Vulnerability of the Indus Delta to Climate Change in Pakistan

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Abstract

Climate has been experiencing a rapidly changing trend embedded with the increased frequency and intensity of extreme events in Pakistan due to global warming. The Indus Delta is a vast tract of fertile land feeding a large proportion of population with food and fiber. Although it is composed of low lying areas of the Indus irrigated plain but the changes occurring in the climatic conditions of the extreme north also directly affect through water deficit or surplus. The Himalaya-Karakoram-Hindukush region, which hosts world's third largest ice mass after the poles, has warmed up more than 1.5 °C almost double than remaining parts of Pakistan (0.76 °C) during last three decades. Increased frequency of torrential rains, prolonged heat waves, frequent tropical cyclones, recurring flooding and persistent drought are the phenomenal changes experienced this deltaic region. Rapid melting of glaciers in the north is not only contributing to floods downstream rather it results into sea level rise. Resultantly, intrusion of saline sea water into the fertile land has been destroying the fertile agricultural land. Wind is a great natural resource possessing huge socio-economic benefits if augmented but increased intensity of storm surges and invasion of tropical cyclones are the great threats to infrastructure. Erratic behavior of monsoon precipitation has resulted in 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. Future climate projections indicate that at least 5 °C rise in temperature over the Indus Delta is expected by the end of 21st century. Due to this increase in temperature, domestic, animal and crop water requirements will rise 1.5 times over the present levels. Over the time population increased but water reservoirs were not developed at the same pace therefore Pakistan entered in the list of water deficit countries. Water availability will further decrease reducing the per capita share. Precipitation pattern is going to be highly variable. Poverty, lack of resources and low adaptive capacity of the local population of the Indus Delta to climate change has been exaggerating the vulnerabilities and posing challenges to sustainable food production.

Introduction

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 (Ansari, 2002). 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 suffers. After industrial revolution, emission of Green House Gases (GHGs) to the atmosphere increased drastically from industry and vehicular fossil fuel burning emission. 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 (WMO statement 2011)

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% receives between 250-500 mm); its rivers are predominantly fed by the Hindu Kush-Karakoram-Himalayan (HKH) 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

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increasingly larger risks of variability in monsoon rains, hence large floods and extended droughts. Under the influence of all these factors the water, food and energy security of the country are under serious threat. Compounding these problems are the expected 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 (Robert, et al., 2009). 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 neighbouring 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. Adaptation to climate change and building resilience among ecosystems and people to respond to climate variability and hazard threats are relatively new concepts (PMD 2009). 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. The delta-wide vulnerability assessment will guess the health of ecosystems across the Indus Delta and in the three selected sites (Keti Bunder, Kharo Chann in District Thatta; and Jiwani in District Gawadar). 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 (Jayatissa et al., 2008). 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).

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 comity 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 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.

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 (2011), 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.

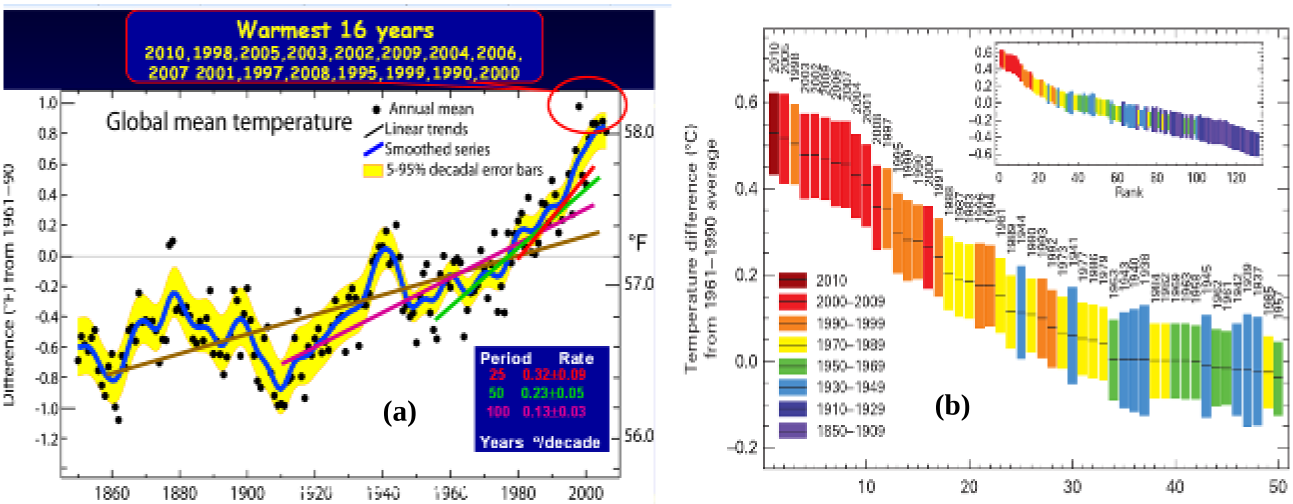

Figure 1: Global average temperature trend **(a)** since 1850 with 16 warmest years ranking (IPCC 2007 updated with recent data) **(b)** colour coded decadal average global temperatures compiled by (WMO 2011).

Pakistan Perspective

Under global warming and changing climate, Pakistan is no exception as both do not follow the political/geographical boundaries. Both precipitation and thermal regimes in Pakistan have suffered changes especially in the recent two decades when global atmospheric temperatures have shown a gradual rise. Pakistan enjoys diverse climate ranging from frozen ice caps in the north to burning deserts in the south. 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 (Bosshard, 2006).

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 Figure 4.

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. Wheat is the major crop of the Indus Delta and water requirement is already higher than northern half of the country (Rasul 1992) which will further increase due to warming. In 1998, the severest El-Nino of the history occurred due to the abnormal heating (> 4 °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 engripped the most parts of the country and atmosphere was not reclaimed to lower its temperature. 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 has shown irreversible rise in temperature.

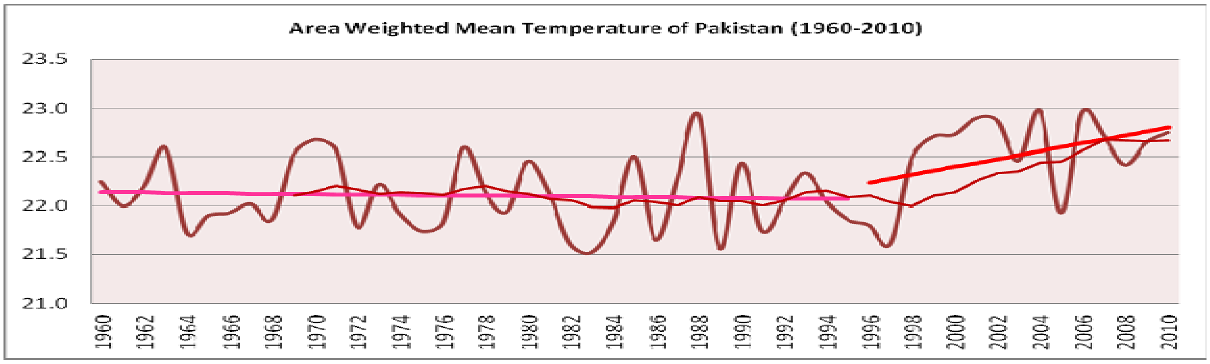

Figure 2: Time series of area weighted mean daily temperatures averaged over each year shows a sharp rise in temperature during the first decade of 21st century except the year 2005.

Summer and Winter Temperature

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 Fig 5, tendency of day and night temperatures in summer and winter seasons during last decade is shown compared with long term average temperature.

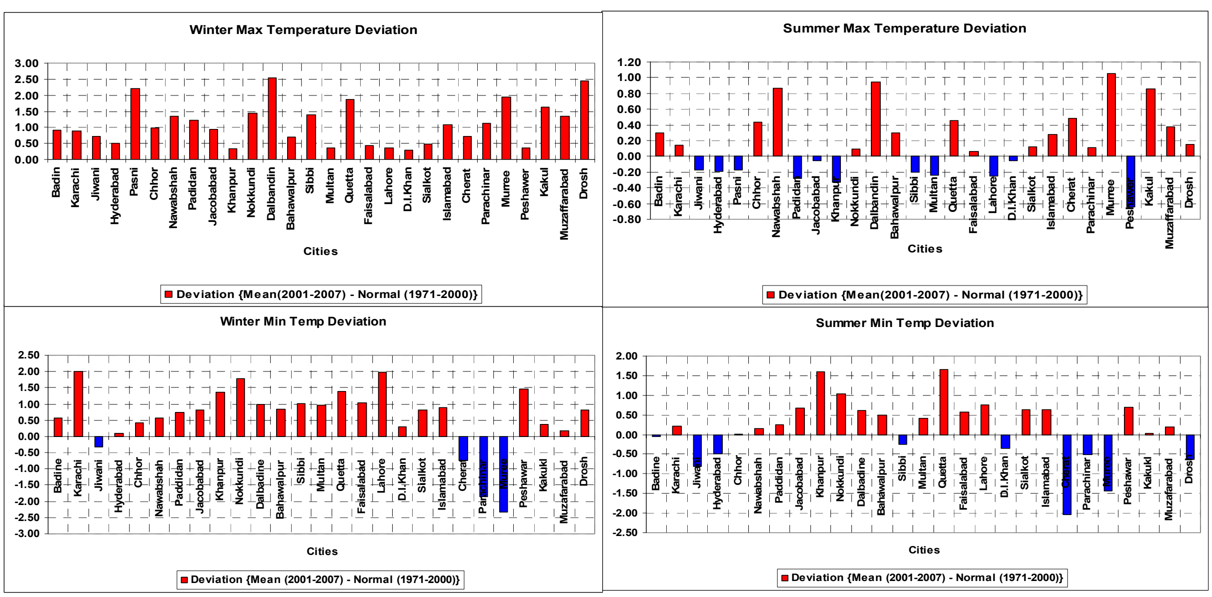

Figure 3: Deviation of maximum (represents day highest) and minimum (represents night lowest) temperature during last decade from normal in summer and winter seasons in Pakistan. Stations are arranged south (left) to north (right).

Respiration is the reverse process of photosynthesis when dry matter produced during the daytime is consumed by the plants 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. Figure 4 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. 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 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.

Precipitation

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 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 rainfall from July to September. Pre-monsoon (May and June) is very hot and dry season and only localized convective rains occur occasionally. Similarly, autumn 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 500 mm and 800 mm 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. 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.

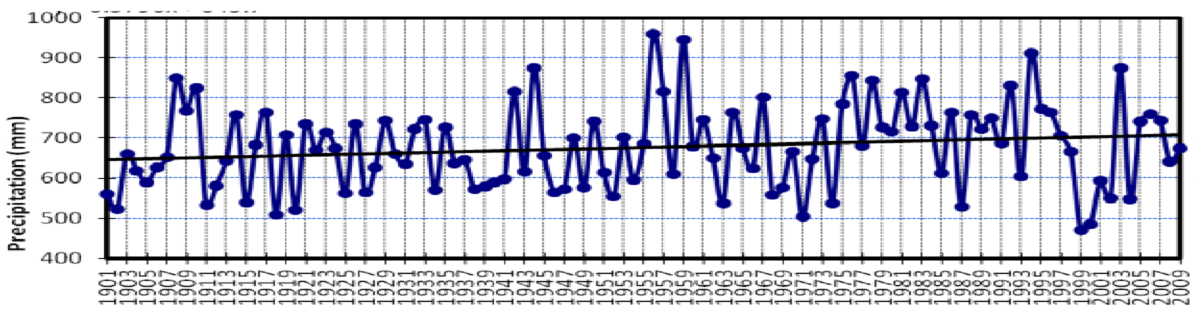

Figure 4: Inter-annual variability of precipitation over Pakistan during the last century and first decade of 21st century. Climate Research Unit (CRU) data used to downscale Pakistan's regional precipitation.

The change in total amount of rainfall on countrywide scale is hardly 61 mm increase over a period of 109 years which makes an average rate of increase around 0.6 mm/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 of various sources such as tree rings, coral reefs, sediments etc. The most important characteristics 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.

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 case 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.

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 national 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 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 hydrometeorological disasters.

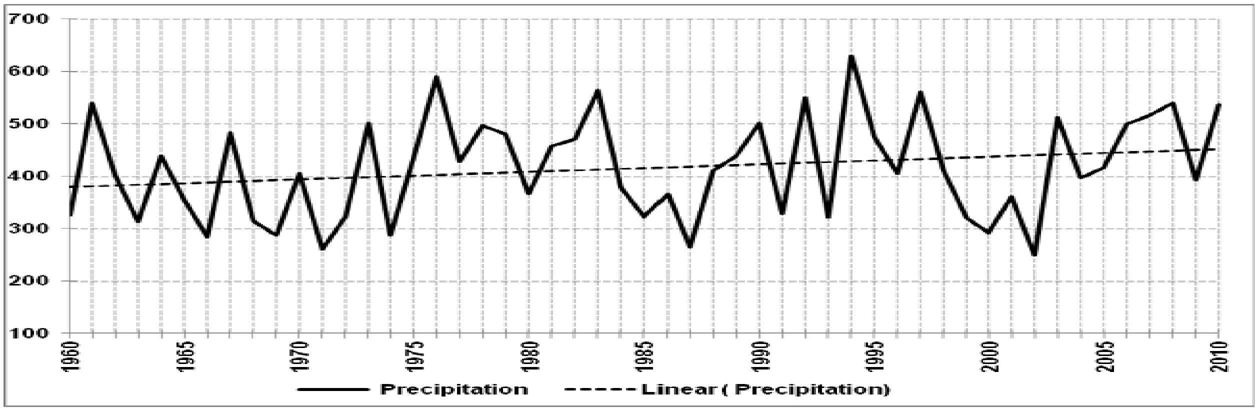

Figure 5: Time series of precipitation over Pakistan based upon data records of 56 meteorological observatories.

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.

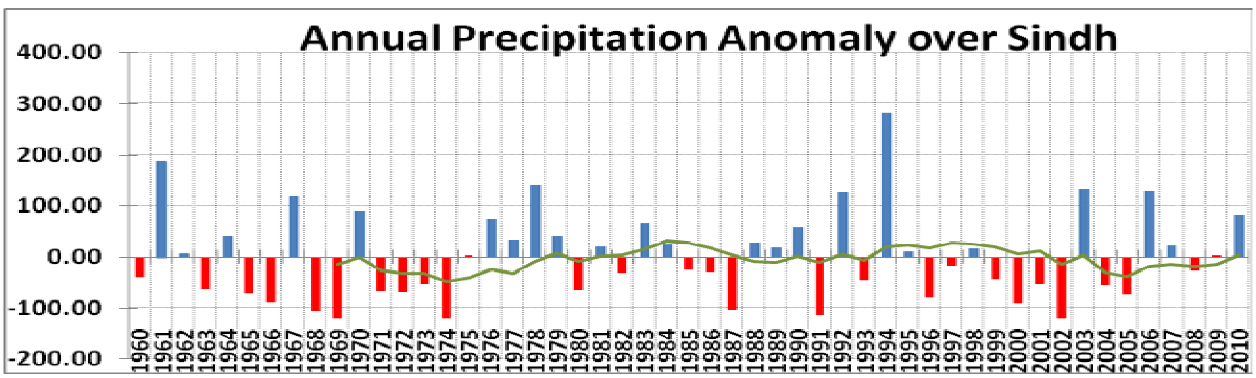

Figure 6: Inter-annual variability of precipitation (mm) over Sindh from long term average.

Long term average precipitation of Sindh Province is 162.2 mm 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 (Memon, 2005). 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 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 Pakhtoonkhwa 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.

Summer and Winter Precipitation

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. 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. 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 summer; therefore floods do not occur in winter.

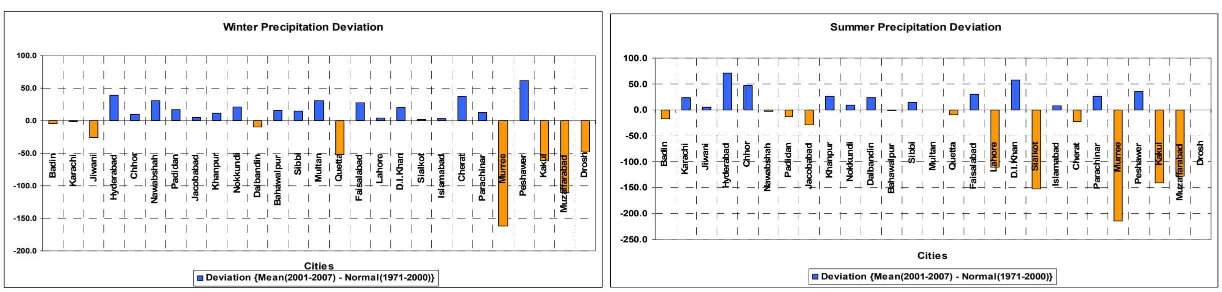

Figure 7: Deviation of rainfall in summer and winter during the recent decade (2001-2010) from normal of 1971-2000.

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 flaviour 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 Fig 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 do not allow the sowing of next crops on time.

Extreme Precipitation Events

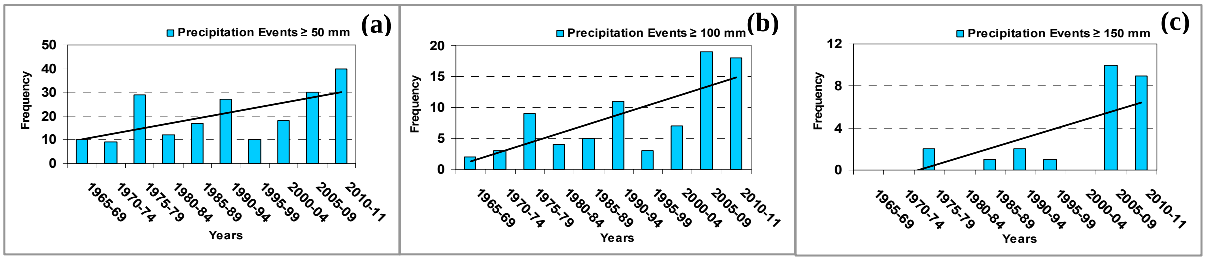

Figure 8: Frequency of extreme precipitation events in Sindh Province on pentad scale compared with two recent years 2010 and 2011. Three thresholds are chosen **(a)** rainfall ≥ 50 mm/day, **(b)** ≥ 100 mm/day and **(c)** ≥ 150 mm/day

The areas which lie in active precipitation zone used to enjoy up to 200 mm 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.

The change in tendency of extreme precipitation events is shown in Fig 10 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 150 mm 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 100 mm and 150 mm 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 100 mm 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 150 mm in a day.

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.

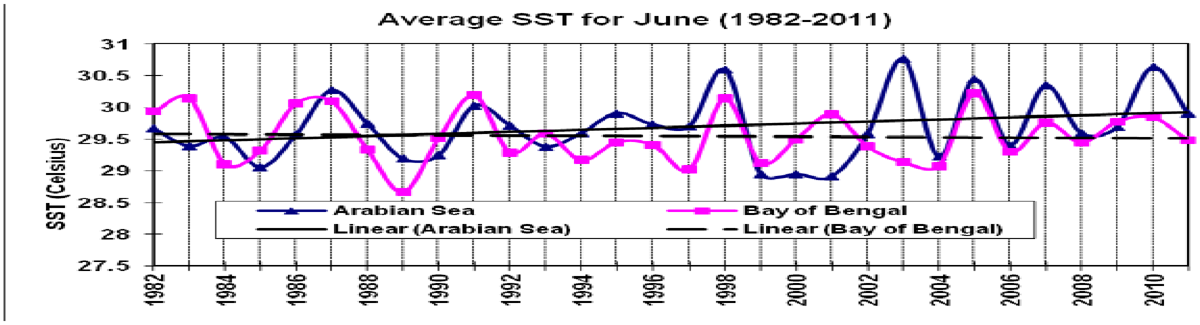

Figure 9: Inter-annual variation of sea surface temperature over the North Arabian Sea and the Bay of Bengal in June from 1982 to 2011. (Source of Data: JRA Reanalysis)

Pakistan receives rainfall in summer mainly from weather systems formed over the North Arabian Sea and the Bay of Bengal. 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. This shift is attributed to the accelerated warming of the North Arabian Sea water than the Bay of Bengal as shown in Figure 11. 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.

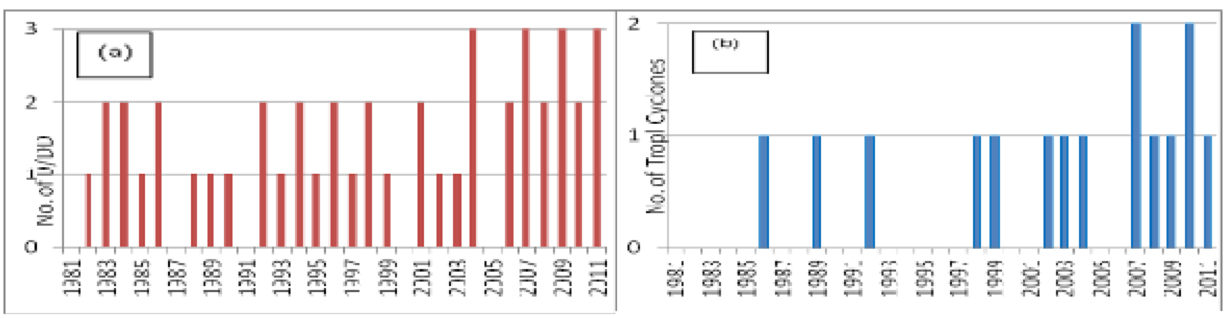

Figure 10: Frequency of depressions (D) and deep depressions (DD) which have the potential to develop into a tropical storm (a) as well as Tropical Cyclones (b) depicts an increasing trend over the North Arabian Sea.

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 (Baig et al., 2008), 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 (Hyder et al., 2008). 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.

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. Figure 2 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. 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 Gawader 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.

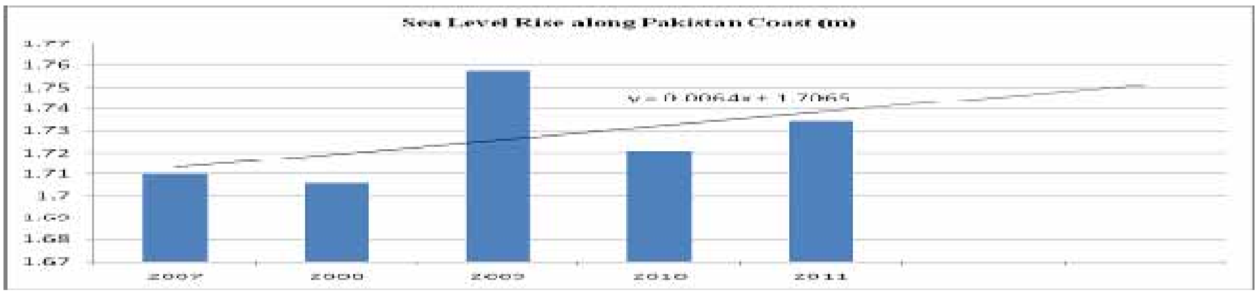

Figure 11: Tide gauge data showing annual average sea level at Gawader along Pakistan coast from 2007 to 2011. (Data Source: National Institute of Oceanography, Karachi).

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.

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 (Salman, 2010) 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.

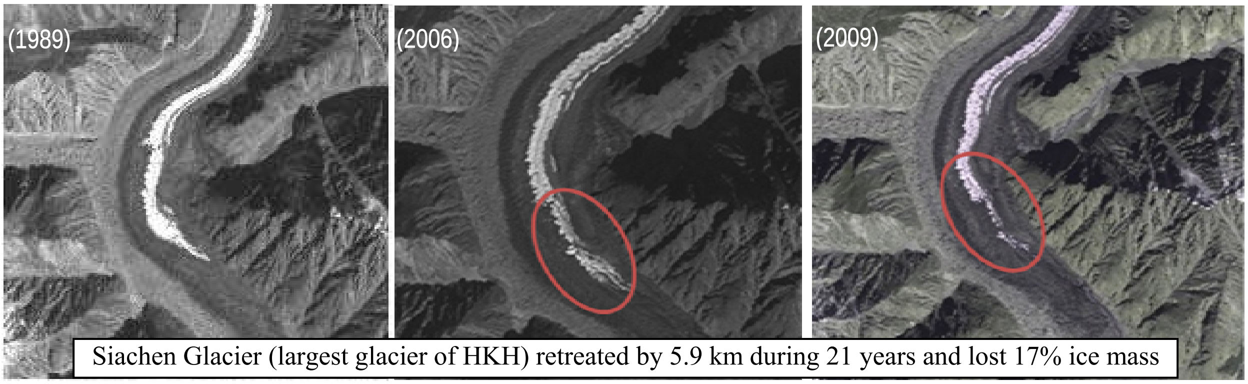

Figure 12: Retreat of Siachen Glacier is visible over the time scale mainly due to anthropogenic reasons being the highest war front of the world between India and Pakistan.

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% visible in Figure 14. 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.

Vulnerabilities of the Indus Delta

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 various climate change induced problems (Gohar et al., 2010) which are discussed briefly in the following paragraphs;

a. Droughts and Floods

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 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). The Indus Delta is also exposed to storm surge flooding and intense rainfall (Rasul et al., 2005) 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 (Ejaz, 2012). Under such scenarios, the sustainable development becomes a great challenge if carried out without scientific planning.

b. 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 Pakhtoon Khwa 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 (Wang et al., 2009) 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 (Chaudhry et al., 2004). 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 exaggerates the situation and heavy rains take the shape of a great disaster (Rasul, et al., 2008).

c. 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 (Chandio et al., 2011) with the passage of time. The saline and sodaic contents of soil (Aziz et al., 2000) would rise to such a critical level which would ultimately deteriorate the yielding potential of fertile deltaic soils (Memon, 2011). 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.

d. 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 Sindh province. As these wind face the coast from south therefore their increased force has been rapidly eroding the land mass along the coast due to the tidal push. Frequent storm surges associated with sea surface depressions cause significant damage.

e. 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. 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.

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 (Robin, et al., 1993) which possessed high warming potential. Ever-increasing concentration of GHGs has been making the situation more and more complex. 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.

a. 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 15. 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.

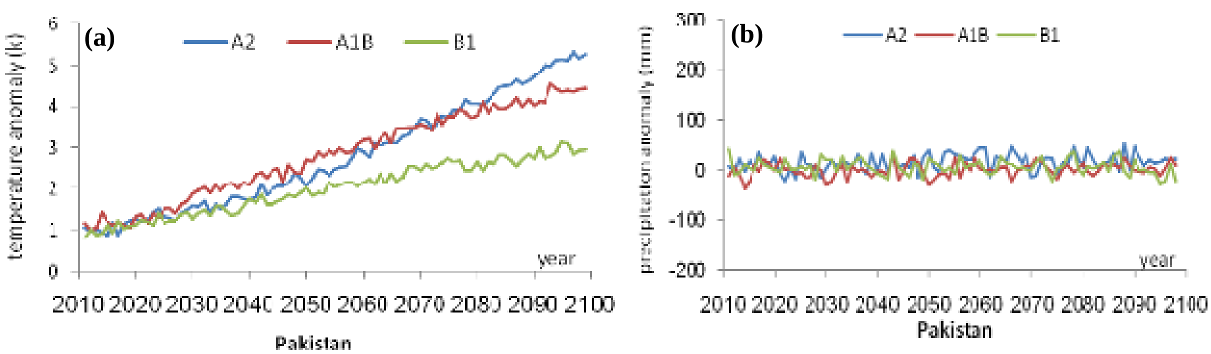

Figure 13: Future temperature **(a)** and rainfall **(b)** projections on decadal scale for Pakistan under A1B, A2 and B1 SERS scenarios for 21st century.

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 2C 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.

b. 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.

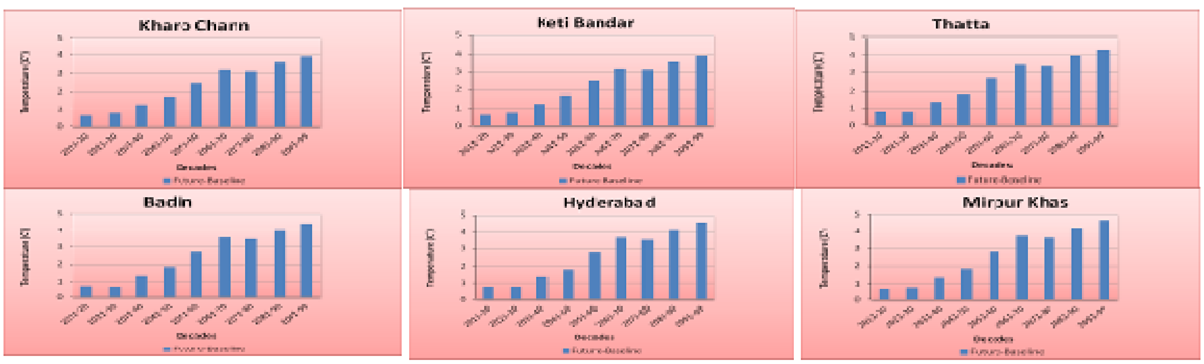

Figure 14: Mean daily future temperature projections for the Indus Delta on decadal basis during 21st century.

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 air mass will prevail with its increased dominance especially in summer making the atmosphere relatively moist. 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.

c. Precipitation Projections of Indus Delta

Precipitation is highly variable parameter over time and space. Its variability is very likely to increase in the coming years under the influence of global warming. Using GCMs and SRES scenarios of IPCC, projections of future precipitation of lower, middle and central parts of the Sindh province at 25 km horizontal resolution on decadal scales have been presented in Figure 17. Some annual projections have also been shown in Figure 18 for selected stations of Sindh over the Delta. It should be kept in mind that Projections are not predictions because they are based upon scenario based options and assumptions as future state of population, economy, land use change, emissions etc. is not known. However, projections of future climate provide a broader image to planners and policy makers for adaptation and mitigation.

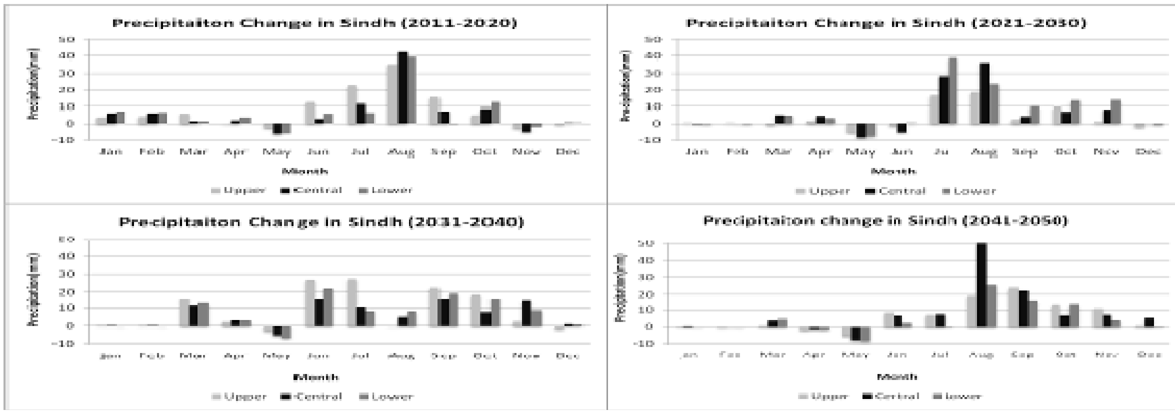

Figure 15: Future projections of precipitation for lower, central and upper Sindh during the first half of 21st century.

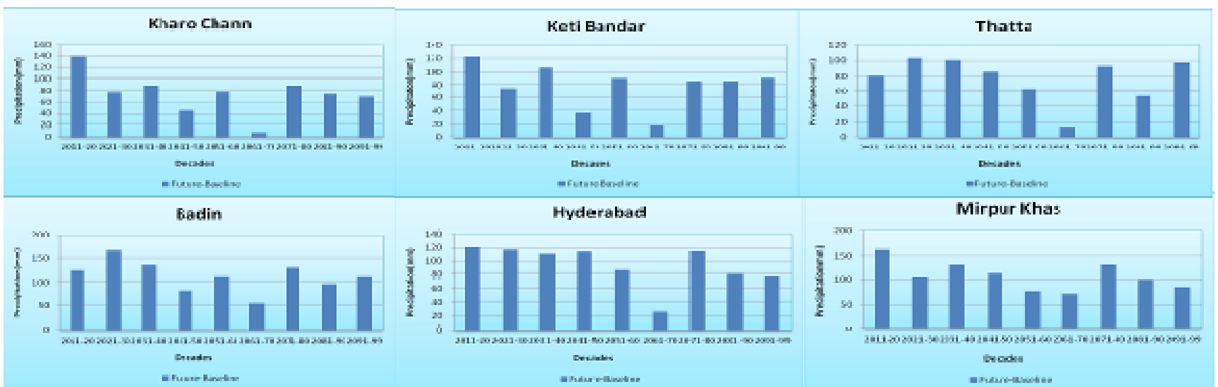

Figure 16: The Indus Delta future precipitation regime projected on the decadal basis for this century.

Major Challenges

The Indus Delta is the most vulnerable area posed to the challenges of climate change such as;

- 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.

Recommendations

To mitigate the risks/threats due to climate change some measures are proposed 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 Sindh coast be harnessed to initiate economic activity in 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 reservoirs should be constructed 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 intrusion of sea water into the Indus deltaic region, the whole range of marine life will be affected 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 the 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

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