BE CIVIL ENGINEERING PROJECT REPORT

CAUSES OF CLIMATE CHANGE AND ITS IMPACT IN RISALPUR

Project submitted in partial fulfillment of the requirements for the degree of

BE Civil Engineering

SUBMITTED BY

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MILITARY COLLEGE OF ENGINEERING,

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ISLAMABAD, PAKISTAN.

2022

This to certify that the

BE Civil Engineering Project entitled

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ACKNOWLEDGEMENT

At the outset, we would like to thank Allah Almighty for giving us the strength to complete the research work assigned to us within the prescribed time and with a profound sense of satisfaction. We are in great debt to those who made this research possible especially to our advisor Maj Umair Ghazi who always encouraged us and under whose able guidance we were able to complete the magnanimous task at hand with great ease. They have always been symbols of great inspiration and encouragement for us. At the last, we would like to extend our special thanks to our parents for their prayers and boundless love.

ABSTRACT

Climate change is becoming a growing concern for the global population. Pakistan is among the most vulnerable countries that is at risk of adverse climate change impacts. Since the country hosts extensive glacial cover in the Himalayas-Karakoram-Hindukush mountain systems which is also the source of all its rivers, climate change and its factors become even more significant water resources. Pakistan has faced some of most devastating weather induced disaster events in recent decades, costing heavy toll on the national economy and social losses. Population growth, increasing water scarcity levels in both rural and urban areas for domestic, commercial as well as agriculture consumers is stressing the boundaries of meeting water demands across the country. understanding the factors of climate change, its impacts on the weather system and hydrological systems both in the long and short term is the only key to mitigate the adverse impacts of climate change. It is important to have a long and short-term hydrometeorological data to understand the water resources availability and hydrological responses within highlands catchments in northern Pakistan. Hydrometeorological data (temperature, rainfall, humidity, domestic and irrigation uses, surface wind, thunderstorm, dust storm) now frequently being experienced across the country in general and of the relevant stations within the study area. These factors were analyzed to infer existing and future trends in seasonal and annual time scales. with rising water demands, development and climate variability in the study area trend analysis was applied for two different time periods, existing (1992 - 2020) and future prediction/ trends (2021 - 2049). The non-parametric Man-Kendall test was used to detect the nature of trends in the hydrological variables. The analysis infer an increase in the temperature in Risalpur while precipitation is generally decreasing.

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LIST OF ABBREVIATIONS

PMD: Pakistan Meteorological Department

DEM: Digital Elevation Model

SDO: Small Dam Organization

Chapter 1

INTRODUCTION

INTRODUCTION

Climate change is an established reality of the current era of earth history and is becoming of the greatest challenges for global population. Intense climatic conditions with devastating impacts on people, socio-economic systems and biodiversity is bearing devastating events like mega flooding, droughts, glacial melting and water crisis all over the globe. Carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O) and the Chlorofluorocarbons (CFCs), the main greenhouses gases (GHGs), are attributed as the anthropogenic contributors in increasing the Earth's mean temperature. An exponential rise in concentration of the GHGs was noted after the industrial evolution (Forster et al., 2007; Labat et al., 2004). However, industrial development is not the only era contributing GHGs into the earth's atmosphere. During the engineering evaluation, the CO2 levels have substantially risen and were recorded to be 367 ppm in 1990 (Etheridge et al., 1996; Houghton et al., 2001; IPCC, 2001; Neftel et al., 1985) and 379 ppm in the year 2005.

According to a report by International Panel on Climate Change (IPCC) published in 2021, climate change impacts are estimated to increase in the coming decades. With an average rise of 1.5˚C causing global warming the frequency of heatwaves, prolonged intense summers and shorter winters, either intense rainfall spells or rain and rising global sea levels would be experienced around the world. The heat extremes are estimated to be above the normal threshold for human health levels and agriculture.

The Sixth Annual Report of IPCC highlights the anthropogenic influence in climate change resulting in adverse and intense weather events. Earth's climate has experienced variation throughout its history, but the current variation is said to be unprecedented and is unequivocally attributed to the human interventions in natural climatic systems. Most of this warming during the last 40 years, the last seven years termed as the warmest according to scientists working on satellite observatories for global climates. 2016 and 2020 are marked as the warmest years on record (IPCC, 2021).

Though most of developed countries and world leaders in economy are major contributors of climate change and global warming but the toll of impacts is paid by either developing or under-developed countries. Developing countries are somehow unfortunately largely dependent on agriculture, tourism and forestry and have relatively warmer climates compared to developed countries. The figure 1.1 below a study conducted various economies were studied to assess the cost of climate impact across the globe. The map depicts that most of the developing countries are ranked among most vulnerable to the risk of climate change (Standard and Poor, 2014).

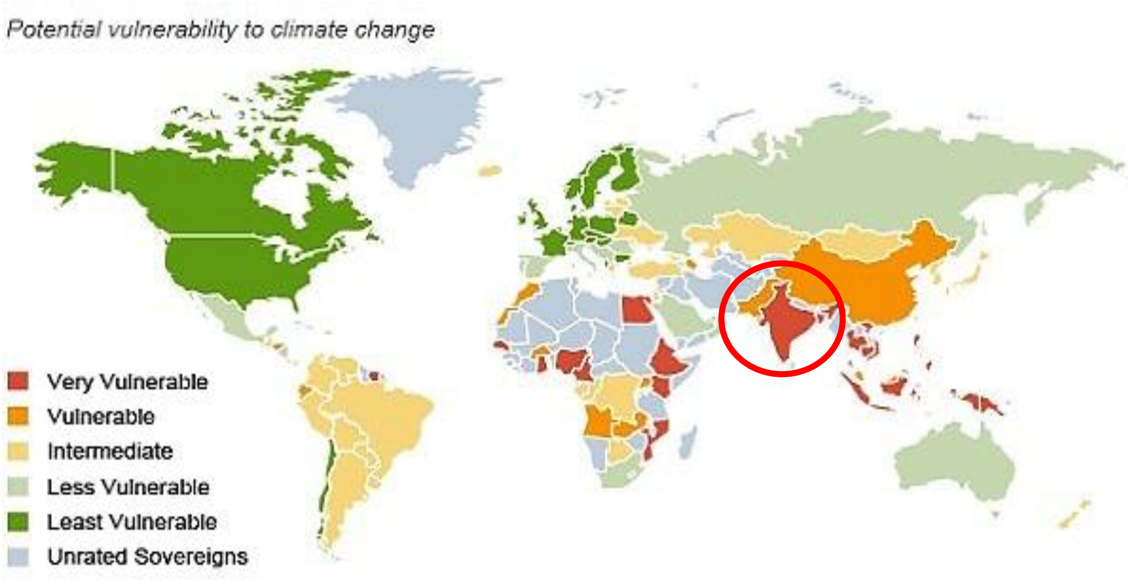


Figure 1.1 Economic toll and risk to climate change on countries around the world (Standard and Poor's, 2014)

In recent time one of main challenges posed to the human civilization is climate change and climate induced disaster events. Earth's climate is experiencing increase in in frequency of extreme spells of precipitation, heatwaves and droughts. These uncertain patterns have significantly affected socio-economic fabric of around the globe and Pakistan is no exception. Even small temperature variations can have devastating impacts on the fluvial system and snow cover, agriculture systems, ocean chemistry and rainfall patterns (Field et al., 2012; Shahid et al., 2013). The changes observed in climatic patterns depict anthropogenic influences and disruptions in atmospheric condition. The unprecedented climatic inconsistency, ever changing vulnerability and exposure dynamics that are dictated by climatic and non-climatic factors are anthropogenically driven (Field et al., 2012). Pakistan is a developing country with limited resources to be spared for recovering from the impacts of climate change and warming. According to study Global Climate Risk Index, Pakistan is among the top 10 most vulnerable countries in the world to devastating impacts of climate change. In last two-three year the country has though invested in climate mitigation, policy initiatives and environmental checks which has resulted in the country moving from its earlier 5th most vulnerable to 8th place in the index in 2021. Data infers estimated financial losses of approximately $3.772 billion with fatalities because of a total of 173 extreme weather events from time span of 2000 to 2019 (GCRI, 2021).

Spatial and temporal dynamics of vulnerability and exposure keep modifying and, in many cases, getting worse with the passage of time across regions. The vulnerabilities and exposure to climate induced hazards vary due to the social fabric and culture, geographic proximity to a risk site, decision making and institutional arrangements, economic profile and environmental factors on a community or country (Adger, 2006). The fast-paced socioeconomic variations, settlement patterns and uncontrolled rural to urban drift has exponential increased the cost of climate induced vulnerabilities and exposure to disasters that put a heavy toll on national economies especially in the developing and underdeveloped countries. (McCarthy et al., 2001).

Unfortunately, Pakistan is also among the countries that are most vulnerable to the impacts of climate change. Being an agriculture driven economy, climate change is particularly of concern for Pakistan. Since the country's fluvial system is sourced in the glaciers hosted in the Himalayan mountain system, rising temperatures with weather shifts is stressing the available of fresh water for drinking purpose as well as agricultural activities. Riverine and flash flooding across the country, rapid glacial melting and heat waves are becoming frequent and intense with each passing year. though the country is not a contributor of climate change, but it is highly vulnerable to the adverse impacts and socio-economic losses.

Pakistan is ranked 18 out 191 countries according to Inform Risk Index depicting some of the highest disaster risk levels (Fig 1.2). Majority of these devastating events are attributed to climate change. data projections for different climate scenarios infer that if adequate measures are not taken, the risk of climate induced disasters will further aggravate soon for Pakistan and acute water shortage may be experienced throughout the country (Table 1.1).

Table 1.1 10 most affected countries due to climate change based on data from 2000-2019 (annual averages) (Source: Global Climate Risk Index 2021)

CRI 2000-2019 (1999-2018)	**Country**	**CRI score**	Fatalities	Fatalities per 100 000 inhabitants	Losses in million US$ PPP	Losses per unit GDP in %	Number of events (2000–2019)
1 (1)	Puerto Rico	7.17	149.85	4.12	4 149.98	3.66	24
2 (2)	Myanmar	10.00	7 056.45	14.35	1 512.11	0.80	57
3 (3)	Haiti	13.67	274.05	2.78	392.54	2.30	80
4 (4)	Philippines	18.17	859.35	0.93	3 179.12	0.54	317
5 (14)	Mozambique	25.83	125.40	0.52	303.03	1.33	57
6 (20)	The Bahamas	27.67	5.35	1.56	426.88	3.81	13
7 (7)	Bangladesh	28.33	572.50	0.38	1 860.04	0.41	185
8 (5)	Pakistan	29.00	502.45	0.30	3 771.91	0.52	173
9 (8)	Thailand	29.83	137.75	0.21	7 719.15	0.82	146
10 (9)	Nepal	31.33	217.15	0.82	233.06	0.39	191

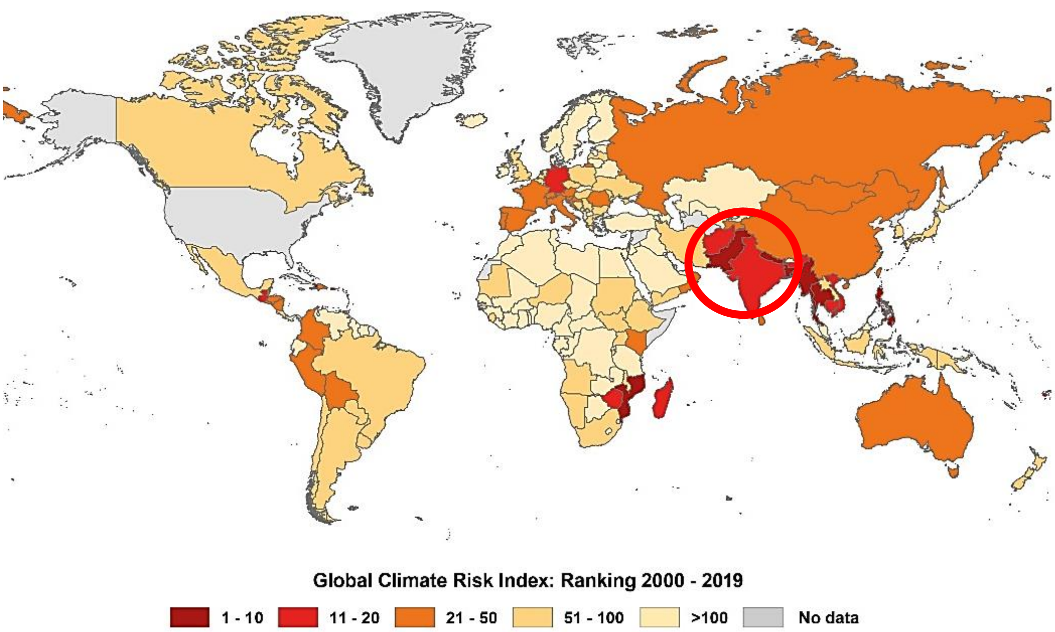


Figure 1.2 Map showing the most vulnerable countries to the impacts of climate change (GCRI, 2021)

1.1 RESEARCH PROBLEM

Pakistan is highly vulnerable to the impacts of changing climate and has witnessed several climatic disasters during the last few decades. Khyber Pakhtunkhwa has experienced intense weather events because of climate change like the 2010 mega floods. With each passing year the meteorological conditions are getting intense with long heat spells during summers and short winters. There is an urgent need to investigate the contributors of climate change and trends of meteorological parameters to understand the nature and pace of worsening climate for timely mitigation in the study area.

1.2 RESEARCH PURPOSE

This study is focuses on Risalpur area and its surroundings because the study area is host to a cantonment and an Air Force Base which makes this study significance in its findings. Detailed analysis of the meteorological parameters will provide an insight into future trends and help in identifying any critical factors that needs mitigation from a future climate emergency in the study area.

1.3 RESEARCH OBJECTIVES

The main objective of this research was the assessment of the critical meteorological factors for Risalpur and its surroundings and to chalk out future patterns for each factor. This purpose was achieved by using the following objectives.

i. To study the causes of climate change and analyze meteorological parameters in the study area.
ii. To draw out future trends for the selected parameters and their impacts on the study area.

1.4 LIMITATION OF THE STUDY

Climate Change is a Global issue and to study its impact on small canvas is a difficult task as it includes large number of different variables and factors. While carrying out the study due to presence important Military and Civil Infrastructures there were many limitations in availability of data and access to it. The Historical Data of Hydro Meteorological Factors was not available with the concerned departments of Nowshera District.

1.5 SCOPE OF THE RESEARCH

A worldwide Hydro-meteorological (temperature, rainfall, humidity, domestic and irrigation uses, surface wind, thunderstorm, dust storm) alteration can affect precipitation and Temperature. The changes in precipitation and Temperature have been very uncertain and, in some cases, (2010 Event) they can be extremely intense in a few territories. Mostly the rainfall takes place from July to September (Monsoon) and the temperature approaches to its extreme range both in summers and winters.

However, little study has been done in this area to understand and compute how these factors add to change SRO, SSRO and GWT. Therefore, there is a strong need to carry out diverse techniques to evaluate the climate change effect on water resources.

The scope of this study is to assess the factors that contribute in climate variation in the last thirty years. The analysis of meteorological factors will help in understanding the pace and intensity of changes in the climatic conditions of the study area in the future.

1.6 RESEARCH STRUCTURE

This report comprises of five chapters defining the background and justification of research, available literature on the topic, methodology used for data analysis, the fourth chapter results obtained from analysis and the fifth chapter gives conclusions and recommendations for a way forward.

Chapter 2

LITERATURE REVIEW

This chapter gives an overview of the literature on climate change, its factors, impacts on global scale and criticality of the issue for Pakistan. It also gives an insight into the consequences of climate change occurring in the country and future challenges from rapidly changing climate in the region.

2.1 CLIMATE CHANGE

Climate Change is known as one of the gravest challenges that the world is in front of today and is expected to impact hydrological process such as precipitation and evapotranspiration. This in turn, possibly will have a relevant impact on river flow and groundwater levels. Likely bearings of predictable climate change on water resources, resultant to international warming due to increasing absorptions of greenhouse gases in the environment, has emerged as a topic of severe concern to decision makers all over the world (Raneesh, 2014).Practical increase in worldwide average surface temperature, frequency and concentration of heat waves and droughts, changes in rainfall frequency and concentration, decreased snow cover, general melting of ice and changes in soil dampness and overflow are some of the important familiar hydrologic changes often linked with global weather change (Huber and Knutti, 2011).

As a consequence of Global warming, the nature, frequency and concentration of severe events, such as tropical cyclones (including hurricanes and typhoons), floods, droughts and profound precipitation events, are expected to rise even with moderately small average temperature increases (Jason M. Vogel et al., 2014).Observational proceedings and climate forecasts provide rich proof that freshwater resources are susceptible and have the potential to be strongly impacted by this change, with extensive consequences for human societies and ecosystems (B. Bates et al., 2008). IPCC also suggests that existing water managing practices may not be desirably enough to cope with the impacts of climate change on water supply reliability, spill over risk, health, agriculture, energy and water ecosystems. Many professionals in the water division now broadly recognize climate change as an important consideration to address responsible and reactive water resources management and planning.

Numerous challenges, including rapid urbanization, vivid population growth, population migration, momentous land use and land cover changes and important development and infrastructure deficits are already being faced by water managers and planners in emerging countries. The present scenario clearly affirms that past climatic data can no longer be used as a guide to set up for the future. Rising temperatures, changing precipitation, sea level rise and disaster events like droughts and floods can have rigorous impacts on freshwater resources. The climate issue adds a new dimension to already established practices of Vulnerability estimation and risk management in the water sector administration. Therefore, there is a strong necessity to prepare for uncertain year to year variability in rainfall and runoff, changing water demands related to population increase and land use changes, and many other factors that affect water supply, water quality, and floods.

2.2 PAKISTAN PROSPECTIVE

In reaction to global warming, Pakistan is also amongst the countries where the climate is changing fast. Pakistan's abrupt climatic change is clearly identified in the study of past hundred years. Changes have already been noticed and observed, for example, increases in the frequency and concentration of heat waves and heavy rainfall events in Pakistan. Global Warming can have noteworthy effects on rain intensity, frequency and patterns. Recently, the monsoon precipitation patterns are also changing fast and the regions which were generally not included in the middle of monsoon belt, are now getting monsoon rains with larger intensity. The rise in average temperature °C in Pakistan during the years 1901-2000 is about 0.6°C and yearly rainfall has increased by 63 mm. The influence of temperature increase on river flows in Pakistan could be much diversified from place to place and have momentous and serious effects on rainfall intensity and patterns (Chaudhry et al., 2009).

Global warming is equally effecting Pakistan as it is the whole world. In last two decades, Pakistan's precipitation and thermal systems have suffered major setback due to intense change in global temperature. Pakistan has wide diversity in temperature range (Rasul et al., 2005). Cold waves are inhibited by highest mountain ranges to enter the south region of Pakistan in winter and hence hinders the extension of monsoon range to propagate in northern region in summers. The moisture produced by the Arabian sea in south, becomes quite beneficial for agricultural and power generation. Rise in temperature is the major cause of change in precipitation, droughts, heat waves and natural disasters.

2.2.1 Impact on Rainfall

Change in rainfall directly disturbs the river flows in Pakistan, however, the changes in rainfall are very unexpectable and at times is damaging in some areas. Overspill patterns are harder to forecast as they are governed by land use as well as doubtful changes in rainfall amounts and patterns. Comparatively small reductions in rainfall will translate into much larger reductions in the overspill. Furthermore, the impacts of climate change are upsetting water quantity, superiority and resulting in disastrous events such as floods and droughts.

2.2.2 Impact on Temperature

The present temperature drifts in Pakistan can be understood once we will go through the past trends given by different statistical studies. The historical trends reveal that for the last 50 years (1952-2009) or even more, the temperature has largely amplified in Pakistan at all time scales analyzed over the preceding few decades. March and the pre-monsoon season were the stages with the highest number of climatic stations showing statistical consequence and also with the highest magnitudes of trends.0.36°C/decade is the rise in mean annual temperature. This increase in temperature is faintly higher than other results found for Pakistan (Río et al., 2013).

2.2.3 Impact on Water Resources

A number of Diverse researches such as (Akhtar et al., 2008), (Ahmed et al., 2012), (Rashid Mahmood; Shaofeng Jia, 2016), (Mahmood R. et al., 2016),(Babur, M. et al., 2016), (Shakir, A. S., Rehman, H and Ehsan, S, 2010)and (Amin, A. et al., 2018) have examined the impacts of climate change on water resources of Pakistan. Most of these studies were applied in the Upper Indus basin using hydrological models and statistical techniques.

2.2.4 Impact on Summer and Winter Behaviour

The result of the climate changes in Pakistan disclose that the trends towards less spring snowpack and earlier spring overflow in mountainous watersheds in the Indus River System. For example, the change in standard seasonal flow is more as compared to annual disparities. Changes in winter and spring releases are normally positive, even with the decrease in rainfall. The changes in flows are generally downward for summer and autumn due to early snowmelt from a raise in temperature.

2.3 STATISTICS OF DISASTERS

Below given table provides insight on most frequent natural disaster in given country and its general impact on people. According to UNISDR, around 1 billion dollars loss is recorded annually due to floods. The graphical representation of the disaster events recorded in history in the country depicts that majority of these events are climate induced, resulting from weather changes and temperature variations during the summer/winter spans. For instance, flooding dominates the history of disaster events in Pakistan, primarily due to the intense rain spells in summer monsoons (July- September). In recent years the monsoon spells have become unpredictable and relatively intense with short heavy rainfall in majority of the areas. This is causing flash floods in mountainous terrains and urban flooding in majority of the cities of the country (fig 2.1 & fig 2.2).

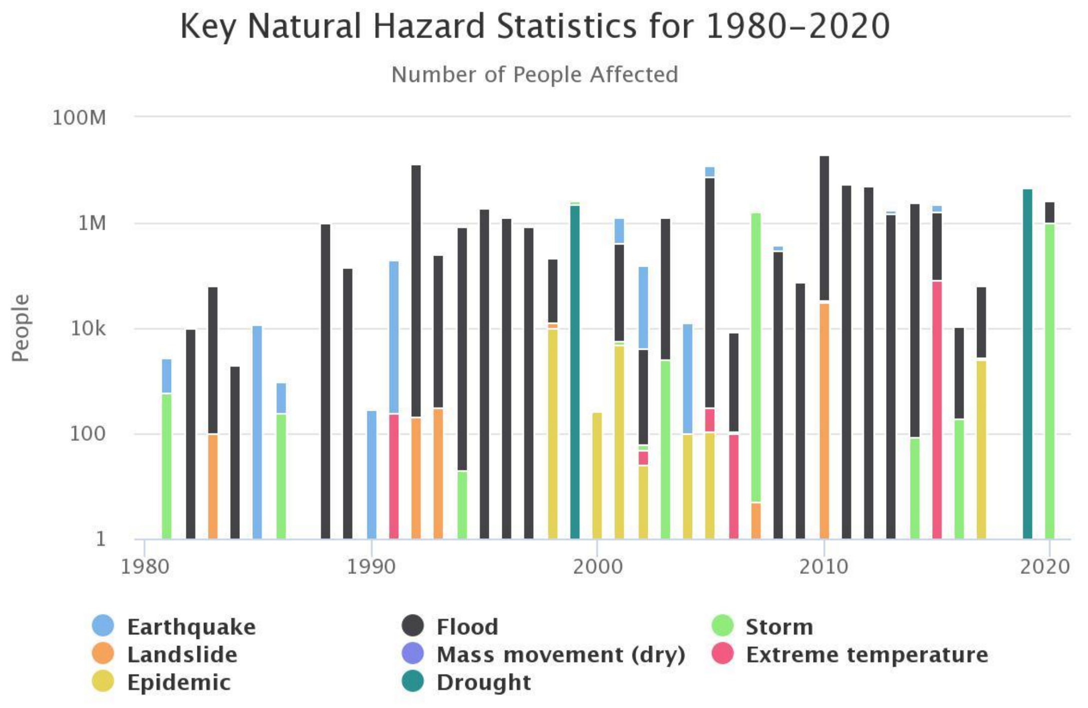


Figure 2.4 Graphical representation of the historical record of disaster events in Pakistan from 1980-2020. The bar chart shows number of people affected by each event

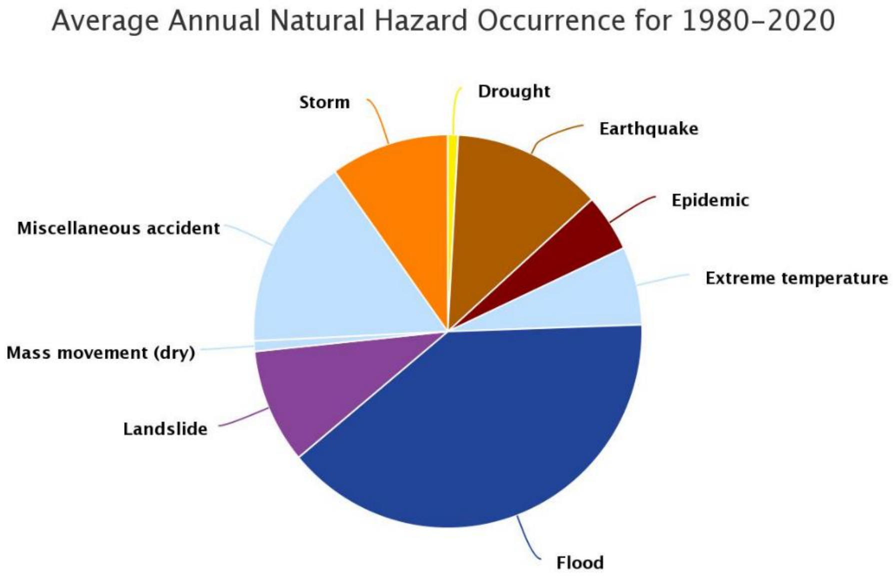


Figure 2.5 Annual frequency of disaster events in Pakistan (data record from 1980-2020)

According to the (Awwa RF & UCAR, 2006), any drift or constant change in the statistical distribution of climate variables (temperature, precipitation, moisture, wind speed, etc.) constitutes a climate change. Climate as a statistical notion, measures not only expected average conditions but also the characteristic range of the unevenness of these conditions Although the extent of a trend may be rather convenient to measure, its statistical significance may be extra ambiguous because of natural climate inconsistency and long-standing persistence (Cohn et al., 2005). Climate change is likely to cause changes to stream flow, rainfall and other hydro-climatic variables. The uninterrupted long-term streamflow and meteorological records are critical for detecting trends or shifts in the statistics of sequential streamflow or other hydroclimatic variables. Such non-stationarity in hydro-climatic conditions would represent a transformation from the assumptions that have been used to design and administer water resource systems. Therefore, it is important to be familiar with if and how trends manifest themselves (Brekke et al., 2009). Therefore, trend finding can help water managers recognize if the data upon which the design and process of water systems were based are no longer consistent with current conditions. Trend analysis is widely implemented to examine and determine hydro-meteorological variables such as stream flow, rain and temperature (Shabehul Hasson et al., 2017), (Khattak et al., 2011), (S. del Rio et al. 2013), (Bocchiola et al., 2013), (Salma et al., 2012), (Khattak et al., 2015), (Shahid et al., 2017). The study findings of this research is based on long-term data analysis reveal that the temperature has normally increased in Pakistan and precipitation is decreasing all over the country. Impact of climate change on water assets to pose suitable guidelines for planning and managing, is found out from the outcomes recommended from the above-mentioned papers

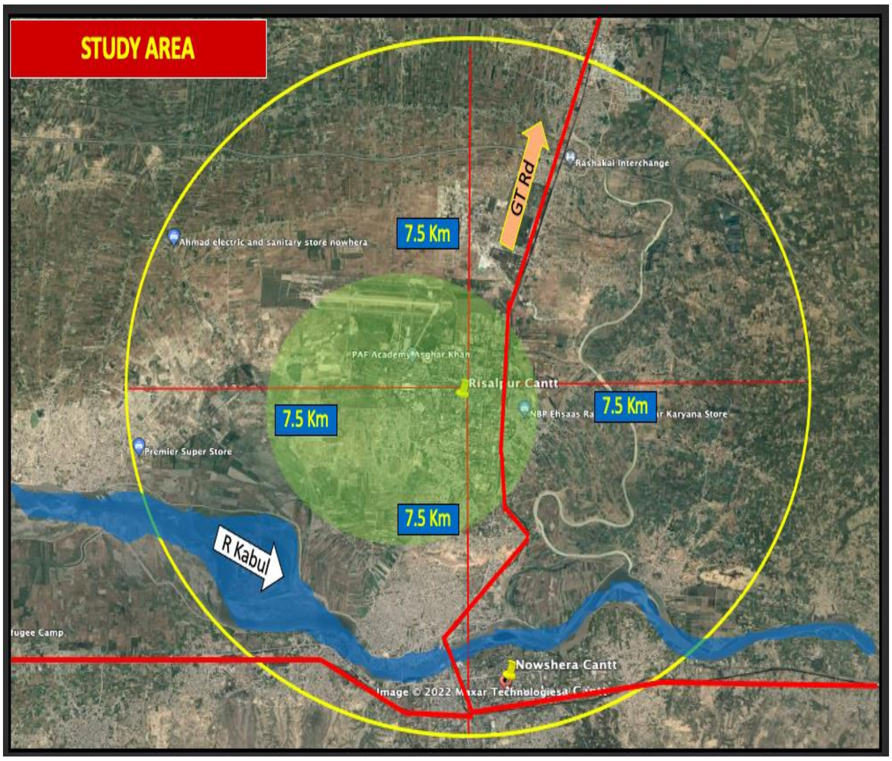
Chapter 3

METHODOLOGY

This chapter gives a brief description of the study area and methodology used for carrying out analysis on different climate parameters.

3.1 STUDY AREA

Risalpur is situation in Nowshera district, 34°4'52N 71°58'21E in the Khyber Pakhtunkhwa province of Pakistan. The area is easily accessible through motorway from Rashakai Interchange and by GT via Nowshera. The total population is estimated to be 37,000. It is 45 km short of Peshawar, the provincial capital of Khyber Pakhtunkhwa and around 18 Km from Mardan city. It is about 1014 feet above sea level and is bounded on south and west by River Kabul and River Kalpani respectively. The famous Khyber Pass lies 90 kilometers to the north of the Risalpur. The city has remained significant due to cantonment set up here during the British era and then



has remained important for Military Infrastructure (Military College of Engineering, PAF Base Asghar Khan) (Fig 3.1).

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Figure 3.1 Map of the study area extracted from Google Maps. Risalpur is marked and highlighted for the ease of readers

For the purposes of the current study which aims at analyzing the effect of climate change, The Hydrometeorological study is carried out on area of 15 km^2 (Risalpur and surroundings). In this study area there are only modest variation within 3 km radius of Risalpur Cantonment with a maximum elevation change of 154 feet and average elevation above Mean Sea Level is 986 feet. Whereas about 50 km of the surrounding area of Risalpur contain significant variation in elevation (8,442 feet). Climate of the study has experienced abrupt variations and now frequently experience prolonged intense summers, short dry winters or phases of high-speed winds in the pre-monsoon time. These weather conditions calls for in-depth study of the various parameters of climate change, weather patterns that are critical to Risalpur. The two Rivers flowing in proximity of the study area had overflown their banks and resulted in heavy losses during the 2010 mega monsoon floods. Risalpur also experience damages due to this mega flood. The area within *3 km* of Risalpur Cantonment is covered by *cropland* (*82%*) and *bare soil* (*16%*), within *16 km* by *cropland* (*66%*) and *bare soil* (*18%*), and within *24 km* by *cropland* (*43%*) and *bare soil* (*34%).*

Climate of Risalpur is semi-arid, hot subtropical continental climate according to the Köppenclimate classification (devised by a Russian climatologist) with five seasons: Winter (Dec−Feb), Spring (March−April), Summer (May−June), Rainy Monsoon (July−September) and Autumn (October-November). The hottest month is July, where temperature usually surpasses 45 °C. The rainiest month is August, with irresistible precipitation. The coolest month is January, with temperatures variable by area, normally below zero degree centigrade.

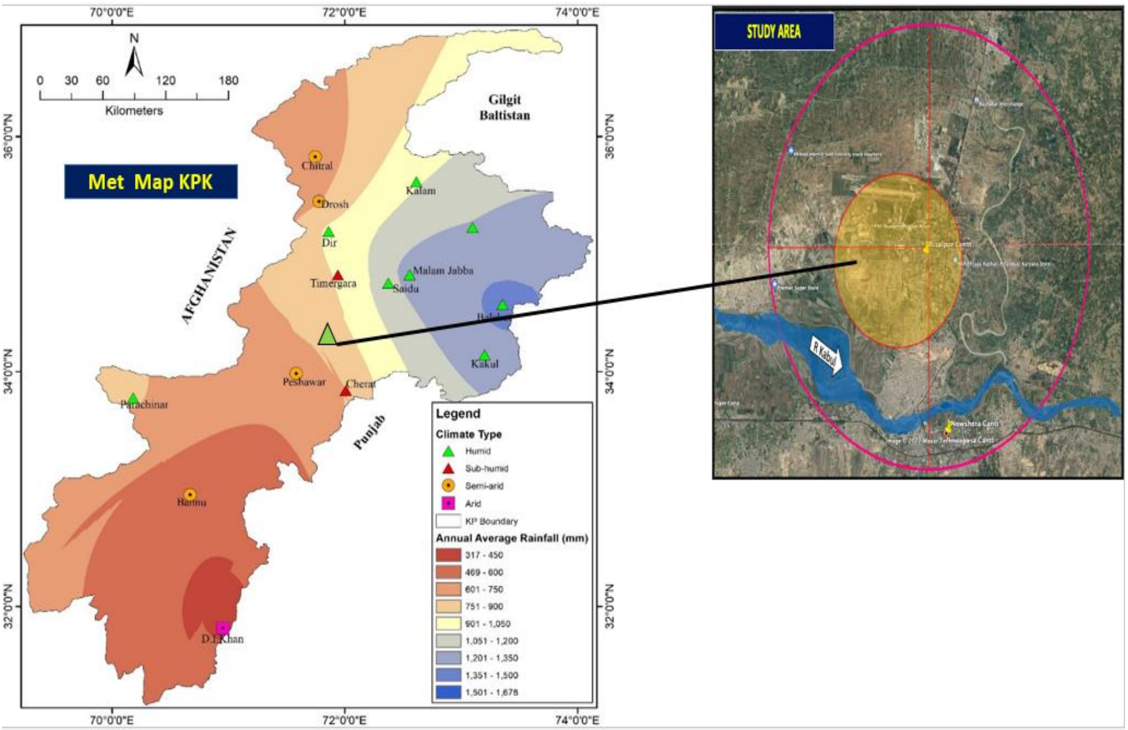
The Western disturbances and the storm are the two principal factors that change the climate over the study area or else, Continental air wins for the rest of the season. In Winters the Western disorder mostly occurs, resulting in light to moderate showers with heavy rainfall and thunderstorm. These westerly waves are robbed of mainly of the humidity as long as they reach study area.

The Study Area mainly receive precipitation through the southwest summer monsoon (from July to September), and rains mainly through western weather disturbances in winter (from Nov to March). The summer monsoon accounts for around 70% of the total annual precipitation of the study area. The climate varies from semi-arid, hot subtropical continental climate where three-fourths of the country receive rainfall of less than 250 millimeters (mm) annually, During winter, the temperatures in this study area drop to as low as –2°C and stays around 50°C in the warmest months of July to September.

From middle of July till September, the Southwest Monsoon is experienced. These storm downpours are very considerable by nature and can cause extreme flooding once they pool resources with westerly waves. Ample precipitation also occurs during the spring monsoon in March and April prior to the monsoon season. Precipitation annually over the study area varies between 734 mm in the monsoon season and 1432 mm of precipitation during the complete year

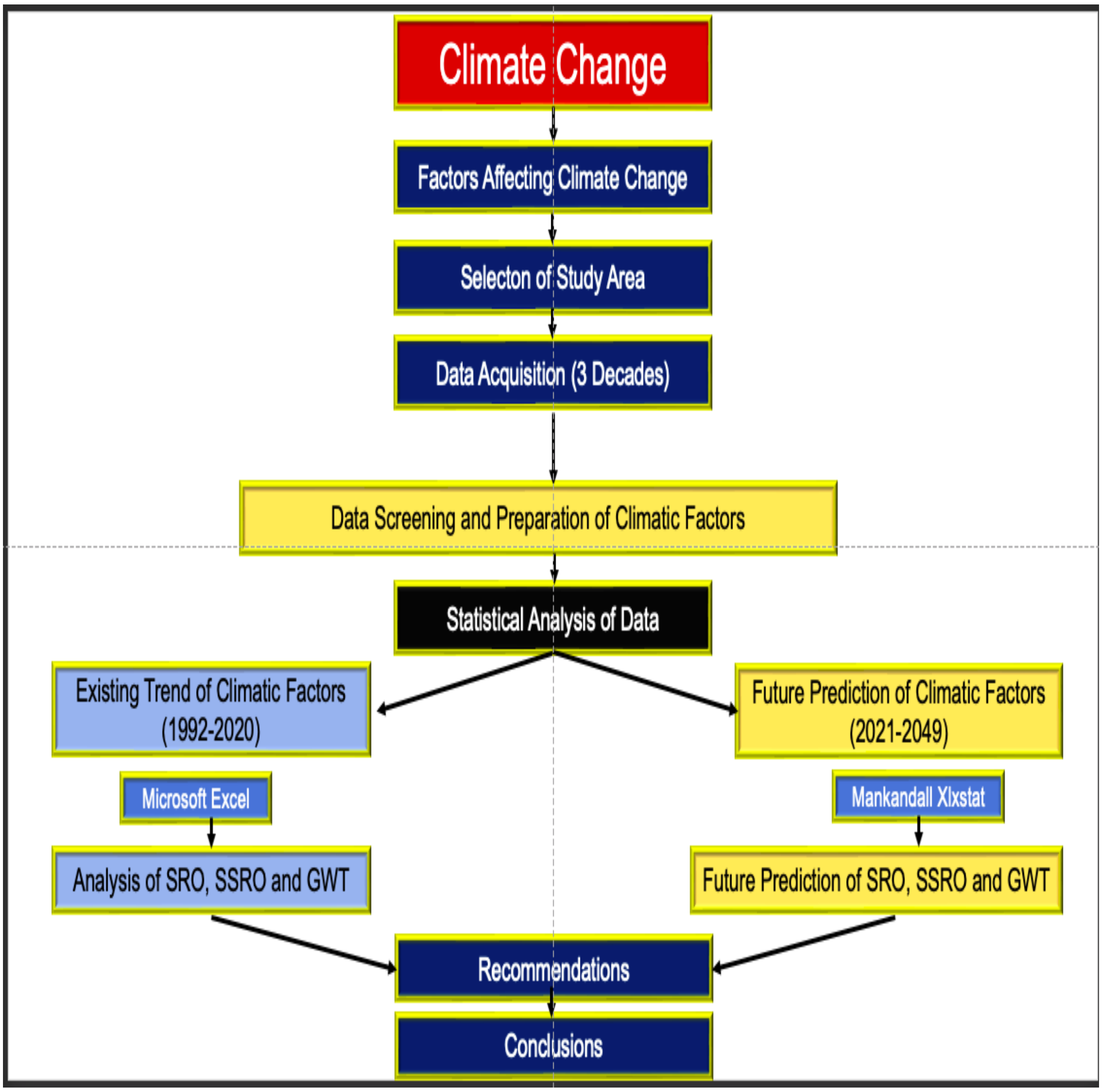
Figure 3.2 Map of the study area showing average rainfall and climate type

3.2 METHODOLOGY



The present study followed a statistical approach for analysing hydro-meteorological parameters to assess current weather trends and extrapolate future trends for critical parameters. Fig 3.3 gives the data sets and parameters selected as input for the analysis (dataset used: 1992-2020) and resulting outputs as future trends for (2021-2050).

Figure 3.3 Flow chart of the methodology and tools used for carrying out the present study



3.3 Data Acquisition

Climate change is probable to cause variations to Temperature, precipitation, and other hydro-climatic variables. The permanent long-standing climatic records are important for detecting trends or shifts in the statistics of historic hydroclimatic variables. Proper data collection techniques and quality assurance procedures are essential for meaningful statistical analysis (Zbigniew et al., 2005) [29]. In this study the hydro-meteorological data was acquired for research on request from Pakistan Air Force metrological department

Peshawar. To further study the effect of these factor on the ground flow pattern of Risalpur including SRO, SSRO and GWT by NASA's MERRA-2 satellite-era reanalysis.

3.3.1 Hydro-climatic Data

The climatic record for the country is being collected and maintained by Pakistan Meteorological Department (PMD) and Pakistan Air Force Meteorological Department Peshawar. Pakistan Air Force Academy Asghar Khan Risalpur (PAF Rsc) office has a historical data archive, but it does not have many stations. PAF Rsc has three climatic stations located in Mianwali, Murree, Mangla and Risalpur. At these climatic stations, weather radars and standard rain gauges, are used for recording and measuring the climatic factors. Daily precipitation is recorded from 8:00 hours in the morning and sum of daily observations in a year is annual precipitation, Temperature is being observed round the clock out of which daily maximum and minimum values are acquired. These values are then assessed on monthly basis to obtain maximum and minimum monthly temperature values. The names, type, elevation and source of data of hydroclimatic places is tabulated in **Table 3.1**. The siting of hydroclimatic stations is shown in **Figure 3.3**. The observed (1992-2020) historical hydroclimatic data (Precipitation, temperature, thunderstorm, wind, humidity and dust storm) required for this study were collected from PAF Rsc, KPK.

Table 3.1 Inventory of Hydro-climatic Stations

Sr. No	Station Name	Type of Station	Latitude “N”	Longitude “E”	Elevation (m)	Data Source
1	Murree	Manual/ Automatic	33° 55' 12"	73° 22' 48"	2291	PAF
2	Mianwali	Manual/ Automatic	33° 42' 0"	73° 4' 48"	210	PAF
3	Risalpur	Manual/ Automatic	33° 37' 12"	73° 5' 60"	309	PAF
4	Mangla	Manual/ Automatic	33° 40' 48"	73° 6' 36"	482	PAF

3.4 Data Screening and Preparation

Three Decades (1992-2020) Hydro Meteorological Data collected from PAF Met Dept Psc was available in hard form due to restrictions imposed by sanctity of the institution. The Data acquired from PAF Met dept was then manually entered into Excel worksheet for statistical analysis and for their graphical representation. The data then was verified by statistical expert Dr. Danish (PhD Statistics) who confirm the significance level of the data suitable for the study of climate. The data was then suitably sifted as per different parameters for their easy analysis and future prediction. These four (4) climatic stations were marked on the catchment map and polygons were drawn. A weighted factor was assigned to each station according to the proportion of polygon area surrounding that particular station. Accordingly, considering weighted factor assigned to each station and period and source of data, Murree station and Risalpur station were taken as representative of average conditions of the study area. In this case, a weighted factor equal to 50% was assigned to each station.

Table 3.2: Detail of Collected and Observed Data

Sr. No	Station Name	Data Source	Daily Observed Data	Duration	years
1	Islamabad Zero Point	PMD	Precipitation Temperature	1968 to 2017	50
2	Murree	PMD	Precipitation Temperature	1968 to 2017	50
3	Islamabad Airport	PMD	Precipitation Temperature	1979 to 2017	28
4	Rawal Dam	SDO	Precipitation Temperature	1975 to 2016	41
			Inflows	1975 to 2016	41

3.5 STATISTICAL ANALYSIS

Many studies on climate change have been paying attention on temperature, rainfall, and evaporation since these are well thought-out to be the key indicative factors of climate transformation. The analysis was performed on 30 years (1992 – 2020) long-term temperature, precipitation, humidity, surface winds, thunderstorms, dust storm records from Murree and PAF Risalpur climatic stations and 30 Years (1992 - 2020) SRO, SSRO and GWT record of NASA's MERRA-2 satellite-era reanalysis.

3.5.1 Statistical Analysis of Exiting Data

The Three Decades (1992-2020) hydro meteorological data acquired from PAF Rsc was then analyzed by graphical representation method on Microsoft Excel. Following factors graphically represented in the report.

1. Precipitation
2. Temperature
3. Humidity
4. Foggy Days
5. Thunderstorm
6. Surface Winds

These factors are divided in to three categories for the analysis. This mainly includes:

1. Time Series of Hydro Meteorological Data (1992-2020)
2. Monthly Graphical Representation of all factors.
3. Precipitation for Monsoon Period (July – Sept)
4. Precipitation for Non-Monsoon Period (Oct – June)
5. Extreme Summer Temperature Months (May – Sept)
6. Extreme winter Temperature Months (Nov – Feb)

3.5.2 Analysis of Surface Runoff (SRO), Sub-surface Runoff (SSRO) and Groundwater Table (GWT)

This report illustrates the typical Water Flow pattern in Risalpur Cantonment, based on a statistical analysis of historical hourly weather reports and model reconstructions from 1st January 1992 to December 31, 2020. Risalpur Cantonment is further than 200 kilometers from the nearest reliable weather station, so the weather-related data on this page were taken entirely from NASA's MERRA-2 satellite-era reanalysis. This reanalysis combines a variety of wide-area measurements in a state-of-the-art global meteorological model to reconstruct the hourly history of weather throughout the world on a 225 Km2 area. The collected data is then divided into following categories for graphical analysis:

1. Time Series SSRO and SRO
2. Decade wise Distribution of Data
3. Existing Trend Analysis

3.6 STATISTICAL FUTURE PREDICTION

Trend examination is a statistical method widely implemented to examine hydrological time series of temperature, rain and other climatic variables (McBean; E.a.M., 2010) [38], (Tabari, H.; Talaee, P. H., 2011) [39], (Bocchiola, D.; Diolaiuti, G., 2013) [40], (Mayowa et al., 2015) [41]. In order to have made assurance on the continuation of a trend in hydroclimatic data including precipitation, temperature, Humidity, Surface Winds, Thunderstorm and Dust Storm. SRO, SSRO and GWT time series Microsoft Xlxstat was used to guess whether there is a significant positive or negative trend. The subsistence of a trend in a Hydro Meteorological data was permitted by the nonparametric test Mann-Kendall Trend Test (Mann, H. B., 1945) [32], (Kendall, M. G., 1975) [33]. The Mann-Kendall Trend Test is applied to evaluate the presence of a trend and to give future prediction of hydro meteorological factors. The statistical analyses were conducted to assess the trends in minimum, maximum and temperatures, respectively, precipitation on monthly to annual timescale. This analysis in the study was carried out in two steps. Nonparametric Mann-Kendall test first of all used to sense the presence of monotonic escalating or declining trend in the time series of the hydro-meteorological random variable and second SRO, SSRO and GWT conditions of the study area

3.6.1 Mann Kendall Trend Test

The rank-based non-parametric Mann Kendall test is mostly used for trend detection, worldwide. The Mann-Kendall test has verified to be functional in determining the possible existence of statistically significant trends at dissimilar probability levels (Shahid, S., 2010) [43]. The Mann Kendall can be applied to data no matter whatever is the probability distribution. It is based on the supposition that the data is serially independent. It is well known that positive autocorrelation increases the possibility of the null hypothesis of no trend to be rejected when it is correct with a probability larger than the assigned level of significance (Bihrat Önöz and Mehmetcik Bayazit, 2012) [44]. This is because the variance of Mann Kendall test statistics is exaggerated by a serial correlation.

The time series values (X_1, X_2, X_3,…X_n) ie 'n' number of values are replaced by their relative ranks (R_1, R_2, R_3,…., Rn), initiating at 1 for the bottom up to 'n'.

The test statistic S is:

$$S = \sum \text{sign} (x_k - x_i) \qquad \text{Eq 3.2}$$

where $\text{sgn}(x) = 1$ for $x > 0$

$\text{sgn}(x) = 0$ for $x = 0$

$\text{sgn}(x) = -1$ for $x < 0$

If the null hypothesis, X_0 is true, then S is normally distributed with $\mu = 0$**. The** Critical test statistic value Z-Statistic, which determines that various significance levels can be obtained from normal probability tables as described in Appendix B.

$$Z = | S | / \sigma^{0.5} \qquad \text{Eq 3.4}$$

"Z" indicates that there are an increasing trend on a positive value and a decreasing trend on a negative value.

Chapter 4

RESULTS AND DISCUSSION

4.1 BACKGROUND

Thirty Year (1992-2020) data of temperature, precipitation and other climatic factors, and its effect on 30 years (1992-2020) records of SRO, SSRO and GWT are analyzed to assess the trend of climate change in the study area. This Chapter is divided into two Portions.

1. Existing Trend of Hydro Meteorological Factors and its effect on SRO, SSRO GWT.
2. Future Trend of Hydro Meteorological Factors and its effect on SRO, SSRO GWT.

The results of the analysis will show whether they are decreasing, increasing or even no trend in the existing data of climatic factor and the Mann Kendall Test confirms the significance of these trend and indicate their future prediction. The other factor that affected the trend will also be discussed in this section. A result of the figured standards of various parameters ensuing from the statistical analysis done in the work is displayed in this section.

4.2 EXISTING TREND OF HYDRO METEOROLOGICAL FACTORS AND SRO, SSRO GWT

4.2.1 Precipitation

Annual Max precipitation recorded from 1992 to 2020 at Murree and PAF RSC station is 431 mm, 416 mm and 413 mm, respectively. In study area minimum total rainfall exceeded and 508 mm and maximum total rainfall per year is exceeded 1164 mm. This shows that study area received extremely rainfall each year as compared to any area in it surrounding (Table 4.1 & fig 4.1(a, b and c)).

Table 4.1 Data set showing precipitation in the study area (1992-2020)

Total Precipation (1992-2020)													
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC	nnual tren
1992	132.0	122.0	76.0	08.0	55.0	12.0	187.0	262.0	138.0	18.0	16.0	00.0	1026.0
1993	66.0	25.0	24.0	22.5	22.0	39.0	69.0	73.0	35.0	25.5	41.0	78.0	520.0
1994	55.0	41.0	11.0	78.0	26.0	01.0	119.0	53.0	97.0	10.0	05.0	115.0	611.0
1995	03.0	291.0	130.0	64.0	07.0	28.0	413.0	125.0	62.0	06.0	31.0	04.0	1164.0
1996	02.0	53.0	52.0	175.0	46.0	04.0	301.0	185.0	51.0	42.0	06.0	12.0	929.0
1997	48.0	77.0	89.0	44.0	15.0	11.0	71.5	201.0	61.0	17.0	54.0	04.0	692.5
1998	66.0	18.0	22.0	22.5	22.0	37.0	69.0	71.5	35.0	25.5	42.0	78.0	508.5
1999	03.0	266.0	150.0	36.0	26.0	82.0	42.0	59.0	51.0	00.0	20.0	01.0	736.0
2000	41.0	72.0	89.0	47.0	15.0	09.0	75.0	203.0	63.0	19.0	56.0	02.0	691.0
2001	TRS	03.0	39.0	12.0	34.0	39.0	185.0	202.0	08.0	TRS	04.0	01.0	527.0
2002	01.0	61.0	72.0	07.0	07.0	56.0	16.0	351.0	83.0	TRS	00.5	32.0	686.5
2003	28.0	173.0	91.0	67.0	20.0	06.0	180.0	123.0	42.0	16.0	12.0	51.0	809.0
2004	84.0	77.0	TRS	63.5	01.0	32.0	59.5	97.5	20.0	117.0	14.5	48.5	614.5
2005	129.0	130.0	79.5	04.0	49.0	10.0	185.0	260.0	136.0	18.0	16.0	00.0	1016.5
2006	64.0	18.0	21.5	22.5	20.0	37.0	67.5	71.5	33.5	25.5	41.0	78.0	500.0
2007	01.0	266.0	148.0	36.0	24.5	82.0	41.0	59.0	49.0	00.0	18.0	TRS	724.5
2008	68.0	23.0	02.0	192.0	09.0	29.0	267.0	155.0	14.0	01.0	05.0	51.0	816.0
2009	62.0	55.0	76.0	134.0	18.0	03.0	163.0	31.0	34.0	06.0	21.0	TRS	603.0
2010	00.0	131.0	14.0	15.0	26.0	31.0	431.0	364.0	23.0	00.0	00.0	16.0	1051.0
2011	05.0	102.0	36.0	56.0	03.0	14.0	416.0	111.0	30.0	32.0	12.0	00.0	817.0
2012	53.0	41.0	09.0	74.0	23.0	01.0	117.0	53.0	95.0	10.0	03.0	113.0	592.0
2013	01.0	291.0	128.0	60.0	05.0	28.0	415.0	125.0	60.0	06.0	29.0	02.0	1150.0
2014	05.0	50.0	171.0	88.0	09.0	32.0	47.0	43.0	52.0	50.0	02.0	00.0	549.0
2015	48.0	108.0	129.0	185.0	33.0	TRS	211.0	231.0	27.0	105.0	12.0	30.0	1119.0
2016	24.0	49.0	181.0	59.0	43.0	06.0	90.0	113.0	15.0	TRS	00.0	TRS	580.0
2017	89.0	64.0	22.0	54.0	07.0	50.0	317.0	201.0	51.0	00.0	52.0	25.0	932.0
2018	00.0	51.0	50.0	173.0	43.0	02.0	301.0	183.0	51.0	44.0	06.0	14.0	918.0
2019	46.0	72.0	87.0	47.0	13.0	09.0	71.5	203.0	61.0	19.0	54.0	02.0	684.5
2020	79.0	28.0	234.0	70.0	68.0	48.0	07.0	49.0	135.0	00.0	125.0	13.0	856.0
Sum	1203.0	2758.0	2233.0	1916.0	689.5	738.0	4934.0	4258.5	1612.5	612.5	698.0	770.5	
Avg	83.0	183.9	154.0	127.7	46.0	50.9	328.9	283.9	107.5	45.4	46.5	57.1	
Max	1203.0	2758.0	2233.0	1916.0	689.5	738.0	4934.0	4258.5	1612.5	612.5	698.0	770.5	
Min	00.0	03.0	02.0	04.0	01.0	01.0	07.0	31.0	08.0	00.0	00.0	00.0	

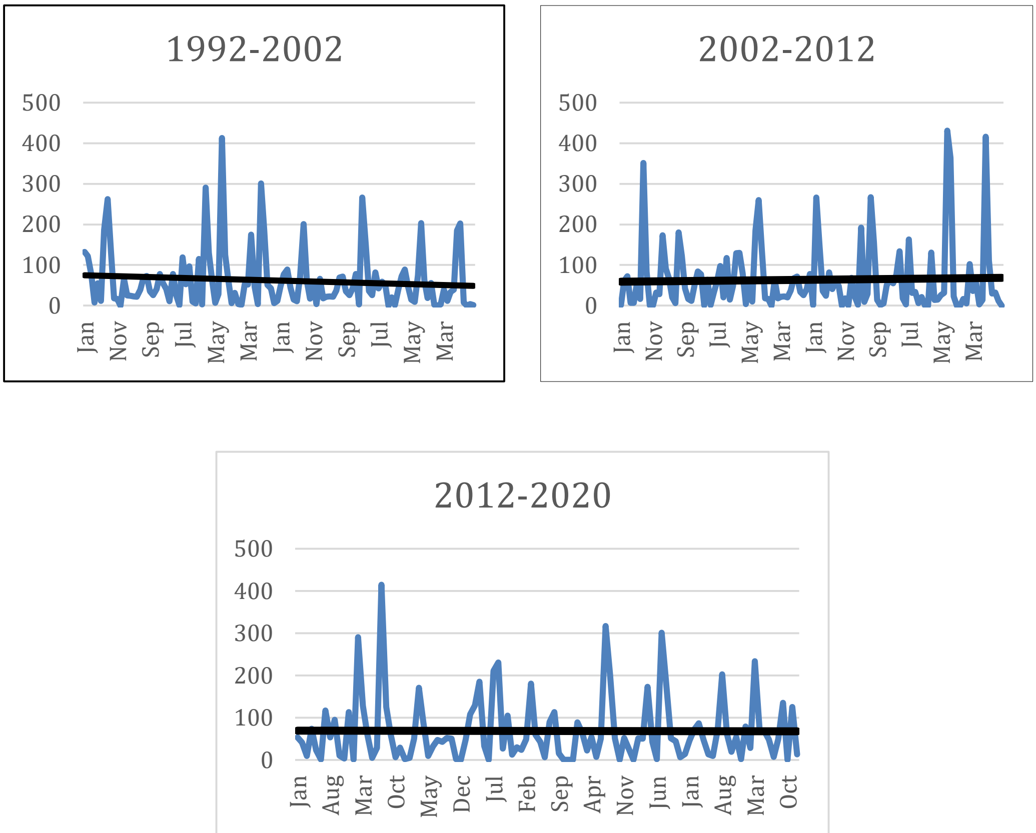


Figure 4.1 (a, b and c) Precipitation trend of the study area for time series 1992-2002, 2002-2012 and 2012-2020

4.2.1.1 Time Series Monsoon Rainfall (1992-2020)

Annual Max Monsoon precipitation recorded from 1992 to 2020 at Murree and PAF Rsc station is 431 mm, 416 mm and 413 mm, respectively. In study area minimum total rainfall exceeded and 508 mm and maximum total rainfall per year is exceeded 1164 mm. This shows that study area received extremely rainfall each year as compared to any area in it surrounding.

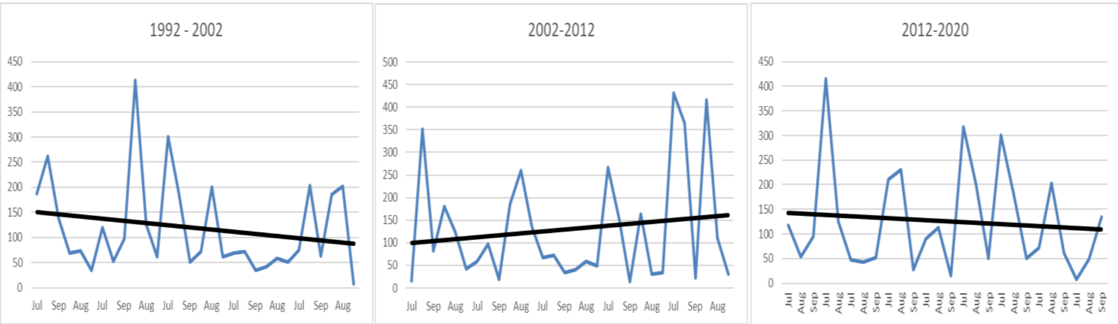


Figure 4.2 (a, b & c) Precipitation trend of monsoon rainfall in the study area for time duration of 1992-2012, 2012-2002 and 2002-2020

4.2.1.2 Time Series Non - Monsoon Rainfall (1992-2020)

Annual Max Nonmonotone precipitation recorded from 1992 to 2020 at Murree and PAF RSC station is 291 mm, 266 mm and 173 mm, respectively. In study area minimum total rainfall exceeded and 132 mm and maximum total rainfall per year is exceeded 665 mm which show that the trend of rainfall is low in Nonmonotone season rainfall as compared to monsoon rainfalls (fig 4.**3** (a, b and c)).

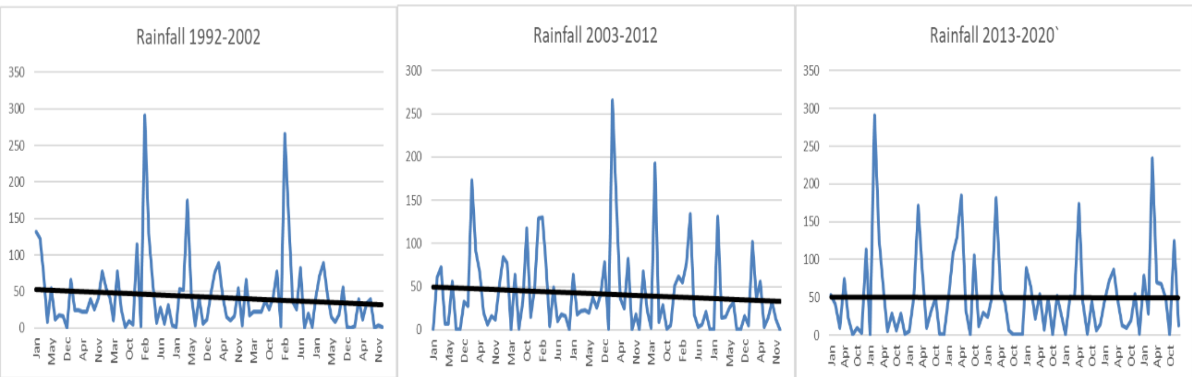


Figure 4.3 Time series of non-monsoonal precipitation in the study area for 1992-2002, 2002-2012, 2012-2020

4.2.2 Temperature

The existing temperature from 1992 to 2020 (30 years) in annual average temperature of study area is shown in **Figure (4.4-a, b, c)**. It is observed that the period of 2012 to 2020 a higher temperature than the earlier period of 1992-2011. The raise in temperature is at the present set as main importance and it is measured in requisites of global warming. Over the last millennium and especially the last 03 decades, the climate change indicators show warming trends in the region. The temperature increase can be related with global warming that significantly affects precipitation. Further, urbanization and industrialization be part of the cause in changing the global climate. The advancement in the study area started in 1990. The analyses are carried out using long-term 30 years (1992-2020) records and most recent 30 years (1992-2020) records considering development activities in the study area started in 1992. The regional existing trends in temperature estimated using excel graphical analysis technique. The results of Murree and PAF Rsc station at study area for the period 1992-2020 as data shown in Table 4.2 (a & b).

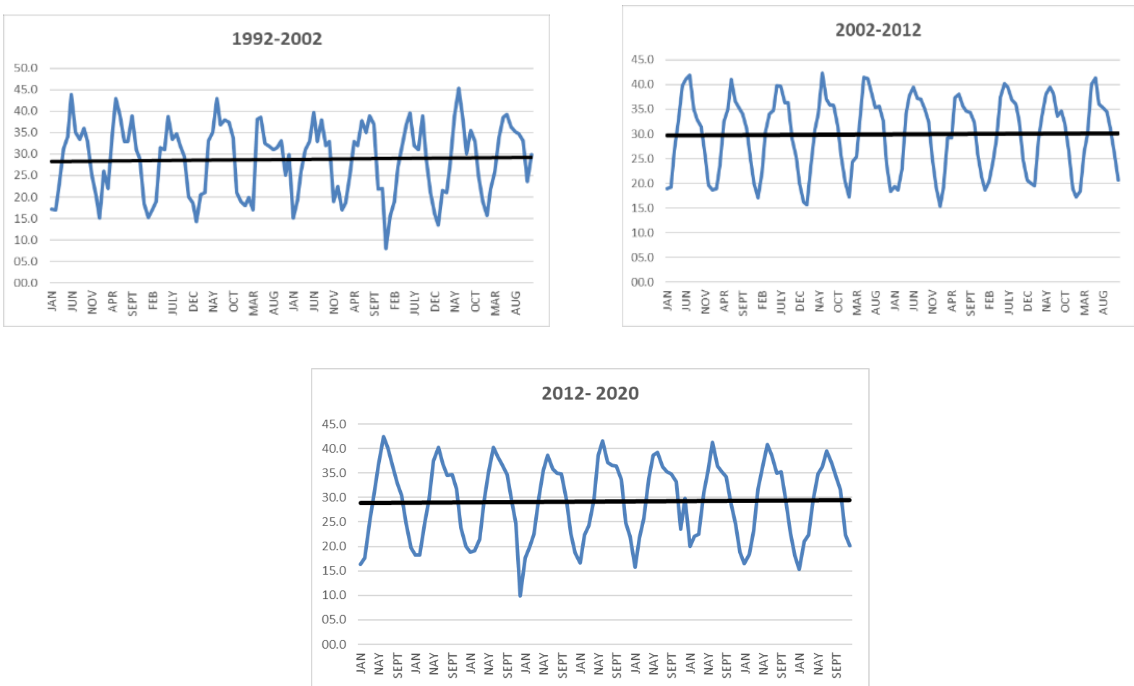


Figure 4.4 (a, b and c) Temperature data showing monthly trend of maximum temperatures for 1992-2002, 2002-2012 and 2012-2020

Table 4.2 (a) Data set showing annual temperature readings from 1992-2020

TEMP (1992-2020)																								
YEAR/	JANUARY		FEBRUARY		MARCH		APRIL		MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER		NOVEMBER		DECEMBER	
Time	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	M
1992	17.1	03.0	17.0	06.6	23.0	13	31.2	14.2	34.1	17.8	44.0	23.4	35.0	12.0	33.4	24.7	36.0	12.6	33.0	15.0	25.2	05.2	20.4	[illegible]
1993	15.0	05.0	16.0	09.2	22.0	9	34.5	14.3	43.0	11.5	39.0	24.3	33.0	11.0	32.9	25.6	39.0	12.2	31.0	14.5	29	10.1	18.4	[illegible]
1994	15.3	03.1	17.1	06.6	19.0	11.0	31.5	15.7	31.0	16.5	38.7	21.0	33.4	12.0	34.8	23.9	31.0	11.5	29.5	17.0	21	11.0	18.7	[illegible]
1995	14.3	04.2	20.5	04.7	21.0	11.5	33.2	15.2	35.0	11.7	43.0	22.9	36.8	18.0	38.0	24.5	37.5	12.0	33.7	12.0	21	08.3	13.0	[illegible]
1996	17.9	03.9	19.9	06.7	17.0	10.7	38.1	15.7	38.6	11.4	32.5	21.7	31.9	17.0	31.0	24.5	31.5	18.6	33.2	14.0	25	10.0	29.9	[illegible]
1997	15.0	03.2	19.3	06.6	26.0	14.0	31.0	18.0	33.0	17.9	39.8	26.8	33.0	11.0	38.0	26.5	33.0	12.9	33.0	17.6	19	06.7	22.5	[illegible]
1998	17.0	01.7	18.6	05.9	25.0	16.0	33.0	17.0	32.0	19.0	37.8	25.7	35.0	14.0	39.0	27.6	37.0	13.6	21.9	16.5	22	06.7	08.0	[illegible]
1999	15.6	01.9	18.9	07.1	27.0	11.0	32.0	13.0	37.0	20.0	39.6	25.1	33.0	12.0	31.0	26	38.9	11.5	28.9	16.5	21	09.1	16.0	[illegible]
2000	13.4	03.2	11.6	05.2	21.0	14.0	38.0	17.0	39.0	11.0	45.4	26.9	38.0	18.0	38.0	21	35.6	12.0	33.0	16.3	14.9	08.3	13.0	[illegible]
2001	15.8	04.1	21.8	06.7	25.8	09.8	33.9	15.7	38.6	11.4	39.2	25.6	36.3	15.6	35.2	24.5	34.8	11.5	33.2	15.9	13.6	08.2	29.9	[illegible]
2002	18.9	0.001	19.3	04.7	26.6	10.3	32.6	16.0	39.7	12.0	41.1	24.6	41.9	16.7	35.0	25.5	33.9	02.4	31.5	15.5	25.7	08.9	19.7	[illegible]
2003	18.6	03.2	18.9	05.9	23.7	10.7	32.5	15.9	35.1	18.9	41.1	24.6	36.6	15.1	35.2	24.5	34.0	13.0	31.0	13.8	14.6	06.8	13.9	[illegible]
2004	17.1	03.5	22.2	04.9	30.3	11.2	34.0	16.7	34.8	10.9	39.7	24.7	39.6	15.7	36.3	24.7	36.4	11.8	28.9	14.3	25.3	07.8	20.0	[illegible]
2005	16.2	03.3	15.7	05.7	23.6	11.6	30.9	13.5	34.1	17.8	42.3	23.4	37.1	15.7	35.9	24.7	35.8	12.6	31.7	13.0	25.6	05.6	20.4	[illegible]
2006	17.3	03.5	14.4	08.3	25.4	10.4	34.0	14.3	41.5	11.5	41.2	24.3	38.0	17.1	35.4	25.6	35.7	12.2	32.6	16.5	13.9	10.3	18.4	[illegible]
2007	19.4	00.7	18.6	07.5	22.9	09.7	34.1	16.1	37.8	20.3	39.5	25.1	37.2	17.6	37.0	25.7	35.0	12.6	32.3	12.6	25.3	07.3	19.2	[illegible]
2008	15.4	03.2	19.2	03.9	29.3	11.2	29.2	15.3	37.3	10.9	38.1	26.5	35.7	15.4	34.6	24.1	34.3	10.5	32.3	16.0	26.0	07.1	21.3	[illegible]
2009	18.6	05.2	20.4	06.5	24.5	09.8	29.0	14.1	37.5	19.0	40.2	22.1	39.5	15.4	35.9	26.4	36.0	11.5	32.7	13.3	14.7	06.8	20.6	[illegible]
2010	20.1	01.5	19.5	06.6	29.1	11.7	33.6	17.3	38.0	20.6	39.5	22.8	38.2	16.7	33.6	24.9	34.7	11.1	32.2	16.3	26.7	06.8	13.0	[illegible]
2011	17.3	00.9	18.4	05.8	26.4	10.7	30.0	14.6	40.0	21.6	41.4	26.1	36.0	15.1	35.3	25.4	34.5	12.1	31.2	14.7	16.2	09.1	20.6	[illegible]
2012	16.4	00.2	17.7	03.5	25.3	09.1	30.8	14.3	36.8	19.7	42.5	23.5	40.1	16.7	36.8	26.1	33.9	12.0	30.4	14.3	14.9	07.6	19.7	[illegible]
2013	18.3	01.5	18.2	06.4	24.8	11.5	29.7	15.4	37.5	20.4	40.3	25.3	36.9	15.8	34.5	24.8	34.7	12.9	31.8	17.6	13.8	06.7	20.0	[illegible]
2014	18.8	01.4	19.1	05.2	21.5	09.5	29.2	14.5	35.0	20.1	40.2	23.9	38.4	17.0	36.7	24.9	34.7	12.8	29.5	16.5	14.7	06.7	08.9	[illegible]
2015	17.7	01.7	19.8	06.6	22.5	09.6	30.1	15.7	35.5	19.6	38.7	24.3	35.8	15.4	34.9	23.9	34.8	20.4	29.5	16.5	13.6	09.1	18.7	[illegible]
2016	16.7	03.0	22.4	04.7	24.3	11.3	29.5	15.2	38.6	11.5	41.5	26.3	37.1	16.3	36.6	24.5	36.5	13.4	33.7	16.2	14.9	08.3	22.0	[illegible]
2017	15.8	04.1	21.8	06.7	25.8	09.8	33.9	15.7	38.6	11.4	39.2	25.6	36.3	15.6	35.2	24.5	34.8	11.5	33.2	15.9	13.6	08.2	29.9	[illegible]
2018	20.0	01.1	22.0	06.0	22.5	16.1	31.0	15.8	35.5	19.3	41.3	24.6	36.5	14.7	35.3	26	34.2	22.3	29.3	14.3	14.6	08.3	18.0	[illegible]
2019	16.5	02.6	18.4	05.5	23.3	09.0	31.8	16.4	36.7	18.6	40.8	22.9	38.7	16.3	34.9	25.1	35.2	14.7	29.8	15.7	11.7	07.9	18.3	[illegible]
2020	15.3	01.9	21.1	05.3	22.3	10.6	29.3	14.8	34.8	19.9	36.3	24.1	39.5	16.8	37.0	26.9	34.3	21.9	31.6	14.6	11.4	07.1	20.1	[illegible]

Table 4.2 (b) Time series for temperature (1992-2020) with monthly maximums

Time Series Temperature (1992-2020)											
YEAR/	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVE
TIme	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MA
1992	17.2	17.0	23.0	31.2	34.1	44.0	35.0	33.4	36.0	33.0	25.
1993	15.0	26.0	22.0	34.5	43.0	39.0	33.0	32.9	39.0	31.0	29
1994	15.2	17.1	19.0	31.5	31.0	38.7	33.4	34.8	32.0	29.5	20
1995	14.3	20.5	21.0	33.2	35.0	43.0	36.8	38.0	37.5	33.7	21
1996	17.9	19.9	17.0	38.1	38.6	32.5	31.9	31.0	31.5	33.2	25
1997	15.0	19.3	26.0	31.0	33.0	39.8	33.0	38.0	32.0	33.0	19
1998	17.0	18.6	25.0	33.0	32.0	37.8	35.0	39.0	37.0	21.9	22
1999	15.6	18.9	27.0	32.0	37.0	39.6	32.0	31.0	38.9	28.9	21
2000	13.4	21.6	21.0	28.0	39.0	45.4	38.0	30.0	35.6	33.0	24.
2001	15.8	21.8	25.8	33.9	38.6	39.2	36.3	35.2	34.8	33.2	23.
2002	18.9	19.3	26.6	32.6	39.7	41.1	41.9	35.0	32.9	31.5	25.
2003	18.6	18.9	23.7	32.5	35.1	41.1	36.6	35.2	34.0	31.0	24.
2004	17.1	22.2	30.3	34.0	34.8	39.7	39.6	36.3	36.4	28.9	25.
2005	16.2	15.7	23.6	30.9	34.1	42.3	37.1	35.9	35.8	31.7	25.
2006	17.3	24.4	25.4	34.0	41.5	41.2	38.0	35.4	35.7	32.6	23.
2007	19.4	18.6	22.9	34.1	37.8	39.5	37.2	37.0	35.0	32.3	25.
2008	15.4	19.2	29.2	29.2	37.3	38.1	35.7	34.6	34.3	32.3	26.
2009	18.6	20.4	24.5	29.0	37.5	40.2	39.5	36.9	36.0	32.7	24.
2010	20.1	19.5	29.1	33.6	38.0	39.5	38.2	33.6	34.7	32.2	26.
2011	17.3	18.4	26.4	30.0	40.0	41.4	36.0	35.3	34.5	31.2	26.
2012	16.4	17.7	25.3	30.8	36.8	42.5	40.1	36.8	32.9	30.4	24.
2013	18.2	18.2	24.8	29.7	37.5	40.3	36.9	34.5	34.7	31.8	23.
2014	18.8	19.1	21.5	29.2	35.0	40.2	38.4	36.7	34.7	29.5	24.
2015	17.7	19.8	22.5	30.1	35.5	38.7	35.8	34.9	34.8	29.5	22.
2016	16.7	22.4	24.2	29.5	38.6	41.5	37.1	36.6	36.5	33.7	24.
2017	15.8	21.8	25.8	33.9	38.6	39.2	36.3	35.2	34.8	33.2	23.
2018	20.0	22.0	22.5	31.0	35.5	41.3	36.5	35.3	34.2	29.3	24.
2019	16.5	18.4	23.2	31.8	36.7	40.8	38.7	34.9	35.2	29.8	22.
2020	15.3	21.1	22.3	29.3	34.8	36.3	39.5	37.0	34.3	31.6	22.

4.2.2.1 Time Series Extreme Summer Temperature (1992-2020)

Monthly Min Summer Temperature recorded from 1992 to 2020 at Murree and PAF Rsc station is 16˚C which is overall minimum temperature in the past three decades and Max Summer Temperature is 44 ˚C which is overall maximum in the past three decades. The study area analysis shows that the temperature values in summer is towards increasing side due to global warming and will further increase in coming future (fig 4.5 (a, b &c)).

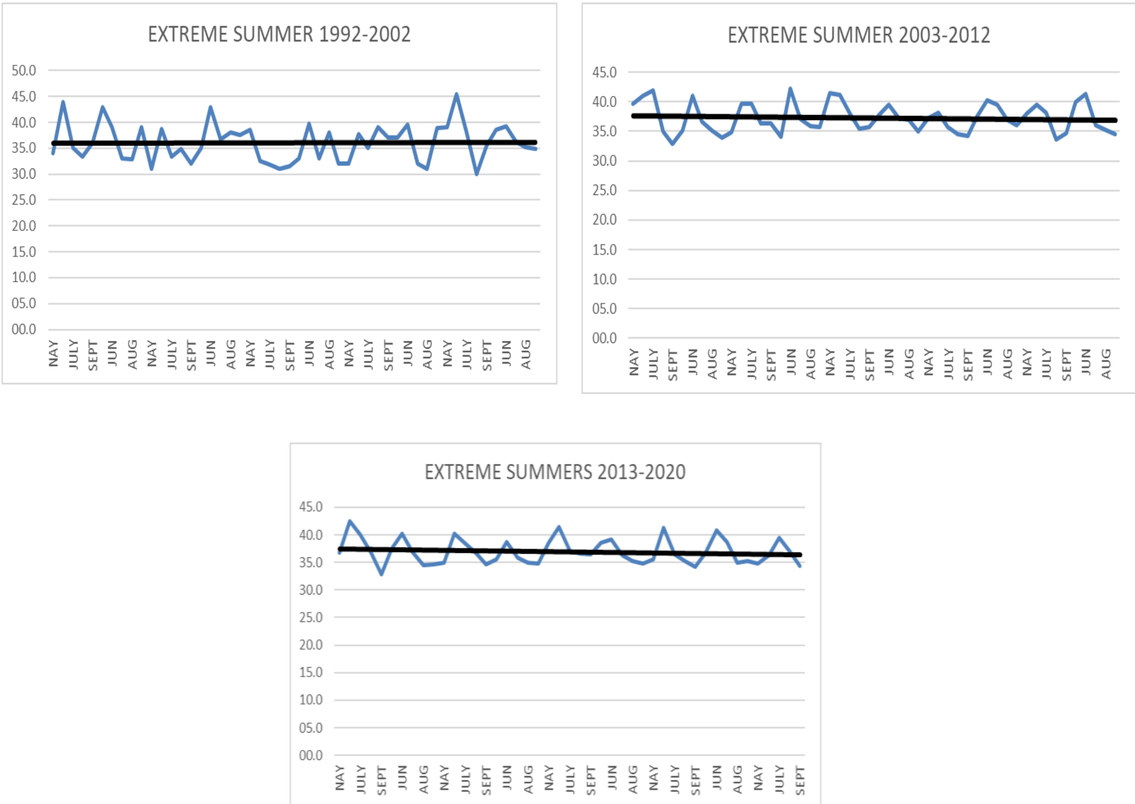


Figure 4.5 (a, b & c) Time series of monthly maximum temperatures during summers for 1992-2002, 2002-2012 and 2012-2020

4.2.2.2 Time Series Extreme Winter Temperature (1992-2020)

Monthly Min Winter Temperature recorded from 1992 to 2020 at Murree and PAF Rsc station is 0 Degree Centigrade which is overall minimum temperature in the past three decades and Max winter Temperature is 15 Degree Centigrade which is overall maximum in the past three decades. The study area analysis shows that the temperature values in winter is towards increasing side and will further increase in coming future (fig 4.6 (a, b & c).

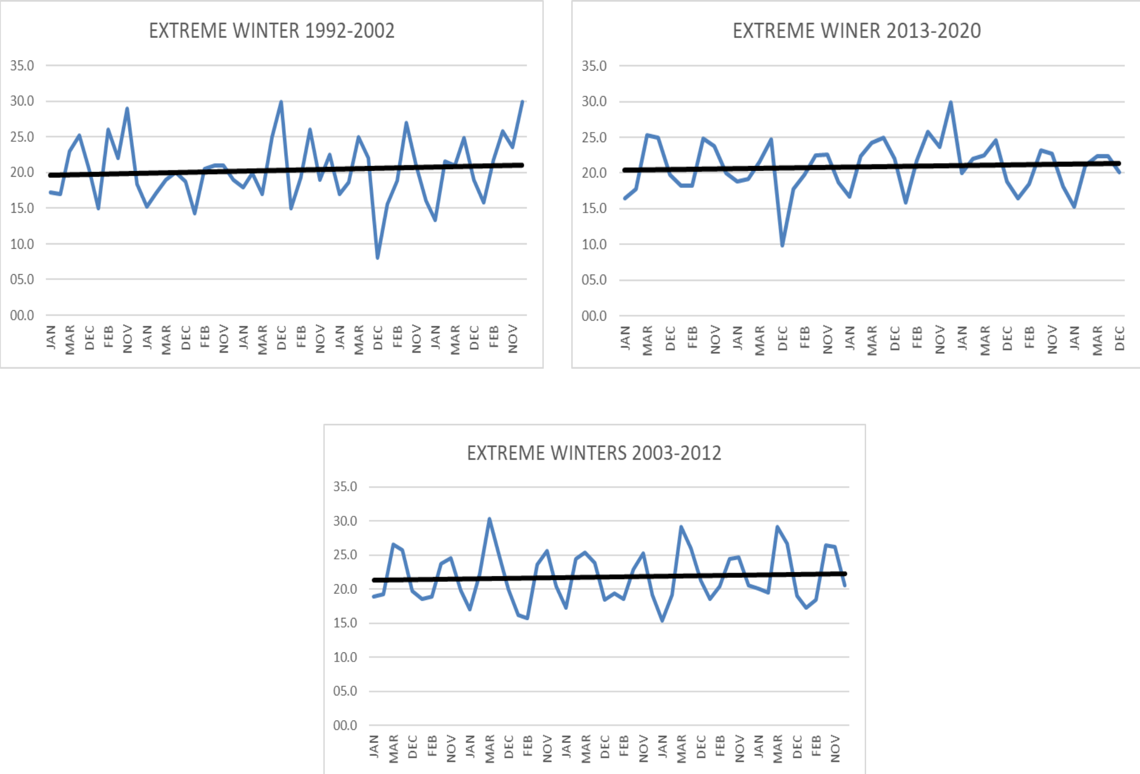


Figure 4.5 (a, b & c) Time series of monthly maximum temperatures during summers for 1992-2002, 2002-2012 and 2012-2020

4.2.3 Fog (1992-2020)

The effect of Fog occur when the temperature reaches the dew point (Less value of Temperature) value which causes conversion of vapor into liquid state resulting in Fog. The foggy days in the study area occurs in two patches. First from Jan-Mar and then from Oct – Dec. There is no trace of fog detected from Apr – Sept due to increase in temperature in summer season as fog decreases due to the rise in temperature, comparatively in winter as the temperature value decreases which causes mixing of cold air with warmer air resulting in increased fog in the area. The maximum no of foggy days from (1992-2020) is 22 days maximum and 1 day minimum in one month.

Table 4.3 Data set for the 30 years showing monthly frequency of foggy days

NO OF FOGGY DAYS LAST 30 YEARS (1992-2020)												
YEARS	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
1992	09	12	03	00	00	00	00	00	00	00	22	10
1993	05	05	00	00	00	00	00	00	00	00	06	16
1994	14	08	02	00	00	00	00	00	00	05	20	17
1995	13	11	01	00	00	00	00	00	00	03	12	13
1996	25	02	00	00	00	00	00	00	00	03	04	26
1997	11	02	00	00	00	00	00	00	00	04	02	23
1998	17	07	02	00	00	00	00	00	00	01	13	22
1999	14	05	03	00	00	00	00	00	00	01	11	16
2000	16	06	00	00	00	00	00	00	00	04	11	13
2001	15	00	00	00	00	00	00	00	00	00	00	23
2002	14	01	00	00	00	00	00	00	00	01	01	11
2003	14	04	00	00	00	00	00	00	00	02	09	10
2004	00	00	00	00	00	00	00	00	00	01	18	19
2005	15	03	00	00	00	00	00	00	00	00	03	23
2006	08	08	00	00	00	00	00	00	00	00	13	11
2007	08	12	02	00	00	00	00	00	00	00	20	08
2008	03	04	00	00	00	00	00	00	00	00	03	15
2009	06	00	00	00	00	00	00	00	00	00	06	03
2010	10	03	00	00	00	00	00	00	00	00	13	22
2011	12	10	00	00	00	00	00	00	00	00	08	11
2012	18	02	00	00	00	00	00	00	00	01	06	07
2013	13	11	00	00	00	00	00	00	00	03	18	15
2014	11	08	01	00	00	00	00	00	00	02	13	17
2015	16	04	02	00	00	00	00	00	00	01	10	20
2016	15	06	01	00	00	00	00	00	00	01	12	14
2017	10	00	00	00	00	00	00	00	00	01	02	09
2018	27	00	00	00	00	00	00	00	00	03	03	24
2019	10	04	00	00	00	00	00	00	00	03	04	21
2020	11	02	03	00	00	00	00	00	00	00	08	16

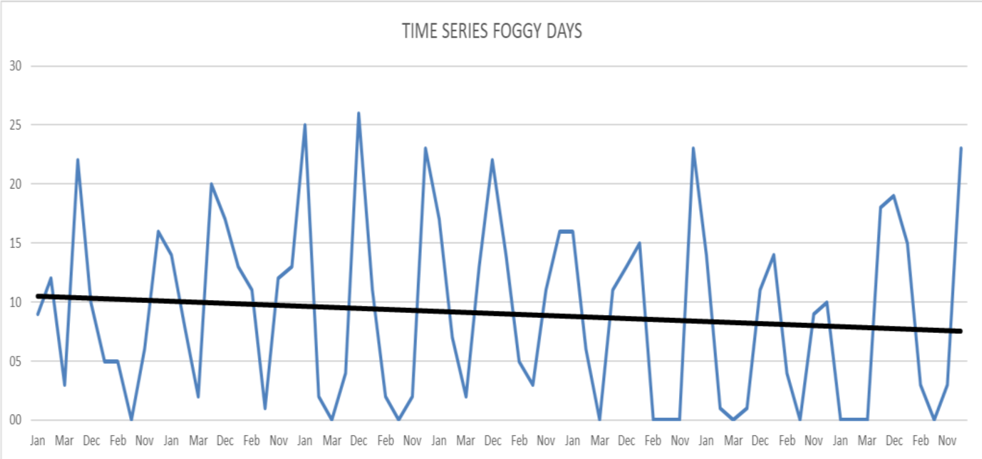


Figure 4.7 Graphical representation of number of foggy days in the last three decades (1992-2020)

4.2.4 Humidity (1992-2020)

Humidity is the measure of water vapour content of air. From 1992-2020 the world warmed about 1.42% degree (0.79 degrees Celsius). There is an inverse relation of Relative humidity and temperature but there is direct relation of humidity and temperature. In atmosphere the measure of relative humidity is in term of its capacity to hold water vapors in the atmosphere. As in summer the capacity to hold water vapour is more and the occurrence of conversion of water into vapour is also increasing which result in decrease in relative humidity of the atmosphere but this causes an increase in humidity of the area due to conversion of more water into vapour. In winter the Capacity of atmosphere to hold water vapour is less as compared to summer and the occurrence of conversion of water in vapour is less which result in increase in relative humidity in the atmosphere and decrease in humidity of the area due to decreased temperature.

Table 4.4 Data showing number of humid days (1992-2020)

RELATIVE HUMIDITY DATA LAST 20 YEARS (2001-2020)																																				
YEAR/	JANUARY			FEBRUARY			MARCH			APRIL			MAY			JUNE			JULY			AUGUST			SEPTEMBER			OCTOBER			NOVEMBER			DECEMBER		
TIME	0000	0900	1200	0000	0900	1200	0000	0900	1200	0000	0900	1200	0000	0900	1200	0000	0900	1200	0000	0900	1200	0000	0900	1200	0000	0900	1200	0000	0900	1200	0000	0900	1200	0000	0900	1200
1992	83	92	49	87	88	54	83	77	41	70	68	36	72	54	33	70	52	34	66	61	49	84	80	63	80	79	55	81	79	40	87	86	47	91	91	53
1993	86	87	65	74	77	43	76	69	39	73	61	33	60	43	27	64	43	32	71	64	51	81	77	52	76	77	41	76	81	41	91	92	60	86	88	47
1994	82	83	53	87	84	55	86	77	45	78	67	42	68	47	26	55	37	22	66	67	37	75	71	49	74	71	48	79	75	48	88	84	56	90	95	55
1995	91	92	63	85	83	47	86	81	57	76	64	42	64	46	32	58	45	32	68	63	46	78	69	49	75	65	43	77	71	35	83	83	47	87	86	44
1996	93	97	60	91	91	53	81	75	42	77	68	39	63	52	30	60	51	34	66	59	45	75	72	34	76	71	47	88	83	54	93	95	54	96	98	65
1997	85	82	52	62	54	321	76	71	43	89	91	52	85	82	52	85	82	52	85	82	52	83	83	41	89	89	49	67	52	35	72	68	52	76	71	35
1998	85	83	47	69	59	31	75	70	53	89	89	56	85	83	47	85	83	47	85	83	47	83	81	46	89	88	55	70	54	35	74	69	49	82	85	48
1999	76	71	43	69	54	30	77	75	51	84	87	49	76	71	43	76	71	43	76	71	43	84	81	50	87	86	44	64	48	32	68	62	43	81	79	41
2000	86	84	51	77	76	40	76	71	35	81	76	50	62	54	321	71	66	46	80	75	57	86	81	60	84	77	54	84	81	49	88	88	50	92	94	56
2001	89	89	45	80	75	36	76	68	35	76	61	32	70	60	40	67	61	47	81	77	60	79	75	58	81	75	51	80	75	48	90	90	47	90	91	43
2002	93	93	44	87	83	51	84	76	45	79	68	45	59	59	28	65	55	35	85	82	52	86	81	64	88	82	56	91	85	56	88	87	60	90	92	53
2003	91	94	50	87	87	52	85	82	52	82	73	49	08	56	32	65	52	30	85	83	47	81	74	55	81	76	55	88	85	49	91	90	52	92	94	65
2004	93	97	60	91	91	53	85	83	47	77	68	39	63	52	30	60	51	34	76	71	43	75	72	34	76	71	47	88	83	54	93	95	54	96	98	65
2005	93	95	64	90	91	65	76	71	43	78	72	40	75	64	34	63	54	30	75	70	53	80	76	54	84	82	55	87	85	45	87	90	48	90	97	51
2006	88	90	51	84	90	48	83	85	30	75	66	36	67	53	28	67	55	33	77	75	51	84	81	61	80	77	47	84	84	50	96	93	53	88	91	57
2007	88	88	41	86	93	65	85	85	54	79	72	39	75	61	38	71	61	40	76	74	52	81	78	56	84	80	56	87	83	42	93	95	56	91	91	56
2008	86	84	51	77	76	40	76	71	35	81	76	50	62	54	321	71	66	46	80	75	57	86	81	60	84	77	54	84	81	49	88	88	50	92	94	56
2009	86	89	56	85	85	40	82	85	48	81	74	48	69	59	31	61	50	29	65	56	37	73	70	53	80	76	48	83	83	41	88	89	47	87	89	46
2010	87	90	49	86	86	54	81	79	41	73	65	36	69	54	30	66	53	34	68	63	48	85	82	52	83	75	51	83	81	46	87	86	47	89	92	55
2011	89	91	52	86	86	59	77	70	43	77	71	42	62	51	41	59	49	31	75	68	51	85	83	47	82	77	54	84	81	50	88	83	57	84	88	50
2012	89	89	56	79	76	48	73	66	37	72	61	41	64	50	30	51	37	23	62	55	36	76	71	43	82	77	57	84	76	48	86	85	51	88	86	56
2013	84	87	49	87	87	57	83	77	53	77	63	42	65	46	29	64	51	32	73	67	49	81	76	59	78	72	51	83	79	49	88	85	51	88	89	51
2014	85	85	44	82	81	49	86	81	54	79	67	43	67	52	35	58	43	26	63	56	42	71	64	46	73	67	37	81	78	51	85	81	44	89	89	49
2015	87	86	50	85	82	52	85	78	57	81	73	48	70	54	35	57	43	28	74	67	53	81	74	57	81	70	45	84	78	48	88	86	55	89	88	55
2016	91	92	63	85	83	47	86	81	57	76	64	42	64	46	32	58	45	32	68	63	46	78	69	49	75	65	43	77	71	35	83	83	47	87	86	44
2017	88	87	63	76	71	43	76	67	39	71	59	33	57	43	27	57	47	32	72	68	52	82	76	56	80	73	47	80	77	38	91	92	60	84	85	45
2018	83	85	44	76	77	41	79	73	41	80	67	40	65	49	30	55	43	25	74	69	49	76	73	54	77	70	47	84	79	43	83	83	44	91	92	50
2019	84	83	53	87	84	51	81	73	45	76	64	42	66	47	28	52	35	22	68	62	43	79	73	51	76	72	49	82	77	46	88	84	56	91	92	57
2020	85	87	58	81	80	44	85	68	39	82	69	45	71	52	34	68	52	36	67	53	38	77	69	51	84	76	45	82	75	32	86	87	52	90	91	52

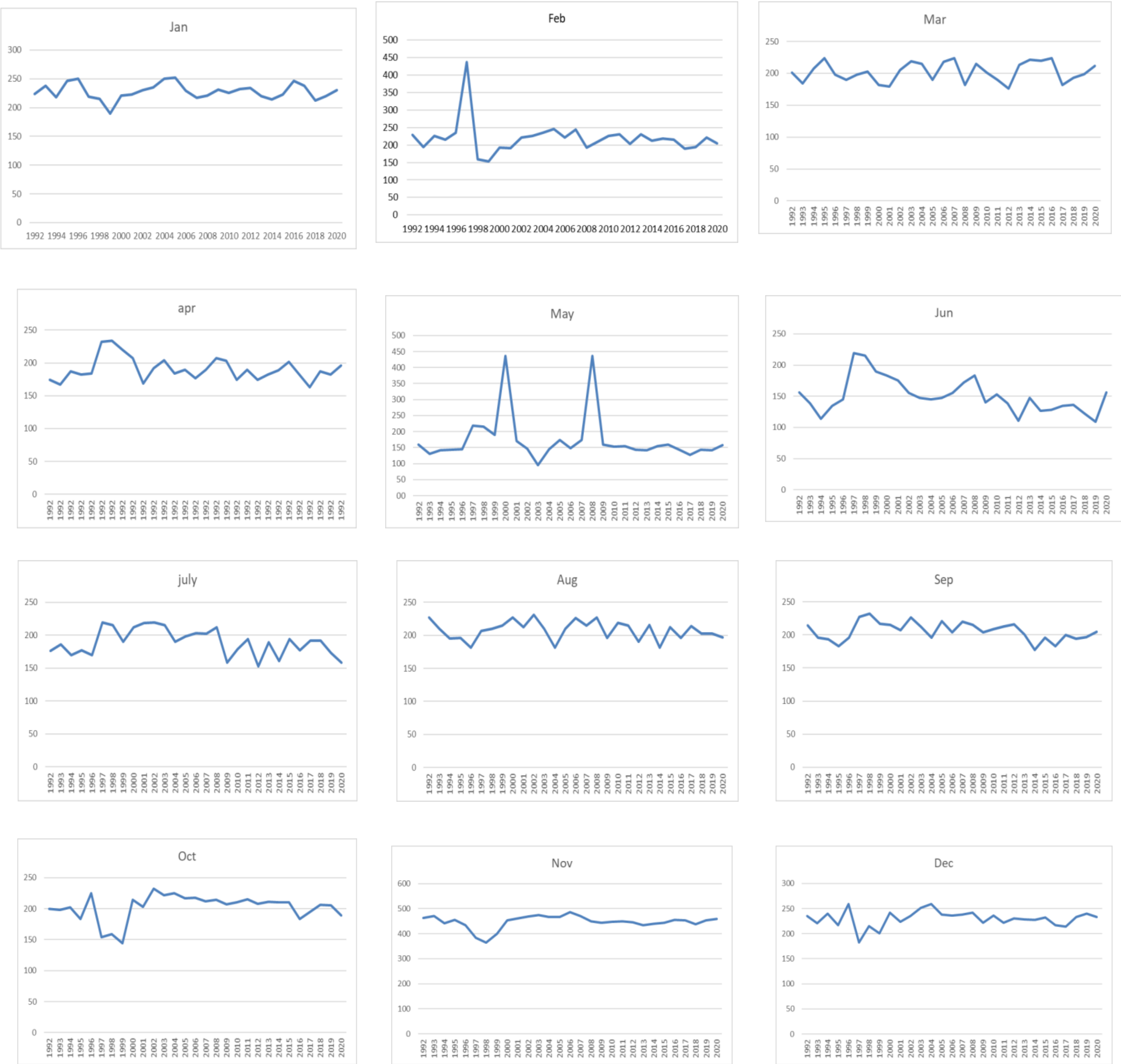


Figure 4.8 Showing monthly representation on humidity for 1992-2020

4.2.5 Surface Winds (1992-2020)

Wind is a major factor in determining weather and climate. Wind Carries heat, moisture, pollutant and pollen to areas. Due to the temperature variation on water and land surface the strong wind blows from colder region (Sea Surface) to warmer region (Land area). The stronger hot wind would carry more water vapour into air which would get condensed as moving upward into the atmosphere causing precipitation. In the study area the graph indicate that surface winder are stronger in summer due to transfer of cold wind from river channel and Kalpani nullah into study area. The max value of surface wind from (1992-2020) is 94 Knot in month of July which is the extreme summer month and min is 30 Knot in November which is extreme winter month. This indicate that because of climate change surface winds are increasing even in the colder months of the year (Table 4.5 & fig 4.9).

Table 4.4 Data showing number of humid days (1992-2020)

Month	Surface Wind (Knots)	
	Highest	Avg
Jan	32	3
Feb	45	5
Mar	65	5
Apr	65	6
May	75	7
Jun	90	8
July	94	8
Aug	90	7
Sept	65	8
Oct	70	4
Nov	30	3
Dec	32	2

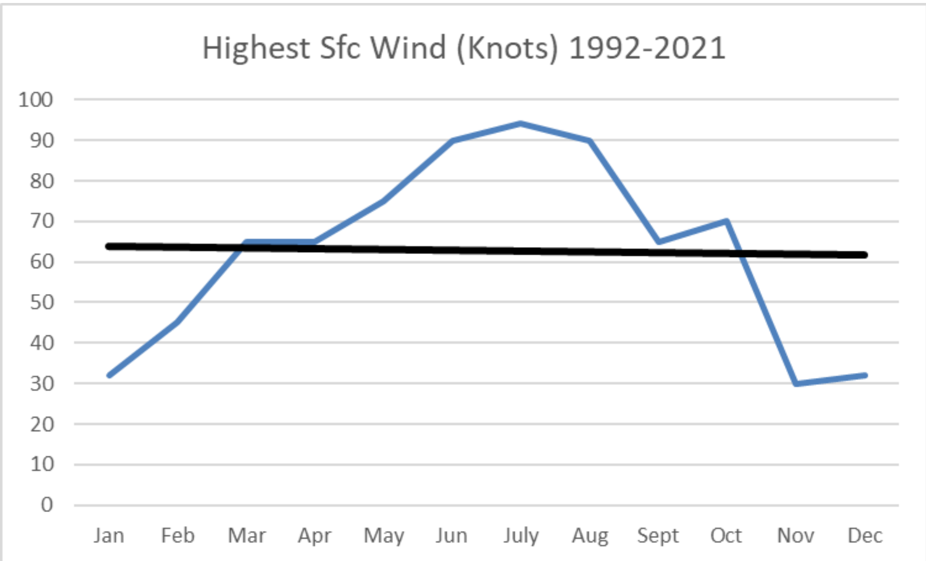


Figure 4.9 Graphical representation of surface wind speeds (in knots) in Risalpur (dataset used: 1992-2021)

4.2.6 Dust Storm (1992-2020)

Dust storm occur most frequently over desert and region of dry soil where the particles of dirt are loosely bound to the surface. Dust storm in summer decreases the temperature.

From the analysis of the study it shows that the no of dust storm is very low due to the presence of wet strata of the area which causes particle to tightly bound with each other however the max no of dust storm occurred in the month of summer and minimum in the Winter as more air flow in summer and less in winter (Table 4.6 & fig 4.10).

Table 4.6 Monthly frequency and averages of dust storm in Risalpur

Month	Dust Storm	
	Max	Avg
Jan	0	0
Feb	1	0.1
Mar	1	0.1
Apr	2	0.4
May	6	1.1
Jun	5	1.9
July	5	0.9
Aug	2	0.6
Sept	3	0.7
Oct	1	0.3
Nov	0	0
Dec	0	0

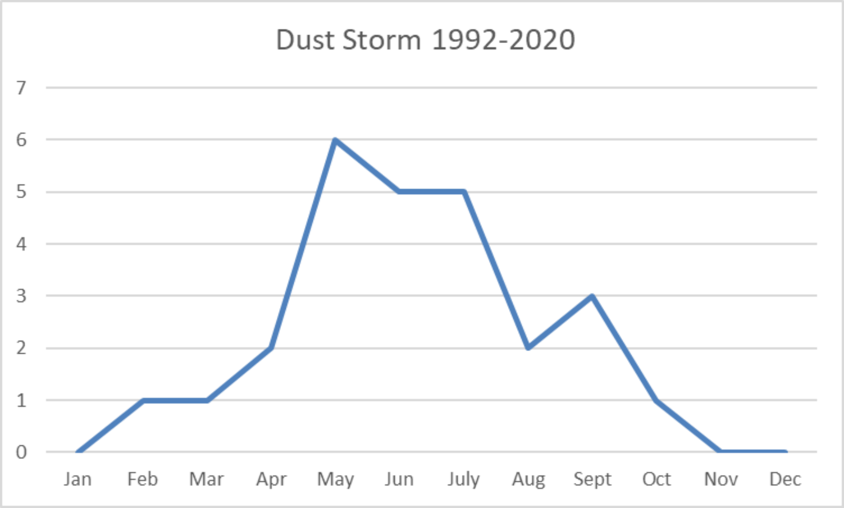


Figure 4.10 Graphical representation of dust storm in Risalpur (Dataset used: 1992-2020)

4.2.7 Thunderstorm (1992-2020)

There is direct relation of thunderstorm and temperature and in rise of 1 degree Centigrade there will 12 % increase in thunderstorm. The concept of thunderstorm is when the warm air swiftly moves upward to the colder region of the atmosphere these two airs collide with each other due to temperature difference resulting in thunderstorm and after that warmer air get vaporized due to decreases in temperature and causes precipitation. The analysis of the study area shows that that intensity of thunderstorm days is more in summer season which is 24 Days in august since 1992-2020 which indicate that the months of May to Aug result in a greater number of thunderstorms how the existing trend is linear (Table 4.7 & fig 4.11).

Table 4.7 Data showing monthly frequency and averages of thunderstorm in Risalpur

Month	Thunder Storm	
	Max	Avg
Jan	5	2
Feb	6	2
Mar	12	7
Apr	13	9
May	14	10
Jun	13	9
July	23	15
Aug	24	16
Sept	14	8
Oct	10	4
Nov	4	2
Dec	3	1

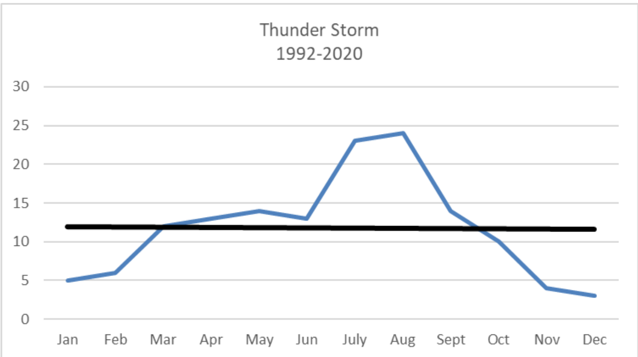


Figure 4.11 Graphical representation of thunderstorms in Risalpur (Dataset: 1992-2020)

4.2.8 Time Series Analysis of Surface Runoff (SRO) and Subsurface Runoff SSRO (1992-2020)

To further study the effect of climatic factor on the ground flow pattern of Risalpur including the data of Surface and Subsurface runoff was collected by NASA's MERRA-2 satellite-era reanalysis. The Existing flow pattern is of 30 Year data from (1992-2020). The analysis of climatic factor shows the alteration in their behavior which has a direct impact on surface and sub surface run off. Due to rise in temperature the total duration and average precipitation is decreasing but their intensity is increasing (mm/Hour). Due to the increase in intensity of precipitation the surface run off mm/Hour has increased which causes less absorption of surface runoff water in to sub surface. From the Data acquire through MERRA-2 Satellite it indicates that in the study areas overall trend of surface runoff is decreasing from 1992 to 2002 (One Decade) due to less precipitations, but from 2003-2012 the trend line become linear and is showing and increased value of surface runoff confirming the effect of increase temperature value causing more intense precipitation. However, there is a direct relationship between surface runoff and sub surface runoff, but their relationship is controlled by gradient of the earth and intensity of precipitation in the study area. The decreasing value of sub surface run off justifies that the due to high intensity precipitation surface runoff is more but due to undulated and sloping ground the water on the surface moves with greater velocity causing less water to percolate in subsurface resulting lower values of sub surface runoff.

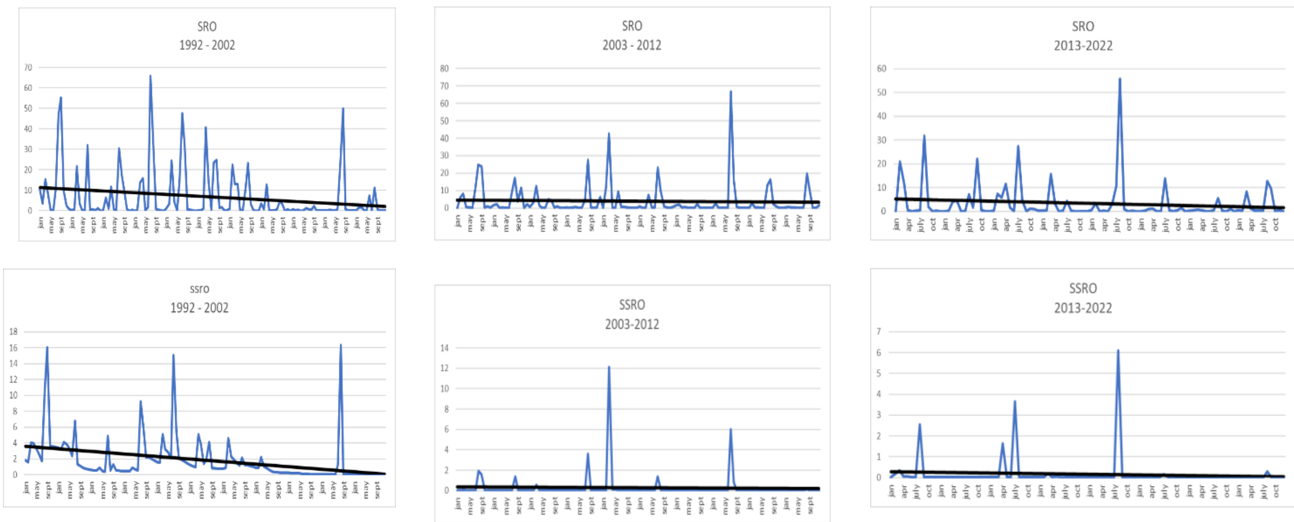


Figure 4.12 Time series analysis of SRO and SSRO for Risalpur (Dataset: 1992-2020)

4.2.8.1 Time Series Analysis of Monsoon and Non-Monsoon SRO (1992-2020)

The graphical comparison is carried out between flow pattern and precipitation during their monsoon and non-monsoon season. From the Graph (fig 4.13 & 4.14) it is analyzed that in monsoon season shows the decreasing average precipitation behavior, but the intensity of precipitation is increasing thus the effect of these rainfall on surface and surface runoff can be seen. Due to decreasing average precipitation the surface runoff and subsurface runoff is also decreasing due to variation in slopes and permeability of the soil. whereas in nonmonsoon season the intensity and duration of rainfall is low which has the same effect on the surface and sub surface runoff.

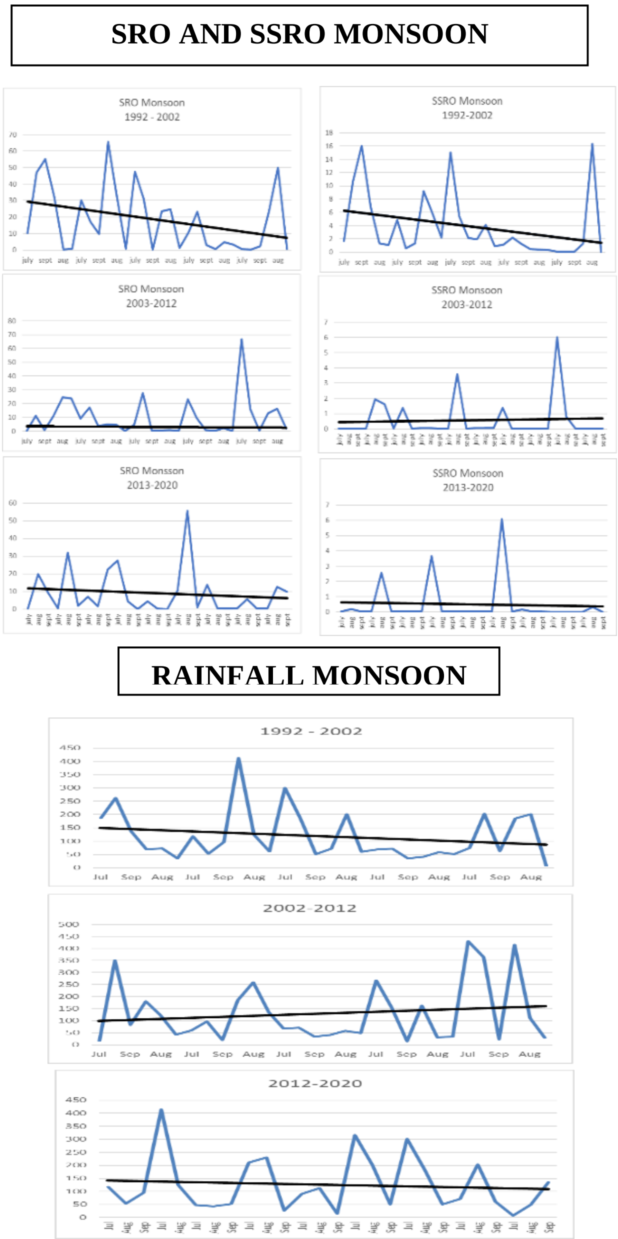
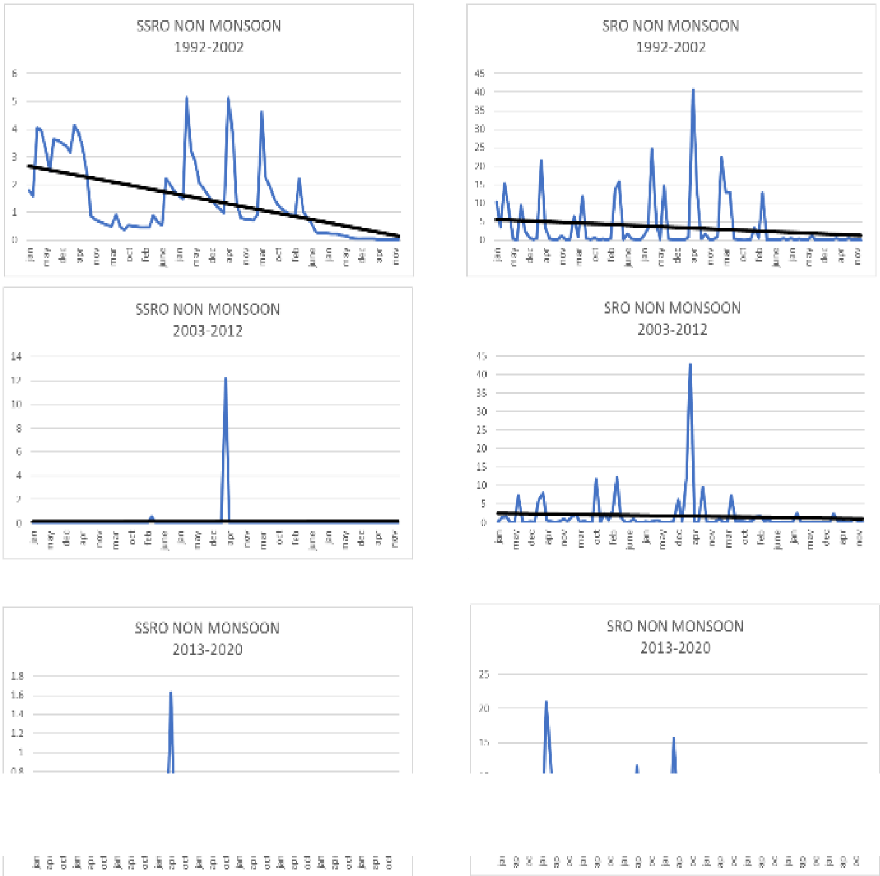


Figure 4.13 (a & b) Time series analysis of SRO, SSRO and rainfall for Risalpur in Monsoon Period (Dataset: 1992-2020)

SRO AND SSRO NON-MONSOON



RAINFALL NON-MONSOON

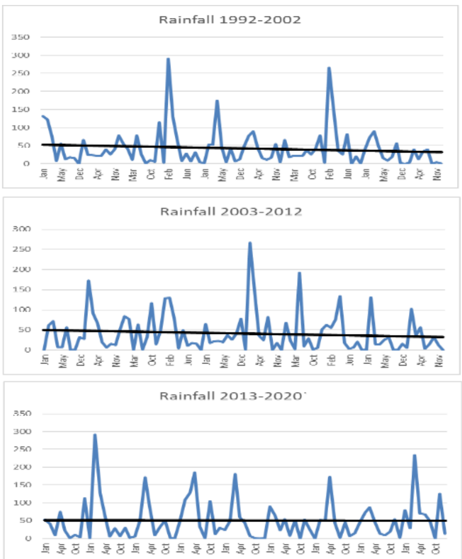
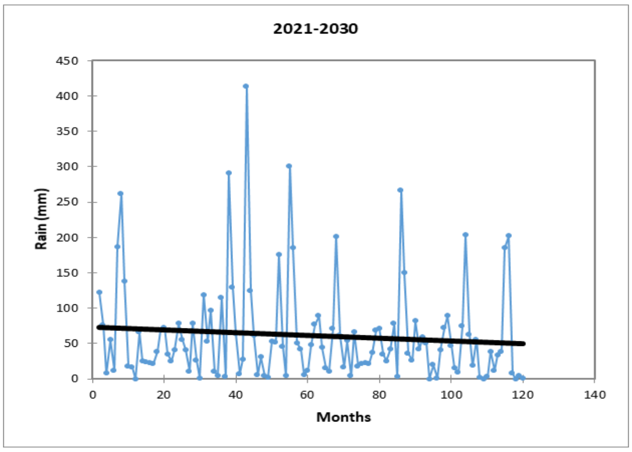


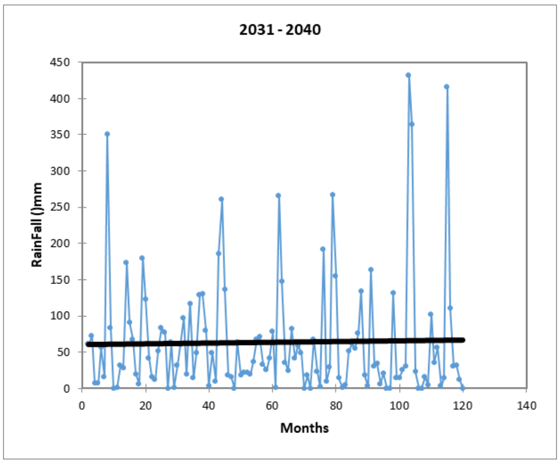
Figure 4.14 (a & b) Time series analysis of SRO, SSRO and rainfall in Risalpur for Non-monsoon period (Dataset: 1992-2020)

4.3 Future Trend of Hydro Meteorological Factors and SRO, SSRO GWT

4.3.1 Precipitation Future Trend

In comparative to the existing trend of the precipitation the future trend of precipitation is reflected in fig 4.15 (a, b & c) which shows that the precipitation pattern is showing variation in its trends. From 2021-2030 the precipitation is gradually decreasing with increase intensity of rainfall but from 2031- 2050 the pattern becomes linear but constant increase in its intensity.





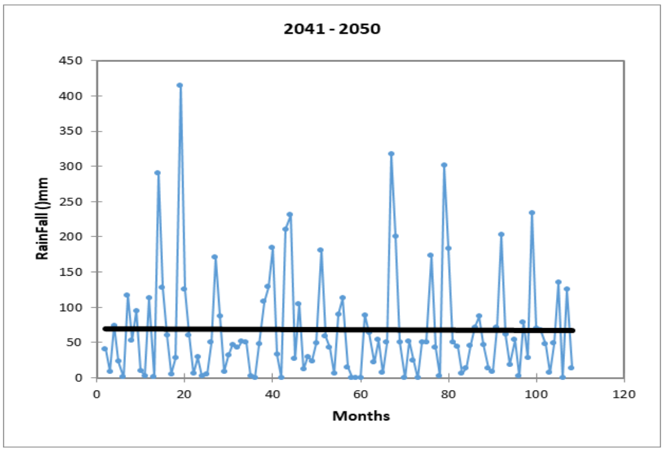


***Figure* 4.15 (a, b & c) Graphical representation of precipitation with future projection for 1992-2002, 2031-2040 and 2041-2050**

4.3.1.1 Future trends for Monsoon Precipitation

Annual Max Monsoon precipitation recorded from 1992 to 2020 at Murree and PAF Rsc station is 431 mm, 416 mm and 413 mm, respectively. In study area minimum total rainfall exceeded and 508 mm and maximum total rainfall per year is exceeded 1164 mm. This shows that study area received extremely rainfall each year as compared to any area in it surrounding. As compared to above from 2021-2040 annual max precipitation recorded in monsoon is 295 mm and 260 mm showing the decrease in in trend whereas 2041-2050 the trend becomes gradual and with annual max precipitation of 292 mm (fig 4.16).

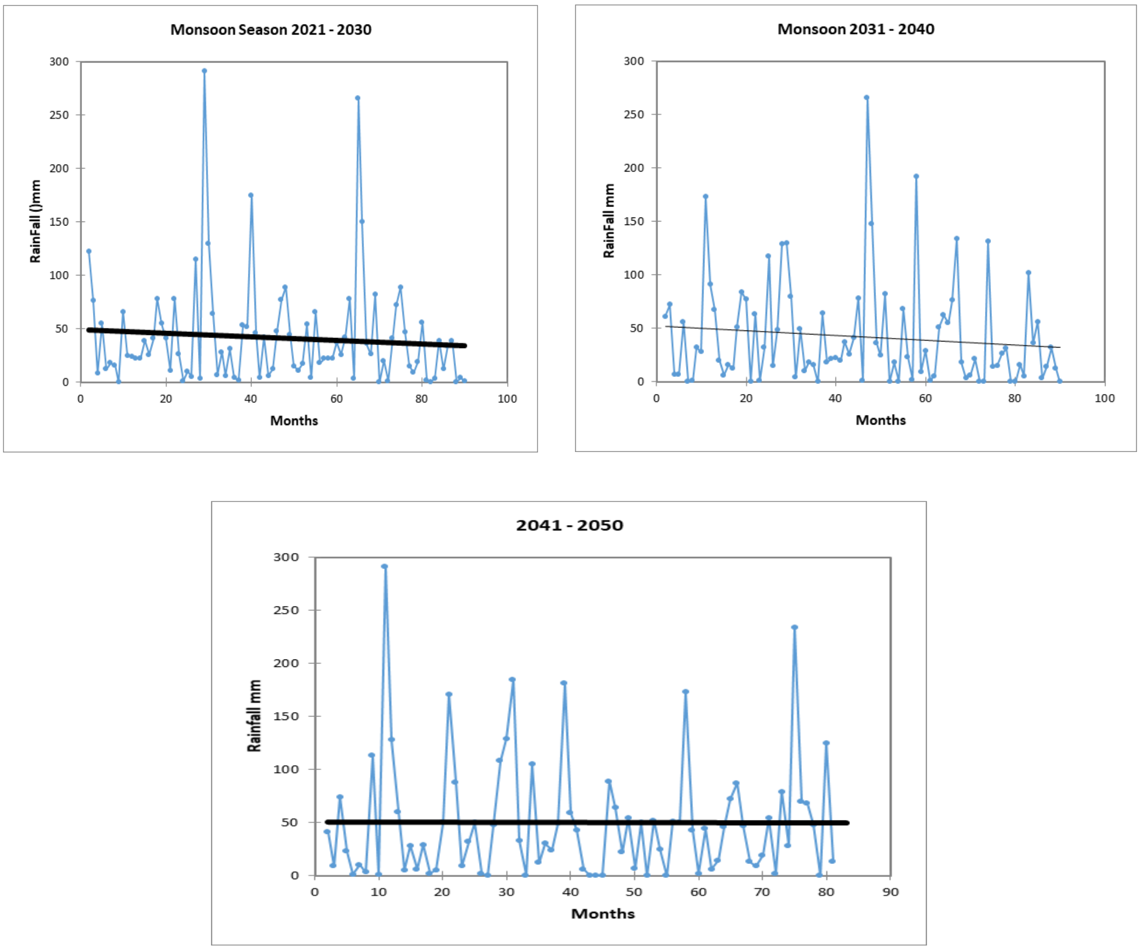
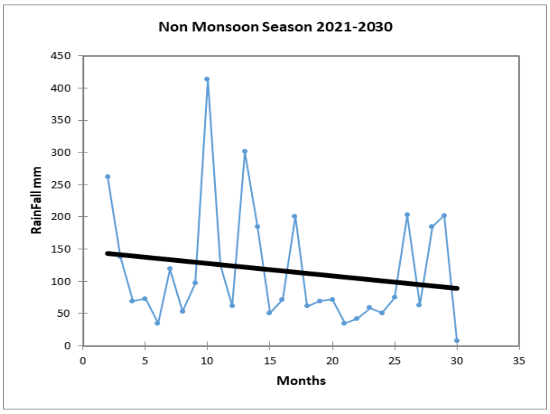
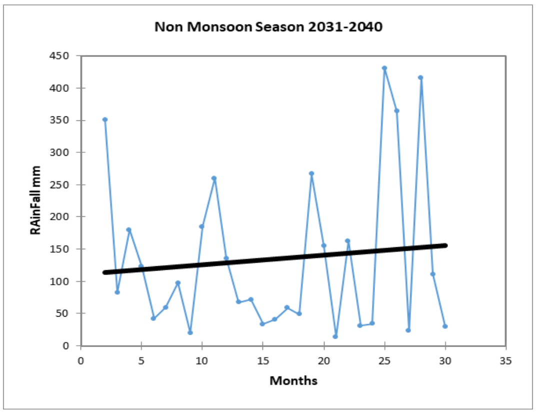


Figure 4.16 (a, b & c) Graphical representation of future trends for Monsoon precipitation for 2021-2030, 2031-2040 and 2041-2050

4.3.1.2 Future trends of Non-Monsoonal Precipitation

Annual Max Non-Monsoon precipitation recorded from 1992 to 2020 at Murree and PAF RSC station is 291 mm, 266 mm and 173 mm, respectively. In study area minimum total rainfall exceeded and 132 mm and maximum total rainfall per year is exceeded 665 mm which show that the trend of rainfall is low in Nonmonsoon season rainfall as compared to monsoon rainfalls. As compared to above from 2021-2030 annual max precipitation recorded in nonmonsoon is 410 with decrease rainfall trend but with considerable increase in its intensity from 2031-2040 the annual max precipitation recorded in non-monsoon is 430 mm with the increase rainfall trend as well as intensity. From 2041-2050 the annual maximum precipitation is 420 mm with the decrease in rainfall trend (fig 4.17).





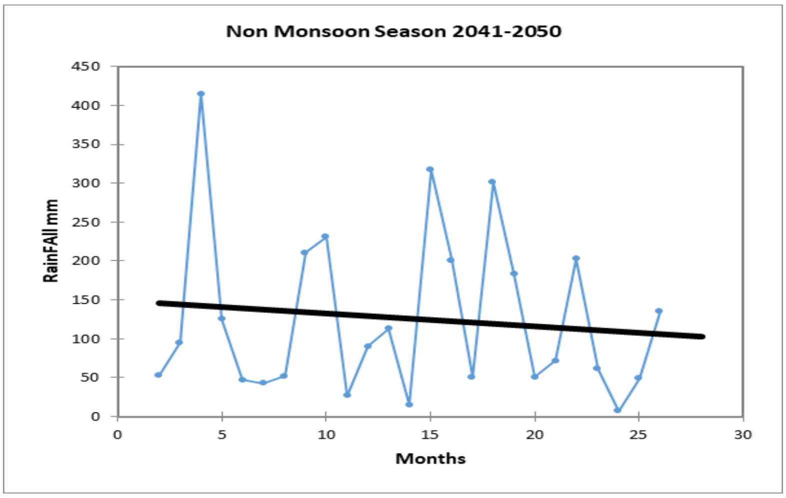


Figure 4.17 (a, b & c) Graphical representation of future trends of non-monsoonal precipitation for Risalpur for 2021-2030, 2031-2040 and 2041-2050

4.3.2 Temperature Future Trend

The future temperature from 2021 to 2050 (30 years) it is observed that over the last millennium and especially the future 03 decades, the climate change indicators show warming trends in the region. The temperature increase can be related with global warming that significantly affects precipitation. Further, urbanization and industrialization be part of the cause in changing the global climate. The regional future trends in temperature estimated using Man Kendall Trend analysis technique.

4.3.2.1 Summer Temperature

Due to the effect of global warming the annual temperature of the earth is rising as the ozone layer is depleting which cause ultraviolet rays to directly reach the earth surface causing the rise in temperature. The study area is in the hot climatic zone of the province where both summer and winters shows their extreme values. Based on results of Man Kendall test it shows that in summers the maximum temperature in the next three decades is increasing with the maximum value of 46 degree Celsius as compared to previous value of 44 degree Celsius moreover the average rise in temperature is also showing increased values from previous analysis (fig 4.18).

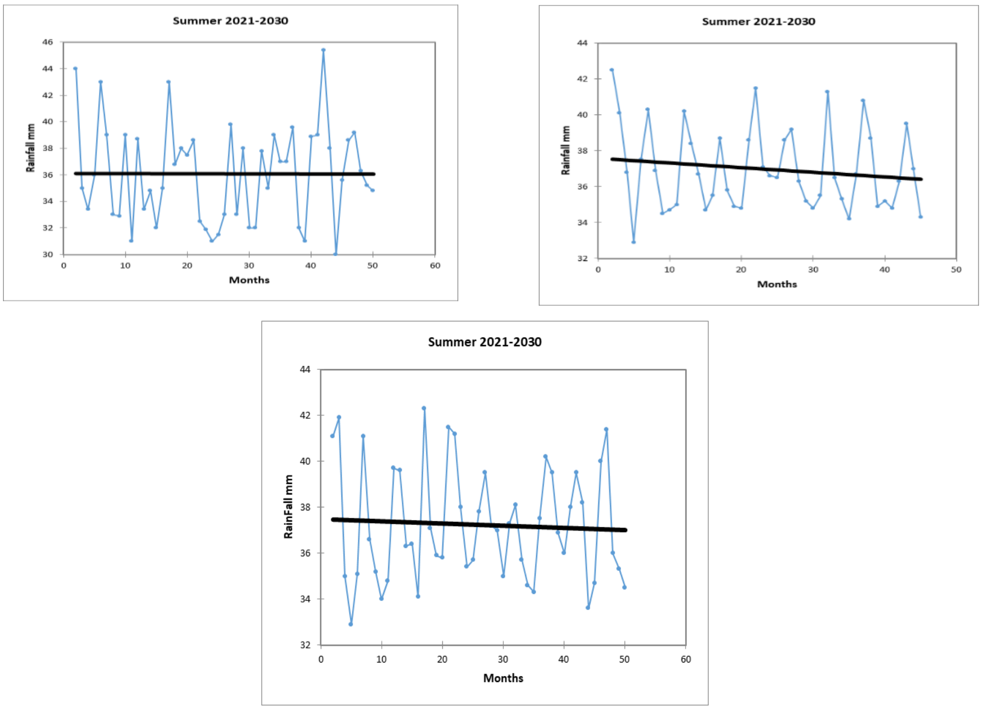


Figure 4.18 (a, b & c) Graphical representation of future trend for temperature in Risalpur (Datasets: 2021-2030, 2031-2040 and 2041-2050)

4.3.2.2 Winters Temperature

From the result generated in man Kendal trend test it can be analyzed that winter is also showing increased temperature value as compared to previous three decades which also confirms the effect of global warming on the season. Based on the test the max winter temperature from 2031-2050 has risen to 30 degree Celsius which higher than the previous decades and the minimum is likely to approach 4 degree Celsius compared to 0 degree Celsius of the previous three decades (fig 4.19).

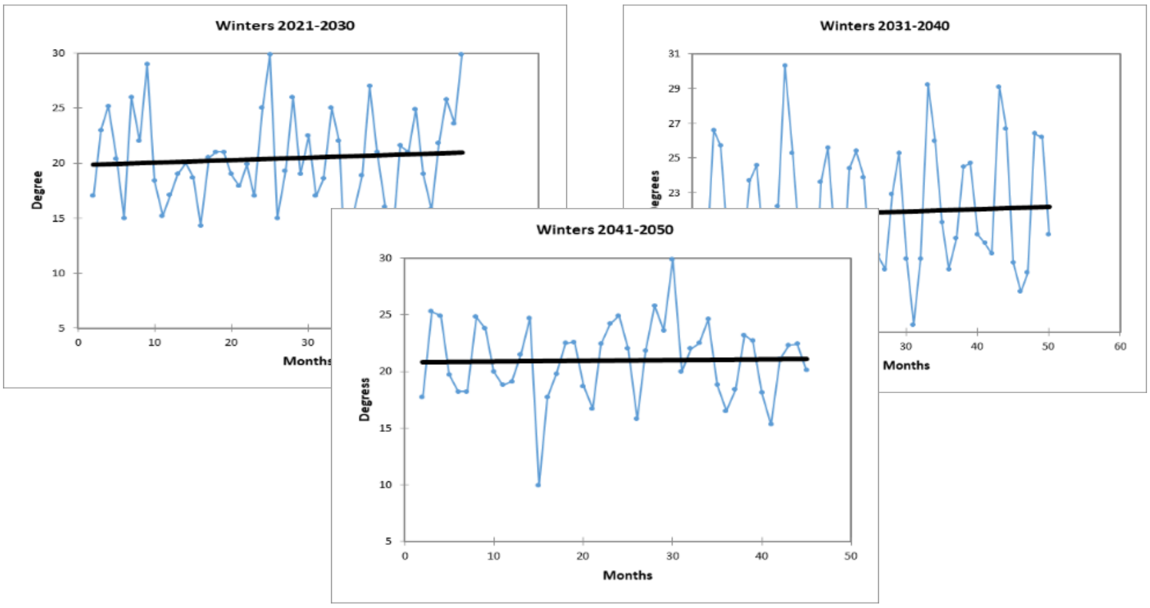


Figure 4.19 (a, b & c) Graphical representation of future trends of winter temperature in Risalpur for 2021-2030, 2031-2040 and 2041-2050

4.3.3 Future Trend in Foggy Days

The effect of Fog occurs when the temperature reaches the dew point (Less value of Temperature) which causes conversion of vapors in to liquid state resulting in Fog. The foggy days in the study area occurs in two patches. First from Jan-Mar and then from Oct – Dec. There is no trace of fog detected from Apr – Sept due to increase temperature values of the summers. However, in winter the fog increases due to the decreased temperature values causing mixing of cold air with warmer air. The man Kendall test indicate that in the next three decades the trend of foggy days will decrease as the temperature will rise to higher values causing less conversion of vapour into liquid state (Fig 4.20).

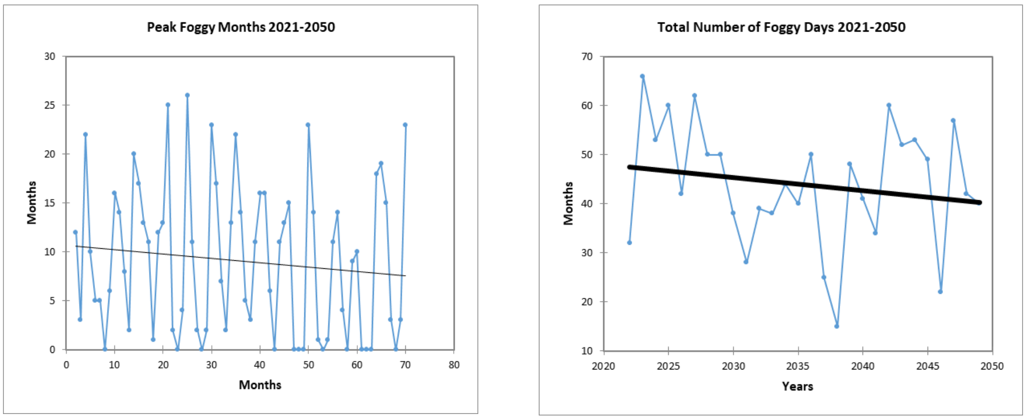


Figure 4.20 (a & b) Graphical representation of Foggy days, monthly distribution and number of foggy in 2021-2050

4.3.4 Highest Surface Wind Future Prediction

From the analysis of past three decades the max value of surface wind from (1992-2020) is 94 Knot in month of July which is the extreme summer month and min is 30 Knot in November which is extreme winter month. However, the man Kendal test shows that from (2021-2050) these values will rise to 97 Knots and the minimum value of 30 Knots. This indicate that due to the effect of climate change surface winds will increase in the next three decades (fig 4.21).

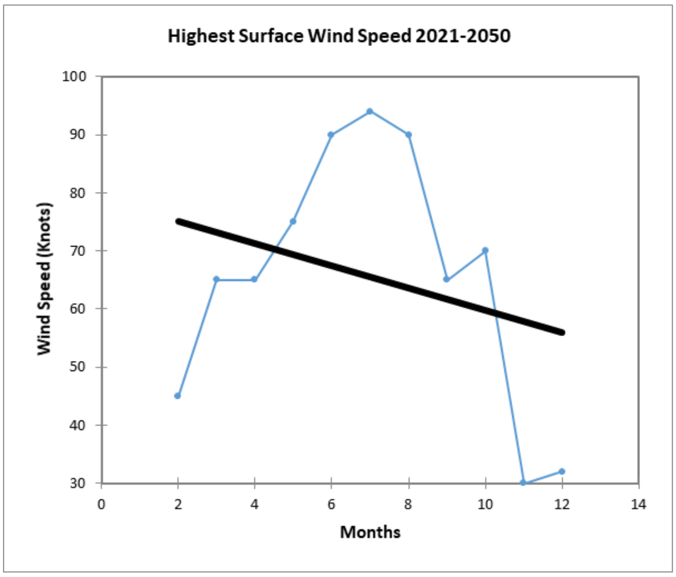


Figure 4.21 Graphical representation of highest surface winds for Risalpur (2021-2050)

4.3.5 Highest Dust storm Future Prediction

Dust storm occur most frequently over desert and region of dry soil where the particles of dirt are loosely bound to the surface. Dust storm in summer decreases the temperature. From the analysis of the study it shows that the no of dust storm is very low due to the presence of wet strata of the area which causes particle to tightly bound with each other however the max no of dust storm occurred in the month of summer and minimum in the Winter as more air flow in summer and less in winter. Keeping in view the analysis of the trend in past three decades man Kendall shows the decrease in trend as temperature is increasing continuously (fig 4.22).

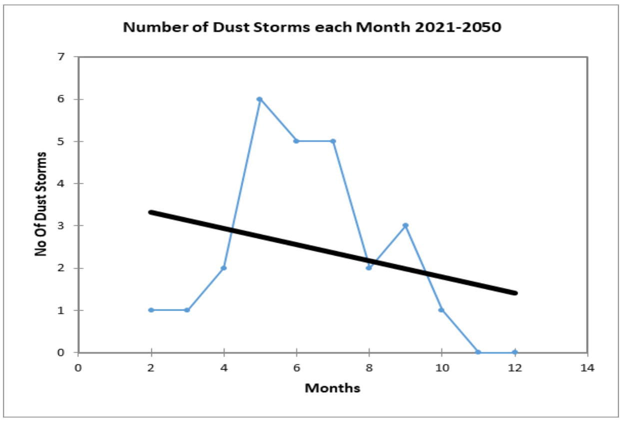


Figure 4.22 Graphical representation of future trend for dust storms in Risalpur (2021-2050)

4.3.6 Highest Thunderstorm Future Prediction

There is direct relation of thunderstorm and temperature and in rise of 1 degree Centigrade there will 12 % increase in thunderstorm. The concept of thunder storm is when the warm air swiftly moves upward to the colder region of the atmosphere these two airs collide with each other due to temperature difference resulting in thunder storm and after that warmer air get vaporized due to decreases in temperature and causes precipitation. The Man Kendal trend analysis of the study area shows that that intensity of thunderstorm days is less in summer season which is 23 Days in august as compared to previous 24 days since 1992-2020 however the future trend is towards decreasing end (fig 4.23).

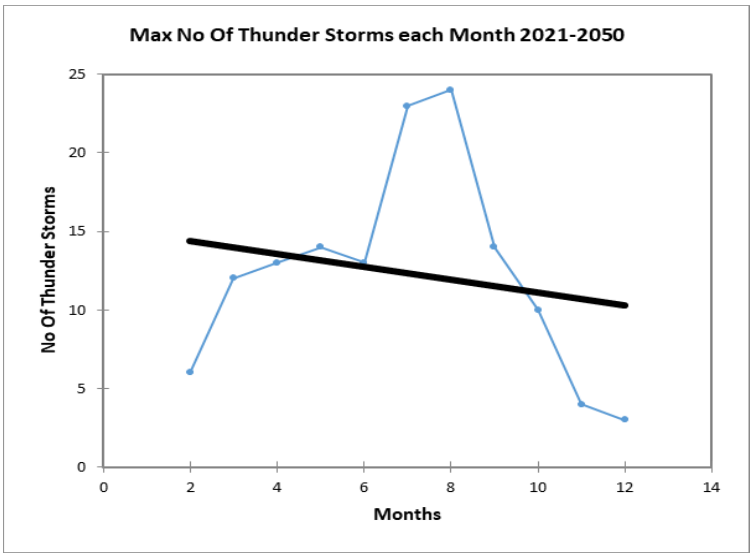


Figure 4.23 Graphical representation of future trend of thunderstorms in Risalpur (2021-2050)

4.3.7 Surface Runoff (SRO) Future Trend

From the Data acquire through MERRA-2 Satellite it indicates that in the study areas overall trend of surface runoff is decreasing from 1992 to 2002 (One Decade) due to less precipitations, but from 2003-2012 the trend line become linear and is showing and increased value of surface runoff confirming the effect of increase temperature value causing more intense precipitation However, from the analysis of Man Kendal trend test it is indicated that same effect will be reflected in the coming decades as intensity of precipitation will increase due to the increase in temperature (fig 4.24).

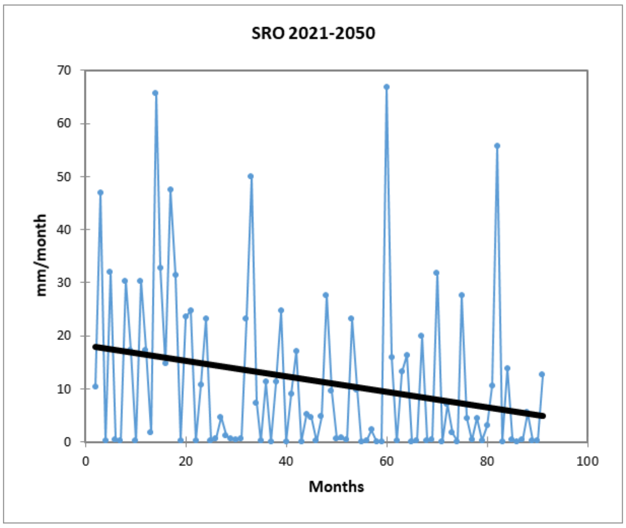


Figure 4.24 Graphical representation of future trend of surface runoff (SRO) for Risalpur (2021-2050)

4.3.8 Future Trending of Monsoon and Non-Monsoon of SRO and SSRO

The graphical comparison is carried out between flow pattern and precipitation during their monsoon and non-monsoon season. From the Graph (fig 4.25 & 4.26), it is analyzed that monsoon season shows the decreasing average precipitation behavior, but the intensity of precipitation is increasing thus the effect of these rainfall on surface and surface runoff can be seen. Due to decreasing average precipitation the surface runoff and subsurface runoff is also decreasing due to variation in slopes and permeability of the soil. whereas in non-monsoon season the intensity and duration of rainfall is low which has the same effect on the surface and sub surface runoff.

SRO AND SSRO MONSOON	RAINFALL MONSOON

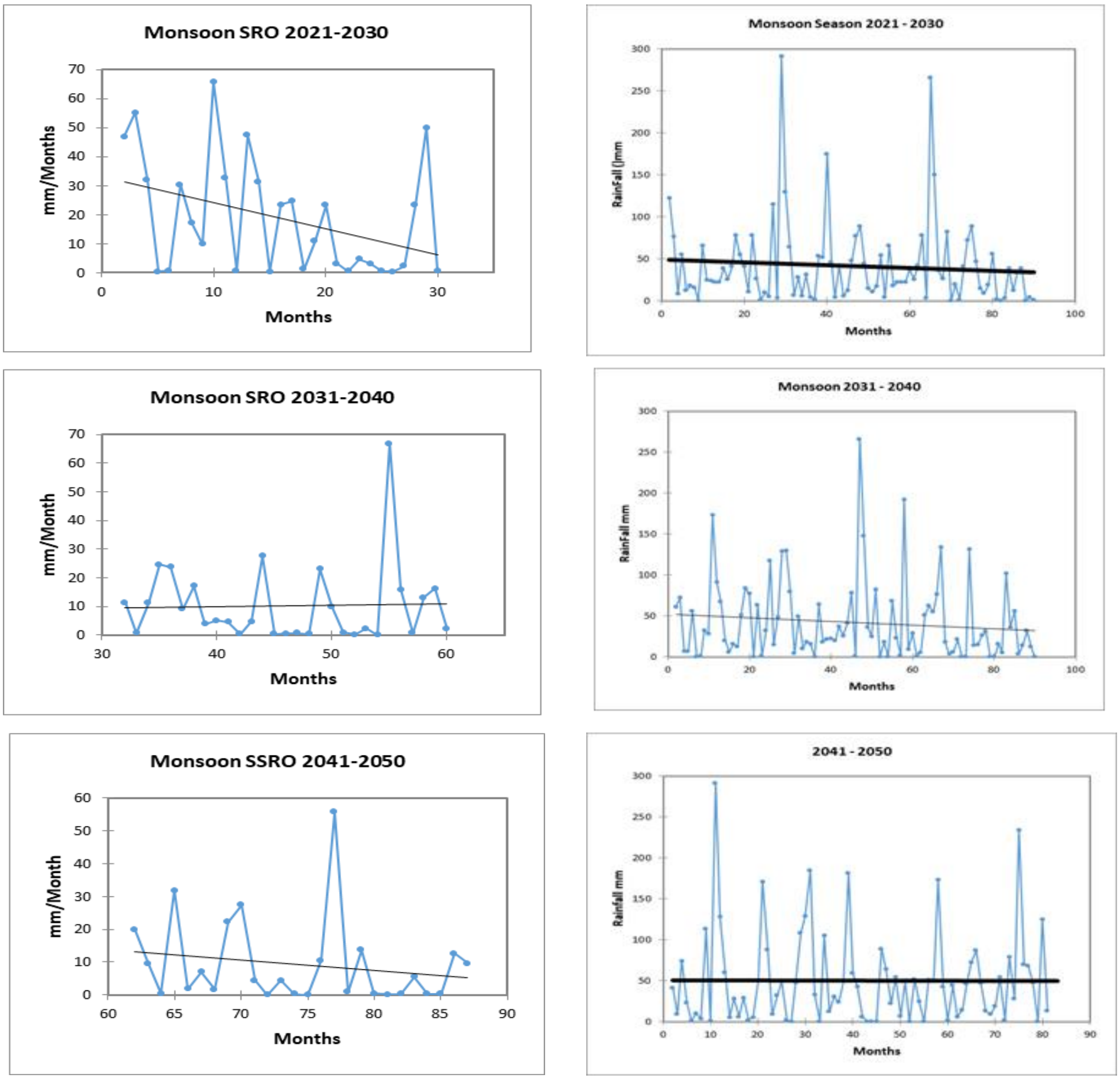


Figure344.25 Graphical representation of future surface runoff (SRO), SSRO sub-surface runoff (SSRO) and rainfall of Risalpur for Monsoon period (2021-2050)

SRO AND SSRO NON-MONSOON | **RAINFALL NON-MONSOON**

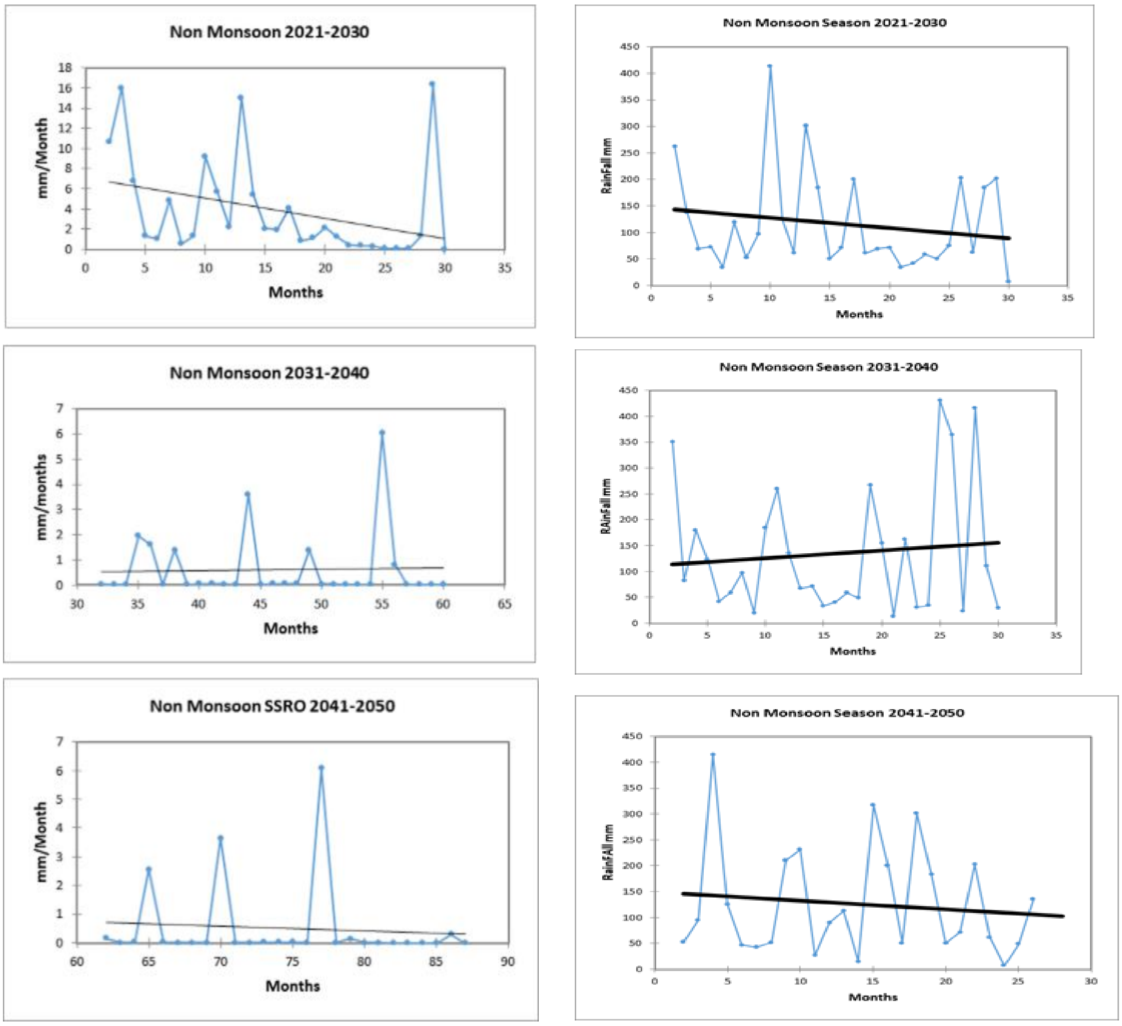


Figure 4.26 Graphical representation of future surface runoff (SRO), sub-surface runoff (SSRO) and rainfall of Risalpur for Non-Monsoon period (2021-2050)

Chapter 5

CONCLUSIONS AND RECOMMENDATION

This chapter draws out conclusions from the analysis conducted and recommend a way forward for the study area for future climate studies.

5.1 CONCLUSION

5.2 CHALLENGES

After having studied the key climate change indicators of the Risalpur region for the past 3 decades and establishing the future trends based on historical data, the following challenges are forecasted; -

1. Analysis of **precipitation** data from 1992 to 2020 in the Risalpur region shows an overall decrease in the yearly rainfall (decreased with a rate of 6.8 mm per decade). In addition, the analysis of data shows an uncertain rainfall pattern during the past years. This overall decrease in the rainfall and uncertain rain pattern is affecting rain-fed agriculture
2. Analysis of **temperature** data from 1992 to 2020 shows a constant increase in temperature over the years (0.3 °C and 0.106 °C increase in minimum and maximum temperature per decade). This uptrend is likely to hold in the coming decades. This increase in temperature leads to a higher rate of evapotranspiration leading to an increased demand for water for irrigation purposes, while the water resources are depleting. This is also leading to a reduction in crops and livestock production.
3. High **temperature** is causing rapid glacier melting and altered flow of rivers, which are leading to uncertain availability of irrigation water. Inadequate storage structures make it difficult to store water when the flow is above requirement and use it in time of need.
4. The analysis of the **humidity** data in the region has indicated more hot and humid summers. These conditions are suitable for the reproduction of disease-causing micro-organisms.
5. **Groundwater table** data for the past three decades suggests an overall decrease in subsurface water in the region. The effects of this phenomenon are well known and include increased pumping costs, deterioration of water quality, scarcity of water, and land subsidence.
6. The data along with increased temperature and decreased rainfall suggests a decrease in the **surface runoff** in the region. The Mann-Kendall analysis suggests

a further decrease in the coming years which will lead to a decrease in the availability of water for rain-fed agriculture.

5.3 Recommendations

This study reveals a positive trend in the temperature and the humidity in the region whereby the precipitation, groundwater table, and surface runoff data showcase a negative trend. The overall impact of these key climate parameters indicates hot weather and a shortage of water. With the future prediction conducted through Mann-Kendall analysis indicating a continuation of the present trends, the following measures must be taken at the national, provincial, and regional levels to counter the adverse effects of the climate change:

1. Modern agricultural methods are to be adopted to ensure an enough supply of food and livestock. To attain an increased crop-yield an advanced and educated agriculture approach needs to be adopted. The need for the conduct of soil test in the area is necessary to determine the PH and nutrient level (nitrogen, phosphorus and potassium mainly). Based on the test results the need for artificial efforts should be articulated. The crop yield should then be maximized by using high yielding variety seeds and chemical fertilizers. Additionally, a due diligence should be paid to the stress management of crops.
2. Anti-evapotranspiration measures to be used to cut down water loss. This can be achieved by reducing the exposure of wet soil to the atmosphere wherever possible by employment of shades. Another effective method to reduce the evapotranspiration is by the employment of drip irrigation.
3. Legislation should be done to formulate a climate change policy stating the role of national, provincial, and local administrations as well as private and public sectors. The emphasis should be laid on attaining and consuming environment friendly energy. Keeping in view the current national situation emphasis should be paid on strict compliance with deforestation policies and enhanced efforts to promote tree plantation.
4. Ensure timely response to adverse events by monitoring the glacial and low elevation plain zones and subsequently organizing impact assessment activities.
5. Storage infrastructure is to be built to ensure the timely availability of irrigation water during times of low supply, regulate the water supply, and cut down the flood losses.

6. Avoid rain-fed and flood irrigation; instead, the focus should be paid to utilizing sprinkler systems and drip irrigation systems. Another area of interest for the authorities should be rainwater harvesting. Water is too precious a resource to be allowed to runoff. Every effort should be made to conserve every possible drop of water.

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