CLIMATE CHANGE AND VARIABILITY TRENDS IN PAKISTAN AND ITS ENVIRONMENTAL EFFECTS

Thesis submitted to Department of Environmental Sciences University of Peshawar in partial fulfillment of the requirements for the degree of Doctor of Philosophy

By

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LIST OF ABBREVIATION

ANOVA	Analysis of Variance
ANP	Asia Pacific Network
Arc GIS	Arc Geographical Information System
ARIMA	Autoregressive Integrated Moving Average
CDPC	Climate Data Processing Centre
CH_4	Methane
CNG	Compressed Natural Gas
CO_2,	Carbon Dioxide
CRCD	Climatologically Record from Climate Data Centre
DTR	Diurnal temperature change
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
GHG	Green House Gases
HCDN	Hydro Climatic Data Network
HMSS	Harmonic Mean Sample Size
IPCC	The Intergovernmental Panel on Climate Change
LCL	Lower Critical Limit
N_2O	Nitrogen oxides
NASA	National aeronautics and Space Administration
NEQS	National Environmental Quality Standards
NOAA	and National Oceanic and Atmospheric Administration
NSIP	National Stream flow Information Program
NWFP	North West Frontier Province
O_3	Ozone
PMD	Pakistan Meteorological Department
SPSS	Special Package for Social Sciences
SRES	Special Report on Emission Scenarios
UCL	Upper Critical Limit
UIB	Upper Indus Basin
UNFCCC	United Nations Framework Convention on Climate Change
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USGS	United States Geological Survey
WAPDA	Water and Power Development Authority
WHO	World Health Organization

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ABSTRACT

The issue of climate change has emerged very strongly during the last two decades on global scale in view of its projected implications on the environment of vulnerable states. Steadily rising temperature and its impacts on the cryosphere, rainfall and river flows are evident in many regions around the world. Changes in rainfall directly affect hydrology, water resources, agriculture, ecosystems, healthcare and disaster management sectors. Seen in the context of Pakistan, a country with very large population, agriculture based economy and high vulnerability index to natural disasters, it was important to ascertain climate variability and determine trends of temperature, rainfall and river flows on spatial and temporal basis. The study was conducted across the country to assess variations in mean minimum and maximum temperatures and rainfall in different climate zones of Pakistan. For this purpose datasets comprising 30 years of weather parameters from 1976 to 2005 were acquired from 30 meteorological observatories from different parts of the country based on the Kööpen classification system. In order to study the impact of change in temperature and rainfall on river flows, discharge record for the past 25 years of six relevant rivers was examined.

The results of temperature analysis have indicated that the climatic zone located in high mountains in north, northwest and west have not been affected much as compared to the plain and coastal areas where a positive trend has been recognized. An increase of about 0.11°C/decade in mean temperature including 0.1°C/decade in minimum temperature and 0.12°C/decade in maximum temperature has been determined for Pakistan as a whole. On the one hand rainfall data has revealed an overall decline of -1.18mm/decade but on the other hand river discharges have increased in Indus and Swat rivers.

Use of statistical models for forecasting future trends indicate an overall increase in the mean minimum & maximum temperature of the country till 2030 while rainfall shows a declining trend. Although the average increase of 0.11°C/decade is less than the global mean, the potential implications are far reaching. It is concluded that climate change phenomenon may be given key consideration in planning, designing, and implementing developmental schemes, food security, and disaster risk management sectors to adapt and mitigate undesirable scenarios.

Chapter # 1

INTRODUCTION

The earth's climate has warmed and cooled for millions of years, long before we appeared on the scene and can be observed from air surface and ocean temperatures (IPCC, 2007). There is no doubt that the climate is growing warmer currently; indications of that change are all around us. Rising of sea levels around the world, frequent and uneven precipitation distribution, flash flooding, prolonged droughts, glacial melting (Alam, 2009), tropical cyclones, hurricanes, severe dust storms, dry and cold spells etc. All these adverse consequences are the direct or indirect results of changing climate and have altered water availability and quality, impact on plantation and land use pattern and many others environmental impacts as shown in the figure 1.1.

Climate is the pattern of weather parameters averaged over a long term (Mishers, 2004). It means that climate change refers to long term fluctuations in maximum and minimum temperature, precipitation in its various forms, surface wind, humidity, cloud type and amount, solar radiation and other elements in earth's climate system. Natural processes such as variation in solar irradiance, change in earth's axial tilt, changes in the ocean circulation and volcanic activity are some of the natural causes responsible for that (Kondratyev, 1998; Rodo, 2003). Changes in cloud cover, precipitation, soil moisture, and atmospheric circulation are the main factors responsible for much of the rising trend differential in all over the globe and cause frequent heat waves, droughts, extreme precipitation events and related impacts such as wildfires, heat stress, vegetation changes and sea-level rise (Dai et al., 1999; Przybylak, 2000; Braganza et al., 2004). The climate system can also be influenced by changes in the concentrations of various gases in the atmosphere, which affect the earth balance of radiation. These gases are called green house gases (GHG), including carbon dioxide (CO_2), methane (CH_4), ozone (O_3), nitrogen oxides (N_2O) etc. The observed increase in temperature is mainly due to combustion of fossil fuels (oil, natural gas, and petrol) for industry and transport, rapid industrialization, fast growing population, deforestation for agriculture, unplanned urbanization and infrastructure developments.

Figure1.1. Climate change due to natural processes and anthropogenic actions and its environmental effects

Natural climate variability

- Variation in solar irradiance
- Change in earth's axial tilt
- Volcanic activity
- Ocean circulation

Anthropogenically induced climate variability

- Up growing Population
- Rapid Industrialization
- Increase use of fossil fuel for Transport and Industry
- Deforestation for Agriculture
- Unplanned Urbanization
- Increase number of Energy Resources

Climate Change and its Environmental

- Global warming
- Sea level rise
- Frequent and uneven precipitation pattern
- Melting of glaciers and sea ice
- Increase in frequency and intensity of Extreme weather events like:
  - Frequent flooding
  - Prolonged droughts
  - Soil erosion and land sliding
- Shortage in freshwater availability
- Altered water quantity and quality
- Contaminations in soil and water bodies
- Threats to natural ecosystem
- Shifting of plants and animals on elevation
- Decrease in crop yields
- Shifts in the growing season
- Loss of biodiversity
- Increase health risks (infections, malnutrition, mental condition)
- Settlement patterns

In IPCC (2001) report it is mentioned that due to the human activities, the earth's green house effect has been intensifying since the later part of the 20^{th} century and global climate will remain warmer in the next decades of the 21^{st} century (Karl et al., 2006; Trenberth et al, 2007). The increased use of fossil fuels has raised the level of CO_2 in the atmosphere, and the destruction of natural vegetation has prevented the environment from restoring the balance. Level of other GHG including CH_4, NO_2 and O_3 has also been arising and the net result has been a gradual global warming (IPCC, 2001). Karl and Trenberth (1999) in their paper described that human induced actions are the dominant factor in recent global warming and if climate mitigation measures are not adopted at the right time, the situations will be worse in near future. For this purpose, the international response to mitigate climate change has been organized under United Nations Framework Convention on Climate Change (UN/FCCC), and in 1997 the first protocol with quantitative GHG emission reduction targets was signed (UN/FCCC, 1998). The Intergovernmental Panel on Climate Change (IPCC) scientifically studied and assessed all aspects of global climate system and its interaction with atmosphere, land surfaces, oceans, glaciers, sea ice and ecosystem. Findings of these IPCC assessments have been arranged in authoritative reports in 1990, 1995, 2001 and 2007, and these reports are the primary source of the scientific information.

IPCC in its 1^{st} report mentioned that emission of GHG are increasing and not remaining stable due to increased energy consumption as a result of population growth and industrialization especially in the developing countries. Further significant increases in GHG levels are expected, particularly as developing countries become more industrialized. Based on present warming trends, World Energy Outlook (2010), predicts a 53% increase in global energy demand by 2030, with 70% of that coming from developing countries. Fossil fuels are considered to be responsible for this increase, and the subsequent result will be to rise the temperature. Recent researches find that these temperature trends are actually much higher than previously thought. From the period of pre-industrial to the present, the concentration of GHG in the atmosphere is 280-430 ppm and increasing by approximately 2.5 ppm per year. It is estimated that, if the world’s GHG emissions remain at a level of 550 ppm at a minimum, then there is a 63% chance of exceeding the dangerous limit of 2^oC temperature increase till 2100 (The Stern Review on the Economics of Climate Change, British report, and 2006).

The studies of Mann and Jones (2003) have shown that the mean surface temperature over the past two millennia detecting that late 20th century warmth is unprecedented and attributed to the anthropogenic forcing of climate (Thorne et al., 2003). Since in the late 19th century, average global surface temperature has been recorded with an increase of approximately 0.6°C, with 95% confidence intervals of 0.4 and 0.8°C and future change is expected in the order of 1.4 °C – 5.8 °C over the 21st century (Folland et al., 2000). This increase has been noted in two periods, from 1910-1945 and 1976 to the present (Jones et al., 2001). The warming rate from 1976, (0.17°C/decade), has been slightly larger than the rate of warming during the 1910-1945 (IPCC, 2007). However, changes in climate are already being observed—the last 60 years were the warmest in the last 1000 years (Wassmann and Dobermann, 2007). The most recent warming period is faster over land as compared to the oceans warming (Christy et al., 2000).

In addition, the 1990 was the warmest decade (Palutikof, 2001) and 2005 was the warmest year followed by, 2010, 2007 2003, 2002, 1998, 1997 (IPCC 2007), since the start of the global mean temperature record is from 1856 (Jones and Moberg, 2003).The data of the global temperature from December 2004 through November 2005 show that 2005 has been recorded as the hottest year in comparison with 1998. The year 2005 show a clear global warming trend of the last several decades by equaling the record warmth of 1998 without the occurrence of El Nino, which in 1998 added extra heat from the ocean to the earth's surface (Hansen et al., 2006; WMO, 2005). Similarly, recent researches from Global Climatologically Record from Climate Data Centre and National Oceanic and Atmospheric Administration (NOAA) and NASA showed that 2010 equal to 2005 as the earth warmest year on record over the lat 131 years (instrumented monitoring stations date back to 1880). According to NOAA the since 1876 show an increase in mean November and December temperatures by 2^oC and 1.5^oC respectively and in October rainfall. Mean humidity in December has also been increasing since 1950.

Similarly, observations from all over the globe detect that an increase in global temperature is considerably, causing seawater to expand and sea level to rise. Rising of sea levels can be observed during the 20th century around the northern and southern Pacific Oceans, Indian Ocean and Caribbean Sea but the rise would not be geographically uniform like warming of the land surface (Cruz et al., 2007; Un-Ohrlls, 2009). In 1961 and 2003 global sea level rose at an average rate of 1.8 mm per year but the rate was more fast at about 3.1 mm per year over the period of 1993 to 2003 (IPCC, 2007, and WMO, 2010). World Health Organization (WHO) (2000) mentioned in its report that about 13 million to 94 million people living near the coast are at increase risks of flooding if sea level rise up to 40 cm. The sea-level rise could cause flash flooding, increase the salinity of water, effect low lying areas like drown wetlands and coastal marshes and erode beaches. Coastal areas of China, India, Bangladesh, Africa and the small island are especially susceptible to increasing salinity of their water resources (UNEP, 2007).

Furthermore, Arctic summer ice is also melting at an alarming rate than ever before due to the global warming as mentioned in several studies. A study conducted by Stroeve et al (2007) found that four out of the five lowest years of sea ice coverage have occurred since 2002. Another similar work on the decline of Arctic summer sea ice melt is done by Overpeck et al (2005). They conclude that the Arctic could be completely free of summer sea ice well before the end of this century or within 1000 years. Records of past ice-sheet melting indicate that the rate of future melting and the related sea-level rise could be faster than last century. This recent study found by Otto-Bliesner et al (2006) that during the last interglacial period approximately 130,000 to 127,000 years ago, sea level ranged from 4 meters to more than 6 meters higher than today. Climate models project that the high northern latitudes will remain warmer than they were during the last interglacial period. Temperatures in the late 21st century would be warm enough to melt at least large portions of Greenland and West Antarctica. Millions of people would be vulnerable to flooding and displacement from the resulting sea level rise, and the economic loss associated with coastal inundation. But it's not just the ice system that is changing. Changes in the permafrost or the permanently frozen ground also reflect a warming trend in the Arctic. Recent study of the National Center for Atmospheric Research's Community Climate System Model (2006) projects that under GHG scenarios; there will be up to 80 % decline in permafrost at the end of the 21st century. If permafrost melting occurs at a greater scale, it might be result in the rapid release of CH_4 gas, a potent global warming pollutant.

Additionally, melting or advancing of glaciers would also affect the land use patterns around the glacier. For instance, agriculture lands or herding near the glaciers, alter the habitat of animals and plants that have become adapted to surviving closer to the glacier (FAO, 2004). Iqbal (2008) from Pakistan reports that large scale melting of mountain glaciers and polar ice caps have been occurred with fastest rate, particularly in the Arctic region. Melting ice and thermal expansion of oceans are the key factors for sea level rise. In addition, rising sea levels will also lead to salt water contamination of groundwater supplies, threatening the quality and quantity of freshwater supply. Since 1990, the IPCC has documented such changes as an evidence of global warming.

Meanwhile, work carried out in Kalimanjaro by Kaser, (2004) concludes that increased air temperature leads to govern the glacial melting in a direct manner. The effect of global warming on the mountainous areas is most visible from the shrinkage of glaciers and reduction in reduced snow cover duration (Barry, 2002). There is some disagreement among the scientists that all glaciers of Himalaya-Karakorum-Hindukush region are retreating. According to the World Glacier Monitoring Service (2002), most of the world's mountain glaciers have been shrinking for the last 30 years, including the greater Himalayan as well (Hasnain, 1999; Mastny 2000; Sherestha, 2004).

According to US global change research, the warmer temperatures are likely to increase evaporation from land surfaces and causing severe rain event. While increasing severe rain events are responsible to the increase surface runoff. Increases in precipitation, of 5-1% per decade in the mid/high latitudes of the Northern Hemisphere, have also been observed since the 20th century (IPCC, 2001). Analysis of heavy rainfall events indicates a probability of over 90% that a 2-4 % increase in frequency has occurred during the past 50 years in the Northern Hemisphere (IPCC, 2001). Similarly, climatologists analyzed temporal and spatial variability in extreme precipitation events like both floods and droughts have increased. In Southern Africa, Latin America, the Mediterranean, and some parts of Southern Asia, temperature rise may also induce a prolonged drought which along with others anthropogenic factors causing deforestation, weathering and soil erosion etc (UNEP, 2007). More intense and longer droughts have been observed since the 1970s, particularly in tropical and subtropical (IPCC, 2001). One effect of the rising temperatures that are expected over the next century is that the atmosphere's capacity to hold moisture will go up. For every 1º C increase in temperature, the water-holding capacity of the atmosphere rises 7%. Increased moisture in the atmosphere will lead to more intense precipitation events – even when the annual total amount of precipitation is slightly reduced. Changes in precipitation patterns are already observable. Over the past century, Eastern North America has gotten wetter, while southern Africa and the Mediterranean have become drier. In the 21st century, the Northeastern U.S. is expected to receive more precipitation, while the Southwest is expected to become even drier (Noah, 2007). Similarly, unpredictable rainfall has been noted in Northern Europe, some parts of North, South and Central Asia. Cruz et al (2007) in his studies revealed that most of the regions of Asia like Eastern and the Southern parts will receive summer as well as intense winter precipitation with a greater probability in the intense precipitation frequency. In the northern Indian Ocean annual rainfall is likely to increase in winter season (December, January, and February), and around the Maldives in summer season (June, July, and August), while decreases occur in Mauritius in the same months of summer (Mimura et al., 2007).

Furthermore warmth environment has also influenced the forest resources and alters biomes production and its quality. Firstly, compared with forest and agricultural lands, temperature variation has greater affect on albedo, soil quality and humidity variations (Bonan, 2002). Similarly, short and long term climate change is also leading to change crop management practices and techniques etc.

As a consequence of climate change, warming may also have considerable impacts on plants carbon nitrogen ratio, biomass production, yields, root morphology, shoots morphology, soil nutrients uptake etc. High CO_2 levels in the atmosphere can affect plant responses to different limiting factors including water, light, nutrient availability. For instance, a mild change may result in vegetation stress, rapid plant loss and desertification in certain circumstances (Rashid, 2008).

Studies have shown that in North Asia an increase of 1°C of average temperature could increase the duration of the wild fire season by 30 times (Cruz et a., 2007), which could have various adverse consequences on key forest ecosystem functions including structure and composition of soil, outbreaks of pest, loss of biodiversity, species habitat quality, and prevalence of diseases. Wildfires in the western United States have been recorded increasingly over the past few decades, but the extent of these changes had never been analyzed until recently. Westerling and Bryant (2007) found that there has been recorded a four time increase in the number of western wildfires and 6.5 times as much area burned in 2003 as compared to 1987. But the wildfire of 1987 has also been recorded more than 1970. The length of the wildfire season was observed 78 days. The average burn duration for large wildfire has observed from 7.5 to 37.1 days over the same time period. They concluded that wildfire in United States is primarily due to changes in climate, specifically increased spring and summer temperatures and earlier spring snowmelt.

In non-temperate climates, climatic warming may enhanced the ability of present day forests to withstand these changes. According to Siddiqui (2001) a change of $3^{o}C$ can lead to an elevation shift of forests of about 500 m, and even though species have the ability to adapt warming since the last Ice Age 10,000 years ago, the predicted change ($2.5^{o}C$ for a doubling of CO_2) is very high and will exceed their rate of "migration" to keep up. A rate of change of $0.010^{0}C$ is a threshold value for many species survival (Siddiqui, 2001). Cruz et al (2007) write that in Asia, approximately 50% of the region's total biodiversity is at threat and becoming almost extinct due to change in temperature. He estimated that in China 105 to 1,522 plant species and 5 to 77 vertebrates and about 133 to 2,835 plants and 10 to 213 vertebrates in Indo-Burma would be extinct at the end of the century.

Further, the main concern in the discussion of climate change is crop yield. At mid to high latitudes, crop yields may increase for low levels of change in temperature, but will decline at higher levels of temperature change. Bruce et al (1998) in their studies on impacts of global climate change on agriculture yields describes that these impacts can be categorized into direct and indirect impacts. Direct impacts include increase in temperature which cause shortening or elongation of growing season, change in duration and intensity of precipitation, water and soil quality and extreme weather events while indirect impacts are sea level rise, rate of soil erosion, and ultra violet radiations. Seshu and Cady (1984) have estimated a yield decrease of 0.71 t/ha with an increase in temperature from (18^{o}C) to (19^{o}C), a decrease of 0.41 t/ha with an increase of temperature from 22^{o}C to 23^{o}C and 0.04t/ha from 27^{o}C to 28^{o}C. There are several reasons for this variation in response to a 1^{o}C changes in temperature at different temperature regimes. Among these are the effect of temperature on different stages of plant growth particularly, sudden sterility of the plant caused by higher temperature (Yoshida, 1981). Beside the adverse effects of climate change, some of them are likely to be beneficial. In middle to high latitudes and at high altitudes there may be an increase in agricultural productivity, depending on crop type, growing season, changes in temperature regimes and the seasonality of precipitation (Parry, 1990; Watson et al., 1997). In these areas, temperature increase can enhance crop growth by allowing earlier planting of crops in the spring, faster maturation and earlier harvesting (Rosenzweig and Hillel, 1995).

Changing climate will also have significant impacts on the availability of water, as well as the quality and quantity of water. Increasing trend in temperature and its association with precipitation can induce stress in hydrological cycle, resulting in dryer dry seasons and wetter rainy seasons, and subsequently enhanced the risks of more extreme flash floods and drought. Melting glaciers will increase flood risk during the rainy season, and reduce the dry-season water supplies to the one-sixth of the World's population (NEF, 2001).

Many of the world's countries are already under struggle for the availability of fresh water supply for drinking, household use, agriculture and industry. Irrigation demand, industrial pollution and water borne sewerage will lead to put the pressure on existing water resources and all these will be significantly intensified by climate change. Due to reduce rainfall and increasing temperatures will further lead to reduce the availability of water supply including smaller flows in springs, rivers and under ground levels.

The quality of existing water supplies will become a further concern in some regions of the globe. Water acquires most of its geochemical and biochemical substance during its cycle from clouds to rivers, through the biosphere, soils and geological layers. Changes in the amounts or patterns of precipitation will change the route/ residence time of water in the watershed, thereby affecting its quality. As a result, regardless of quantity, water could become unsuitable as a resource if newly-acquired qualities make it unfit for the required use (IPCC, 2007). For example, in areas with relatively high water tables, or under intensive irrigation, increased evaporation due to higher temperatures will raise the concentration of dissolved salts. Further, increased flooding could raise water tables to the point where agrochemicals/ industrial wastes from soil leach into the groundwater supply. Likewise, higher ocean levels will lead to salt water intrusion in coastal groundwater supplies, threatening the quality and quantity of freshwater access to large percentages of populations.

The largest impacts of global warming mainly come from the incidence of the extreme weather events, such as heavy rainfall, severe storms, heat waves and droughts. In most parts of the Europe and US, extreme cold waves and record snowfalls were observed during winter season of 2009/2010 in Europe. In 2008 severe prolonged drought hit the several states of the South Africa such as Argentina, Uruguay, Paraguay and southern Brazil causing severe damage to agriculture, livestock and water resources. For most parts of the South Africa it was observed as one of the driest years on record. Heavy rainfall in 2010 in China contributed to floods and landslides along with devastating mud/rockslide in the northwest of the country. Similarly extreme precipitation events in West Africa have been observed in 2010 year, with the worst flooding in 50 years (WMO, 2010). But by their very nature, extreme events are hard to study and predict precisely because they are relatively rare and can be influenced by local factors, such as terrain and snow pack. Unfortunately, the increase in heavy rains would not necessarily make more water available for hydropower or irrigation because natural and engineered reservoirs are greatly affected by severe storms. Moreover, both the Northwest and the Gulf Coast would also see an increase in the number of dry days (Diffenbaugh et al, 2005). It is estimated in the Special Report on Emission Scenarios (SRES, 2000), 120 million to 1.2 billion will experience increased water stress by 2020s and by the 2050s the number will range from 185 to 981 million people. New evidence on recent trends, particularly, on the increasing tendency in the intensity and frequency of extreme weather events are more evident in Asia in the 21st century. For instance, a decline in summer precipitation was observed over the central parts of the arid and semi-arid Asia and leading to the expansion of deserts and periodic severe water stress conditions. Increased rainfall intensity, particularly, during the summer monsoon, could increase flood prone areas in temperate and tropical Asia. In South-East Asia, extreme weather events associated with El-Nino were reported to be more frequent and intense in the past 20 years.

Significantly longer heat wave duration has been observed in many countries of Asia, as indicated by pronounced warming trends and several cases of severe heat waves (Mukhopadhyay, 1998; Kawahara and Yamazaki, 1999; Zhai et al., 1999; Lal, 2003; Zhai and Pan, 2003; Ryoo et al., 2004; Batima et al., 2005a; Cruz et al., 2006; Tran et al., 2005). Generally, the frequency of occurrence of more intense rainfall events in many parts of Asia has increased, causing severe floods, landslides, and debris and mud flows, while the number of rainy days and total annual amount of precipitation has decreased (Zhai et al., 1999; Khan et al., 2000; Shrestha et al., 2000; Izrael and Anokhin, 2001; Mirza, 2002; Kajiwara et al., 2003; Lal, 2003; Min et al., 2003; Ruosteenoja et al., 2003; Zhai and Pan, 2003; Gruza and Rankova, 2004; Zhai, 2004). However, there are reports that the frequency of extreme rainfall in some countries has shown a decreasing tendency (Manton et al., 2001; Kanai et al., 2004).

Increasing frequency and intensity of droughts in many parts of Asia are attributed mainly due to rise in temperature, particularly during the summer and drier months of the year (Webster et al., 1998; Duong, 2000; PAGASA, 2001; Lal, 2002, 2003; Batima, 2003; Gruza and Rankova, 2004; Natsagdorj et al., 2005). The recent studies conducted by Fan and Li (2005) indicate that the frequency and intensity of tropical cyclones originating from the Pacific Ocean have been increased over the last few decades. While, cyclones originating from the Bay of Bengal and Arabian Sea have been noted to decrease since 1970 but the intensity has increased (Lal, 2001). In both cases, the damage caused by intense cyclones has risen significantly in the affected countries, particularly India, China, Philippines, Japan, Vietnam and Cambodia, Iran, Bangladesh and Tibetan Plateau (PAGASA, 2001; ABI, 2005; GCOS, 2005a, b). About 80% of Bangladesh is prone to floods and every year at least one-third of the country's territory is affected (Hoque 1995). Over the last 30 years South Asia has experienced more than 65,000 deaths and about a billion people have been affected by floods and landslides. This accounts for around 33% of all flood events in Asia. The India and Bangladesh floods of 1998 caused over 2,600 deaths, displaced 25 million people, and caused an estimated US$ 3.4 billion of damage. In 2007, floods in India, Nepal, and Bangladesh caused more than 3,400 deaths, affected 30 million people, and caused an estimated US$ 5 billion in economic damage. The impact of floods can only rise as the population in floodplains grows and the value of infrastructure increases (Mandira et al., 2008).

Occurrence of extreme events like outbreaks of flood, prolonged droughts, decreasing water availability, intense rainfall, tropical cyclones and unexpected cold and heat waves have been considered the widespread of diarrhea and other infectious diseases like cholera, Hepatitis, dengue fever etc, in South Asian countries like India, China and Bangladesh (Hajat et al., 2003; Ebi et al., 2006; Takahashi et al., 2007; Knowlton et al, 2007; Shah, 2008). According to a study by Adams (1997), there are annually about 1200 deaths due to cold and hot weather. The direct and indirect impact of climate change are mainly responsible for the transmission of vector born infectious diseases, alteration of water quality and change in the productivity of agro-ecosystems (Haines et al., 2000).

Further, many researches such as (WMO, 2010; Cavallo and Ilan Noy, 2010; Peduzzi, 2005; Munich, 2002; International Federation of the Red Cross and Red Crescent Societies, 1999; Erbach and Gaudet ,1998) have been conducted on the occurrence and intensities of the extreme weather events. According to those reports, temperature rising and frequent rainfall are the main factors of economic damage in the world. Mozaharul et al (2007) in his report, suggests that increase in the intensities and frequencies of these extreme events will further lead to hunger, susceptibility to diseases, economic losses, human survival and well being of current as well as future generations. According to Munich report (2002) extreme climatic events took heaviest toll on human life and high damage costs, resulting in more than 725,000 lives and economic costs of

US$ 700 billion worldwide during the second half of the 20th century. The same has been mentioned by Mirza, (2003) in his report about the economic damage occurring in the developing countries due to extreme weather events. Around US$ 35 billion are spent annually during the past decade in the developing countries (Mirza, 2003). Many scientists from different parts of the world have consensuses that extreme weather events are due to global warming and it is assumed that occurrence and intensities of extreme events will increase with the increase in the global temperature as in IPCC report (Shah, 2008). The dramatic increase in extreme events is likely to have significant economic consequences on the order of hundreds of billions of dollars annually, as estimated by Ackerman et al, (2008).

Like other countries in the world, recently, abnormal weather behavior caused extreme events in Pakistan about 40% of the people of Pakistan are highly prone to frequent multiple disasters with variations in rainfall patterns, storms, floods and drought (Hussain et al, 2010, Oxfam Report on Climate Change, 2011). According to data published by Pakistan Meteorological Department:

- ✓ In 1992, worst flood in Jhelum River.
- ✓ In 1998 to 2001 severe droughts occurred in the southern and central parts of the country.
- ✓ Severe cyclonic storm in 1999, hit the coastal areas of Pakistan and India.
- ✓ At least one million people were affected by seasonal monsoon rains in southern Pakistan in 2003. Heavy rains caused 162 deaths in the Sindh province.
- ✓ Heavy rains in the south and snow in the north as well as Kashmir region triggered flooding and avalanches, killing at least 486 people during second week of February 2005.
- ✓ Heavy rainfall of 1300mm, far above than normal figure of 900mm recorded in Balakot in the monsoon of 2006.
- ✓ Similarly temperature up to 43^{o}C has been recorded for more than a week in Chitral and other cities of northern areas in June 2005. While minimum temperature dropped as low as -12^{o}C in Parachinar, Kalam, Malamjaba and Dir for consecutive ten days in the 1st week of Jan 2007 whereas their normal is -1^{o}C to -2^{o}C.

- ✓ Country has faced super flood in 29th July 2010, after heavy monsoon rainfall hit the Khyber Pakhtunkhwa, Sindh, Punjab and many parts of Balochistan in over eighty years. In this worst flood, an estimated 2000 people were dead and has damaged or destroyed over 700,000 homes (Encyclopedia, 2011). In Sindh Province approximately 26 million people got infected from this super killing flood. The Pakistan Meteorological Department reported that over 200 mm of rain fell over a 24-hour period in Khyber Pakhtunkhwa and Punjab. A record-breaking 274 mm rain fell in Peshawar during 24 hours; the previous record was 187 mm of rain in April 2009.
- ✓ Sever dust storm phenomenon occurred frequently causing more than 100Km/h wind speed in many cities of Pakistan during recent decades.
- ✓ Current temperature of January 2012 is recorded -13/-15 ^{o}C

1.1. Climate of Pakistan

Climatically, Pakistan's climate is varied because of the difference in elevation from one end of the country to another. Pakistan is situated in the extreme northwestern part of the Indian subcontinent, between latitude 24^{o}N to 37^{o}N and longitude of 61^{o}E and 75^{o}E. The plains of Pakistan, drained by the river Indus and its tributaries, are surrounded by many mountain ranges in the north, northwest and the west (Rodo, 2003). The country has Arabian Sea in the south bordering India in the east and Iran in the south east, Afghanistan on the north-west and china in the north. High mountains ranges comprise Himalaya and Karakorum ranges with a small part of the Hindukush range are present in the north of the country. Pakistan is the only place where these three great mountain ranges meet. Besides the northern mountains, there are western highlands separated by Kabul river from the mountainous north and consist of series of dry and lower hills. Some parts of Balochistan and Sindh provinces constitute deserts (Hussain et al., 2005). The country occupies a total geographical area of 803943 km^2 (Pant and Rupa Kumar, 1997).

Climate variability in Pakistan is due to its unique geography and geology. During the summer months from April to September the mountainous north is pleasant and temperate, but the Indus Valley swelters in temperatures of 40ºC or more. In late summer the southern region experiences monsoons, particularly along the coast. In winter the low-lying areas cool down appreciably to average temperatures of between 10ºC to 25ºC, while the northern mountains ice up with the air well below freezing (Rodo, 2003). The dominant component of the climate variations was spatial shifts in the rainfall patterns, associated with fluctuations in the general circulation of the atmosphere in the Indian sub- continent (Rodo, 2003), like the monsoon winds that bring rainfall in summer. The Western Depression originating from the Mediterranean region and entering Pakistan from the west that brings rainfall in winter. These mid-latitudinal cyclones make a long land journey and are thus robbed most of the moisture laden air by the time they reach Pakistan. Other climate controlling factors are the sub-tropical location of the country that keeps the temperature high particularly in summer and the oceanic influence of the Arabian Sea that keeps down the temperature at the coast. In the west and north higher altitudes keep the temperature down throughout the year. During the summer in the south, a temperature inversion layer is created which does not allow the moisture-laden air to rise and condensation to take place.

The precipitation received by the country can be divided into two main seasons, winter and monsoon precipitation. The monsoon rainfall enter into Pakistan from east and north east during the month of July to September. During this duration a good amount of rainfall is received in the north and north eastern catchments areas of the country. Winter precipitation (December to March) are mainly received from western disturbances entering from Iran and Afghanistan. The weather systems entering from Afghanistan are called the primary western disturbances and cover only the north and north western parts of the country, whereas those approaching from the Iran are secondary and cover a large area of the country including Balochistan, Punjab, KPK, Kashmir and northern areas and sometimes Sindh province (Kazi et al, 1951; FAO, 1987; Khan, 1993 and 2002; Kureshy, 1998; Luo and Lin, 1999). A large amount of snowfall is received in the northern areas, upper KPK, Kashmir and northern Balochistan and is the main source of water supply for water reservoirs of the country in dry season. This water received from the snow melt, and from the seasonal rains plays an important role in the agricultural and socioeconomic activities of the country. The agricultural of Pakistan is mainly climate dependant and every area has its own crops and fruits according to its climate. The country’s most important crops and fruits are grown in winter season in different areas according to its climate conditions. If there is any abnormality in the usual climate condition the nation suffers it for the whole year and there is also a huge loss to the economy (Shah, 2008).

However, due to the heterogeneity in the topography and climatic conditions in Pakistan, the rise in the surface temperature, rainfall and others climate parameters will not be same in all its regions. In terms of meteorological variable, atmospheric temperature is observed in every synoptic hour but daily maximum temperature, minimum temperature, mean temperature its impact on rainfall and discharge of the ensuing rivers play an important role in assessing the climate and hydrology of a certain area. Therefore, these variables are considered the main indicators for the determination of trends in climatic variables. Determination of recent trends over the last three decades, after comparing with the global temperature trends, indicate that the consequences of climate change have already occurred in Pakistan.

Although Pakistan has a reasonably good network of observatories, but there are very few studies on the climate variability. Rasul and Chaudhry (2006) conducted research on global warming and expected snowline shift along northern mountains of Pakistan. They found that rising trend in temperature is not due to natural processes but mainly because of excessive anthropogenic activities. Growing population and accelerated deforestation which they believed to be the main cause of atmospheric heating among others. Snow and ice extent is shrinking must faster than ever now, as a whole, on the Himalayan, Karakorum and Hidukash ranges. Similarly Chaudhry and Rasual (2007) in their study describe the frequency and intensity of extreme precipitation events along the foothills of southern slop of Himalayan region. They found that due to these extreme events, number of landslides and lightening increasing and cause many causalities and damage to existing infrastructure.

Another attempt has been made by Bhutiyani et al (2007). Their results showed that the northwest Himalayan region has warmed significantly during the last century at a rate which is higher than the global average. The rise in temperature in the northwest Himalayan has been primarily due to rapid increase in both maximum as well as minimum temperatures. But maximum temperature increasing more rapidly than minimum temperature. Recently, Shah (2008) attempted to construct an all Pakistan minimum temperature trend, by taking 30 stations, including the hilly regions of the country parallel to Himalayan, Hindukash and Koh-e-Suleiman ranges. He obtained a value of 0.4 ^{o}C for all Pakistan mean minimum temperature in winter season for two periods i.e. 1976-1990 to 1991-2005 and found per decade increase 0.133 ^{o}C. Therefore the present study was conducted to achieve the following objectives

1.2. Objectives

- To determine the change and variability in minimum and maximum temperatures and rainfall of the study area.
- To evaluate their effects on water discharge in the ensuing rivers.
- To compare the results of the study area with the global trends.
- To determine the future trends of the said variability and change.

1.3. Justification

Now- a-days climate change has become an important additional stress on ecosystem like other environmental problems such as population growth, increasing resource demands, unsustainable development and pollution. All these problems in many cases may be greater or equal than those of climate change. The impacts of climate change or GHG on environment are multiple and most significant. Firstly, compared with forest and agricultural lands, climate has greater affect on albedo, soil quality and humidity variations (Bonan, 2002). Similarly, short and long term climate change is also leading to change air humidity, cloud density, precipitation intensity and duration, water quality and crop management practices and techniques etc. Study of climate change involves changes in trends of minimum and maximum temperatures, precipitation rate and water discharge in the rivers, comparing them to global or regional causes. According to my knowledge, no published data and research is available on climate change in Pakistan. Research on climate change and variability trends will give us a valuable insight into how, when and why the study area's climate has changed in the past, how it is currently changing and what will be in the future. Interpreting the past and present data and its possible predicting models for future climate change and its effects on the environment.

Chapter # 2

LITERATURE REVIEW

The rising trend in temperatures, associated with the changes in precipitation pattern, enhance the hydrological cycle because as much of the heat at the land surface is evaporated. Temperature change is one of the major factor, affecting precipitation distribution, may be in the form of snow, glacier melting, and rainfall which are considered the major contributors to the ground water source. Many studies have been reported on the effects of climatic change and variability in a variety of disciplines. Most of these studies have focused on the increased temperature trends and its impact on precipitation pattern during the 20^{th} century. This increase trend in temperature has been evident over a range of precipitation pattern, particularly in the form of heavy and extreme hydrological events like floods in most parts of the world (Karl and Knight, 1998; Groisman et al, 2004). Increase intensities in precipitation distribution, and prolonged droughts are likely to be the most important issues in determining the impacts of climate change (Allen and Ingram 2002). Reviews of relevant researches including detection of temperature trend, rainfall trend and river discharge ratio are as follows:

2.1. Studies related to the determination of Temperature trend

- Rupa, Kumar and Pant (1994, 1997) found 0.4°C/100 years statistically significant increase in the surface temperature data of India. According to their research, the increasing tendency of mean temperature is mainly due to the increasing trend in maximum temperature, as the minimum temperature trend is found less during the current century. However, it has also been reported that there do exist some smaller sub-regions with statistically significant increasing and decreasing trends.
- Easterling et al (1997) conducted research on monthly and daily dataset of 5400 meteorological stations all around the world by obtaining the data from respective national metrological center. They found an increase of 0.5^{o}C in the mean temperatures 0.050 ^{o}C in maximum temperature and 0.018° ^{o}C in minimum temperature respectively for the globe during the last century. They found in their

research increase in the minimum temperature at a rate faster than the maximum temperature.

- From Turkey, the study of Mikdat (1997) indicates an increase of $1.1^{o}C$ during the analysis period of 1939-1989. The study of the temperature trend is carried out from 18 stations from all over the Turkey. Statistically no significant trend is indicated because of downward trend from 1955-1989. Mostly increasing trend occurred in the spring and winter minimum rather than the maximum temperature
- Shrestha et al (1999) analyzed the temperature data of Nepal during the period 1977-1994. From the study they found 0.06 ºC increase in the mean temperature per year, mostly in high altitude regions such as Middle Mountain and the High Himalaya. Significantly downward trends were observed in Terai and Siwalik regions. Further winter was found warm as compared to other seasons.
- In another study Shrestha et al (2005) found a rising trend of about 0.04 ^{o}C in mean temperature for all over Nepal during the time period of 1975-2005.
- Similarly, Bonsal et al (2001) in his study described that spatial and temporal characteristics of climatic variables can easily be understand and explain by using long period time series of reliable and homogenous set of temperature data.
- Houghton et al (2001), in his study revealed that warming in daily minimum temperature is stronger than that for maximum temperatures. On the basis of these identifiable changes, they conclude that there would also be changes in extreme temperature events in the recent future, such as the frequency of days with extremely low or extremely high temperatures. Their studies have revealed that there is a significant decrease in days with extremely low daily temperatures but no significant decease has been observed in days with extremely high temperatures.
- Yan et al, (2002), investigate a comprehensive change in extreme temperature over Europe and China. A decrease in the cold extremes and a warming trend in the minimum temperature over the china during the last few decades were observed by them.
- In the context of temperature variability, Ahemad et al (2003) found a rise $0.5^{o}C$ to $1^{o}C$ has been observed in the northern arid and western dry mountains and

coastal areas of Pakistan. Both minimum and maximum temperatures have been dropped in the north western mountains while an increased has been noted in the western parts of the country.

- Zhai and Pan (2003) computed data of daily surface air temperature data for about 200 stations during 1951–1999 in China. Studies were carried out on the basis of trends assessment and changes in frequencies of some extreme temperature events. For China as a whole, maximum temperature over 35^{o}C were considered hot days found with decreasing trends and minimum temperature below 0^{o}C were considered frost days recorded with significant upward trends. Meanwhile, rising trends were observed in the frequencies of warm days and warm nights and declining trends were found in the frequencies of cool days and cool nights in China.
- In the study conducted by Russel et al (2004) found an increase of 0.296 °C per decade in mean temperature for the globe and 0.287°C and 0.296°C per decade for maximum and minimum temperatures respectively during the time period from 1950-2004. For their study they selected from all over the globe approximately 4280 stations for maximum temperature, 4284 for minimum, and 4157 for DTR stations
- Similarly Farooq and Khan (2004) analysis of past climatic data depicts that there is found temporal as well as spatial change in the rate of temperature variation. This change will result a greater impact on all aspects of life.
- Sheikh et al (2005) in his final report submitted to Asia Pacific Network (APN) for Global Change research found an increasing trend in the annual mean minimum temperature in monsoonal dominated areas of the Pakistan.
- According to Kumar et al (2003) and Yadav et al (2004) western Himalayan region is showing a different response to global warming they experienced in their data that there is an increase in diurnal temperature change (DTR) a cooling of mean temperature in some seasons, possibly result of local forcing factors.
- Nadia and Islam (2006), found in their study for Pakistan that trend in temperature indices reflects an increase in both maximum and minimum temperature. There is significant change in minimum temperature than maximum temperature.

Percentile shows that the daily minimum temperature will become warmer as compared to the increase of daily maximum temperature in summer where in winter the change in maximum temperature is high than threshold value.

2.2. Studies related to the determination of Rainfall trend

- Chaudhary (1994) attempted to construct an all- Pakistan summer monsoon rainfall series, by taking the area- weighted average of 38 stations, excluding the hilly regions of the country parallel to the Himalayan mountain range, and covering about 88% of the total area of the country. Chaudhary obtained a value of 13.3 cm for all Pakistan mean summer monsoon rainfall, which accounts for about 58.5% of the annual rainfall, based on the data during 1901-1990.
- Singh and Sontakke (1996) used 34 stations for precipitation and 15 stations for temperature. The earliest records available are from 1856 for precipitation and 1876 for temperature. They computed the monthly percentage departures from the long term mean at the available stations and then average all the available months and stations to obtain the all- Pakistan mean annual rainfall anomaly series for the period 1856-1993. They obtained a low –frequency variability of all Pakistan mean annual rainfall, in terms of 31 year moving averages and decadal means of both mean rainfall and variability.
- Brunetti et al (2001) has aimed to investigate the precipitation pattern (intensity and extreme events) for about seven stations located in the northeastern Italy for the period 1920–1998. In their study they found a negative trend in the number of wet days associated with an increase in the number of heavy rainfall events to total precipitation
- Liu et al (2005) analyzed heavy precipitation events in China over the studied period (1960-2000). They found only 2% increase in the total precipitation and 5 % increase in total extreme precipitation events at 95% confidence interval.
- Similarly Zhai et al (2005) assessed trends in total precipitation and frequency of daily precipitation extremes over china by taking into account the daily precipitation dataset of 740 stations for the period 1951-2000. Their results showed no significant trend in total precipitation for China as a whole, but its intensity and frequency has been noted with significant increased. Meanwhile

annual total precipitation has been found significantly decreased over southern northeast, north China, and over the Sichuan Basin except western and the southeastern coast.

- In India rainfall trend analysis was carried out by Parthasarathy and Rajeevan (2006) to examine the trends in Monthly, seasonal and annual rainfall time series for about 36 meteorological sub-divisions using a large network of about 1476 raingauge stations. Their results showed that rainfall trend is decreasing in June, July and September time series to annual rainfall while contribution of August rainfall is increasing in few subdivisions
- Zhang et al (2007) detected the anthropogenic impact on global precipitation. They showed a latitudinal redistribution of mean global precipitation, indicating increased precipitation at high latitudes while decrease at lower latitudes and found significant impacts on ecosystems, agriculture and human health in regions that are sensitive to changes in precipitation.
- In Pakistan, the IPCC reports (2007) 10–15% decrease in precipitation in the coastal belt and hyper-arid plains. In Northern Pakistan, there has been an increase in summer and winter precipitation over the last 40 year.
- Shahid (2010) analyzed the spatial pattern of annual and seasonal rainfall trends in Bangladesh by selecting 17 stations during the time period 1958-2007. He also assessed the possible change in wet and dry events in Bangladesh by using standardized precipitation index method. His result showed a significant increase in the mean annual and pre-monsoon rainfall and the number of wet months of Bangladesh. While found decreased in the dry months in the most parts of the country.

2.3. Collective studies related to the determination of Temperature, Rainfall and River Discharge trends

- Lettenmaier et al (1994) examine trends in monthly stream flow, as well as temperature and precipitation, for 1948–1988, finding large increases in cold-season stream flow in the Northeast and Midwest of the US over that period.
- Gan (1998) found in their results warming trend in more weather stations than are the drying trends by selecting the 37 weather stations, along with 50 stream flow

basins and 13 sets of evapotranspiration. Their data detected that Canadian Prairies have become warmer and somewhat drier in the last 4–5 decades.

- Arnell (1999a) studied the effect of climate change on water resources for specific geographic regions in Europe. Arnell (1999b) also investigated the changes in water resource stress as a result of predicted climate change and population growth with its socio-economic problems.
- Olsen et al (1999) describe that in the developing countries, variation in climate change and river discharge can cause devastating floods in both urban and rural areas, or droughts that create potentially catastrophic food shortages and frequently serious human health.
- Lins and Slack (1999) focus on streams with multi-decade records that extend through 1993 and find that many streams have shown significantly larger low and medium flows, while high flows do not increase as much.
- Furthermore, Vörösmarty et al (2000) argue that changes in mean climate in the next 25 years will increase the demand for water supply in a greater degree with increasing population and economic development.
- Bart Nijssen et al (2001) stated that global increases in temperatures has directly affect the hydrology of the land surface through changes in the accumulation and melting of snow, as well as in evapotranspiration by plants. Climatic changes are also predicted due to the result of changes in precipitation amounts, intensities and patterns.
- Manton et al (2001) have analyzed the trends in extreme daily temperature and rainfall in Southeast Asia and South Pacific by taking 91 stations from 15 countries including Australia, New Zealand, French Polynesia, New Caledonia, Indonesia, Japan, Malaysia, Myanmar, New Guinea, Fiji, Samoa, Thailand, Vietnam, Philippine and Solomon Islands during the period 1961 to 1998. Significant increases were detected in the annual number of hot days and warm nights, with significant decreases in the annual number of cool days and cold nights. For precipitation pattern, the number of rain days has been found significantly decreased throughout Southeast Asia and the western and central South Pacific, but found increased in the north of French Polynesia, in Fiji, and at

some stations in Australia. Further the total proportion of annual rainfall from extreme events has been found increased at a majority of stations.

- McCabe and Wolock (2002), focusing on the period 1941–1999, find the same pattern of increasing minimum and median annual flow, but point out that the increase took place abruptly around 1970, coincident with an increase in recorded precipitation.
- Kahya and Kalayci (2004) documented the trend analysis of stream flow in Turkey. They selected 31 years period of monthly stream flow for 26 basins all over the country. Basins located in western of the country show significant trend at ($p < 0.05$) whereas eastern basins show no trend. Moreover some basins in the southern Turkey exhibit rising trend.
- Boer and Faqih (2004), conducted research on mean annual temperature and rainfall data from all over Indonesia. They found in their studies an increasing trend of approximately 0.3^{o}C and declining trend in rainfall pattern approximately 2% to 3%.
- Small et al (2006), have analyzed trends in stream flow and total annual precipitation over the drainage of 218 basins across the eastern half of the United States during the period of 1948-1997 using significance level of ($p < 0.05$). They found increasing trend of precipitation in fall season with primarily increase rate of stream flow and no change has been recorded in flow rate of stream and precipitation at the basin scale during the other seasons.
- Archer and Fowler (2006) have analyzed Karakoram and Hindu Kush Mountains of the Upper Indus Basin (UIB) for seasonal and annual trends over the period 1961–2000. Strong contrasts are found between the data of winter and summer temperatures and between maximum and minimum temperatures. In the data analysis winter mean and maximum temperature show significant increases while mean and minimum summer temperatures show downward trend. Decreases of approximately 20% in summer runoff are recorded in the rivers of Hunza and Shyok. This is because of 1°C observed downfall in mean summer temperature since 1961.

- Dash et al (2007) in their study describe that climate change is mainly due to over exploitation of the natural resources such as deforestation, change in land use pattern, shortage of fresh water sources, destruction of the ecosystems, environmental pollutions etc. All these factors cause changes on regional sectors in the short time scale and on the whole global climate in the long run.
- Rose (2007) analyzed a 68 years trend of rainfall and runoff during the period 1938-2005 in a five-state region in the southeastern United States such as Georgia, South Carolina, North Carolina, Virginia, and Maryland. The average annual precipitation for this study area was found 1201 mm and the average runoff was calculated 439 mm. There was observed no significant consistent trend with respect to runoff, rainfall, and time in the study area. Declining trend in the rainfall and runoff were found in the recent decade (1996-2005) than the previous one.
- Krakauer and Fung (2008) analyzed a subset of approximately 1000 United States geological survey stream gauge stations to calculate the annual stream flow per unit area since 1920 on a uniform grid over the coterminous (Being of equal extent or scope or duration) United States. They found no regular increase in stream flow with time scale except the record of late 1960 in which the precipitation trend is recorded higher. In their study both precipitation and stream flow show non significant declining trends in the early 1990, but the overall analysis supports decreasing trend in stream flow and in precipitation amount as result of rising temperature and GHG.
- Luce and Holden (2009) have conducted research on distribution of annual stream flow from 43 Hydro Climatic Data Network (HCDN) gages in the Pacific Northwest of the United States between 1948 and 2006 using techniques of least squares and quantile regression. At 25th percentile annual flow record 72%of the stations showed significant ($p < 0.10$) declines, with half of the stations exceeding a 29% decline and a maximum decline of 47% between 1948 and 2006. Very fewer stations showed statistically significant declines in either median or mean annual flow, and only five had a significant increase change in the 75th percentile results trend from the substantially drier period.

Chapter # 3

RESEARCH METHODOLOGY

3.1. Data Acquisition

The dataset used in this study consisted of daily minimum and maximum temperatures and rainfall records obtained from the Climate Data Processing Centre (CDPC) of Pakistan Meteorological Department (PMD). The dataset spreads over a period of 30 years (1976-2005) covering the whole country i.e. 30 stations from extreme north to south and east to west along with some missing periods. The criterion for selection of these stations is that they cover almost whole of Pakistan. The period of the study has been chosen as long as possible in function of data availability. Also in this study , the data set of those stations has been used which were not changed/ displaced in last 30 years, because some of the meteorological stations were re-established/ relocated and the change of site may give difference in the data value. The basic geographical information is presented by Fig (3.1) and their detail is shown in Table (3.1) in Annexure.

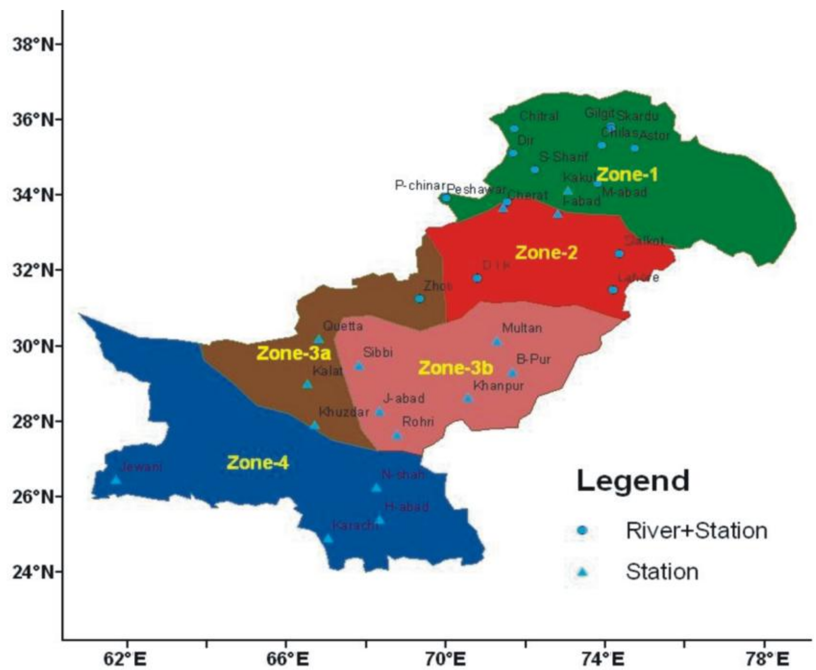


Figure 3.1 Basic information of the selected climatic zones, stations and ensuing rivers along with their longitudes and latitudes.

The climatic variables such as temperature and rainfall is greatly affected by altitude, location in relation to the coast, rivers, desert, mountainous area and other such geographical features. Therefore, for analysis, it is difficult to consider the whole country as one region because different stations have different geography and microclimates. For this purpose the country was divided into five zones, considering their climatic conditions as defined by the survey of Pakistan based on Kööpen classification of microclimate. These zones were named zone 1, 2, 3a, 3b, 4, along with their latitude and longitude and selected meteorological Observety (Fig. 3.1).

3.2. Climate Zones of the Study Area

3.2.1. Zone 1

Zone one comprises those stations having cold climate and high mountains, situated in the north of Pakistan. These stations are Chitral, Gilgit, Muzaffarabad, Said-u-Sharif, Skardu, Astor, Dir, Chilas Parachinar and Kakul. These are mostly hill stations located between 34 N to 38 N in the Himalaya, Hindukash and Koh-e- Sufaid mountain ranges. The Indus tributaries pass in the north are Chitral river, Astor river, Gilgit river, Indus river at Chitral, Swat river, Panjgora river, Shingar and Shayok rivers. Ensuing river at Parachinar is Kurram River and Neelam River at Muzaffarabad station.

3.2.2. Zone 2

This zone has mild cold climate and Sub Mountains, located between 31N to 34 N. The stations are Sialkot, D.I.Khan, Islamabad, Peshawar, Cherat and Lahore. In this zone Kabul River is present at Peshawar station Ravi River at Lahore and Chenab River is near to Sialkot. .

3.2.3. Zone 3a

Climate is cold in winters and hot in summers. Most of them are mountainous stations with high elevations from mean sea level and cover an area between 27N to 32N and 64 E to 70 E. Stations included in this zone are Quetta, Zhob, Kalat and Khuzdar. The river present in this zone is Gomal River.

3.2.4. Zone 3b

This is the hottest and dry zone of the country where highest maximum temperatures are recorded in stations of Sibbi and Jacobabad. The area is almost plain with some area included in Thar Desert. Stations included are Sibbi, Jacobabad, Bahawalpure, Khanpur, Multan and Rohri. No river passes near to these stations.

3.2.5. Zone 4

Zone 4 is a big zone having many stations and coastal cities, near to Arabian Sea. The coastal part comprises only a small part of this region and climate above coastal parts in Balochistan as well as in Sindh province is mostly arid to hyper arid. The selected stations from this zone are Hyderabad, Karachi, Nawabshah and Jewani.

Spatial and temporal changes in temperature trend and rainfall pattern mainly cause changes in the flow rate of river discharge. A change can be occurred abruptly (step change) or gradually (trend) and sometimes may be converted into complex form. Climate change is often recognized as a progressive trend towards rising. Studies of temperature, precipitation change are typically complicated by factors such as missing values, seasonal and other short-term fluctuations or climate variability and by lack of homogeneity of the data e.g. due to changes in instrument and observation techniques and location change of the station. The time series used have been chosen according to the PMD data quality check and in function of the length of the period of records. All time series used are continuous from 1976 to 2005, as the PMD has estimated the missing values.

For the present study, river discharge time series are available for northern areas rivers for six gauge-stations with record length of twenty five years from 1976-2000. The river discharge data is acquired from Water and Power Development Authority (WAPDA) of Pakistan as shown in Table (3.1) along with their longitude and latitude and other basic geographical information.

Table 3.1 Ensuing rivers and their geographical information

River	Station	Basin	Catchment's area (km^2)	Altitude (m)	Latitude	Longitude	Province	Installed
Astor	Doyan	Indus	4040	1550	35° 31'	74° 44′	AJ&K	1974
Chitral	Kelash Chitral	Indus	11396	2810	35° 50′	71° 48′	KPK	
Gilgit	Alam Bridge	Indus	25900	2195	35° 45′	74 ° 37′	AJ&K	1966
Indus/ Chilas	Paratap Bridge	Indus	142709	1100	35° 44′	74° 37′	AJ&K	1962
Indus/ Skardu	Kachura	Indus	112665	2341	35° 27′	75 ° 25′	AJ&K	1970
Swat	Kalam	Kabul	2020	1921	35°30′	72° 35‵	KPK	1961

Source: Pakistan Water and Power Development Authority, 1990

3.3. Limitation of the data

The reliability and consistency in data quality control is justified in the following way:

1. This data set of climate variables covers the period of 1976-2005 for the 30 stations, from all over Pakistan except the dataset of Astor station which has randomly missing seven years data in minimum temperature record. In the study area there are fourteen ensuing rivers but the data set available for river flow consists of six rivers of north areas and covers 25 years record from 1976-2000.
2. The record length of the available data is not sufficient as compare to the other similar studies conducted for the same purpose. But according to World Meteorological Organization the "climate normal is considered for a minimum period of 30 years". However they provided a good basis for assessing variation in climate variables.
3. Due to complex orography and different microclimate conditions of the country, the corresponding data is divided into five zones as defined by Kööpen for classification of different climates.
4. Another reason to divide the country into zones is to find out the homogeneity in the means for the trend analysis for each zone and then for the country.
5. There was no specific change in the position of any selected observing station during the considered time period (1976-2005).
6. The reliability of the real time data mainly depends on the measuring device and the observer. Any change in the data record and equipment up- gradation and failure, such changes are accounted by PMD and WAPDA.
7. Although meteorological and hydrological data is quality controlled by PMD and WAPDA bodies respectively. But for the present study, the quality and consistency of the data is rechecked for missing values, outliers and occurrence of non-realistic extreme values such as 30th February etc.
8. The reliability of the data is also checked through descriptive statistics, significance tests and visualization of the data using SPSS and MS Excel.

3.4. Data Analysis

The first step of the analysis includes the understanding of the climate variables not only for time series of each individual station, but also for the zonal or regional averages. For this purpose, descriptive statistics has been used to determined the deviation of the 30 years mean annul data from the average values. Statistical indicators such as standard deviation, standard error, medians, and skewness were calculated for all five zones and individual stations as well. The Descriptive procedure displays summary statistics for several variables in a single table and calculates standardized values. Statistical procedures involved in this study are:

3.4.1. Mean: It is also known as arithmetic average and has been calculated by using the following formula

$$\bar{x} = \frac{\sum x_i}{n}$$

Where $\bar{X}$ is mean of climate variable, xi is each independent variable and n is the total number of variables or in other words it can be defined as**,** the arithmetic mean $\bar{X}$ is the sum of all observations divided by the number of observations *n*. It is the most widely used measure of central tendency. One problem with using the mean is that it does not reveal the typical outcome. If there is one outcome that is very far from the rest of the data, then the mean will be strongly affected by this outcome. Such an outcome is called outlier.

3.4.2. Outliers: An outlier is an observation whose value is distant from the values of the majority of observations. It is sometimes more technically defined as “a value whose distance from the nearest quartile is greater than 1.5 times the inter-quartile range”. Outliers pull the mean in their direction, and have always been carefully examined.

3.4.3. 5% Trimmed Mean: This mean is used for getting rid of the outliers from the data or remove the 5% extreme values on the top and 5% extreme values on the bottom of the data. Trimmed mean mainly concerns with outliers of the data; however the median is used more often since more people understand it.

3.4.4. Median: An alternative measure is the median. The median is the middle value. If there are even numbers of events, then medians is the average of the two middles. The median is better for describing the typical value. There is an alternative value that also is resistant to outliers. When there are n observations and these are sorted from smaller to larger, and then the median is equal to the value with order number (n+1)/2. The median is equal to the 50th percentile. If the distribution of the data is Normal, then the median is equal to the arithmetic mean. The median is not sensitive to extreme values or outliers, and therefore it may be a better measure of central tendency than the arithmetic mean.

3.4.5. **Standard Deviation**: A measure of how dispersed are the data from the mean value or in other words variability of the population from which the sample was drawn.

$$s = \sqrt{\frac{1}{n-1}\sum\left(x_i - \bar{x}\right)^2}$$

3.4.6. Standard Error: the standard error of the sample mean is calculated by dividing the standard deviation by the square root of the sample size.

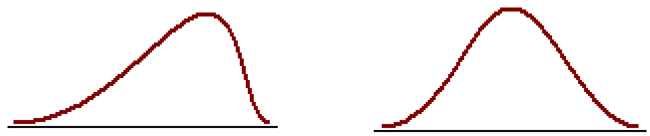
$$\text{S.E.M.} = \frac{s}{\sqrt{n}}$$

Standard error depends on the sample size increase, as the extent of chance variation is reduced.

3.4.7. 95% confidence interval (CI) for the mean: This is a range of values which contains the population mean with a 95% probability or the 95% CI for the mean represents a statistical uncertainty of the arithmetic mean.

3.4.8. Skewness: A measure of the data's symmetry (Kenney and Keeping, 1962) or in simple words the situation of the data in terms of its departure from the mean value. If the data distribution is "Normal" skewness will be equal to zero. A distribution with a significant positive skewness value has a long right tail and mass of the distribution is concentrated on the left of the figure. If the left tail is longer, the mass distribution is concentrated on the right of the figure. This distribution is said to be left skewed. In other words there are one or more extreme large values.

$$Sk = \frac{1}{n}\sum\left(\frac{x_i - \bar{x}}{s}\right)^3$$



Negatively skewed distribution or Skewed to the left Skewness <0

Normal distribution Symmetrical Skewness = 0

Positively skewed distribution or Skewed to the right Skewness > 0

3.4.9. ANOVA test

After the interpretation of descriptive statistics, the reliability and homogeneity of the data is determined by applying the ANOVA test. For analysis work, the entire period 1976-2005 were divided into three decades extending from 1976 to 1985 (1^{st} decade), 1986 to1995 (2^{nd} decade) and 1996 to 2005(3^{rd} decade), and fifteen years of two groups from 1976-1990 and 1991-2005 to recognize the trend of variation of each climatic parameter and their effect on the flow rate of river discharge. The ANOVA test in the means provides linearity tests and association measures to help in the understanding of structure and strength of the relationship between the zones and their means. The ANOVA procedure generates a one-way analysis of variance for a dependent variable by an independent variable. ANOVA is used to test the hypothesis that several means are equal. This test is an extension of the two-sample t test. In addition to determining that differences exist among the means and which means differs from others. For this purpose, there are two types of tests for comparing means. The first one is contrast tests and second one is post hoc tests. Contrasts are tests set up before running the experiment and post hoc tests are run after the experiment has been conducted.

Post hoc tests are designed for situations in which a significant F- test value with a factor that consists of three or more means and additional exploration of the differences among means are obtained. They provide specific information on which means are significantly different from each other. Post hoc tests further contain two types of analysis i.e. a number of tests for assuming equal variances for example Duncan Multiple Range test and second tests involved assuming unequal variances like Dunnett T3 test. Duncan’s Multiple Range test provides different critical difference values for particular comparisons of means depending on how adjacent the means are (Kirk, 1982: Winer et al., 1991). The homogeneity of the data is determined through Levens test, mostly used for the equality of group variances. This test is not dependent on the assumption of normality (Aguilar, 2003). For example, for assessment of trend in the mean of a series:

The null hypothesis = H_0 assumed that there is no change in the mean of a series and

The alternative hypothesis = H_1 assumed that the mean is either increasing or decreasing over time.

It is the probability that a test detects trend when none is present. Thus a 5% significance level would be considered as strong evidence against the null hypothesis. In climatic variables the chance of error or assumption (alternate hypothesis) of differences in group means of two variables would be analyzed by keeping into account the probability value up to 85%. After determining the fact that the data is homogeneous, for the dataset of temperature and river discharge analysis, Duncan test is applied. The main reason for the application of this test is that if in analysis of variance, the null hypothesis is rejected, i.e., at least two of the group means differ significantly, and give no clear results about the means of groups that which group means differ and how many group means differ from each other. For this purpose the Duncan test is designed to answer these questions. Similarly the Dennett T3 also gives the same results but it is most appropriate to use when the variances are unequal. Therefore, for analysis of rainfall data Dunnett t3 is used.

The following procedure is used for the calculation of ANOVA test (Dundas, 2009).

In the first step, for each dependent variable mean is calculated separately for each station, zone and for country, like:

$$\bar{a} = \frac{a_1 + a_2 + a_3 + \ldots + a_n}{n}$$

$$\bar{b} = \frac{b_1 + b_2 + b_3 + \ldots + b_n}{n}$$

$$\bar{c} = \frac{c_1 + c_2 + c_3 + \ldots + c_n}{n}$$

In the second step grand mean is calculated from all of the means of dependent variables:

$$\bar{x} = \frac{\bar{a} + \bar{b} + \bar{c} + \ldots}{m}$$

Third step is carried out by calculating the sample variance for each variable:

$$S^{*2} = \frac{s_a^2 + s_b^2 + s_c^2 + \ldots}{m}$$

Like 3rd step, in the forth step sample variance is calculated for each dependent variable:

$$s_a^2 = \frac{(a_1 - \bar{a})^2 + (a_2 - \bar{a})^2 + \ldots(a_n - \bar{a})^2}{n-1}$$

$$s_b^2 = \frac{(b_1 - \bar{b})^2 + (b_2 - \bar{b})^2 + \ldots(b_n - \bar{b})^2}{n-1}$$

$$s_c^2 = \frac{(c_1 - \bar{c})^2 + (c_2 - \bar{c})^2 + \ldots(c_n - \bar{c})^2}{n-1}$$

Then in next step grand mean is calculated from all of the sample variances:

$$S^2 = \frac{s_a^2 + s_b^2 + s_c^2 + \ldots}{m}$$

In the last step F Statistic is calculated:

$$F = \frac{nS^{*2}}{S^2}$$

SPSS automatically calculates the absolute difference between each observation and the group mean by performing ANOVA test on those differences. It means that ANOVA test gives a measure of the difference between all means for all combinations of means.

In this study, sample size (n) is kept 10 in decadal analysis and 15 in two group analyses. The critical significance level of the test is of at least p= 0.05 with 95% confidence interval. The principle feature of these methods is that to simply filter the mean annual temperature and rainfall records and their influence on the increase/decrease of the river flow rate. In this sense, the use of ANOVA test makes it easy to compare the means of different periods and to assess the significance of the changes for individual station, zone and country.

3.5. Trend Visualization

Furthermore, through visualization process, the climate variability and change is determined with the help of mapping and graphical presentation.

3.5.1. Mapping

As a consequence of data visualization, ArcGIS software is used for ten and fifteen years trend analysis. The main application in ArcGIS is ArcMap, which is used for all mapping and editing tasks as well as for map-based query and analysis. A map is the most common view for users to work with geographic information. It's the primary application in any GIS to work with geographic information. ArcMap represents geographic information as a collection of layers and other elements in a map view. Common map elements include the data frame containing map layers for a given extent plus a scale bar, north arrow, title and a symbol legend.

3.5.2. Graphical Presentations

Graphical presentations have been carried out by plotting the hydrology data into time series and flow duration curve for the entire study period i.e. 19760- 2000. In this study, the four annual seasons were used according to their meteorological definition, whereby summer encompasses the months of June, July and August; fall is September, October and November; winter is December, January and February; and spring is March, April and May. The definitions of the seasons used in this study are according to Nayava (1980) who used this division of seasons for Sri Lanka‘s climate description. The main seasons experienced on the Indian sub-continent are the Southwest Monsoon (June–September), post-monsoon season (October–November), winter (December– February) and the pre-monsoon season (March–May).The basic aim of this analysis is to find out the particular season in which climate is going towards a warmer trend and to detect the period (month) where discharge rate of the river is more than the ordinary level.

3.6. Trend forecasting

In the end of the data interpretation, forecasting procedure is used on 30 years data of minimum, maximum, mean temperatures and rainfall records, to get a trend for future. For river flow record forecasting procedure is not applied because of short data record and minimal number of observing gauge stations. According to the National Stream flow Information Program (NSIP) under the United States Geological Survey (USGS), river discharge records of at least 30 years, and greater than 50 years, are essential for assessing trends because climate naturally varies from year-to-year and decade-to-decade. Such short-term natural variations can falsely indicate a long-term trend.

Expert Modeler in SPSS automatically select the best fit model for the dependent variables along with model fit descriptive statistics table. The table measures the statistics for selected models are stationary R-square (R2), root mean square error (RMSE), mean absolute error (MAE), mean absolute percentage error (MAPE), maximum absolute error (MaxAE), maximum absolute percentage error (MaxAPE), normalized Bayesian information criterion (BIC). Residuals: autocorrelation function, partial autocorrelation function etc.

The application of adequate series of statistical tests on annual minimum, maximum temperatures, rainfall and river discharge data are to investigate the temporal as well as spatial changes in hydro-meteorological parameters, either in the form of a regular trend or in the form of a abrupt change.

Chapter # 4

RESULTS AND DISCUSSION

In order to analyze the data and determine trends in temperature, rainfall changes and their effects on the ensuing river flow, means were computed for the entire period (1976-2005) and by breaking datasets into 10 years and 15 years, for each station and for the country as a whole. The reliability of data and homogeneity of means were statistically tested by applying different statistical tests, using SPSS as mentioned in Chapter 3. Interpretation of each variable i.e., minimum and maximum temperatures, rainfall and river flow was performed separately and compared with global results cited in Chapter 2.

In order to determine trends in temperature and rainfall and their influence on the river discharge rate datasets of all variables were divided into following combinations:

1. **10 Years Trend:** Zonal analysis was carried out on decadal scale i.e. 1st decade (1976-1985), 2nd decade (1986-1995) and 3rd decade (1996-2005) to work out their mean values and statistical significance by ANOVA test.
2. **15 Years Trend:** Single station and whole study area analysis were also performed on two groups of 15-years period i.e. 1976-1990 and 1991-2005. The data was visualized through maps, using Arc GIS software.
3. **30 Years Trend:** Entire Study period was analyzed by plotting the 30 years data into real time series graphs
4. **Hydro-Meteorological Characteristics:** Influence of temperature and rainfall on ensuing rivers has been determined through hydro-meteorological characteristic of river basin analysis. Data presentation has been carried out through graphical presentation into Ms. Excel sheets.
5. **Trend Forecasting:** Entire study period was analyzed into trend forecasting models by using SPSS.

4.1. TEMPERATURE

4.1.1. Introduction

Climate change, as one of the most important global environmental challenges facing humanity, could cause far-reaching environmental effects. The observed increase in temperature has great implications on agriculture, ecosystem, loss of biodiversity, fresh water supply and increased health risks (Alam, 2009). According to Folland et al (1999) climate warming due to anthropogenically induced actions is evident more prominently from minimum temperature as compared to the maximum temperatures in most parts of the worlds. Some researchers have found in their studies that an increase in daily minimum temperatures at a rate nearly twice than that of maximum temperatures since approximately 1950 (IPCC, 2001). Not all regions show greater warming at night, but it is the dominant signal in many regions. Therefore, all these signals call for the urgency of monitoring minimum and maximum temperature records (Jones, 2001). Increase in daytime temperatures much above normal however was not so evident. The magnitude of change in temperature varies from region to region for instance in North America the east coast is projected to warm by 2ºC, while in Alaska and North Canada it is estimated to be 10ºC. In addition, summer temperatures in the American Southwest are found to be significantly rising as compared to North American temperature averages (IPCC, 2001). In most parts of the world there have been differential changes in daily maximum and minimum temperature, resulting in both a narrowing of diurnal temperature range (DTR) and an increase in mean temperature (Karl et al., 1993; Easterling et al., 1997; Jones et al., 1999). Most regions of Europe, US and Australia have shown increase in the daily maximum and decrease in the intra-seasonal daily temperature variability except fewer days with extremely low minimum temperature. No significant increase has been recorded in days with extreme high maximum temperature (Karl et al., 1995; Collins et al., 2000).

4.1.2. Data collection and analysis

As mentioned above data comprising daily minimum and maximum temperatures records from 30 meteorological stations, covering the whole of Pakistan, from 1976 to 2005 has been analyzed for this study. The data were obtained from the Climate Data Processing Centre (CDPC) of Pakistan Meteorological Department. The stations included in this study were selected on the basis of their latitudinal position, elevation from sea level, length of record, completeness and reliability of data so that a synoptic view of the entire country could be obtained. For determination of trends, averages were computed for 10, 15 and 30 year periods for each zone and the whole the country. The reliability of data and homogeneity of means were statistically tested by applying ANOVA. In this sense, the use of different statistical tests makes it easy to compare the means of different periods and to assess the significance of the changes for each zone and country.

4.1.3. Results

4.1.3.1. Descriptive statistics and ANOVA result of Mean Minimum and Maximum Temperatures

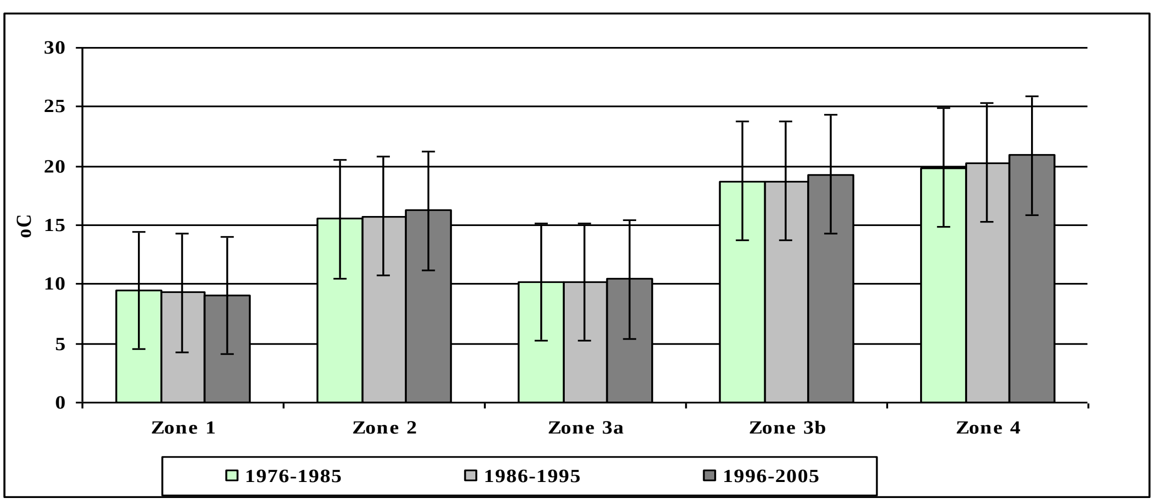
Monthly and annual means of minimum and maximum temperatures, 5% trimmed mean, 95% confidence interval of the mean, medians, standard errors and percentile were carried out by using descriptive statistics for real time data.

Table 4.1 contains the descriptive statistics of minimum and maximum temperatures of different climate zones of Pakistan. The number of valid cases indicate the length of data (30 years from 1976-2005). The results indicate that zone1 shows the lowest value of mean Min and Max temperatures i.e. 9.26 and 22.89^{o}C respectively with median of 8.84^{o}C and 23.31^{o}C. Zone4 in minimum temperature and zone3b in maximum temperature shows the highest value of mean i.e. 20.35 and 33.70 ^{o}C and median (20.86 and 33.65^{o}C). Similarly, the highest value of standard error is observed for zone3a (0.35^{o}C) and lowest value for zone3b (0.09^{o}C). Besides, zone2 (0.32^{o}C) has higher value of standard error in maximum temperature but zone 3b (0.08 ^{o}C) shows lower value of standard error. Percentile at 75th shows larger value for zone4 and zone3b and at 25th percentile show lower value for minimum temperature. For maximum temperature percentile shows higher value for zone3b and lower value for zone1. In the data set of minimum temperature skewness is found negative for zone1, zone2, zone3b and zone4 respectively and only zone3b shows positive value. Similarly for maximum temperature in zone3a and zone3b, the skewness has been recorded with positive sign while for rest of the zones it is negative. The ANOVA results for minimum temperature ($F= 608.601$, $p= 0.00$) and for maximum temperature ($F= 453.944$, $p= 0.00$) are found most significant at p-value (0.05) level within the zones and between the zones. But it is significantly different from each other in the homogenous subset of Alpha at 0.05 in the Duncan test, as shown in the Table (4.1 in Annexure) and Fig. (4.1 A & B).

Table. 4.1 Descriptive statistics and ANOVA results of minimum and maximum temperatures for all climate zones

Minimum temp (F= 608.601, p = 0.00)						
		Zone 1	**Zone 2**	**Zone 3a**	**Zone 3b**	**Zone 4**
Stations		10	6	4	6	4
30 Years	Valid/Missing Values	293/7	180/0	120/0	180/0	120/0
Mean	All value used	9.26	15.83	10.27	18.92	20.35
	5%trimmed mean	9.32	15.84	10.26	18.96	20.37
Median		8.84	15.94	9.66	19.09	20.86
Std. Error		0.20	0.20	0.35	0.09	0.15
95% CI	Lower Bound	8.87	15.54	9.58	18.74	20.05
	Upper Bound	9.66	16.11	10.97	19.11	20.65
Percentile	25	7.07	14.37	7.55	17.93	18.72
	50	8.84	15.94	9.66	19.09	20.86
	75	12.29	17.17	13.69	20.03	21.37
Skewness		-0.12	-0.20	0.02	-0.33	-0.49
Maximum temp (F= 453.944, p = 0.00)						
		Zone 1	**Zone 2**	**Zone 3a**	**Zone 3b**	**Zone 4**
Stations		10	6	4	6	4
30 Years	Valid/Missing values	300/0	180/0	120/0	120/0	120/0
Mean	All value used	22.89	29.21	25.51	33.70	32.86
	5% trimmed mean	23.04	29.36	25.49	33.70	32.86
Median		23.31	29.78	25.57	33.65	32.87
Std. Error		0.20	0.32	0.24	0.08	0.20
95% CI	Lower Bound	22.50	28.57	25.04	33.55	32.46
	Upper Bound	23.29	29.85	25.99	33.86	33.25
Percentile	25	21.11	28.52	23.31	32.92	31.00
	50	23.31	29.78	25.57	33.65	32.87
	75	25.65	31.70	27.69	34.47	34.63
Skewness		-0.69	-0.84	0.12	0.06	-0.04

(A)



(B)

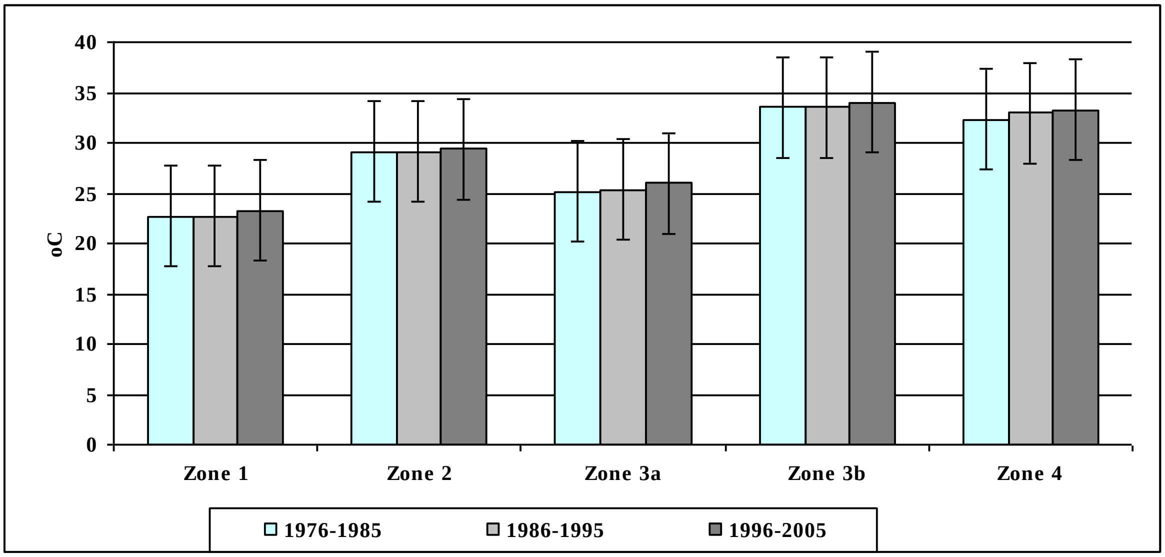


Figure: 4.1. Mean annual temperatures in all climate zones of the study area. (A): Mean annual Minimum temperature; (B) Mean annual Maximum temperature. The error bars indicate the standard deviation and all zones show significant increase in temperature at p=0.05 level.

Similarly the overall trend for the whole study area (country) is found most significant at ($p<0.05$) level between the decades and within decades in mean maximum and minimum temperatures as shown in the Table (4.2). The trend of minimum temperature for the whole study area over the three decades is found non-significant ($p>0.1$). However, in the Duncan test (Fig. 4.2 & Table. 4.2 in Annexure), mean minimum temperature of the whole study area is found slightly significant, having probability (87%).

Table. 4.2 Descriptive statistics and ANOVA results (three decades) for the whole study area

Whole Study Area						95% CI for Mean	
	N	F-value	Sig.	Mean	Std. Error	Lower	Upper
Min temp	30	1.47	0.25	14.16	0.08	14.01	14.32
Max temp	30	4.48	0.02	27.99	0.10	27.80	28.19
Mean temp	30	4.06	0.03	21.08	0.07	20.93	21.23

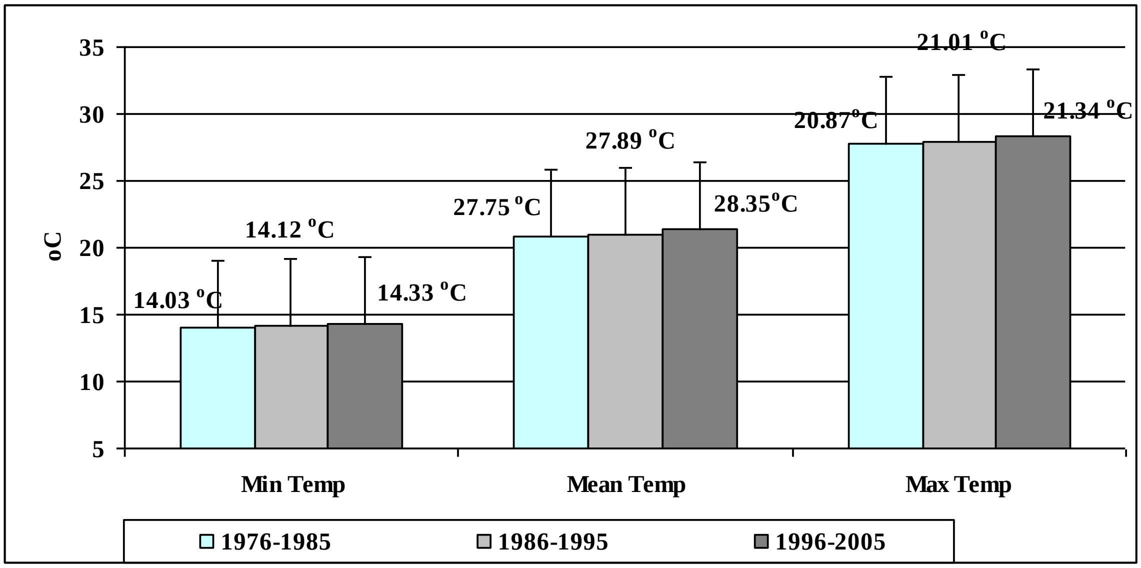


Figure 4.2. Mean annual Minimum, Maximum and Mean temperatures in the whole study area. The error bars indicate the standard deviation and all temperatures show significant increase at p= 0.05 level.

4.1.3.2. Zonal Analysis

To examine temperature variations among different zones, the mean monthly data of minimum and maximum temperatures for all individual stations were averaged to obtain the zonal annual mean and whole study area mean. All data were compiled into 10 and 15 and in the last for trend forecasting models.

4.1.3.2.1. Zone1

Zone1 comprise ten stations, mostly covering the north parts of the country. These stations are located between 34^{o}N to 38^{o}N in the Himalayan, Hindukash and Koh-e-Sufaid mountain ranges. The Analysis of Variance shows mixed results. In the Table (4.3) Kakul ($F = 4.58$, $p = 0.02$) and Parachinar ($F= 16.42$, $p= 0.00$) show the most significant results at alpha of 0.05 and the remaining stations are found non-significant in mean minimum temperature. On the other hand for maximum temperature Astor, Chilas, Chitral, Gilgit, Kakul, Muzaffarabad, Parachinar, and Said-u-Sharif are found with most significant results ($p< 0.05$). In the Duncan test (Table 4.4) for minimum temperature, Astor station is found significant having probability significance greater than rejecting the null hypothesis. Similarly, differences between the decadal means indicate increase in the 1st decade, decrease in the 2nd and again increase in 3rd decade in all stations except

Chital, Gilgit, Parachinar and Skardu stations. The overall ANOVA result for zone1 (F = 0.37, p = 69) is not found significant between the decades and within the decades for minimum temperature which means null hypothesis is accepted and alternate is rejected. Standard error computed for the zone in minimum temperature is 0.20 ^{o}C. Similarly for maximum temperature in the Duncan test, Dir (0.07 ^{o}C) and Skardu (0.08 ^{o}C) stations are not found with significant trend in the first and third decades. But their probability is greater than rejecting the null hypothesis. The mean of these stations in the 3rd decade is quite different from the previous two decades with increasing trend. The ANOVA result for maximum temperature (F= 0.98, p= 0.38) is found non-significant among the decades and within the decades.

Table. 4.3 Descriptive statistics and ANOVA result for zone1

Minimum temp (Zone1 F= 0.37, p= 0.69)					**95% C I for Mean**		
Station	**N**	**F-value**	**Sig.**	**Mean**	**Std. Error**	**Lower**	**Upper**
Astor	23	1.66	0.22	3.53	0.24	3.02	4.03
Chilas	30	0.33	0.72	14.54	0.09	14.36	14.72
Chitral	30	1.01	0.38	8.71	0.12	8.47	8.95
Dir	30	0.76	0.48	7.96	0.14	7.67	8.26
Gilgit	30	1.25	0.30	7.72	0.08	7.55	7.89
Kakul	30	4.58	0.02	10.50	0.15	10.20	10.80
M-abad	30	2.65	0.09	13.54	0.09	13.35	13.73
P-Chinar	30	16.42	0.00	7.50	0.49	6.50	8.50
Skardu	30	0.12	0.89	5.15	0.14	4.85	5.44
S-Sharif	30	0.30	0.75	12.15	0.14	11.85	12.45
Maximum temp (Zone 1 F= 0.98, p= 0.38)					**95% C I for Mean**		
Station	**N**	**F-value**	**Sig.**	**Mean**	**Std. Error**	**Lower**	**Upper**
Astor	30	3.54	0.04	15.60	0.15	15.30	15.91
Chilas	30	6.68	0.00	26.35	0.14	26.06	26.64
Chitral	30	2.63	0.09	23.54	0.16	23.22	23.86
Dir	30	2.08	0.15	22.87	0.14	22.58	23.16
Gilgit	30	5.01	0.01	24.36	0.13	24.09	24.63
Kakul	30	3.28	0.05	22.61	0.12	22.37	22.84
M-abad	30	3.89	0.03	27.36	0.18	27.00	27.73
P-Chinar	30	4.31	0.02	21.39	0.14	21.11	21.67
Skardu	30	1.84	0.18	18.91	0.18	18.54	19.27
S-Sharif	30	3.34	0.05	25.94	0.16	25.62	26.26

Table. 4.4 Duncan test for homogenous subset of Alpha for zone1

Minimum temp (Zone 1)				Subset for alpha = 0.05		
Station	**HMSS**	**1st Decade**	**2nd Decade**	**3rd Decade**	**Sig (1)**	**Sig (2)**
Astor	7.45	3.90	2.83	3.63	0.1	
Chilas	10	14.64	14.46	14.52	0.46	
Chitral	10	8.93	8.69	8.52	0.19	
Dir	10	8.05	7.72	8.13	0.28	
Gilgit	10	7.61	7.90	7.65	0.18	
Kakul	10	10.46	10.04	11.01	0.20	0.10
M-abad	10	13.46	13.33	13.82	0.56	0.11
P-Chinar	10	9.47	8.19	4.85	1.00	0.14
Skardu	10	5.25	5.12	5.07	0.66	
S-Sharif	10	12.31	12.06	12.08	0.52	
Maximum temp (Zone1)				**Subset for alpha = 0.05**		
Station	**HMSS**	**1st Decade**	**2nd Decade**	**3rd Decade**	**Sig (1)**	**Sig (2)**
Astor	10	15.71	15.11	15.99	0.09	0.42
Chilas	10	26.82	25.75	26.47	1.00	0.26
Chitral	10	23.34	23.26	24.02	0.06	
Dir	10	22.55	22.83	23.23	0.07	
Gilgit	10	24.25	23.97	24.86	0.34	1.00
Kakul	10	22.28	22.60	22.95	0.24	0.19
M-abad	10	26.78	27.43	27.88	0.12	0.26
P-Chinar	10	20.90	21.51	21.76	0.05	0.42
Skardu	10	18.47	18.97	19.28	0.08	
S-Sharif	10	25.69	25.66	26.47	0.93	1.00

4.1.3.2.2. Zone2

Zone2 contain six stations as shown in the Table (4.5), situated in the plain sub mountain areas between 31^{o}N and 34^{o}N. Three stations of Zone2 show increasing trend in the mean minimum temperature. Islamabad (F= 6.01, p= 0.01), Lahore (F=18.69, p= 0.00) and Peshawar (F=18.09, p= 0.00) indicating most significant results at 0.05 while Cherat and D.I.K is found non-significant. But in Duncan test the probability of D.I.K station (Sig= 0.14) between the first two decades is greater (85%) for rejecting the null hypothesis. The overall minimum temperature for zone2 (F= 2.21, p= 0.1) is observed almost significant with standard error 0.2^{o}C. The significant trend in zone2 for maximum temperature (F= 0.09, p= 0.91) and for all stations in the zone such as Cherat, DIK, Islamabad, Lahore, Peshawar and Sialkot are found almost negligible (p>0.05) as depicted by the Table 4.5. Similarly Duncan test for the mean of decadal differentiation also shows no significance in the sub homogenous set of Alpha 0.05 in the Table 4.6.

Table. 4.5 Descriptive statistics and ANOVA result for zone2

Minimum temp (Zone2 F= 2.21, p= 0.1)					95% C I for Mean		
Station	**N**	**F-value**	**Sig.**	**Mean**	**Std. Error**	**Lower**	**Upper**
Cherat	30	0.48	0.62	12.75	0.12	12.51	12.99
DIK	30	1.35	0.28	16.87	0.16	16.55	17.19
Isl-bad	30	6.07	0.01	14.45	0.11	14.22	14.68
Lahore	30	18.69	0.00	18.49	0.14	18.20	18.78
Peshawar	30	18.09	0.00	16.03	0.14	15.74	16.32
Sialkot	30	2.48	0.10	16.36	0.11	16.14	16.58
Maximum temp (Zone2 F= 0.09, p= 0.91)					**95% C I for Mean**		
Station	**N**	**F-value**	**Sig.**	**Mean**	**Std. Error**	**Lower**	**Upper**
Cherat	30	0.88	0.43	20.75	0.14	20.45	21.04
DIK	30	0.98	0.39	31.62	0.13	31.35	31.88
Isl-bad	30	1.44	0.25	28.74	0.14	28.45	29.04
Lahore	30	0.71	0.50	34.89	0.14	34.61	35.17
Peshawar	30	0.48	0.63	29.80	0.12	29.54	30.05
Sialkot	30	0.32	0.73	29.46	0.12	29.21	29.71

Table. 4.6 Duncan test for homogenous subset of Alpha for zone 2

Minimum temp (Zone2)					Subset for alpha = 0.05		
Station	**HMSS**	**1st Decade**	**2nd Decade**	**3rd Decade**	**Sig (1)**	**Sig (2)**	**Sig (3)**
Cherat	10	12.61	12.75	12.89	0.36		
DIK	10	16.53	17.14	16.95	0.14		
Isl-bad	10	14.06	14.42	14.88	0.06		
Lahore	10	17.85	18.37	19.26	1.00	1.00	1.00
Peshawar	10	15.55	15.70	16.83	0.52	1.00	
Sialkot	10	16.43	16.06	16.59	0.14	0.53	
Maximum temp (Zone2)					**Subset for alpha = 0.05**		
Station	**HMSS**	**1st Decade**	**2nd Decade**	**3rd Decade**	**Sig (1)**		
Cherat	10	20.61	20.62	21.02	0.28		
DIK	10	31.54	31.45	31.87	0.22		
Isl-bad	10	28.62	28.53	29.08	0.15		
Lahore	10	34.69	35.10	34.88	0.27		
Peshawar	10	29.66	29.76	29.96	0.38		
Sialkot	10	29.38	29.39	29.60	0.51		

4.1.3.2.3. Zone3a

This zone includes four stations, located in the southwestern part of the country. It covers an area between 27^{o}N to 32^{o}N and 64^{o}E to 70^{o}E. All four stations are mountainous with high elevation from mean sea level. Decadal analysis of thirty years time series data for zone3a (F= 0.06, p= 0.94) shows no significant results as shown in Table 4.7.

Similarly Duncan test (Table 4.8) also shows no significant probability for individual stations in decadal means of the homogenous subset of data. All decadal means are significantly different from each other and also from the means of the other stations and show no significant results. Kalat station shows no change in the mean of the first two decades. The means are almost same but in the 3rd decade the value of the mean is larger than the 2nd decade for minimum temperature analysis. Quetta and Khuzdar stations indicate the most significant results in terms of maximum temperature except Zhob station ($p>0.05$). The significance values computed for the data of Kalat station are higher than the critical tabulated value but the probability of the station is quite high (~87%: Table 4.7). Duncan test for maximum temperature (Table 4.8) also shows significant probability (0.08 ^{o}C) for Kalat in the 1st and 3rd decade. The overall analysis of variance for zone3a is observed with non-significant result ($F= 1.30$, $p= 0.28$).

Table. 4.7 Descriptive statistics and ANOVA result for zone 3a

Minimum temp (Zone 3a F= 0.06, p= 0.94)						**95% C I for Mean**	
Station	**N**	**F-value**	**Sig.**	**Mean**	**Std. Error**	**Lower**	**Upper**
Kalat	30	0.33	0.72	5.41	0.23	4.95	5.88
Khuzdar	30	0.01	1.00	14.83	0.29	14.24	15.43
Quetta	30	0.57	0.57	8.41	0.12	8.16	8.66
Zhob	30	0.45	0.64	12.44	0.25	11.94	12.94
Maximum temp (Zone 3a F= 1.30, p=0.28)						**95% C I for Mean**	
Station	**N**	**F-value**	**Sig.**	**Mean**	**Std. Error**	**Lower**	**Upper**
Kalat	30	2.30	0.12	22.19	0.15	21.88	22.50
Khuzdar	30	4.70	0.02	28.99	0.18	28.61	29.37
Quetta	30	6.45	0.01	24.88	0.17	24.53	25.23
Zhob	30	0.77	0.47	25.99	0.18	25.62	26.35

Table. 4.8 Duncan test for homogenous subset of Alpha for zone 3a

Minimum temp Zone3a				**Subset for alpha = 0.05**	
Station	**HMSS**	**1st Decade**	**2nd Decade**	**3rd Decade**	**Sig (1)**
Kalat	10	5.28	5.28	5.68	0.51
Khuzdar	10	14.82	14.81	14.87	0.94
Quetta	10	8.22	8.48	8.52	0.37
Zhob	10	12.47	12.14	12.72	0.38

Maximum temp Zone3a					**Subset for alpha = 0.05**	
Station	**HMSS**	**1st Decade**	**2nd Decade**	**3rd Decade**	**Sig (1)**	**Sig (2)**
Kalat	10	21.99	21.96	22.63	0.08	
Khuzdar	10	28.43	28.89	29.65	0.26	0.07
Quetta	10	24.34	24.72	25.58	0.30	1
Zhob	10	25.74	25.93	26.28	0.26	

4.1.3.2.4. Zone 3b

This zone is the hottest zone of the country where highest maximum temperature is recorded for Sibbi and Jacobabad. It consists of six stations and all of them indicate significant increase in temperature. The ANOVA result (Table 4.9) for zone 3b (F= 4.17, p= 0.02) is found most significant at 0.05 level for minimum temperature. Duncan test shows a significant increase in the mean of 3rd decade i.e. 1996-2005 for all stations in this zone for minimum temperature (Table 4.10). All of the decadal means are found significantly different from each other but not revealed significant results. Furthermore for maximum temperature, Zone 3b shows most significant result (F= 3.38, p= 0.04). Two stations, Bahawalpure (0.08^{o}C) and Rohri (0.08^{o}C) are found with significantly higher value than p=0.05 level as shown in the Table 4.9. Similarly Multan (0.11 ^{o}C) and Sibbi (0.13 ^{o}C) exhibit higher significance level with 88% and 86% probability, respectively, for the decadal comparison of means in the Duncan test (Table 4.10). It means that alternate hypothesis can be rejected for all these four stations, because of their greater probability value.

Table. 4.9 Descriptive statistics and ANOVA result for zone 3b

Minimum temp (Zone 3b F=4.17, p= 0.02)				**95% C I for Mean**			
Station	**N**	**F-value**	**Sig.**	**Mean**	**Std. Error**	**Lower**	**Upper**
B-Pur	30	2.83	0.08	18.22	0.13	17.95	18.50
Jaco-bad	30	3.31	0.05	20.11	0.08	19.93	20.28
Khanpur	30	10.20	0.00	17.23	0.14	16.95	17.52
Multan	30	4.57	0.02	18.22	0.09	18.04	18.41
Rohri	30	3.66	0.04	19.78	0.11	19.55	20.00
Sibbi	30	5.80	0.01	19.98	0.11	19.76	20.20
Maximum temp (Zone3bF= 3.38, p= 0.04)				**95% C I for Mean**			
Station	**N**	**F-value**	**Sig.**	**Mean**	**Std. Error**	**Lower**	**Upper**
B-Pur	30	2.85	0.08	32.88	0.13	32.61	33.16
Jaco-bad	30	0.83	0.45	34.21	0.15	33.90	34.53
Khanpur	30	0.30	0.74	33.46	0.13	33.19	33.73
Multan	30	1.57	0.23	32.65	0.12	32.39	32.90
Rohri	30	2.81	0.08	34.18	0.11	33.95	34.42
Sibbi	30	1.46	0.25	34.82	0.14	34.54	35.10

Table. 4.10 Duncan test for homogenous subset of Alpha for zone 3b

Minimum temp Zone 3b					Subset for alpha = 0.05	
Station	**HMSS**	**1st Decade**	**2nd Decade**	**3rd Decade**	**Sig (1)**	**Sig (2)**
B-Pur	10	17.85	18.23	18.59	0.23	0.26
Jaco-bad	10	20.04	19.90	20.38	0.47	0.09
Khanpur	10	16.76	17.04	17.90	0.29	1.00
Multan	10	17.93	18.21	18.53	0.16	0.13
Rohri	10	19.94	19.39	20.00	1.00	0.82
Sibbi	10	19.93	19.62	20.38	0.17	0.06
Maximum temp Zone 3b					**Subset for alpha = 0.05**	
Station	**HMSS**	**1st Decade**	**2nd Decade**	**3rd Decade**	**Sig (1)**	**Sig (2)**
B-Pur	10	32.72	32.63	33.30	0.78	0.07
Jaco-bad	10	33.95	34.25	34.44	0.24	
Khanpur	10	33.42	33.35	33.60	0.49	
Multan	10	32.61	32.40	32.93	0.11	
Rohri	10	34.16	33.89	34.51	0.31	0.19
Sibbi	10	34.60	34.73	35.14	0.13	

4.1.3.2.5. Zone 4

Zone 4 contains four stations, out of which only two stations Hyderabad and Karachi shows significant trend in minimum temperature. The overall trend of this zone (F= 3.80, p= 0.03) shows increase among three decades (Table 4.11). In the Duncan test the decadal means indicate significantly increasing trend except for Jewani station, which show downward trend in the 3rd decade (1996-2005) as shown in the Table 4.12. In terms of maximum temperature, three out of four stations reveal significant trend except Jewani (Table 4.11) but in homogenous subset of alpha Jewani shows significant change (p=85 %) in the first two decades (Table 4.12). The mean of the 3rd decade is slightly lower than the previous decadal mean. However the significant p –value for zone is found slightly greater (p= 84%).

Table. 4.11 Descriptive statistics and ANOVA result for zone 4

Minimum temp (Zone 4 F= 3.80, p= 0.03)						95% C I for Mean	
Station	**N**	**F-value**	**Sig.**	**Mean**	**Std. Error**	**Lower**	**Upper**
H-abad	30	3.86	0.03	21.54	0.14	21.25	21.82
Jewani	30	0.91	0.41	20.92	0.12	20.67	21.18
Karachi	30	13.58	0.00	20.73	0.34	20.03	21.42
N-Shah	30	2.02	0.15	18.21	0.11	17.99	18.42
Maximum temp (Zone 4 F= 1.88, p= 0.16)						**95% C I for Mean**	
Station	**N**	**F-value**	**Sig.**	**Mean**	**Std. Error**	**Lower**	**Upper**
H-abad	30	5.08	0.01	33.84	0.14	33.56	34.12
Jewani	30	1.64	0.21	30.10	0.14	29.82	30.38
Karachi	30	16.83	0.00	31.94	0.13	31.67	32.21
N-Shah	30	6.70	0.00	35.55	0.14	35.26	35.83

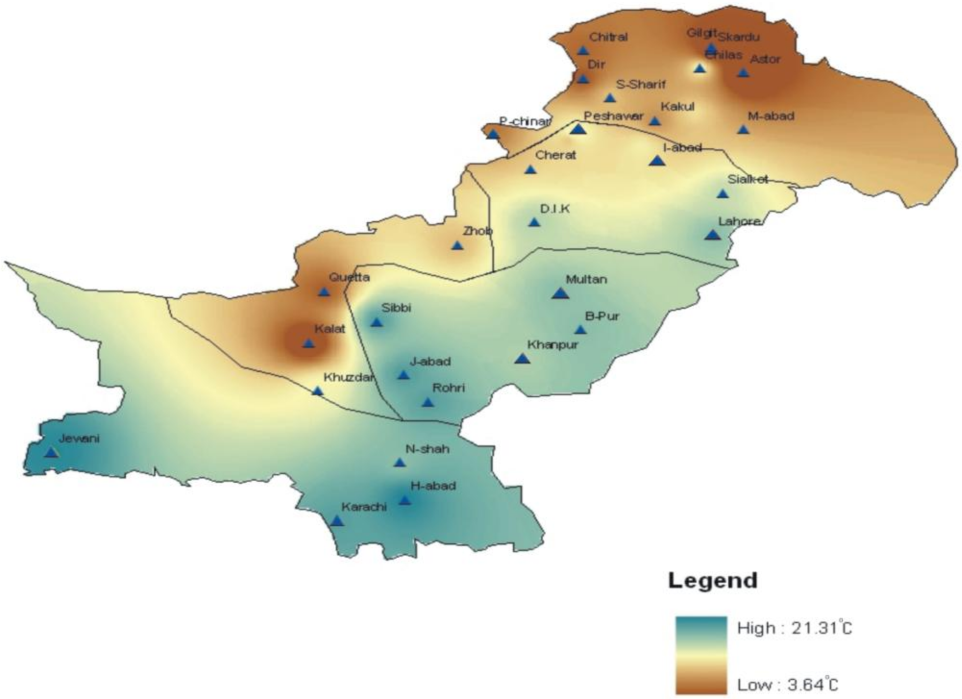
Table. 4.12 Duncan test for homogenous subset of Alpha for zone4.

Minimum temp Zone4					Subset for alpha = 0.05		
Station	**HMSS**	**1st Decade**	**2nd Decade**	**3rd Decade**	**Sig (1)**	**Sig (2)**	**Sig (3)**
H-abad	10	21.29	21.28	22.04	0.98	1.00	
Jewani	10	21.07	21.02	20.69	0.25		
Karachi	10	19.12	20.77	22.29	1.00	1.00	1.00
N-Shah	10	18.01	18.13	18.49	0.08		
Maximum temp Zone4					**Subset for alpha = 0.05**		
Station	**HMSS**	**1st Decade**	**2nd Decade**	**3rd Decade**	**Sig (1)**	**Sig (2)**	
H-abad	10	33.31	33.97	34.24	1.00	0.37	
Jewani	10	29.75	30.28	30.27	0.14		
Karachi	10	31.20	32.26	32.37	1.00	0.63	
N-Shah	10	35.10	35.41	36.13	0.29	1.00	

4.1.3.3. Single Station Analysis

Although single station analysis of temperature on the basis of 15-years period suggests differences in the two time periods (1976-1990 to 1991-2005), but the overall trends for minimum temperature of all seasons were found increasing. Out of thirty stations, six stations were observed with great increase in minimum temperature during the 1991-2005 period as shown in Fig.4.3 (B) compared to 1976-1990 period as shown in Fig. 4.3 (A) and their significant values are shown in Table 4.3 (Annexure).

(A)



(B)

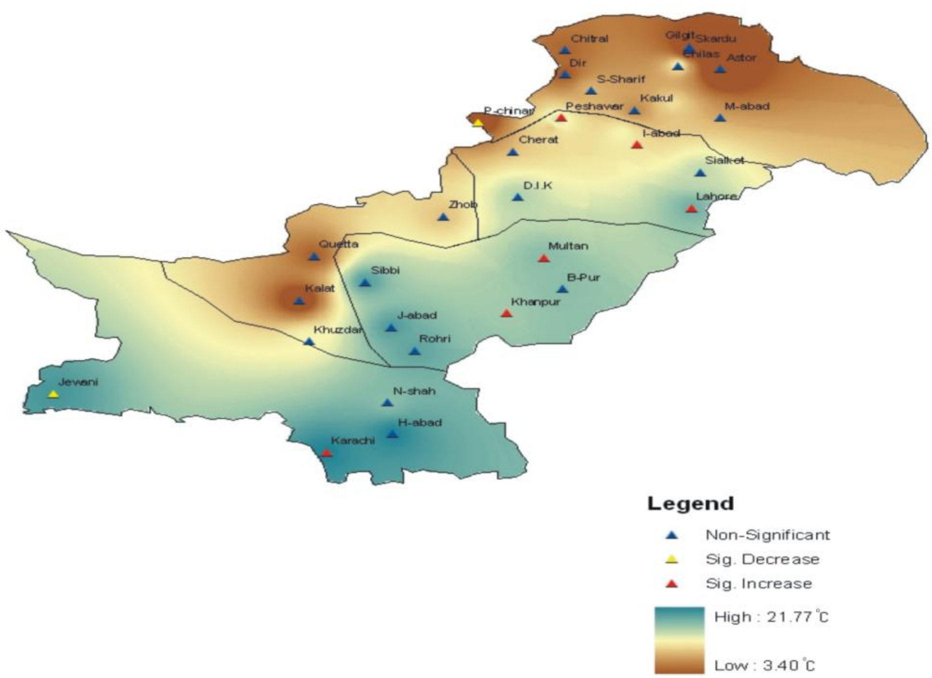


Figure 4.3: Map of Pakistan showing significant increase, decrease and no change in the minimum temperature. (A): For period 1976-1990; (B): For period 1991-2005.

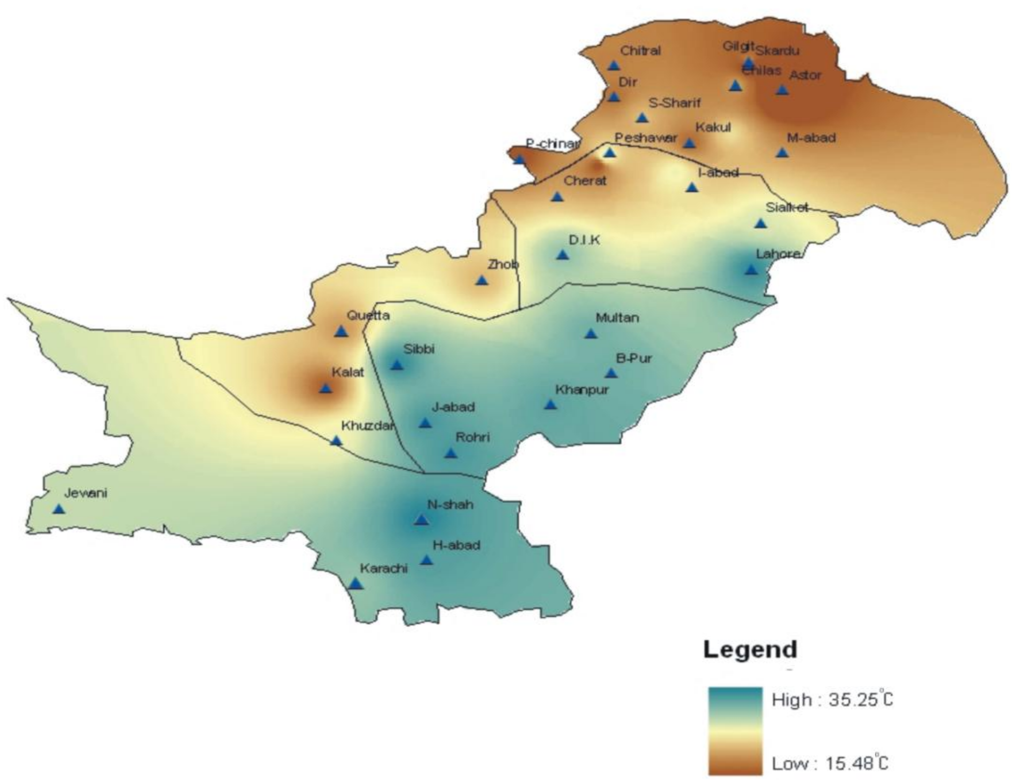
In the above figure six out of thirty stations show an increase of significance. These stations are Islamabad (0.55^{o}C), Peshawar (0.67^{o}C), Karachi (2.09^{o}C), Lahore (1.04^{o}C), Multan (0.40^{o}C) and Khanpur (0.63 ^{o}C). Except Khanpur, all of these stations are big and congested cities of the country; located in different zones i.e. zone2, zone3b and zone4, having large populations, big industrial estates, high environmental pollution and less cultivated areas. Khanpur (0.63^{o}C), Sibbi (0.36^{o}C), Jacobabad (0.32^{o}C) and Kalat (0.76^{o}C) are relatively small cities of Pakistan with less urbanization and population effects.

It was also observed that Astor, Chitral, Saidu Sharif, Skardu, Kakul and Khuzdar indicate a significantly less drop of temperature during the 2nd 15-year period (1990-2005) but their significant values are larger than alpha ($p>0.05$) therefore, no change in the trend is considered. Two stations namely Parachinar and Jewani have been observed with significantly decreasing trend i.e. -4.09 ^{o}C and -0.46 ^{o}C respectively, while rest of the stations including Astor, Skardu, Gilgit, Chitral, Saidu Sharif, Dir, Chilas, Kakul, Cherat, Sialkot, Quetta, Rohri, Hyderabad, Nawabshah, Khuzdar, Muzaffarabad, Zhob, D.I. Khan and Bahawalpure have shown no significant change. The intensity of the colors on the map (Fig. 4.3) from high to low shows the range of minimum temperature from 3.40 - 21.77 ^{o}C. Parachinar and Jewani are situated in different zones (zone1 and zone4) and completely different in terms of their latitude, longitudes and atmospheric conditions. Jewani is a coastal area situated at comparatively low altitude in the southwest bordering the Arabian Sea while Parachinar is a town situated in the Kurram Agency (Federally Administrated Tribal Area) in northwestern part of the country in Koh-e-Sufaid mountain range along Pak-Afghan border. The sudden drop of temperature in both stations indicates their abnormal behavior. Hence, further research is needed to investigate other meteorological variables in detail.

Similarly for the mean maximum temperature, Fig.4.4 (A) depicts a greater rising trend for Karachi (0.82^{o}C), Quetta (0.67 ^{o}C) and Nawabshah (0.57 ^{o}C) while Parachinar, Kalat, Hyderabad, Khuzdar and Zhob show variation from 0.5 ^{o}C to 0.7 ^{o}C in the second 15-years period i.e. 1991-2005 as compared to 1976-1990 as shown in Fig.4.4 (B). The intensity of the map color (Fig.4.4 A) from high to low shows range from 35.25 ^{o}C -15.47

^{o}C. Those stations which show significant increase are located in different parts of the country and included in different zones mainly from zone3a, zone4 and zone1. Table 4.4 (Annexure) lists all four stations of zone3a (Quetta, Zhob, Khuzdar and Kalat) located in southwestern part of the country show maximum increase in temperature and display significant trend. Quetta is the capital city of Balochistan province and considered as one of the atmospherically polluted city while Kalat, Khuzdar and Zhob are mountainous towns of the province with less population and environmental pollution. Karachi and Hyderabad (zone4) are big urban centers with heavy industry and transport vehicles. The remaining stations are observed with variation in temperature from 0.1 to 0.5 ^{o}C and come under the category of non significant change because of higher p-value. Only Chilas station shows downfall in temperature by about -0.5 ^{o}C during the first half of the study period (1976-1990). The temperature range from 35.82 - 15.76 ^{o}C in Fig.4.4 (B) shows the intensity of the maximum temperature from high to low.

(A)



(B)

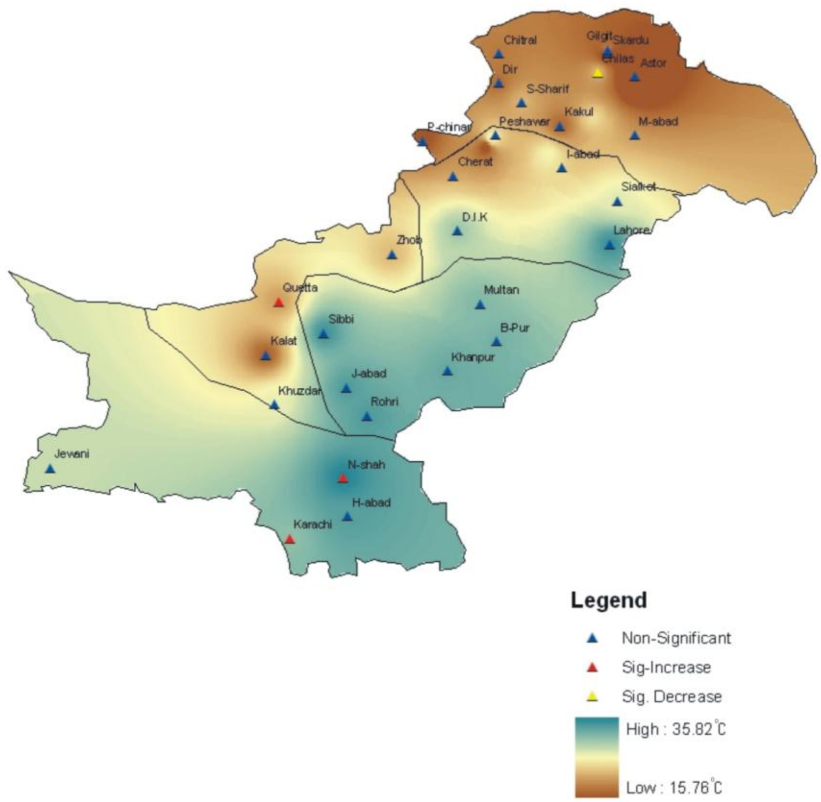
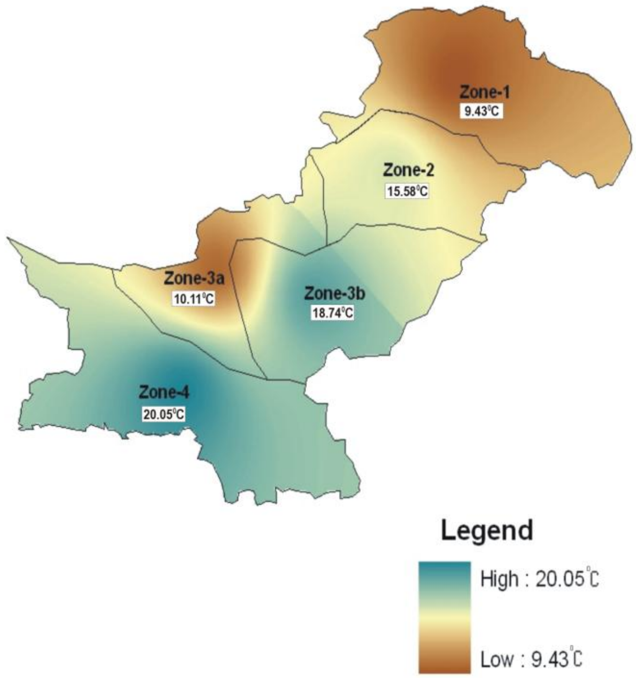


Figure 4.4: Map of Pakistan showing significant increase, decrease and no change in the maximum temperature. (A): For period 1976-1990; (B): For period 1991-2005.

4.1.3.4. Whole Study Area Analysis

Analysis of the minimum temperature spatially and temporally across the country has been summarized, by dividing the study area into distinct climatic zones and study period into two 15-years intervals (Table 4.5 in Annexure & Fig. 4.5). A general progressive increase in mean minimum temperature with inter-zonal variations can be easily recognized across the country, except zone1, from the first half of study period (1976-1990) to the second half (1991-2005). Figures 4.5 (A & B) show zonal means of minimum temperature ranging from 9.43 - 20.04 ^{o}C during the first half to 9.10 - 20.65 ^{o}C during the second half respectively. Zone 4 clearly exhibits the highest increase of 0.61 ^{o}C among other zones.

(A)



(B)

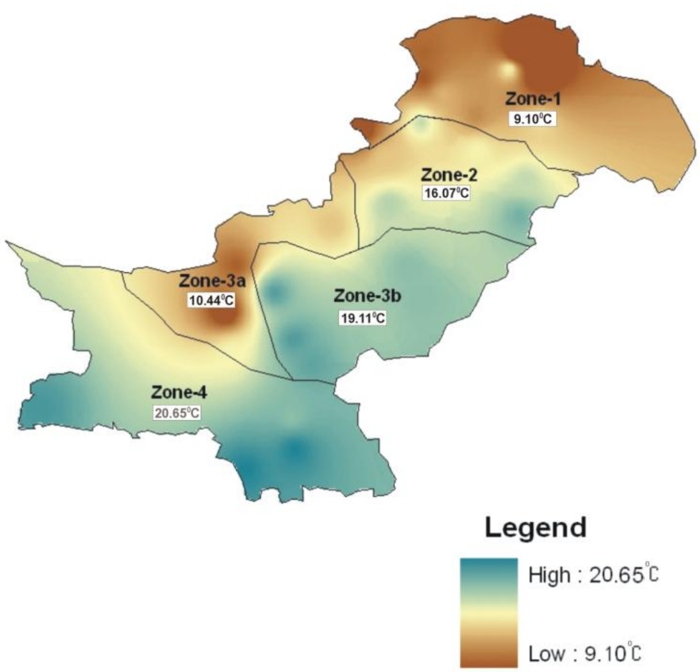
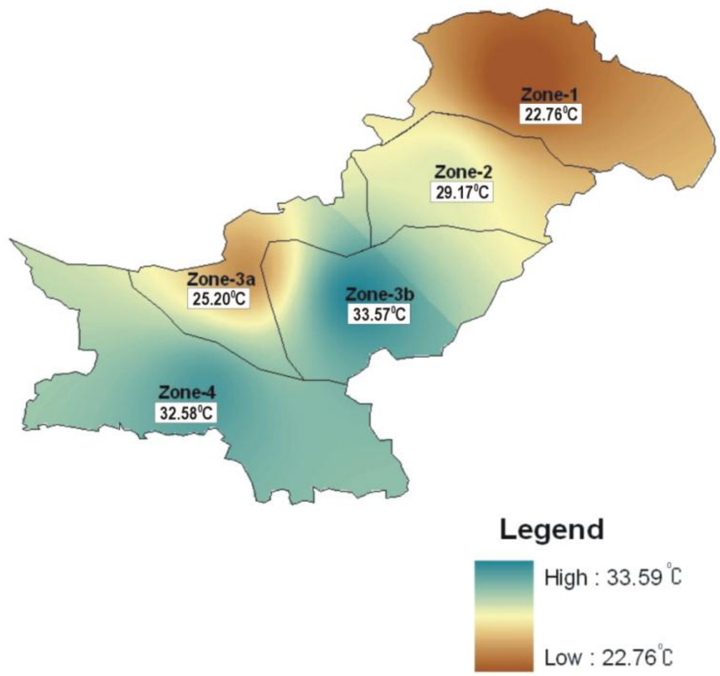


Figure 4.5: Whole study area analysis showing significant increase, decrease and no change in minimum temperature. (A): For period 1976-1990; (B): For period 1991-2005.

The overall change observed for the whole study area is 0.29 ^{o}C from the first half to second half of the study period and works out to 0.10 ^{o}C rise per decade in the minimum temperature. The variations observed in zonal analysis are most significant (zone1 p= 0.00, zone2 p= 0.00, zone3b p= 0.047 and zone4 p= 0.048) for all zones except zone3a (p= 0.635> 0.05), which is non-significant. Although the variations are different but the overall trend is increasing. The overall change for the study area in two time periods of fifteen years is not found significant (F= 0.408, p= 0.523). From the above analysis it can be inferred that plain areas of the country show a clear warming trend during the period 1991-2005 as compared to 1976-1990. It is also observed that temperature variations in northern parts of the country from Himalayan and Hindukush mountain ranges (zone1) are found negligible. Similarly in the south and southwest (zone3a) of the country variations are negligible but the southeast (zone3b) shows an increasing trend. Both these zones lie in the same latitudinal window but zone3a lies in mountainous region having moderate to cold climate, whereas zone3b lies near the Thar Desert, having hot climate.

In similar manner, the maximum daily temperatures of the study area have also registered a temporal increase from the first half to the second half of the study period (Table 4.5 in Annexure). Figure 4.6 (A & B) shows that zones 3a and 4 exhibit more increase (0.62^{o}C & 0.56^{o}C) as compared to other zones of the study area. The variations observed in zonal analysis are also found most significant i.e. p= 0.012 and p= 0.011 for zone3a and zone 4 respectively

(A)



(B)

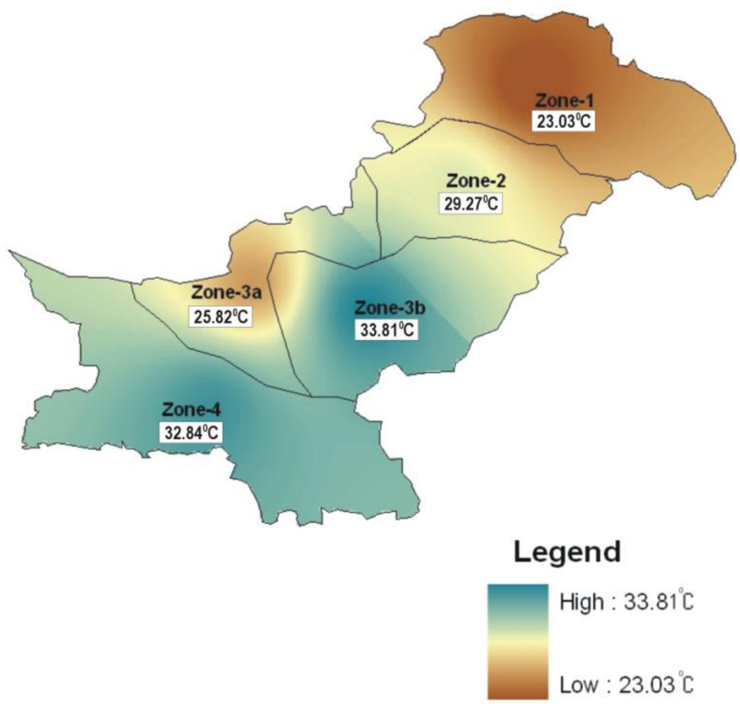


Figure. 4.6: Whole study area analysis showing significant increase, decrease and no change in maximum temperature. (A): For period 1976-1990; (B): For period 1991-2005.

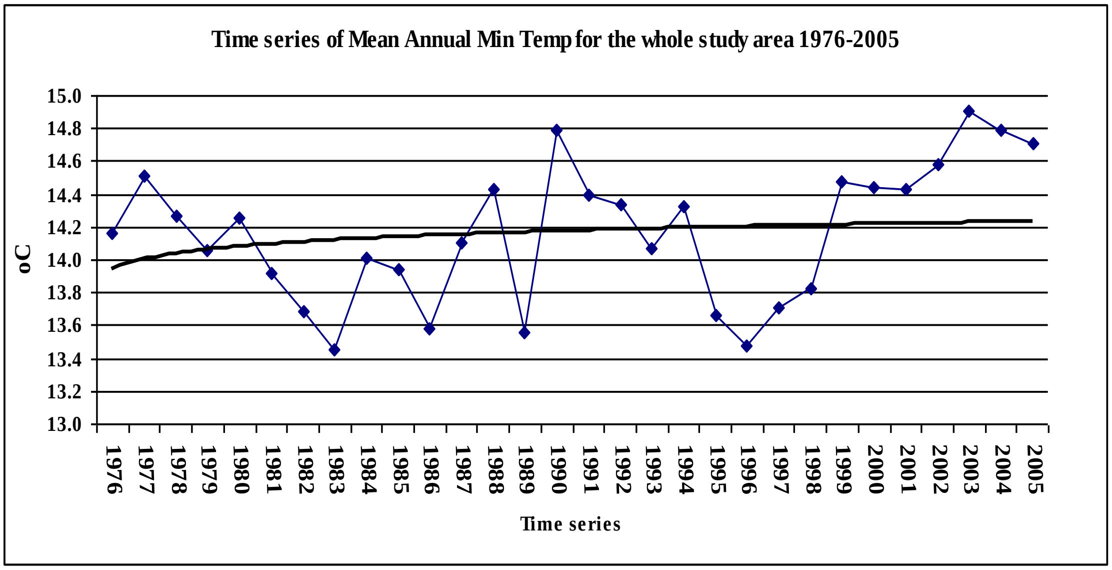
The overall increase in maximum temperature for the whole study area from first half to the second half works out to 0.36^{o}C and 0.12^{o}C per decade. The result of ANOVA test is found non-significant (F= 0.762, p= 0.383).

From the above analysis it is concluded that in the decadal analysis zone3b is found statistically most significant in comparison to other zones. It was observed that stations included in zone3a show a greater warming trend. Warming trend seems to be more prominent in southwestern parts of the country although other parts of the country also show a gradual increase except the central plains and high mountain areas in the north.

4.1.3.5. Entire Study Period Analysis

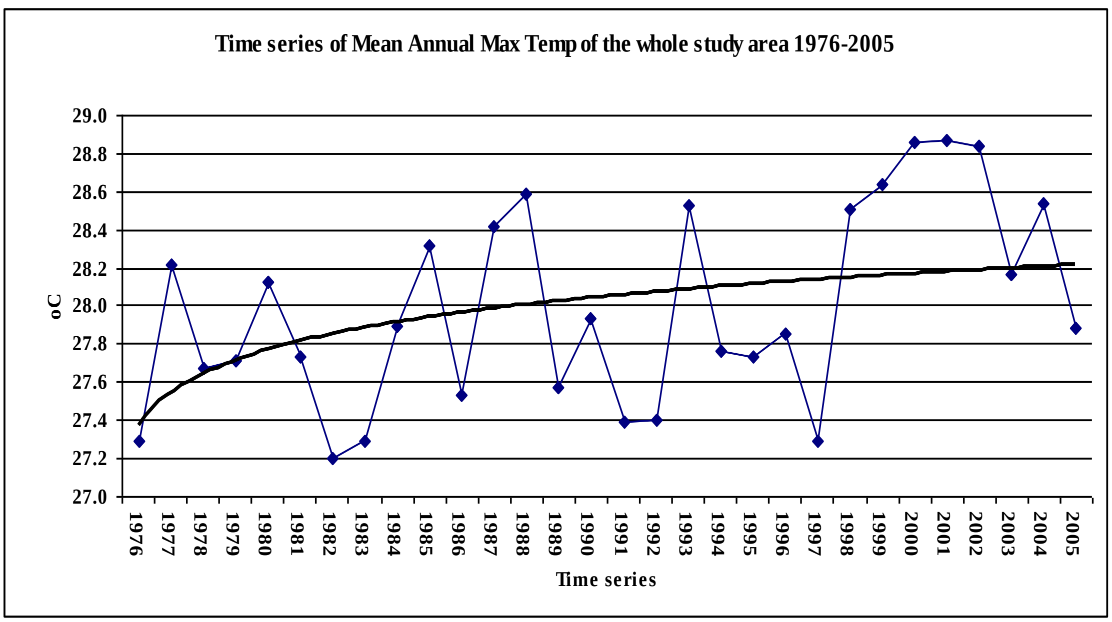
The time series of 30 years annual mean minimum and maximum temperatures clearly showed that the overall change in temperature is not found uniform during the study period. Figure 4.7 (A & B) is the combine result of minimum and maximum temperatures showing the regular increase in the last decade with some significant decreasing fluctuations in 1976 to 1990. Overall results in Fig. 4.7 (C) show that mean temperature increased with fluctuations but have the significant trends of rise in temperature during the whole study period but this change in two decade is not more significant than the last decade. The time series plot also shows the highest mean annual Min and Max temperatures for the year 2003 and 2004 (14.8 ^{o}C & 21.7 ^{o}C) respectively whereas the lowest mean annual Min and Max temperatures of 13.4 ^{o}C and 20.4 ^{o}C were recorded in 1982-1983 and 1997 respectively. The trend line generated by the software through the scattered data point also indicates a clear rising trend for temperatures from 1976-2005.

(A)



Time series of Mean Annual Min Temp for the whole study area 1976-2005
15.0
14.8
14.6
14.4
14.2
14.0
13.8
13.6
13.4
13.2
13.0
oC
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
Time series

(B)



Time series of Mean Annual Max Temp of the whole study area 1976-2005
29.0
28.8
28.6
28.4
28.2
28.0
27.8
27.6
27.4
27.2
27.0
oC
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
Time series

(C)

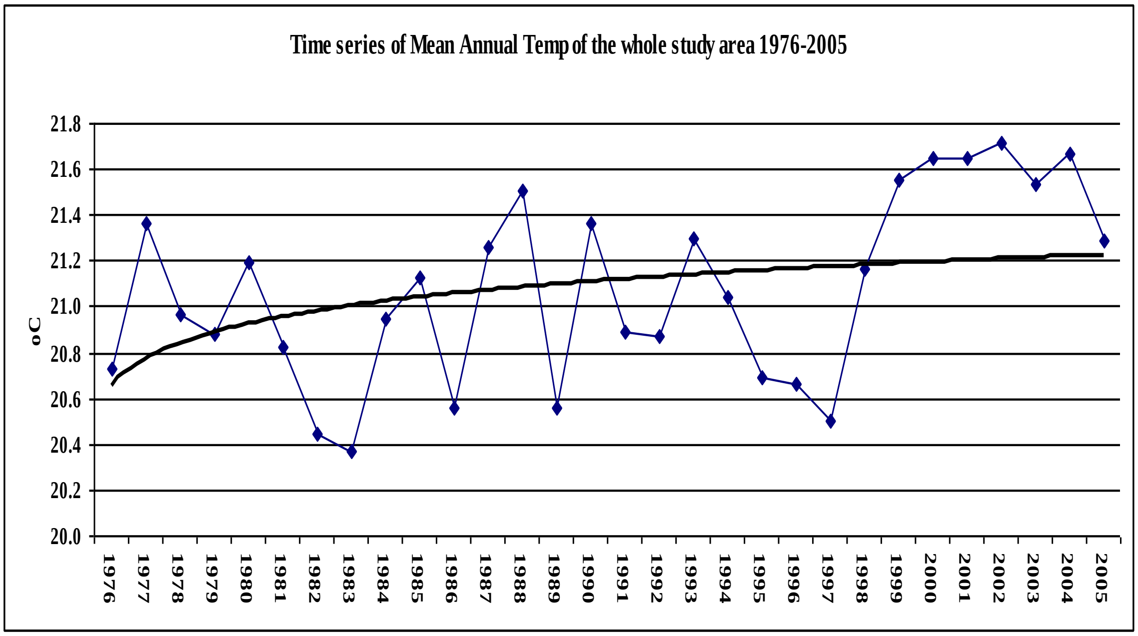


Figure. 4.7: Mean annual temperatures of the entire period 1976-2005. (A): Mean annual Min temp; (B): Mean annual Max temp; (C): Mean annual Mean temp.

4.1.4. Discussion

The study has revealed a mixture of results. The descriptive analysis shows that zone1 has the lowest means (9.26°C & 22.89°C) and medians (8.84°C & 23.31°C) both in minimum and maximum temperatures respectively while zone4 shows the highest mean values (20.35 & 20.86 °C) followed by zone3b (mean, 33.70 °C and medians, 33.65 °C). In the zonal analysis of the country, other statistics involved in the descriptive procedure are quite different from each other and show significant means and medians.

Furthermore, for determination of temporal and spatial variation in temperatures of the study area, analysis of variance (ANOVA) test was applied to two combinations of the dataset. First ANOVA test was applied to the three decadal datasets and secondly to the two 15-years periods. In decadal analysis ANOVA test was found significantly different between all the zones at significant level ($p=0.05$). The p-values of minimum temperature, computed for zone3b and zone4 are found most significant ($p<0.05$) but for zone1, zone2 and zone3a, they are non-significant because of higher p-values. Orogrphically speaking zone1 and zone3a are mostly mountainous areas lying in north and west of the country respectively. These two zones play an important role in the water availability of the country. Several tributaries of the two big rivers i.e. Indus and Kabul originate from areas included in zone1. These two rivers are fed by the snow and glacial melt derived from zone1 as most stations of these zones receive a lot of snowfall in winter and the pre- monsoon dry season (April-May). The freshwater supply derived from snow and ice melt serves as a critical resource for irrigation and hydropower generation in the country. Forests present in these two zones are the main source of timber supply and medicinal plants of the country (Shah, 2008).

Similarly the zonal analysis for maximum temperature indicates that zone3b is most significant but zone4 also cannot be ignored as it has higher probability (84%) or p-value. The remaining areas such as zones 1, 2, and 3a, show similar results as were observed for the minimum temperature. Zone2 and zone3b are plain areas of the country and play a vital role in the agriculture sector of the country, especially for production of cotton, rice, wheat, sugarcane and mangoes. These zones contain large cities like Lahore, Multan, Sialkot, Faisalabad, Bahawalpure and Peshawar. These cities are highly polluted because of congestion traffic, industry and fewer plantations. Zone4 mainly constitutes the coastal belt of the Arabian Sea and most southerly part of the country. It is most significant for minimum temperature and slightly significant for maximum temperature. This is largely because of the Karachi station, which has been recorded with significant increasing trend in temperature.

Analysis of minimum temperature carried out on the basis of two 15-years periods indicate that with the exception of zone3a all zones are most significant having smaller p-values i.e. zone1 ($p= 0.00$), zone2 ($p= 0.00$), zone3b ($p= 0.047$) and zone4 ($p= 0.048$) but zone3a ($p= 0.635> 0.05$) is non-significant. Similarly in terms of maximum temperature, only zone3b ($p= 0.04$) can be considered most significant while other four zones show a non-significant trend. Single station analysis shows that Islamabad (0.55^{o}C), Peshawar (0.67^{o}C), Karachi (2.09^{o}C), Lahore (1.04^{o}C), Multan (0.40^{o}C) and Khanpur (0.63^{o}C) recorded a significant increase in minimum temperature while Karachi (0.82^{o}C), Quetta (0.67 ^{o}C) and Nawabshah (0.57 ^{o}C) recorded a rising trend in maximum temperature. These stations are located in different regions of the country, mainly from zone2, zone3a, zone3b and zone4. Most of these are big cities having diverse microclimatic conditions, huge population, heavy traffic, industrial estates and scarce vegetation. All these environmental factors could be the causes of rising trend of temperatures in these cities (For details see references, Munich Report, 2004 and Shirazi and Ali. 2009) and require further research works which are not possible in the present study. Khanpur (0.63^{o}C), Sibbi (0.36^{o}C), Jacobabad (0.32^{o}C) and Kalat (0.76^{o}C) are relatively smaller cities of Pakistan with less urbanization, population, transportation and industrial effects. Two stations, Parachinar and Jewani, from zone1 and zone4 have been observed with significant decrease in the temperature i.e. -4.09^{o}C and -0.46^{o}C, respectively albeit both stations are located in entirely different regions, latitude, longitude and atmospheric conditions. Jewani is situated in the coastal area at lower latitude in the south bordering of Arabian Sea while Parachinar – the capital of Kurram Agency in Federally Administrated Tribal Area (FATA) is a valley in high mountainous range of Koh-e-Sufaid along Pak-Afghan border in the northwest of the country. In both stations, the abrupt decline of minimum temperature during the second half (1990-2005) indicates their abnormal behavior and requires further work to investigate other meteorological variables beyond the scope of the present study. The remaining stations such as Astor, Chitral, Said-u-Sharif, Skardu, Kakul, Khuzdar also show a certain but relatively smaller drop in the minimum temperature during the 2nd half of study period. However, their significance values are larger than the critical value of ($p=0.05$) therefore, no change in the trend is considered. Similarly Gilgit, Dir, Chilas, Cherat, Sialkot, Quetta, Rohri, Hyderabad, Nawabshah, Muzaffarabad, Zhob, D.I.Khan and Bahawalpure have shown no significant change in the minimum temperature. While Chilas (-0.47), Kalat (0.55 ^{o}C), Khuzdar (0.66 ^{o}C) and Zhob (0.60 ^{o}C) from zone1 and zone3a were noted with slightly higher value of significance ($p> 0.05$), but the probability for rejecting the null hypothesis is greater (90%). These stations are small mountainous towns, located along western border of the country. No station was observed with significant decreasing trend in the maximum temperature except Chilas town located in the Gilgit Baltistan province.

Although variations were noticed among the five zones but generally the overall trend was found increasing. The p-value computed for the whole study area trend shows a decrease in the mean minimum temperature of zone1 (-0.33 ^{o}C) during 1991-2005 period, which looks anomalous when compared with the increasing trend of other zones. A similar decreasing trend has been advocated by other workers for the western Himalaya (Kumar et al. 1994; Yadav et al. 2004). The overall increase in minimum temperature of the country is 0.29 ^{o}C from 1976-90 to 1991-05 periods which can be inferred as 0.10 ^{o}C per decade. The p-value for maximum temperature of the country is significant ($p<0.05$) for 0.36 ^{o}C increase between the two consecutive 15-years time periods and 0.12 ^{o}C per decade. Zone3a (0.62 ^{o}C) and zone4 (0.55 ^{o}C) have recorded highest increase in the maximum temperature.

It is evident from this study that all climatic zones of the study area show a consistently rising trend in the minimum and maximum temperatures except certain high elevation areas situated in the north, northwest and west of the country e.g. zone1 and zone3a. However, zone2, zone3b and zone4, situated in the plains, southwest and coastal areas show a rising trend. This study has determined an increase of 0.1^{o}C per decade in mean minimum temperature, 0.12 ^{o}C per decade in mean maximum temperature and 0.11 ^{o}C in mean temperature. These values are higher than the global mean value of 0.018^{o}C for minimum temperature and 0.050 ^{o}C for maximum temperature (Easterling et al. 1997) but lower than 0.296 ^{o}C, 0.287°C and 0.296°C per decade for mean, maximum and minimum temperatures respectively as shown by Russel et al (2004).

Afzaal et al (2009) have also reported a sharp increase of 0.06°C per decade and a cumulative rise of 0.64°C over the period 1901-2007 by merging datasets of the Climatic Research Unit (CRU) of University of East Anglia and Pakistan Meteorological Department real time series (PMD).

Dash et al (2007) have determined an increase of 0.25 ^{o}C/decade in the mean annual minimum temperature in India for post monsoon and winter seasons. Likewise Shrestha et al (2005) have found an increase of 0.04^{o}C from 1975 - 2005 in the mean temperature of Nepal. Similarly Islam et al (2007) have observed increase of 0.61^{o}C for Bangladesh from 1961-1990 while comparing observational data with PRECIS modeling data. In Turkey, Mikdat (1997) has indicated an increase of 1.1^{o}C during their study period from 1939 to 1989. A similar analysis was conducted by Zhou et al (2004) for southeast China for period 1979-1998 where they show an increase of 0.6^{o}C per decade of minimum temperature, a rate faster than that of maximum temperature. Similarly for other parts of the world an increase of 0.3 to 0.6^{o}C for different seasons has been observed by Russel et al (2004). It means the results of the rising temperature trends in Pakistan are in harmony with other published works in south Asia as well globally.

4.2. RAINFALL

4.2.1. Introduction

Like the rising trend of global temperature in 21^{st} century, no clear evidence with regard to long-term change in the global precipitation has been found (IPCC, 2001; Karl and Trenberth, 2003; Allen and Ingram, 2002). Recent studies show a rising trend of only 9mm, which is approximately 0.98% per decade for 20^{th} century (New et al. 2001). However, the above mentioned increase has been observed over high latitude areas and tropical oceans with a decrease over tropical lands (New et al., 2001; Kumar et al., 2003; Bosilovich et al., 2005). It is obvious that climate warming leads to increased moisture-holding capacity of air and cause changes in the characteristics of precipitation events, including their frequency, intensity, amount and duration Karl et al., 1995; Karl and Knight, 1998; Trenberth, 1999; Treydte et al, 2006). Other evidence for increasing precipitation rates can be found in Japan (Iwashima and Yamamoto, 1993), China (Zhai et al., 1999), Australia (Suppiah and Hennessy, 1996), and South Africa (Mason et al., 1999).

According to the IPCC (2001) report, it is estimated that although total rainfall increase may be smaller (1.0 - 3.4%) but its intensity was slightly larger (Allen and Ingram, 2002). Recent studies, based on climate models and past observational records, predict a future increase in droughts in the south of Europe as a result of increased evapo-transpiration and a relatively slow decrease of rainfall and precipitation frequency (Kostopoulou and Jones, 2005; Vicente-Serrano and Cuadrat-Prats, 2007).

4.2.2. Data Collection and Analysis

In order to analyze spatial and temporal variations in the mean rainfall of study area similar statistical treatment of the data was likewise carried out as mentioned in the previous section on Temperature analysis.

4.2.3. Results

4.2.3.1. Descriptive statistics and ANOVA results

Mean monthly and mean annual precipitation data of the same 30 stations of the study area for 30 years has been statistically analyzed. It was observed that the distribution of precipitation is not normal on the basis of large inter-annual variations. Therefore, rainfall data was analyzed using ANOVA and Dunnett T_3 for multiple comparison of alpha 0.05 between the decadal analyses. The principle feature of these methods is that they can be used for analyses of datasets which do not display a normal distribution. In order to show deviation of annual zonal data from average values, statistical indicators such as standard error, skewness, percentile, 5% trimmed mean and median were calculated. Results of the descriptive statistical analysis are presented in Table 4.13 including ANOVA result for rainfall of the study area.

It is evident from these statistical indicators that highest zonal means and medians were observed for zone1 (66.64 mm, 57.22 mm) and zone2 (66.99 mm, 57.05 mm) for 30 years average rainfall while zone 3b shows the lowest value of mean (22.65 mm) and median (19.29 mm) respectively. Similarly other statistics such as standard error, 95% confidence interval and quartile all are also higher for zone1 and 2 as compared to other zones. The skewness shows positive values for all five zones with zone3a and 4 being higher. Results of the ANOVA test are most significant ($F= 71.64$, $p= 0.00$) not only within each zone but also for inter-zonal analysis on decadal and inter-decadal scales. In Dunnett T3 test (Fig. 4.8 & Table. 4.6 in Annexure) all zones are quite different from each other but not significant except zone3a and zone4 which show significance ($p< 0.05$) in the last two decades i.e. 1986-1995 and 1996-2005.

Table. 4.13 Descriptive statistics and ANOVA result of rainfall for all climate zones.

Rainfall (F= 71.64, p= 0.00)						
		Zone 1	**Zone 2**	**Zone 3a**	**Zone 3b**	**Zone 4**
Stations		10	6	4	6	4
30 Years	Valid/Missing values	297/3	175/5	116/4	172/8	118/2
Mean	All value used	66.64	66.99	32.92	22.65	32.10
	5%trimmed Mean	64.72	64.42	31.74	21.76	29.62
Median		57.22	57.05	30.47	19.29	25.04
Std. Error		2.70	2.77	1.39	1.05	2.35
95%CI	Lower Bound	61.31	61.52	30.16	20.58	27.45
	Upper Bound	71.96	72.46	35.68	24.72	36.75
Percentile	25	23.25	39.02	24.16	13.80	13.02
	50	57.22	57.05	30.47	19.29	25.04
	75	107.18	90.34	39.59	29.16	48.16
Skewness		0.46	1.12	1.56	1.15	1.45

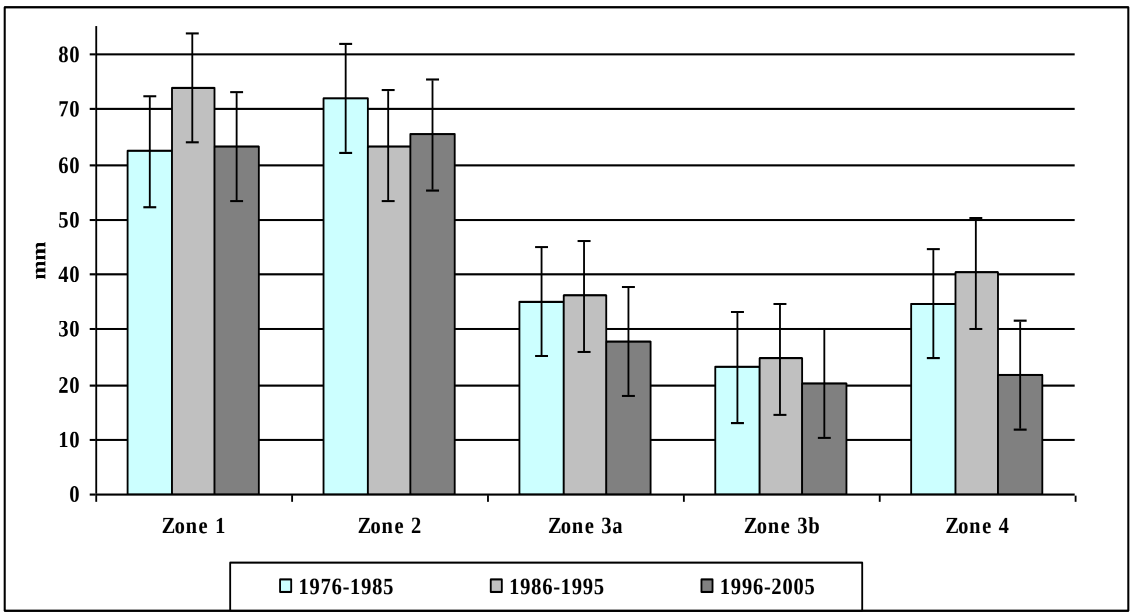


Figure: 4.8. Mean annual rainfall in all climate zones of the study area. Zone3a and Zone4 show significance at p= 0.05 level.

The overall trend for the study area is most significant for intra-decadal and inter-decadal comparison with ($p<0.05$) as shown in Table 4.14 and Fig.4.9 (Table.4.7 in Annexure).

Table. 4.14 Descriptive statistics and ANOVA result for the whole study area

Whole Study area						95% CI for Mean	
	N	F-value	Sig.	Mean	Std. Error	Upper	Lower
Mean Rainfall	30	3.65	0.04	48.99	1.38	46.16	51.82

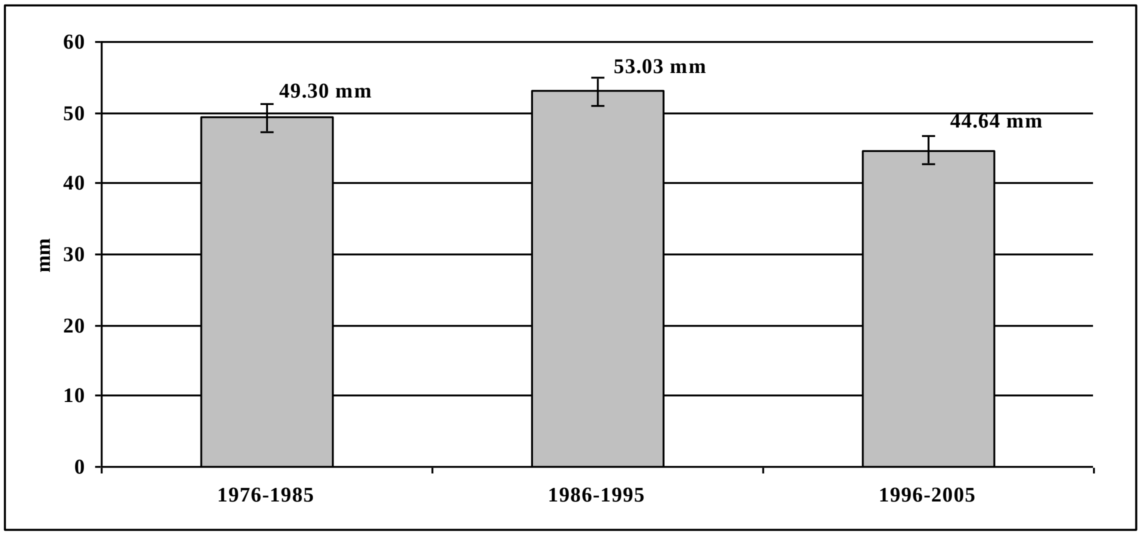


Figure: 4.9. Mean annual rainfall in the whole study area. Show significant decrease at p=0.0.5 level.

4.2.3.2. Zonal analysis

Similar calculations have been carried out for rainfall data analysis, as were done for the maximum and minimum temperature, except the Dunnett T3 test because rainfall data show unequal variances in homogeneity test (mainly used for equality of means).

4.2.3.2.1. Zone1

Probability for zone1 ($F=1.93$ $p=0.15$) is not significant as the computed values are higher than the critical value ($p> 0.05$). However, different stations of zone1 such as Chitral ($p=0.00$), Dir ($p=0.05$), Muzaffarabad ($p=0.02$), Skardu ($p=0.04$) and Said-U-Sharif ($p=0.00$) show most significant results (Table 4.15). Similarly, results of Dunnett T3 test for multiple comparison (Table 4.16) show most significant trend ($p<0.05$) in the mean rainfall of Chitral, Dir, Muzaffarabad, Skardu and Said-U-Sharif stations for all three decades.

Table. 4.15 Descriptive statistics and ANOVA result for zone 1

Zone1 (F= 1.93, p= 0.15)						95% C I for Mean	
Station	**N**	**F-value**	**Sig.**	**Mean**	**Std. Error**	**Lower**	**Upper**
Astor	29	0.08	0.92	43.83	2.49	38.72	48.94
Chilas	30	2.24	0.13	19.33	2.01	15.22	23.45
Chitral	30	10.40	0.00	40.29	2.20	35.78	44.79
Dir	30	3.47	0.05	123.98	4.44	114.90	133.07
Gilgit	30	0.22	0.81	14.82	1.37	12.03	17.62
Kakul	28	2.23	0.13	116.84	3.64	109.36	124.32
M-abad	30	4.59	0.02	132.52	4.39	123.55	141.49
P-Chinar	30	0.07	0.94	67.53	2.29	62.84	72.23
Skardu	30	3.81	0.04	20.84	1.50	17.76	23.91
S-Sharif	30	10.76	0.00	88.96	4.46	79.84	98.09

Table 4.16. Dunnett T3 test for multiple comparison

Stations	(I) Decade	(J) Decade	Mean Difference (I-J)	Sig.
Astor	1	2	2.24	0.98
		3	2.21	0.99
	2	1	-2.24	0.98
		3	-0.03	1.00
	3	1	-2.21	0.99
		2	0.03	1.00
Chilas	1	2	-5.73	0.25
		3	-9.98	0.24
	2	1	5.73	0.25
		3	-4.25	0.79
	3	1	9.98	0.24
		2	4.25	0.79
Chitral	1	2	-18.84	0.00
		3	-12.45	0.03
	2	1	18.84	0.00
		3	6.39	0.42
	3	1	12.45	0.03
		2	-6.39	0.42
Dir	1	2	-19.80	0.12
		3	5.38	0.92
	2	1	19.80	0.12
		3	25.17	0.11
	3	1	-5.38	0.92
		2	-25.17	0.11
Gilgit	1	2	-2.03	0.94
		3	-1.87	0.87
	2	1	2.03	0.94
		3	0.17	1.00
	3	1	1.87	0.87
		2	-0.17	1.00

Kakul	1	2	-2.19	0.99
		3	15.08	0.28
	2	1	2.19	0.99
		3	17.27	0.25
	3	1	-15.08	0.28
		2	-17.27	0.25
M-abad	1	2	-26.16	0.03
		3	-1.94	1.00
	2	1	26.16	0.03
		3	24.22	0.07
	3	1	1.94	1.00
		2	-24.22	0.07
Parachinar	1	2	1.78	0.98
		3	-0.11	1.00
	2	1	-1.78	0.98
		3	-1.88	0.98
	3	1	0.11	1.00
		2	1.88	0.98
Skardu	1	2	-9.30	0.02
		3	-4.72	0.42
	2	1	9.30	0.02
		3	4.58	0.58
	3	1	4.72	0.42
		2	-4.58	0.58
S-Sharif	1	2	-38.21	0.00
		3	-11.50	0.42
	2	1	38.21	0.00
		3	26.71	0.01
	3	1	11.50	0.42
		2	-26.71	0.01

4.2.3.2.2. Zone2

ANOVA test applied on zone2 data (Table 4.17) display non significant results for all six stations ($p > 0.05$ or 0.1). Similarly zone2 is also observed with non-significant trend for the mean rainfall. No significant change is noted in Dunnett T3 test (Table 4.18) between decadal and inter-decadal analysis of the stations.

Table. 4.17 Descriptive statistics and ANOVA result for zone2

Zone2 (F= 0.91, p= 0.41)						**95% CI for Mean**	
Station	**N**	**F-value**	**Sig.**	**Mean**	**Std. Error**	**Lower**	**Upper**
Cherat	27	0.46	0.64	54.35	2.80	48.59	60.11
DIK	30	0.54	0.59	29.58	1.62	26.27	32.88
Isl-bad	30	1.74	0.20	110.50	5.33	99.60	121.39
Lahore	30	2.61	0.09	69.35	6.15	56.78	81.92
Peshawar	28	0.17	0.84	42.61	2.43	37.63	47.60
Sialkot	30	0.05	0.95	92.67	5.34	81.75	103.59

Table. 4.18 Dunnett T_3 for multiple comparison

Stations	(I) Decade	(J) Decade	Mean Difference (I-J)	Sig.
Cherat	1	2	5.23	0.82
		3	6.40	0.83
	2	1	-5.23	0.82
		3	1.17	1.00
	3	1	-6.40	0.83
		2	-1.17	1.00
D.I.Khan	1	2	-4.00	0.65
		3	-0.97	0.99
	2	1	4.00	0.65
		3	3.03	0.82
	3	1	0.97	0.99
		2	-3.03	0.82
Isl-bad	1	2	20.09	0.42
		3	20.99	0.32
	2	1	-20.09	0.42
		3	0.90	1.00
	3	1	-20.99	0.32
		2	-0.90	1.00
Lahore	1	2	31.74	0.18
		3	22.41	0.49
	2	1	-31.74	0.18
		3	-9.33	0.66
	3	1	-22.41	0.49
		2	9.33	0.66
Peshawar	1	2	1.79	0.98
		3	-1.91	0.99
	2	1	-1.79	0.98
		3	-3.70	0.94
	3	1	1.91	0.99
		2	3.70	0.94
Sialkot	1	2	-4.26	0.98
		3	-1.19	1.00
	2	1	4.26	0.98
		3	3.07	0.99
	3	1	1.19	1.00
		2	-3.07	0.99

4.2.3.2.3. Zone3a

Two stations i.e. Khuzdar (p=0.04) and Quetta (p=0.02) are most significant to the change while Kalat and Zhob show no trend in the 30 years mean rainfall as shown in Table 4.19. The ANOVA result for zone3a (F=3.81, p=0.03) is found most significant to the change. Multiple comparisons for the decades show no significance for Kalat & Zhob while Quetta and Khuzdar ($p < 0.05$) are significant in the last two decades (Table 4.20).

Table. 4.19 Descriptive statistics and ANOVA result for zone3a

Zone3a (F= 3.81, p= 0.03)						**95% C I for Mean**	
Station	**N**	**F-value**	**Sig.**	**Mean**	**Std. Error**	**Lower**	**Upper**
Kalat	26	0.94	0.41	28.47	3.12	22.04	34.90
Khuzdar	30	3.67	0.04	31.12	2.29	26.45	35.80
Quetta	30	4.88	0.02	40.47	3.46	33.40	47.55
Zhob	30	1.85	0.18	31.02	1.58	27.79	34.25

Table. 4.20 Dunnett T3 for multiple comparisons

Stations	**(I) Decade**	**(J) Decade**	**Mean Difference (I-J)**	**Sig.**
Kalat	1	2	-10.94	0.44
		3	-9.08	0.56
	2	1	10.94	0.44
		3	1.85	0.99
	3	1	9.08	0.56
		2	-1.85	0.99
Khuzdar	1	2	-5.82	0.65
		3	8.06	0.18
	2	1	5.82	0.65
		3	13.88	0.08
	3	1	-8.06	0.18
		2	-13.88	0.08
Quetta	1	2	12.73	0.41
		3	23.48	0.06
	2	1	-12.73	0.41
		3	10.75	0.04
	3	1	-23.48	0.06
		2	-10.75	0.04
Zhob	1	2	-5.60	0.42
		3	1.18	0.99
	2	1	5.60	0.42
		3	6.78	0.21
	3	1	-1.18	0.99
		2	-6.78	0.21

4.2.3.2.4. Zone 3b

Like zone2, ANOVA Table (4.21) for zone3b also show no significant trend (p> 0.05) for all stations of the zone. Besides, the test for analysis of variance of the zone is also found non-significant (F=1.53, p=0.22). Table 4.22 depicts no significant trend in the Dunnett T3 test for multiple comparisons of the decades.

Table. 4.21 Descriptive statistics and ANOVA result for zone3b

Zone 3b (F=1.53,p= 0.22)						**95% CI for Mean**	
Station	**N**	**F-value**	**Sig.**	**Mean**	**Std. Error**	**Lower**	**Upper**
B-Pur	30	0.65	0.53	23.19	2.75	17.57	28.81
Jaco-bad	23	1.20	0.32	21.65	3.36	14.68	28.62
Khanpur	29	1.08	0.36	16.00	1.96	11.98	20.03
Multan	30	0.36	0.70	25.64	2.06	21.43	29.85
Rohri	30	0.89	0.42	25.77	3.05	19.53	32.01
Sibbi	30	0.09	0.92	23.17	1.94	19.20	27.15

Table. 4.22 Dunnett T3 for multiple comparison

Stations	**(I) Decade**	**(J) Decade**	**Mean Diff (I-J)**	**Sig.**
B-Pur	1	2	6.35	0.82
		3	7.02	0.75
	2	1	-6.35	0.82
		3	0.67	1.00
	3	1	-7.02	0.75
		2	-0.67	1.00
Jaco-bad	1	2	1.81	1.00
		3	11.13	0.35
	2	1	-1.81	1.00
		3	9.32	0.73
	3	1	-11.13	0.35
		2	-9.32	0.73
Khanpur	1	2	-5.22	0.52
		3	1.48	0.99
	2	1	5.22	0.52
		3	6.70	0.49
	3	1	-1.48	0.99
		2	-6.70	0.49
Multan	1	2	-0.56	1.00
		3	3.45	0.89
	2	1	0.56	1.00
		3	4.01	0.81
	3	1	-3.45	0.89
		2	-4.01	0.81

Rohri	1	2	-9.52	0.50
		3	-2.13	0.98
	2	1	9.52	0.50
		3	7.39	0.77
	3	1	2.13	0.98
		2	-7.39	0.77
Sibbi	1	2	-1.54	0.98
		3	-1.94	0.97
	2	1	1.54	0.98
		3	-0.40	1.00
	3	1	1.94	0.97
		2	0.40	1.00

4.2.3.2.5. Zone 4

The ANOVA Table for zone4 (4.23) shows most significant result (F=5.92, p=0.00) compared to other climatic zones of the country. Karachi station is observed with most significant trend for thirty years average rainfall. The rest of stations i.e. Hyderabad, Jewani and Nawabshah are not found significant for change during decadal analysis in the Dunnett T3 test (Table 4.24).

Table 4.23 Descriptive statistics and ANOVA result for zone4

Zone 4 (F= 5.92, p= 0.00)						**95% CI for Mean**	
Station	**N**	**F-value**	**Sig.**	**Mean**	**Std. Error**	**Lower**	**Upper**
H-abad	30	1.53	0.24	36.01	6.12	23.50	48.52
Jewani	30	1.97	0.16	25.93	2.90	20.00	31.86
Karachi	29	4.87	0.02	35.20	3.93	27.16	43.25
N-Shah	29	2.20	0.13	31.34	5.20	20.69	41.98

Table.4.24 Dunnett T3 test for multiple comparison

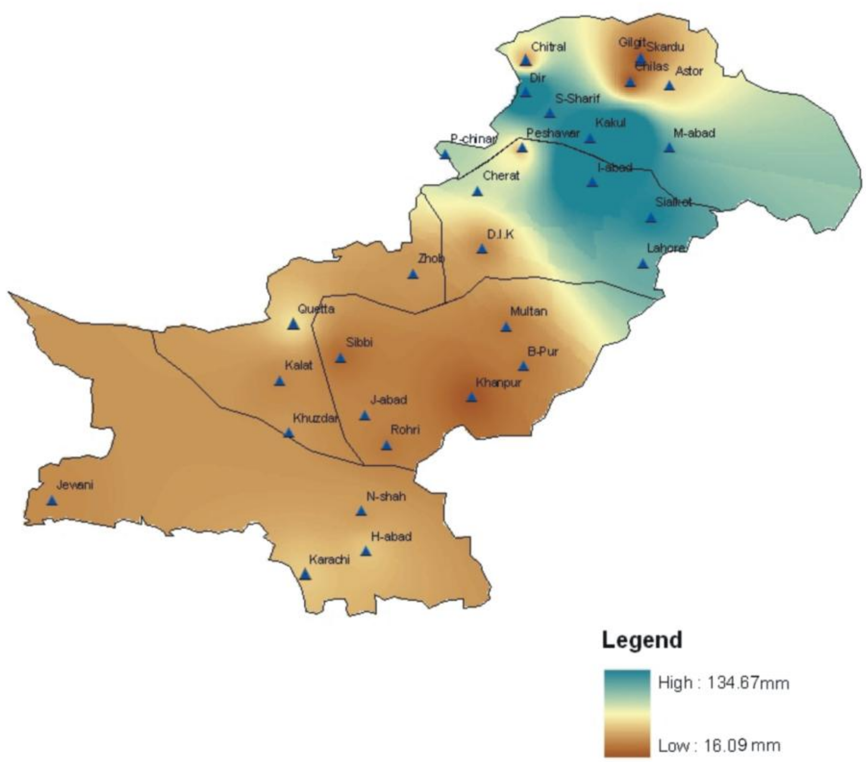
Stations	(I) Decade	(J) Decade	Mean Diff (I-J)	Sig.
H-abad	1	2	-13.79	0.75
		3	11.93	0.63
	2	1	13.79	0.75
		3	25.72	0.39
	3	1	-11.93	0.63
		2	-25.72	0.39
Jewani	1	2	-8.57	0.58
		3	4.91	0.80
	2	1	8.57	0.58
		3	13.48	0.21
	3	1	-4.91	0.80
		2	-13.48	0.21
Karachi	1	2	16.80	0.20
		3	25.77	0.01
	2	1	-16.80	0.20
		3	8.97	0.73
	3	1	-25.77	0.01
		2	-8.97	0.73
N-Shah	1	2	-16.13	0.40
		3	9.57	0.79
	2	1	16.13	0.40
		3	25.70	0.25
	3	1	-9.57	0.79
		2	-25.70	0.25

4.2.3.3. Single Station Analysis

By dividing the 30-years rainfall data into two 15-years periods (1976-1990 and 1991-2005) and computing change from the 1^{st} half period to the 2^{nd}, for each station, zone and the country, the results are outlined below. The average rainfall in the country was 50.48 mm during 1976-90 period while 47.5 mm was recorded for the 1991-2005 period. This shows a decline of 2.98 mm from the first half with non significant mean variance ($F=1.273$, $p= 0.259$).

The trend analysis for individual stations is presented in Table 4.8 (Annexure) and shown in Fig.4.10. The intensity of the map color shows mean inter-zonal rainfall variation from 134.19 - 16.09 mm in Fig.4.10 (A) to 130.19 - 14.26 mm (B) for different zones from the first half study period to the second half. Among the stations Chitral shows a significantly higher trend with 11.23 mm increase between the two 15-years periods while rest of the stations show an increasing trend in the range of 1 – 6 mm but with no significance value (p>0.05). On the other hand rainfall data for Quetta (-13.77mm) and Karachi (-14.72 mm) stations indicate a significant decrease in the mean rainfall during the second half period. Similarly Dir, Gilgit, Kakul, Muzaffarabad, Islamabad, Lahore, Kalat, Khuzdar, Bahawalpure, Khanpur, Hyderabad, Jewani, and Nawabshah stations also show decrease in the average rainfall, albeit with a non-significant trend. The overall difference in mean rainfall for each individual station is observed with a decreasing trend in the 1991-2005 period as compared to 1976-90. In the zonal analysis of rainfall, these zones show opposite trend to that as observed in case of minimum and maximum temperatures, having lower values of means (22.65 and 32.10 mm) and medians (19.29 and 25.04 mm) for zone3b and zone4, respectively.

(A)



(B)

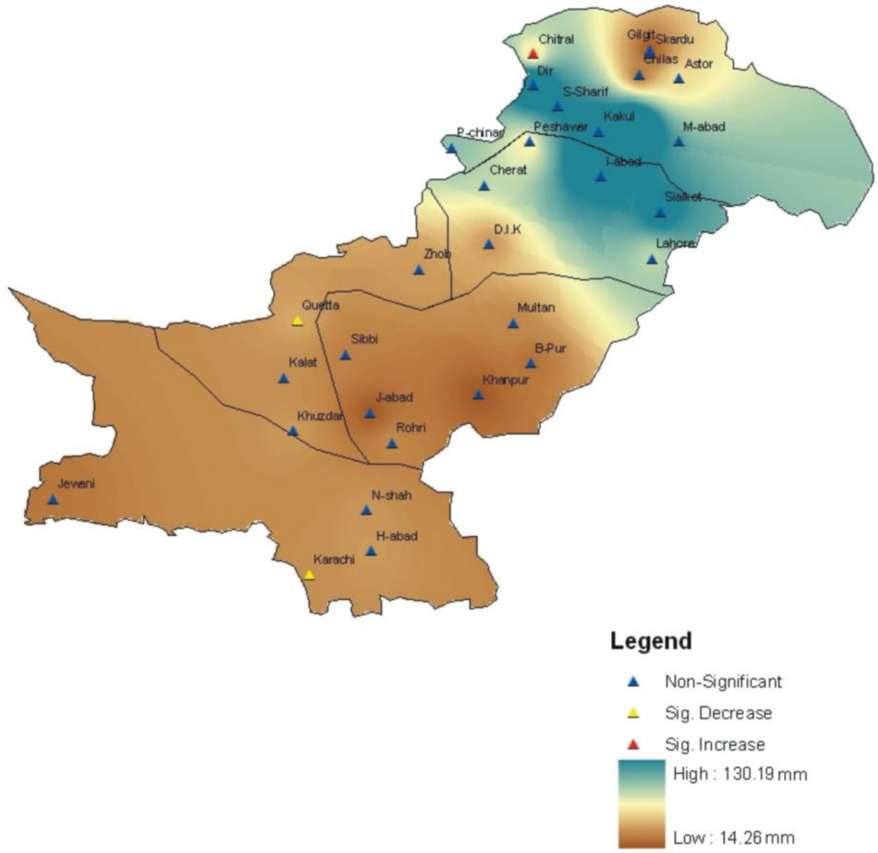
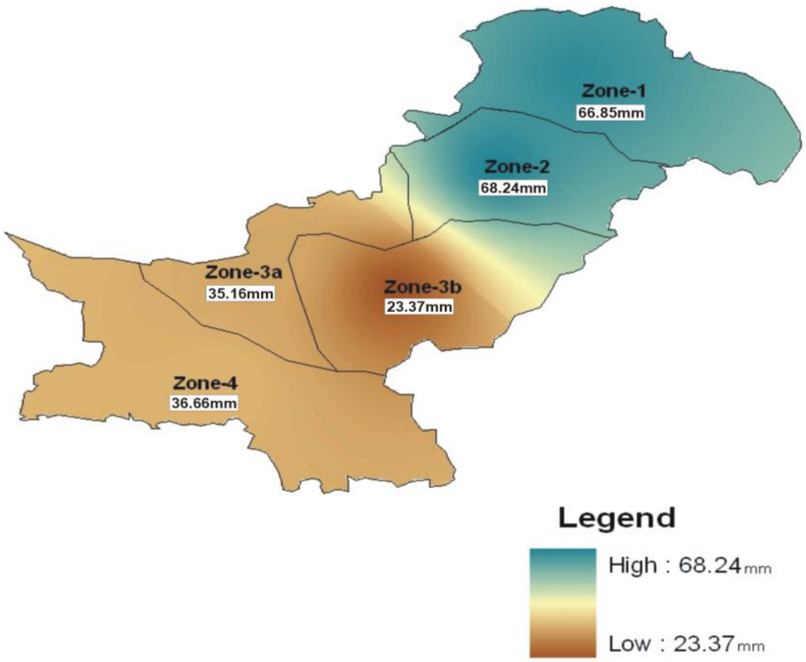


Figure 4.10: Map of Pakistan showing significant increase, decrease and no change in the mean annual rainfall. (A): For period 1976-1990; (B): For period 1991-2005.

4.2.3.4. Whole Study Area Analysis

It is evident that all five zones in Fig. 4.11 (A & B) and Table 4.9 (Annexure) show a decreasing trend in average rainfall between the two 15-year periods. Spatial variation in mean rainfall across the country ranges from 68.23 - 23.37 mm during 1976-90 period while it decreases to 66.41- 21.91 mm during 1991-2005 period. ANOVA test for the two periods is found most significant only for zone4 (F=3.719, p-0.05) which indicates a negative change in the mean rainfall (-8.96mm) followed by zone3a (-4.33mm) that also shows a higher decreasing trend with a relatively higher p-value (F= 2.439, p= 0.1) than the significant tabulated value.

(A)



(B)

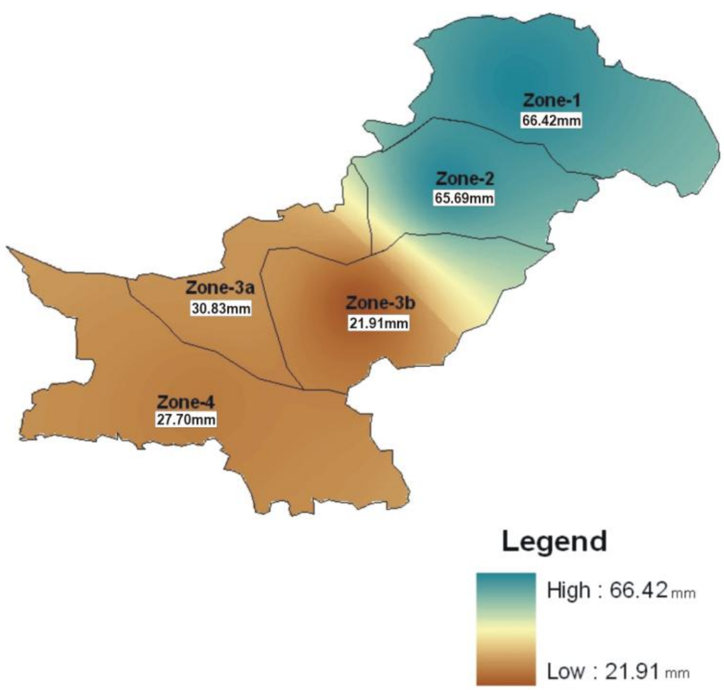


Figure 4.11: Whole study area analysis showing significant increase, decrease and no change in Mean annual rainfall (A): For period, 1976-1990; (B): For period, 1991-2005.

It can be summarized from the above analysis that the overall trend calculated for average rainfall is decreasing on both decadal and 15-years scales. Karachi and Quetta stations located in different zones show a significant downward tendency in rainfall while only Chitral station is found with an increasing trend. In the decade-wise analysis stations of zone1 like Dir, Muzaffarabad, Skardu, and Said-u-Sharif show a significant trend ($p<0.05$) but in terms of comparison between the two 15-years periods, all these stations show a non-significant trend ($p>0.05$). Similarly zone3a and zone4 are most significant in decadal analysis but in 15-years analysis zone3a is not much significant. ANOVA result for the country into two time periods is found non-significant ($F=1.273$, $p= 0.26$).

4.2.3.5. Entire Study Period Analysis

In Figure (4.12) the time series data of mean annual rainfall for the entire study period is observed with decreasing trend. Mean annual rainfall is showing up and down fluctuation but in last decade observed with sudden downfall. The highest mean annual rainfall was recorded in the year 1992 (63.9 mm) while lowest mean annual rainfall of 32.8mm - 35.8mm were observed in 1998-2002. The trend line generated through the scattered data point also indicates a downward trend for rainfall in the entire study period from 1976-2005.

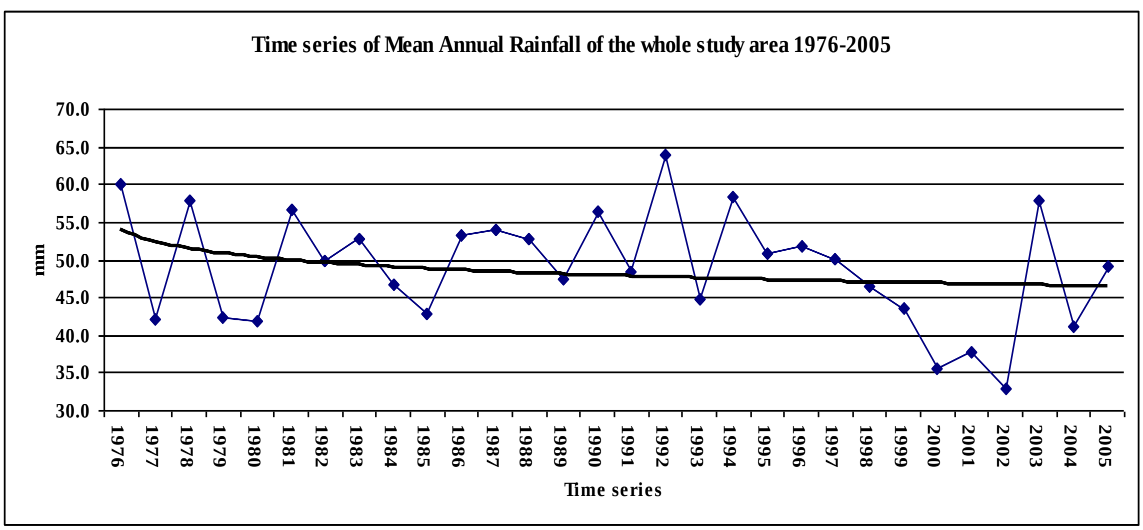


Figure: 4.12. Mean annual rainfall trend for the entire study period from 1976-2005.

4.2.4. Discussion

The analysis of rainfall data shows that zone1 (mean 66.64 mm & median, 57.22 mm) and zone2 (mean 66.99 mm and median 57.05 mm) show higher standard error (2.7mm). In the ANOVA test for decadal analysis, zone3a and zone4 were found most significant ($p<0.05$) and zone1 slightly significant, with probability approximately 85%. The single station analysis suggests that Chitral was found significantly higher with mean difference of 11.23mm in the two 15-year periods while rest of the stations were observed with a increasing trend in the range of 1 to 6 mm but with no significance value ($p>0.05$) except for Chilas ($p=0.09>0.05$) with approximately 90% of probability. Quetta (-13.77 mm) and Karachi (-14.72 mm) are observed with significantly lower mean value and Jacobabad (-12.2 mm) slightly significant mean value in the second half period. Similarly Dir, Gilgit, Kakul, Muzaffarabad, Islamabad, Lahore, Kalat, Khuzdar, Bahawalpure, Khanpur, Hyderabad, Jewani, and Nawabshah have shown decrease in the average rainfall with non significant trend. But in the decadal analysis Dir, Muzaffarabad, Skardu, and Said-u-Sharif were observed with a significant trend ($p<0.05$). The overall mean difference in the average rainfall for each individual station and for the country shows a decrease in from 1976-90 to the 1991-2005 periods. Zone4 was found most significant in comparison between the two time series ($p<0.05$) with a negative change in mean rainfall (-0.97 mm) followed by zone3a with slightly higher p-value approximately ($p=0.1$). It is also clear that zone1, zone3a and zone4 situated in different regions of the country showed an overall positive trend while plain areas and southwest of the country have been recorded with no significant trend during the last two decades.

The negative difference observed in rainfall data for the whole country is (-3.55 mm) between the two 15-years intervals, which works out to -1.18 mm per decade. This observational decrease in rainfall data is supported by the published data in IPCC (2001) report, which talks about 0.3% average decrease in rainfall per decade for the subtropical land areas as opposed to tropical lands with 0.3% increase per decade. Similarly most parts of Europe and East Asia are observed with a positive trend in the annual maximum consecutive days having rainfall below 1.0 mm and a negative trend in the number of rainy days during 1950-1995 period (Kiktev et al, 2003). The results of Kiktev et al (2003), were found relevant with the research conducted on the Mediterranean areas by

Trigo et al (2000), and Alpert et al (2002), during the period 1951-1995. Their research works, in the Mediterranean areas, indicate a larger frequency of drought periods, with associated impacts on agriculture, water resources and socio-economic activities. Decreasing trends in annual mean rainfall are observed in Russia, North-East and North China, coastal belts and most parts of North-East India, Indonesia, Philippines and some areas in Japan. Annual mean rainfall exhibits increasing trends in Western China, South-Eastern coast of China, Arabian Peninsula, Bangladesh and along the western coasts of the Philippines (IPCC, 2007). Liu et al (2005), analyzed heavy precipitation events in China over the period 1960-2000. They found that the increased frequency of heavy precipitation events in China contributed 95% of the total increase of precipitation and only 2% increase in total precipitation was observed over that time period. Otherwise total rainy days trend was observed negative. For India, Roy and Balling (2004), found about two thirds of increasing trend for precipitation extremes during all the study period from 1910–2000 and also observed some regions with significant increase and decrease all over India.

4.3. RIVER FLOWS

4.3.1. Introduction

Global warming induced changes in the temperature and rainfall trends and their impact on river flows are already evident in many parts of the world, particularly in South Asia. Heating of the earth is not only due to natural processes but mainly because of non-environment friendly anthropogenic activities (Rasul et al., 2006). Because of this phenomenon certain unpredictable changes occurred in the climate of Pakistan. Hazards like floods, droughts, cyclones and others adverse consequences are being experienced more frequently than ever before. Rising temperature and uneven temporal and spatial distribution of rainfall is causing floods on one hand and droughts on the other. These extreme weather events have altered the hydrological cycle globally and resulted in the intensification of available water resources. (Lai et al., 1998; Vörösmarty et al. 2000; Allen and Ingram, 2002). Changes in water resources mainly depend on changes in precipitation and temperature. These climate variables have a direct effect on watersheds or rivers as changes in water flow or discharge resemble the overall nature of precipitation in large part because precipitation is the primary factor in determining surface runoff. The increased flow of water has been noted in higher latitude regions and decreases in sub-tropical areas. Demand for agricultural and domestic water in particular increases significantly at hotter and drier times of the year. Agriculture has always been the dominant end-user of surface water for irrigation. Meanwhile, demands for industry are also expected to rise and become a greater issue in competition with agricultural and domestic water supply.

4.3.2. Data Collection and Analysis

Temporal variability in river discharges was investigated for six gauge stations of five relevant rivers of the country, comprising 25-years data length.. ANOVA test was used to identify whether the time series has a declining or rising trend or no significant trend at all in decades and fifteen year periods.

4.3.3. Results

4.3.3.1. Descriptive statistics and ANOVA results

Duncan test was applied to the dataset of river flows also because of its equal variances. Table 4.25 indicates descriptive statistics for river discharges in the study area. Among the different rivers included in this study, the Indus river being the major river of the country shows the highest mean discharge and median values at both of its gauging stations i.e. Chilas (1786 & 1748 m^3/s) and its upstream station Skardu (1091 & 1052 m^3/s) respectively. The smallest mean and median discharge among the studied rivers is shown by the Swat River (87 & 89 m^3/s) and Astor River (138 & 135 m^3/s). Swat River also has the lowest value of standard error i.e. 2.33 m^3/s and its distribution negatively skewed in comparison to other rivers with positively skewed.

The result of analysis of variance on decadal scale is most significant for Astor river ($F= 7.134$, $p= 0.00$) and in decreasing order for Swat river ($F= 5.488$, $p= 0.01$) and Indus river at Skardu ($F= 5.4$, $p= 0.01$) as shown in the Fig (4.13). ANOVA test shows that Chitral river ($F= 1.643$, $p= 0.22$), Indus at Chilas ($F= 0.992$, $p=0.39$), and Gilgit river ($F= 0.7$, $p= 0.51$) are non-significant. The homogenous subset of alpha (0.05) in Duncan test (Table 4.10 in Annexure), decadal means of all rivers are significantly different from each other and non-significant at all.

Table 4.25 Descriptive statistics and ANOVA result for ensuing rivers

Ensuing Rivers							
Rivers		**Astor**	**Chitral**	**Gilgit**	**Indus/Chilas**	**Indus/Skardu**	**Swat**
25 years	Valid/Missing values	25/0	25/0	25/0	25/0	25/0	25/0
Mean	All value used	137.65	276.59	612.9	1786.19	1091.19	87.24
	5% trimmed Mean	136.94	277.03	611.9	1771.17	1087.06	87.52
Median		134.99	275.06	608.9	1748.08	1052.47	88.79
Std. Error		5.9	5.48	12.32	51.96	37.57	2.33
95%CI	Lower Bound	125.47	265.28	587.5	1678.94	1013.64	82.43
	Upper Bound	149.84	287.89	638.3	1893.44	1168.74	92.05
Percentile	25	116.11	257.99	569.4	1534.93	919.04	80.24
	50	134.99	275.06	608.9	1748.08	1052.47	88.79
	75	162.27	294.59	652.9	1952.78	1251.6	94.19
Skewness		0.26	0.03	0.19	0.73	0.36	-0.46
ANOVA	**F-value**	7.134	1.643	0.7	0.992	5.4	5.488
	Sig.	0.00	0.22	0.51	0.39	0.01	0.01

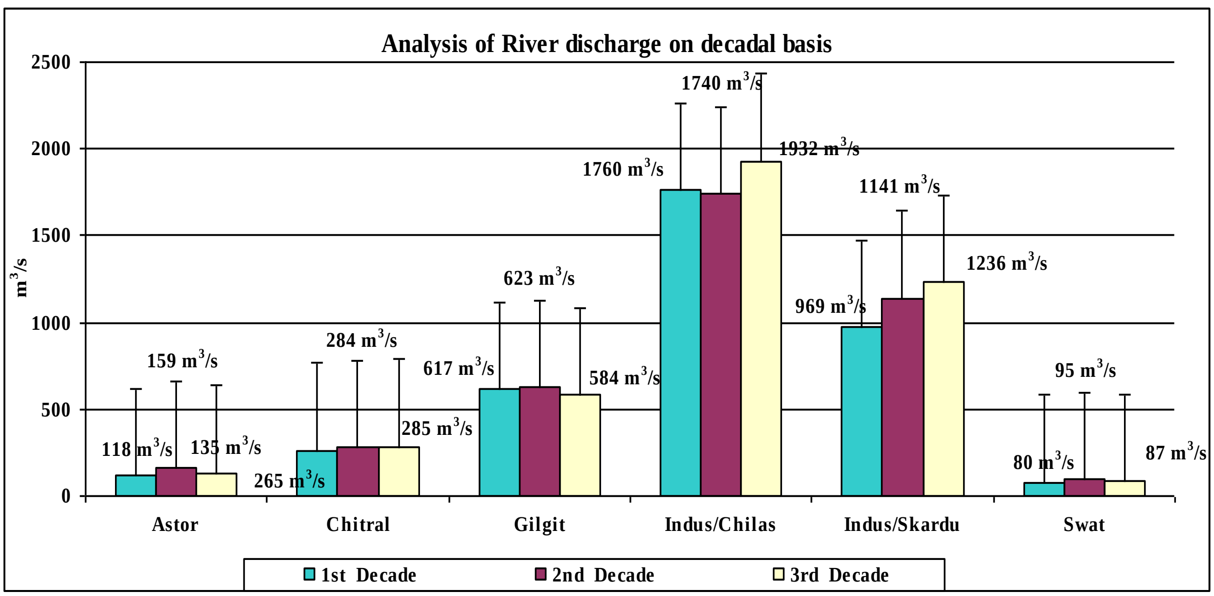


Figure 4.13: Single river discharge on decadal basis

4.3.3.2. Single Gauge-Station Analysis

Temporal variations in river discharge during the study period were examined by dividing the dataset into two unequal periods i.e. 15-years from 1976-90 and 10-years from 1991-2000. Analysis shown in Table 4.26 indicates that three out of six stations are most significant, having p- values less than 0.05, whereas the remaining are non-significant ($p>0.05$). The highest increasing trend in discharge was observed for Indus river at Skardu followed Chitral river with mean differences of 175.72 and 22.76 m^3/s respectively from the 1976-90 period to the 1991-2000 period.

Table. 4. 26 Single Gauge station data analysis for trend determination

River	F-value	Sig.	Mean (1976-1990)	Mean (1991-2000)	Mean Diff
Astor	3.07	0.09	129.54	149.82	20.27
Chitral	4.80	0.04	267.48	290.25	22.76
Gilgit	0.11	0.74	616.30	607.80	-8.51
Indus/Chilas	4.05	0.06	1705.74	1906.86	201.13
Indus/Skardu	6.44	0.02	1020.90	1196.62	175.72
Swat	4.96	0.04	83.31	93.14	9.83

The analysis of ensuing rivers has revealed mixed results. It is evident that both Indus/Skardu and Chilas and Swat rivers show significant increase and almost similar trend was observed for the Astor River. Further, on 15-years scale Chitral River shows a significant increasing trend but on decadal scale it shows no significance.

4.4. HYDRO-METEOROLOGICAL CHARACTERISTICS

Hydro-meteorological characteristics have been determined through water yield or contribution per annum in catchment's basin and each river basin analysis. In Table (4.27) Swat river shows highest value (1,366,352 m^3/s) of water contribution per annum in the catchments's area while Indus river at Skardu Station shows the lowest value (305,434 m^3/s) of water yield per annum.

Table. 4.27 Water Yield per Annum in Catchment's Basin

Ensuing Rivers (m^3/s)						
Rivers	**Astor**	**Chitral**	**Gilgit**	**Indus/Chilas**	**Indus/Skardu**	**Swat**
Mean	138	277	613	1786	1091	88
Catchment's Area (Km^2)	4040	11396	25900	142709	112665	2020
Water Yield Per Annum	1,074,488	766,622	746,271	394,714	305,434	1,366,352

4.4.1. River Basin Analysis

In this section characteristics of each river basin along with their temperature and rainfall record have been described to examine their influence on the river flow.

4.4.1.1. Astor River

Astor River, a tributary of the Indus River and rises in a glacier on the north-facing slopes of the great Himalayan, range near the Burzil Pass in the Ladakh region of Jammu and Kashmir. It flows in a northwesterly direction and joins Gilgit River at coordinates between 34°00′ and 74°41′ (Wikipedia, 2012). Many small snow-fed streams originating from different depressions on the great Himalayan range join the Astor River in its short course. Its catchment's area consists of 4040 km^2 and having U-shaped. As shown in Table (4.25) the mean annual discharge rate of Astor River is approximately 138 m^3/s, whereas the maximum discharge of 400 m^3/s takes place in July while the minimum discharge or base flow is recorded in February i.e. approx. 29 m^3/s (Table 4.28). A comparison of the mean monthly maximum temperature of Astor station for the month of July with the discharge of Astor river for the same month corresponds very well because the temperature of July (27.21 ^{o}C) is highest among all the months. In has been noted that although maximum rainfall takes place in the month of August but it does cause a significant increase in the discharge of Astor River. The table also shows that 49% flow takes place in the monsoon period i.e. Jul-Sep while 36% flow is received in the pre-monsoon period (Apr-Jun). The flow duration curve for Astor River (Fig. 4.14) indicates that approximate 35% of the time the discharge remains above the mean while 65% of the time the discharge is less than the mean. It also shows that up to 5% of the time the discharge in access of 200 to 500% of the mean flow. The time series plot for Astor River (Fig. 4.15) shows that the highest annual discharge took place in 1996 (200 m^3/s) whereas the lowest discharge of 88 m^3/s was recorded in 1985 and 1997. The trend line (best fit curve) generated by the software through the scattered data point also indicates a clear increasing in the discharge rate from 1976 to 2000. The same is corroborated by the ANOVA result presented in Table 4.3.

Table. 4.28 Hydro-meteorological characteristics of Astor River Basin

Astor River					
Months	**Mean Monthly Min Temp (°C)**	**Mean Monthly Max Temp (°C)**	**Mean Monthly Rainfall (mm)**	**Mean Monthly Discharge (m^3/s)**	**Mean Monthly Discharge (%age)**
Jan	-6.63	2.53	46.02	31.53	2
Feb	-6.14	4.25	44.12	28.78	2
Mar	-1.50	8.50	88.93	29.92	2
Apr	4.10	15.2	78.93	56.71	3
May	7.40	19.7	66.02	183.92	11
Jun	11.12	24.40	27.76	372	23
Jul	13.42	27.21	26.13	408.72	24
Aug	14.30	27.05	33.34	261.48	16
Sep	9.94	23.44	28.05	130.26	8
Oct	4.71	17.68	23.63	65.04	4
Nov	-1.10	11.30	27.54	46.71	3
Dec	-4.60	5.67	35.18	36.76	2

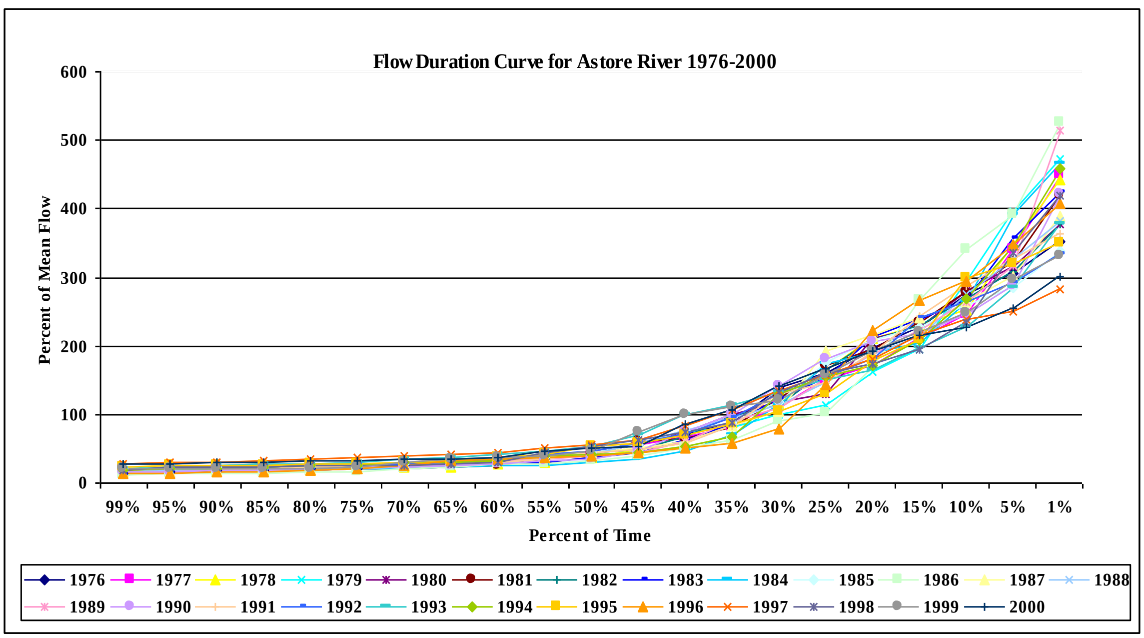


Figure: 4.14. Flow duration curve for Astor River from the period 1976-2000

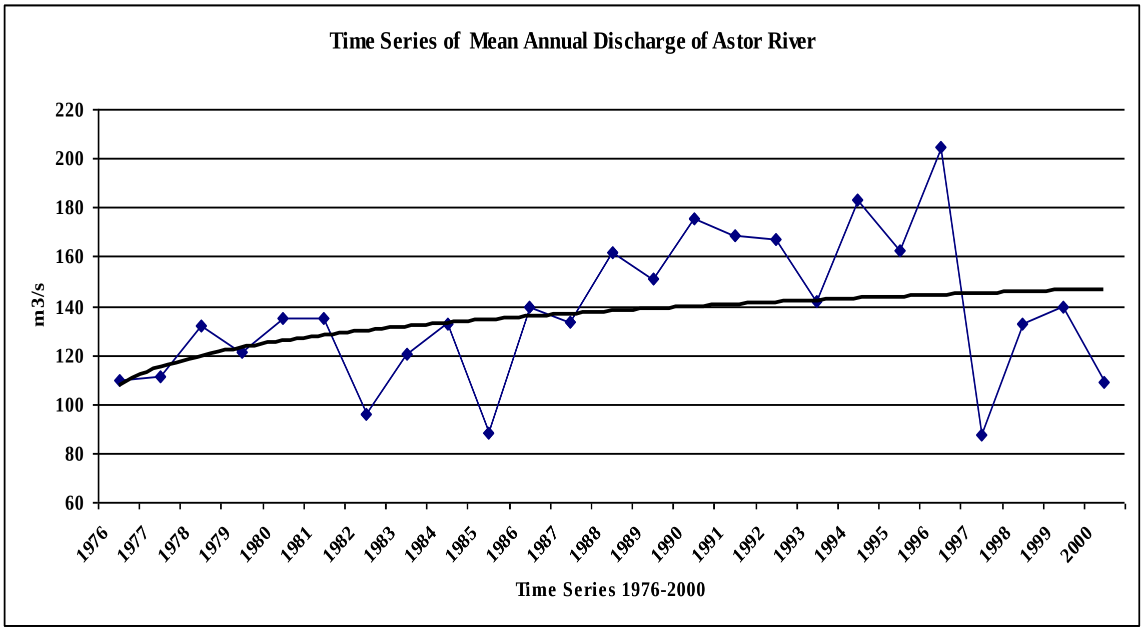


Figure: 4.15. Hydrograph of mean annual discharge of Astor River at Doyian station.

4.4.1.2. Chitral River

Chitral River is one of the major indirect tributaries of the Indus River arises near the Baroghil pass in Hindukush Mountains. The upper most section of the Chitral River is known as Yarkhum River, between Mastuj and Chitral towns and downstream it is called Chitral River located between 35^{o}50 and 71^{o}48. The drainage area of Chitral River at Chitral is 7080 km^2. According to WAPDA (1997b) that precipitation rate in Chitral river catchment's area is comparatively lows, especially the influence of the monsoon rainfall, which makes the more northern parts of the valley quite arid. Because of high altitude, precipitation mostly comes in the form of snowfall that feeds snowfields and glaciers of Hindukush Mountains. The dataset of Chitral River shows the mean annual discharge of 277 m^3/s (Table 4.25) with a strong monthly variance ranging from a maximum of 841.90 m^3/s in July to a minimum of 66.44 m^3/s in March (Table 4.29). It has also been noted from the weather record of Chitral station that on average July is the hottest and driest month of the year having mean maximum temperature of 36 ^{o}C and 8mm of average rainfall whereas the mean maximum temperature of March is about 15^{o}C and an average of 117mm rainfall. Hence it is clear that temperature has a profound influence on the snow/glacial melt in comparison to rainfall. The discharge of Chitral River increases almost 12 times from March to July. The analysis also shows that maximum flow (60%)

takes place in the monsoon period i.e. Jul-Sep followed by 23% flow in pre-monsoon period. The flow duration curve (Fig. 4.16) indicates that the discharge remains above the mean approximately 30% of the time while 60% of the time the discharge is less than the mean value. It also shows that up to 10% of the time the discharge in access of 300 to 900% of the mean flow. It means that snow/glacial cover of the area melt or retreats with respect to the climate and respond in similar way to seasonal and annual variations in discharge as suggested by Ferguson (1984). Plotting discharge values as time series (Fig.4.17) shows that the highest annual discharge took place in 1988 and 1992 (320 m^3/s) whereas the lowest discharge of 220 m^3/s was recorded in 1982. The trend line indicates a clear increasing trend in the discharge rate from 1976 to 2000. The same significance trend is shown by the ANOVA result presented in Table 4.3.

Table. 4.29 Hydro-meteorological characteristics of Chitral River Basin.

Chitral River					
Months	**Mean Monthly Min Temp (^oC)**	**Mean Monthly Max Temp (^oC)**	**Mean Monthly Rainfall (mm)**	**Mean Monthly Discharge (m^3/s)**	**Mean Monthly Discharge (%age)**
Jan	-0.51	9.45	47.82	77.15	2
Feb	0.80	10.68	57.19	68.36	2
Mar	3.91	14.83	117.27	66.44	2
Apr	8.28	22.60	70.45	90.61	3
May	12.12	28.31	43.28	191.34	6
Jun	16.92	34.14	14.61	463.97	14
Jul	19.99	36.02	8.39	841.90	25
Aug	18.48	34.56	6.49	758.03	23
Sep	13.10	31.73	14.14	386.19	12
Oct	7.16	25.29	18.35	172.03	5
Nov	2.59	18.94	30.40	112.77	3
Dec	0.23	12.53	39.36	90.27	3

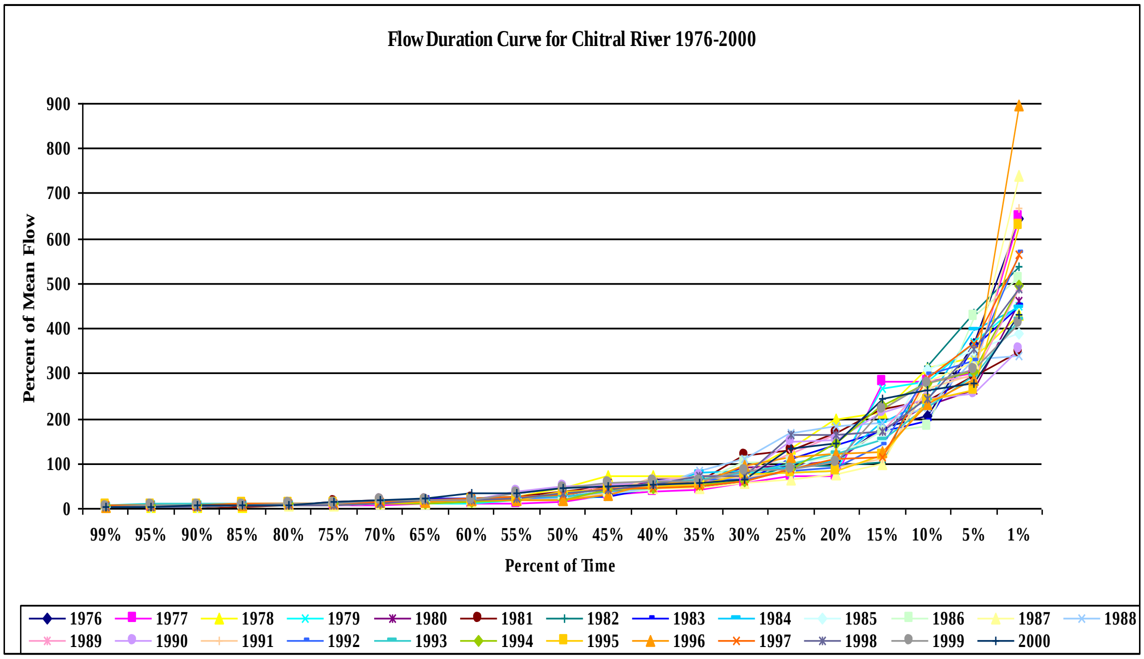


Figure: 4.16. Flow duration curve for Chitral River from the period 1976-2000

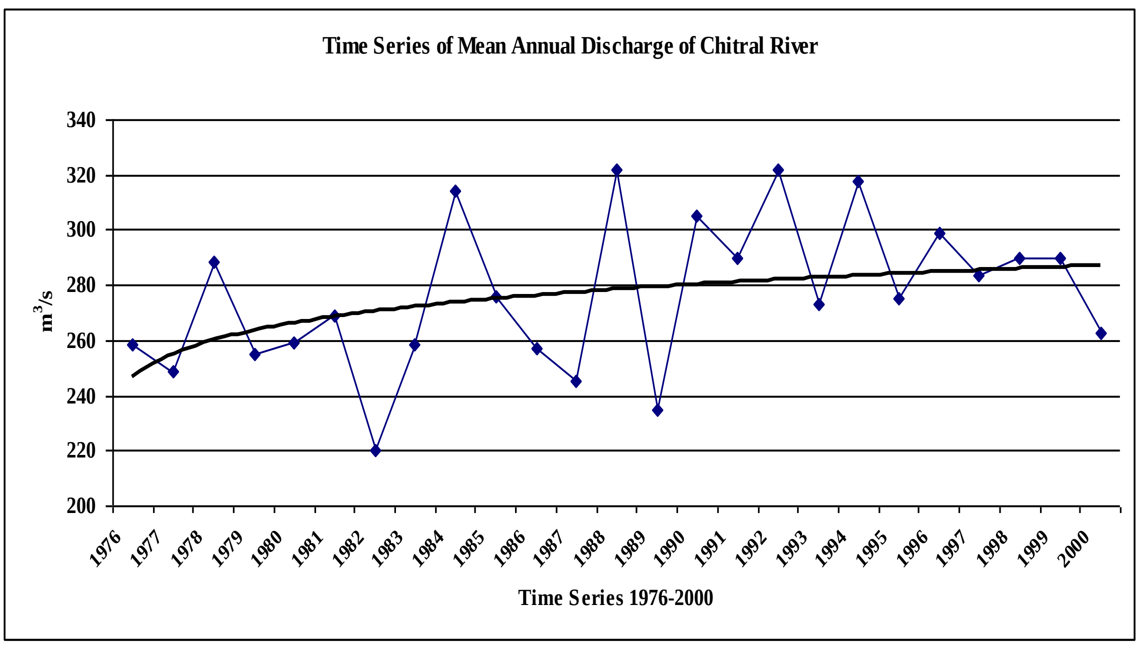


Figure: 4.17. Hydrograph of mean annual discharge of Chitral River at Kelash station.

4.4.1.3. Gilgit River

Gilgit River is a tributary of the Indus River, and flows past the town of Gilgit. It is located in the Northern Areas of Gilgit–Baltistan, Pakistan. The Gilgit starts from

Shandur Lake. Gilgit River at Alam Bridge is a junction point between Indus and Gilgit rivers at coordinates between 35^o 45’ and 74 ^{o} 37’. The drainage area of Gilgit river at Alam bridge is 25900 Km^2. Likewise, the Gilgit River shows the maximum discharge rate in July i.e., approximately 2030 m^3/s with highest mean maximum temperature of 36^{o}C while minimum discharge rate is recorded in March (95 m^3/s) with mean maximum temperature of 18^{o}C as shown in the Table 4.30. Further mean annual discharge rate from 1976-2000 is found 613 m^3/s as indicated in the Table 4.25. The table also shows that 63% flow takes place in the monsoon period i.e. Jul-Sep while 25% flow is received in the pre-monsoon period (Apr-Jun). The flow duration curve for Gilgit River (Fig. 4.18) indicates that approximate 25% of the time the discharge remains above the mean while 65% of the time the discharge is less than the mean. It also shows that up to 15% of the time the discharge in access of 200 to 500% of the mean flow. The time series plot for Gilgit River (Fig. 4.19) shows that the highest annual discharge took place in 1978 (753 m^3/s) whereas the lowest discharge of 494 m^3/s was recorded in 1997. The trend line through the scattered data point also indicates a clear increasing in the discharge rate from 1976 to 2000. The same is corroborated by the ANOVA result presented in Table 4.3.

Table.4.30 Hydro-meteorological characteristics of Gilgit River Basin

Gilgit River					
Months	**Mean Monthly Min Temp (°C)**	**Mean Monthly Max Temp (°C)**	**Mean Monthly Rainfall (mm)**	**Mean Monthly Discharge (m^3/s)**	**Mean Monthly Discharge (%age)**
Jan	-1.98	10.06	4.57	115.90	2
Feb	-0.06	12.44	7.16	102.06	1
Mar	5.48	17.66	13.08	95.33	1
Apr	8.81	24.45	26.29	124.85	2
May	11.67	28.91	31.90	422.81	6
Jun	14.62	33.96	9.96	1222.36	17
Jul	17.41	36.43	15.59	2029.36	28
Aug	17.20	35.33	19.63	1791.04	24
Sep	12.44	32.09	11.84	821.46	11
Oct	6.28	25.54	9.53	310.19	4
Nov	0.24	18.52	5.68	181.43	2
Dec	-1.63	12.18	8.75	138.02	2

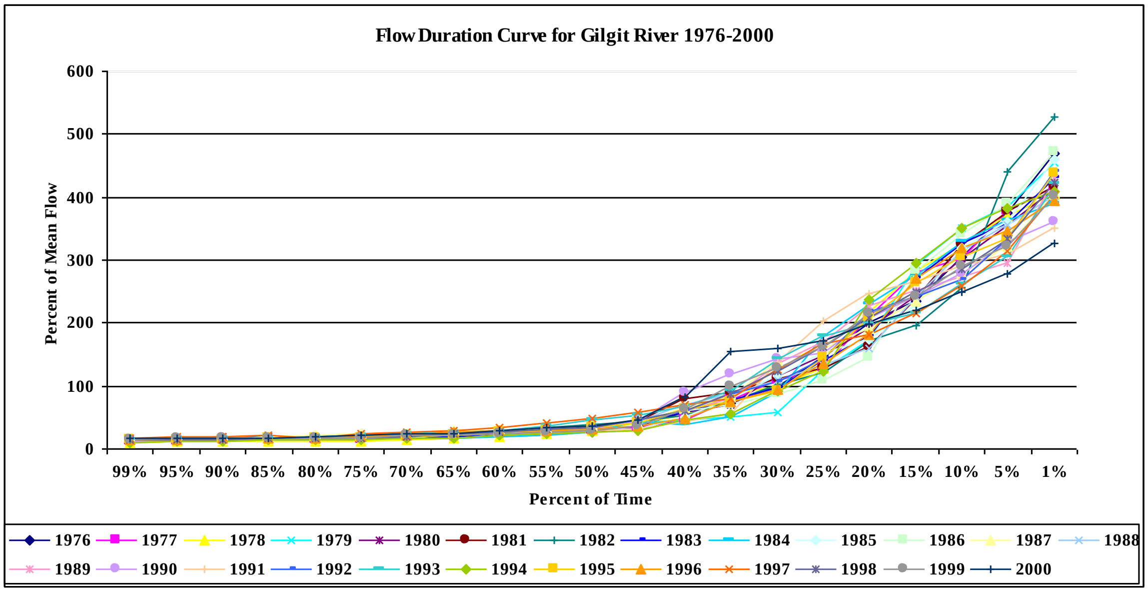


Figure: 4.18. Flow duration curve for Gilgit River from the period 1976-2000

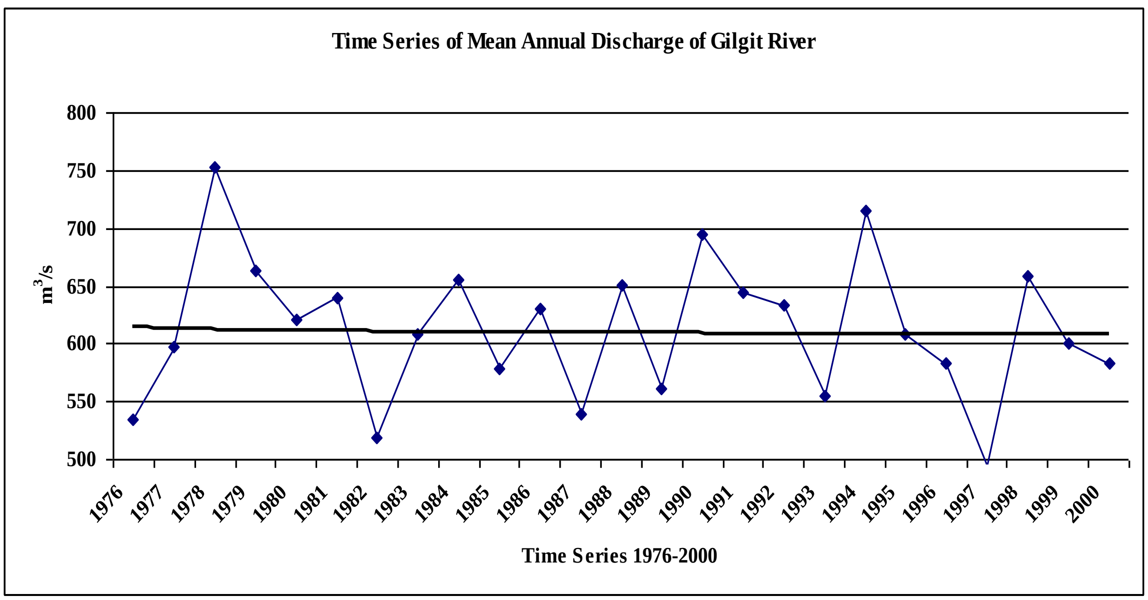


Figure: 4.19. Hydrograph of mean annual discharge of Gilgit River at Alam Bridge.

4.4.1.4. Indus River/Chilas

Indus river at Chilas station coordinates at 35^{o} 44’ to 74^{o} 37’ over the old suspension bridge, historically known as Partab Pul, it forms part of Astor district of the Gilgit-Baltistan region. The Gilgit River joins the Indus a few kilometers above Bunji, while the Astor River falls into the Indus a little below Bunji from the south-east. The total drainage area of Indus River at Chilas is 142709 Km^2. The data of Indus River at Chilas station indicates the mean annual discharge of 1786 m^3/s (Table 4.25) with monthly variance ranging from a maximum of 5657 m^3/s in July to a minimum of 307 m^3/s in March (Table 4.31). It has also been observed that July is the hottest and driest month of the year having mean maximum temperature of 39 ^oC and 14mm of average rainfall whereas the mean maximum temperature of March is about 19 oC and an average of 27mm rainfall. Hence it is clear that maximum flow (62%) takes place in the monsoon period i.e. Jul-Sep followed by 25% flow in pre-monsoon period. The flow duration curve (Fig. 4.20) indicates that the discharge remains above the mean approximately 25% of the time while 65% of the time the discharge is less than the mean value. It also shows that up to 15% of the time the discharge in access of 200 to 500% of the mean flow. Plotting discharge values as time series (Fig.4.21) shows that the highest annual discharge took place in 1977 (2412 m^3/s) whereas the lowest discharge of 1472 m^3/s was recorded in 1986. The trend line indicates a clear increasing trend in the discharge rate from 1976 to 2000. The same significance trend is shown by the ANOVA result presented in Table 4.3.

Table.4.31 Hydro-meteorological characteristics of Indus River Basin at Chilas

Indus River at Chilas					
Months	**Mean Monthly Min Temp (^oC)**	**Mean Monthly Max Temp (^oC)**	**Mean Monthly Rainfall (mm)**	**Mean Monthly Discharge (m^3/s)**	**Mean Monthly Discharge (%age)**
Jan	1.66	11.10	14.53	344.94	2
Feb	4.29	14.44	15.30	312.72	1
Mar	8.42	19.18	27.11	306.63	1
Apr	14.26	26.05	40.50	413.71	2
May	18.80	31.15	26.30	1249.12	6
Jun	24.03	36.98	14.49	3659.72	17
Jul	27.49	39.48	14.42	5675.64	27
Aug	26.48	38.43	11.08	5230.40	24
Sep	22.64	35.08	7.31	2424.24	11
Oct	14.79	28.24	15.31	875.02	4
Nov	7.70	20.88	17.31	532.50	3
Dec	2.38	13.90	16.27	409.61	2

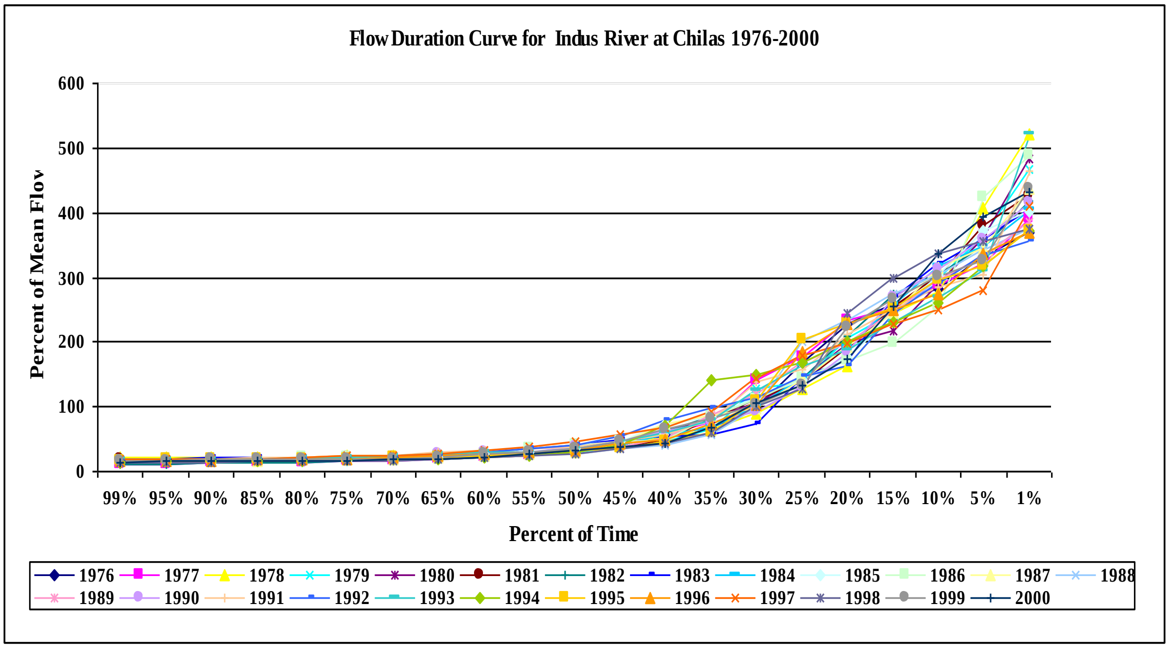


Figure: 4.20. Flow duration curve for Indus River/Chilas from the period 1976-2000

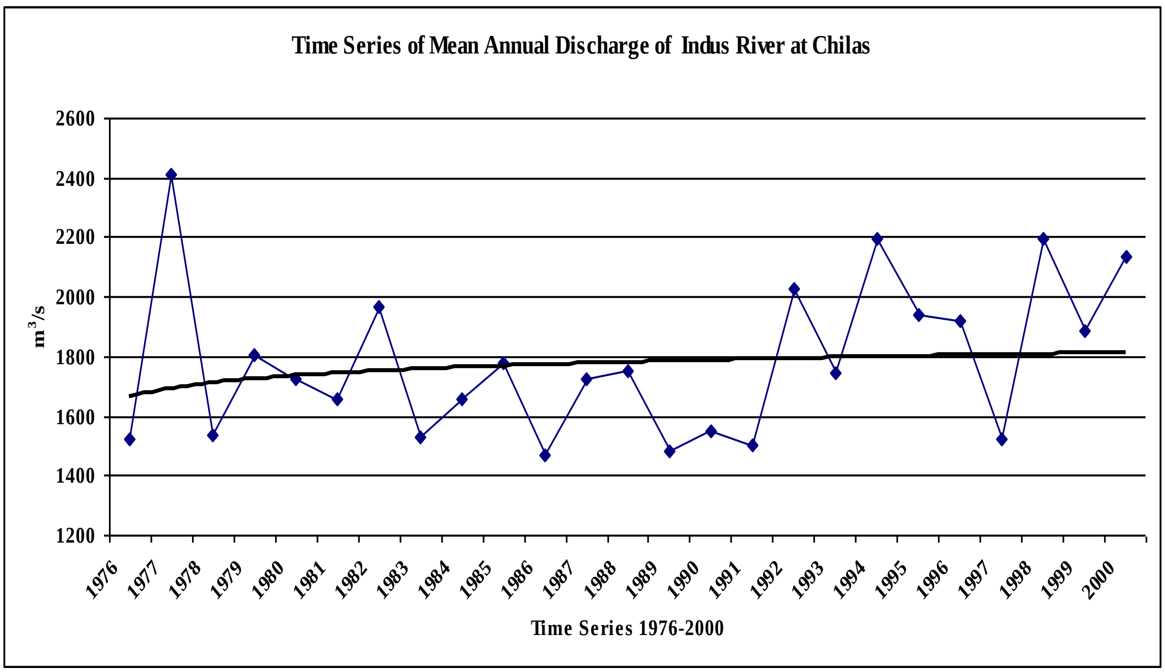


Figure: 4.21. Hydrograph of mean annual discharge of Indus river/Chilas at Partab Bridge

4.4.1.5. Indus River/Skardu

Indus River at Skardu located between coordinates 35^{o} 27’ and 75 ^{o} 25’ on right bank 32.18Km downstream from Skardu town, 3.22Km upstream Ayub bridge on

Kachura Kuwardo road. The drainage area of Indus River near Kachura is 112665 Km^2. As shown in Table (4.25) the mean annual discharge rate of Indus River at Skardu is approximately 1091 m^3/s, whereas the maximum discharge of 3461 m^3/s takes place in July with mean monthly maximum temperature 32 ^oC and average rainfall 11mm while the minimum base flow is recorded in March i.e. approx. 184 m^3/s with mean monthly temperature 12 ^oC (Table 4.32). The table also shows that 63% flow takes place in the monsoon period i.e. Jul-Sep while 24% flow is received in the pre-monsoon period (Apr-Jun). The flow duration curve for Indus River (Fig. 4.22) indicates that approximate 20% of the time the discharge remains above the mean while 60% of the time the discharge is less than the mean. It also shows that up to 20% of the time the discharge in access of 200 to 500% of the mean flow. The time series plot for Indus River (Fig. 4.23) shows that the highest annual discharge took place in 1994 (1442 m^3/s) whereas the lowest discharge of 811 m^3/s was recorded in 1978. The trend line (best fit curve) generated by the software through the scattered data point also indicates a clear increasing in the discharge rate from 1976 to 2000.

Table.4.32 Hydro-meteorological characteristics of Indus River Basin at Skardu

Indus River at Skardu					
Months	**Mean Monthly Min Temp (^oC)**	**Mean Monthly Max Temp (^oC)**	**Mean Monthly Rainfall (mm)**	**Mean Monthly Discharge (m^3/s)**	**Mean Monthly Discharge (%age)**
Jan	-7.76	2.99	34.30	200.82	2
Feb	-4.42	5.93	27.10	186.25	1
Mar	1.60	11.99	37.35	184.34	1
Apr	6.62	19.23	28.22	260.90	2
May	9.93	23.75	25.24	821.58	6
Jun	13.12	28.83	11.15	2122.84	16
Jul	16.46	32.07	11.38	3460.96	26
Aug	15.74	31.35	15.75	3234.76	25
Sep	11.44	27.75	11.89	1532.32	12
Oct	4.19	20.60	16.37	519.72	4
Nov	-1.51	13.64	14.53	325.52	3
Dec	-5.14	6.94	21.06	244.27	2

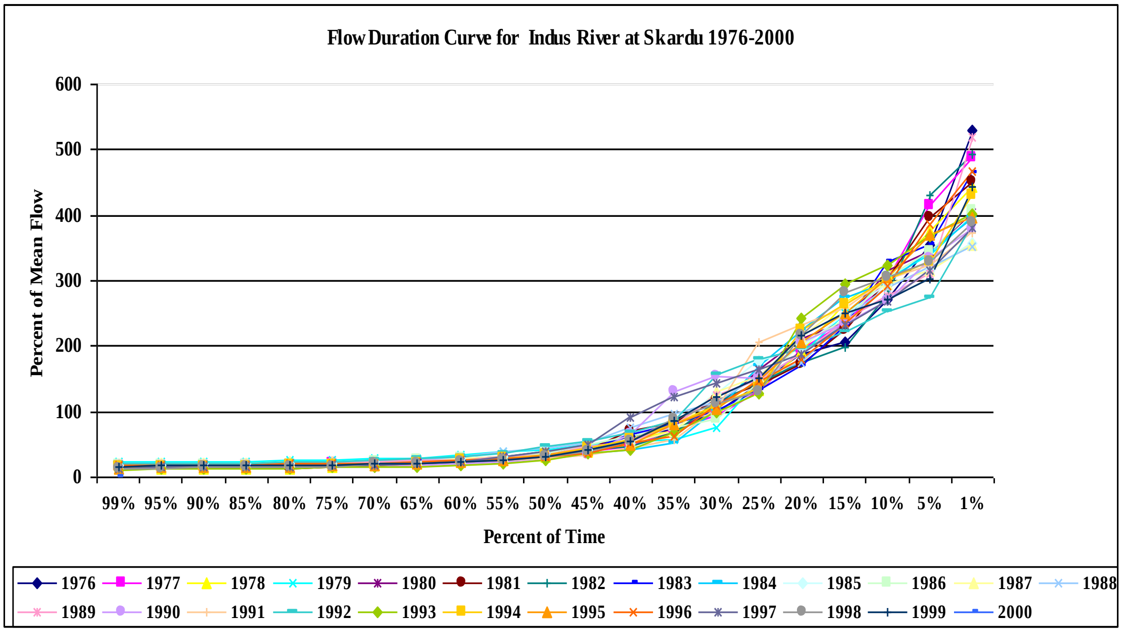


Figure: 4.22. Flow duration curve for Indus River/Skardu from the period 1976-2000

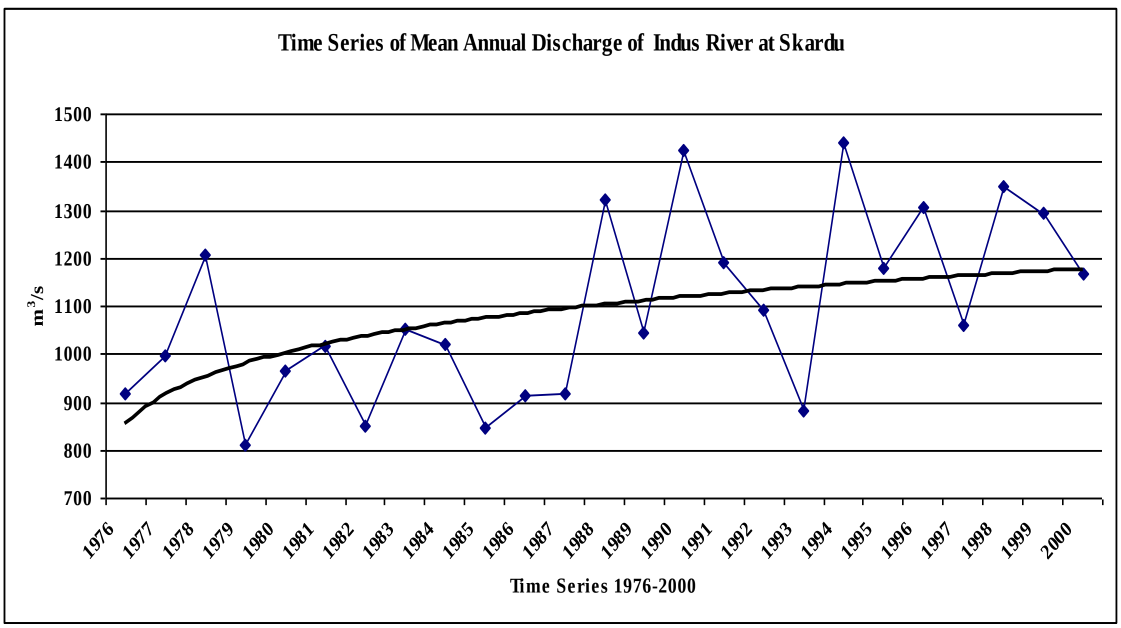


Figure: 4.23. Hydrograph of mean annual discharge of Indus River/Skardu at Kachura station.

4.4.1.6. Swat River

The main source of Swat River is in the Hindukush Mountains, from where it flows through the Kalam Valley and Swat District. From Lower Dir District it flows through Malakand District to enter the Kabul River at Charsadda in the Peshawar valley. The river is located at 35°30'and 72° 35'. The guage station is on the right bank of the river about 3.28 Km downstream from the Kalam village. The data of Swat River indicates the mean annual discharge of 87m^3/s (Table 4.25) with monthly variance ranging from a maximum of 261 m^3/s in July to a minimum of 16 m^3/s in March (Table 4.33). It has also been observed that maximum flow (48%) takes place in the monsoon period i.e. Jul-Sep followed by 41% flow in pre-monsoon period. The flow duration curve (Fig. 4.24) indicates that the discharge remains above the mean approximately 20% of the time while 60% of the time the discharge is less than the mean value. It also shows that up to 20% of the time the discharge in access of 200 to 500% of the mean flow. Plotting discharge values as time series (Fig.4.25) shows that the highest annual discharge took place in 1991 (110 m^3/s) whereas the lowest discharge of 60 m^3/s was recorded in 1982 and 2000. The trend line indicates a clear increasing trend in the discharge rate from 1976 to 2000. The same significance trend is shown by the ANOVA result presented in Table 4.3.

Table. 4.33 Hydro-meteorological characteristics of Swat River Basin

Swat River					
Months	**Mean Monthly Min Temp (°C)**	**Mean Monthly Max Temp (°C)**	**Mean Monthly Rainfall (mm)**	**Mean Monthly Discharge (m^3/s)**	**Mean Monthly Discharge (%age)**
Jan	1.71	13.88	84.23	15.35	1
Feb	4.06	15.57	107.86	14.15	1
Mar	7.84	19.31	179.21	16.17	2
Apr	12.17	26.40	120.36	47.04	5
May	16.58	32.50	69.35	131.43	13
Jun	20.25	36.42	47.23	244.02	23
Jul	22.79	34.32	144.05	261.45	25
Aug	21.72	32.86	121.54	164.04	16
Sep	17.79	31.77	75.17	77.48	7
Oct	12.05	27.62	54.53	35.09	3
Nov	6.40	22.06	31.69	23.03	2
Dec	3.42	16.50	53.09	17.63	2

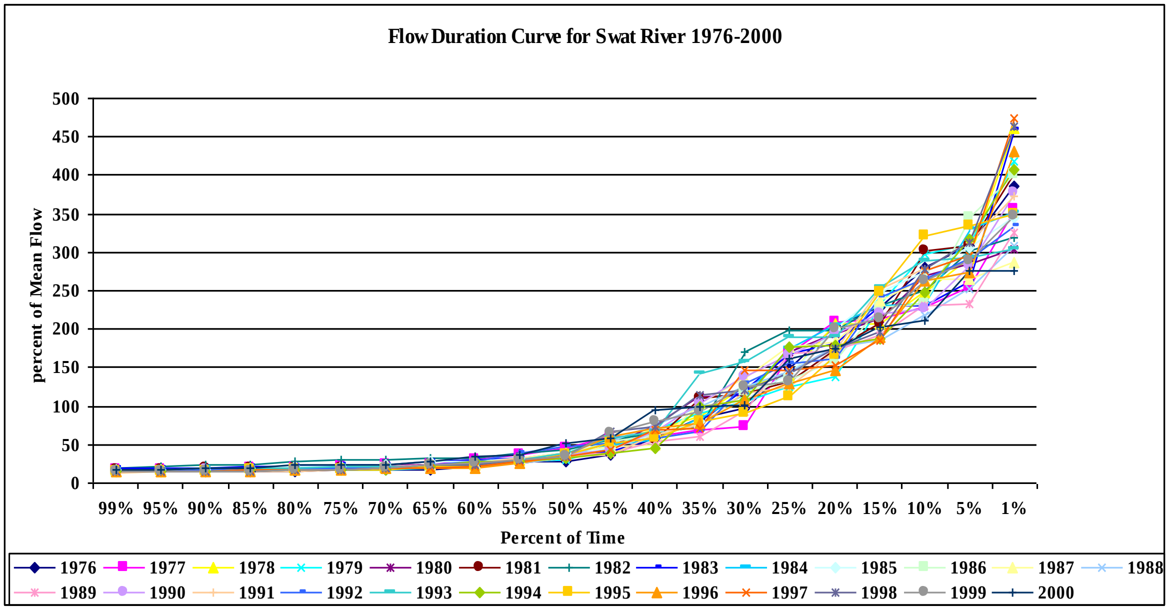


Figure: 4.24. Flow duration curve for Swat River from the period 1976-2000

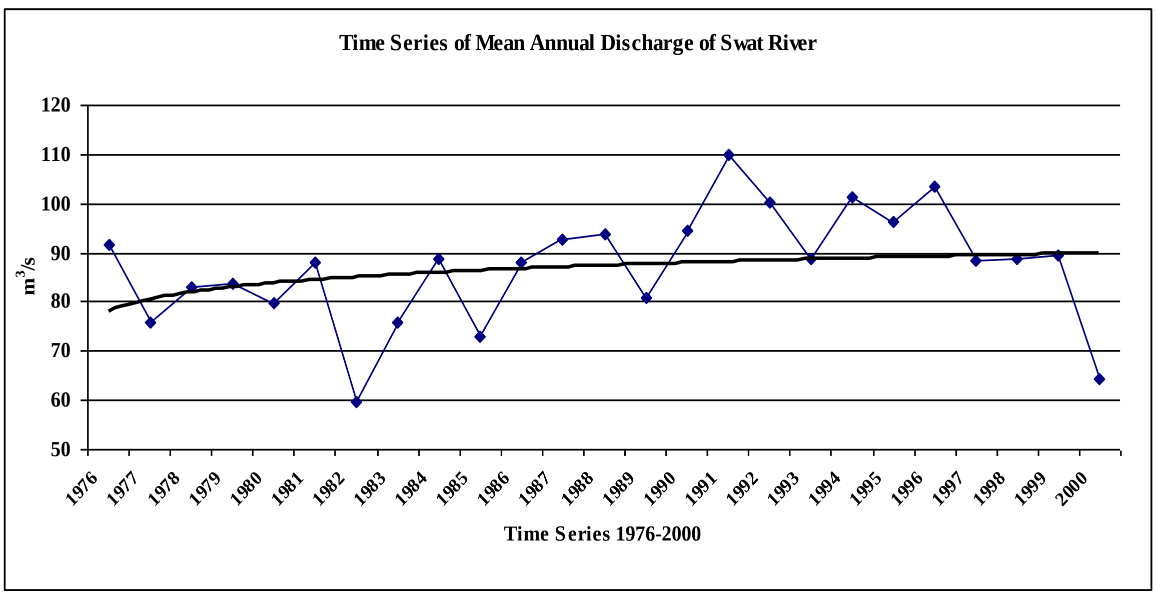


Figure: 4.25. Hydrograph of mean annual discharge of Swat River at Kalam station.

4.4.2. Discussion

Variability in river flows was determined for six gauge stations of those rivers whose headwater regions lie in zone1. Among these, results of ANOVA test are observed most significant ($p<0.05$) for Indus (at Skardu) and Swat rivers while Chitral and Gilgit rivers along with Indus at Chilas are non-significant ($p>0.05$) both on decadal as well as

15-years scale. Astor River appears considerably significant on decadal scale but on 15-years scale it shows no significant increasing trend. From the single river basin analysis, it is clearly manifested by the data that mean monthly maximum temperature has strong influence on river discharge and impact of rainfall is relatively small because large bulk of river discharge occurs during May to September due to snow/glacial melt. The present study is found in contrast with the global study like Karl and Riebsame (1989) have found fluctuations in the decadal analysis of mean temperature up to $1^{o}C$ annually and $2^{o}C$ seasonally and changes in precipitation up to 10% in most areas of United States during the modern climate record in the last 60 years. They also investigated the impact of these fluctuations on the runoff of 82 rivers across the United States. Their research has revealed that recent temperature increase has minimal impact on river flows but the impact of precipitation is relatively large i.e. up to 10%, because of climatic influences and dependence on the location, size and storage capacity of the drainage basin. Similarly many researchers have found in their study that the melting of glaciers do not effect annual discharge greatly but have impact on seasonal discharge. This is evident from the research work of the Thayyen et al (2007) on Himalayan watershed. They found that approximately 29% of the annual flow comes from snowmelt, but up to 70% in specific months. Furthermore, by plotting the data into time series it is observed that the trend line (best fit curve) generated by the software through the scattered data point also indicates a clear increasing trend in the discharge rate from 1976 to 2000 for all of included rivers. According to the study of Gleick (1986, 1987) annual river flow is greatly affected by precipitation changes, not by temperature, while the seasonal distribution of river flow is affected by changes in mean monthly temperature. During the past two decades numerous studies have been conducted on the hydrological effects of climate change such as Nemec and Schaake (1982), Mather and Feddema (1986), Gleick (1986; 1987; 1989; 1999), McCabe and Ayers (1989), Lettenmaier and Gan (1990), Schaake (1990) and Ayers et al. (1994) from different regions of the world. These studies mainly focus on the effects of changes in temperature and precipitation on mean monthly, seasonal, or annual river flows. Similarly for global studies Probst and Tardy (1987, 1989), examined discharge records of 50 large rivers for influence of rainfall on flows. They observed increasing river flows over 1910–1975 in Africa and America, decreasing flow in Europe and Asia, and 3% linear increase worldwide over the study period, which they attributed to the global warming. Similarly Labat et al. (2004), analyzed runoff records of 221 large rivers, for the periods 1900–1975 and 1925–1994. They observed increasing flow rates in Africa, America and Asia and decreasing flows only in Europe, a global increase of 3% over 1900–1975 and 8% over 1925–1994, because of accelerated hydrologic cycle caused by global warming.

4.5. TRENDS FORECASTING

After 30 years analysis it is clear that the overall change in temperature is not found uniform during the study period. Figure 4.26 (A & B) is the combine result of minimum and maximum temperatures showing the regular increase in the last decade with some significant decreasing fluctuations in 1976 to 1990. Overall results in figure 4.26 (C) show that mean temperature increased with fluctuations but have the significant trends of rise in temperature during the whole study period but this change in two decade is not more significant than the last decade. Mean annual rainfall in the fig. 4.26 (D) show abrupt downfall after 1997 up to 2003 because of droughts (1998-2001) in the country. In 2004 showing considerable rising trend but again in 2005 moving downward. Therefore, the observed data of Fig.(4.26 E) forecasts an upward trend up to 50mm till 2035 with excluded drought period from the real time series.

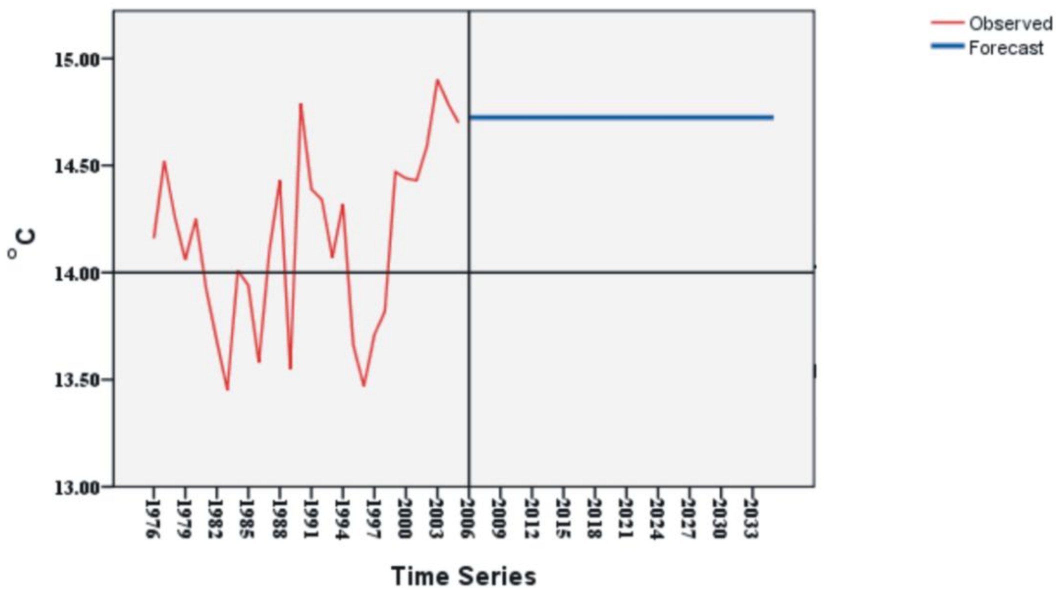
As consequence of trend forecasting, the Time Series Modeler procedure estimates exponential smoothing models for time series data of minimum, maximum, mean temperatures and mean annual rainfall and produces forecasts. The procedure includes an Expert Modeler that automatically identifies and estimates the best-fitting ARIMA (Autoregressive Integrated Moving Average) or exponential smoothing model for one or more dependent variable series. Models type and forecast of the mean minimum, maximum, mean temperature and mean rainfall trend in the future are presented in the Table (4.34) and model fit descriptive statistics Table (4.11) is attached in the Annexure.

Table. 4.34 Show the trend forecasting of the climatic variables through different climatic models.

			Forecast of the trend														
Variable	Model		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Minimum	Simple Model	Forecast	14.72	14.72	14.72	14.72	14.72	14.72	14.72	14.72	14.72	14.72	14.72	14.72	14.72	14.72	14.72
		UCL	15.49	15.59	15.68	15.77	15.85	15.92	15.99	16.05	16.11	16.17	16.23	16.28	16.34	16.39	16.44
		LCL	13.96	13.86	13.76	13.68	13.6	13.53	13.46	13.4	13.33	13.28	13.22	13.16	13.11	13.06	13.01
Maximum	Holt Model	Forecast	28.44	28.46	28.49	28.52	28.55	28.58	28.61	28.63	28.66	28.69	28.72	28.75	28.77	28.8	28.83
		UCL	29.43	29.46	29.49	29.52	29.55	29.58	29.61	29.64	29.67	29.71	29.74	29.77	29.8	29.83	29.86
		LCL	27.45	27.47	27.5	27.52	27.55	27.57	27.6	27.62	27.65	27.67	27.7	27.72	27.75	27.78	27.8
Mean temp	Simple Model	Forecast	21.48	21.48	21.48	21.48	21.48	21.48	21.48	21.48	21.48	21.48	21.48	21.48	21.48	21.48	21.48
		UCL	22.24	22.29	22.34	22.38	22.43	22.47	22.51	22.54	22.58	22.62	22.65	22.68	22.72	22.75	22.78
		LCL	20.71	20.66	20.61	20.57	20.53	20.49	20.45	20.41	20.37	20.34	20.3	20.27	20.24	20.2	20.17
Rainfall	ARIMA	Forecast	48.99	48.99	48.99	48.99	48.99	48.99	48.99	48.99	48.99	48.99	48.99	48.99	48.99	48.99	48.99
		UCL	64.47	64.47	64.47	64.47	64.47	64.47	64.47	64.47	64.47	64.47	64.47	64.47	64.47	64.47	64.47
		LCL	33.51	33.51	33.51	33.51	33.51	33.51	33.51	33.51	33.51	33.51	33.51	33.51	33.51	33.51	33.51

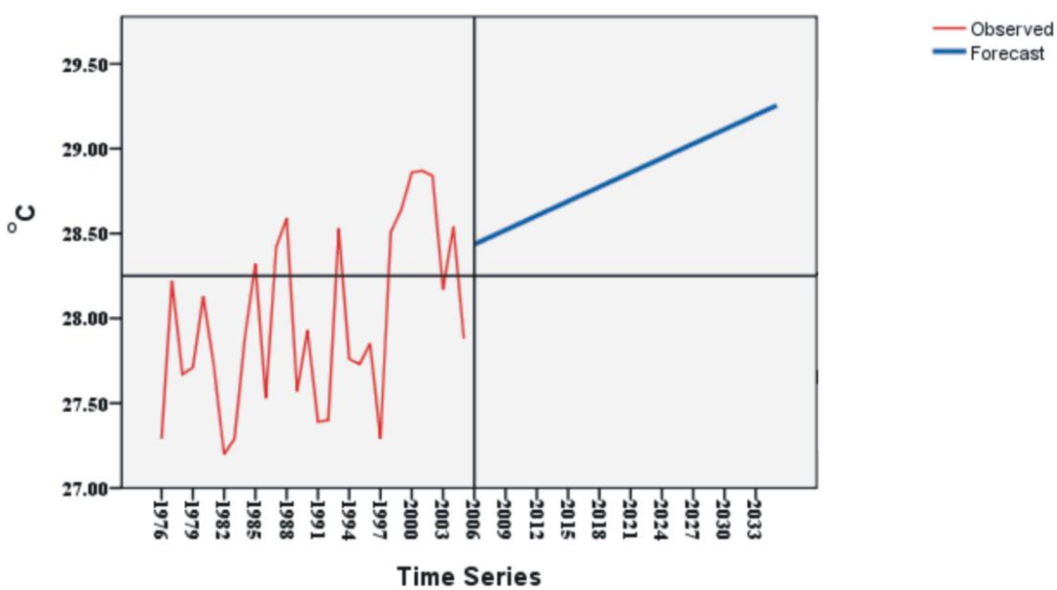
UCL: stands for Upper Critical Limit, LCL: stands for Lower Critical Limit.

(A)



Observed
Forecast
15.00
14.50
14.00
13.50
13.00
°C
1976
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
Time Series

(B)



Observed
Forecast
29.50
29.00
28.50
28.00
27.50
27.00
°C
1976
1979
1982
1985
1988
1991
1994
1997
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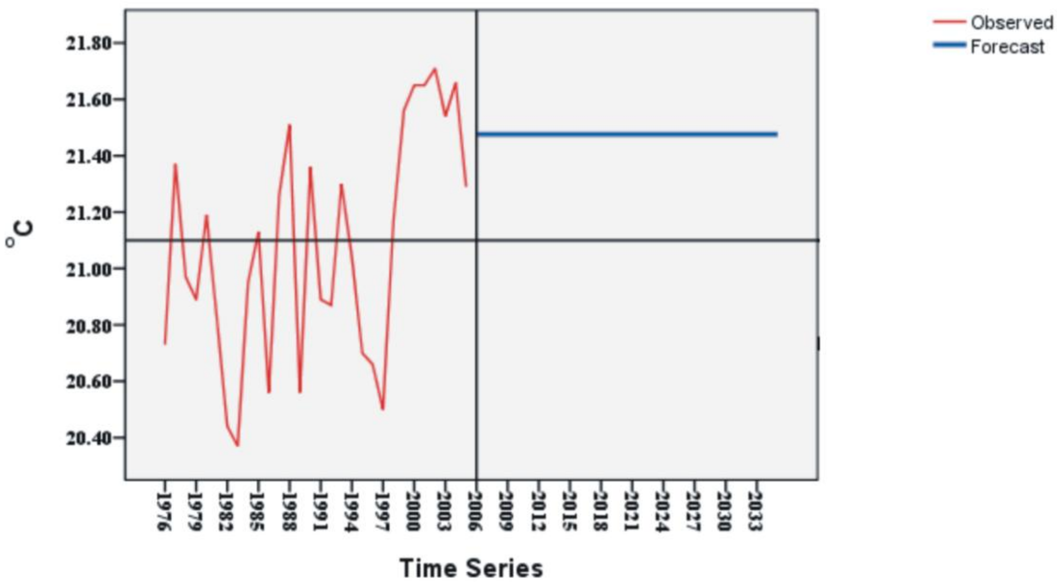
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
Time Series

(C)


Observed
Forecast
21.80
21.60
21.40
21.20
21.00
20.80
20.60
20.40
°C
1976
1979
1982
1985
1988
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2006
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2021
2024
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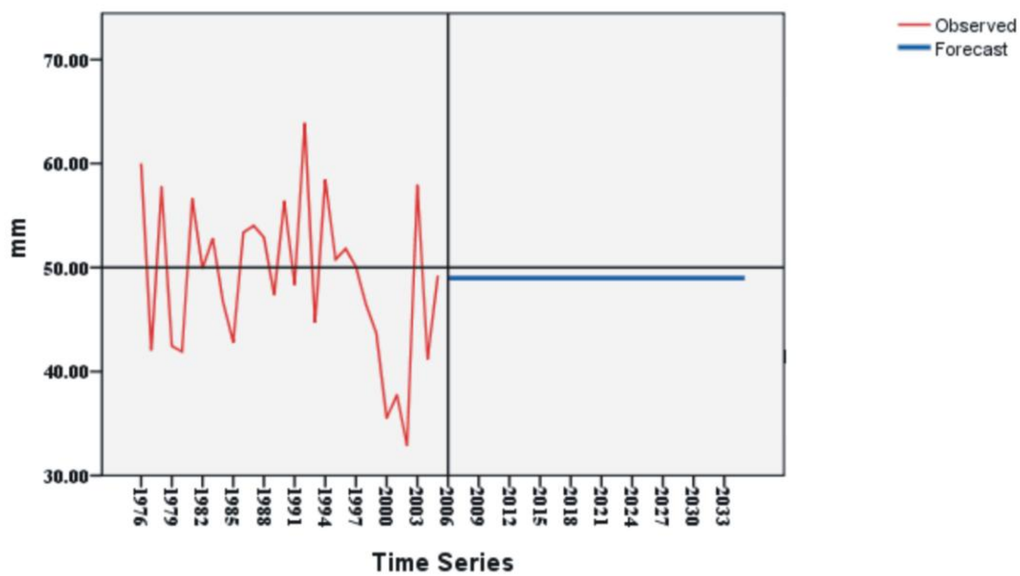
2030
2033
Time Series

(D)


Observed
Forecast
70.00
60.00
50.00
40.00
30.00
mm
1976
1979
1982
1985
1988
1991
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2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
Time Series

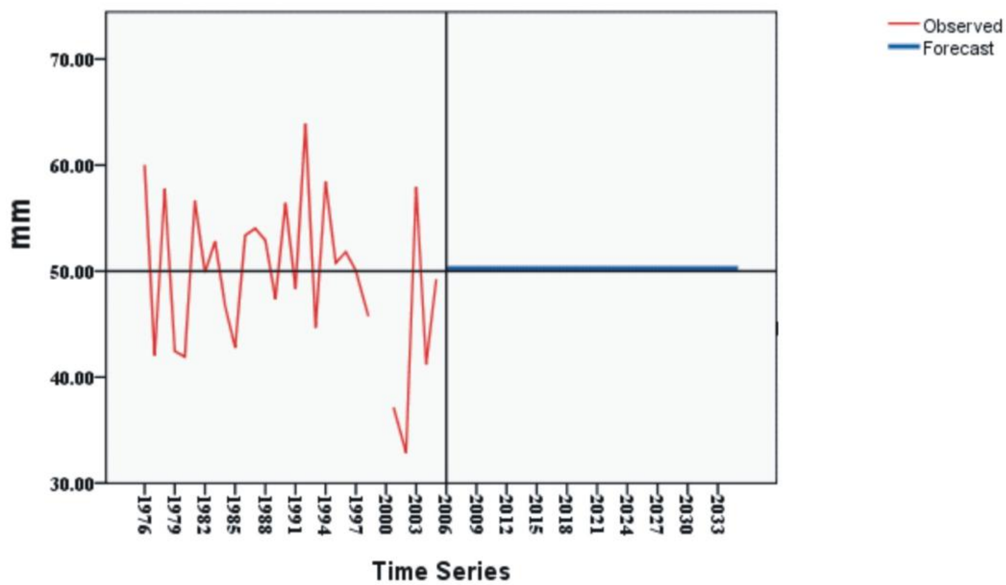

Figure: 4.26. (A): Mean minimum temperature trend from 1976-2035; (B): Mean maximum temperature trend from 1976-2035; (C): Mean Annual Temperature trend from 1976-2035; (D): Mean Annual Rainfall trend from 1976-2035 with included drought period from 1998-2001; (E) Mean Annual Rainfall trend from 1976-2035 with excluded drought period from 1998-2001.

4.5.1. Discussion

Analysis revealed that observed change in river flow is insufficient to explain the river flow increasing trend because of less number of gauge stations and 25 years of data record length. Therefore, for the prediction of the trend in the future, data of river discharge was not accounted for consideration. Exponential Smoothing Model for temperatures data and Autoregressive Integrated Moving Averages for rainfall data analyses indicated a dominant periodicity of between (2006-2035) years within the study area. The time series modeler estimated upward moving trend for minimum, maximum and mean temperatures and downward moving trend for rainfall data. This declining trend of rainfall data is due to the presence of drier period from 1998 to 2001 in which Pakistan has faced severe drought, mainly in the southern and central parts of the country. According to Awan (2002) Pakistan has experienced several droughts in the past, of which the most severe one occurred in 1998-2002. Surface water availability was reduced by over 30% and the total surface discharge in the major rivers declined from 162 billion cubic meters (BCM) to 109 BCM, while rainfall was below normal. Furthermore irrigation- based agriculture suffered to a great extent during the drought period, up to

51% of water supply through canal diversions than normal years supply. It means that downward trend in the data of rainfall is just seasonal fluctuation or variability and not be consider a trend of average pattern change. In study, rainfall shows non significant declining trends in the last decade, but the overall analysis supports decreasing trend in rainfall amount as result of rising temperature. The issue of detecting a climate change impact on ensuing river flow data is very complex because the process of river flow is the integrated result of several factors, such as rainfall amount and pattern, catchments area and capacity of storage water and evaporation losses (Solow et al. 1989: Solow and Broadus 1989: Lins and Slack 1999).

4.6. Environmental Effects of Climate Change in Pakistan

Like other countries of the world Pakistan is also experiencing direct and indirect effects of climate change. A rise of 0.1^{o}C per decade in the mean temperature, computed through this study is comparable to other parts of the globe. The rising trend differential and related impacts of climate change in Pakistan vary from zone to zone in the whole study area. However, in general terms the most significant environmental effects include extreme weather events such as heat waves in June 2007 and May 2010 in most parts of Punjab, Sindh and Baluchistan, and heavy torrential rains across Pakistan in Jul. – Aug. 2010 and Aug – Sep 2011 leading to heaviest floods and land sliding in the history of the country. Among other impacts felt or perceived are reduction in crop yields, local food supplies, soil erosion and species extinctions. Although, Pakistan contributes very little in GHG emission (up to 0.43%) but rated as the 12th most vulnerable country in the world in terms effects of climate change (Maplecroft, 2007). Agriculture sector is one example where reduced productivity, water shortage and different crop management practices are further worsening the situation. Agriculture is the largest income and employment-generating sector of Pakistan’s economy with about two thirds population of the country living in rural areas and earning livelihood directly or indirectly from agriculture and cattle farming (Ali, 2000). Agriculture contributes about 24% of the GDP of Pakistan and provides an employment to 48% of the labor force (EAW, 2003) where industries and 80% exports are almost agro-based, where the forest cover is low (4.5%) while deforestation rate is 0.2- 0.4 % per annum (World Bank, 2006). The reports of Pakistan

Agricultural Research Council (2003) show that temperature increase in winter months (Dec-Mar) have negative impacts on the big crops of food grains, sugarcane and fruits. The production volume and quality have been adversely effected because of changes in reproductive periods (Spring/late winter season), irrigation water requirements and its supply for Kharif and Rabi crops, altering soil characteristics, and increasing the risk of pests and diseases (TFCC, 2010).

Additional challenges imposed by climate change include changes in water resource availability as demand for water has been steadily rising both in domestic and agriculture sectors. In the pre-monsoon period (April-June) surface water requirements of the country are mostly fulfilled by the perennial snow-fed rivers but due to shortening of the winter season or increase in the minimum temperature snow/glacial melting is likely to start early and may lead to reduced water availability at the time of heaviest demands. This will have major impacts not just on hydropower generation but also on urban water supplies and agricultural sectors (Roohi, 2004). Reduction in river flows will negatively affect hydroelectric power generation. In a country already infested by the worst load shedding of the history this impact will lead to an increase in fossil fuel combustion and hence more GHG emissions. In addition, higher temperature, particularly in the summer season has already increased demand for electricity for air-conditioning and refrigeration in domestic and commercial sectors. This demand is likely to go further up and hence necessitates additional generation capacity. According to the World Bank (2006), Pakistan is among the 17 countries that are already facing water shortages and is among the 36 countries where there is a serious threat of food crisis.

Farooqi et al (2005) have outlined several environmental effects of climate change on Pakistan. Among many other effects such as strengthening of monsoon circulation, intensification of tropical cyclones and diminishing flows in Indus basin, they have also identified ecological impacts on wetlands and mangrove forests. Pakistan could face the loss of mangrove forests - a vital source of fuel wood and seafood for local consumption and exports.

Similarly, accelerated melting of glaciers and seasonal snow cover in Himalayas, Karakoram and Hindu Kush ranges is threatening the natural habitat of rare animals such as the Markhor and Ibex and hence, hundreds of rare plants and animals are in danger of extinction (UNEP, 1995). The glaciers present in the Himalayan region are reported to be melting faster than in any other part of the world and fears have been expressed that they might disappear till 2035 (Rees and Collins 2004; WWF 2005; IPCC 2007). Further, the studies of National Institute of Oceanography indicate that the sea level along the coast of Pakistan has been rising approximately at 1.2 mm per year since 1960. Besides these, weather related disasters hit the countries regularly like cyclones, hurricanes (Katrina and Nargis), heat waves, super floods, droughts and intense rainfall. According to a World Bank Report (2006), the country loses nearly $4.5 billion annually from environmental disasters.

In most areas of the country, rainfall patterns have become very unreliable and unpredictable, making it difficult for communities to make necessary arrangements for their safety, crops and livestock. For intense, on the one hand the super flood of 2010 was caused by very intense and extended rainfall that affected extensive parts of the country but on the other hand droughts have become more evident with the worst drought hitting the country during the period 1998-2001. According to PMD, “in recent years there has been a slow but steady change in monsoon pattern, particularly in locations where Pakistan's major rainfalls concentrate. In past, monsoon rains fell most intensely over central and northern Punjab, Kashmir and parts of Hazara and Swat areas but slowly and steadily the concentration of rainfall has moved north and west to the Khyber Pakhtunkhwa”.

Furthermore, Margalla Hills would continue to suffer from some impacts related to climate change. During summers most of the forest fire incidents have been reported from the Margalla Hills. Although the cause of the fire is yet to be ascertained, however, officials of the Capital Development Authority (CDA) attribute these fires to scorching weather. Sadly summer fires at Margalla hills have become an annual feature, which not only destroy the natural beauty but also harm the wildlife (The Nation, 2012).

From the above facts and perceived threats it becomes imperative to protect the country from such adverse impacts of climate change through adaptation and mitigation. It is, however, essential to continue scientific research not only to further ascertain climate change in Pakistan but also on aspects of timing, frequency and intensity of the projected and perceived threats so as to be able to predict and mitigate hazardous events before they strike.

Chapter # 5

CONCLUSION

Climate change, variability and its adverse impacts on the environment are growing concern worldwide. The major cause of these adverse consequences is the increase concentration of GHG. According to the IPCC (1996) the burning of fossil fuels is the major factor of contributing the more atmospheric CO_2 concentrations than double their pre-industrial levels within the next 100 years. Similarly, there is the growing consensus among the world's scientists that climate warming would effect precipitation pattern and modify the hydrological cycle and induced stressed in freshwater supply.

In the context of climate change, the present study finds a closer examination of the relationship between temperatures, rainfall and river discharge and analyzed the climate fluctuation between these variables and associated river discharge rate over the past 30 years from 1976-2005 in Pakistan. The dataset consist of 30 stations from all over the country and divided into five different climatic zones according to the Kööpen based classification for different microclimate of the world. All of the five climate zones are different from each other in their climatic conditions, elevation from the sea level, longitude, latitude, geography and in orography (e.g. mountainous study). A series of statistical tests were applied on the data in different combination of ten, fifteen and thirty years for making comparison in trends and find climate variability among hydro-meteorological parameters such as minimum, maximum and mean temperatures and rainfall with river flow rate. The statistical tests applied for data verification are skewness, outlier and ANOVA. For equal variances of means Duncan test is applied and for unequal variances Dunnett T_3 is used. Besides theses analysis, the data is also computed for monthly analysis and future trend of forecasting for the said variability, using Ms Excel sheets and SPSS. The visualization of the data through mapping is carried out by using the Arc GIS tool. The observed trend is then matched with global studies for making comparison easy.

In the light of results and discussion (chapter 4), it is concluded that the trend of temperature is showing increase such as $0.11^{o}C$ per decade, especially in those zones where big cities of country situated. From the analysis it is clear that all the climate zones showed a consistent rising trend in minimum and maximum temperatures except those zones situated in the North, North West and West of the country e.g. zone1 and zone3a. Whereas those Zones (zone2, zone3b and zone4) situated in the plain, South West and coastal areas showing great rising trend. The overall rising trend in minimum temperature for the country is observed approximately (0.29 ^{o}C) for two time periods from (1976-1990; 1991-2005) and (0.10 ^{o}C) per decade which is found non-significant at p-value such as ($p= 0.25>0.05$). Similarly, for maximum temperature, p- value of the country is observed significant ($p= 0.02<0.05$) with (0.36 ^{o}C) increase in temperature in two time intervals and per decade (0.12 ^{o}C). The overall trend in mean temperature of the country is found most significant ($p=0.03< 0.05$) in decadal analysis. Zone 3a (0.62 ^{o}C) and zone4 (0.55 ^{o}C) are recorded with highest value of mean maximum temperature difference into two time periods. While rainfall data showing overall declining trend approximately (-1.18mm) per decade and found most significant ($p=0.04<0.05$). In contrast to the mean annual rainfall, river discharge data is also recorded with increasing trend, especially for Indus River at Chilas and Skardu Stations, Swat Rivers and Astor River. Hence, it is clear from the river basin analysis that temperature has a profound influence on the snow/glacial melt in comparison to the mean monthly rainfall. This is because majority of the ensuing rivers derived from zone1 are faded by the snow and glacial melt as most stations of this zone receive a lot of snowfall in winter (Dec-Feb) and the pre- monsoon dry season (April-May) Furthermore, models used for trend forecasting show overall increasing trend in mean minimum, maximum and mean temperature of the whole study area till 2030 while rainfall data depicts declining trend because of drought from 1998-2001. By excluding the drought period from the real time series of the mean annual rainfall data, the observed data forecasts an upward trend up to 50mm till 2030. There will be no forecasting model used for river discharge data because of short record length. However, different studies on climate change scenario revealed that short and long term changes in the climate may lead to environmental challenges in the future, like water shortage, dryness of land, change in land use pattern like shifting of plants and animals on elevation, threats to biodiversity and ecosystems and effects on agricultural practices etc. Similarly increase in population growth and associated demands for fresh water, food and energy would be a matter of concern for the future climate scenario. Climate change is a global issue but its impacts can be felt severely in South Asian countries, especially in Pakistan, with weak economy and vulnerability to extreme climate events like droughts, sever cold and heat waves, and flash flooding. Pakistan economy is mainly based on agriculture sector. Due to increased temperature and shortening of the winter season, the snow will start early melting which can greatly affect the water management sector by reducing the average flow of snow fed rivers, urban water supply and agriculture sector. Although this change (0.11^{o}C/ decade) in mean temperature is not found too much, but if steps advised by IPCC in its 4th assessment report, are not taken at the right time for the mitigation of the excessive anthropogenic activities, the situation can be worse in the next two to three decades. To minimize or reduce any actual or potential adverse effect of climate change, key consideration should be given in disaster mitigation strategies and developmental schemes like in planning, designing, and implementation, in terms of minimizing economic losses.

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ANNEXURE

Table 3.1. Basic geographical information of climate zones of the study area.

S. No	***Station***	***WMO Ref***	***Altitude (m)***	***Latitude***	***Longitude***	Ensuing Rivers
1	Astor	41520	2168	35 ^{o}20'N	74 ^{o} 54'E	Astor River
2	Chilas	41519	1250	35 ^{o} 25'N	74 ^{o} 06'E	Indus River
3	Chitral	41506	1499	35^{o}51'N	71 ^{o} 50'E	iverChitral R
4	Dir	41508	1375	35 ^{o} 12'N	71 ^{o} 51'E	Pangora River
5	Gilgit	43516	1459	35 ^{o} 55'N	74 ^{o} 20'E	River Gilgit
6	Kakul	41535	1308	34 ^{o} 11'N	73 ^{o} 15'E	
7	M-abad	43532	701	34 ^{o} 22'N	73 ^{o} 29'E	Neelam River
8	P-Chinar	41560	1725	33 ^{o} 52'N	70 ^{o} 05'E	Kurram River
9	S- Sharif	41523	961	34 ^{o} 44'N	72 ^{o} 21'E	Swat River
10	Skardu	43517	2209	35 ^{o} 18'N	75 ^{o} 41'E	Shingar River
11	Cherat	41565	1372	33 ^{o} 49'N	71 ^{o} 33'E	
12	DIK	41624	173	31 ^{o} 49'N	70 ^{o} 55'E	Gomal River
13	Isl-abad	41571	507	33 ^{o} 37'N	73 ^{o} 06'E	
14	Lahore	41640	213	31 ^{o} 33'N	74 ^{o} 20'E	Ravi River
15	Peshawar	41530	359	34 ^{o}01’N	71 ^{o} 35'E	Kabul River
16	Sialkot	41600	255	32 ^{o}31'N	74 ^{o}32'E	Chenab River
17	Kalat	41696	2015	29^{o} 02' N	66^{o} 35' E	
18	Khuzdar	41744	1231	27 ^{o} 50'N	66 ^{o} 38'E	
19	Quetta	41660	1719	30^{o} 15' N	66^{o} 53' E	
20	Zhob	41620	1405	31^{o} 21'N	69^{o} 28' E	Gomal River
21	B-pure	41700	110	29 ^{o}20'N	71 ^{o}47'E	
22	J-abad	41715	55	28 ^{o} 18'N	68 ^{o} 28'E	
23	Khanpur	41718	87	28 ^{o} 39'N	70 ^{o} 41'E	
24	Multan	41675	122	30 ^{o} 12'N	71 ^{o} 26'E	
25	Rohri	41725	66	27 ^{o} 40'N	68 ^{o} 54'E	
26	Sibbi	41697	133	29 ^{o} 33'N	67 ^{o} 53'E	
27	H-abad	41764	28	25 ^{o} 23'N	68 ^{o} 25'E	
28	Jewani	41756	56	25 ^{o} 04'N	61 ^{o} 48'E	
29	Karachi	41780	21	24 ^{o} 54'N	67 ^{o} 08'E	
30	N-shah	41749	37	26 ^{o} 15'N	68 ^{o} 22'E	

WMO Ref: Stands for World Meteorological Observety Reference Number

Table. 4.1 Duncan Test for homogenous subset of Alpha for all climate zones.

Minimum temp		Subset for alpha = 0.05				
Zone	**N**	**Means of all climate zones**				
Zone 1	293	9.26				
Zone2	120		10.27			
Zone3a	180			15.83		
Zone3b	180				18.92	
Zone4	120					20.35
Sig.	893	1.00	1.00	1.00	1.00	1.00

Max temp		Subset for alpha = 0.05				
Zone	**N**	**Means of all climate zones**				
Zone 1	300	22.89				
Zone2	120		25.51			
Zone3a	180			29.21		
Zone3b	120				32.86	
Zone4	180					33.70
Sig.		1.00	1.00	1.00	1.00	1.00

Table. 4.2 Duncan test for homogenous subset of Alpha for the whole Study Area.

Whole Study Area			**Subset for alpha = 0.05**			
	HMSS	**1st Decade**	**2nd Decade**	**3rd Decade**	**Sig (1)**	**Sig (2)**
Min Temp	10	14.03	14.12	14.33	0.12	
Max Temp	10	27.75	27.89	28.35	0.51	1
Mean Temp	10	20.87	21.005	21.34	0.48	0.05

Table. 4.3 Stations are showing significant increase, decrease, and no change in mean minimum temperature.

Station	F	Sig.	Mean (1976-1990)	Mean (19912005)	Mean Diff	Zone
Increase in minimum temperature						
Isl-bad	7.253	0.01	14.18	14.73	0.55	2
Lahore	24.147	0.00	17.97	19.01	1.04	2
Peshawar	6.762	0.02	15.70	16.36	0.67	2
Khanpur	6.271	0.02	16.92	17.55	0.63	3b
Multan	5.556	0.03	18.02	18.42	0.40	3b
Karachi	13.599	0.00	19.68	21.77	2.09	4
Decrease in minimum temperature						
P-Chinar	43.188	0.00	9.55	5.46	-4.09	1
Jewani	3.835	0.05	21.15	20.69	-0.46	4
No change in minimum temperature						
Astor	0.238	0.63	3.63	3.39	-0.24	1
Chilas	0.081	0.78	14.52	14.57	0.05	1
Chitral	0.135	0.72	8.76	8.67	-0.09	1
Dir	0.35	0.56	7.88	8.05	0.17	1
Gilgit	0.476	0.50	7.66	7.78	0.12	1
Kakul	0.132	0.72	10.56	10.45	-0.11	1
M-abad	0.73	0.40	13.46	13.62	0.16	1
Skardu	0.205	0.65	5.21	5.08	-0.13	1
S-Sharif	0.864	0.36	12.28	12.02	-0.27	1
Cherat	0.282	0.60	12.69	12.81	0.13	2
DIK	1.01	0.32	16.71	17.03	0.32	2
Sialkot	1.642	0.21	16.23	16.49	0.27	2
Khuzdar	0.016	0.90	14.87	14.80	-0.07	3a
Quetta	0.309	0.58	8.34	8.48	0.14	3a
Zhob	1.097	0.30	12.18	12.70	0.51	3a
B-Pur	1.736	0.20	18.05	18.40	0.35	3b
Rohri	0.42	0.52	19.70	19.85	0.14	3b
H-bad	2.446	0.13	21.32	21.75	0.43	4
Kalat	3.041	0.09	5.03	5.80	0.76	3a
Jaco-bad	3.968	0.06	19.94	20.27	0.32	3b
Sibbi	3.174	0.09	19.80	20.16	0.36	3b
N-Shah	3.011	0.09	18.03	18.38	0.35	4

Table. 4.4 Stations are showing significant increase, decrease, and no change in mean maximum temperature.

Station	F	Sig.	Mean (1976-1990)	Mean (19912005)	Mean Diff	Zone
Increase in Maximum temperature						
Quetta	4.346	0.05	24.55	25.22	0.67	3a
Karachi	13.84	0.00	31.53	32.35	0.82	4
N-Shah	4.688	0.04	35.26	35.83	0.57	4
No change in Maximum temperature						
Astor	0.889	0.35	15.46	15.74	0.28	1
Chilas	2.854	0.09	26.58	26.11	-0.47	1
Chitral	0.225	0.64	23.46	23.61	0.15	1
Dir	1.478	0.23	22.70	23.04	0.34	1
Gilgit	1.291	0.27	24.21	24.51	0.30	1
Kakul	1.846	0.19	22.45	22.76	0.31	1
M-abad	2.205	0.15	27.11	27.62	0.51	1
Skardu	2.155	0.15	18.65	19.16	0.51	1
S-Sharif	0.843	0.37	25.79	26.08	0.29	1
Cherat	0.052	0.82	20.71	20.78	0.07	2
DIK	0.049	0.83	31.59	31.65	0.06	2
Isl-bad	0.052	0.82	28.71	28.78	0.07	2
Lahore	0.844	0.37	34.76	35.02	0.25	2
Peshawar	0.069	0.80	29.76	29.83	0.07	2
Sialkot	0.635	0.43	29.36	29.56	0.20	2
B-Pur	2.074	0.16	32.70	33.07	0.38	3b
Jaco-bad	0.529	0.47	34.10	34.33	0.23	3b
Khanpur	0.229	0.64	33.39	33.52	0.13	3b
Multan	0.08	0.78	32.61	32.68	0.07	3b
Rohri	2.046	0.16	34.02	34.34	0.32	3b
Sibbi	0.467	0.50	34.73	34.92	0.19	3b
Jewani	1.746	0.20	29.92	30.28	0.36	4
P-Chinar	2.883	0.09	21.16	21.62	0.45	1
Kalat	3.501	0.07	21.92	22.46	0.55	3a
Khuzdar	3.486	0.07	28.66	29.32	0.66	3a
Zhob	2.982	0.09	25.69	26.28	0.60	3a
H-bad	3.317	0.08	33.60	34.08	0.49	4

Table. 4.5 Whole Study Area analysis of minimum and maximum temperatures

Zones	F	Sig.	Mean (1976-1990)	Mean (1991-2005)	Mean Diff
Minimum temp (Whole Study Area F= 0.408, p= 0.523)					
Zone1	0.67	0.00	9.43	9.10	-0.33
Zone2	2.91	0.00	15.58	16.07	0.49
Zone3a	0.227	0.635	10.11	10.44	0.34
Zone3b	3.998	0.047	18.74	19.11	0.37
Zone4	3.976	0.048	20.05	20.65	0.60
Maximum temp (Whole Study Area F= 0.762, p= 0.383)					
Zone1	1.543	0.225	22.76	23.03	0.27
Zone2	0.441	0.512	29.15	29.27	0.12
Zone3a	7.225	0.012	25.20	25.82	0.62
Zone3b	1.323	0.26	33.59	33.81	0.22
Zone4	7.471	0.01	32.58	33.14	0.56

Table. 4.6 Dunnett T3 for homogenous subset of alpha.

Zone	N	Mean	(I) Decade	(J) Decade	Mean Diff (I-J)	Sig.
Zone 1	99	62.39	1	2	-11.65	0.25
				3	-0.98	1.00
	100	74.04	2	1	11.65	0.25
				3	10.67	0.30
	98	63.37	3	1	0.98	1.00
				2	-10.67	0.30
Zone 2	59	72.11	1	2	8.66	0.52
				3	6.71	0.73
	60	63.44	2	1	-8.66	0.52
				3	-1.96	0.98
	56	65.40	3	1	-6.71	0.73
				2	1.96	0.98
Zone 3a	36	35.12	1	2	-0.97	0.99
				3	7.34	0.14
	40	36.09	2	1	0.97	0.99
				3	8.31	0.01
	40	27.78	3	1	-7.34	0.14
				2	-8.31	0.01
Zone 3b	59	23.15	1	2	-1.51	0.92
				3	2.91	0.59
	55	24.65	2	1	1.51	0.92
				3	4.42	0.23
	58	20.23	3	1	-2.91	0.59
				2	-4.42	0.23
Zone 4	40	34.76	1	2	-5.48	0.70
				3	13.04	0.02
	38	40.24	2	1	5.48	0.70
				3	18.52	0.01
	40	21.71	3	1	-13.04	0.02
				2	-18.52	0.01

Table 4.7 Dunnett T3 test for multiple comparison

Mean Rainfall Decades	(I) Decade	(J) Decade	Mean Difference (I-J)	Sig.
1st Decade	1	2	-3.73	0.50
		3	4.67	0.44
2nd Decade	2	1	3.73	0.50
		3	8.40	0.04
3rd Decade	3	1	-4.67	0.44
		2	-8.40	0.04

Table. 4.8 Single station data analysis for the determination of significant trend in two time periods

Station	F	Sig.	Mean (1976-1990)	Mean (1991-2005)	Mean Diff	Zone
Increase in Rainfall						
Chitral	8.09	0.01	34.67	45.90	11.23	1
Decrease in Rainfall						
Quetta	4.43	0.04	47.36	33.59	-13.77	3a
Karachi	3.87	0.05	42.82	28.10	-14.72	4
No change in Rainfall						
Astor	0.04	0.84	43.31	44.32	1.01	1
Chilas	2.87	0.10	16.03	22.63	6.60	1
Dir	0.43	0.52	126.91	121.05	-5.86	1
Gilgit	0.56	0.46	15.85	13.79	-2.06	1
Kakul	1.68	0.21	121.19	111.83	-9.36	1
M-abad	0.25	0.62	134.76	130.28	-4.48	1
P-Chinar	0.35	0.56	66.16	68.90	2.74	1
Skardu	0.62	0.44	19.64	22.03	2.38	1
S-Sharif	0.02	0.91	88.42	89.51	1.10	1
Cherat	0.03	0.85	54.86	53.80	-1.06	2
DIK	0.27	0.61	28.73	30.43	1.70	2
Isl-bad	0.91	0.35	115.58	105.41	-10.18	2
Lahore	2.02	0.17	77.94	60.76	-17.18	2
Peshawar	1.73	0.20	39.68	46.00	6.33	2
Sialkot	0.03	0.87	91.78	93.56	1.79	2
Kalat	0.00	1.00	28.48	28.46	-0.02	3a
Khuzdar	0.09	0.77	31.83	30.42	-1.40	3a
Zhob	0.01	0.92	31.19	30.85	-0.34	3a
B-Pur	0.48	0.49	25.12	21.26	-3.86	3b
Jaco--bad	3.69	0.07	27.48	15.28	-12.20	3b
Khanpur	0.08	0.78	16.54	15.43	-1.11	3b
Multan	0.09	0.77	25.03	26.25	1.22	3b
Rohri	0.04	0.85	25.18	26.36	1.18	3b
Sibbi	0.59	0.45	21.67	24.67	3.00	3b
H-abad	0.77	0.39	41.39	30.63	-10.77	4
Jewani	1.57	0.22	29.53	22.33	-7.20	4
N-Shah	0.10	0.76	33.06	29.74	-3.32	4

Table. 4.9 Whole Study Area data analysis of Mean Rainfall.

Rainfall (Whole Study Area F=1.273, p= 0.26)					
Zones	**F**	**Sig.**	**Mean (1976-1990)**	**Mean (1991-2005)**	**Mean Diff**
Zone1	2.483	0.12	66.85	66.42	-0.43
Zone2	0.21	0.65	68.24	65.69	-2.55
Zone3a	2.439	0.1	35.16	30.83	-4.33
Zone3b	0.735	0.39	23.37	21.91	-1.46
Zone4	3.719	0.05	36.66	27.7	-8.96

Table 4.10 Duncan test for homogenous subset of alpha

Duncan Test					Subset for alpha = 0.05	
River	**HMSS**	**1st Decade**	**2nd Decade**	**3rd Decade**	**Sig (1)**	**Sig (2)**
Astor	7.5	118.15	158.59	134.79	0.19	0.07
Chitral	7.5	264.75	284.2	285.04	0.18	
Gilgit	7.5	616.85	623.43	583.95	0.26	
Indus/Chilas	7.5	1759.59	1740.08	1931.6	0.19	
Indus/Skardu	7.5	968.91	1141.24	1235.66	1	0.27
Swat	7.5	79.96	94.69	86.9	0.19	0.14

Table 4.11 Model Fit descriptive statistics for forecasting trend

Model Fit descriptive statistics											
					Percentile						
Fit Statistic	**Mean**	**SE**	**Min**	**Max**	**5**	**10**	**25**	**50**	**75**	**90**	**95**
Stationary R-squared	0.296	0.33	9.81E-15	0.769	9.81E-15	9.81E-15	0.049	0.208	0.632	0.769	0.769
R-squared	0.129	0.088	9.81E-15	0.194	9.81E-15	9.81E-15	0.038	0.162	0.189	0.194	0.194
RMSE	2.2	3.58	0.374	7.569	0.374	0.374	0.374	0.429	5.798	7.569	7.569
MAPE	4.581	5.77	1.475	13.226	1.475	1.475	1.494	1.811	10.437	13.226	13.226
MaxAPE	15.385	22.551	2.897	49.129	2.897	2.897	2.962	4.756	38.436	49.129	49.129
MAE	1.794	2.9	0.292	6.144	0.292	0.292	0.301	0.37	4.711	6.144	6.144
MaxAE	4.638	7.668	0.68	16.139	0.68	0.68	0.708	0.865	12.339	16.139	16.139
Normalized BIC	-0.194	2.919	-1.856	4.162	-1.856	-1.856	-1.855	-1.54	2.814	4.162	4.162