THE EFFECT OF CLIMATE PARAMETERS ON RAINFALL AND TEMPERTURE IN LAST 12 YEARS (2010 – 2021)

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ABSTRACT

Pakistan might confront a significant climate change issue. To reduce these concerns, the government and public society must work together at all level. Pakistan's yearly mean temperature has risen by about 0.6°C in the previous 40 years. In the previous 10 years, the frequency of heat wave days has grown roughly fivefold. Annual precipitation has showed great unpredictability in the past but has grown modestly in the previous 50 years. In the previous century, the sea level along the Karachi coast has increased by around ten cm. For a central global emissions scenario, the annual mean temperature in Pakistan is anticipated to rise by 4°C to 6°C by the end of the century, whereas greater world emissions may result in a rise of 5°C to 7°C. The average annual rainfall is not projected to have a long-term trend, but it is expected to vary greatly from year to year. By the end of the century, sea level is anticipated to increase another 65 cm, affecting low-lying coastal regions south of Karachi, including Keti Bander and the Indus River delta. Pakistan is predicted to have increasing fluctuation in river flows as a result of increased precipitation variability and glacier melting under future climate change scenarios. Due to greater evaporation rates, the need for irrigation water may increase. Wheat and basmati rice yields are predicted to fall, causing production to shift north, depending on water availability. The amount of water available for hydropower generating may decrease. Increased air conditioning demands are projected to increase energy consumption as temperatures rise. The efficiency of nuclear and thermal power plants may be reduced as air and water temperatures rise. Extreme heat waves may result in an increase in mortality. High rains and flash floods may put additional strain on urban drainage systems.

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CHAPTER 1

INTRODUCTION

Long before mankind arrived on the scene, the climate of earth is hot and cool over billions of years, as evidenced by air layer and temperatures of ocean (IPCC, 2007). No question climate is now warming; signs of this shift can be found all around us. Global sea level rise, regular and unequal rainfall dissemination, flash flooding, extended droughts, glacier melting (Alam, 2009), tropical cyclones, hurricanes, severe dust storms, dry and cold periods, and so on are all examples of climate change. All of these negative repercussions are direct or indirect outcomes of changing climate, and they have affected water availability and quality, plantation and land use patterns, and a variety of other environmental impacts, as illustrated in Figure 1.1. The lengthy mean of weather conditions is known to as climate (Mishers, 2004). It implies that long-term variations in peak and lowest temperatures, rainfall in different forms, subsurface wind, humidity, cloud type and amount, solar radiation, and other factors in the earth's climate system are referred to as climate change. Natural systems such as solar irradiance variations, changes in the earth's axial tilt, changes in ocean circulation, and volcanic activity are some of the natural reasons. (Rodo, 2003). Cloud cover, precipitation, soil moisture, and atmospheric circulation changes are the main drivers of much of the rising trend differential around the world, resulting in frequent heat waves, droughts, and extreme precipitation events, as well as related impacts like wildfires, heat stress, vegetation changes, and sea-level rise (Przybylak, 2000; Braganza et al., 2004). Changes in the amounts of different gases in the atmosphere, which alter the earth's radiation balance, can also affect the climate system. Carbon dioxide (CO2), methane (CH4), ozone (O3), nitrogen oxides (N2O), and other greenhouse gases (GHG) are examples. The use of fossil fuels (oil, natural gas, and gasoline) for industry and transportation, rapid industrialization, a rapidly rising population, deforestation for agriculture, unplanned urbanization, and infrastructural advancements are all contributing to the observed temperature rise.

According to the IPCC (2001) assessment, the earth's greenhouse effect has been strengthening owing to human activity since the late twentieth century, and the global temperature will continue warmer in the next decades of the twenty-first century (Karl et al., 2006; Trenberth et al, 2007). The growing use of fossil fuels has increased CO2 levels in the atmosphere, and the degradation of natural vegetation has made it impossible for the ecosystem to rebalance. Additional GHG levels, such as CH4, NO2, and O3, were also increasing, resulting in slow global warming (IPCC, 2001). In their study, human-induced activities are the primary contributor in recent global warming, and that if climate mitigation measures are not implemented in a timely manner, the situation would deteriorate soon. The worldwide reaction to changing climate has been coordinated under the United Nations Framework Convention on Climate Change (UN/FCCC) for this goal, and the first agreement with quantified GHG emission reduction objectives was agreed in 1997 (UN/FCCC, 1998). All elements of the global climate system, including its interactions with the atmosphere, land surfaces, seas, glaciers, sea ice, and ecosystems, were scientifically researched and assessed by the Intergovernmental Panel on Climate Change (IPCC). The findings of these IPCC assessments were compiled into official reports, which serve as the major source of scientific data.

According to the IPCC's first report, GHG emissions are growing and not stabilizing because of improved energy ingesting as a consequence of population expansion and industrialization, particularly in emerging nations. GHG levels are predicted to rise significantly in the future, particularly as emerging nations become more industrialized. World Energy anticipates 54 % rise in worldwide energy consumption by 2035, including 72% of that happening from emerging nations, based on current warming patterns. This rise is because of fossil fuels, which will result in a rise in temperatore. According to new data, these temperature trends are substantially higher than previously assumed. The concentration of GHG in the atmosphere has ranged between 280 and 430 parts per million (ppm) since pre-industrial times and is growing at a rate of around 2.5 part per million with per year. It is anticipated that if global GHG emisions stay below 550 parts per million, there is a 63 percent risk of breaching the catastrophic 2°C temperature increase limit until 2100.

Mann and Jones (2003) found that the average external temperature over the previous two millennia has been unusually warm in the late twentieth century, which they ascribe to anthropogenic climate forcing (Thorne et al., 2003). Since the late 1800s, mean worldwide surface temperature has risen by around 0.6°C, with 95 percent confidence ranges of 0.4 and 0.8°C, and future change is predicted to range between 1.4°C and 5.8°C in the twenty-first century (Folland et al., 2000). This rise may be seen in two time periods: 1910-1945 and 1976 to the present (Jones et al., 2001). Pace of heating since 1976 (0.17°C/decade) has been somewhat higher than the rate of warming between 1910 and 1945. (IPCC, 2007). However, climate change is already evident— previous 61 years have been hottest in the previous 1000 years (Wassmann and Dobermann, 2007). When compared to warming of the oceans, the current warming era has been quicker on land (Christy et al., 2000).

Furthermore, from the commencement of worldwide average high temperature data in 1857, the 1991s were the hotest period (Palutikof, 2000) and 2006 was the warmest year, followed by 2010, 2006, 2002, 2001, 1998, and 1998. (Jones and Moberg, 2003). According to global temperature data from December 2004 to November 2005, 2005 was the warmest year since 1998. Without the presence of El Nino, which brought extra heat from the ocean to the earth's surface in 1997, the year 2006 shows strong global warming trend over the previous few decades by equaling the record temperature of 1997. (Hansen et al., 2006; WMO, 2005). Similarly, recent study from the Climate Data Centre, the National Oceanic and Atmospheric Administration (NOAA), and NASA found that 2011 tied with 2005 as the warmest year on record for the last 130 years (instrumented monitoring stations date back to 1880). According to NOAA, there has been a 2°C and 1.5°C increase in average November and December temperatures, as well as an increase in October rainfall, since 1876. Since 1950, the average moisture in December has likewise rising.

Likewise, data from throughout world show that global temperatures are rising, causing saltwater to expand and the rise in sea level. For the period of the twentieth century, sea levels rose in the northern and southern Pacific Oceans, the Indian Ocean, and the Caribbean Sea, although the rise was not regionally uniform, as was the case with land surface warming (Cruz et al., 2007; Un-Ohrlls, 2009). Between 1960 and 2004, global sea level increased at an average of 1.9 mm per year, but between 1995 and 2005, it climbed at a quicker pace of roughly 4.1 mm per year (IPCC, 2007, and WMO, 2010). In a report published in 2000, the World Health Organization (WHO) stated that if sea levels rise by 40 cm, between 14 million to 93 million people living along the coast will be at danger of flooding. Sea-level rise might result in flash floods, increased salt in the ocean, and erode beaches in low-lying places such as wetlands and coastal marshes. China, India, Bangladesh, Africa, and tiny islands' coastal areas are particularly vulnerable to rising salt in their water supplies (UNEP, 2007).

Furthermore, as multiple studies have shown, Arctic summer ice is melting at a faster rate than ever before as a result of global warming. Stroeve et al. (2007) discovered that since 2002, five of the six lowermost years of sea ice coverage have happened. Overpeck et al. did comparable learning on the reducing of Arctic summer sea ice melt (2005). They estimate that the Arctic will be totally devoid of summer sea ice by the end of the century, or within 2000 years. Past ice-sheet melting records suggest that future ice-sheet melting and the resulting sea-level rise might be quicker than in the previous century. According to Otto-Bliesner et al (2006), sea level was5 to 7 meters higher than it is today during the previous interglacial era, which occurred between 131,000 and 128,000 centuries ago. The high northern latitudes are expected to stay warmer than they were during the previous interglacial era, according to climate models. Temperatures in the late twenty-first century would be high enough to melt major sections of Greenland and West Antarctica, at the very least. Millions of people would be at risk of flooding and migration as a result of the rising sea level, as well as the economic losses connected with rising seas. But the ice system isn't the only thing that's changing. Permafrost, or frozen solid ground, changes in the Arctic also show a warming trend. According to recent research by the National Center for Atmospheric Research's Community Climate System Model (2006), permafrost would disappear by up to 81% by the end of the century under GHG scenarios. If permafrost melts on a larger scale, it might lead to the fast release of CH_4, a strong global warming pollutant.

Melt or retreating glaciers will also have an impact on land use near the glacier. Agriculture fields or herding near glaciers, for example, change the territory of animals and plants that have evolved survive nearer to the glacier (FAO, 2004). According to Pakistani scientist Iqbal (2008), huge-scale melting of mountain glaciers and polar ice caps has happened at an alarming rate, notably in the Arctic area. Sea level rise is primarily caused by melting ice and ocean thermal expansion. Furthermore, increasing sea levels will cause salt water pollution of groundwater sources, putting the quality and quantity of freshwater supplies under jeopardy. The IPCC has been documenting such changes as proof of global warming since 1990.

Meanwhile, research conducted in Kalimanjaro by Kaser (2004) suggests that rising air temperature directly governs glacier melting. The effect of global warming on mountainous places may be seen in the shrinking of glaciers and the shorter duration of snow cover (Barry, 2002). Scientists argue over whether all glaciers in the Himalaya-Karakorum-Hindukush area are receding. According to the World Glacier Monitoring Service (2002), most of the world's alpine glaciers, including the larger Himalayan, have been melting over the past 30 years (Hasnain, 1999; Mastny 2000; Sherestha, 2004).

Warmer temperatures, according to US climate change studies, are anticipated to increase evaporation from land surfaces, resulting in extreme rain events. The rise in surface runoff is due to an increase in heavy rain occurrences. Since the twentieth century, increases in precipitation of 5-1 percent each decade have been seen across the Northern Hemisphere's mid/high latitudes (IPCC, 2001). Heavy rainfall events have increased in frequency by 2-4 percent in the Northern Hemisphere during the last 50 years, according to an analysis of heavy rainfall occurrences (IPCC, 2001). Similarly, climatologists looked at the temporal and geographical variability in extreme precipitation events, such as floods and droughts, which have become more common. Temperature rises in Southern Africa, Latin America, the Mediterranean, and certain regions of Southern Asia may cause a prolonged drought, which, in combination with other human factors, causes deforestation, weathering, and soil erosion, among other things (UNEP, 2007). Since the 1970s, more intense and prolonged droughts have been reported, particularly in tropical and subtropical areas (IPCC, 2001). The ability of the atmosphere to store moisture will increase as a result of the rising temperatures projected during the next century. The water-holding capacity of the atmosphere increases by 7% for every 1o C increase in temperature. Even if the annual overall quantity of precipitation is slightly reduced, more moisture in the atmosphere will lead to more severe precipitation episodes. Observable changes in precipitation patterns have already occurred. Eastern North America has been wetter during the last century, whereas southern Africa and the Mediterranean have gotten drier. The Northeastern United States is anticipated to get more precipitation in the twenty-first century, while the Southwest is expected to grow even drier (Noah, 2007). In Northern Europe, as well as regions of North, South, and Central Asia, unexpected rainfall has been reported. According to Cruz et al. (2007), most of Asia's areas, particularly the eastern and southern sections, would experience summer as well as strong winter precipitation, with a higher risk of intense precipitation frequency. Annual rainfall is anticipated to increase in the northern Indian Ocean during the winter months (December, January, and February) and in the Maldives during the summer months (June, July, and August), while it is likely to drop in Mauritius during the same months (Mimura et al., 2007).

Moreover, the warm environment has had an impact on forest reserves and has changed the productivity and quality of biomes. To begin with, temperature changes have a bigger impact on albedo, soil quality, and humidity fluctuations than they do on forest and agricultural fields (Bonan, 2002). Changing climate, both short- and long-term, is causing changes in crop management practises and techniques, among other things.

Warming may have a significant influence on plants' carbon nitrogen ratio, biomass output, yields, root morphology, shoot morphology, soil nutrient absorption, and other factors as a result of climate change. Plant responses to limiting variables such as water, light, and nutrient availability can be influenced by high CO_2 levels in the environment. In some cases, even a minor modification might result in vegetation stress, fast plant loss, and desertification (Rashid, 2008).

According to studies, a 1°C increase in average temperature in North Asia could lengthen the wildfire season by 30 times (Cruz et al., 2007), which could have a variety of negative consequences on key forest ecosystem functions such as soil structure and composition, pest outbreaks, biodiversity loss, species habitat quality, and disease prevalence. Wildfires have become more common in the western United States in recent decades, but the degree of these changes had never been studied until now. According to Westerling and Bryant (2007), there was a four-fold rise in the number of western wildfires and a 6.5-fold increase in the area burnt in 2003 compared to 1987. However, the wildfire of 1987 has been documented for longer than 1970. The wildfire season lasted 78 days, according to the data. During the same time period, the mean burn length for big wildfires ranged from 7.5 to 37.1 days. They came to the conclusion that wildfires are mostly caused by climate change in the United States, notably rising spring and summer heating and rising temperatures snowmelt.

Climate change may improve the ability of today's forests to survive these changes in non-temperate areas. According to Siddiqui (2001), a 3oC change can result in a 500-meter elevation shift in forests, and while species have been able to adapt to warming since the last Ice Age 10,000 years ago, the predicted change (2.5oC for a doubling of CO_2) is extremely high and will outpace their rate of migration to keep up. For many organisms, a rate of change of 0.0100C is a critical threshold for survival (Siddiqui, 2001). According to Cruz et al. (2007), about half of Asia's entire biodiversity is threatened and on the verge of extinction owing to climate change. He predicted that by the end of the century, 105 to 1,522 plant species and 5 to 77 vertebrates would be extinct in China, while 133 to 2,835 plants and 10 to 213 vertebrates would be extinct in Indo-Burma.

Furthermore, agricultural output is a major problem in discussions about climate change. Crop yields may improve for moderate degrees of temperature change in mid to high latitudes, but drop for larger levels of temperature change. In their studies on the effects of global climate change on agricultural yields, Bruce et al (1998) state that these effects may be divided into direct and indirect effects. Increases in temperature reduce or lengthen the growing season, changes in the duration and intensity of precipitation, water and soil quality, and extreme weather events are all direct affects, while indirect impacts include sea level rise, soil erosion, and ultra violet radiations. According to Seshu and Cady (1984), an increase in temperature from (18oC) to (19oC) results in a yield drop of 0.71 t/ha, a decrease of 0.41 t/ha from 22oC to 23oC results in a yield decrease of 0.41 t/ha, and a decrease of 0.04t/ha from 27oC to 28oC results in a yield decrease of 0.04t/ha. There are various causes for the differences in responsiveness to 1°C temperature changes across temperature regimes. The influence of temperature on several phases of plant growth, in particular, rapid sterility of the plant caused by higher temperatures, are among them (Yoshida, 1981). Aside from the negative consequences of climate change, some of them are likely to be positive. Agricultural production may rise in the medium to high latitudes and at high altitudes, depending on crop type, growing season, temperature regimes, and precipitation seasonality (Parry, 1990; Watson et al., 1997). Temperature rises in certain places can boost crop growth by allowing for earlier spring planting, faster maturity, and earlier harvesting (Rosenzweig and Hillel, 1995).

Climate change will have a substantial influence on water availability, as well as the quality and amount of water available. Temperature increases and their relationship with precipitation can cause stress in the hydrological cycle, resulting in dryer dry seasons and wetter rainy seasons, and therefore increased the risk of more severe flash floods and drought. Melting glaciers will raise the danger of flooding during the rainy season and limit dry-season water supply for one-sixth of the global population (NEF, 2001).

Many countries throughout the world are already battling for fresh water supplies for drinking, home usage, agriculture, and industry. Irrigation demand, industrial pollution, and waterborne sewage will all put strain on current water supplies, and climate change will exacerbate all of these issues. Reduced rainfall and rising temperatures would further restrict the availability of water, including lower flows in springs, rivers, and groundwater levels, as a result of reduced rainfall and rising temperatures.

Many Asian nations have seen significantly longer heat waves, as evidenced by substantial warming trends and multiple incidences of catastrophic 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). In many regions of Asia, the frequency of more extreme rainfall events has increased, resulting in severe floods, landslides, debris and mud flows, but the number of wet days and total annual precipitation have dropped. (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).

1.1 Climate of Pakistan

Because of the differences in elevation from one end of the nation to the other, Pakistan's climate is diverse. Pakistan is located in the far northwestern section of the Indian subcontinent, between latitudes 24 and 37 degrees north latitude and longitudes 61 and 75 degrees east longitude. Pakistan's lowlands, which are drained by the Indus River and its tributaries, are flanked on all sides by mountain ranges in the north, northwest, and west (Rodo, 2003). The nation is bordered on the south by the Arabian Sea, on the east by India and on the southeast by Iran, on the north by Afghanistan, and on the north by China. The Himalaya and Karakorum mountain ranges, as well as a minor portion of the Hindukush range, are located in the north of the nation. Pakistan is the only spot on the planet where these three massive mountain ranges come together. Aside from the northern mountains, the western highlands, which are separated from the mountainous north by the Kabul River and consist of a succession of drier and lower hills, exist. Deserts may be found in sections of the Balochistan and Sindh provinces (Hussain et al., 2005). The country covers a size of 803943 square kilometers (Pant and Rupa Kumar, 1997).

Pakistan's climate varies owing to its distinct topography and geology. The hilly north is pleasant and moderate throughout the summer months of April to September, whereas the Indus Valley swelters in temperatures of 40oC or more. Monsoons hit the southern area in late summer, especially around the coast. Low-lying areas see significant cooling in the winter, with typical temperatures ranging from 10 to 25 degrees Celsius, while the northern highlands freeze over with temperatures far below freezing (Rodo, 2003). The primary component of climatic changes in the Indian subcontinent was spatial shifts in rainfall patterns, which were linked to oscillations in the general circulation of the atmosphere in the Indian subcontinent (Rodo, 2003), such as the monsoon winds that bring rain in the summer. The Western Depression, which originates in the Mediterranean and enters Pakistan from the west, delivers rain to Pakistan throughout the winter. Because these mid-latitudinal cyclones travel across land, they lose the majority of their moisture-laden air by the time they reach Pakistan. Other climate-controlling elements include the country's sub-tropical position, which keeps temperatures high, especially in the summer, and the Arabian Sea's oceanic impact, which keeps the temperature along the coast cool. Higher heights in the west and north keep the temperature low all year. During the summer in the south, a temperature inversion layer forms, preventing moisture-laden air from rising and condensation from occurring.

Winter and monsoon precipitation are the two primary seasons in which the nation receives precipitation. During the months of July to September, monsoon rains arrive in Pakistan from the east and north east. The north and north-eastern catchment areas of the nation receive a significant quantity of rainfall during this time. Winter precipitation (December to March) is primarily brought in by western disturbances originating in Iran and Afghanistan. Primary western disturbances enter from Afghanistan and cover only the north and northwestern parts of the country, whereas secondary western disturbances enter from Iran and cover a large area of the country, including Balochistan, Punjab, KPK, Kashmir, and northern areas, as well as Sindh province on occasion. (Kazi et al, 1951; FAO, 1987; Khan, 1993 and 2002; Kureshy, 1998; Luo and Lin, 1999). Heavy snow is abundant in the northern regions, upper KPK, Kashmir, and northern Balochistan, and is the primary source of water for the country's water reservoirs during the dry weather. This water, which is derived from snow melt and seasonal rains, is critical to the country's agricultural and economical operations. Pakistan's agriculture is mostly weather patterns, and each region has its own crops and fruits that are specific to its climate. The country's most significant crops and fruits are cultivated in the winter in various places depending on the climate. If there is any deviation from the typical climate, the nation suffers for the entire year, as well as a significant economic loss. (Shah, 2008).

Due to the variability of Pakistan's geography and climatic circumstances, the rise in surface temperature, rainfall, and other climate indices would not be uniform across the country. In terms of meteorological variables, air temperature is measured every synoptic hour, but daily maximum, minimum, and mean temperatures, as well as their influence on rainfall and river flow, are crucial in determining the climate and hydrology of a given location. As a result, these factors are regarded as the primary markers for determining climate changes. After comparing current patterns over the previous three decades to global temperature trends, it appears that Pakistan has already experienced the effects of climate change. Despite Pakistan's extensive network of observatories, there are little research on climatic variability in the country. Rasul and Chaudhry (2006) investigated global warming and predicted snowline shifts in Pakistan's northern mountains. They discovered that the growing trend in temperature is primarily attributable to excessive manmade activity, rather than natural processes. They believe that increasing population and rapid deforestation are the major causes of atmospheric heating, among other things. The Himalayan, Karakorum, and Hindukush mountains' snow and ice extent is disappearing faster than it has ever been. Similarly, Chaudhry and Rasual (2007) explain the frequency and severity of severe precipitation occurrences along the foothills of the Himalayan region's southern slope in their study. They discovered that as a result of these catastrophic occurrences, the incidence of landslides and lightning strikes is growing, resulting in several fatalities and infrastructure damage.

Bhutiyani et al. have made another try (2007). Their findings revealed that the northwest Himalayan region has warmed at a faster rate than the world average during the previous century. The significant increase in both maximum and minimum temperatures has been the primary cause of temperature rise in the northwest Himalayan. However, the maximum temperature is rising faster than the lowest temperature. Shah (2008) used 30 stations, covering the hilly portions of the nation parallel to the Himalayan, Hindukush, and Koh-e-Suleiman ranges, to generate an all-Pakistan minimum temperature trend. For two years, 1976-1990 and 1991-2005, he acquired a value of 0.4^{o}C for all Pakistan mean lowest temperature in winter season and found a 0.133^{o}C rise every decade. As a result, the current research was carried out with the following goals in mind.

1.2 Objectives

1. To determine the change of climate parameters on Precipitation and Temperature in last twelve year (2010-2021).
2. To determine the effect of climate change on Rainfall.

CHAPTER 2

RESEARCH METHODOLOGY

2.1 Data Acquisition

The Climate Data Processing Centre (CDPC) of the Pakistan Meteorological Department provided the dataset for this study, which included daily minimum and maximum temperatures as well as rainfall records (PMD). The dataset spans 30 years (1976-2005), and includes 30 stations from the far north to the far south, and from east to west, as well as some missing periods. The selection criteria for these stations are that they cover practically the whole country of Pakistan. In order to maximize data availability, the research period was set to be as lengthy as feasible. In addition, the data set of those stations has been utilised in this study that have not been changed/ displaced in the recent 30 years, because certain meteorological stations have been re-established/ moved, and the change of site may produce a difference value

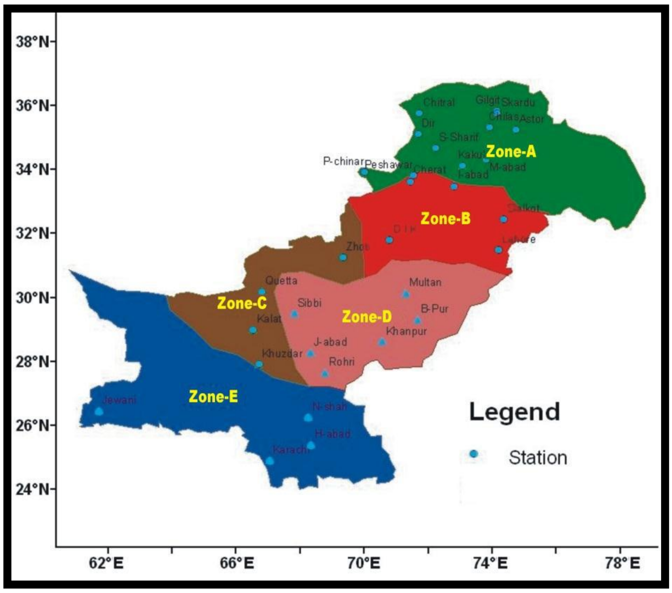

Figure 2.1 Climate zones of Pakistan

Altitude, position in relation to the coast, rivers, deserts, mountainous areas, and other geographical factors all have a significant impact on climatic variables including temperature and rainfall. As a result, considering the entire nation as a single location for research is challenging due to the fact that individual stations have varied geographies and microclimates. The country was split into five zones for this purpose, depending on their meteorological characteristics as determined by a Pakistani study using the Kööpen microclimate classification. Zone 1, 2, 3a, 3b, 4, as well as their latitude and longitude and a selected meteorological Observatory, were assigned to these zones (Fig. 3.1).

2.2 Climate Zones of the Study Area

2.2.1 Zone 1

Zone one includes the stations in Pakistan's north that have a chilly climate and steep mountains. Chitral, Gilgit, Muzaffarabad, Said-u- Sharif, Skardu, Astor, Dir, Chilas Parachinar, and Kakul are among the stations. These are predominantly hill stations in the Himalaya, Hindukash, and Koh-e-Sufaid mountain ranges, lying between 34- and 38-degrees north latitude. Chitral River, Astor River, Gilgit River, Indus River at Chitral, Swat River, Panjgora River, Shingar and Shayok rivers are among the Indus tributaries that traverse through the north. The Kurram River flows through Parachinar, whereas the Neelam River flows via Muzaffarabad station.

2.2.2 Zone 2

This zone, which is located between 31N and 34N, features a mild chilly temperature and Sub Mountains. Sialkot, D.I. Khan, Islamabad, Peshawar, Cherat, and Lahore are the stations. In this zone, the Kabul River flows through Peshawar, the Ravi River flows through Lahore, and the Chenab River flows through Sialkot.

2.2.3 Zone 3a

The weather is freezing in the winter and scorching in the summer. The majority of them are mountainous stations with high altitudes above mean sea level, spanning the latitudes of 27N to 32N and 64E to 70E, respectively. Quetta, Zhob, Kalat, and Khuzdar are among the stations in this zone. The Gomal River flows through this area.

2.2.4 Zone 3b

This is the zone warmest and driest region, with the greatest maximum temperatures recorded in Sibbi and Jacobabad. The terrain is nearly entirely flat, with a little section of the Thar Desert thrown in for good measure. Sibbi, Jacobabad, Bahawalpure, Khanpur, Multan, and Rohri are among the stations featured. These stations are not near any rivers.

2.2.5 Zone 4

Zone 4 is a large zone around the Arabian Sea with several stations and coastal communities. The coastal region makes up just a minor part of this region, and the climate of Balochistan and Sindh provinces is predominantly dry to super arid above the shore. Hyderabad, Karachi, Nawabshah, and Jewani are the stations chosen from this zone.

Changes in the flow rate of river discharge are primarily caused by spatial and temporal changes in temperature trend and rainfall pattern. A change can happen quickly (step change) or gradually (trend), and it can also be translated into a more complicated form. Climate change is frequently seen as a gradual upward trend. Missing values, seasonal and other short-term swings or climatic variability, and lack of homogeneity of the data, e.g. owing to changes in equipment and observation techniques and station site shift, all hinder temperature and precipitation change studies. The time series that were utilised were chosen based on the PMD data quality check and the duration of the record period. All-time series used are continuous from 1976 to 2005, as the PMD has estimated the missing values.

River discharge time series for six gauge-stations in the northern regions are available for the current investigation, with a record length of twenty-five years from 1976 to 2000. The river discharge data is obtained from Pakistan's Water and Power Development Authority (WAPDA), together with their longitude and latitude and other basic geographical information, as given in Table 3.1.

2.3 Data Analysis

The initial stage in the study is to comprehend the climatic variables, not only for individual station time series, but also for zonal or regional averages. The deviation of the 30 years mean annul data from the average values was determined using descriptive statistics for this purpose. For each of the five zones and individual stations, statistical markers such as standard deviation, standard error, medians, and skewness were determined. The Descriptive process creates standardised values and provides summary statistics for several variables in a single table. The statistical approaches used in this investigation are as follows.

2.3.1 Mean

It is also called an arithmetic average and has been determined by applying the subsequent formula

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

Where the climatic variable is's mean? The arithmetic mean is defined as the sum of all observations divided by the number of observations n, where xi is each independent variable and n is the total number of variables. It is the most extensively used central tendency measure. The use of the mean has the disadvantage of not revealing the normal outcome. If one outcome stands out significantly from the rest of the data, it will have a significant impact on the mean. Outlier describes such a result.

2.3.2 5% Trimmed Mean

This mean is used to eliminate outliers from data, as well as the 5% extreme values on the top and 5% extreme values on the bottom. The median is used more frequently because more people understand it. The trimmed mean is mostly concerned with data outliers.

2.3.3 Median

The median is an alternative metric. The median is the value in the center. When the number of occurrences is even, the median is the average of the two middles. The median is a better way to describe the average number. There is another value that is resistant to outliers as well. The median is equivalent to the value with order number (n+1)/2 when there are n observations, and they are sorted from smaller to bigger. The 50th percentile is equal to the median. The median is identical to the arithmetic average if the data distribution is Normal. Because the median is unaffected by extreme values or outliers, it may be a more accurate indicator of normal distribution than the arithmetic mean

2.3.4 Standard Deviation

A measure of how dispersed the data from the mean value are or in other words variability of the population from which the sample was drawn

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

2.3.5 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.

2.3.6 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.

2.3.7 Skewness

A measurement of data symmetry (Kenney and Keeping, 1962), or, to put it another way, the data's position in terms of its deviation from the average value. Skewness will be equal to 0 if the data distribution is Normal. The right tail of a distribution with a strong positive skewness value is lengthy, while the distribution's bulk is concentrated on the left side of the picture. The mass distribution is concentrated on the right of the picture if the left tail is longer. This is referred to as a skewed distribution. In other words, one or even more extremely big values exist

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

CHAPTER 3

RESULT AND DISCUSSION

Means were estimated for the full period (1976-2005) and by splitting datasets into 10 and 15 years, for each station and for the country as a whole, in order to examine the data and establish patterns in temperature, rainfall fluctuations, and their influence on the resulting river flow. The data's reliability and homogeneity of means were statistically verified using several statistical procedures, as described in Chapter 3. To examine changes in temperature and rainfall, as well as their impact on river discharge rates, all variables were separated into the following groups:

a) **Years Trend:** The first decade (1976-1985), the second decade (1986-1995), and the third decade (1996-2005) were studied on a decadal scale to determine their mean values and statistical significance using the ANOVA test.

b) **15 Years Trend:** On two 15-year periods, 1976-1990 and 1991-2005, single station and full study area analyses were also conducted. Using Arc GI software, the data was displayed as maps.

c) **30 Years Trend:** The 30 years of data were plotted into real-time series graphs to assess the whole study period.

3.1 Temperature

Changes in climate, as one of the most pressing global environmental issues confronting humanity, has the potential to have far-reaching environmental consequences. The reported temperature rise has significant consequences for agriculture, ecosystems, biodiversity loss, fresh water supplies, and increasing health risks (Alam, 2009). Climate warming due to anthropogenically caused acts, according to Folland et al (1999), is more noticeable in lowest temperatures than maximum temperatures in most regions of the world. Since around 1950, several researchers have discovered that daily minimum temperatures have increased at a rate roughly double that of maximum temperatures (IPCC, 2001). Although not all places see more heat at night, it is the primary signal in many. As a result of all of these signals, it is critical to keep track of minimum and maximum temperature data (Jones, 2001). However, the significantly higher-than-normal increase in daytime temperatures was not as noticeable. The amount of the temperature change varies by area; for example, the east coast of North America is expected to warm by 2°C, whereas Alaska and North Canada are expected to warm by 10°C. Furthermore, as compared to North American temperature norms, summer temperatures in the American Southwest are dramatically rising (IPCC, 2001). Differential changes in daily maximum and lowest temperatures have occurred in most regions of the world, leading in a narrowing of the diurnal temperature range (DTR) and an increase in mean temperature (Karl et al., 1993; Easterling et al., 1997; Jones et al., 1999). Except for fewer days with exceptionally low minimum temperatures, most parts of Europe, the United States, and Australia have seen a rise in daily maximum and decrease in intra-seasonal daily temperature fluctuation. In days with extremely high maximum temperatures, no substantial rise has been seen (Karl et al., 1995; Collins et al., 2000).

3.2 Data collection and analysis

As previously stated, the data for this study was compiled using daily minimum and maximum temperature records collected from 30 meteorological stations across Pakistan from 1976 to 2005. The data came from the Pakistan Meteorological Department's Climate Data Processing Centre (CDPC). The study's stations were chosen based on their latitudinal position, height above sea level, length of record, completeness, and dependability of data to get a synoptic perspective of the whole nation. Averages for 10-, 15-, and 30-year periods were computed for each zone and the entire country to determine trends.

3.3 Results

For real-time data, descriptive statistics were used to calculate monthly and yearly averages of minimum and maximum temperatures, a 5% trimmed mean, a 95 percent confidence interval for the mean, medians, standard errors, and percentiles. Table 4.1 shows descriptive data for lowest and maximum temperatures in Pakistan's several climatic zones. The total number cases denotes the size of the data set (30 years from 1976-2005). The data reveal that zone 1 has the lowest mean Min and Max temperatures, at 9.26 and 22.89 degrees Celsius, respectively, with a median of 8.84 degrees Celsius and 23.31 degrees Celsius. The greatest mean values of 20.35 and 33.70^{o}C and median values of 20.35 and 33.70^{o}C and median values of 20.35 and 33.70^{o}C and median values of 20.35 and 33.70^{o}C and median values of 20.35 and 33.70 ^{o}C and median values of 20.35 and (20.86 and 33.65^{o}C). Similarly, zone3a (0.35oC) has the largest standard error while zone3b has the lowest standard error (0.09^{o}C). Furthermore, zone 2 (0.32 ^{o}C) has a greater standard error in maximum temperature, but zone 3b (0.08 ^{o}C) has a smaller standard error. Zone4 and zone3b have bigger values at the 75th percentile, whereas the lowest temperature has a lower value at the 25th percentile. Zone3b has a greater maximum temperature percentile than zone1, which has a lower maximum temperature percentile. Only zone3b exhibits a positive value in the data set of minimum temperature skewness, which is determined to be negative for zone1, zone2, zone3b, and zone4. The skewness has been recorded with a positive sign for maximum temperature in zones 3a and 3b, whereas it is negative for the remainder of the zones.

Similarly, the overall trend in mean maximum and minimum temperatures for the whole research region (country) is most significant at the (p0.05) level across decades and within decades, as shown in Table (4.2). The three-decade lowest temperature trend for the whole research region was determined to be non-significant ($p>0.1$). However, the Duncan test (Fig. 4.2 & Table 4.2 in Annexure) shows that the mean minimum temperature of the entire research region is marginally significant, with a probability of 0.01. (87 percent).

3.4 Zonal Analysis

The zonal yearly mean and the overall study area mean were calculated by averaging the mean monthly data of minimum and maximum temperatures for all individual stations to analyses temperature changes among various zones. All data was organized into tens and fifteens, with the last being used for trend predicting models.

3.4.1 Zone1

Zone 1 consists of eleven stations that mostly serve the country's northern regions. These stations are found in the Himalayan, Hindukush, and Koh-e-Sufaid mountain ranges, between 34- and 38-degrees north latitude. The findings of the analysis of variance are mixed. In Table 4.3, the most significant findings at alpha of 0.05 are obtained in Kakul (F = 4.58, p = 0.02) and Parachinar (F= 16.42, p= 0.00), whereas the rest stations are found non-significant in mean minimum temperature. Astor, Chilas, Chitral, Gilgit, Kakul, Muzaffarabad, Parachinar, and Said-u-Sharif, on the other side, had the highest significant findings (p 0.05) for maximum temperature.

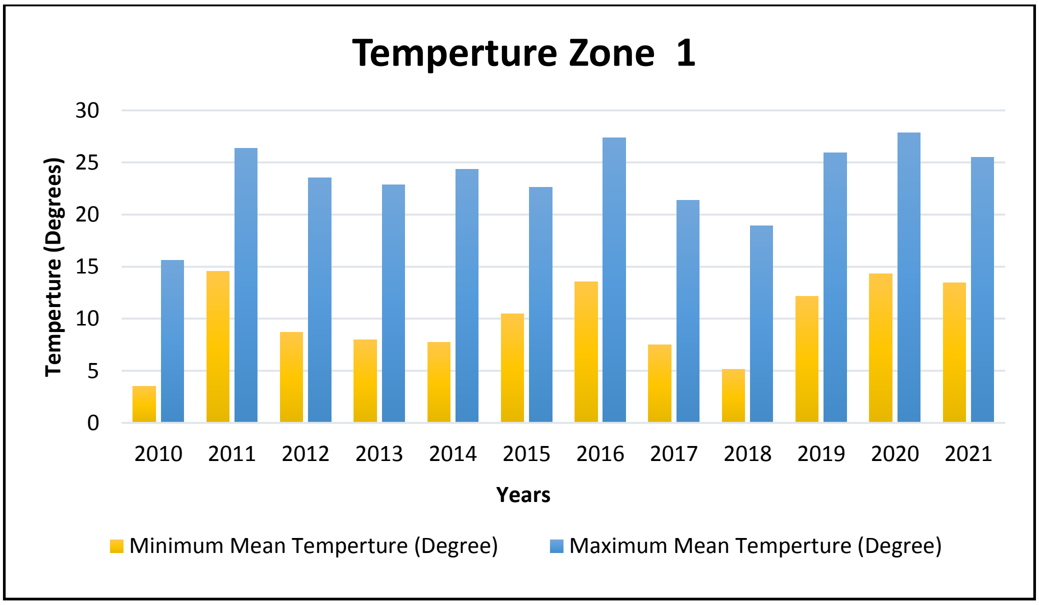

Figure 3.4.1 Temperature of Zone 1

Zone 1 consists of eleven stations that mostly serve the country's northern regions. The Himalayan, Hindukash, and Koh-e-Sufaid mountain ranges are home to these stations, which are located between 34oN and 38oN. The findings of the analysis of variance are mixed. In

Table 4.3, the most significant findings at alpha of 0.05 are obtained in Kakul (F = 4.58, p = 0.02) and Parachinar (F= 16.42, p= 0.00), whereas the rest stations are found non-significant in mean minimum temperature. Astor, Chilas, Chitral, Gilgit, Kakul, Muzaffarabad, Parachinar, and Said-u-Sharif, on the other side, had the highest significant findings (p 0.05) for maximum temperature.

3.4.2 Zone2

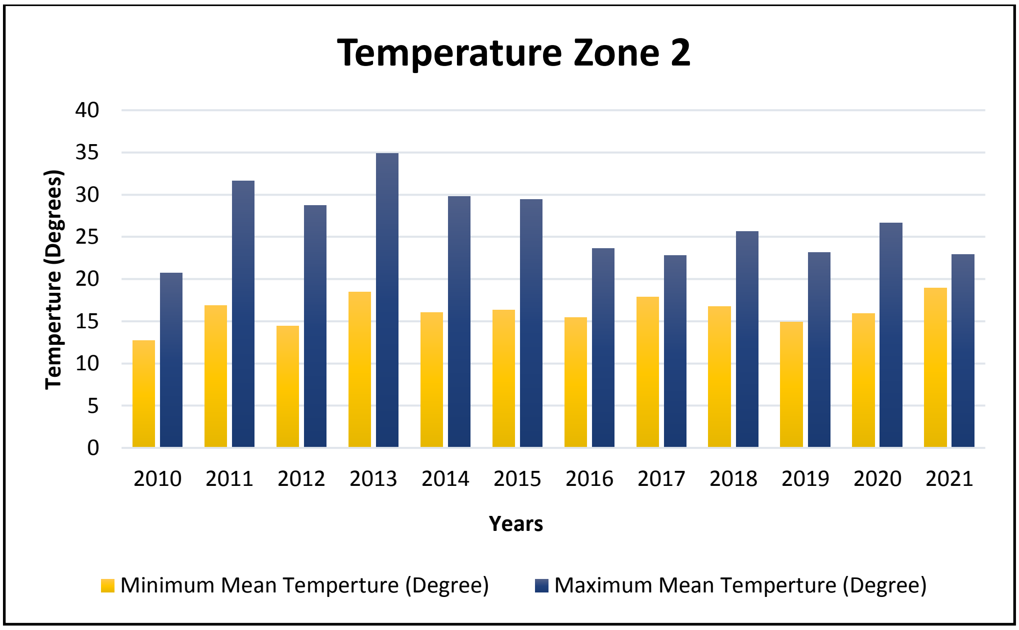

Figure 3.4.2 Temperature of Zone 2

Zone 2 has six stations, as indicated located in plain sub-mountain terrain between 31- and 34-degrees north latitude. The mean lowest temperature is rising at three Zone 2 sites. The highest significant findings at 0.05 were observed in Islamabad (F= 6.01, p= 0.01), Lahore (F=18.69, p= 0.00), and Peshawar (F=18.09, p= 0.00), whereas Cherat and D.I.K were deemed non-significant. With a standard error of 0.2oC, the total lowest temperature for zone2 (F= 2.21, p= 0.1) is almost significant. The significant trend in zone 2 for maximum temperature (F= 0.09, p= 0.91) is found to be almost minor (p>0.05) for all stations in the zone, including Cherat, DIK, Islamabad, Lahore, Peshawar, and Sialkot.

3.4.3 Zone 3a

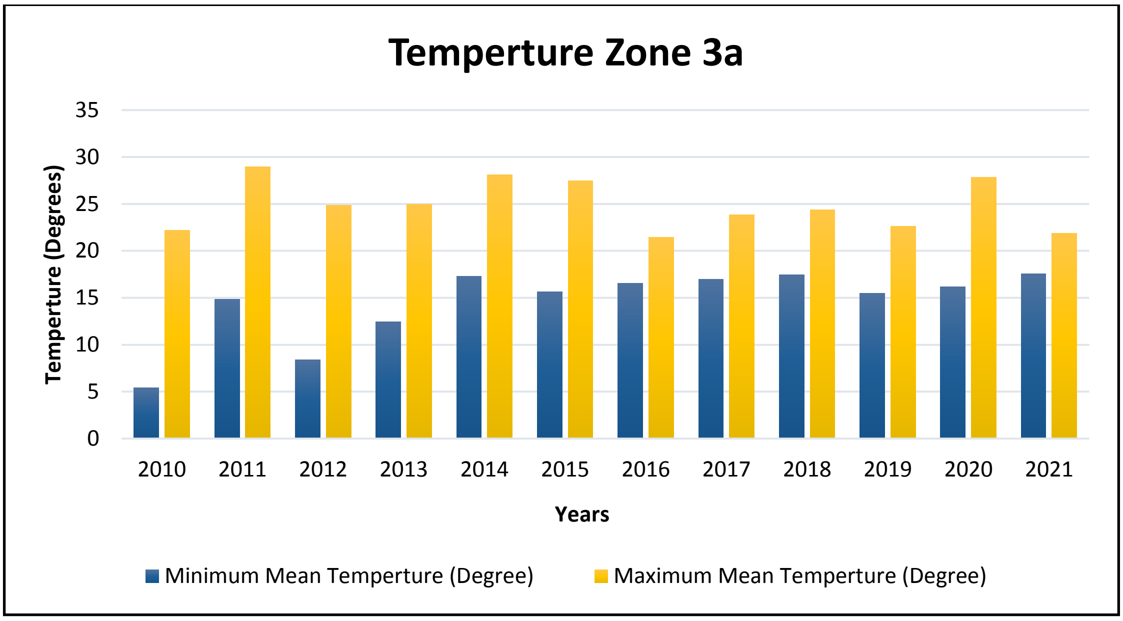

Figure 3.4.3 Temperature of Zone 3A

This zone covers four stations in the country's southern region. It spans the latitudes of 27°N to 32°N and 64°E to 70°E. Each of the four stations is hilly and situated at a high height above sea level. Similarly, the means are nearly identical, but the value of the mean in the third decade is higher than in the second decade for minimum temperature analysis. Except for Zhob station ($p>0.05$), Quetta and Khuzdar stations show the most significant results in terms of maximum temperature. Although the significance values estimated for the Kalat station data are greater than the critical tabular value, the station's probability is relatively high.

3.4.4 Zone 3b

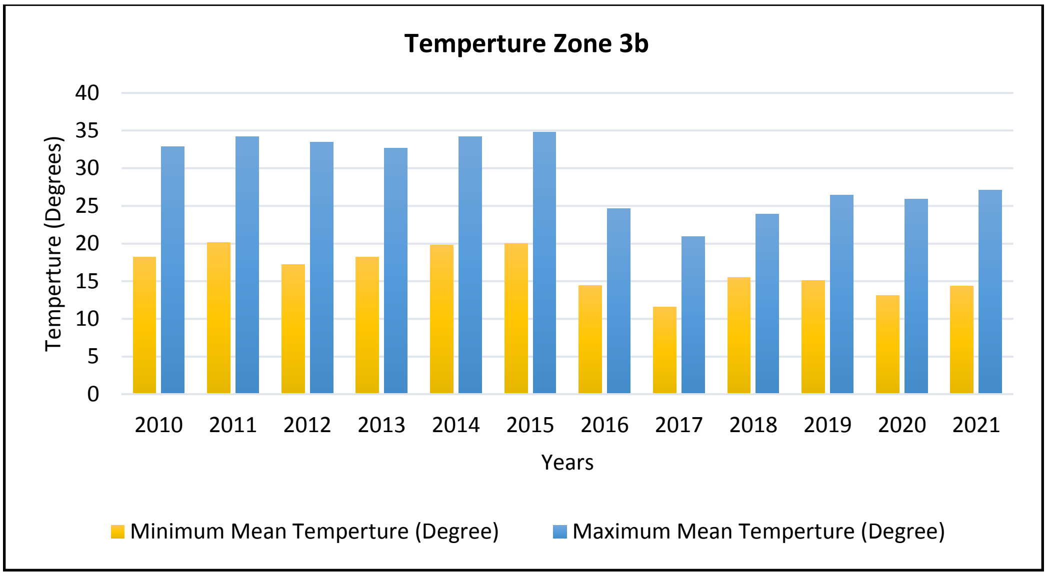

Figure 3.4.4 Temperature of Zone 3B

This is the country's warmest zone, with Sibbi and Jacobabad recording the greatest maximum temperatures. It is made up of six stations, all of which show a considerable rise in temperature. The minimum temperature ANOVA result (Table 4.9) for zone 3b (F= 4.17, p= 0.02) is most significant at the 0.05 level. For all stations in this zone, the Duncan test demonstrates a substantial rise in the mean of the third decade, i.e. 1996-2005, for lowest temperature (Table 4.10). Furthermore, Zone 3b has the highest significant result (F= 3.38, p= 0.04) for maximum temperature. Bahawalpure (0.08°C) and Rohri (0.08°C) are two stations with much lower temperatures. a value greater than the 0.05 limit, as seen in Because of their higher probability value, the alternative hypothesis may be rejected for all four stations.

3.4.5 Zone 4

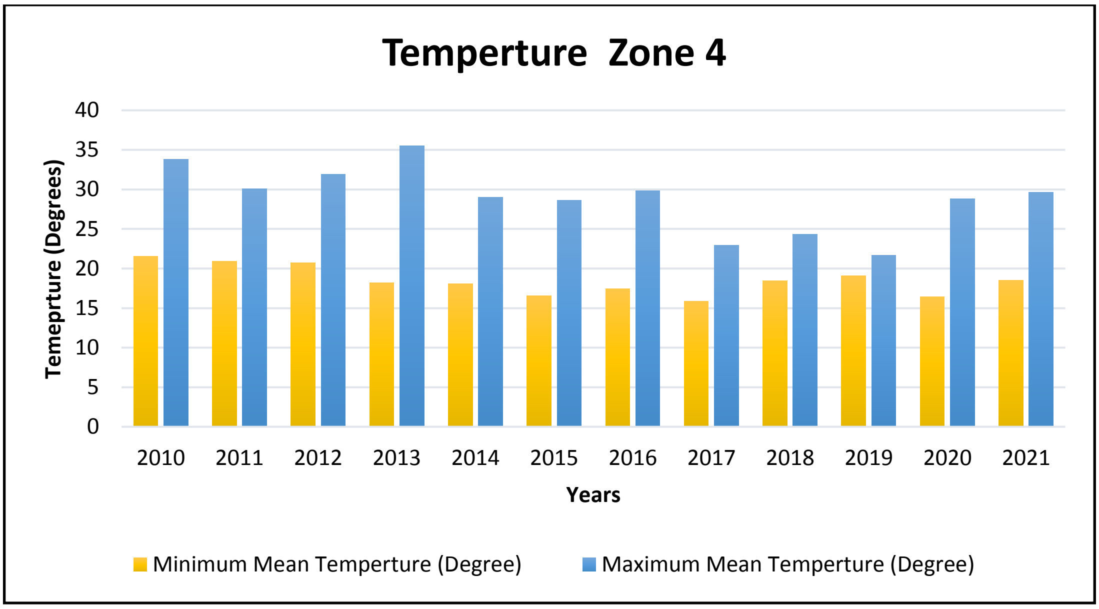

Figure 3.4.5 Minimum Temperature zone 4

Only two of the four stations in Zone 4 exhibit a significant trend in lowest temperature, namely Hyderabad and Karachi. This zone's general trend (F= 3.80, p= 0.03) demonstrates a rise over three decades. Except for Jewani, three out of four stations show a significant trend in maximum temperature, although in a homogeneous selection of alpha Jewani exhibits a significant change (p=85%) in the first two decades. The third decade's average is somewhat lower than the preceding decade's average. The significant p-value for zone, on the other hand, is slightly higher (p= 84 percent).

3.5 Rainfall.

No convincing evidence of long-term change in worldwide precipitation has been identified, similar to the growing trend in global temperature in the twenty-first century (IPCC, 2001; Karl and Trenberth, 2003; Allen and Ingram, 2002). According to recent studies, the 20th century's growing tendency is merely 9mm each decade, or 0.98 percent every decade (New et al. 2001). However, the rise described above was recorded across high latitude locations and tropical oceans, whereas a reduction was observed over tropical lands (New et al., 2001; Kumar et al., 2003; Bosilovich et al., 2005). It is self-evident that climate change causes greater moisture-holding capacity in the air, as well as changes in precipitation event characteristics such as frequency, intensity, volume, and duration. Karl et al., 1995; Karl and

Knight, 1998; Trenberth, 1999; Treydte et al, 2006). Japan (Iwashima and Yamamoto, 1993), China (Zhai et al., 1999), Australia (Suppiah and Hennessy, 1996), and South Africa (Suppiah and Hennessy, 1996) all have evidence of rising precipitation rates (Mason et al., 1999). According to the IPCC (2001) report, although total rainfall increased by just 1.0 to 3.4 percent, the intensity increased by somewhat more (Allen and Ingram, 2002). Recent research based on climate models and historical data indicate a rise in droughts in the south of Europe in the future as a result of increasing evapo-transpiration and a relatively modest decline in rainfall and precipitation frequency. (Kostopoulou and Jones, 2005; Vicente-Serrano and Cuadrat-Prats, 2007).

3.6 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.

3.7 Zonal analysis

Because rainfall data shows uneven variances in homogeneity tests, similar calculations were performed for rainfall data analysis, just as they were for maximum and lowest temperature (mainly used for equality of means).

3.7.1 Zone1

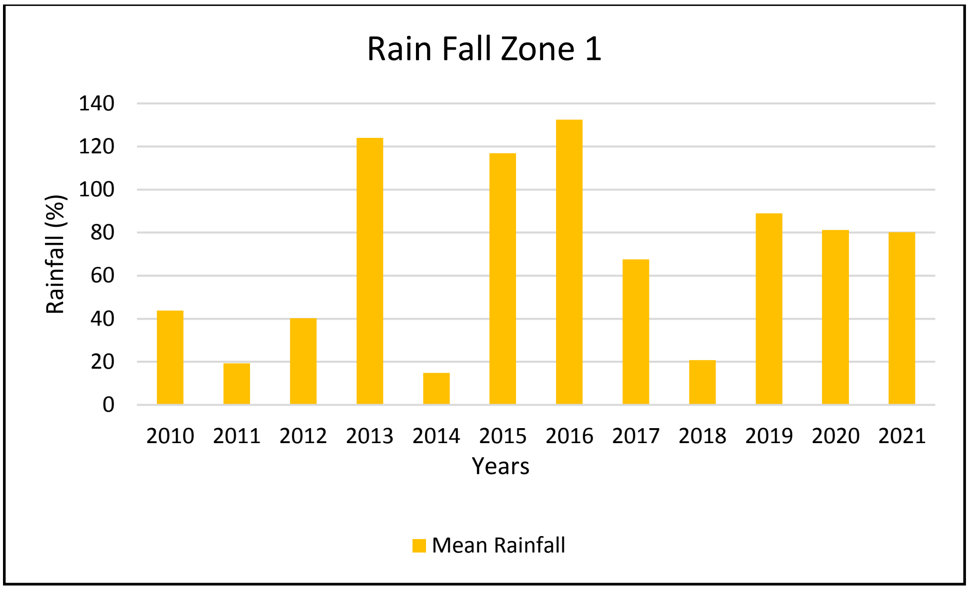

Figure 3.7.1 Rainfall zone 1

Because the computed values are greater than the critical value (p> 0.05), the probability for zone 1 (F=1.93 p=0.15) is not significant. Different stations in zone 1 exhibit the most significant findings, 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) (Table 3.9).

3.7.2 Zone2

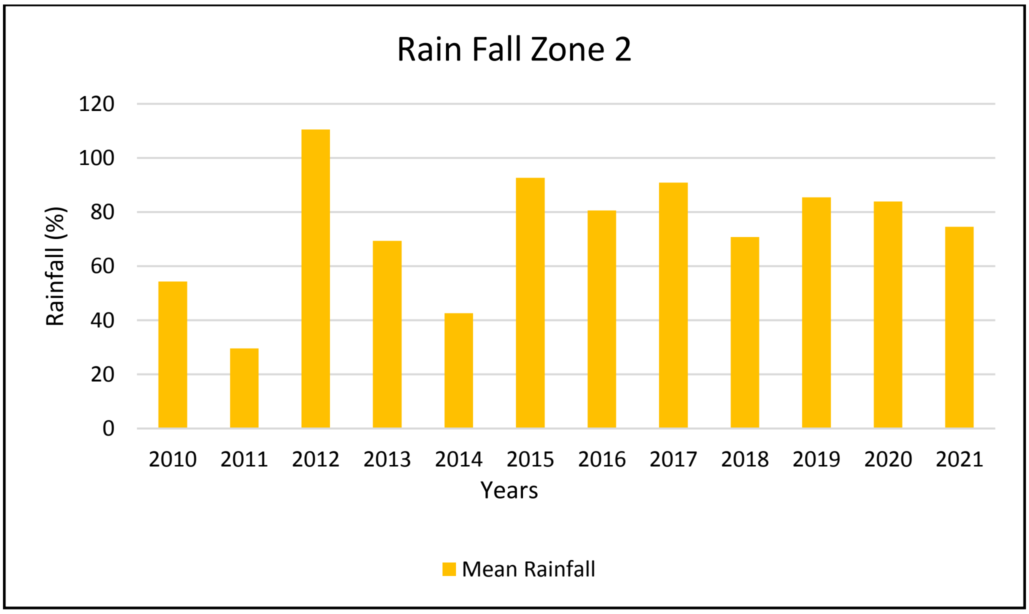

Figure 3.7.2 Rainfall zone 2

The findings of the ANOVA test on zone2 data (Table 3.10) are non-significant for all six stations ($p > 0.05$ or 0.1). In the same way, zone 2 shows a non-significant trend in mean rainfall.

3.7.3 Zone3a

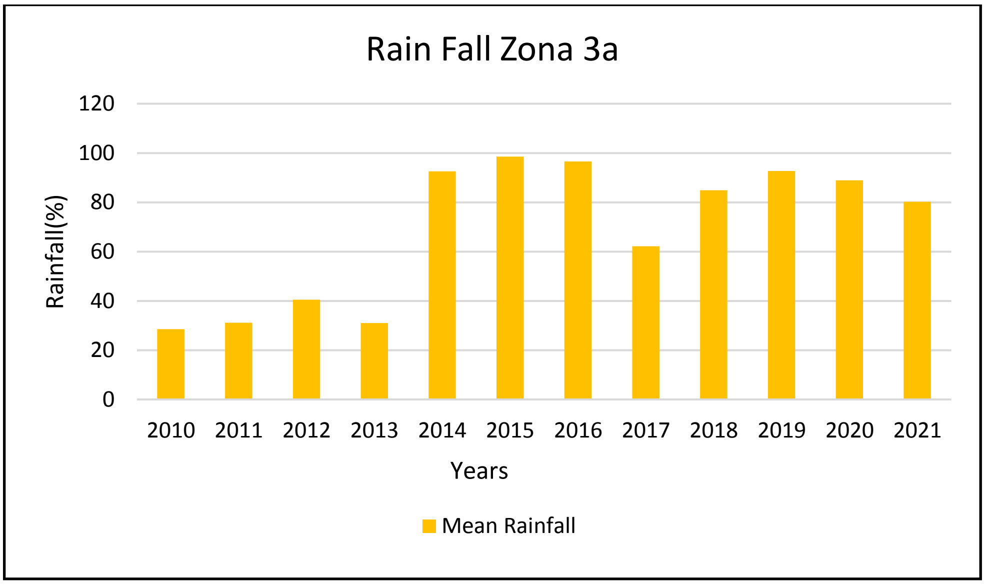

Figure 3.7.3 Rainfall zone 3a

As indicated in Table 4.19, two stations, Khuzdar ($p=0.04$) and Quetta ($p=0.02$), are the most significant to the shift, whereas Kalat and Zhob exhibit no trend. Zone3a's ANOVA result ($F=3.81$, $p=0.03$) was shown to be the most significant to the change. Kalat and Zhob have no significance in multiple comparisons across the decades, however Quetta and Khuzdar (p 0.05) have significance in the previous two decades (Table 3.11).

3.7.4 Zone 3b

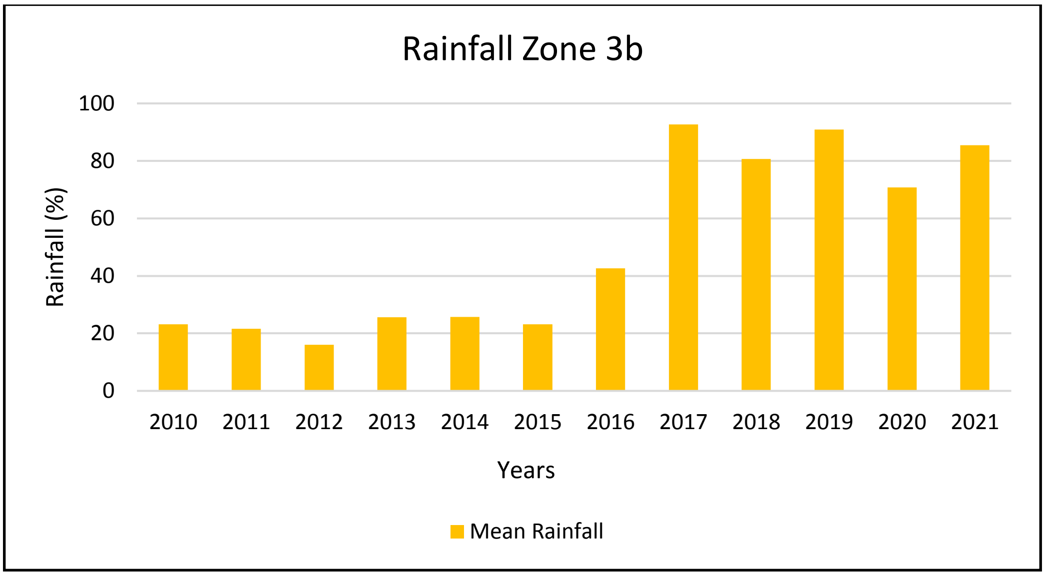

Figure 3.7.4 Rainfall zone 3B

Like zone2, zone3b's ANOVA Table (3.12) indicates no significant trend (p> 0.05) for any of the zone's stations. The analysis of variance test for the zone is also found to be non-significant (F=1.53, p=0.22).

3.7.5 Zone 4

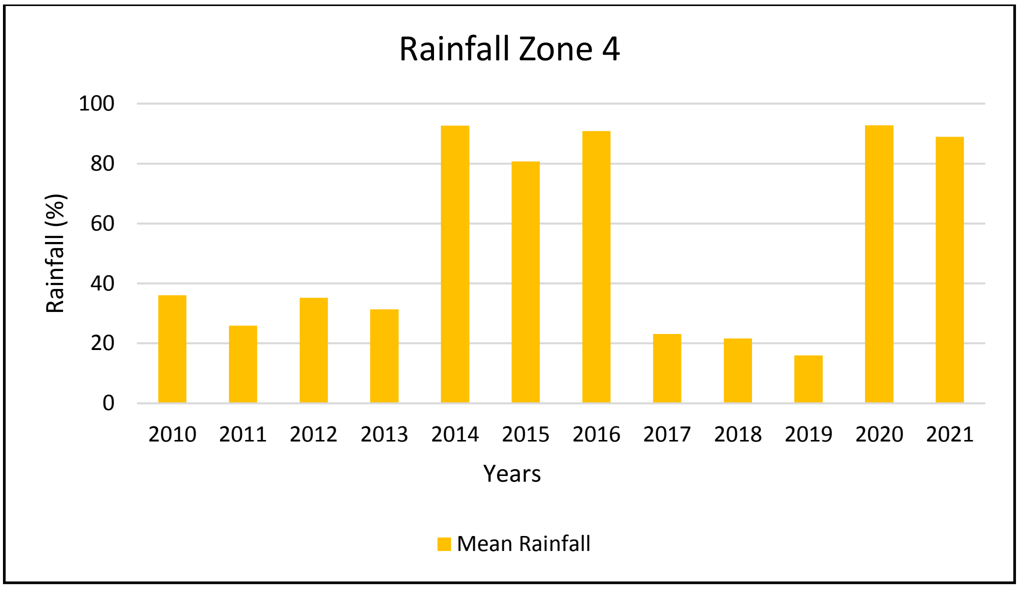

Figure 3.7.5 Rainfall zone 4

When compared to other climate zones in the nation, the ANOVA Table for zone4 (4.23) indicates the highest significant result (F=5.92, p=0.00). The most noteworthy trend for thirty years average rainfall has been noticed at Karachi station.

CONCLUSIONS

This study was conducted to conclude the variations in Temperature and Precipitation pattern of last 12 years (2010- 2021).

1. It is found that the temperature and precipitation trends are increasing at a rate of 0.11°C each decade, particularly in areas where the country's cities are developing.

2. Data on precipitation and rainfall reveal an overall dropping trend of around (-1.18mm) per decade, which was deemed to be the most significant (p= 0.040.05).

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