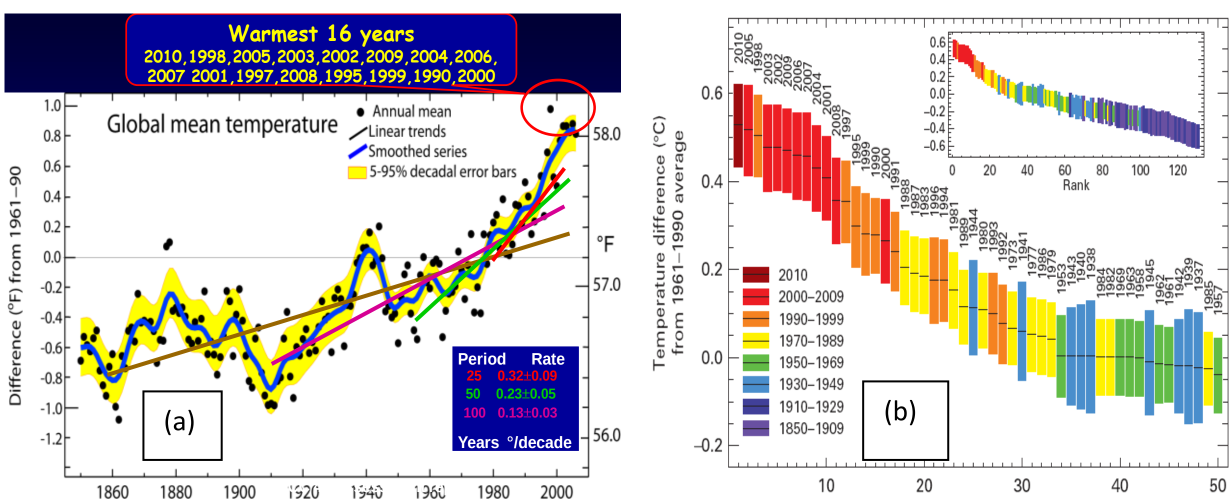


Figure 1: Global average temperature trend (a) since 1850 with 16 warmest years ranking (IPCC 2007 updated with recent data) and color coded decadal average global temperatures compiled by WMO (2011).

2.1 Increase in Temperature

Climate sciences made marvelous progress in theoretical and practical field in 19th century which gave rise to increased instrumental meteorological monitoring. Instrumental records show that climate of earth followed natural variable behavior in 19th century but a significant rise in temperature on earth started from World War-I (Figure 1a). After a little fall, it was further triggered by the Second World War and industrialization in 1940s causing an accelerated increase in global temperature booming the national economies at the cost of environment.

According to WMO, among the warmest decadal ranking (Figure 1b), the first decade of 21st century 2001-2010 topped the rank followed by 1990s and 1980s respectively placed at the second and third positions. Likewise among the 16 warmest years recorded over the globe, 9 occurred during the first decade of this century. 2010 tied for the warmest year in records dating back to 1880. The temperature increase in 2010 was recorded as +0.53°C (than long term average) ranks just ahead of those of 2005 (+0.52°C) and 1998(+0.51°C). We may recall that El~Nino event of 1998 was the severest one of the recorded history (Eastern equatorial Pacific sea surface temperatures rose by 4°C above mean) which disturbed the global weather pattern over a period of a couple of years (Chester, 1999).

2.2 Glaciers and sea level rise

Glaciers are the most sensitive indicators of the global warming and give quick response in the form of volume of melt water which finally adds to the sea level. Global warming causes sea level rise in two ways; firstly by thermal expansion of water and secondly by addition of melt water from snow and ice of mountain glaciers. Because of inverse relationship between temperature and snow/ice, the glaciers all over the world have been losing their mass due to increase in interacting air temperature as shown in Figure 2a. A sharp decline in the mass balance of all the glaciers can be seen since 1990s. Black line represents the Asian mountain glaciers which are mainly housed in Himalaya-Karakoram-Hindukush mountain ranges. They possess the largest ice mass after the Polar Regions and feed 1.7 billion people through seven large Asian River Systems such as Indus, Ganges, Brahmaputra, Mekong and Yangtze.

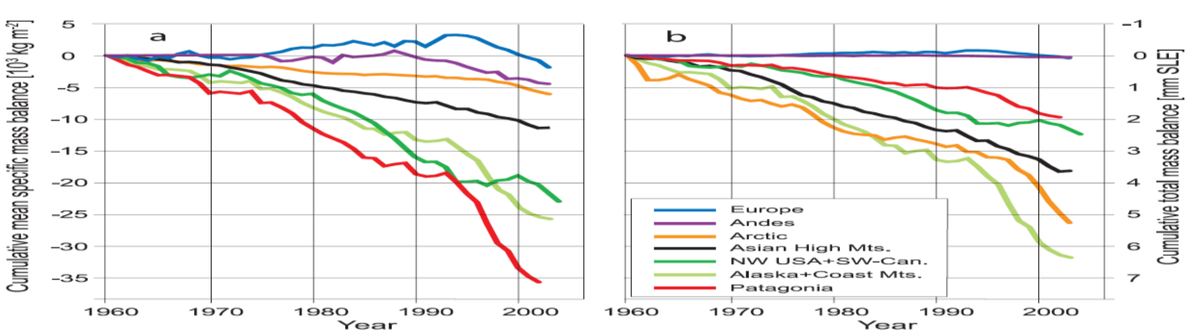


Figure 2: Status of global glaciers (a) under global warming, Himalayan glacier's retreat is shown by black line and contribution of melt water (b) to equivalent sea level rise (IPCC 2007).

A continuous increase in temperature has been causing expansion of the sea water which has been raising the level of sea along with bringing changes in the physical processes due to sea-atmosphere interaction. Accelerated melting process of seasonal snow and that of glacier ice from glaciers have been adding more volume of water into the sea than the normal discharges. Figure 2b presents the equivalent rise in sea level due to the simultaneous decrease in mass balance of the glaciers. Alaskan glaciers have the highest contribution to the sea level rise followed by Arctic and Asian (Berthier et el., 2010).

2.3 <u>Reasons of Climate Change</u>

Climate is a product of weather which always experiences variations over space and time. Natural reasons result in climate variability over different time scales but they are least responsible for a significant change in climate. Solar and volcanic activities fall under natural processes and they cause short lived changes in weather conditions as a result producing fluctuations in climatic pattern. Land, ocean and atmosphere interactions have been resulting into usual cyclic variations in weather and hence climatic conditions over the globe. Anthropogenic activities are mainly blamed for global warming and climate change. Detail of various natural and anthropogenic reasons related to human activities is given in Figure 3. Anthropogenic reasons are controllable but they been dominating now over the natural, due to which balance of the atmospheric heat budget has been disturbed and more amount of heat has been trapped in the biosphere than usually required to regulate the life processes (Peter et al., 1997).

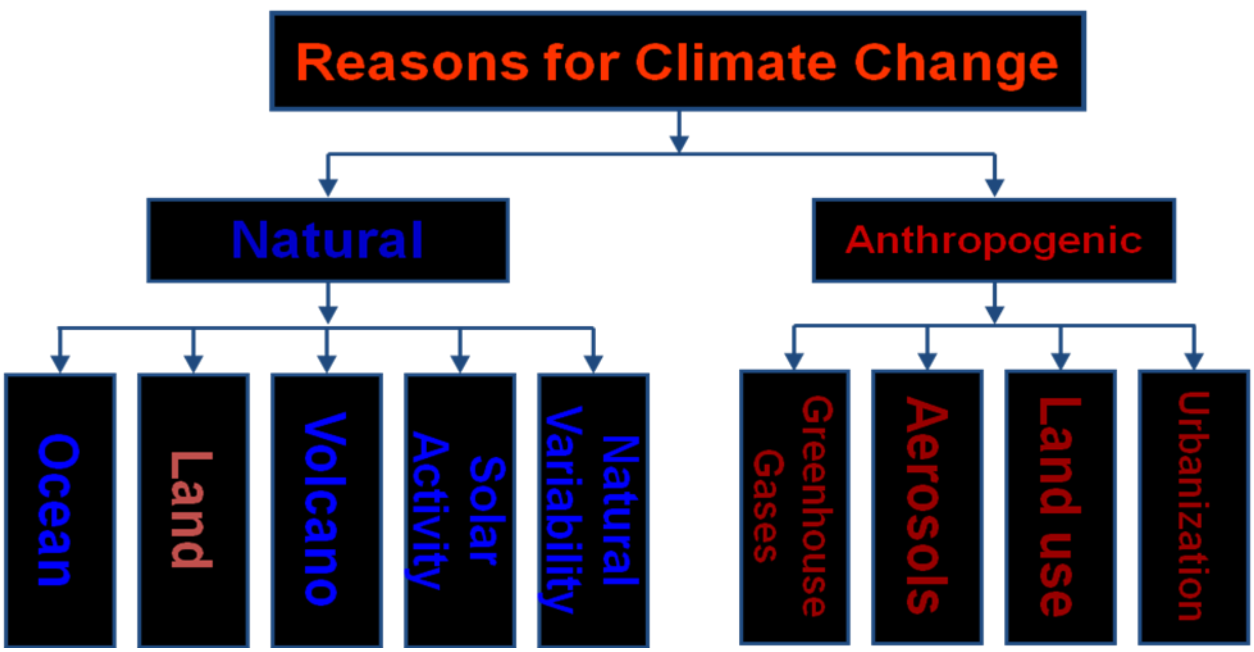


Figure 3: Reasons of climate change include natural as well as anthropogenic related to human activities. Anthropogenic reasons have surpassed the natural giving push to rapid warming of the biosphere.

After industrial revolution, the atmospheric composition changed drastically due to addition of the emitted Greenhouse Gases (GHGs) which have very high warming potential and long life time to exist in the biosphere (Montzka et al., 2011).

Table 1: Life time, global warming potential and change in concentration level of different Greenhouse Gases (GHGs) in the atmosphere. For life time and warming potential, the reference is taken as CO_2.

S.No.	**GHGs**	**Level in 1870**	**Level in 2007**	**Life Time in years (Relative to CO_2)**	**Warming Potential (Relative to CO_2)**
1	Carbon Dioxide	280ppm	399ppm	1	1
2	Methane	700ppb	1745ppb	12	72
3	Nitrous Oxide	270ppb	314ppb	114	310
4	CFC-12	0	533ppt	270	12000
5	Sulphur Hexafluoride	0	480ppt	3200	16300

For the interest of policy makers who wish to peep through the future, some facts about GHG emissions and their consequences are presented in Table 1. First three gases naturally occur in the atmosphere due to biological and chemical processes but last two are purely the products of the industrial emission (Prather, 2010). The atmospheric concentration of all the GHGs has been increased and ratio of increase varies from gas to gas. Life time of their existence in the air may be defined as the length of time the atmosphere returns to equilibrium state (normal level) after its entry. For example Carbon Dioxide molecule after entry interacts physically and chemically with several others and finally absorbed by the oceans. Life time of all the other gases is taken relative to (times) Carbon Dioxide. For example, a molecule of sulphur Hexafluoride (SF_6) can exist in atmosphere 3200 times longer time than a molecule of Carbon Dioxide (Maiss, 1996 and Metz et el., 2005). Due to the longer life time of these gases, the scientists say that even if the emission of GHGs stop now, the ongoing warming trend will continue for the next 50 years at the prevailing rate. Similarly, the warming potential of each gas is given relative to CO_2 (Anderson et al., 2009). For example, a kilogram of methane can heat up atmosphere 72 times more than a kilogram of carbon can (Neue, 1993). A common message from this information evolves that the increasing concentration of GHGs in the atmosphere is not only creating problems related to climate variability but also signals severe consequences in future. Therefore *act today for tomorrow.*

Section 3

Pakistan Perspective

Under global warming and changing climate, Pakistan is no exception as both do not follow the political/geographical boundaries. Precipitation and thermal regimes in Pakistan have suffered changes especially in the recent two decades when global atmospheric temperatures have shown sharp jump. Pakistan enjoys diverse climate ranging from frozen ice caps in the north to burning deserts in the south (Rasul et al., 2005). It is bound by the world's highest mountains in the north which act as barrier to the cold waves to penetrate to south in winter and obstruct monsoon rains to further extend into the north in summer. The Arabian Sea making the southern border brings lot of moisture in the form of summer monsoon to nourish the water needs for agriculture, power generation, industry and domestic usage. Due to rise in temperature, visible changes in hydrological cycle have been observed in the form of changing precipitation pattern, cropping pattern, droughts, water availability periods, frequency and intensity of heat waves, precipitation events and weather-induced natural disasters.

3.1 Temperature Variations

The mean daily temperature is defined as the average of maximum temperature and minimum temperature during the day. The maximum temperature usually occurs in the afternoon of a sunny day while the lowest temperature termed as minimum reaches just before the sunrise under cloud free sky conditions. In broader terms maximum temperature is generally referred to day time and minimum temperature to night time temperature. To be on the safer side letting both daily extremes to occur in observation time domain, the maximum temperatures are recorded at 5 PM local time in each country and minimum at 8 AM local time according to World Meteorological Standard. Whenever the minimum or maximum temperature reaches, the respective indices or indicators stay there until the observer resets them. The discussion should not focus on the mean daily temperatures rather the day and night trends should also be taken care of as both have different impacts of biological, chemical and physical processes.

3.2 Annual Temperature Variations

Pakistan

In Pakistan, 56 meteorological stations having long as well as continuous records of weather parameters were selected to include in this report. Selection criteria was determined keeping in mind that all the climatic zones of Pakistan could be represented with uniform weighing factor allocated according to the surface features of the region. A time series of area weighted annual averages for mean daily temperatures has been presented in Figure4.

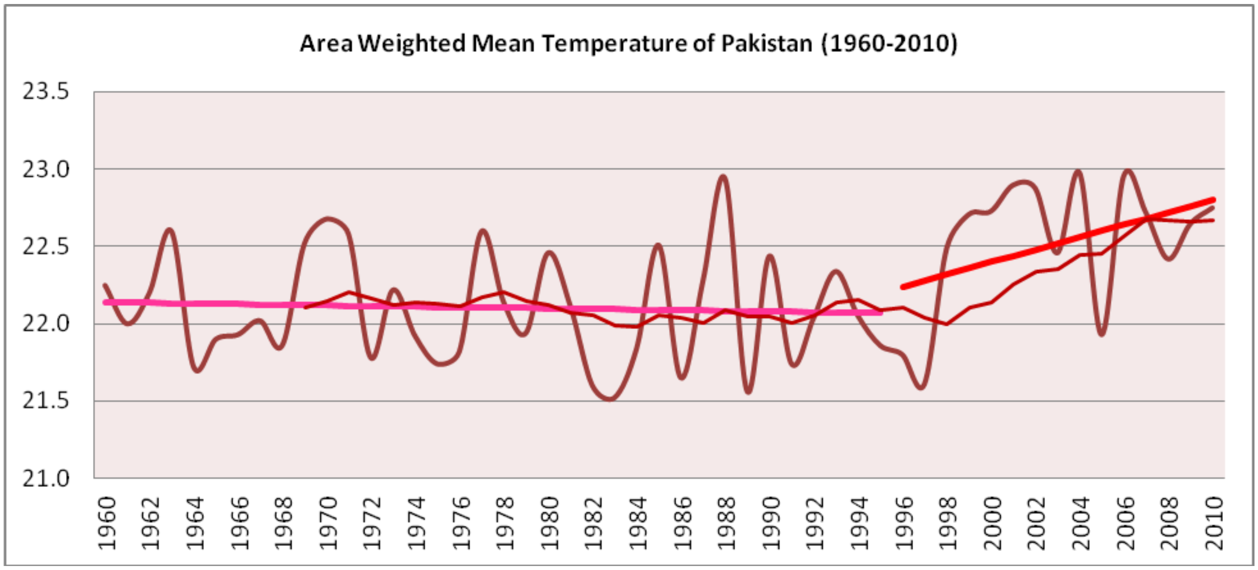


Figure 4: Time series of area weighted mean daily temperatures averaged over each year shows a sharp rise in temperature during the first decade of 21st century except the year 2005.

Since 1960 up to 1997, there was inter-annual variability of mean daily temperatures subsequently featuring alternative cold and hot spells but amplitude of variations maintained the average pace. In 1998, the severest El~Nino of the history occurred due to the abnormal heating (>4^{o}C above normal) of the East-Equatorial Pacific water which sent shock waves all around globe affecting the weather pattern of the world. In Pakistan this happened to be the hottest year compared to the past. Due to failure of summer rains, four years long drought conditions gripped the most parts of the country and atmosphere was not reclaimed to lower its temperature (Thenkabail, 2004). Heat continued to persist due to loss of vegetation, deforestation, irregular cycle of rains and increased frequency/intensity of heat waves. There was an exception with 2005 when good summer and winter rains kept the temperatures in normal range otherwise this decade would have shown an irreversible rise in temperature.

3.3 <u>Summer and Winter Behavior</u>

It is interesting to know how day and night temperatures have been behaving in Pakistan when mean daily temperatures show consistent rise. Are both getting equally heated up or some differential behavior is observed? Knowing these facts carry its own importance because both have different role in growth and development of crops as well as flora and fauna dynamics. Day temperatures in sufficient daylight regulate the photosynthetic activity to produce carbohydrates and results in dry matter production. In Figure 5, tendency of day and night temperatures in summer and winter seasons during last decade is shown compared with long term average temperature.

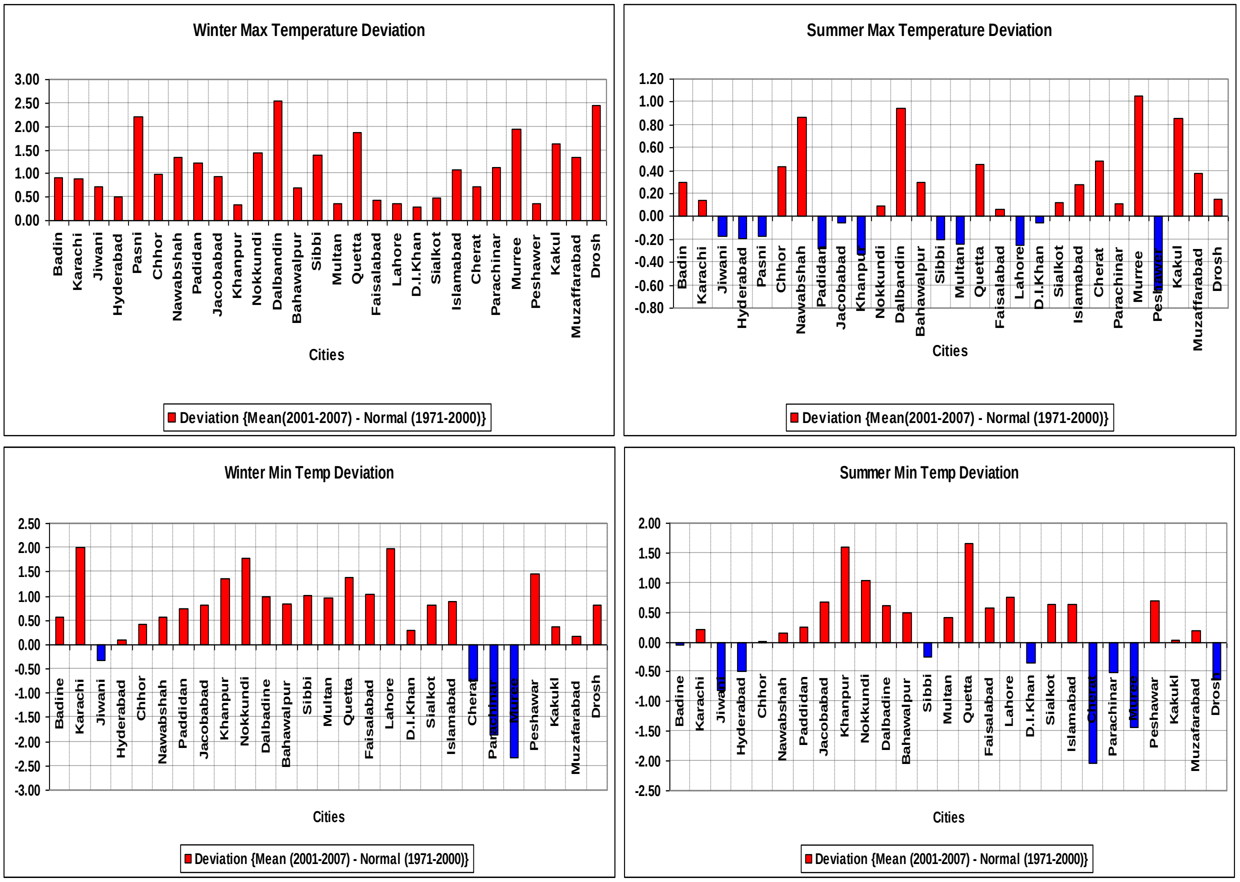


Figure 5: Deviation of maximum (represents day highest) and minimum (represents night lowest) temperature during last decade from normal in summer and winter seasons in Pakistan. Stations are arranged south (left) to north (right).

Respiration is the reverse process of photosynthesis when dry matter produced during the daytime is consumed by the plants and animals at night. Higher the night temperatures, the more will be the respiration. Net dry matter production which provides fuel for the plant growth and development is the difference of day time production and night time consumption. Net dry matter production is also direct measure of the economic yield of the crop. Hence, higher than normal night temperatures have negative impact on animal and crop production.

The minimum temperature which is the measure of lowest night temperature and the maximum temperatures commonly representing day's highest temperature have increased in both summer and winter seasons almost throughout Pakistan (Afzaal, 2009). Figure 5 presents the summer and winter behavior of the maximum and minimum temperature during the last decade compared to long term average from south (left) to north (right) of Pakistan. Winter season has shown more warming trend than the summer which shows that the extent of winter season has been reduced on both ends leaving the summer season extended. Night temperatures have shown larger increase than the day temperatures indicating their negative impact on animals and crop production due to heat stress, increased water requirements and higher rates of respiration. In summer, a mixed trend prevailed during the last decade in maximum temperatures. However, the minimum temperature in summer over central parts of Pakistan have pronounced warming trend while extreme north and south have shown slightly cooling trend in some climatic zones. (Tank et al., 2006) The coastal belt in general and the Indus delta in particular have not shown any alarming warming or cooling trend. However, the changes in thermal regime taking place in the surrounding regions would ultimately affect the climatic condition of deltaic region.

Implications for Indus Delta

Increase in maximum and minimum temperature in winter season results in shorter winter and longer as well as summer. Following implications are foreseen due to ongoing trend;

- Late onset and early ending winter will reduce the length of the growing season for crops which will complete their biological life cycle quickly causing reduction in the economic yields as the plants will gain accelerated maturity without reaching proper height and size.
- Early end of winter means that temperatures will start rising in February when wheat crop reaches the grain formation stage. Sharp rise in temperature will cause forced maturity of grains. Neither the grains will gain proper size and weight nor accumulate optimum starch contents hence reducing the grain yield.
- Banana is another major crop of Indus Delta in which pollination will be affected due to early end of winter and high spring temperatures. Thermal stress would result in poor fruit set and dwarf yields.
- Such adverse effects are already visible and there is a dire need of adaptation strategies by introduction of crop varieties which require shorter span and bear the stress conditions.

3.4 Precipitation

All sort of water (liquid or solid) which fall from the clouds is known as precipitation. It includes rain, snow, hail, sleet, precipitating fog and virga. This is the yielding component of hydrological cycle. Water evaporates from the surface of soil, vegetation and water bodies due to increase in temperature then reaches to the upper layers of the atmosphere because moist and warm air is lighter than dry air. In the upper layers, temperature is low, therefore cooling causes condensation of water vapors to form the clouds. Due to lower temperatures vapors combine to make droplets or ice crystals heavier and heavier in clouds which finally drop in the form of precipitation when gravity overcomes buoyancy. Precipitation occurs as rain or hail at low elevation plains whereas in the form of snow at high elevations especially in winter when surface temperatures in mountainous terrain becomes well below freezing point i.e. 0°C. There are three main types of rainfall; orographic, frontal and convective. Pakistan experiences all the three types of rainfall depending upon the location and season of the year. It may also be emphasized that precipitation is the most variable parameter of all weather factors over the temporal and spatial scales.

Pakistan

There are two major rainy seasons in Pakistan which corresponds to winter and summer. In winter, the mid-latitude westerly waves move across the lower latitudes and their troughs generally extend down to 35°N sometimes further south. Under the influence of the troughs of westerly waves as well occluded frontal systems, northern half of Pakistan receives substantial rainfall over low elevation plains and snowfall in mountainous regions during winter season. Summer bring monsoon to Pakistan which contributes about 60% of the annual total precipitation from July to September. Pre-monsoon (May and June) is very hot and dry season and only localized convective rains occur occasionally. Similarly, autumn (October and November) is the dry season without summer or winter rains but low temperatures do not produce as much stress as pre-monsoon does. Pakistan's total annual precipitation ranges between 500mm and 800mm with higher amounts in the northern half which receives handsome share from both winter and summer. Southern half of the country receives hardly 50% of the northern one because neither monsoon establishes well nor winter precipitation approaches with generous downpours. Southern half is mainly composed of Sindh and Balochistan provinces which experience arid climate and agriculture is not possible without supplementary irrigation (Chaudhary et al., 2004). In Balochistan, annual total precipitation is very low as precipitation seldom reaches there in summer as well as in winter. High mountains get meager amount of snow in winter which hardly stays until spring leaving no reserves to maintain sustained water supply in hot summer. On the other hand, lower Sindh adjoining the coast covering the Indus Delta receives better rainfall than the upper one because of monsoon incursion along with southwesterly winds from the north Arabian Sea. Solid precipitation accumulated over the northern mountains in winter in association with the glaciers feed the river flows in the summer season especially when dry and hot weather prevails in pre-monsoon period. Figure 6 presents the time series of precipitation over Pakistan for the last 109 years. It shows slightly increasing trend but not well-marked change when compared with the centurion scales.

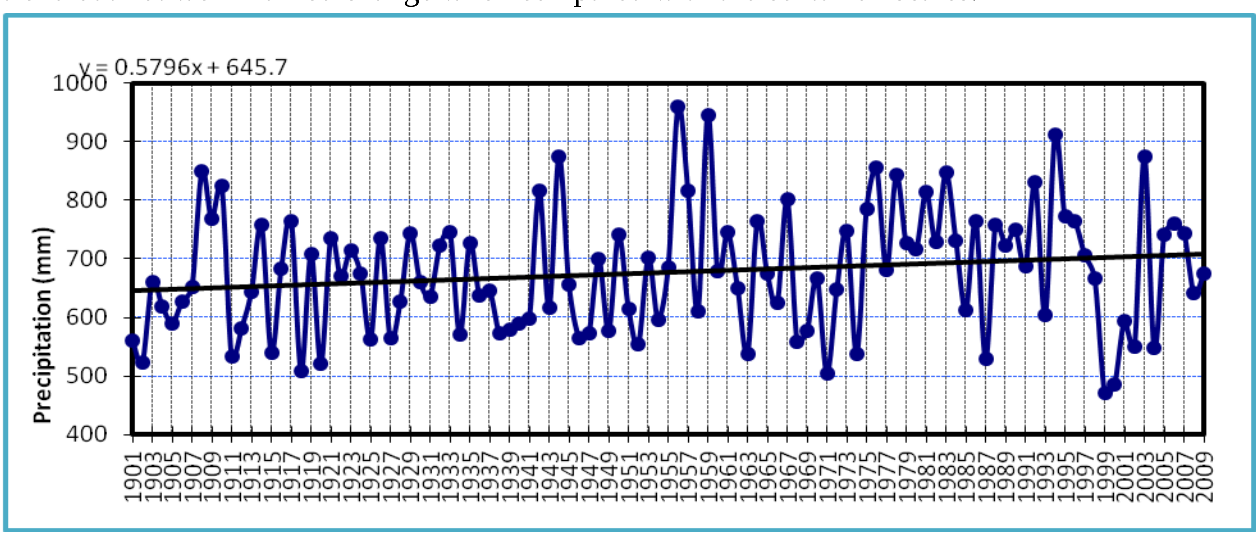


Figure 6: Inter-annual variability of precipitation over Pakistan during the last century and first decade of 21st century. Climate Research Unit (CRU) data used to downscale Pakistan's regional precipitation.

The change in total amount of rainfall on countrywide scale is hardly 60 mm increase over a period of 109 years which makes an average rate of increase around 0.5mm/year which is negligible when considered in terms of its quantitative impact. The number of meteorological observatories was less in 19th century and most of the data presented in Figure 6 was produced from reconstructed proxy data from various sources such as tree rings, coral reefs, sediments etc. The most important characteristic of precipitation is its variability over time and space which needs detailed study on its dynamic behavior. Although, this meteorological parameter has always experienced large scale variability but during recent few decades continuous dry and wet spells spanned over a couple of years at least have ascertained the impacts of global warming and climate change in Pakistan too.

3.5 Annual Rainfall Variability

Present Pakistan inherited only 8 observatories when recognized as independent country in 1947. Of course this number was not enough to reflect the climatic features of such a vast geographical land mass of highly variable terrain, therefore number of observatories increased sharply to cater the needs of different stakeholders. In this part of study, the real time precipitation records of 56 meteorological stations have been incorporated to study the trend of change and inter-annual variability on national scale. Figure 7, presents the temporal variation of precipitation during the recent half century over Pakistan from 1960 to 2010. The years falling under the trend line are graded as drought years which have dominant frequency as compared to flood peaks with surplus amount of precipitation.

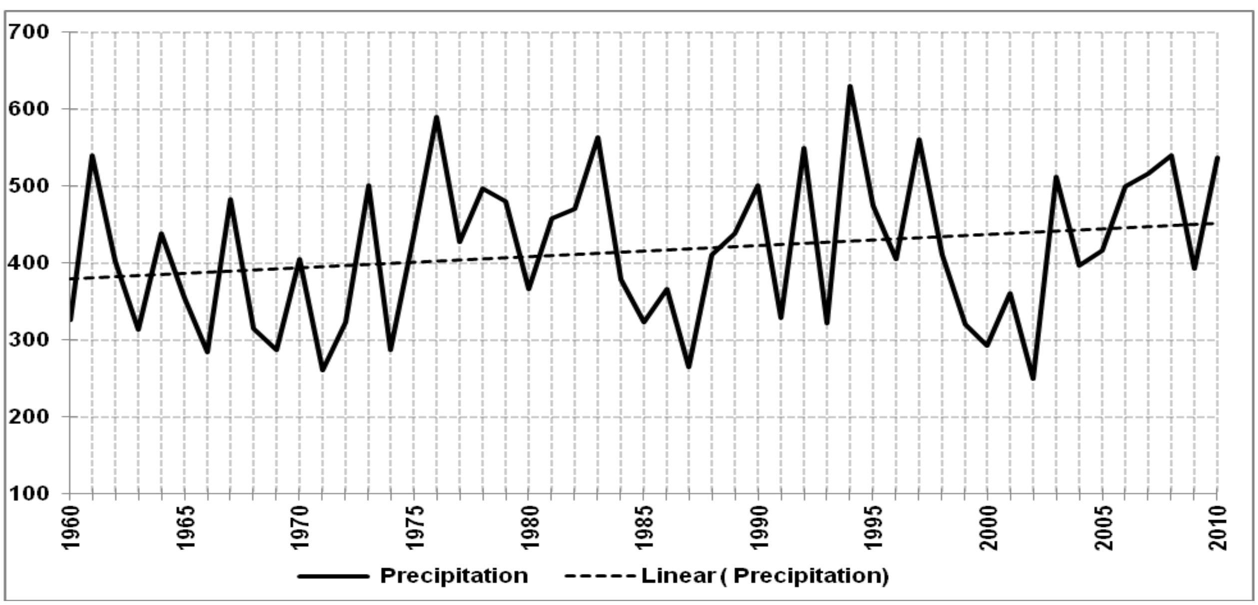


Figure 7: Time series of precipitation over Pakistan based upon data records of 56 meteorological observatories located in all the climatic zones of the country.

The flooding years 1961, 1976 and 1994 are clearly visible from the precipitation peaks but 2010 which was the severest flood event so far is not showing any significant features in terms of total precipitation average. The only explanation is that large amount of precipitation concentrated over the small catchment area of steep slopes for a few days. The terrain was composed of several small streams perennial in nature running down slope over the sub-mountainous plateau. The gravitational stream flows converged to produce historic floods in the Indus downstream. Peak flows were later maintained by the persistent heavy spells of intermittent rain downstream the largest reservoir at Tarbela on the River Indus. Previous record high flows of such scales were documented in 1929 but not of that persistence. More than one million cusec peak flows were maintained at certain gauge stations for a couple of weeks leaving the foot prints of the largest volume of flood water ever experienced by the mighty Indus in the living history of hydro-meteorological disasters.

The emphasis is on the point that annual totals of precipitation for any particular region or a country neither gives true reflection of floods nor the dry spells. Total precipitation of any two particular years may be same if one experienced extreme dry conditions in a growing season while the other was badly flooded. It is therefore highly desirable to look into the finer temporal and spatial scales for identification of such extreme condition. For this reason, the seasonal pattern of precipitation has been studied to identify some visible shift in normality of this highly variable weather parameter in different climatic zones of Pakistan. Such deviations are generally taken from the long term averages not less than 30 years.

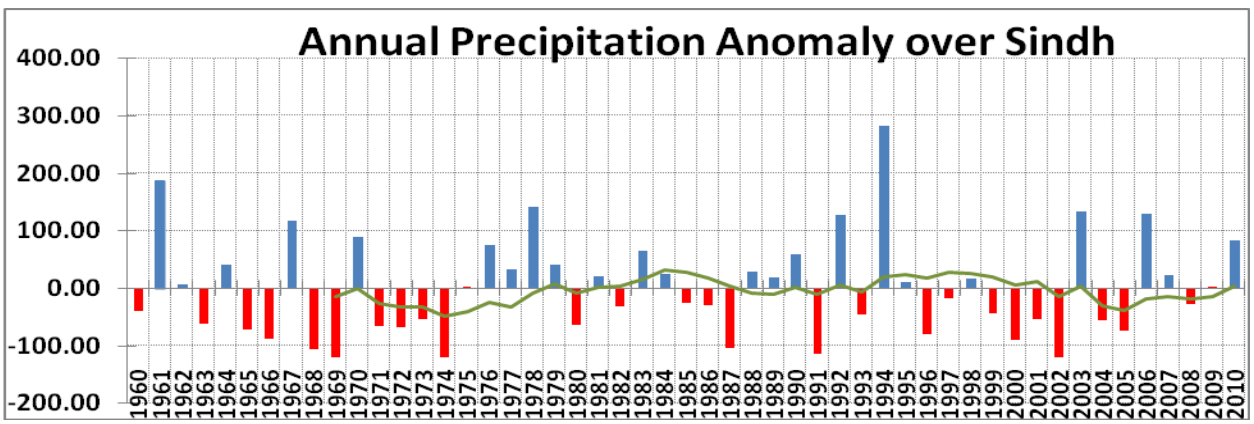


Figure 8: Inter-annual variability of precipitation (mm) over Sindh about the long term average showing predominant drought as well as some flood years.

Long term average precipitation of Sindh Province is 160mm taking into account the data of 50 years from 12 meteorological stations. Annual deviation of the precipitation (in millimeters) over the province is shown in Figure 8 which depicts it as a drought prone area with occasional surplus extremes resulting into flooding conditions. The province has long history of droughts which persisted over a stretch of at least couple of years. For instance, 1968-69, 1971-74, 1985-87 and 1999-2002 are known for their damages to crops, livestock, soil and natural ecosystem in addition to massive migrations; increasing pressure on marginal natural resources in surrounding areas. Floods were relatively uncommon in the province due to local rain storms as 10 such events occurred during last 50 years. But the problem of Sindh floods has been connected mostly to upstream water flowing downstream through the mighty river Indus. Hence attention should be focused simultaneously on local conditions as well as changing behavior of precipitation in the Upper Indus Basin (UIB). Both such flooding phenomena have co-occurred in the province during 2010 when heavy downpour of Khyber Pakhtunkhwa inundated the Indus Delta followed by 2011 localized province scale heavy rainfall. Just looking on precipitation data of Sindh, one can not guess the vulnerability of floods for the province. Similarly adverse effects of drought conditions resulting due to lack of rainfall in the Indus Delta can be mitigated if required water supply is maintained through canal irrigation from upstream water reservoirs.

3.6 Summer and Winter Behavior

Summer precipitation concentrates in monsoon season from July to September and this is generally associated with the monsoon depressions (low pressure systems) formed over the Bay of Bengal which reach Pakistan crossing India due to their westward motion. Their reach is related to their strength otherwise they dissipate over central India. Another mechanism of the summer monsoon precipitation is the southwesterly flow of moisture from the Arabian Sea which gets activated in case of persistence of a depression. Both the phenomena reinforce the precipitation process after interaction and produce high intensity rainfall i.e. heavy amount of water in a short interval of time (Das et al., 2003; Rasul et al., 2004).

Winter precipitation is produced by western disturbances which are the troughs of westerly waves passing across the mid-latitudes. Under the influence of such waves, northern half of Pakistan (north of 30°N latitude) get good amount of precipitation in the form of rainfall as well as snowfall. Southern half seldom receives winter precipitation due to its existence beyond their effectiveness (Robin et al., 1993). However, in case of strong activity, the troughs of westerly waves extend sufficiently southward and sometimes yield good precipitation in Balochistan and Sindh. It is important to note that winter precipitation is generally of very low intensity as compared to that of summer, therefore floods do not occur in winter.

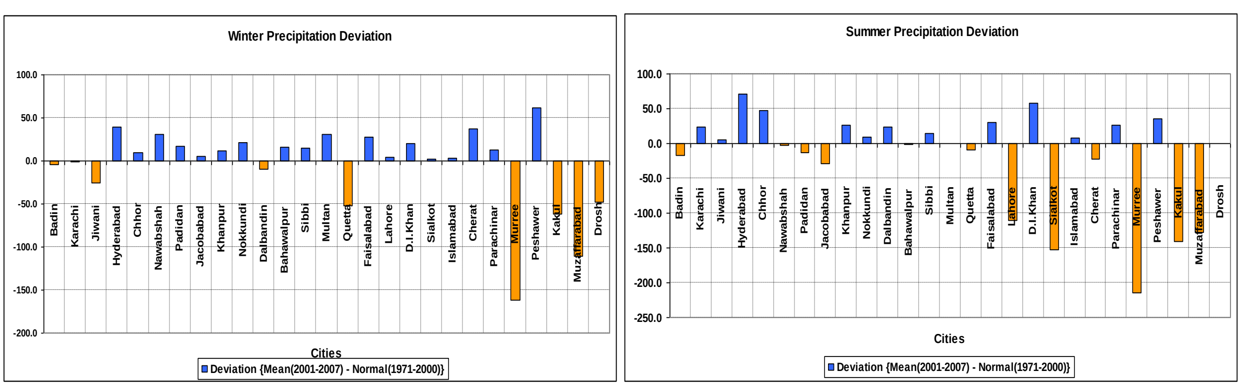


Figure 9: Deviation of rainfall in summer and winter during the recent decade (2001-2010) from the long term average of 1971-2000. The stations are placed in increasing order of latitudes from south (left) to north (right).

From the above discussion it is clear that the northern half of Pakistan receives the major share of annual precipitation and mainly in summer monsoon season while lower half gets minimal in both the precipitation seasons. Extensive debate is going on about the pattern and regime shift of precipitation in different parts of the world due the global warming and climate change. Pakistan has also been experiencing the flavor of such changes at different scales in different climatic zones in the form of extreme climatic anomalies. An average change in precipitation amount during the decade 2001-2010 in different climatic regions of Pakistan compared to long term normal of 1971-2000 is presented in Figure 9 for summer and winter seasons. In winter, there is a significant decline in precipitation in northern mountainous regions during the last decade and rest of the areas followed the normal behavior. Summer precipitation in northern half of the country has decreased in terms of total amount but its inter-annual variability has increased a lot. Lower half of Pakistan, especially the Indus Delta, has shown a moderate increase in total amount of rainfall due to frequent localized heavy spells of precipitation during the summer monsoon season. This increase over the Indus Delta does not support the socio-economic activities rather it is attributed to the disastrous downpours posing challenges to the sustainable development in the region. Heavy soils with poor drainage leave the heavy amounts of rain water to remain stagnant destroying the standing crops and not allowing the plantation of next seasonal crops on time.

3.7 Trends of Heat waves in Pakistan

Heat waves are the byproduct of climate extremes. These are now more frequent and intense during summer over most parts of the world. They are not only responsible for deaths of living beings but can also change the rate of evapotranspiration and soil moisture ultimately causing crop failure. Asian mountain glaciers are facing serious threat of global warming and accelerated recession (IPCC 2007; Rasul et al. 2008). It is expected that elevated temperatures will raise the regularity of heat waves in future. The duration of heat waves play vital role in its harmful impacts which may disturb the water cycle through enhancing the rate of convection evapotranspiration, condensation and precipitation.

Heat waves can be defined as "The location during summer months (Apr–Jun), with normal maximum temperature of ≥40°C is considered to be under moderate heat-wave (HW) conditions when the maximum temperature is 3–4°C above normal. The situation with a temperature of 5°C or more above normal is referred to as severe heat-wave (HW) conditions. For a location with a normal maximum ≤40°C, the limits are 5–6°C for a moderate heat wave and 7°C or more for severe heat-wave conditions" (Mohanty and Panda 2003). Heat waves generally developed during Pre-Summer (March/April) and Pre- Monsoon (May/June) in Pakistan. The heat waves conditions observed during pre summer period was not very frequent prior to 90's but most probably due to climate change now Pakistan receive more heat waves in this period. The heat wave conditions appear during Pre Summer period is because of the grip of Arabian STH over Pakistan as shown in Figure 10. This frequent occurrence in the month of March/April has increased the summer season length in Pakistan. Whereas position of Tibetan STH is the prime cause of heat waves conditions observed in Pre-Monsoon season.

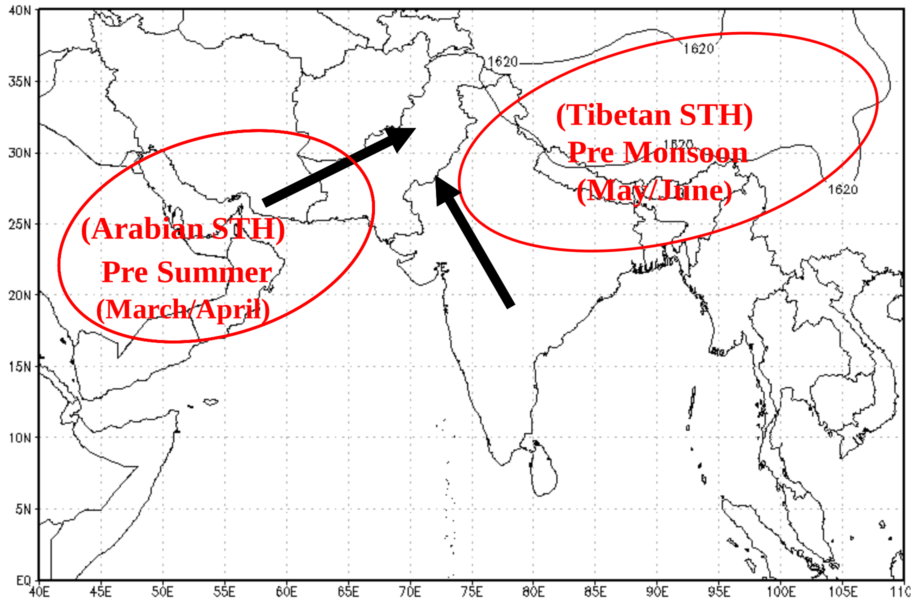


Figure 10: Development of Heat Waves during Pre Summer and Pre Monsoon season over Pakistan

3.7.1 Frequency of Heat Waves in Pakistan

Heat waves are a big threat to the human, animals and plant health. When temperature rises above a certain threshold, it starts obstructing the biological growth process in living things and its persistence for a longer period cause serious damages in the form of sun burn and sun strokes in human beings and animals while flower/fruit fall and leaf burn in plants. Damages of heat waves are largely detrimental and irreversible. Persistent heat waves often result in water shortages for crops, animals and human beings due to their increased demand.

3.7.2 Trends of Heat Waves Frequency in Sindh

The linear trend is positive for the heat waves frequency at 5, 7 and 10 consecutive days of moderate heat waves (≥ 40°C) in Sindh as shown in Figure 11. The trends for 5, 7 and 10 consecutive days are quite sharp indicating the increase frequency of heat waves in Sindh from 1961-2011. The number of events of heat waves sustained for 5 days showed increase in the analysis. While in 7 and 10 days analysis although heat waves conditions prevail in almost every year but their number has slightly increase. The severe heat waves (HW) events calculated at ≥ 45°C for 5, 7 and 10 consecutive days for the Sindh has also shown in the Figure 11. The linear trends drawn for 5, 7 and 10 continuous days demonstrate the sharp increase in the study. During the period 1961-1990's the heat waves events were not frequent and lesser in number however from 1990 to 2011 increase in frequency of these events have been noticed. It is anticipated that with a long term rise in temperatures around the globe, heat waves will become more frequent and intense in all parts of the world, including Pakistan (Maida et al., 2011).

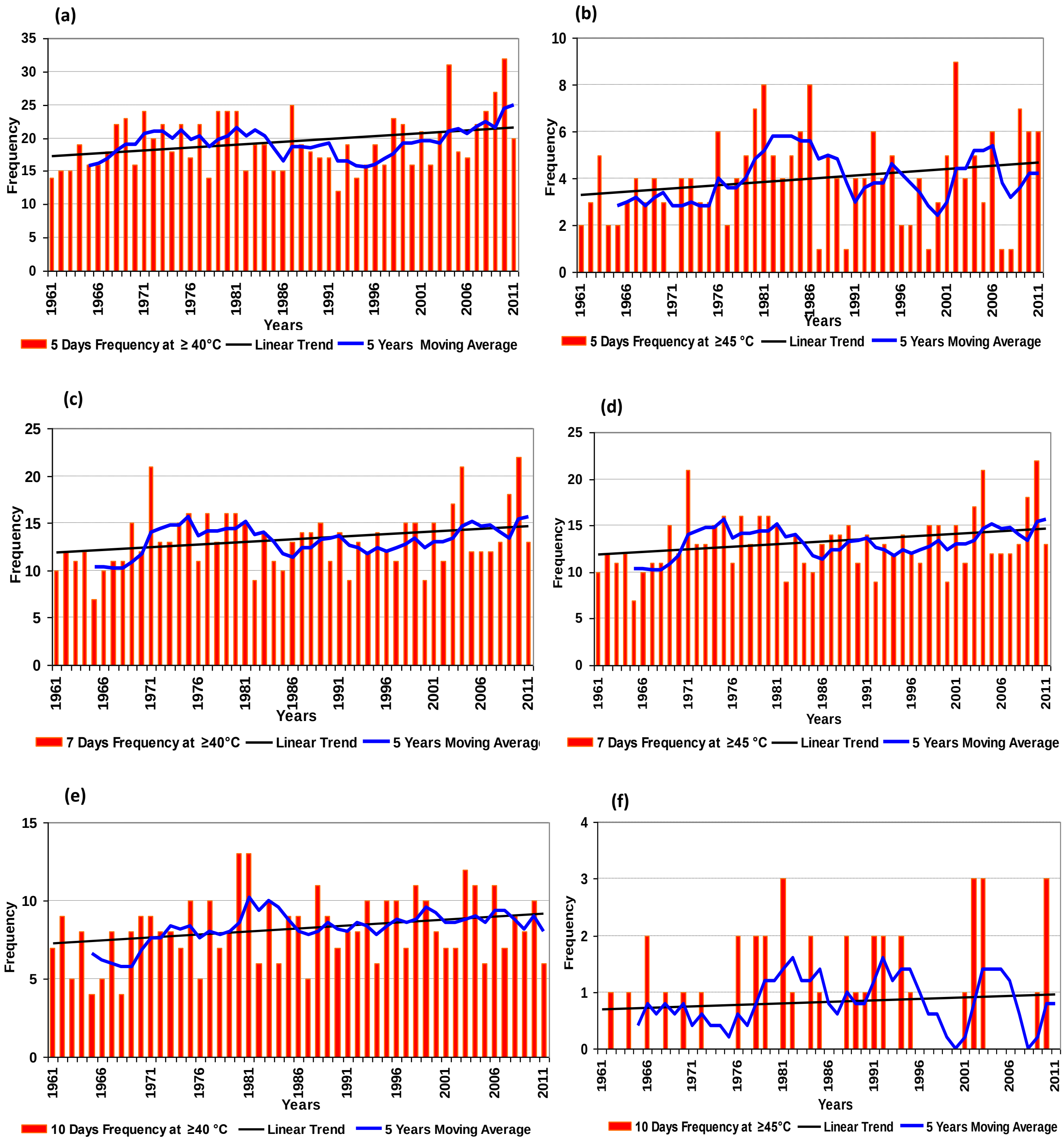


Figure 11: HW frequency in Sindh at ≥ 40°C & ≥ 45°C (a) & (b) 5 days (c) & (d) 7 days (e) & (f) 10 days

3.7.3 Extreme Precipitation Events

The areas which lie in active precipitation zone used to enjoy up to 200mm rainfall as a common feature but such events appear as a disaster where this much rain makes the total of the year. Lower half of Pakistan comprising Balochistan and Sindh represents the latter zone where annual total rainfall is a few hundreds of millimeters and it occurs mainly during summer in 15-20 days. Occasionally a few heavy precipitation events in active monsoon period brings lot of rainfall which results in devastation instead of casting benefits. It has been clearly mentioned in the 4th Assessment Report of IPCC (2007) that It is very likely (more than 90% confidence) that the frequency and intensity of extreme events will increase due to climate change in 21st century. However, the scale of increase will differ from region to region. Such change is quite visible in Pakistan now.

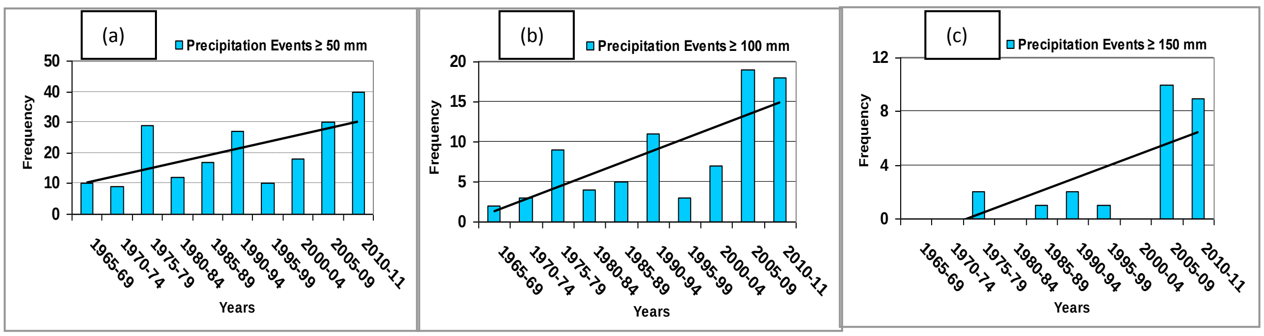


Figure 12: Frequency of extreme precipitation events in Sindh Province on pentad scale compared with two recent years 2010 and 2011. Three thresholds are chosen (a) rainfall ≥50mm/day, (b) ≥100mm/day and (c) ≥150mm/day.

The change in tendency of extreme precipitation events is shown in Figure 12 in intervals of pentads from 1965-2009 and last two years 2010 and 2011. Keeping in view the amount of rain over certain period of time it turns to a disaster from blessing as endurance differs case to case, three thresholds have been selected (i.e., 50, 100 and 150mm per day) for analysis of 47 years data sets of 12 meteorological observatories of Sindh.

The analysis of data shows a clear-cut increase in frequency of occurrence of extreme precipitation events in Sindh at all the three thresholds; rather the height of bars during last 7 years at 100mm and 150mm or more per day has been showing a serious concern for planners and policy makers. Province of Sindh remained in the grip of history's severest drought during the first pentad of 21st century when summer monsoon failed to attain its active phase repeatedly but the second pentad prevailed with enhanced energy. During 2005-2009, there were 19 rainy days when rainfall exceeded over 100mm in a single day (highest frequency 1931-2009). This recently established record was broken by the two years (2010 and 2011) total; still there are three more years to come to complete this pentad. Similar is the situation in case of threshold rainfall more than or equal to 150mm in a day.

3.8 Sea Surface Temperature

Land, ocean and atmosphere interact to produce weather systems over the globe and energy from the sun is believed to play the driver role in the climate system dynamics. Global warming is simply the greater proportion of sun's energy trapped in the earth's atmosphere due to thicker GHG envelop around the earth. These gases also scatter heat energy in all directions increasing temperature of interacting land, ocean and atmosphere. Water being the fluid goes through dynamic processes giving rise to cyclogenesis, ENSO, expansion of water and hence sea level rise. Warmer sea surface water makes the interacting air lighter and hot which rises up creating intense low pressure over the sea surface. Such low pressure areas under favourable atmospheric conditions produce cyclonic storms known as Tropical Cyclones, Typhoons and Hurricanes in different parts of the world. It has been predicted in IPCC AR4 (2007) that frequency and intensity of cyclonic storms will increase during 21st century.

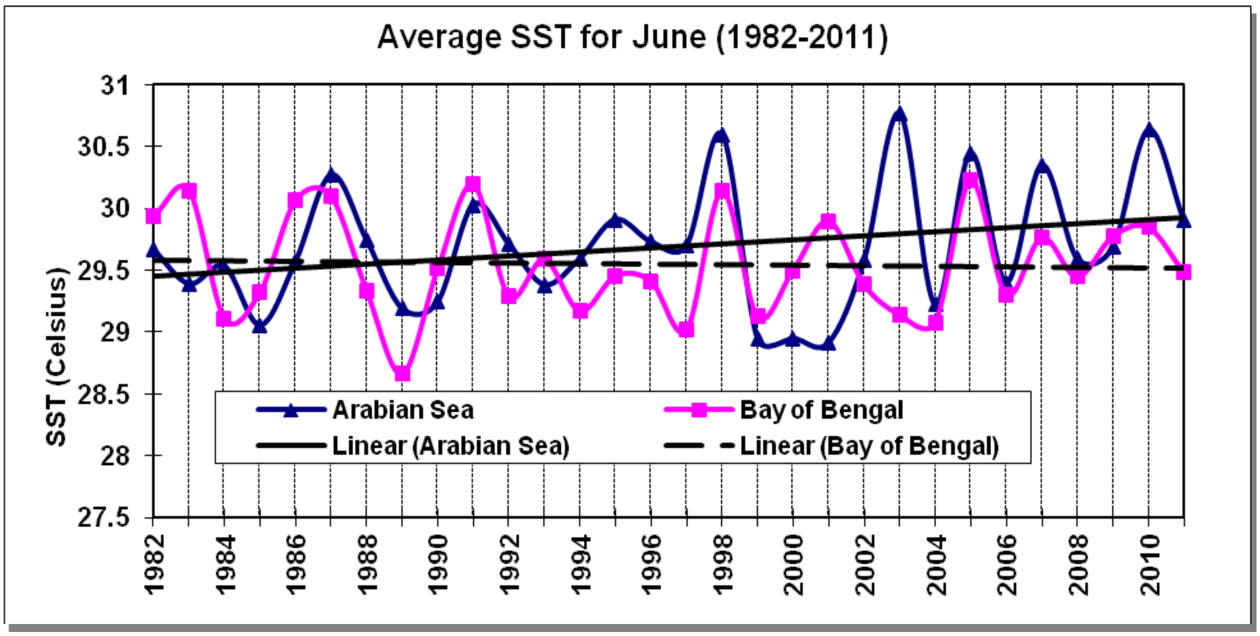


Figure 13: Inter-annual variation of sea surface temperature over the North Arabian Sea and the Bay of Bengal in June from 1982 to 2011. (Source of Data: JRA, Japan)

Pakistan receives rainfall in summer mainly from weather systems formed over the North Arabian Sea and the Bay of Bengal (Krishnamurti, 2004). In addition to the monsoon, the Tropical Cyclones have also attained the significance during the recent years due to the surprising rise in their frequency and their dominance in the North Arabian Sea instead of the Bay of Bengal (Haider at al., 2008). This shift is attributed to the accelerated warming of the North Arabian Sea water than the Bay of Bengal as shown in Figure 13. Both the sea surface temperature trend lines show a scissor like inversion over the timeline. The analysis of data revealed that the Bay of Bengal was warmer than the North Arabian Sea till mid 1990s. The trend started inverting gradually and now the latter is slightly warmer than the former. Although it is not always the case but this is the general trend in recent days.

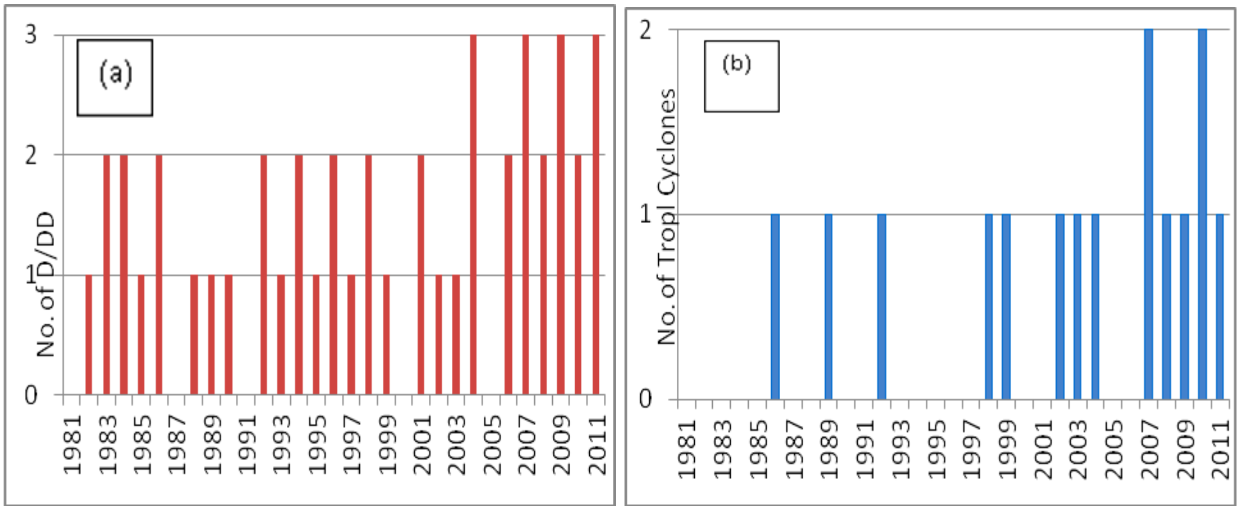


Figure 14: Frequency of depressions (D) and deep depressions (DD) which have the potential to develop into a tropical storm (a) depicts an increasing trend over the North Arabian Sea. Number of Tropical Cyclones (b) has also increased recently in the North Arabian Sea.

The Bay of Bengal was considered to be the birth place of the Tropical Cyclones which used to invade Bangladesh and India. Hardly any of them reached Pakistan while moving westward. Due to the favourable thermal regime of the North Arabian Sea, now cyclogenesis is more common and cyclones hit Oman (west), Pakistan (north) and western Indian coast. Tropical cyclones often form during pre-monsoon season spanning from April to June as well as in post monsoon i.e. October and November but less frequent. Pakistan has already been experiencing larger threat from such disasters as their increased frequency in the North Arabian Sea has been recorded. Among them the most worth-mentioning are Gonu, Yemyin and Phet during last four years.

3.9 Sea Level Rise

Warming of thermal regime of the interacting atmosphere with land and ocean has been causing the change in the dynamics of weather processes, accelerated melting of seasonal snow/glaciers and expansion of water. All these changes are related to the sea level rise either temporarily or permanently. El~Nino phenomenon is an example of upwelling of sea water as well as pushing toward the nearby coastline. It results in rise of sea level in the windward side of the coastline for a period of time El~Nino conditions exist in a particular oceanic part. Due to rapid recession of glaciers, larger volume of water has been reaching the oceans raising their normal level in spite of increased evaporation due to rise in temperature (Meier et el, 2007. Figure 15 has presented the retreat of world glaciers in general and resultant increase in the sea level. Both the rates have been noticed increasing with an alarming trend. At the same time, enhanced rate of thermal expansion has also been seen in the shallow layers of the sea water. Not all the years are getting warmer; rather there is a mixed trend in seasonal and annual thermal regimes on spatial scale also.

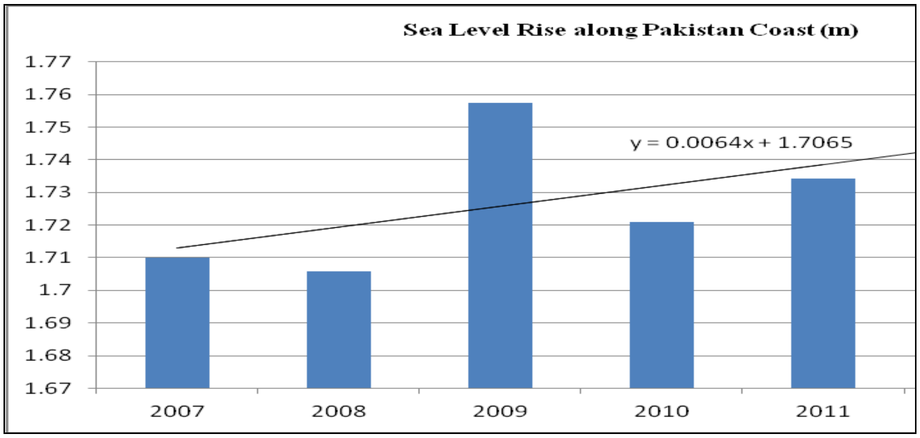


Figure 15: Tide gauge data showing annual average sea level at Gwadar along Pakistan coast from 2007 to 2011. (Data Source: National Institute of Oceanography, Karachi).

Like other parts of the world, there is an evidence of sea level rise along the Pakistan coast also. Sea level monitoring had never been considered as an important issue until the uproar of global warming and climate change in 1990s. Impact of global warming on melting process of glaciers and thermal expansion of water urged the global community to keep an eye on sea level rise which may swallow small islands already at the sea level. Even the best-case scenarios indicate that a rising sea level would have a wide range of impacts on coastal environments and infrastructure. Effects are likely to include coastal erosion, wetland and coastal plain flooding, inundation of deltaic plains, salinization of aquifers and soils, and a loss of habitats for fish, birds, and other wildlife and plants Five years data collected at Gwadar is presented in Figure 13 which also shows a mixed behavior but overwhelming rising trend is quite evident. On the average, the trend line indicates 6mm rise per annum if the thermal regime continues to heat up at the present rate.

During the 20th century, sea level rose about 15-20 centimeters (roughly 1.5 to 2.0 mm/year), with the rate at the end of the century greater than over the early part of the century (IPCC 2007). Satellite measurements taken over the past decade, however, indicate that the rate of increase has jumped to about 3.1 mm/year, which is significantly higher than the average rate for the 20th century. Projections suggest that the rate of sea level rise is likely to increase during the 21st century, although there is considerable controversy about the likely size of the increase. Models have a diverse range of output 30cm to 80cm rise in sea level by the end of 21st century. Irrespective of this diversity, all the models agree on two facts; firstly, there will be an increase in the sea level and secondly, this rise will be higher than that we experienced during 20th century.

3.10 Rapid Glaciers Retreat

Himalaya-Karakorum-Hindukush together makes the largest mountain chain over the earth and they are custodian of the third largest ice reserves after the Polar Regions. Located side by side north-south makes difficult to distinguish where one ends and other starts. They are elongated almost east-west drawing a border between China and south Asian nations including Pakistan, India, Nepal and Bhutan. Existence of these ranges is a blessing for South Asia. They protect the inhabitants from the cold surges in winter associated with northerly winds. They confine the monsoon precipitation to this region which is the great resource of water. In addition to that they possessed a treasure of solid water which melts with high temperature in summer and makes this precious resource available in rivers during needy times. Several famous rivers such as the Indus, the Ganges, and the Yangtze are fed by the runoff from the glaciers of these ranges which serve as the lifeline for more than a billion people in Asia. 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 as below:

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

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

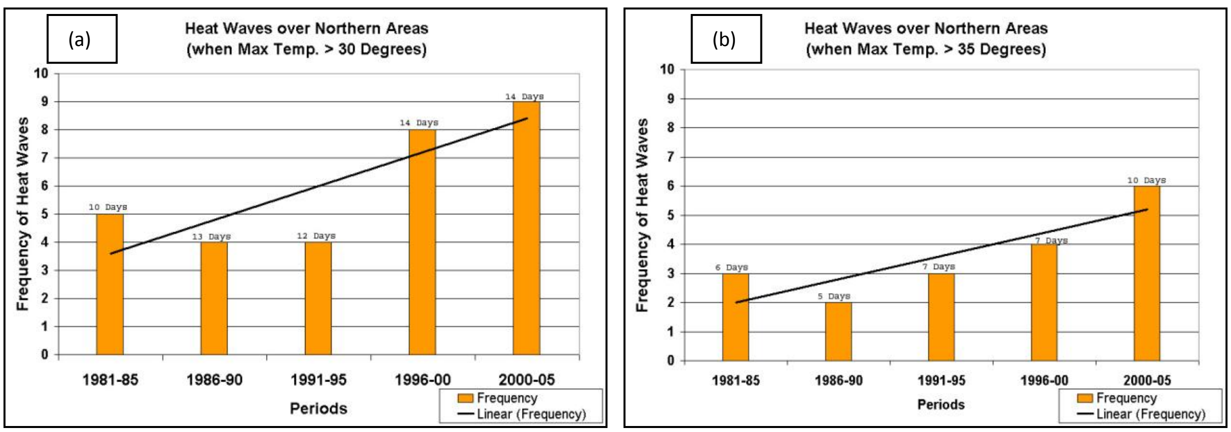


Figure 16: Frequency of moderate (a) and severe (b) heat waves of 10-days duration (bars) and their linear trend. The numbers on the top of the bars indicate the longest duration of heat wave recorded during that pentad.

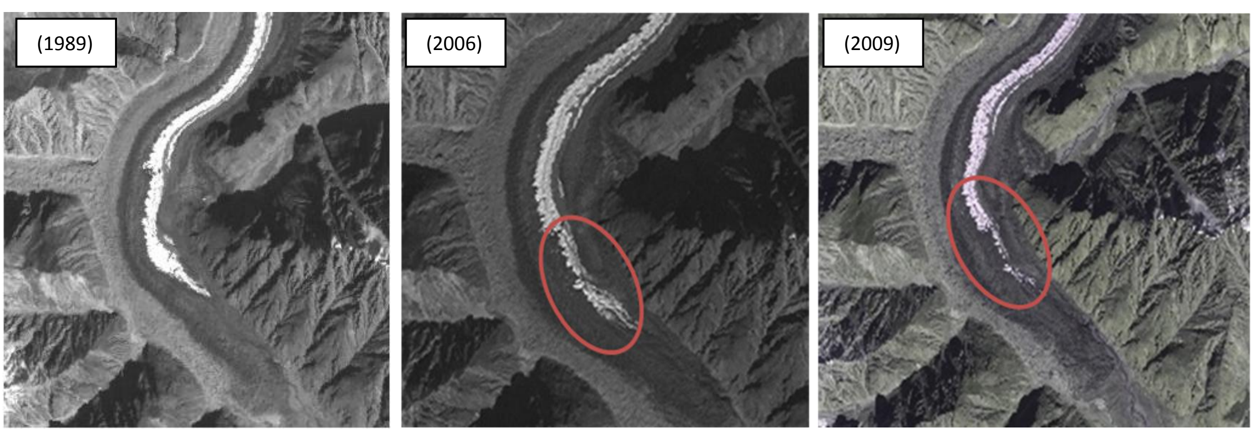


Figure 17: Siachen Glacier (largest glacier of HKH) retreated by 5.9 km during 21 years and lost 17% ice mass

Since temperature maxima have been increasing at a greater rate, the thinning of ice and retreat of glacial extent has taken place simultaneously at an alarming rate. The decay estimates calculated by remote sensing techniques show that Siachen Glacier has reduced by 5.9km in longitudinal extent from 1989 to 2009. Thinning of ice mass is evaluated 17% (Rasul et al., 2008).

It is also speculated that human presence at Siachen Glacier has also been affecting the neighbouring glaciers such as Gangotri, Miyar, Milan and Janapa which feed Ganges (first two glaciers), Chenab and Sutlej Rivers respectively.

Recent extreme weather events which inflicted great loss to the socio-economic sector

- Cloudburst Events 2001, 2003, 2007, 2008,2009, 2010, 2011
- Prolonged Drought 1999-2002
- Historic River Flooding 2010
- Tropical Cyclones 1999,2007,2009,2010, 2011
- Severe Urban Flooding 2001, 2003, 2007, 2008, 2009, 2010, 2011
- Heat Waves in Spring 2006, 2007, 2010, 2011 (Reduced the wheat yield)
- Snowmelt flooding 2005, 2007 and 2010
- Drought at sowing stage 2004. 2006. 2007. 2009. 2010 and 2011

3.11 <u>Vulnerabilities of the Indus Delta</u>

Indus Delta is the fertile piece of land located in climatically arid zone of intense heat and highly variable annual rainfall. Being closer to the sea all the phenomenal changes over the sea and land due to global warming have been affecting it. Pakistan is a country which enjoys all types of climates ranging from extremely arid to very humid one at elevations from sea level to the highest mountains of the world. Whatever the hydrometeorological phenomena happens in the north its impacts will be immediately felt over the Indus Delta. Likewise sea-borne weather activities also directly influence the life of delta dwellers. Deltaic region is vulnerable to some climate change induced problems which are discussed briefly in the following paragraphs;

3.11.1 <u>Droughts and Floods</u>

Droughts and floods are the hydrological extremes which occur due lack of rainfall and surplus rain respectively. Frequency of both has been following an increasing trend over time and space. Droughts are generally categorized into three groups i.e. meteorological, hydrological and agricultural drought. One thing is common among them as all of them grow from the short fall of rainfall. In Pakistan, meteorological drought is considered when monthly or seasonal rainfall is less than 60% of the long term average (in WMO terminology it is called normal) in particular area. Lack of rainfall causes the reduction in stream/river flows that in turn affects the soil moisture level, irrigation scheduling and ultimately growth and development. Floods result from either the persistent and prolonged rainfall or heavy amount of rainfall in a short span of time (cloud burst), (Rasul et al., 2005). The Indus Delta is also exposed to storm surge flooding and intense rainfall associated with the Tropical Depressions and Tropical Cyclones increasingly developing now over the warmer water of the Arabian Sea. Drought grows slowly and extends its areal extent towards the regions of low rainfall but floods, once generated, do not care the precipitation regime.

The Indus Delta is located at the mouth of the Indus River before it falls into the Arabian Sea. It is vulnerable to all sorts of droughts and floods (rain, riverine and flash floods) whether their origin is local or in the upper catchments of the Indus and its tributaries. Frequency of both these extremes has increased considerably since the last decade. There is a complete consensus of the scientific community that frequency and intensity of such extreme events will further increase with the passage of time due to ongoing trend of global warming. Under such scenarios, the sustainable development becomes a great challenge if carried out without scientific planning.

3.11.2 Historic Floods 2010 and 2011

Such back-to-back occurrence of the history's worst flooding is at least a unique phenomenon in case of Pakistan which brought many surprises to all the stakeholders ranging from weather pendants to the local population. In 2010, intense precipitation concentrated over the elevated plains of Khyber Pakhtunkhwa due to the interaction of three weather systems from east, south and north. Such interactions are very rare in the pre- and post-partition meteorological history of this region and also that was not the heavy precipitation zone of monsoon season.

Similarly another historic climatic anomaly occurred in 2011 when monsoon axis set its orientation from head Bay of Bengal to Southern Sindh which was commonly found parallel to the Himalayas in case of heavy precipitation in Pakistan. Rain storm persisted for a couple of weeks over the Indus Delta and adjoining areas experiencing arid climatic conditions. Generally, this region receives less than 200mm rain during the year but in a couple of weeks some eastern parts gathered more than 1000mm precipitation. Poor slope of land, heavy soil and abandoned drainage infrastructure exaggerated the situation and happening took the shape of a great disaster.

Some people emphasize that floods brought lot of fertile sediments to Sindh and recharged the depleting ground water reserves of the agricultural plains but one should be realistic in terms of cost benefit ratio. Standing kharif crops were totally destroyed including paddy which is known for its water-loving characteristics (in this case it remained sub-merged for more than a month).

Most of the farmers would not be able to plant their rabi crops due to stagnant water till December 2011. Wheat is the major crop which is the basis of livelihood of poor farmers.

3.11.3 Saline Water Intrusion

Water table in lower Sindh including deltaic region is quite high water contained is saline. Heavy soils have poor percolation and porosity to support natural drainage and reclamation. Therefore, salinity and water logging dominate already in various zones not letting the farmers to harvest their potential yields. Due to increased frequency of storm surges combined with the sea level rise, the sea water intrusion has become an emerging challenge which would claim more land area with the passage of time. The saline and sodaic contents of soil would rise to such a critical level which would ultimately deteriorate the yielding potential of fertile deltaic soils (Bot et al., 2000). There is a clear evidence of elimination of natural habitat along the shoreline and northward shift of biodiversity due to over-riding push of sea water.

3.11.4 Coastal Erosion

Increased stormy conditions in the north Arabian Sea has given rise to the enhanced tidal activity. Along the coast line, increased to- and fro motion of tides and waves continue encroaching the shoreline posing threats to agricultural land, infrastructure and development activities. In summer, generally southwesterly winds prevail along the coastal areas of Sindh which bring monsoon rains to the area. Dynamics of south westerly has increased significantly producing enhanced precipitation over southeastern parts of the province. As these wind face the coast from south therefore their increased force has been rapidly eroding the land mass along the coast.

3.11.5 Increased Crop Water Requirement

Crop water requirement is a function of temperature, radiation intensity, cloud cover, air humidity and wind speed, among them temperature is the major player. Due to global warming and climate change, thermal regime of the Indus Deltaic plains has also been heating up like other parts of Pakistan. This increase has not been following a uniform increasing trend rather it is embedded by frequent heat waves of mild, moderate and severe intensity spanned over different time scales. The occurrence and persistence of heat waves have also been predicted to rise in future posing another challenge to sustainable crop production meeting the increased crop water requirement with limited available surface water supply and saline ground water not suitable for crops (Ghazala et al, 2009). Frequent droughts and floods expected in future would need a science-based policy for assurance of food security in that region. There are several initiatives by public and private sector organizations on different issues of the Indus Delta but integration and coordination is missing.

Section 4

Future Projections

It is hard to predict future weather and climatic conditions to an extended scale of several years and decades with sufficient accuracy. The reason is the lack of knowledge and information about the major contributors which determine the state of climate. They are both natural and anthropogenic; the latter has dominated the former one. Green House Gases emission after the industrial revolution of 1940s has triggered the changes to the composition of lower atmosphere by addition of gases which possessed high warming potential. Ever-increasing concentration of GHGs has been making the situation more and more complex (Prathar, 2010). Although several efforts are under way to control the emissions further but there is no substantial success. Future climatic conditions can be determined precisely if the correct information about emissions, population, socio-economic parameters and technology is known.

4.1 Characteristics of Special Report on Emissions Scenarios (SRES)

As nothing is known with certainty, different options/assumptions have been taken care of while projecting the future climate of a particular region. Four possible options with further 3 sub-divisions are presented in Table 2. Among them some are highly optimistic and some very pessimistic to be followed. However, looking at the slow and highly selfish behavior of global community, it seems that at least status-co will be maintained. For this reason A2 scenarios (commonly known as *business-as-usual scenarios*) have been selected to project future climate of Pakistan. B1 and A1B are also considered for Pakistan.

Table 2: Summary characteristics of four SRES (Special Report on Emission Scenarios)

A1	A2
World: market-oriented	World: differentiated
Economy: fastest per capita growth	Economy: regionally oriented; lowest per capita growth
Population: 2050 peak, then decline	Population: continuously increasing
Governance: strong regional interactions; income convergence	Governance: self-reliance with preservation of local identities
Technology: three scenario groups: • A1FI: fossil-intensive • A1T: non-fossil energy sources • A1B: balanced across all sources	Technology: slowest and most fragmented Development

B1	**B2**
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	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

To estimate the future climatic condition at an extended time scale for any region, it is pertinent that the global conditions should be incorporated because the global general circulation distributes the whole stuff around the world emitted by any nation. General Circulation Models (GCMs) are the credible tools which scientific community has developed at institutions for global climate projections based upon the assumptions made through different climate change scenarios. The output of GCMs is generally coarse (100-300km grid points) therefore regional climate models are required to interpret that output to finer scales desired by the user according to the capacity of the computing machines. Finer the resolution greater will be the computing power and processing speed of the machine.

4.2 Global Emission Projections

Emission projections for four Green House Gases (GHGs) i.e. Carbon Dioxide (CO_2), Methane (CH_4), Nitous Oxide (N_2O) and Sulpher Dioxide (SO_2) under different SRES set of scenarios are presented in Figure 15 for the 21st century. Presently about 8 gigaton carbon is being emitted to the atmosphere from various sources including industry, agriculture, forest, land use etc. which is expected to rise to the level of 30 gigaton by the end of this century if emissive rate is maintained. Nitrous Oxide is another important GHG with large warming potential of air and it is released from industry, fertilizers and polluted stagnant water (Prather et al., 2010). Its concentration in the air is likely to reach 26gt from the present state of 16gt if status-co is maintained. Methane is largely emitted from paddy fields as rice cultivation is generally done by flood irrigation. China, Bangladesh and Philippines are the major producers of rice and largely blamed as main emitter of methane (Neue, 1993). Other sources include animal dung and swamps. Present level of methane emitted to atmosphere is 590 terra grams which is most likely to be doubled by the end of 21st century. Sulpher Dioxide is highly hazardous gas for living things and it makes sulphuric acid when joins atmospheric moisture. First spells of precipitation in areas of its higher concentration occur as acid rains and this water not only contaminates the soil and open water sources but affect the

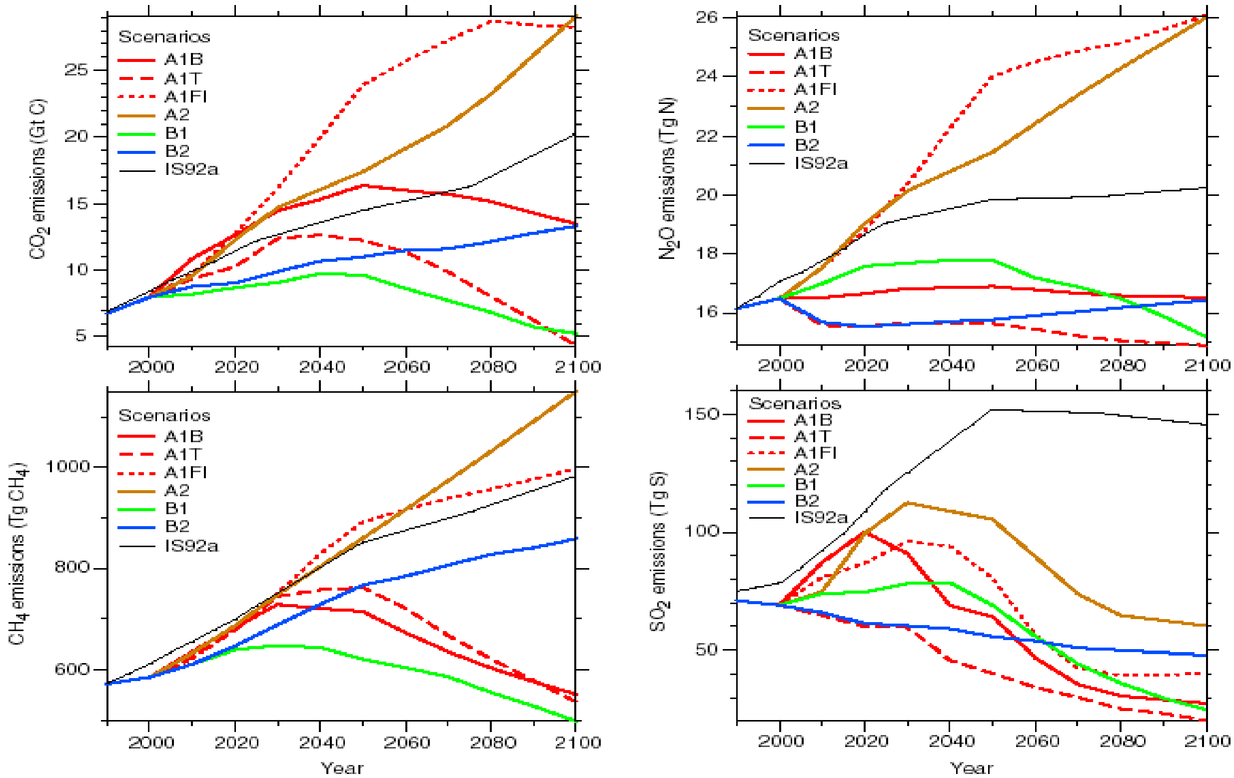


Figure 18: Global emission projections of Carbon Dioxide (CO_2), Methane (CH_4), Nitous Oxide (N_2O) and Sulpher Dioxide (SO_2) under different scenarios during 21st century.

biological processes in animals and plants. The crops, fruit and vegetables which we grow with the acid rain water are consumed by the human beings and animals. Liver cancers have largely reported from the affected areas. This gas is mainly emitted by the chemical industry in liquid and gaseous forms where no measures are taken to cap it. Although the amounts of concentration seem the lowest as compared to other gases but its damages to the climate and health are far more serious. The warming potential of major GHGs is given in Table 2 as multiple of that what Carbon Dioxde of same magnitude can do.

4.3 Pakistan Temperature and Precipitation Projections

Future projections of climate depend upon the authentic knowledge of future state of emissions, level of environmental governance, demographic parameters, socio-economic condition and technological advances. Likely state of future affairs is incorporated in Global Climate Models to produce their outputs on extended scales for the globe. There are numerous models and they produce diverse output which rather confuse the users which should be adopted and why. To overcome this problem, a set of 17 GCMs was selected and sensitivity test was applied based upon two parameters i.e. standard error and correlation coefficient. All of them were run on past data set of 50 years (1961-2010) and correlation as well as standard error of output against actual was computed. Four models which have shown minimum error and high correlation coefficient were chosen for application to generate future projections of temperature and precipitation.

Ensemble of four selected models which qualified the sensitivity test was developed and their output is presented in Figure 19. Just to cater extremes on optimism and pessimism on future state of climate three open ended scenarios A1B, A2 and B1 were taken care of during simulations. According to Bussiness-as-usual scenarios (A2), the mean daily temperature in Pakistan is likely by 5.5°C while the moderate scenarios project it to the level of 4.5°C by the end of 21st century. The optimistic category assuming clean environment and highly human friendly demographic features (B1) produced 3.4°C rise in temperature over the present level.

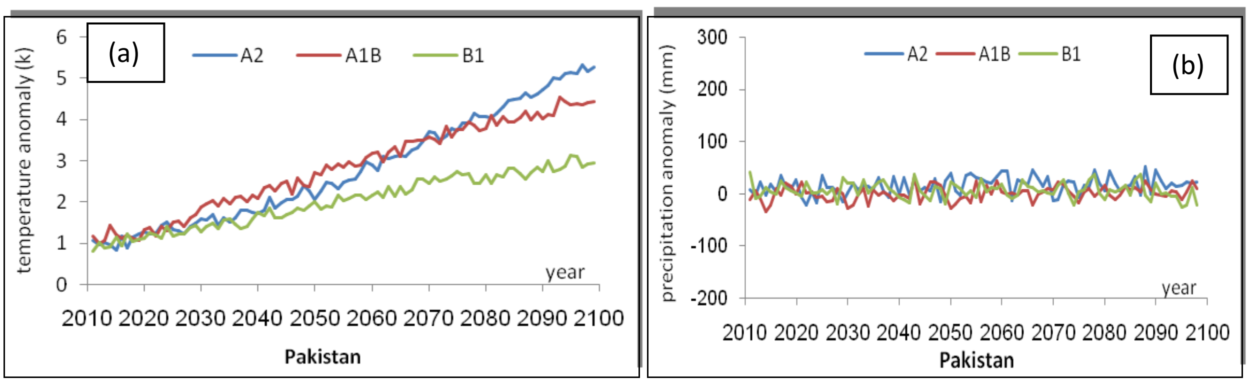


Figure 19: Future temperature (a) and rainfall (b) projections on decadal scale for Pakistan under A1B, A2 and B1 SERS scenarios for 21st century.

These projections were made on the basis of 40 years baseline data (1961-2000) and processing was completed for 21st century on decadal time step. According to A2 scenarios, during the first half of this century the increase in temperature is about 2°C but in the later half rate has risen to almost double. This is the case which relates to the lifetime of the emitted GHGs into the atmosphere and the warming potential. Scientists say if all the emissions are brought to zero now, the GHG concentration in the air is enough to continue warming for the next 50 years at the present rate.

4.4 Temperature Projections for Indus Delta

The Indus delta is highly vulnerable part to the impacts of climate change in terms of frequent floods and droughts due to the added energy to the physical processes producing local weather systems and the advected air masses from adjoining land and sea. To understand the features of thermal regime of the deltaic region in future, the projections on yearly and 10-yearly basis have been prepared by the regional climate models at city scales. Temperature increase over the long term average (1961-2010) for six cities/towns Kharo Chann, Keti Bandar, Thatta, Badin, Mirpur Khas and Hyderabad in this region have been presented in Figure 16. First two decades do not show any abrupt rise in temperature rather stable conditions are evident. Afterward there is a sharp rise in temperature at a rate of 0.5°C per decade until 2070 later it becomes minimal. In general, 4°C rise in temperature over the deltaic plains is expected by the end of this century. However, warming rate is less at locations near the coast where maritime airmass will prevail with its increased dominance especially in summer making the atmosphere relatively moist.

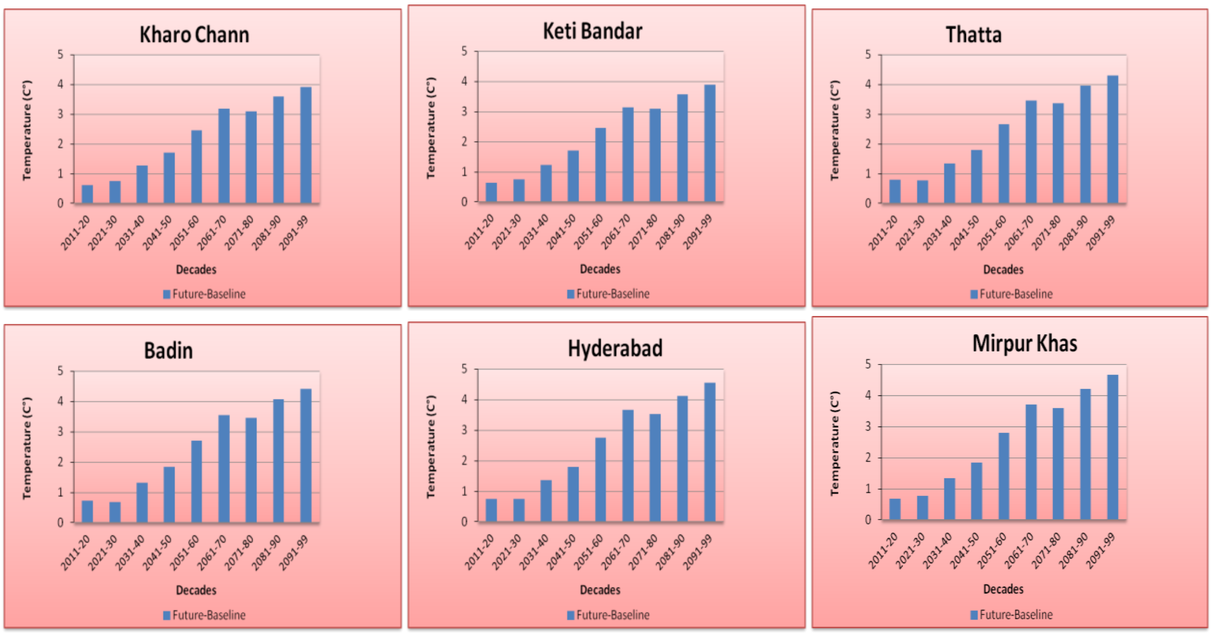


Figure 20: Mean daily future temperature projections for the Indus Delta on decadal basis during 21st century.

It is once again emphasized that projections should not be considered as predictions as they are based upon certain assumptions. They provide a generic overview of future if the assumed trends are not mismatched with the future happening. They pave the way forward to plan the adaptation strategies against the adverse effects of the most likely futures.

4.5 Temperature Projections for Makran Coast

Makran coast is also most vulnerable area to all the anomalous weather phenomena likely to develop in the Arabian Sea. Formation of such disastrous weather systems in this oceanic zone is on the rise as both air and sea temperatures have been increasing with the march of time. All

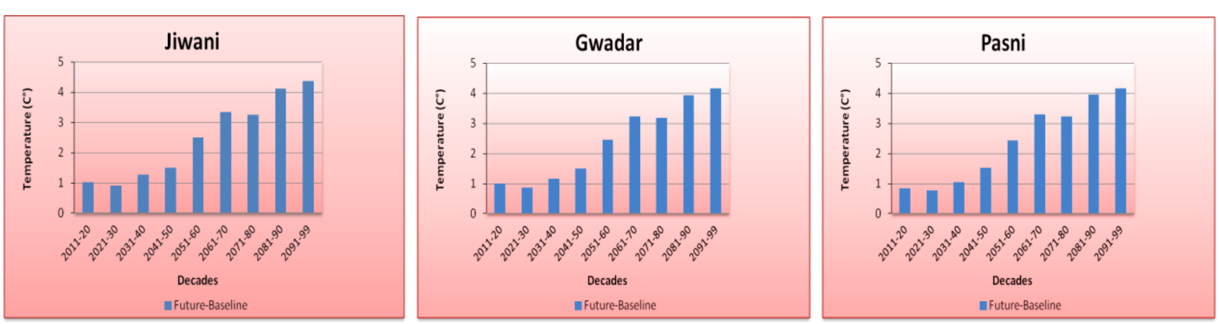


Figure 21: Future temperature projections along the Makran Coast of Pakistan on Dacadal basis for 21st century.

the three selected stations are located along the Balochistan coast commonly known as Makran coast and they are the meteorological stations two having a long history of more than 80 years. During the first half of this century the temperature increase is less i.e. upto1.5°C but in the later half warming is more than 2.5°C. In general, the increase of 4°C in 21st century is less than other parts of the country where it is more than 5°C. The reason isthe influence of meritime airmass.

4.6 Precipitation Projections of Indus Delta

Due to high temperatures and low elevations, the precipitation occurs in the form of rainfall and its amount as well as its timing is very important for the dwellers of the Indus Delta. In future projections, a special attention is given monthly rainfall pattern decade wise dividing the Sindh province in three zones viz. upper, central and lower.

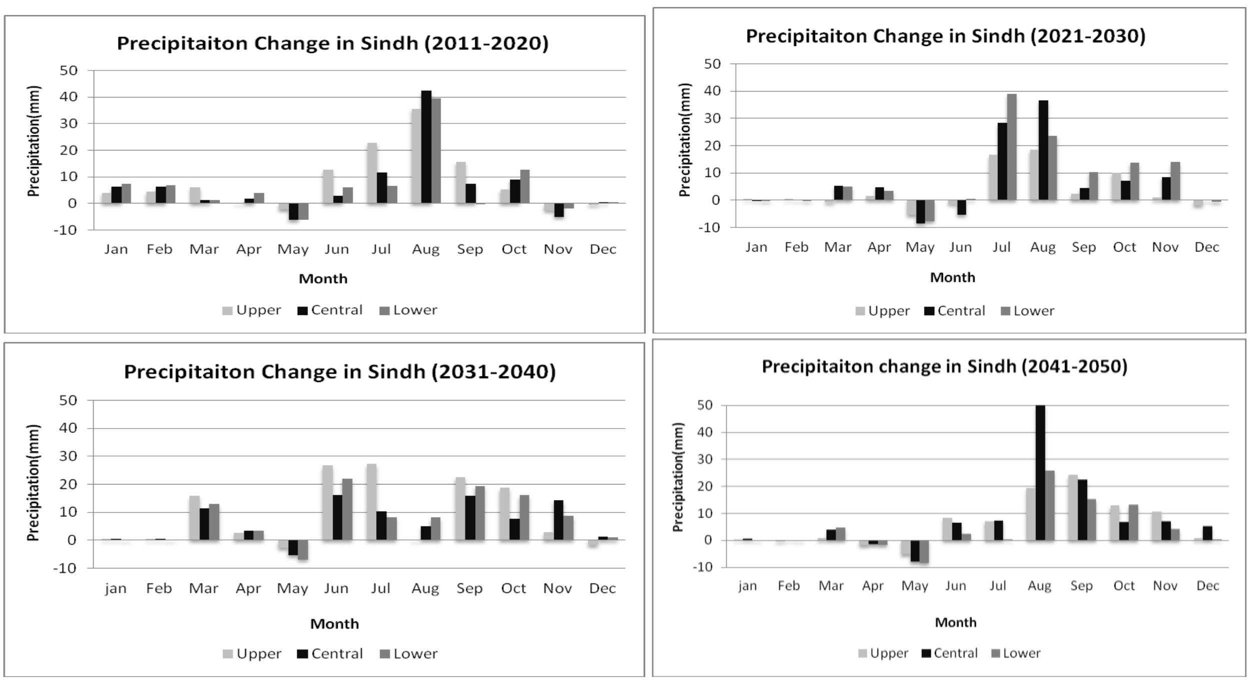


Figure 22: Future projections of precipitation for lower, central and upper parts of the Sindh province during the first half of 21st century.

According to the model output, Sindh provice is expected to reveive heavier than normal rainfall during the monsoon season but no well-marked change is foreseen in winter rainfall which hardly reach this part of Pakistan. The month of August is going to be the peak observer followed by July during the first half of the century. Future projections of rainfall also indicate that rainy season in Sindh may extend towards autumn. If it happens then this will be a great challenge for the wheat cultivators to plant their crops on time as wet season will not let the soil dry to carry out field operation for sowing. Looking at the features of changing trends and phenomenal changes in aquaculture, the planners and policy makers have to play a proactive role to devise strategies related to drainage and reclamation of soils in low lying deltaic region.

4.7 Location Specific Annual Precipitation Projections

Although it is hard to make annual predictions of rainfall with an acceptable accuracy level yet the regional climate models are able to project the future precipitation based on the global emission scenarios. In Figure 23, annual total rainfall for the decade 2011-2020 for the selected locations in the Indus Delta is presented which shows lot of inter-annual variation. A clear message can be drawn from the future pattern that surplus and deficit of water will be a real challenge for the food security in this region. In comparative terms, the surplus of water will pose a more serious threat to agriculture by raising the water table, degrading soil drainage and promoting water logging and salinity while deficit of water will provoke drought condition may be overcome up to some extent through canal or ground water irrigation.

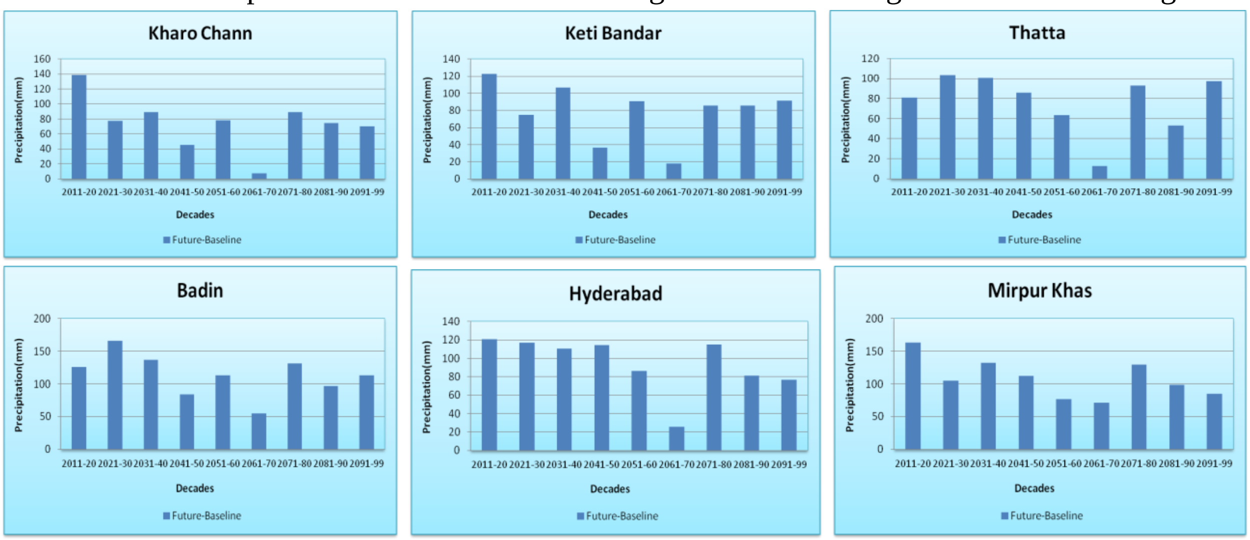


Figure 23: The Indus Delta future precipitation regime projected on the decadal basis for this century.

4.8 Future Rainfall Projections of Makran Coast

The climate change related problems of the Makran Coast are entirely different from the Sindh coastal belt. The latter comprises the Indus Delta which is although arid in the context of aridity index but due to irrigation it enjoys satisfactory water supply as per demand. However, former has no such mechanism and totally dependent on rain which is already meager in amount.

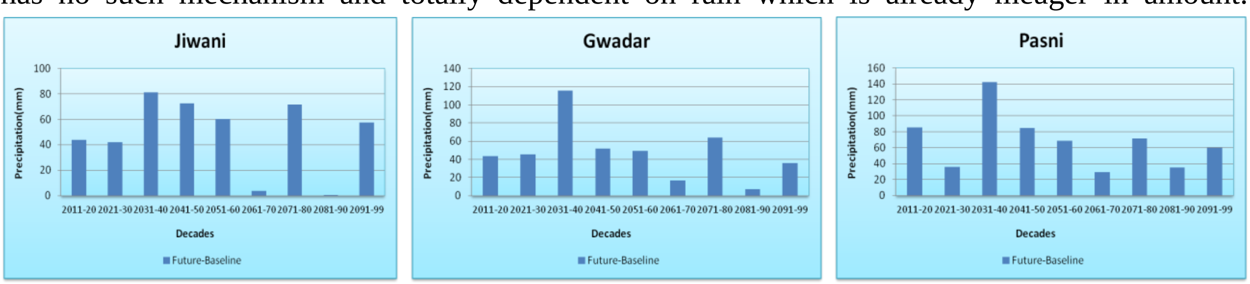


Figure 24: Projected precipitation variability along the Makran Coast during 21st century.

The inter-annual rainfall pattern shown in Figure 24 clearly indicates a gradually declining trend along the Makran Coast during the time period 2011-2020. The scaricity of the fresh water in the western parts of the Balochistan coast is expected to exaggerate with the passage of time. There are some high marks visible in the picture but most probably they are related to the influence or landfall of the tropical cyclones whose frequency is likely to increase in the north Arabian Sea during to climate change.

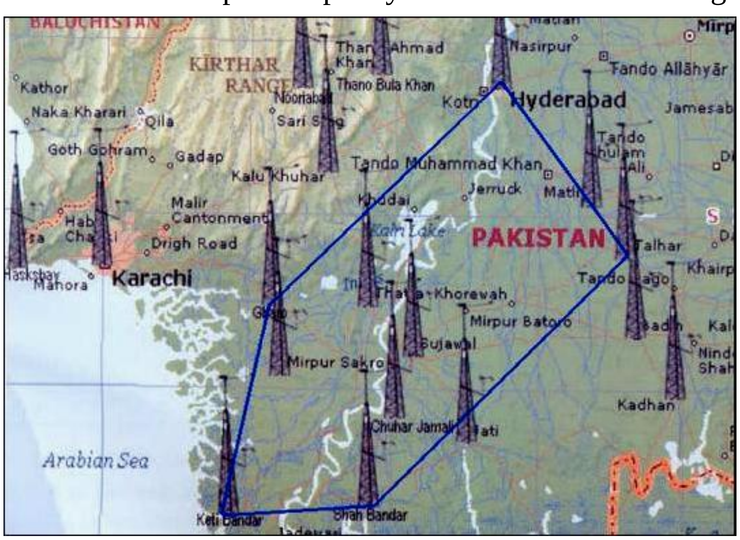
Section 5

Chalenges and Recommendations

5.1 Major Challeges

The Indus Delta is the most vulnerable area to the challenges of climate change. Some of them are enumerated below:

- Reduced productivity of crops and livestock due to heat stress and other adverse impacts of change in climate parameters;
- Increased requirements of irrigation water due to higher evapotranspiration at elevated temperatures; while less water will be available.
- Uncertainty to timely availability of irrigation water caused by changes in river flows due to glacier melting and altered precipitation pattern; 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 such as floods, drought and cyclones 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 areas such as those suffering from water erosion, wind erosion, water-logging, salinity etc;
- Intrusion of sea water into deltaic region affecting coastal agriculture, forestry and biodiversity;
- Lack of technical capacity to predict with reasonable certainty the expected changes in climatic parameters such as temperature, precipitation, extreme events etc.; and
- Low adaptive capacity to adverse climate change impacts.



Gharo Wind Corridor

These areas having coverage of 9700 sq. km in Sindh have a gross wind power potential of 43000 MW. Keeping in view the area utilization, technical/ mechanical constraints etc. the exploitable electric power potential of this area is about 11000 MW. (PMD 2009)

5.2 Recommendations

To mitigate the risks/threats due to climate change some measures have to be taken at national, provincial and local level, some of them are stated below:

- Nationwide climate change policy should be devised through legislation clearly defining the role of federation and provinces as well as public and private sector organizations
- Climate change monitoring and impact assessment activities should be organized on scientific basis by filling the observational gaps over low elevation plains and glaciers zones
- Climate resilient infrastructure should be built along the coastal belt and wind power potential already identified along Sind coast be harnessed to initiate development opportunity in the deltaic region
- Increasing losses of crops and livestock due to frequent floods, drought and tropical cyclones having been pressing the farming community's marginal economic condition harder and harder. Insurance industry should be urged to play its role
- In the upper catchments of the Indus, water reservoires should be contructed to reduce the flood losses and regulated water supply over the Indus Delta. National water policy should devise the mutually accepted water distribution method
- Low elevation and poor drainage have been causing water logging and salinity which required technically viable drainage infrastructure to reclaim the heavy soils of the delta
- Due to sea level rise, increased intrusuion of sea water into the Indus deltaic region, the whole range of marine life will be affected besides causing damage to mangroves, coral reefs and coastal lagoons. Minimum environmental flow in the Indus must be ensured to stop sea water intrusion
- Avoid flood irrigation and adopt modern efficient irrigation methods such as use of sprinkler, drip and trickle irrigation systems; Reduce seepage from the canals and distribution network which has been degrading the fertile soils

Policy Imperatives of Climate Change

“A key emerging issue in the climate change debate that exemplifies this challenge is **food”**

“We need to grow much more food over coming decades”

From probably less land and with less available water than we have now; with much higher costs for energy, water and nutrients, in a much more hostile climate

Annexure 1

Methodology

Future Temperature and Precipitation Projections

Future projections of climate depend upon the authentic knowledge of future state of emissions, level of environmental governance, demographic parameters, socio-economic condition and technological advances. Likely state of future affairs is incorporated in Global Climate Models to produce their outputs on extended scales for the globe. There are numerous models and they produce diverse output which rather confuse the users which should be adopted and why. To overcome this problem, a set of 23 GCMs was selected and sensitivity test was applied based upon two parameters i.e. standard error and correlation coefficient. All of them were run on past data set of 50 years (1961-2010) and correlation as well as standard error of output against actual was computed. Nine models which have shown minimum error and high correlation coefficient were chosen for application to generate future projections of temperature and precipitation.

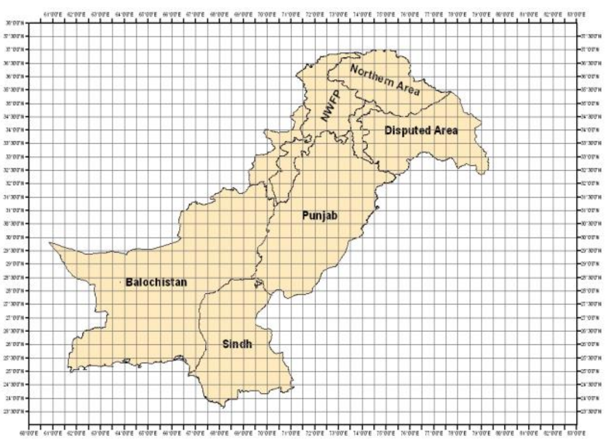
SASM	60--110, 0--30												
Precip	April		May		June		July		August		Sep	Average	
bcc_cm1	0.435363	2.20293	0.351957	3.98466	-0.18979	7.33585	-0.11612	7.69707	0.006347	7.01232		0.013101	6.507475
bccr_bcm2_0	0.822327	1.16383	0.782646	1.82927	0.614945	3.55863	0.560668	3.88737	0.495542	3.63477		0.61345	3.22751
cccma_cgcm3_1	0.710679	1.43027	0.610501	2.43838	0.583323	3.53722	0.489887	4.15787	0.458204	3.98371		0.535479	3.529295
cccma_cgcm3_1_t63	0.633155	1.62093	0.593776	2.513	0.545908	3.64895	0.479107	4.21173	0.427661	4.13408		0.511613	3.62694
cnrm_cm3	0.47961	1.91267	0.45875	2.6902	0.363655	3.98952	0.522781	4.0102	0.454721	3.75038		0.449977	3.610075
csiro_mk3_0	0.681304	1.89885	0.584026	3.18901	0.421825	4.4756	0.602058	4.07465	0.721789	2.96891		0.582425	3.677043
csiro_mk3_5	0.731134	1.78203	0.601754	2.6487	0.335894	4.76901	0.462052	4.52435	0.637283	3.3684		0.509246	3.827615
gfdl_cm2_0	0.80774	1.62894	0.724765	2.37888	0.541752	3.81331	0.722062	3.28271	0.727984	2.86793		0.679141	3.085708
gfdl_cm2_1	0.814813	1.39847	0.759711	1.8663	0.648857	3.22663	0.670102	3.47762	0.679901	3.11751		0.689643	2.922015
giss_aom	0.772134	1.62301	0.648293	2.65074	0.178269	5.19428	0.297611	5.14706	0.497111	3.94056		0.405321	4.23316
giss_model_e_h	0.447221	3.66635	0.542641	4.38294	0.497848	5.58869	0.433207	6.63656	0.408023	5.8409		0.47043	5.612273
giss_model_e_r	0.355913	3.64394	0.301088	4.70783	0.322233	5.48228	0.453387	5.71674	0.484256	4.78768		0.390241	5.173633
iap_fgoals1_0_g	0.797573	1.40983	0.527911	3.08208	0.070555	5.26543	0.103627	5.26839	0.305703	4.1879		0.251949	4.45095
ingv_echam4	0.795484	1.4553	0.746763	1.93977	0.848967	2.26529	0.608655	3.73567	0.651684	3.14852		0.714017	2.772313
inmcm3_0	0.775592	1.36879	0.533247	2.63827	0.460578	4.21037	0.422828	4.86108	0.42993	4.11046		0.461646	3.955045
ipsl_cm4	0.816262	1.58434	0.662895	2.49371	0.179387	5.16682	0.161723	5.90075	0.422998	4.52524		0.356751	4.52163
miroc3_2_hires	0.785238	1.40889	0.721657	2.06697	0.737769	3.02901	0.427264	4.82263	0.324318	4.9501		0.552752	3.717178
miroc3_2_medres	0.84779	1.12375	0.796952	1.90864	0.714404	3.23897	0.364235	5.00753	0.253745	4.87638		0.532334	3.75788
mpi_echam5	0.815629	1.44921	0.741905	2.65412	0.622195	3.6512	0.513517	4.28713	0.529275	3.84724		0.601723	3.609923
mri_cgcm2_3_2a	0.761313	1.53091	0.682407	2.59346	0.435668	4.59874	0.331338	5.27683	0.326953	4.81737		0.444092	4.3216
ncar_ccsm3_0	0.679412	1.54697	0.510291	2.39872	0.467235	3.75278	0.414303	4.39304	0.447615	4.13599		0.459861	3.670133
ncar_pcm1	0.622624	1.61	0.518716	3.10274	0.617724	3.79834	0.334982	5.10899	0.346659	4.65725		0.45452	4.16683
ukmo_hadcm3	0.770506	2.13181	0.708289	2.4777	0.511767	4.10427	0.607112	3.96262	0.593314	3.97023		0.605121	3.628705
ukmo_hadgem1	0.788502	1.97911	0.699569	2.84554	0.522098	4.58143	0.637898	4.81879	0.627638	4.66448		0.621801	4.22756
												0.51711	3.883696

Calculated monthly Standard Correlation (SCorr) and Root-Mean Square Error (RMSE) for each 23 GCM models, and then obtained averages. If a model satisfies both Scorr and RMSE better than total model average, it is counted as a good model for the precipitation over the South Asian Summer Monsoon domain.

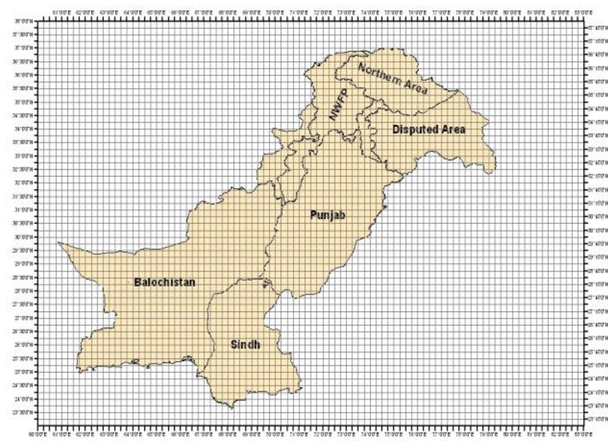
Models Used and Their Domain

Two regional climate models PRECIS (UK) and RegCM4 (Italy) were used to downscale the output of GCMs for development of future projection on temperature and precipitation at different time intervals of 21st century on areal coverage of the country and point based information. The domain was extended to a wider region of Asia to overcome the possible biases and boundary noise in case of narrow limits. The models were run on two resolutions i.e. 50km and 25km selecting baseline of 1971-2000 and processing on annual steps.

Domain for PRECIS and RegCM Future Scenarios (50 km)



Domain for PRECIS and RegCM Future (25 km)



The task of the development of climate change scenarios was undertaken in this assignment for the entire Indus Basin at 50km and 25km spatial grid resolutions to address the complexity of the rugged terrain of the Upper Indus Basin. It was also envisaged that temporal scales should also be kept in reasonably acceptable limits. Therefore the scenarios were developed on decadal scale instead of centurion scales. For both the spatial resolutions, domain was kept same extending from 23 to 38 °N latitude and 60 to 83°E longitude.

PRECIS Model

Input Data

ECHAM5 is the 5th generation of the ECHAM general circulation model. Output of ECHAM5 model data for to be used in PRECIS is prepared by the Hadley centre of UK Met office. This data has a horizontal resolution of 140km×210km. input data is available from 1949 to 2100.The data for the current experiment is obtained from the Hadley Center of UK Met office.

Horizontal Resolution

Model is run at 0.22° (~=25km) and 0.44° (~=50km) grid resolutions. The number of grid points in are 108×98 and 54×49 respectively for 0.22° (~=25km) and 0.44° (~=50km) grid resolutions.

At 0.22° (~=25km) the model has successfully run for the period 1950-2099 with the ECHAM5 data under A1B future scenario.

At 0.44° (~=50km) the model has successfully run for the period 2000-2099 with the ECHOM5 data under A1B future scenario.

Brief Description of Model

PRECIS is a regional climate model developed by Hadley Centre of UK Met Office and it can be run on a simple Personal Computer (PC) under the Linux operating system (OS). It is a hydrostatic, primitive equation grid point model. There are 19 vertical levels of pressure and 4 levels in the soil (Hijmans, 2005). The model uses the output of different global models GCMs (like HadAM3P, ECHOM4, ECHOM5 etc) and different data sets (ERA-40, ERA-Interim, etc.) for its lateral boundary conditions. The model takes one year time as spin-up time to allow the land and atmosphere processes to adjust and reach a mutual equilibrium state. Time to complete the experiment depends on the computing capacity of the computer on which the model is run. The output from the model PRECIS is in post processing (PP) format under the $ARCHIVE/runid/stash-code directory, where runid is the name of the experiment (pmdaa is the runid of current experiment) and stash code is a five digit number used by PRECIS model to represent the different parameters for example the stash code for temperature is 03236. Naming convention of files is required to get the desired daily data files of temperature and precipitation from the output.

Methods of data extraction (Post processing of the data)

Temperature and precipitation daily data pp files from the output directory are regrided to regular latitude longitude grid points by using the pp2regrid utility with the PRECIS model software. These regrided pp (post processing) files are then converted to Network Common Data Format (NetCDF) files so that the data can be extracted and displayed through GrADS (Grid Analysis and Display System) software. Grads scripting language is used to get the daily data in CSV (comma separated values) form from these NetCDF files for the period 1950-2099(Dec).

RegCM4

Input Data

ECHAM5 is the 5th generation of the ECHAM general circulation model. Output of ECHAM5 model data is freely available on the following link: http://clima-dods.ictp.it/data/data/regcm4/data/ATM/EH5OM/. This data has a horizontal resolution of 140km X 210km. input data is available from 1940 to 2100.

Horizontal Resolution

Model is run at 0.22° (~=25km) and 0.44° (~=50km) grid resolutions. The number of grid points in are 108×98 and 54×49 respectively for 0.22° (~=25km) and 0.44° (~=50km) grid resolutions. At 0.22° (~=25km) the model has successfully run for the period 1950-2100 with the ECHOM5 data under A1B future scenario. At 0.44° (~=50km) the model has successfully run for the period 2000-2100 with the ECHOM5 data under A1B future scenario.

Brief Description of Model

RegCM4 is a 3 dimensional, σ-coordinate, primitive equation regional climate model. It has been designed by people at the International Center for Theoretical Physics (ICTP) at Trieste, Italy.

The model is flexible, portable and easy to use. It can be applied to any region of the World, with grid spacing of up to about 10 km (hydrostatic limit), and for a wide range of studies, from process studies to paleoclimate and future climate simulation.

The model can be run on parallel computing so for the current study the model is run on 64 processors (each with 3.33 GHz). Before running the simulation the model takes the sea surface temperatures and terrain information, and then initial conditions and boundary conditions (ICBC) are created. The output of the model is in CTL (control file) format that can be read through GrADS. The model generates one file for each month and there are four types of output files ATM(Atmosphere), RAD(Radiations), SRF(Surface) and SAV(Saved i.e. to resume the experiment if its stopped) files.

Methods of data extraction (Post processing of the data)

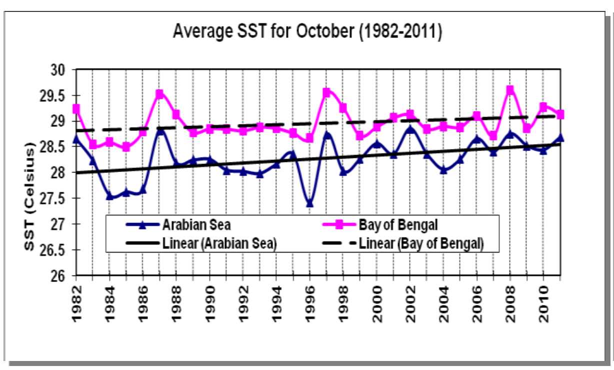
Temperature and precipitation daily data is obtained from the CTL files in the output directory of the RegCM4 model. GrADs scripting language is used to get the daily data in CSV (comma separated values) form from these CTL files for the period 1950-2100.

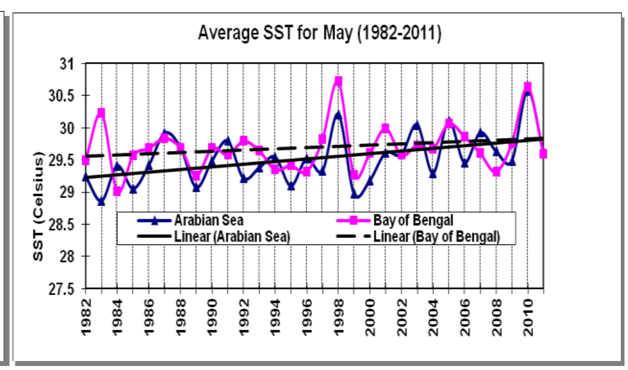
Annexure 2

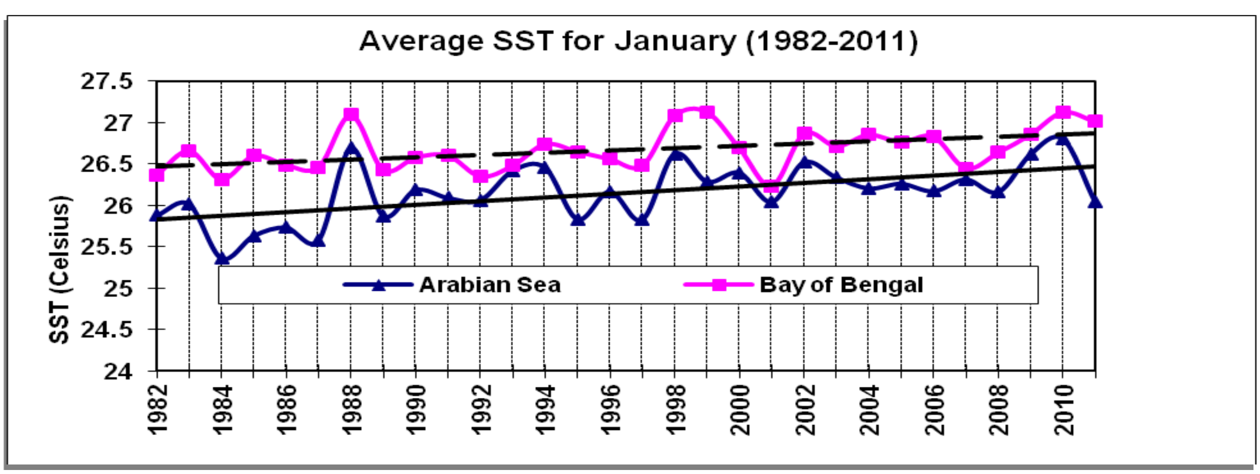
Past Sea Surface

Cyclogenesis takes place in the sea due to conducive thermal regime, near surface wind shear and instable atmosphere in the vertical column. The sea surface temperature plays the basic role in the foormation of depressions over the surface of water and other two helps in further development of tropical cyclones, typhoons and hurricanes. In South Asian region, the tropical cyclones develop over the Bay oof Bengal and the Arabian Sea; former was rich in their production while latter was poor. In general, there are two seasons when tropical cyclones form i.e. pre-monsoon (May-June) and post-monsoon (October-November). It should be noted that they do not develop near the equator due to weak coriolis force although the temperatures are more suited there.

An interesting anomoly has been seen in the two tropical cyclone sources under the global warming and changing climate. Time series analysis shows that the Bay of Bengal was warmer than the Arabian Sea in the past. Gradually that difference was narrowed down as shown in the following graphs of May and October. Even in May, the Arabian Sea has surpassed the Bay of Bengal in heat contents that justifies the evidence why tropical cyclones have become more common along Pakistan and Oman coast. October is also giving a clear message that in a period of a few years tropical cyclones will develop in post-monsoon season too.

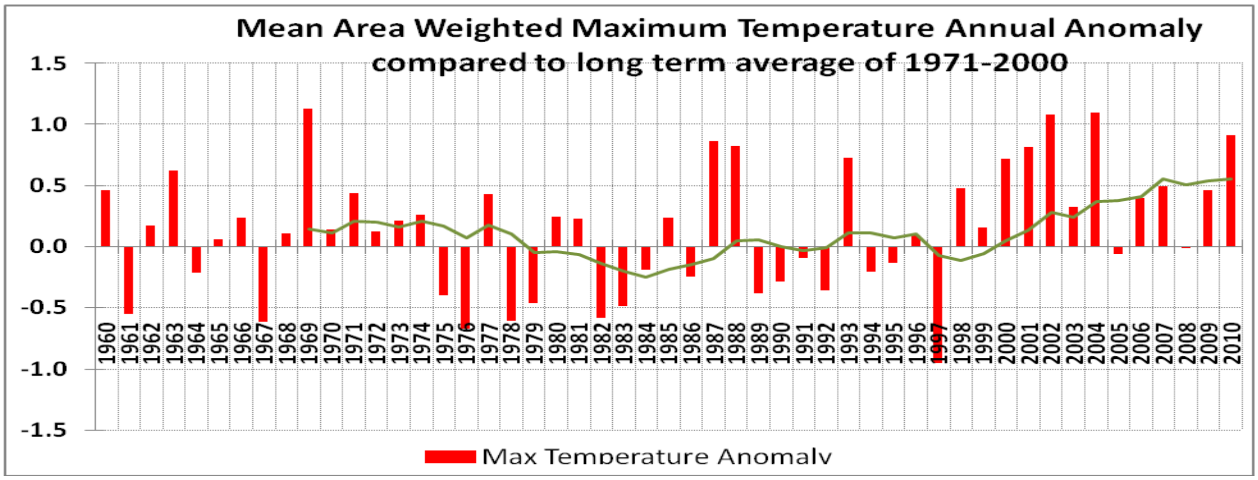




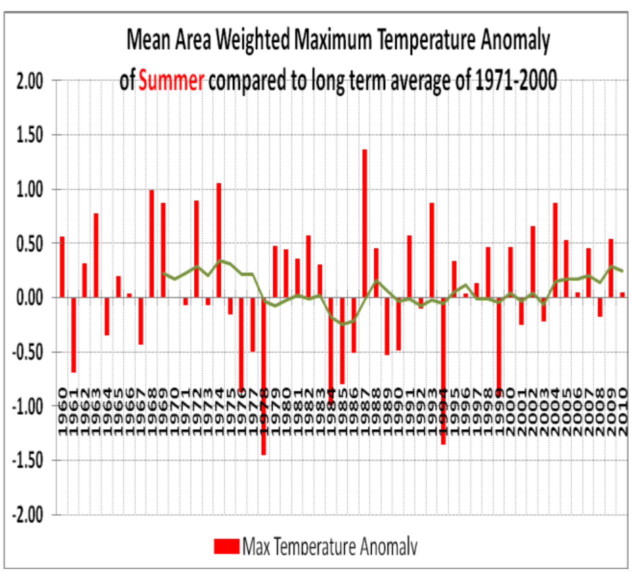


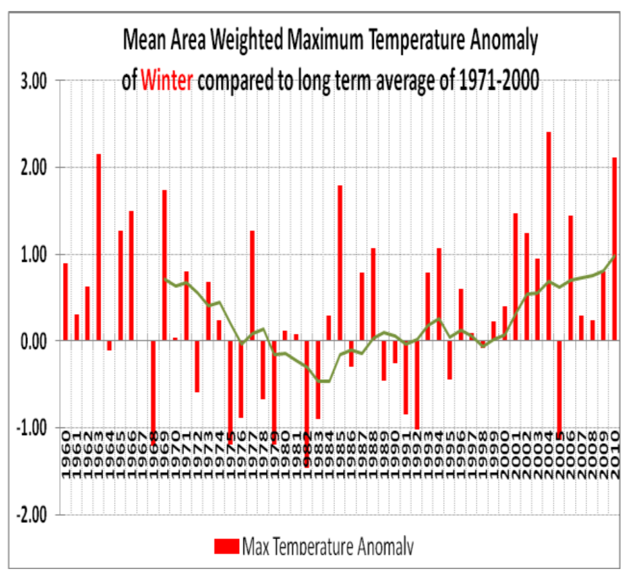
Time Series of Maximum Temperature Variation over Sindh

Maximum temperature represents the day time maximum temperature and it has its own significance to different users including travellers, tourists, general public, farmers, agriculture scientists, hydrologists, meteorologists and climatologists. A detailed study of inter-annual variation about the long term mean of day time temperature has been conducted on annual, seasonal and monthly basis for Sindh province from 1961-2010 which may serve the requirement of every kind of users. Graph shown below shows the trend of temperature in aggregate of all meteorological stations of Sindh province taking annual average into account.



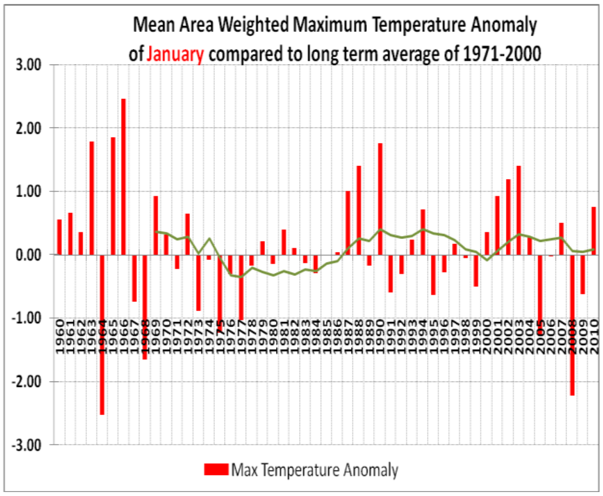
The behavior of maximum temperature has been investigated in summer and winter which incorporate the crop growing seasons i.e. Rabi and Kharif as well as the precipitation seasons. Following two graphs show the each year's summer or winter maximum temperature deviation (1961 to 2010) with reference to the long term avarage of 1971-2000. The days in winter season are getting warmer while summer is showing a mix behavior in Sindh province.

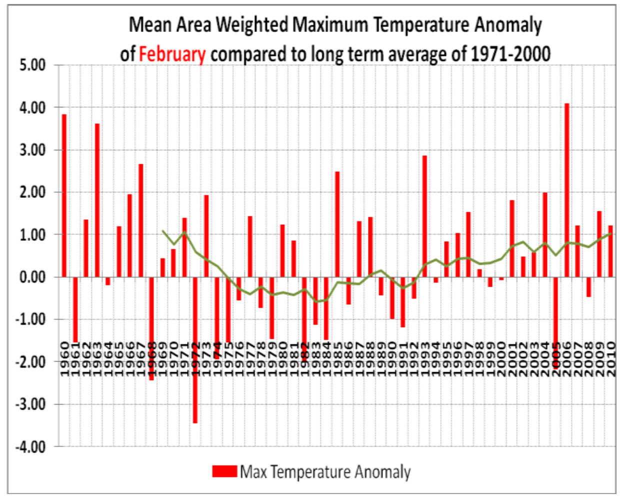


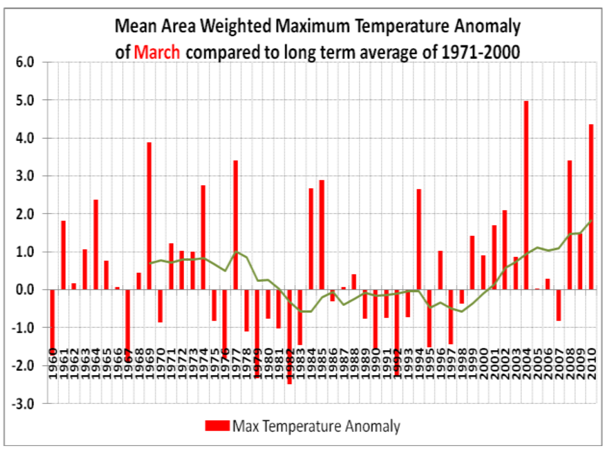


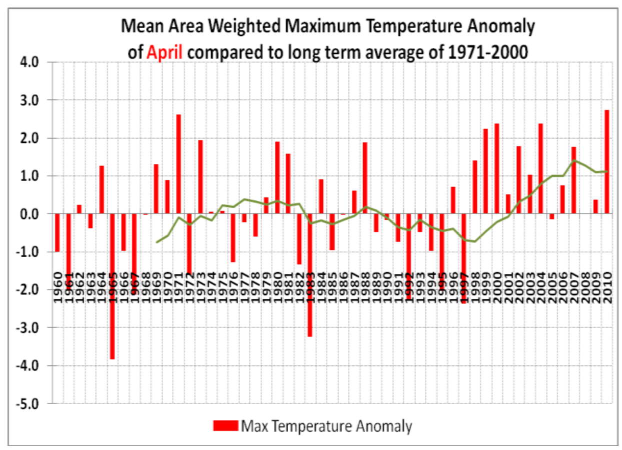
Monthly Maximum Temperature Trend

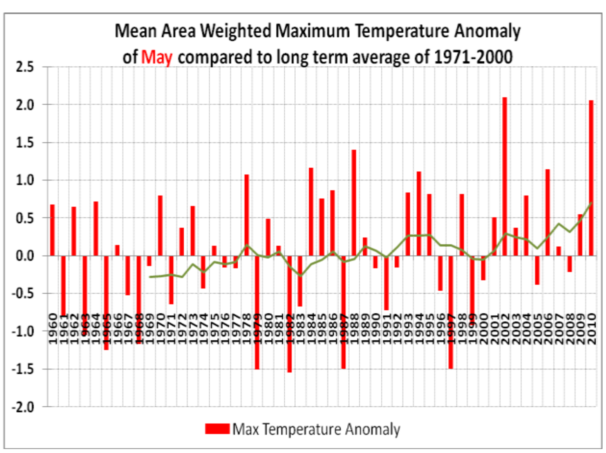
The detailed analysis of day temperatures is extended to monthwise inter-annual variation from the longterm mean for the convenience of diverse range of users especially agricultural research community in the Sindh Province. They should notice the sharp rise in February temperature when wheat is at its grain forming stage, rapid maturity may lead to reduction in grain yield.

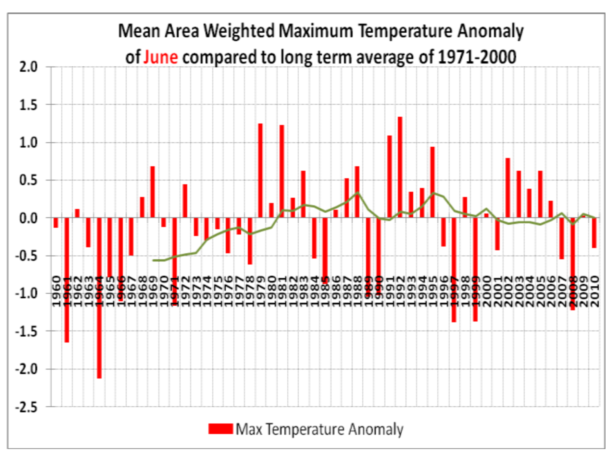




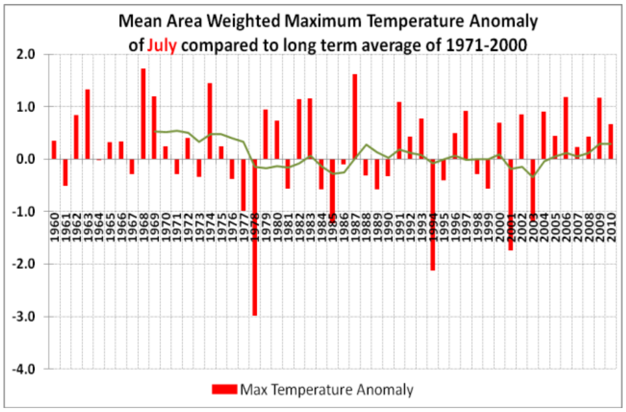


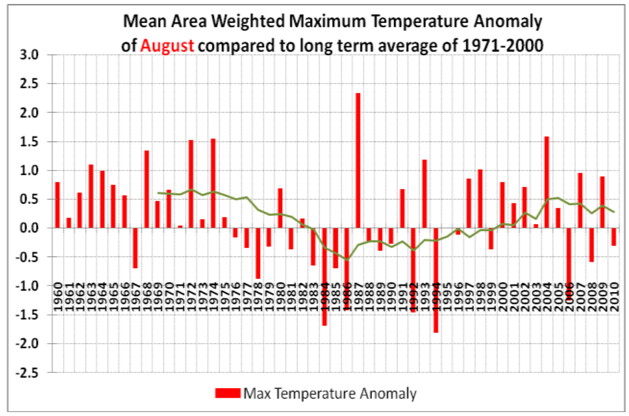


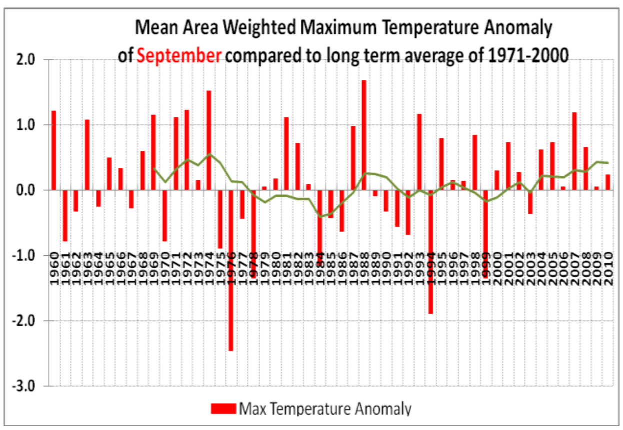


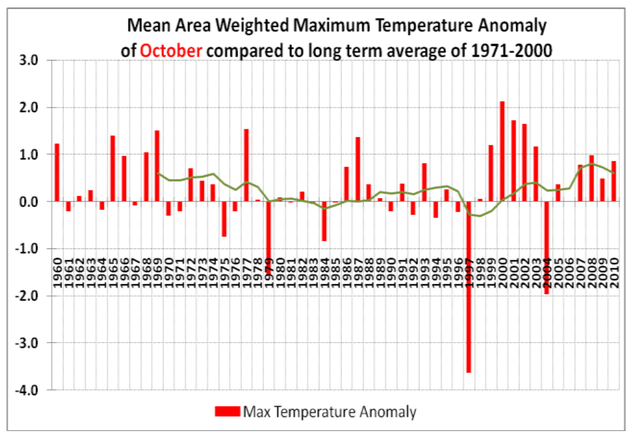


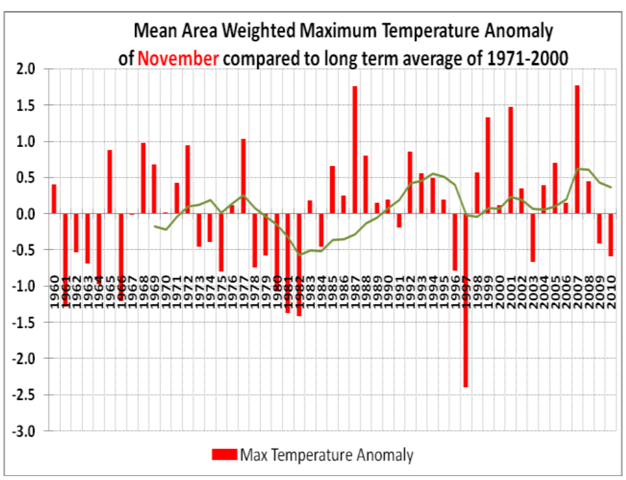
Recently temperature in March and April during the day is showing an increasing trend at all the stations of Sindh Province. This is a healthy sign for crop production as it tallies with the maturity of Rabi crops. Dry and hot weather is pre-rquisite for harvesting, threshing and storage operations. Such weather conditions keep the post-harvest losses at the lowest possible level.

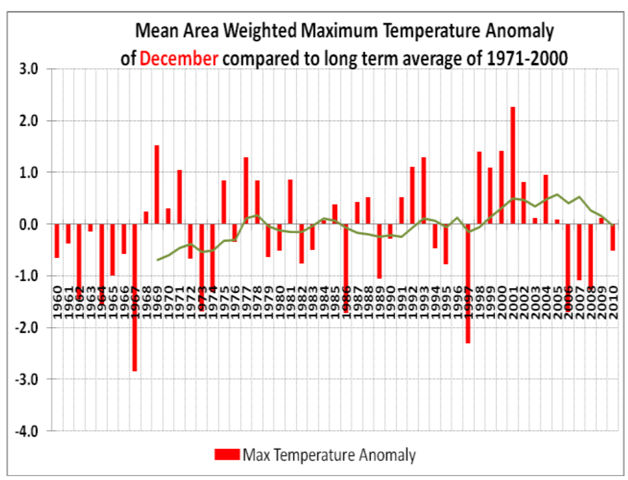








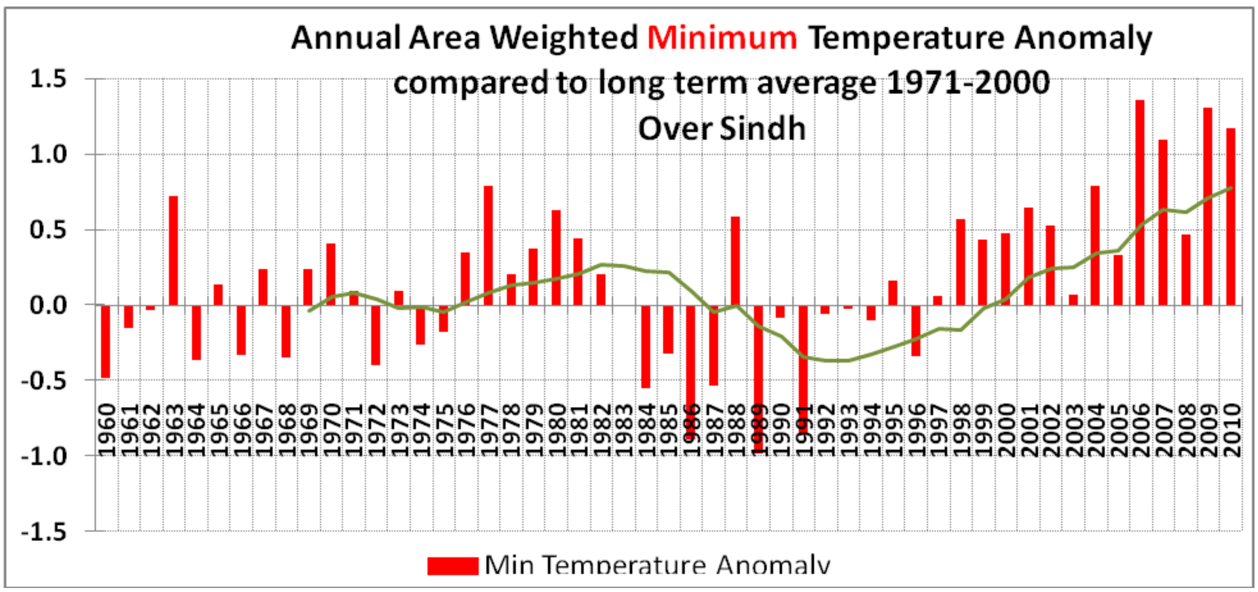


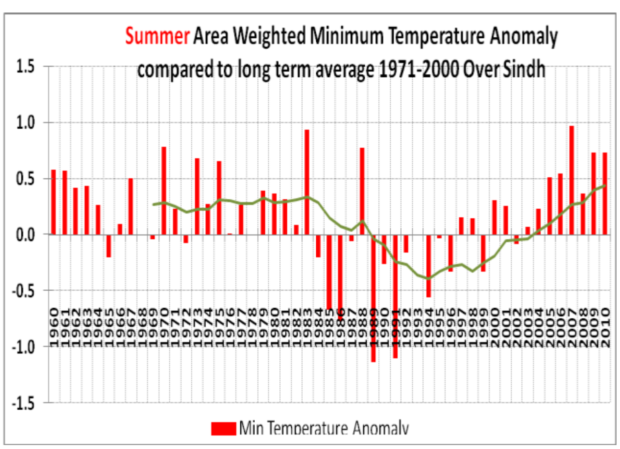


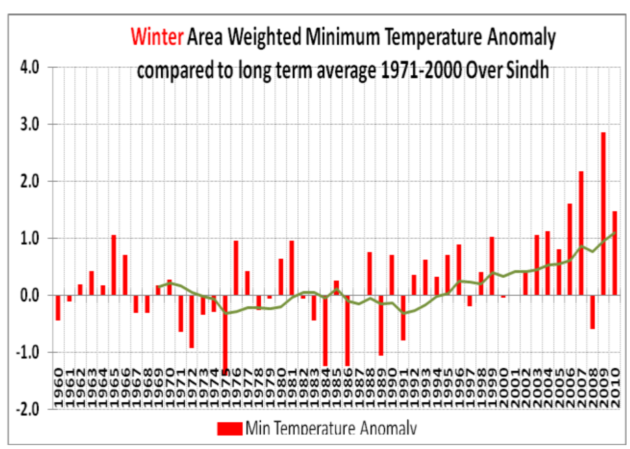
Minimum Temperature Time Series for Sindh

The day's lowest temperature generally occurs at night time therefore the minimum temperature is commonly considered as night temperature which is very important in the biological life of the crop plants. Photosynthesis is a process which takes place in day light and plants generate carbohydrates (dry matter production) while a reverse process called respiration starts at night when plant consumes what is produced during the day. The net gain is the diet of the plant for its growth and development. It should be noted that warmer nights accelerate the respiration process which means the net gain is inversely related to night time temperature.

For the convenience of users, the general trend of the minimum temperature in the Sindh province on annual and seasonal basis is given in the foloowing three graphs where 40 years time series tells the story of the past and present. A well-marked rising trend of night time lowest temperature can be seen in annual and seasonal series of summer and winter which invites the attention of crop breders as well as agronomists to adjust their cultivars accordingly.



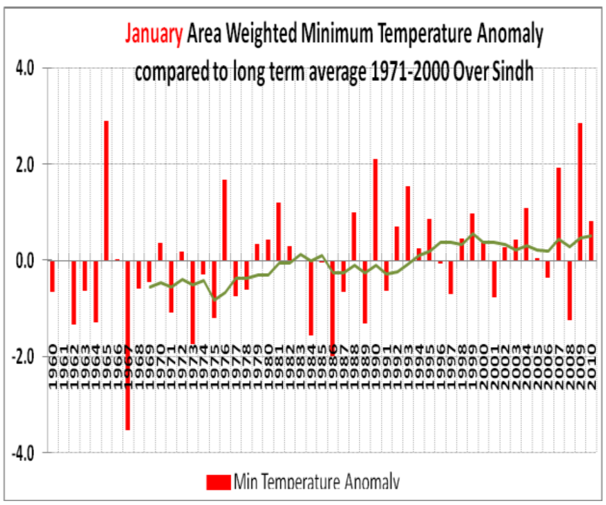


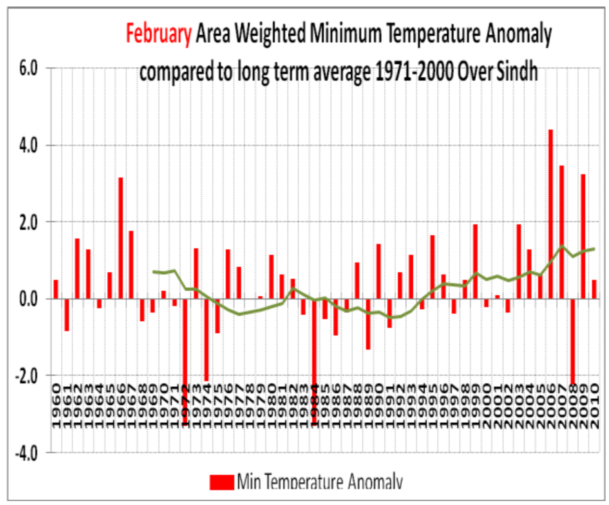


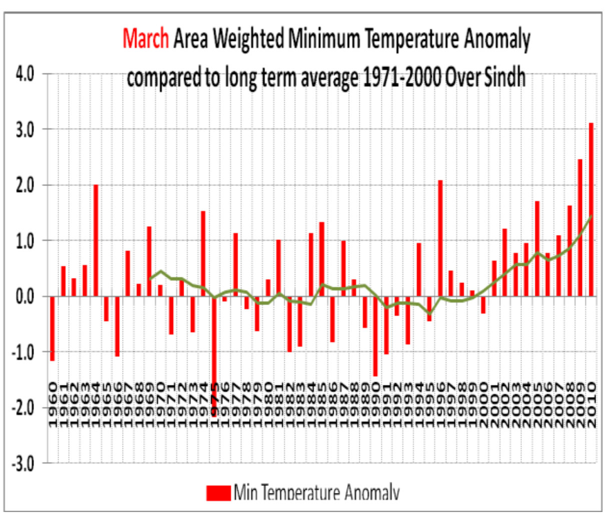
Minimum Temperature Trend

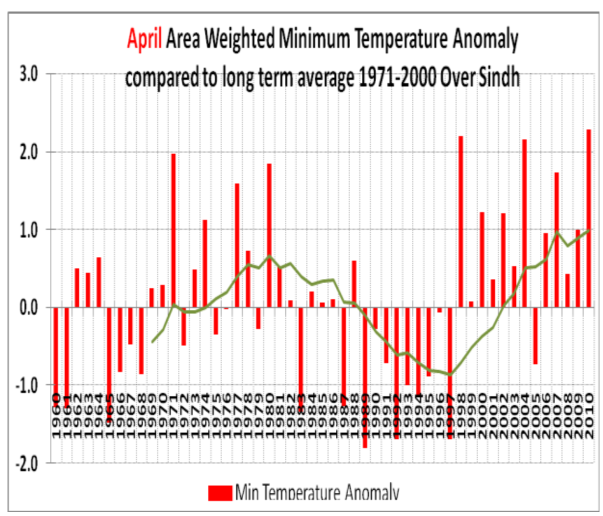
Monthwise temperature regime gives a better picture to understand the micro-effects of crop environment on crop health, growth, development and production. There is a common message that nights in Sindh are warmer now as they were in the 20th century. As mentioned in the case of maximum temperatures, February is the critical time in the life cycle of wheat crop when it is at reproductive stage. Higher temperatures during the day as well as at night are deterimental because the grain formation to maturity occurs in a short period of time not allowing the grain to gain proper size, weight and startch contents. Hence reducing the final yield. This has happed as a surprise to the farmers recently because their crops were apprently very healthy and naturally their expectations were high.

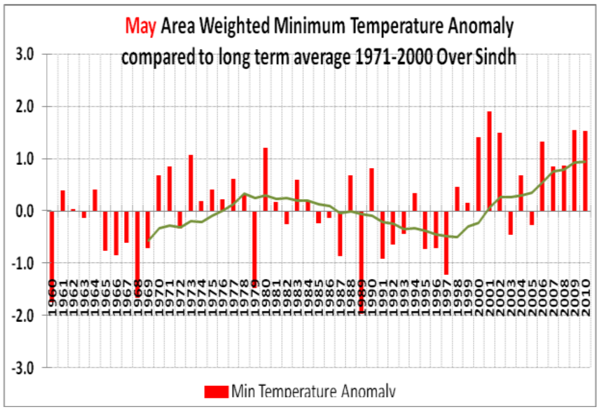
Now this is the challenging task for the agriculture scientists posed by the notorious segments of climate change. For in-depth knowledge of monthly thermal regime at night in Sindh, following graphs can be utilized which connect the past with the present.

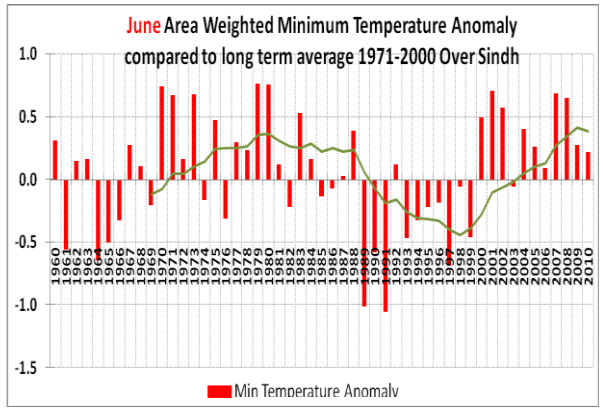


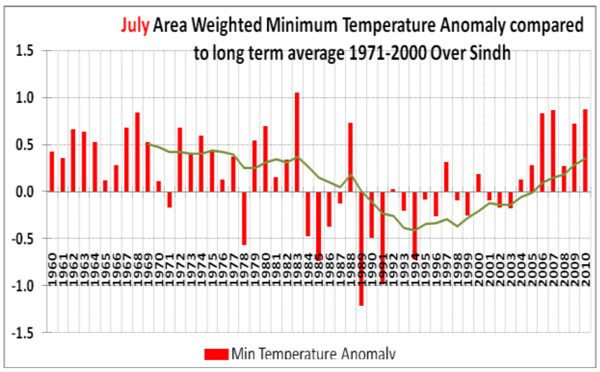


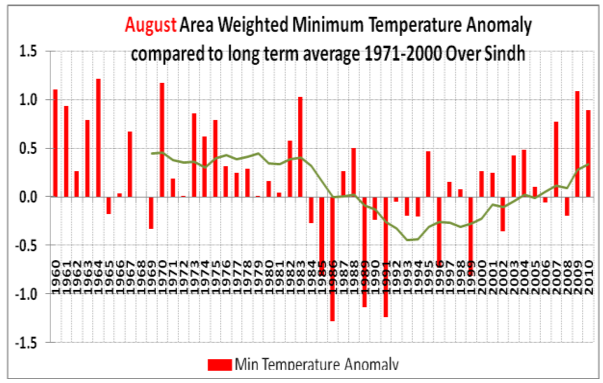


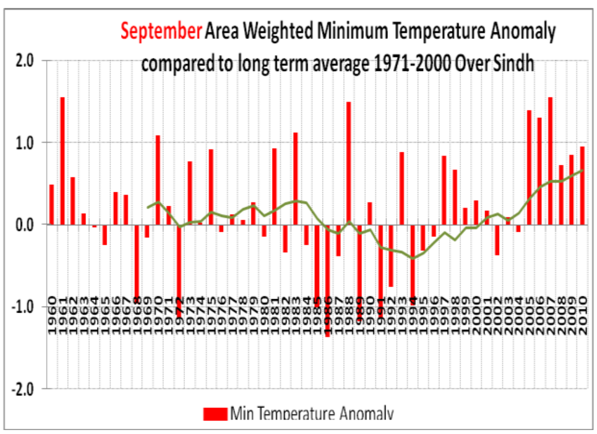


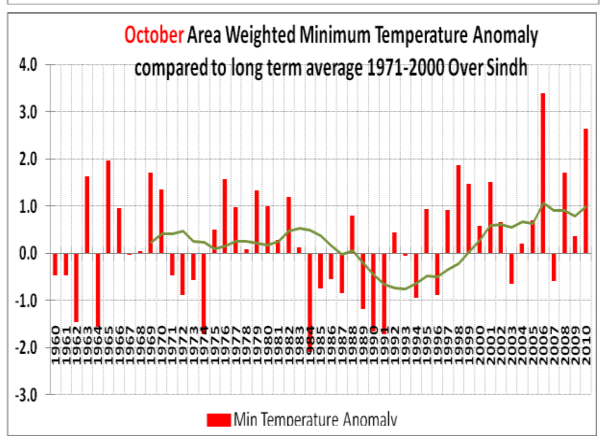

May Area Weighted Minimum Temperature Anomaly
compared to long term average 1971-2000 Over Sindh
3.0 2.0 1.0 0.0 -1.0 -2.0 -3.0
1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
Min Temperature Anomaly

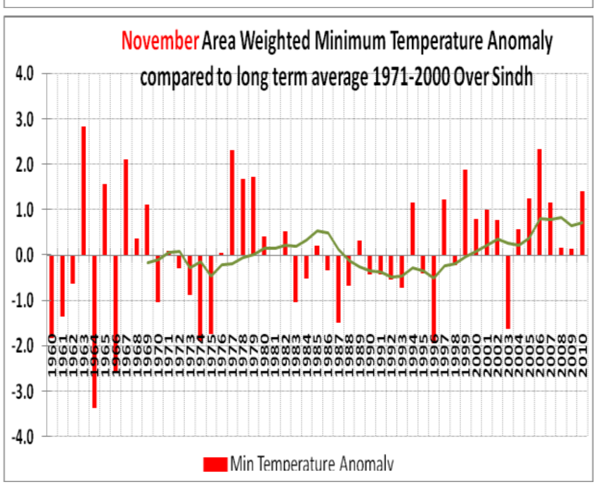

June Area Weighted Minimum Temperature Anomaly
compared to long term average 1971-2000 Over Sindh
1.0 0.5 0.0 -0.5 -1.0 -1.5
1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
Min Temperature Anomaly

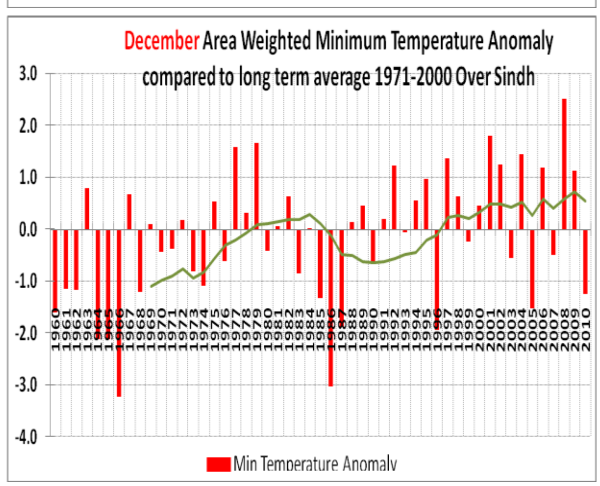

July Area Weighted Minimum Temperature Anomaly compared
to long term average 1971-2000 Over Sindh
1.5 1.0 0.5 0.0 -0.5 -1.0 -1.5
1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
Min Temperature Anomaly


August Area Weighted Minimum Temperature Anomaly
compared to long term average 1971-2000 Over Sindh
1.5 1.0 0.5 0.0 -0.5 -1.0 -1.5
1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
Min Temperature Anomaly


September Area Weighted Minimum Temperature Anomaly
compared to long term average 1971-2000 Over Sindh
2.0 1.0 0.0 -1.0 -2.0
1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
Min Temperature Anomaly


October Area Weighted Minimum Temperature Anomaly
compared to long term average 1971-2000 Over Sindh
4.0 3.0 2.0 1.0 0.0 -1.0 -2.0 -3.0
1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
Min Temperature Anomaly


November Area Weighted Minimum Temperature Anomaly
compared to long term average 1971-2000 Over Sindh
4.0 3.0 2.0 1.0 0.0 -1.0 -2.0 -3.0 -4.0
1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
Min Temperature Anomaly


December Area Weighted Minimum Temperature Anomaly
compared to long term average 1971-2000 Over Sindh
3.0 2.0 1.0 0.0 -1.0 -2.0 -3.0 -4.0
1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
Min Temperature Anomaly

Annexure 3

Precipitation Variability

Using station rainfall dataon daily basis from 56 meterological observatories of Pakistan spread all over the country, the area weighted precipitation was calculared by thesein polygone method. After calculation of the long term average, the annual deviation was computed to check the inter-annual variability. The graph of area weighted precipitation anomaly presented below shows highly variable precipitation in the country without any significant trend. However, there is a discrete trend visible in the time series. There is a decreasing trend in rainfall from 1961 to mid 1970s then increasing trend prevailed till early 1980s. An increasing tendency is seen through 1996 which again suffered a fall till the rise of 21st century.

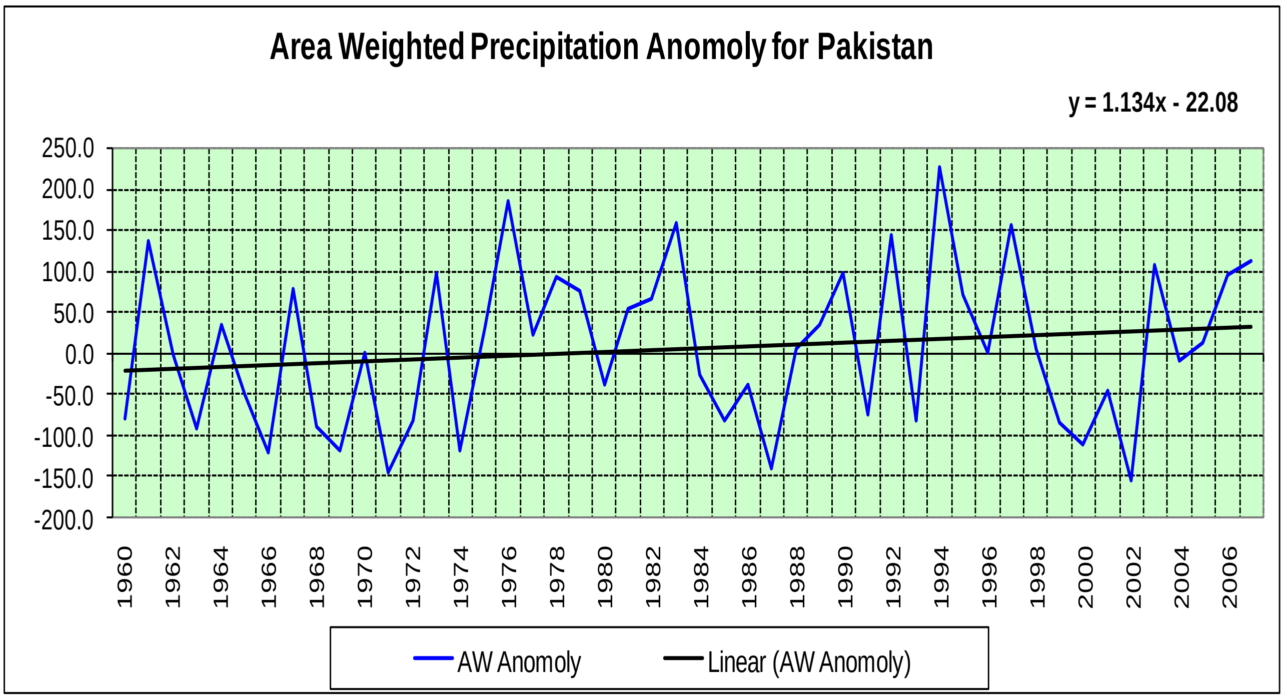


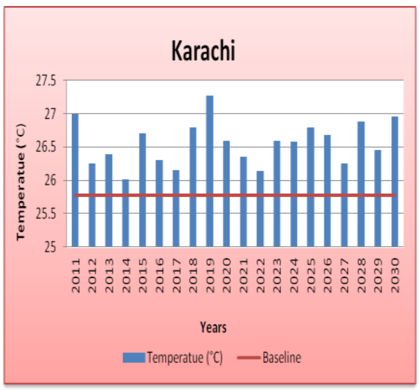
Figure: Time series of the area weighted precipitation anomaly about the long term avaerage for Pakistan based upon 56 meteorological stations.

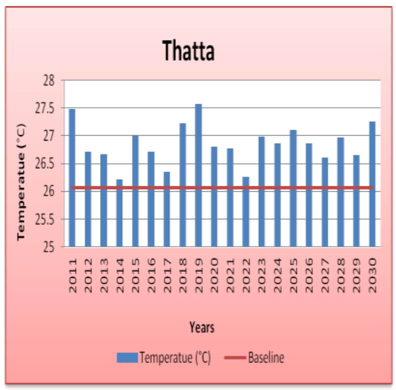
In the given time series, the upward peaks indicate the very wet years when flooding conditions prevailed in different parts of the country. The downward peaks are the indicators of drought which in many cases persisted for more than one year contineously. For example 1998-2002 was driest spell of this data set and this prolonged drought engripped 75% of the country causing damage of billions of dollars to the economy of Pakistan. It should be noted that this longest drought was triggered by the strongest El~Nino of the last century in 1997-98. However, floods did not repeat that tally although their frequency is following an increasing trend. Their areal extent was not so vast as the drought did.

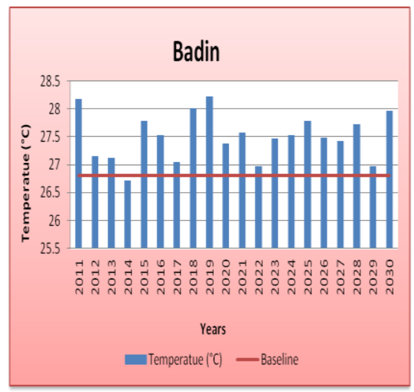
Annexure 4

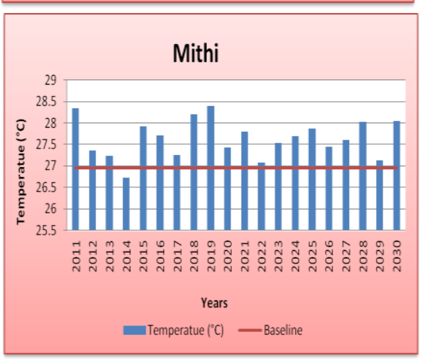
Annual Temperature Projections for Next 20 Years in Sindh

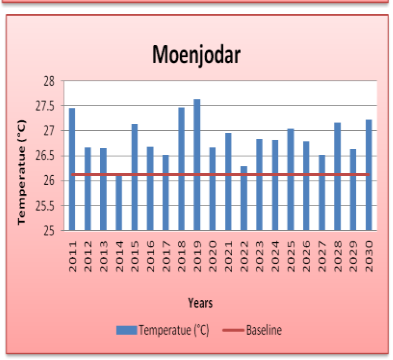
Temperature is not highly variable weather parameter like rainfall over the monthly, annual and decadal scales. However, a better guess of expected temperatures provide ample time for planning purposes both at the farmers and policy makers level. During the next 20 years, the mean daily temperatures are expected to range from 26-27°C along the coastal belt of Sindh, 27-28°C in central parts of the province while upper Sindh will experience them between 27-29°C. Following graphs present a picture of the thermal regime of main towns and cities of the Sindh province likely to prevail during 2011-2030.

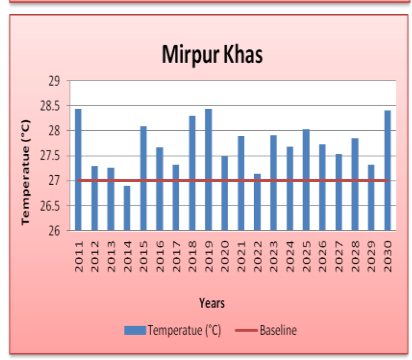


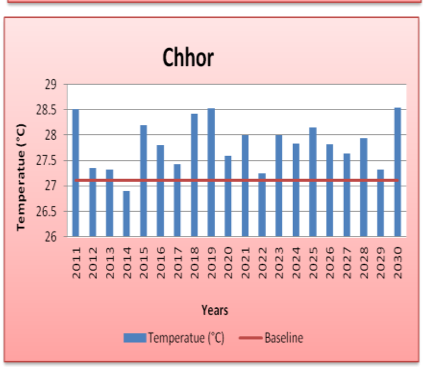


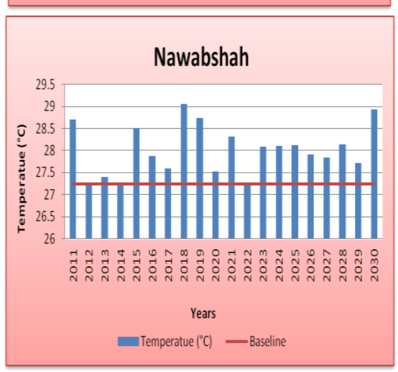


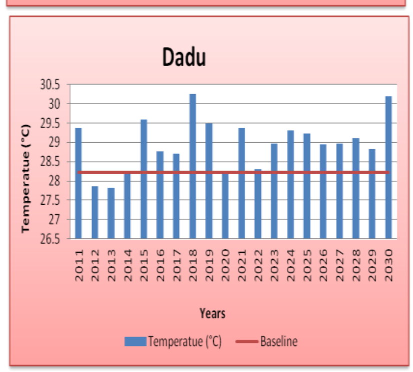


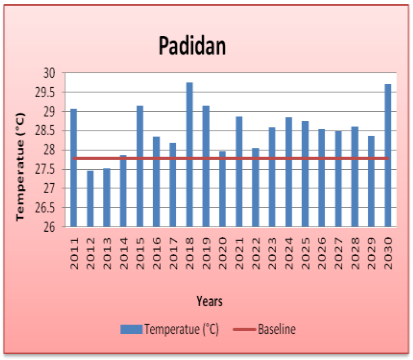


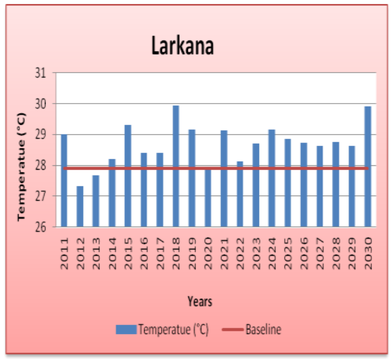


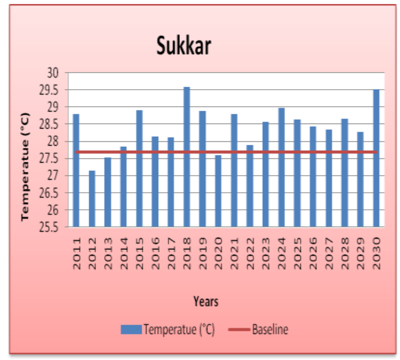


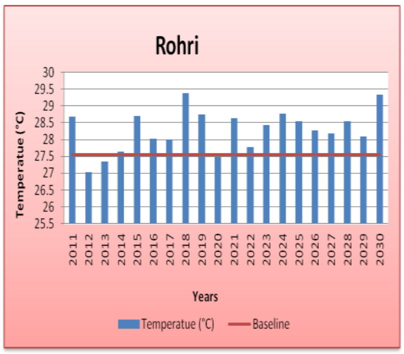


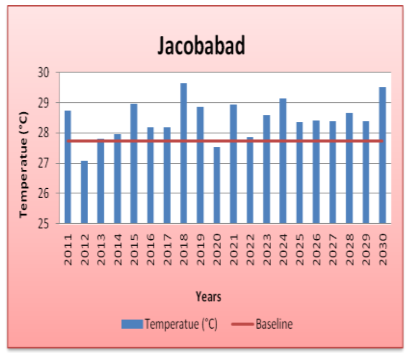








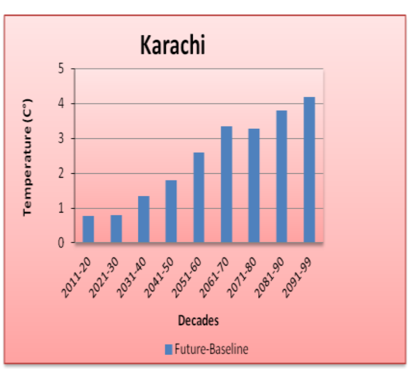


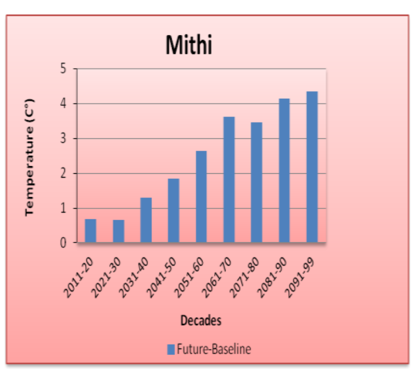


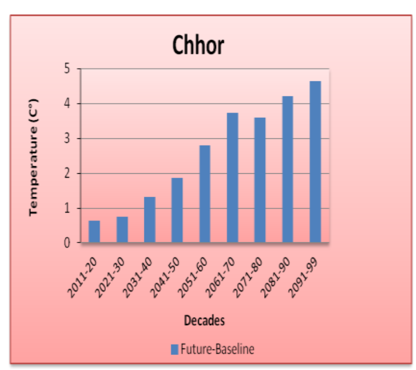
The rise in temperature will increase the rate of evaporation of moisture from the soil surface and transpiration from the plant tissues in the vegitated areas of the province. They will directly enhance the water requirement of field crops, animals, human beings as well as the domestic and the industrial sectors. Water is going to be a limiting factor as population increase and warming climate will claim a larger share to satisfy their demands. Although some additional amount of glacier melt water is expected to improve the river discharge but uncertainty of availability on temporal and spatial scales will be a great challenge.

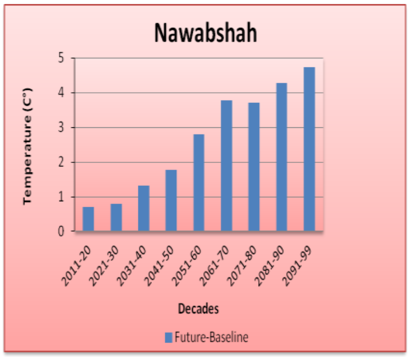
Future Dacadal Temperature Projections for Sindh Province

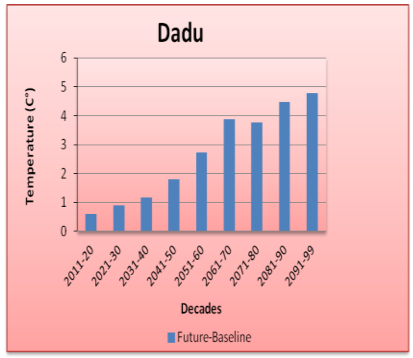
For a long term planning, climate change scenarios on decadal scales are widely used in the leading nations which are determined for a strategic adaptation to the expected changes in the regional and global climate. For all the climatic zones of the Sindh province, the temperature projections for this century on decadal scale are presented in the following graphs.

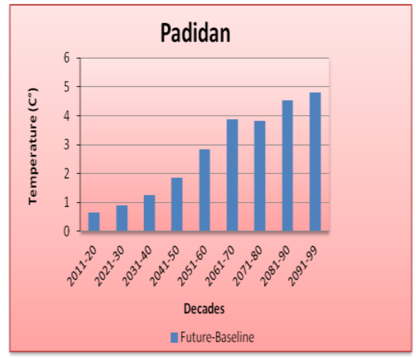


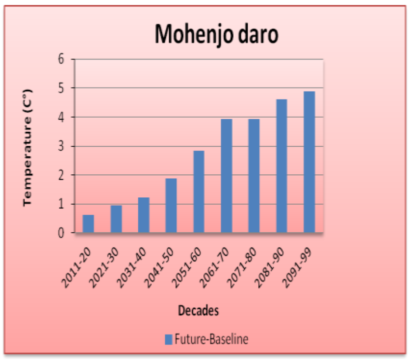


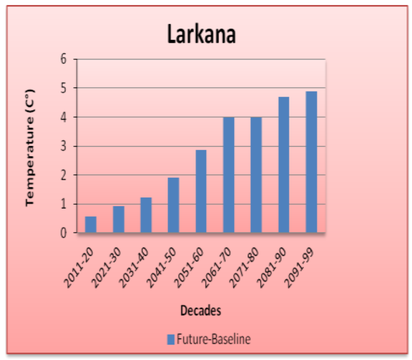


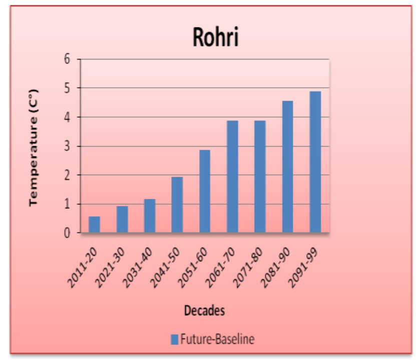












It is a general consensus in the output of most of the climate models that the mean daily temperatures in Sindh province will increase by about 5°C during 21st century which is about 1°C less than the northern parts of Pakistan. The pattern of temporal change is similar throughout the country. During the first half of the century, the increase in temperature is about 2°C whereas in second half it has been estimated as 3°C. Any rise and fall in temperature brings complex changes to the echosystem and then its feedback resultantly cause non-linear variations which cannot be guessed by simple linear interpolations. The decadal pattern shown above also depicts the inter-decadal non-uniform trend of change.

Annexure 5

Future Precipitation Change in Sindh Province

Rainfall is a highly variable climate parameter over time and space. Future projections of rainfall on decadal scale for central and upper climatic zones of the Sindh province are given in the following graphs which on one hand indicate large inter-decadal variations and on the other hand a decreasing trend of rainfall can be clearly seen at all stations of the province. Climate models project the future rainfall pattern in such a way than in the first half of the century, the amounts of rainfall is likely to increase whereas the second half will follow a sharp decline with highly variable occurrence. The decade of 2060s is predominantly a drought stricken decade for the whole province of Sindh.

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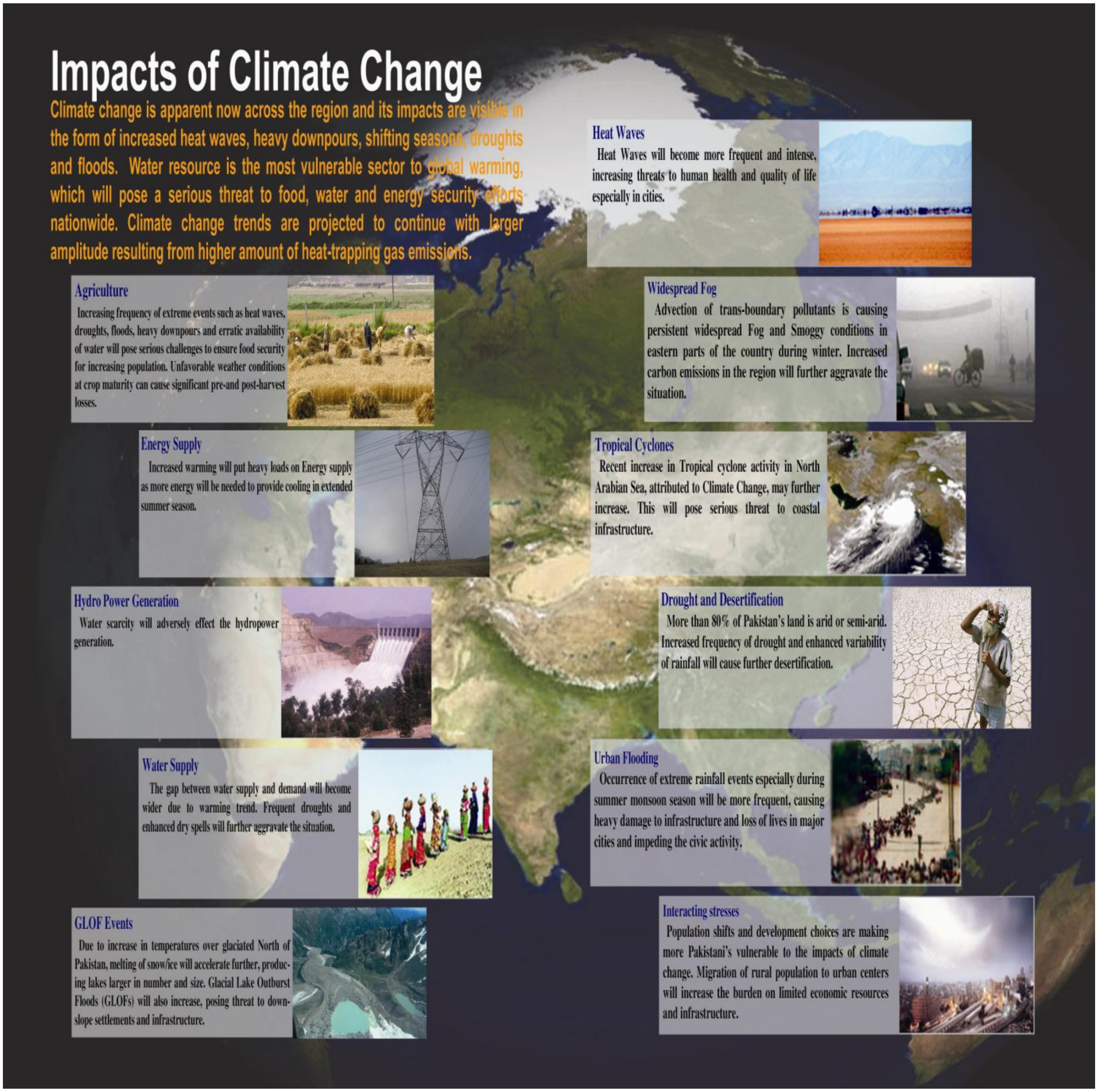
Dr. Ghulam Rasul is Chief Meteorologist, in Pakistan Meteorological Department (PMD) and heads Research & Development Division. He completed his Master degree in Physics from University of Agriculture, Faisalabad in 1984 and joined Pakistan Agricultural Research Council as Research Officer and counterpart to Dr. George W. Robertson (Canadian Agrometeorologist). In 1987, he moved to PMD as a meteorologist.Research remained his passion since early stage of his professional career. He received SAARC (South Asian Association for Regional Cooperation) Best Young Scientist Award in Meteorology in 1993 on development of a model for Hygrothermal Stress. He received his Ph. D. degree in Meteorology from Institute of Atmospheric Physics, Chinese Academy of Sciences on Numerical Modeling of Extreme Precipitation in Monsoon. His thesis ranked among top ten and was given Grace Award. In 2007, he won SAARC Senior Scientist Award on Diagnostic Analysis of Cloud Burst Event in Pakistan. He has been serving as a lead scientist at various international fora and reviewer of international projects, scientific reports and journals. Dr. Rasul took initiative on glaciers climate monitoring in Pakistan and study of the impact of global warming on the melting process which has now extended to whole range of HKH cryosphere including GLOF. He is author of 90 research papers, co-author of 3 books and produced several technical reports.



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