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Analysis of Climate Change Effects on the Temporal Distribution of Surface Water in Khuzdar

by

Kavish Mehboob

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This research work is wholeheartedly dedicated to Almighty Allah, without HIM I am nothing and I can't complete this study. To my beloved parents and my fiancee and to my whole family, who have been my source of motivation, inspiration and strength. When I thought of giving up, they constantly provide their moral, spiritual, emotional and financial support. To my respected supervisor, without his intellectual support and guidance it couldn't be possible to take the first and the most important step towards achieving my goal, all my teachers and all those friends who have supported me since the beginning of the research.

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Abstract

Balochistan is the most water-stressed province of Pakistan. Geographically, the second largest District of the province is Khuzdar, which has an area of 35,380 square kilometer. The district lies in mountainous region with arid climate experiences suffering severe water shortage having an average rainfall of 200 mm. With scarce and unevenly distributed surface water, groundwater resources have also been extensively exploited. The 74% population depends on ground water source in the form of tube wells and boreholes. It has been considered as a data-scarce region both temporally and spatially with limited capability to measure hydro-meteorological parameters with in situ gauges. The current study focuses on Mula river (Nari basin) which lies in the northeast of Khuzdar. Agriculture is the major economic activity followed by livestock farming in district Khuzdar. Depletion of groundwater level and extinction of surface water sources have compelled the population to migrate from their locations. This situation is expected to be worsen under current climate change scenarios. Sudden climate and soil changes can lead to food shortage as climatic changes can adversely affect the agriculture and crops. The assessment of climate change factors i.e., minimum and maximum temperature, precipitation impacts on the temporal distribution of flow on Mula river have been done and suggested the remedial measures to cope up the issues. Foe scenario generation, the available downscaled MarksimGCM data (2010-2015,2030,2060,2090) under RCP 8.5 (Representative Concentration Pathways) is used in this study and model efficiency assessed with Nash-Sutcliffe efficiency. The data calibrated and validated with available flow data used from 2010 to 2015, the common years of availability of all used datasets. The values of all stations then are averaged over Mula river for each month and the changes are calculated for future periods of 2030s, 2060s, and 2090s.

The results from all 3 GCMs suggests an increasing trend in maximum and minimum temperature in the future, as compared to the baseline. The increases for maximum temperature range from +0.96^{o}C to +1.23^{o}C under RCP 8.5. The increases for minimum temperature range from -1.67^{o}C to +3.73^{o}C under RCP 8.5.

The projections for precipitation mainly show a decreasing trend under RCP 8.5. The results of GCMs as compared to the base period have shown -1.60%, -6.32% and +2.74% change in flows with respect to the base years average in 2030, 2060 and 2090, respectively. The flow changes are mostly in line with the simulated trend of precipitation and temperatures.

This study recommends that the future projections of temperature and precipitation are highly uncertain and policy makers should include a range of projections while making the decisions for development plans and adaptation strategies. Temperature is projected to increase in future for the study area but the results suggest that it might create further opportunities due to increase in the water availability and decrease in the cold temperature stress for the crops. However, lack of infrastructure might lead to further problems due to the possibility of more frequent and extreme floods and droughts. This study can be used as an outline for other river basins in Khuzdar because there is need to focus surface water control and distribution in Khuzdar.

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Abbreviations

AGW	Anthropogenic Global Warming
AR4	Fourth assessment report of IPCC
AR5	Fifth assessment report of IPCC
CC	Climate Change
CDPC	Climate Data Processing Centre
CMIP5	Coupled Model Intercomparison Project 5
DSSAT	Decision Support System for Agrotechnology Transfer
FAO	Food and Agriculture Organization of the United Nations
GCM	Global Climate Model/General Circulation Models
GHGs	Green House Gases
IAHS	International Association of Hydrological Sciences
IPCC	Intergovernmental Panel of Climate Change
NSE	NashSutcliffe model efficiency
PMD	Pakistan Meteorological Department
PUB	Prediction in Ungauged Basin
RCP	Representative Concentration Pathway
UNDP	United Nation Development Program
WAPDA	Water & Power Development Authority

Chapter 1

Introduction

1.1 General

Water is life, without water life cant be imagined. Water has an undeniable value on earth from the first minute of conception to the time of its birth. Water is one of the important elements of nature. Water has always been centered on the attention of science, philosophy, mythology, religion, and other grounds. Also, the fundamentals of popular culture have always been water [1]. Water is closely linked to health and explains the emergence of human culture for centuries. Heavily populated communities are built near rivers, without water there would have been no human civilization in fact life itself could not begin. Human civilization has historically flourished along rivers, lakes, and other major waterways.

Specifically, on the shores of the Mediterranean came the most important societies such as the Minoans, the ancient Greeks, the Phoenicians, the Egyptians, the Arabs, and the Romans. In Mesopotamia (Iraq) culture, the region developed along the Tigris and Euphrates rivers, the ancient Egyptian culture developed on the bank of Nile River, the ancient Indian culture is mainly inhibited along mighty rivers such as the Ganges [2]. The Indus civilization of Harappa and Mohenjo-Daro began along the Indus River (Pakistan) [3]. Ancient Chinese culture also began to surround the Yellow River and the coast of the country [2]. In ancient societies, people used surface water as a way to survive. They had established means to utilize surface water for drinking purposes, irrigation and other public uses. For which, they built irrigation canals, water mills, pipelines, and dams also established an aqueduct by building qanats [4]. Reservoirs serves well to irrigate the lands. Ancient irrigation ways still astonish current irrigation experts. In future civilizations, the climate change has major effect on planning and development of water resources [4].

1.2 Climate Change (An overview)

By the 18th century, industrial revolution had begun and from there it spread to other parts of the world [5]. At the advance of the industrial era, the oceanic coating of CO_2 led to the formation of sea acidification; the pH of the seawater above decreased by 0.1, which is accompanied by a 26% increase in acidity [5].

Industrial demand of the worlds energy consumption increased about 30 percent and contributed about 40 percent of all energy-related emissions. Steel, cement, iron, chemicals, petroleum products, and paper and aluminum production are mainly responsible for strongest carbon-emissions, which in return polluting the atmosphere. Industrial and agricultural development has shaped a climate change problem which is global warming; factors contributing to it are emissions of greenhouse gases (GHGs) and anthropogenic global warming (AGW) [5].

Human activities such as burning fossil fuels, natural gas, urbanization, agriculture, and land-use changes such as deforestation help increase in greenhouse gases (GHGs). Carbon dioxide, methane, and nitrous oxide accounting for 80%, 14%, and 6% of total GHG emissions respectively [6]. GHGs are good absorbers of heat radiation from the earth's surface. hence it acts as a blanket blocking the heat from escaping in to space, resulting in increase to temperature as the rate at which energy is derived from the Sun, and the degree to which it is lost in space determine the equilibrium temperature of the earth's climate. This energy is distributed worldwide by winds, currents, and other forms of natural phenomenon [6]. Climate change now has begun to severely impact life on earth. Around the world, seasons are changing drastically, where there are wild temperature fluctuations and constantly rising sea levels. Climate change is affecting the world especially the poorest countries who contribute least in carbon emissions but their people and habitats suffer the most adverse changes [6]. Emissions of anthropogenic greenhouse gases have increased since pre-industrial times but it become amplified due to the industrial revolution, largely driven by economic and population growth that has led to atmospheric concentration of carbon dioxide, methane and nitrous oxide [7]. Worldwide, the number of vehicles and refrigerators is increasing [7]. As the world's population continues to grow, governments and scientists are increasingly concerned about the prospects for sustainable development. Population growth with unintended consequences have a major impact on the global climate that links to the local land-use changes. Population growth is somehow responsible for the exploitation of groundwater resources, due to uneven distribution which cause scarcity of water is forcing people to migrate from their areas. Sudden climate change and soil erosion can lead to food shortages as climate change can adversely affect agriculture and vegetation. The local agricultural sector cannot produce enough food to fill the existing gaps. Growing water scarcity and the misuse and management of existing water resources pose significant threats to the sustainable development of various sectors, especially domestic, industrial, and agricultural. Future predictions of climate limits are uncertain. Lack of infrastructure amidst dangerous climate changes can lead to humanitarian problems where there is a strong possibility of more terrible and frequent floods and droughts [8].

1.3 Important Climate Parameters

In addition to hundreds of other climatic parameters, the most commonly considered parameters are temperature, precipitation, solar radiation, humidity, wind speed, evapotranspiration [9]. Rainfall is one of the most important variables to include in global models but it is a difficult endeavor to prepare rainfall data [10]. The traditional method is to measure rainfall by rainfall patterns, but the limited distribution of gauges makes it problematic to detect variations in weather, especially in mountainous areas where disturbances are high and data collection may require large amounts of rainfall measurements. The worldwide accessibility of satellite data provides an advantageous and cost-effective way to measure spatial rainfall in unequal pits [8]. These rainfall-based measurements can provide important information about rainfall, quantity, and distribution of rainfall [10].

The Observation based hydrological data are the basic necessity for effectual water management. Despite that, since data records are generally insufficient in length, extensiveness, quality, and spatial distribution, models are used to produce a time-series. Hydrological systems are still uncertain and some of these features are unidentified [12].

1.4 Global and Regional Weather Trends

Other models of atmospheric circulation predict that the dry area of the world can be drier and warmer and that global warming may melt eternal ice and snow. Climate change researchers are showing a tendency for harmful global warming effect on Pakistan. As a province heavily oppressed by water, Balochistan faces worse floods and droughts compared to other provinces in Pakistan [13].

This study has been carried out to focus not only on technical insight against the frightening problem of water resource shortage but to provide vital information to cope up with the present and upcoming challenges due to climate change effects on the availability and distribution of freshwater, which is one of the dire issues being faced by the people living in District Khuzdar (Balochistan). Institutional weaknesses have posed serious threats to long-term availability of water and increased the need for its effective distribution through water resource management.

1.5 Problem Statement & Research Motivation

Khuzdar is the third-largest city population wise having almost 0.8 million inhabitants and is area wise the second biggest district of Balochistan spreading over an area of 35,380 square Kilometers. The major part of population lives in rural areas of the district. Nearly 70 percent of the population has no access to pure drinking water. In Khuzdar city almost every household has a shortage of pure drinking water and people are obliged to drink contaminated and unhealthy water [14]. Farming and livestock are the main livelihoods of the rural population but in recent years due to persistent droughts both these professions have suffered considerably. As a result, the volume of unemployment and poverty has risen at an alarming level [14]. Thousands of cattle have died due to droughts. The information gathered in this research study is of dire importance for the policymakers of not only Khuzdar administration but in the general whole of the province. This study is intended to provide not only technical insight against the alarming issue of water resource shortage, destruction of natural habitat due to the said problem, and long-term sustainability of infrastructural projects but to provide essential information to cope with the present and upcoming challenges due to climate change effects.

Thus, the problem statement is as follows:

In recent years due to climate change, Khuzdar faced persistent droughts as well as heavy flash flood problems. Farming and livestock have suffered considerably. Thousands of cattle have died due to droughts. This situation is expected to be worsen under increasing demand of water usage in portable, agriculture and Livestock in the current climate change scenarios i.e., extreme floods and droughts. Climatic change can adversely affect agriculture and crops. On the other hand, hazardous flash flood in Balochistan province especially in district Khuzdar are reported in the Balochistan flood report [15] prepared by Pakistan Disaster Management Authority Balochistan. It is essential to analyze and mitigate the adverse effects of these climatic changes and explore a wider range of options for policymakers.

1.6 Objectives

The proposed research work aims

- The assessment of climatic changes precarious effects on the temporal distribution of water resources and suggests the remedial measures to cope with the issue.
- To enhance our understanding on the connection of natural and anthropogenically induced climate change and its effects for adaptation of mitigation response decisions.

1.7 Limitations of the Study

The limitations of this study are:

This study focuses on climate change impacts on the surface water of the selected basin. Investigation has done based on changes in climatic parameters (precipitation and temperature). Losses (such as infiltration, evaporation etc.) are not considered in this study. The study area is limited to the Mula river basin located in District Khuzdar. There are no specific arrangements available at selected study areas for measurement of discharge rate. The limited data was available of flow which is used in this study.

1.8 Thesis Outline

Chapter 01: This chapter is titled Introduction. It explains the background of the topic and its ancillary subtitles including climate change, research motivation, objectives, problem statement, and limitations of the study.

Chapter 02: This chapter gives a detailed review related to previous researches on climate change effects. It consists of a background of different methods and measuring techniques of climate change on surface water.

Chapter 03: This chapter provides an overview of the study area, data set, and methodology. It also includes the research methodology.

Chapter 04: This chapter covers the background, climate change effects on water resources. It also contains results of climatic factors (temperature, precipitation) on discharge, simulation, model scenarios, etc.

Chapter 5: This chapter is a summary of the research work. It consists of the conclusion and future recommendations

References: - It lists all references of literature studied.

Chapter 2

Literature Review

2.1 Background

Freshwater can be the most vital renewable resource on earth. Water is essential for food production, economic development, and even life sustainability. thats why major civilizations of the world developed along the rivers. The water cycle is strongly influenced by industrial transformation, release of greenhouse gases (GHGs) because of human activity. Industrial revolution started from 18th century and passed through different stages. Now the 5th stage of Industrial revolution has begun but the previous four stages contributed in the carbon dioxide emissions to a great extent. The GHGs has impacted the climate at its worst. Anthropogenic activities are formerly responsible for accelerating the negative impact of climate change. Rising sea levels, flood growth, and drought which will inevitably increase in the future in most parts of the world [5]. Unprecedented human growth rates have alarming environmental effects [6]. Economic costs are likely to be high and overall yields could be reduced, increasing the risk of poverty and hunger [6]. Various methods used by researchers and organizations to assess the effects of climate change on temperature and precipitation. Literature that is addressing climate change and is discussing different climatic parameters and models is being noted in this chapter particularly the effect of changing temperature and precipitation trends on surface water.

2.2 Water as a supply for Humans and Civilizations

2.2.1 Status of Water and its Development in Early Periods

Ariadne Tsambali's (2014) [1] study of "water and human civilization" explained the importance of water to humanity in the past. In early times, man needed fresh water to survive and began to live near rivers and lakes. The first civilizations have emerged on the lowlands of North Africa and Southwest Asia, where water was excessively available. In these areas, people are identified with the status of water and started to take advantage of this important resource. They enhanced their knowledge and also technological skills of the time and used it to the irrigation and drainage practices of their crops.

Yevjevich, Vujica (2009) [4] described the different methods used by humans for their survival in ancient times in his paper Water and civilization. In ancient times, it was not uncommon to grind grain into flour or to grind it into flour mills. The idea of harnessing the power of river water led to the development of water mills. They installed water wheel to use kinetic force of water to produce mechanical work[4]. Many times, the water would not be easily available and was needed to be carried out far from the source of water for the purpose to be used for drinking, hygiene and irrigation. Thus, for the need of drainage water canals and pipelines were first proposed and utilized; this obligation has led to further advances in water resource development technologies as the world is advancing towards modern age. Similarly, the difference of water availability periods when it was needed led to the construction of tanks [4].

From the earliest period, humans have built dams to contain water which later could be used when needed, as in these modern times dams are used to produce energy utilizing kinetic or potential energy of flowing or falling water [5] hence, gradually all sectors including development, conservation, defense, and water resource management were initiated [4].

2.2.2 Role of Water in Civilization Development

As human civilization marched from ancient times of Babylonia, Maya, Petra and Egyptian civilization which entered in the era of Hittite civilization forming powerful kingdoms like Greek, Roman, Chinese, Japanese and other empires the water resource management technologies have played vital role in humans development. Long aqueducts in the major cities of the ancient Mediterranean countries show their advancement in managing water resources, some of which serve the same purpose to this day. The emergence and rise of great civilizations in Egypt, Mesopotamia, and China were the results of excessive availability and use of water. The first human settlements, dating back to the fourth century, developed important technologies and projects for the use and distribution of water. there we find water projects that were built in the second millennium in Egypt, China, Persia, Egyptian civilization, the Mesopotamian civilization of the Tigris, and the Euphrates, Greek culture were rich in water resources [4].

Major source for drinking water in areas having drought seasons is rivers and lakes, as they are dependent on these resources they have to use means and methods to store water. Almost all great civilizations purposefully constructed conduits to benefit there residents, to supply them with essential water for their drinking, hygiene, plantation, irrigation, vegetation and cattle [4]. Extracting water from underground resources was done by means like digging qanats from the ancient times till this moment extracting and supplying water through underground resources has been a matter of great interest for experts and administrators All greatness of mighty civilizations lie in their skill of not only providing water to millions of people, but also draining dirty water off households and cities. For storage purposes, they dug basins, known as cisterns, in the earth and rock. The bottoms of these cisterns, made water-resistant by clay, which were covered with gravel to filter the water and eliminate remnants of vegetation and other impurities. by using filtration techniques, they made water drinkable [16].

After the rise of Islam as powerful Muslim governments and kingdoms emerged engineers of that time played an important role in improving water systems that led to agricultural revolution. They were able to transmit the course of rivers, built high dams, and also created artificial lakes and pools. They built galleries below rivers and flooded lands to protect their cities and villages. Like their predecessors they built embankments to protect their land from flooding. Construction of embankments helped them to resist floods for a longer period keeping safe their selves, property, cattle and food [17].

The populations of the ancient cities along the great Indian river used the natural river banks to protect themselves against flooding. Many things that people used in those times are still in use today one of which is taps. Today, piping is a common way to transfer and distribute water but grievously the lead pipes used in the United States of America in late 1800s polluted or say poisoned the water and called as lead poisoning which compromised with people health. The use of lead pipes for water distribution in buildings was one of the first disasters caused by water technology [3].

This incident led to further advancements in material and use of pipes to supply water to households. So, it was understood at a later date that pipes should be made of steel, stone, or plastic so as not to harvest polluted water [5]. There is a standpoint that water poisoning was also among the other factors that led to the fall of developed civilizations like the great Roman Empire. Many water flow systems inherited from past have thus developed the way for modern hydraulics, water engineering, and the development of hydro-resources [18].

Over the 16th century, Islamic civilizations from Spain to Oman are qualified in science and technology, especially hydrology. For the rapidly increasing population of cities like Crdoba, Damascus, Baghdad, Fez, and Marrakech required advance methods of water management to supply the population [17].

2.2.3 Role of Water in Agricultural Development

When men first learnt irrigation and started growing crops and vegetation almost 8000 years ago the importance of water heightened. The first farmers needed water to cultivate more land so food needs of society could manage. When the soil was cultivated, they realized that water was very important for the plants. Great rivers like the Nile, the Tigris, and the Euphrates flooded the land numerous times in a year but crops required water practically every day. The early man works on that and dug canals from the banks of the river. The water was transported where it was most needed. Digging was done by traditional means [16].

The irrigation canals are most important things to be considered, they should have a solid and continuous current to avoid absorption by the dry earth. The early men constructed canals having a slight slope for effective water flow plus he utilized stones and mud which delay the flow of water [16].

Legends are known for the irrigation projects of the Copais, Acheloos, and Alpheus regions, in prehistoric times in Greece [4]. From 1250 to 800 BC, a period of uncertainty followed by the first formal use of Athenian water resources in the interior of Pisistratus. From Solon, the legislature drafted appropriate rules relating to water management which prevented the opening of a well in the same place where there is some distance from another source [2].

In addition to that, water as a center of transmission, which closes the need for trade and commodity exchanges, has transformed that adequate human and economic progress [1].

2.3 Industrial Revolution and Climate Change

The Industrial Revolution which began in Britain in the 18th century and from there transcended to United States, in the 1830s and 40s and eventually reached the whole world. This is referred to as the first industrial revolution, separating it from the second phase of the revolution, in the late 19th to the early 20th century where in this Post-industrial Age of 21st century it has progressed much in the fields of material, mechanical, electrical, and automotive industries [5].

If we take a look at Industrial and Post-industrial Age of the 20th and 21st centuries this era developed modern technologies for sewage disposal, construction of dams and reservoirs, hydroelectric power plants, drainage, pollution control, irrigation, and river and canal flow. Here expansion of water sciences is witnessed in areas like space sciences and search of water beyond earths atmosphere. The operation of water resources mainly focuses on these areas of development, protection, control and conservation. From start to finish water resources management is no doubt a multidisciplinary approach where simple to complex goals are to be addressed [19].

Over the centuries and as the industrial revolution progressed, the use of freshwater varied, strengthened human activities, in contrast to this the developing modern world also appeared to threaten the quality of water. The surface water usage increased so the burden on lakes and rivers used for water supply elevated. Hype is seen in water usage for irrigation, hygiene, energy, agriculture, recreation, and industrial areas [7]. Before the industrial revolution began, the dynamic activity of the bio-geo-physical space has been able to compensate (cleanse itself) and balance with human activities and preserving water and its resources. However, the development of a modern production system, coupled with an increase in consumer demand and ascended industrial usage has strengthened the various activities that have disrupted the balance of natural water resources both above and below ground. Added to that it increased water pollution. Today, the worst forms of water pollution include chemical pollution, industrial waste, sewage and agricultural runoff, radiation pollution, oil pollution, and heat pollution. Within a few decades the situation is getting more severe, where the need for greater consolidation together with better living conditions regarding water availability and supply will be needed more. Due to which the improved water quality and the need to integrate water services is need of the hour this is to cope up with multiple challenges, especially in areas with worse water scarcity where extreme water shortage can harm life and life supplies critically [19].

Unfortunately, as the demand for drinking water gradually increases, the reserves that continue to be used are reduced. At the same time, quality and problems are threatened due to severe soil exploitation by crops. Therefore, groundwater, natural resources are strategic and therefore in need of special protection and management [4]. As water being most essential element of earths ecosystem helps balance and maintain life, our biosphere and environmental patterns. humans have gained tremendous power utilizing science and technology. This has increased influence of modern human over nature which was not enjoyed by ancient people on the scale that is witnessed today. Along with it the humanity as a whole has made changes to earth on such a scale that those alterations can clearly be seen from space. Human activities clearly impact the habitat and resources that it exploit which on a larger scale definitely change the natural course of things on global level, that too in a bad way [4].

The natural cycle of gases which consist our atmosphere is clearly disturbed as compared to pre-industrial times that is before 1750 to this day. Greenhouse gases (GHG) which are mainly carbon dioxide (CO_2), Methane (CH_4) and nitrous oxide (N_2O) in times between 1750 and 2011, the cumulative emissions of CO_2 in the atmosphere were 2040 310 $GtCO_2$ [20]. About 40% of these emissions remain available in the atmosphere (880 35 $GtCO_2$); the other part is either absorbed in the ground or sea by plants, organisms and soil. The amount that sea absorbs is about 30% of the anthropogenic CO_2 emitted, resulting in sea acidification that is increasing desert areas below the water. What is more alarming about the situation is that about half of the anthropogenic CO_2 emissions occurred in last 40 years. Which leaves no doubt that human activity in modern times is capable to produce tenfold more CO_2 content than the natural phenomenon could produce [20].

After the advent of industrial age, it was needed to develop technologies to effectively use water which can be comprised in these four categories which are water resource management, water conservation, risk management and protection of water resources. Water resource development means to build infrastructure to effectively contain, store, utilize and supply water. The infrastructures where hydroelectric power can be harnessed, building water pathways canals etc. Water conservation technologies which have a clear goal of reducing water loss either by evaporation, unnecessary losses when is being supplied to satisfy water demand. Water management technologies are meant to combat the negative effects of floods and the inevitable drought. Water protection meant protecting its territories from the increasing pollution caused by human hustle and bustle. Most important marvel of these technologies is the production of hydroelectric power generation which is running large metropolitans and industries. With the rapid increase of trade new market centers from where new cities and industries emerged. They too need effective flood protection, clean water, gaseous and hard waste disposal. New scientific discoveries, introduction of new materials and advanced technologies have redesign old standards and touched new heights in area of water resource management [5].

This post-industrial revolution era has also led to a significant increase in coal consumption. Coal was replaced by wood and other fuel sources because it was plentiful, efficient, and required less work to dig mine than cutting wood. Coal was also used to make steel, which was later used in production of machinery and equipment, as well as for the construction of ships and bridges. The Industrial Revolution also saw another significant development; the invention of engine, initially coal was main source to run the engines. Steam engines were used in transportation and power plants [5]. Growing industries and agriculture increased the rate of deforestation, causing the carbon dioxide and other carbon compounds stored in the trees to be released into the air, releasing heat in the process. Deforestation also leads to the loss of biodiversity. This can reduce plant and animal habitats and weaken the standard environment [5].

Urbanization on the other hand, brought us face to face with more complex challenges of overpopulation, decreasing living standards and ever-increasing demand of life supplies like water, food, residence, medicine etc. Despite the strains brought upon earths environment and inhabitants it is to be accepted that the Industrial Revolution brought forth period of strong economic development [19].

2.4 Population Growth Vs Water Shortage

Water resources in Pakistan are already under severe pressure and it is likely to become more frequent with the rapid increase in population. In the paper "Monitoring and Measuring Surface Water in Semi-Arid Environment Using Satellite Data: A Case Study of Karachi" the author mentioned the Contrary connection between Population growth and per capita water availability in Pakistan since 1951 [21]. In Figure 2.1 shows the population in millions and per capita water availability in m3 indicating decreasing trend from 1951 to 2025.

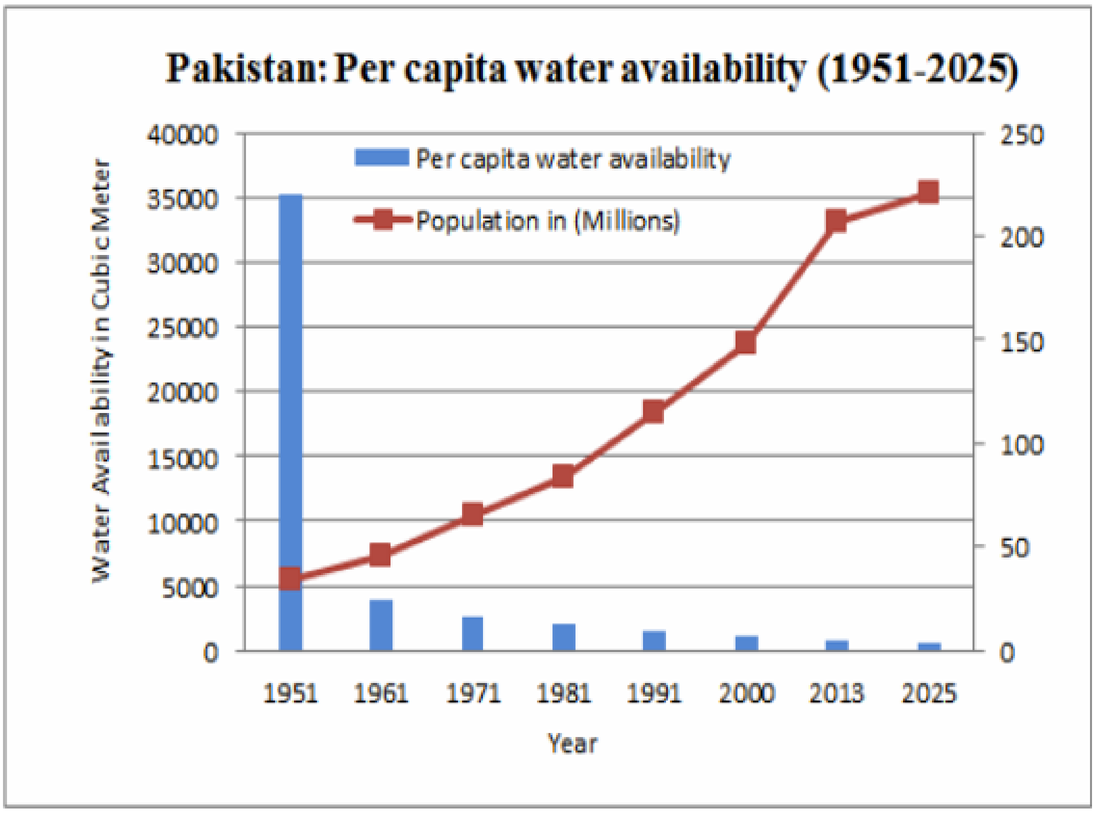


FIGURE 2.1: Trend of Population Increase and Per capita Water Availability in Pakistan (After [21])

Water shortage is an undeniable reality in Pakistan but the problem has intensified due to further population concentration at a specific space, contributing to is exploitation of water and its reservoirs, ineffective water management, lack of dams, low public interest and least previous surfaces. The population concentration on a specific place made the infiltration or recharging the ground water level even more difficult. The study on Rainwater Harvesting-an alternative water supply in the Future for Pakistan the author suggested “roof size is 220 m^2 for single family (4 persons) and 400 m^2 for two family units (8 persons) to meet 45% needs of non-potable water demands in areas with appreciable rainfall. On the other hand, for areas with lesser rainfall, the minimum suggested size is 280 m^2 for single family and 400 m^2 for two family units”. The suggestion will support saving of 45% of drinkable water [22].

This rapid urbanization brought great challenges to overcrowded cities. They are suffering from pollution, sanitation, and a lack of clean drinking water. The benefits of city life created the need for many products, such as clothing and non-essential items that believed to improve quality of life. New technologies were developed to meet the growing demand for these products, leading to early industrialization. Soon, people were moving to cities in large numbers to find work as factory workers. Industrialization and mass production accelerated progress and had an impact on our environment especially water cycle [23].

In a report by Vorosmarty et al., [24] the contribution to climate change, human development, and their integration into the future of the world's water resources discussed. They introduced a high level of water use and availability, assessing the vulnerability of water resources to future climate change, population growth and migration, and industrial development between 1985 and 2025. They used the topology of river systems to control the sustainable water supply and its use by people.

The water table (annual and surface water table) collected as a river flow (Q) where local people collect it. They have also mapped the distribution of water and water consumption. Water consumption is calculated each year in which domestic and industrial sectors (DI/Q), irrigated agriculture (A/Q), and their combination (DIA/Q) are considered. It will help to specify the area of water stress and to determine the degree to which people interact with a sustainable water supply [24].

Change of Population density and economic development will determine the future relationship on global level between water supply and demand on a considerably greater scale than in the present scenario. To understand a larger picture of future water hazards, the consideration of climate change and development relationship, land and groundwater, water engineering, and human systems, including social cohesion in water scarcity is essential [24].

Archer et al., [25] argued that climate change has threat to food security and the environment. Pakistan's water resources are already at risk and it will become more grave with the change in the population [26].

2.5 Balochistan, Present Situation of Water Resources Particularly Surface Water

In planning long-term national resource strategies, it is important to balance these outcomes with local and time-based water resource allocation. The importance of clean water in our lives is well known and can be seen in the international context (e.g., Agenda 21, World Water Fora, Millennium Ecosystem Assessment, and World Water Development Report). Freshwater is essential to almost all human activities. As Balochistan suffers from floods and droughts and is the most water-stressed province as compared to other provinces of Pakistan [27].

Balochistan is a barren region with low rainfall and frequent droughts. Water scarcity is one of the biggest problems in Balochistan. Although, geographically the largest province of Pakistan, Balochistan suffers from severe water shortages. “Balochistan struggling with population growth and increasing need for economic development consequently demand uninterrupted supply of water while not having large water reservoirs (rivers, lakes) have availability of merely 9% groundwater resources”[28]. To meet the supply of water demand deep groundwater is being extracted through drilling tube wells up to a depth of 300 meters due to which underground water table is dropping on alarming rate of 2-6 meters per annum. The lowering water table and depletion of groundwater is a critical situation in Balochistan basin and is matter of great concern [13].

The major input of fresh water in reservoirs of the province is rainfall. The monsoon wind brings summer rain, and western disturbances cause winter precipitation in the province. Westerly disturbance usually extends east across the higher latitudes of Balochistan, so regions are at 34-36 in the north receive the heaviest rainfall. This western disturbance produces secondary rainfall in low-lying areas in the province [29].

Balochistan receives an annual rainfall of 200 to 350 mm. This annual amount may include snow in winter and heavy rains in summer [30]. The Government of Balochistan will to address a difficult task of not only preserving existing water resources but at the same time building an effective water resource management system so that present resources could be utilized more efficiently. The climate change has certainly disturbed the course of rains where future of areas with below average rainfall seems uncertain. Hazards of climate change also include floods and droughts calling for precautionary measures taken according climate change analysis. It is very important to ensure infrastructural development due to the possibility of severe and catastrophic floods [31].

Oxfam has researched Climate Change, Poverty and Environmental Crisis in Disaster-prone areas of Pakistan in three districts located in the Punjab, Sindh, and Balochistan provinces. Studies have shown an increase in the severity of extreme weather. Extreme rainfall in coastal areas, severe storms, severe flooding in flood-prone areas near the Indus, and severe drought in the arid areas of Khuzdar (Balochistan) [31]. According to the Human Development Report 20072008 by the United Nations Development Program, people in rural areas are particularly vulnerable to climate change., as it directly affects the natural resources on which their livelihood depends [32].

Population growth increases in demand for basic resources and when it comes to limited resources and lack of proper management system it can be difficult to ensure the availability of limited resources, particularly freshwater to everyone. Due to population growth, an uneven distribution of surface water resources has been observed. Increasing water shortages in arid regions such as Balochistan are now a well-known fact. With surface water being distributed unevenly, groundwater resources are also widely depleted. Decreased groundwater levels and depletion of groundwater resources have forced communities to relocate[33]. This situation is expected to worsen under the current climate change context. Sudden weather changes and soil erosion can lead to food shortages as climate change can adversely affect agriculture and vegetation [34].

World Commission on Environment and Development has put it on record that, about 80 countries with 40% of the world's population already suffer from life-threatening water dearth. Let alone the fact even developed countries are now facing sparseness of hydro resources the example of South Africa is fearsome which is close to day zero. Descending water availability over and above poor management of existing water resources forecast uncertain future. Temperatures are expected to elevate by-and-by with respect to time in the focused area but the results infer that it may create more opportunities owing to inflated water availableness and decreased cold temperature pressures [32]. Settlement of the influence of climate change has on water cycle is key to management and planning of water means. Eventually all regions of the world will go through the negative affect of climate change on water resources and the attainability of freshwater [35]. Due to amplifying drive, a large portion of population are at risk of water and life supply shortages following rising sea levels, floods, and droughts in coming times. Global warming and climate change is one of the upmost call-in question for the development. The Intergovernmental Committee on Climate Change (IPCC, 2007), has consistently displayed that climate change is the result of anthropogenic activities. The Intergovernmental Panel on Climate Change (IPCC) also stated that the poorest communities and nations will get worst out of climate change upsets [36].

Furthermore, Batchelor and Martinez's [37] working Papers output from the analysis show that the number and depth of agricultural wells have increased significantly over the past three decades and that this practice has a negative impact on domestic water supply.

2.6 Predictions in Data-Scarce Regions

The International Association of Hydrological Sciences (IAHS) has launched a campaign in 2003 to inquire onto the solution for Prediction in Ungauged Basin (PUB). This endeavor aimed at insight into the climate and landscape that constrains water processes on all measures which will improve the faculty to forecast the flow of water in ungauged basins to foretell uncertainty. An ungauged basin is widely described as a basin that does not have sufficient records to observe hydrological observations. Some of these variables are rainfall, runoff, and erosion rates.

PUB methods are listed as follows [38]

1. Observe on site: this method being costly is also not related to the PUB.
2. Extrapolate from gauged basins (regionalization): the heterogeneity of land faade and absence of nearby similar gauged basins bring about aberrations which induce limitations to this method.
3. Observe by remote sensing: in this method satellites and their labors can be utilized. The issue with this method is the grainy resolution of any of those products and onsite validation of the data received.
4. Hydrological model simulation: absence of climatic intake and dearth of basic data for validation are some of the restraints for this method.
5. Integrated meteorological and hydrological model: parameter identifiability and other such factors confine this method.

Foreseeing future flow fluctuations and changes in ungauged basins remains a mighty task due to a deficit of data [39]. K. C Abbaspour et al., [40] discussed in their research that fleeting economic progress in eastern European countries and uncertainty about attainment of freshwater poses threats for water management. At the same time, climate change may bring a new height of uncertainty to obtainability of clean water. In this article, they analyzed problems with data availability, large-scale distribution of high-density models, as well as procedures for interpreting model measurement and uncertainty analysis. Determining the trend of climate parameters is a challenging task as many other factors can be involved such as land-use changes, changes in water infrastructure, etc. [41]. The main focus of the investigators working on the ungauged basins is to understand the ungauged basin the expected behavior, which should or should not happen in a particular ungauged reservoir [38].

2.7 Climate Change

The "Fifth Assessment Report (AR5) [20] of the Intergovernmental Panel on Climate Change (IPCC)" is the most detailed evaluation in the scientific field on climate change since 2007 when the Fourth Assessment Report (AR4)[42] was published. AR5 was published in four volumes (September 2013 and November 2014). It is compiled by comprehensive reports prepared for a wide range of Working Groups (I contributing to the body science of climate change, II contributes to adaptability and vulnerability, and III contributes to the mitigation of climate change effects). The analysis of the socio-economic characteristic of climate change, and its effect for sustainable development, is emphasized in this new report.

It is anticipated that climate change will readily take on rainfall and evapotranspiration patterns [43] accordingly disturb the factors as availability of water locally, river discharge, and periodic water availability [44]. Worldwide rush for freshwater has amplified as a result of numerous factors such as growth in population, water pollution, economic progress, land use, and climate change, all of which reduce water availability under uncertain forthcoming conditions [45].

Social elements combining with environmental factors including agriculture, tourism, and conservation considering the quality and quantity of water resources, so moves to assimilate to the hydro sector is directly affixed to policies in various sectors [46].

Climate change is anticipated to strengthen the worldwide water cycle, takes one to results on the attainability of water resources for domestic, industrial and agricultural use [47]. The absorption of greenhouse gases (GHGs), aerosols, volcanic activity, and solar radiation are the main factors succumb to drastic changes in the past 2,000 years [48]. The major GHGs associated with climate change is carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These GHGs come from both natural resources (e.g., volcanic eruptions and wildfires) as well as human-influenced sources (e.g., mineral oil burning and deforestation)[20].

In IPCC [49] article it is expressed that many ecosystems are impacted by climate change in multiple regions, especially by global warming. By the middle of the century, river water levels and water availability are expected to increase by 10-40% in the highlands and other tropical areas and to decrease by 10-30% in some arid regions in the middle of the latitudes and in the tropics, some of which are currently in the tropics. Drought-affected areas are likely to grow at a hasty rate. Heavy rain events, which may occur several times, will increase the risk of flash flooding.

Nearly all regions of the world are expected to experience the devastating effects of climate change on freshwater and its resources. The vehemence and characteristics of the distress, however, can vary greatly from region to region. Some regions may experience water shortages. Together with the growing demand, this is likely to result in a surprising increase in the number of people at risk of water scarcity. Rising sea levels in densely populated coastal regions can, on the other hand, threaten the lives and livelihoods of millions of people [41].

Adding to austerity recurring flash floods and droughts will inevitably pop up in much of the world. Inflation is likely to raise and overall yields could be minimized, compounding to the risk of poverty and hunger. In the long-term strategic planning of the country's aqua resources in the face of the intensifying repercussions of climate change, these impacts must be kept in watch [42].

CMIP3 and CMIP5 scenarios [50] are generally used for future climate projections. The Special Report on Emission Scenarios (SRES) scenarios are named as (A1, A2, B1, and B2) and the Representative Concentration Pathway (RCP) scenarios are simply showing the change in radiative forcing (from +2.6 to +8.5 watts per square meter) that results by 2100. The older SRES scenarios are slightly higher besides the RCP 2.6 scenario is much lower than any SRES scenario because it includes the option of using policies to achieve net negative carbon dioxide emissions before end of century, while SRES scenarios do not.

2.8 Climate Change and Water Resources

According to the Germanwatch Global Climate Risk Index [51], Pakistan is at 5th spot on the list of countries most vulnerable to climate change. In the last half-decade, Pakistan has experienced devastating floods by and large every year, and the heatwave of 2015 in Karachi resulted in 1200 deaths. Although the trend is in line with global trends except for it will leave Pakistan hard-bitten for water resources.

The hydrological cycle relies on a change in atmospheric temperature and radiation balance. Increase in global warming is the clear indication of the change in climate systems in recent decades. Some of the evidence includes observations of an increase in global warming, melting glaciers and maximized evapotranspiration, and rising sea levels [42]. To evaluate hydrological based changes emerging from climate change, long-term observed data are needed to create basic settings and perceive if a little variation befall over time [52]. Bates et al., [53] argued in their book that Observational records and climate forecasts provide ample evidence that clean water resources are vulnerable and have a profound impact on climate change. Gadiwala and Burke [54] examined previous changes in climate patterns in various regions of Pakistan and computed future climate change that will affect water resources, affecting the ecosystem, health, food security, and sustainable water resources in the country. Trend analysis and variability analysis have been applied to meteorological data for the period 1961-2010. The study showed an increase of 0.66 degrees centigrade in temperatures and a heavy and intense trend of 106mm rainfall over the past 110 years that increased the need for food and water supply in the southern part of the country. This increasing temperature of 0.06 degrees centigrade over ten years accelerates the water cycle and evapotranspiration processes. The trend of atmospheric pressure also showed an increasing trend of 0.96mm per anum in the water cycle. Extreme weather conditions that cause droughts and floods indicate a change in the climate. Pakistan must combat water shortages by improving existing water dams and building new dams, regulating river water flow, and adopting alternative water conservation measures to manage food and water demand.

2.9 Summary

- Water is essential for the survival of life. The early civilizations established their communities along the river banks because they needed that not only for drinking but the agricultural demands of the area.

- Industrial revolution has begun from 18th century and continuous through different stages. The 5th stage of Industrial revolution contributed to carbon dioxide emission but the previous four stages also Influenced in the carbon dioxide emissions to a great extent. The GHGs has impacted the climate at its worst.

- Population density immensely effected the water storage and supply hence it led to water shortage. Population concentration has increased the water demand and land utilization resulted water storage badly.

- Water scarcity is one of the supreme challenges in Balochistan. The climate change consequences are uncertain on available water resources. Extreme event i.e., unforeseen and frequent floods and droughts are expected in the region. Lack of infrastructure make population and other life resources prone to calamities on account of these mishaps.

- Predicting future runoff in ungauged basin is a major challenge and it requires additional efforts to minimize the uncertainty.

- According to AR4 and AR5 report of IPCC, the climate change affect the rainfall pattern and it is directly disturbing the local water availability, water extraction, river discharge etc.

Chapter 3

Study Area and Methodology

3.1 Background

Water is a cardinal and scarce resource regarding sustained economic development. Rainfall pattern in district Khuzdar has become very erratic having average annual precipitation is around 200 mm but is unevenly distributed [28]. Population growth increases in the demand for basic resources especially water for drinking and hygiene. With minimal and unevenly distributed surface water, groundwater resources have also been extensively exploited, making it difficult to ensure freshwater availability to everyone. Agriculture is the major economic activity followed by livestock and farming in district Khuzdar. In khuzdar the main source of irrigation mostly depends on Tube wells and area irrigated from different other sources are Canals, wells, karezes/springs. Sudden climate and soil changes can adversely affect agriculture and crops which subsequently can lead to food shortages. The extreme variability in seasonal rainfall directly affects river flows, which vary considerably during the Rabi and the Kharif seasons. Mula river has an ungauged basin, is broadly defined as a basin without adequate records of hydrological observations. This creates an inability to compute the runoff at appropriate temporal scales. For this study, the variables of climatic data are precipitation, maximum temperature, minimum temperature. The study area, data collection, and methodology are discussed in this chapter.

3.2 Study Area

The study area as shown in figure 3.1 (a) and (b) below is district Khuzdar and Mula river basin. It lies in the water scarce province of Pakistan i.e., Balochistan. Balochistan is an arid region characterized by low rainfall and frequent dry spells and persistent droughts. The scarcity of water is one of the most critical issues of Balochistan. The increase in population and demand for economic development has resulted in an indiscriminate abstraction of groundwater, which is only 9% of the total water resource available in Balochistan [55]. In Balochistan, monsoon winds bring summer rainfall, whereas westerly disturbances cause winter precipitation in the province. Westerly disturbances tend to travel east across the higher latitudes of the Balochistan so that regions that are at 3436^o north receive maximum rainfall. These westerly disturbances generate secondary precipitation in the lower areas of the province [56]. Balochistan receives 200 to 350 mm of annual precipitation. This annual amount may include snow in the winter and heavy rains in the summer [30].

The geographical area of Khuzdar around 35,380 Square kilometers (3538000 ha). It is located between latitudes $25^o$and 28 North, and longitudes $65^o$and 67^o East. The district is located in the center of Balochistan, sharing its boundaries in the east with Sindh Province via Jhal Magsi, while Awaran and Washuk Districts are in the west. Lasbela is in the south and Kalat in the north. Khuzdar city is situated on the National Highway (N25) previously known as Regional Cooperation Development Highway that links Pakistan with Iran and Turkey.

The district is subdivided into four tehsils: Khuzdar, Zehri, Naal and Wadh. Khuzdar city's elevation is about 1,237 meters above main sea level (MSL).

Khuzdar is located in the arid zone. It receives annual rainfall less than 200 mm on average and is thus indicate a dry/arid district. Khuzdar's 30% West receives about average annual rainfall between 90 to 200 mm. Minimum temperature varies from 7-17 ^oC and the maximum temperature from 22.5-33.5 ^oC. District's 70% part receives average annual rainfall, varies from 180 mm in the south to 400 mm in the north [57]. The average minimum temperature varies from 14-19 ^oC

and the maximum temperature varies from 26-35.5 °C. Climate change is expected to have different impacts on rainfall and temperature patterns across regions and consequently on the temporal distributions of the various components of water resources. Hence farmers dependent on rainfall for growing crops are low, which deepens their search for a more reliable water source to secure irrigation to ensure high crop yields.

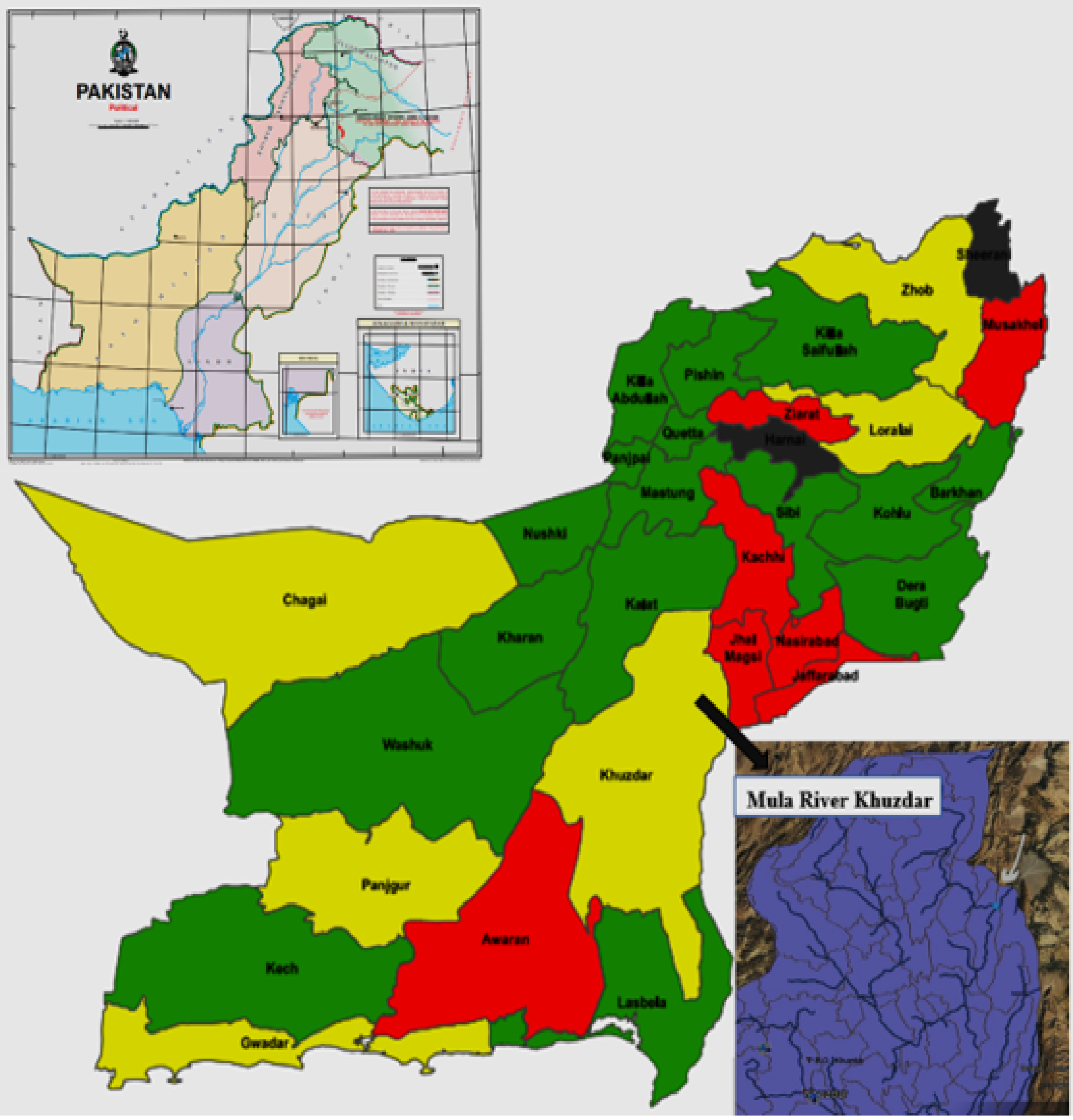


FIGURE 3.1: (a) Location Map of Khuzdar district (Source: [58] and [59])

According to the Agricultural Statistics 2008-09 [19], the Government of Balochistan has divided irrigation water into four classes as shown in Table 3.1 below It shows that the source of irrigation mostly depends on Tube wells about 57.94%. And area irrigated from different other sources are Canals, wells, karezes/springs.

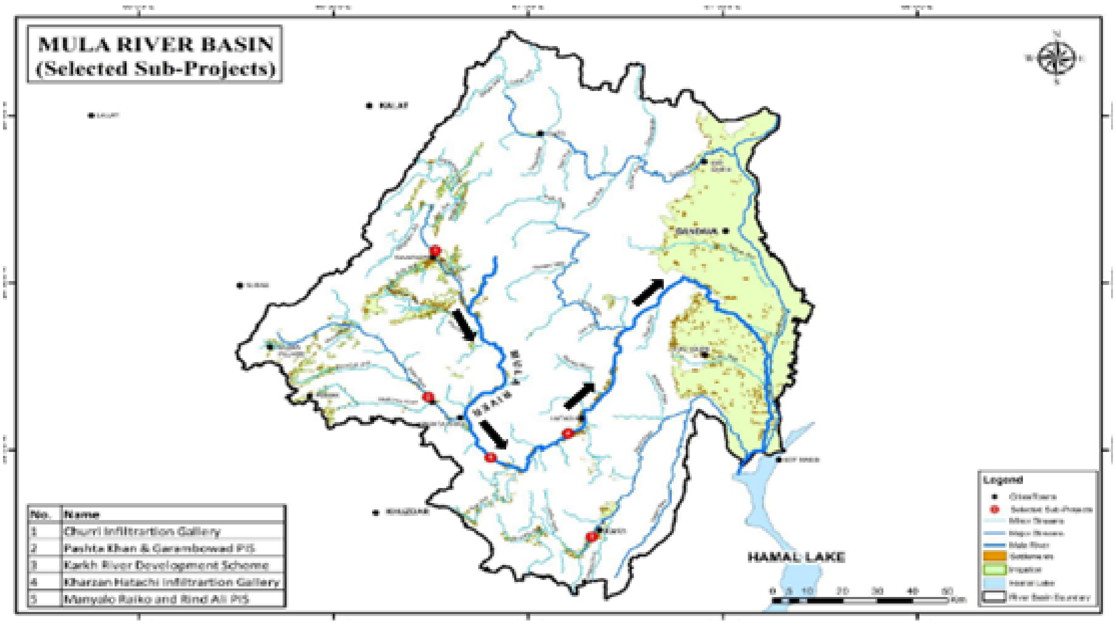


Figure 3.2: (b) Location Map of Mula River Basin in District Khuzdar Balochistan (After [13])

Table 3.1: Type of source and Irrigation area (Agricultural Statistics 2008-09)

Source	**Irrigation area (%)**	**Cultivation Area (ha)**
Tube wells	57.94%	69,575 hectares
Wells	33.07%	23,010 hectares
Canals	8.62%	6,000 hectares
Karezes (kanats)/Springs	0.59%	408 hectares

Khuzdar valley has two cropping seasons: Rabi and Kharif. Khuzdar falls in the temperate-ecological zone bearing a total potential agricultural area approximately 33.8% of the total geographical area of District Khuzdar [60]. According to land utilization Statistics of Balochistan 2013-14 [61] as shown in Table 3.2, From the total geographical area of the District Khuzdar, available for crop cultivation is not as much of cultivation land. The ratio of cropping intensity decreased during both Rabi and Kharif seasons between 2004-05 and 2008-09, this most likely reflects the non-availability of irrigation water. As shown in Table 3.3 the dependence on tube wells/boreholes and dug wells are high in percentage, which is affecting groundwater balance drastically.

A household survey conducted in 2010, has shown that Khuzdar's 74% population mainly depend on groundwater resource [61], of which, protected dug wells (33%) constitutes major source followed by tube wells or boreholes (20%) and piped

Table 3.2: Land utilization Statistics of Balochistan 2013-14

Total Geographical area (ha)	**Total Reported area (ha)**	**Irrigation method**	**Cultivated Area (ha)**	**Un-cultivated (ha)**
3538000	3304749	Traditional and modern technique	134414	3170335

Table 3.3: Improved and Un-Improved Sources of Irrigation

Improved Sources in Khuzdar	**73.9%**	**Un-Improved Sources**	**26.1%**
Piped water	20		
Protected dug well	33	Unprotected dug well	23
Tube well/boreholes	20	Surface Water (River, canal or stream)	0.1
Rainwater collection	0.2	Tanker truck	0.2
Filter plant	0.1	Cart with small tanker/ drum	0.1
Protected spring	1.1	Unprotected Spring	2.2
Public standpipe or tape	0.2		

water (20%). Only 1% use minor improved surface water sources i.e., protected springs. Major unimproved groundwater sources are unprotected dug wells (23%) and unprotected surface water springs (2%). Khuzdar has an estimated population of 802,207 (2017). Annual Population growth rate was 3.73% [61]. The district consists of a plateau mostly comprised of hilly terrain, consisting of numerous ridges and valleys. Jhalawan, Moda, Pab, and Kirthar. Mula, Mosina, Nal, and Kolachi are the main rivers in the district. The Mula river (Nari Basin) was selected for this study to analyze the effect of climate change on the Flow of the river. Mula River originates from peaks of Herboi Mountains in Kalat district. It carves its course through hilly terrain and runs through plains of Jhal Magsi till it drains out into Hammal Lake at Shambani. The total length of the Mula River is 301 km and elevation ranges between 2,500 m to 47 m from head to tail. The river basin covers 15,082 km2. Mula river basin has adjacent boundaries of the Kachhi river basin in the north and east, the Gaj river basin in the south, and Hingol and Pishin-Lora river basins in the west. The annual water availability at 50% probability in the Mula river basin is around 305 Million Cubic Meter (MCM).

3.3 Methodology

The methodology adopted in this study is shown in figure 3.2. The stages indicated in figure 3.2 are further elaborated in following sections.

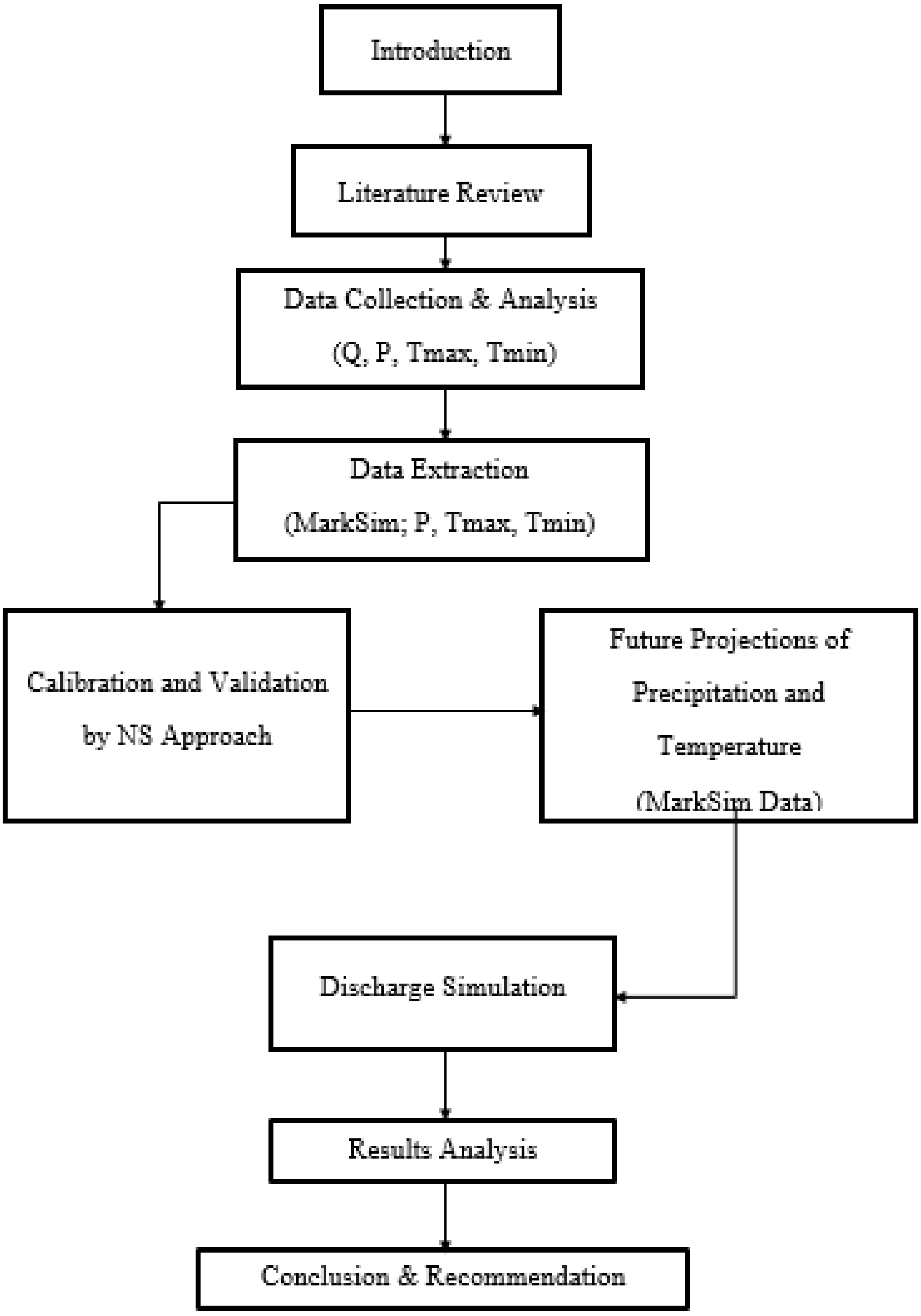


Figure 3.3: Flow chart of Methodology

3.4 Data Collection and Analysis

3.4.1 Discharge Data

No historical flow data was available for district Khuzdar due to absence of flow measurement mechanism. WAPDA started measurement of flow for 2008 onwards. After a great effort, only data from 2008 to 2015 was made available through an official of WAPDA.

The maximum, minimum and average daily discharge data from 2008 to 2015 are shown in Table 3.3 in which the maximum daily discharge varies from 10.83 (m^3/s) to 168.4 (m^3/s), minimum daily discharge varies from 0.083 (m3/s) to 3.078 (m^3/s) and average daily discharge varies from 5.457 (m^3/s) to 85.939 (m^3/s).

TABLE 3.4: Maximum, Minimum and Average Discharge Data from 2008 to 2015

Year	**Maximum Discharge (m^3/s)**	**Minimum Discharge (m^3/s)**	**Average Discharge (m^3/s)**
2008	10.83	0.083	5.457
2009	13.72	3.505	8.613
2010	21.65	3.163	12.407
2011	22.81	1.158	11.984
2012	17.47	3.249	10.36
2013	21.06	3.708	12.384
2014	15.45	3.391	9.421
2015	168.4	3.477	85.939

3.4.2 Meteorological Data

For average temperature and precipitation data, Climate Data Processing Centre (CDPC) Karachi of Pakistan Meteorological department (PMD) was approached through letter from Civil Engineering department CUST. The said department provided data of Temperature and Precipitation from 1986 to 2016.

The data included daily Maximum, Minimum temperatures and daily precipitation records. Since, flow data spanned from 2008 to 2015, therefore, this study utilized

Temperature and Precipitation data over the same period i.e., 2008 to 2015. The maximum, minimum and average daily temperature data from 2008 to 2015 are shown in Table 3.4 in which the maximum daily temperature varies from 41.5 (^oC)to 43.5 (^oC) minimum daily temperature varies from -4.5 (^oC) to 2 (^oC) and average daily temperature varies from 18.5 (^oC)to 22 (^oC).

TABLE 3.5: Maximum, Minimum and Average Temperature Data from 2008 to 2015

Year	**Maximum Temperature** (^oC)	**Minimum Temperature** (^oC)	**Average Temperature** (^oC)
2008	41.5	-4.5	18.5
2009	42	2	22
2010	42.5	-2.5	20
2011	42	-1.5	20.25
2012	41.5	-1.5	20
2013	41.5	-3.5	19
2014	43.5	-2.5	20.5
2015	40	1.5	20.75

The maximum, minimum and average precipitation daily data from 2008 to 2015 are shown in Table 3.5 in which the maximum daily precipitation varies from 17.7 (mm) to 60.4 (mm), minimum daily precipitation varies from 0.1 (mm) to 1.1 (mm) and average daily precipitation varies from 9.40 (mm) to 30.70 (mm).

TABLE 3.6: Maximum, Minimum and Average Precipitation Data from 2008 to 2015

Year	**Maximum Precipitation (mm)**	**Minimum Precipitation (mm)**	**Average Precipitation (mm)**
2008	60.4	1	30.7
2009	27	1	14
2010	19.3	0.1	9.7
2011	32.8	0.2	16.5
2012	24.6	0.2	12.4
2013	45.2	0.2	22.7
2014	40	1	20.5
2015	17.7	1.1	9.4

3.4.3 Analysis of Flow Data

The flow data which was obtained from the concerned department is shown in Table 3.6. In this Table the value mentioned as ”H.F” means High Flood conditions. To find the flow of missing data series value, methods like, interpolation or curve fitting could be applied. But in case of data with many missing values, these methods are not adoptable.

Table 3.7: Flow Data of River Mula Khuzdar mentioned Highest Flood

Year Days	**2010 (Aug)**	**2011 (Sep)**	**2012 (AUG)**	**2012 (SEP)**	**2013 (AUG)**	**2014 (SEP)**
1.	4.203	6.835	3.622	6.376	H.F	**4.944**
2.	H.F	H.F	3.491	6.112	H.F	H.F
3.	H.F	H.F	3.417	6.994	H.F	15.45
4.	5.101	16.46	3.438	6.534	H.F	7.973
5.	4.582	9.06	3.249	H.F	H.F	6.62
6.	4.167	H.F	H.F	H.F	H.F	5.403
7.	4.088	H.F	H.F	H.F	H.F	4.678
8.	H.F	8.36	10.26	H.F	H.F	4.285
9.	H.F	3.26	6.644	H.F	H.F	4.179
10.	H.F	H.F	6.152	H.F	H.F	4.19
11.	H.F	H.F	5.561	H.F	H.F	4.132
12.	9.066	H.F	5.115	H.F	21.06	4.115
13.	5.521	H.F	5.296	H.F	16.91	4.243
14.	4.582	H.F	5.213	H.F	14.69	4.339
15.	4.104	H.F	5.116	12.56	12.55	4.236
16.	4.088	H.F	H.F	11.66	-1	4.105
17.	4.124	H.F	H.F	17.47	17.54	4.027
18.	4.258	H.F	8.79	15.61	8.935	3.948
19.	4.396	7.539	5.789	13.32	7.443	3.985
20.	4.434	5.744	5.391	H.F	6.787	3.929
21.	4.287	5.742	4.938	13.63	7.183	3.93
22.	4.339	6.164	4.565	12.4	6.409	4.148
23.	4.392	4.736	4.346	12.18	5.727	4.023
24.	H.F	3.865	H.F	11.5	5.087	4.105
25.	H.F	4.809	H.F	7.693	4.972	4.058
26.	19.3	4.005	10.77	7.472	4.928	4.14
27.	9.822	H.F	H.F	7.248	4.877	4.157
28.	5.681	H.F	H.F	7.26	4.957	4.175
29.	5.407	14.13	H.F	6.337	4.869	4.259
30.	4.988	7.208	8.966	6.41	4.983	4.211
31.	4.728	-1	6.035	-1	4.886	-1

So, the missing value is determined as an average value of other known values in a particular month e.g., an average value of 5.637 cusecs is considered in 2010 august month to fill missing values. A sample table showing filling of missing values is given in Table 3.7.

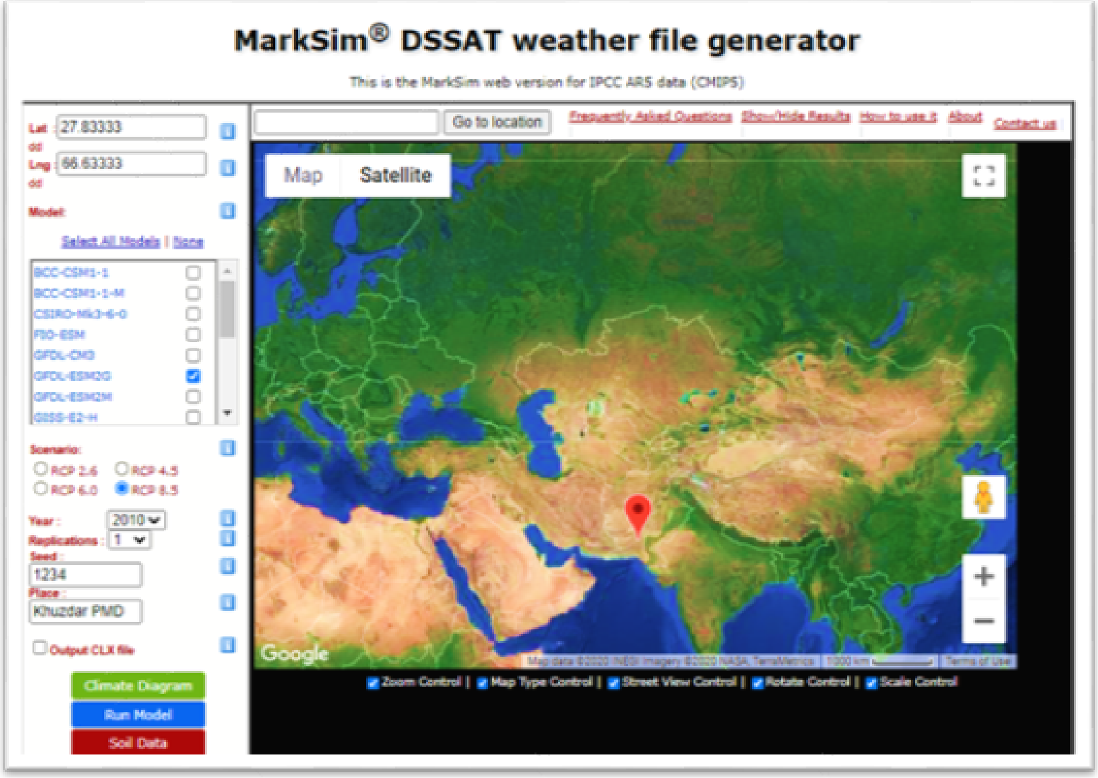
Table 3.8: Calculated Flow Data at the place of Highest Flood of River Mula Khuzdar

Year Days	**2010 (Aug)**	**2011 (Sep)**	**2012 (AUG)**	**2012 (SEP)**	**2013 (AUG)**	**2014 (SEP)**
1.	4.203	6.835	3.622	6.376	8.483	4.944
2.	5.637	7.194	3.491	6.112	8.483	4.827
3.	5.637	7.194	3.417	6.994	8.483	15.45
4.	5.101	16.46	3.438	6.534	8.483	7.973
5.	4.582	9.06	3.249	9.935	8.483	6.62
6.	4.167	7.194	5.735	9.935	8.483	5.403
7.	4.088	7.194	5.735	9.935	8.483	4.678
8.	5.637	8.36	10.26	9.935	8.483	4.285
9.	5.637	3.26	6.644	9.935	8.483	4.179
10.	5.637	7.194	6.152	9.935	8.483	4.19
11.	5.637	7.194	5.561	9.935	8.483	4.132
12.	9.066	7.194	5.115	9.935	21.06	4.115
13.	5.521	7.194	5.296	9.935	16.91	4.243
14.	4.582	7.194	5.213	9.935	14.69	4.339
15.	4.104	7.194	5.116	12.56	12.55	4.236
16.	4.088	7.194	5.735	11.66	4.869	4.105
17.	4.124	7.194	5.735	17.47	17.54	4.027
18.	4.258	7.194	8.79	15.61	8.935	3.948
19.	4.396	7.539	5.789	13.32	7.443	3.985
20.	4.434	5.744	5.391	9.935	6.787	3.929
21.	4.287	5.742	4.938	13.63	7.183	3.93
22.	4.339	6.164	4.565	12.4	6.409	4.148
23.	4.392	4.736	4.346	12.18	5.727	4.023
24.	5.637	3.865	5.735	11.5	5.087	4.105
25.	5.637	4.809	5.735	7.693	4.972	4.058
26.	**19.3**	4.005	10.77	7.472	4.928	4.14
27.	9.822	7.194	5.735	7.248	4.877	4.157
28.	5.681	7.194	5.735	7.26	4.957	4.175
29.	5.407	14.13	5.735	6.337	4.869	4.259
30.	4.988	7.208	8.966	6.41	4.983	4.211
31.	4.203	-1	6.035	-1	4.886	-1
Avg.	**5.637**	**7.194**	**5.735**	**9.935**	**8.483**	**4.827**

3.5 Data Extraction

3.5.1 Temperature and Precipitation Data Extraction from MarkSim

MarkSim is a web version of IPCC AR5 (CMIP5) data. The module, called MarkSimGCM, is freely available at http://gismap.ciat.cgiar.org/MarkSimGCM/. The user selects a location (the system will work anywhere in the world where WorldClim has normal weather conditions) and then selects one of the GCMs out of 17, and a scenario out of RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 and then selects the year e.g., select 2010 to start extraction of daily weather data (MarkSim data available from 2010 onwards). MarkSimGCM generates daily data, in the form of annual graphs. Data includes daily rainfall, maximum and minimum temperatures and solar radiation data.



MarkSim® DSSAT weather file generator

This is the MarkSim web version for IPCC AR5 data (CMIP5)

Lat dd: 27.83333
Lng dd: 66.63333
Model:
☐ BCC-CSM1-1
☐ BCC-CSM1-1-M
☐ CSIRO-Mk3-6-0
☐ FIO-ESM
☐ GFDL-CM3
☑ GFDL-ESM2G
☐ GFDL-ESM2M
☐ GISS-E2-H
Scenario: ○ RCP 2.6 ○ RCP 4.5 ○ RCP 6.0 ● RCP 8.5
Year: 2010
Replications: 1
Seed: 1234
Place: Khuzdar PMD
☐ Output CLX file

FIGURE 3.4: MarkSim interface to Run Model for data extraction

Annual data files are fully compliant with DSSAT (Agrotechnology Transfer System Support Fund Decision). These DSSAT files can be downloaded by the user as a zip file. MarkSim provides free access to global and regional (downscaled) climate data. It can be used to do the trend analysis in future as seldom General Circulation Models (GCMs) result in a form that can be directly used [62].

Figure 3.4 shows the interface of MarkSim wherein latitude, longitude or location of study area, selection of GCM, RCP and year of interest are scheduled for running model.

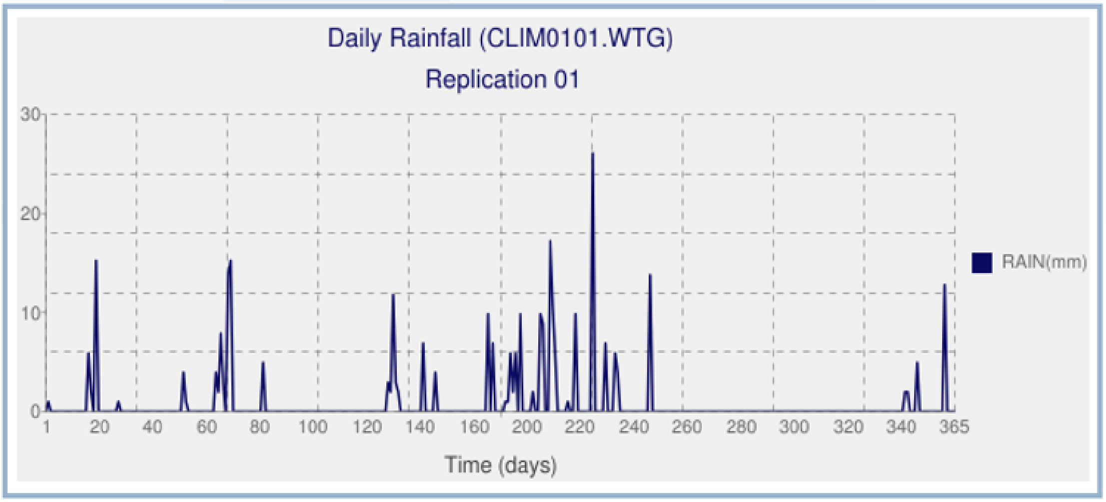


FIGURE 3.5: Daily Rainfall of GFDL-ESM2G model for the year of 2010 in mm for RCP 8.5

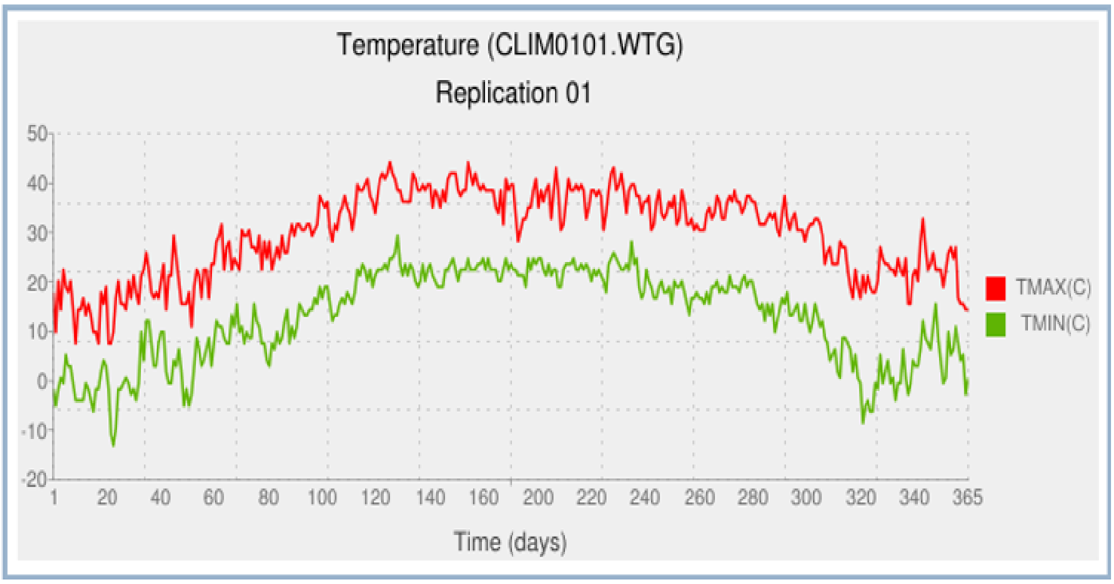


FIGURE 3.6: Daily Maximum and Minimum Temperature of GFDL-ESM2G model for the year of 2010 in ^{o}C RCP 8.5

Figures 3.4 and 3.5 are the annual graphs (of precipitation, maximum temperature and minimum temperature) generated after running the model for the year 2010.

Tabular form of these annular graphs is downloaded as zip file in WTG format and then it is converted into .txt zip file which is transformed into .xlsx to do further analysis.

3.5.2 Representative Concentration Pathways (RCP)

Representative Concentration Pathway (RCP) is the standardized set of future greenhouse gas emissions used by the General Circulation Models for the IPCC 5th approximation (CMIP5). RCP 8.5 scenario assumes a high population with low-income growth/ technological change and energy development capabilities leading to long-term demand to high energy and GHG emissions lacking climate change policies.

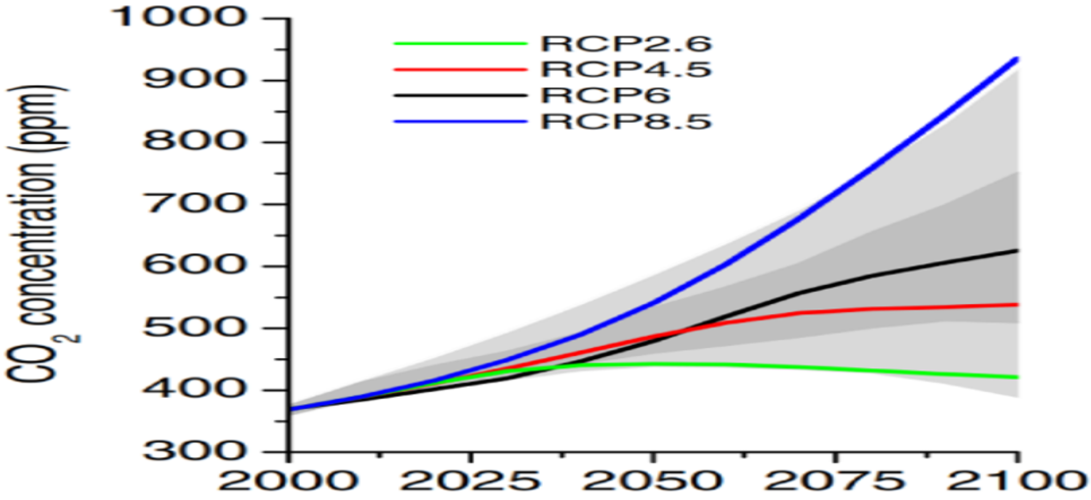


FIGURE 3.7: CO_2 concentration (parts per million) under 4 scenarios (After [64])

Compared to the total set of Representative Concentration Pathways (RCPs), RCP 8.5 thus corresponds to the pathway with the highest greenhouse gas emissions [63]. RCP 8.5 represents a very high baseline scenario where emissions continue to rise throughout this period [64] as shown in figure 3.8. GHG emissions of the RCP 8.5 remain to rise as a product of the high fossil-intensity of the energy sector as well as growing population and related high demand for food.

In the RCP 8.5 emissions/scenario, about three-quarters increase is due to CO_2 emissions; the rest increase is attributed to the increasing use of fertilizers and the strengthening of agricultural production which are source of N_2O emissions. Further, increases in the live-stock population, rice production, and enteric fermentation processes drive emissions of methane (CH_4), thus causing high pollution of GHGs [63].

It is because of the reason that RCP 8.5 is selected for use in current study. Carbon dioxide accumulates in the atmosphere and stays there for decades. Even if emissions start reducing in 2020, the concentration continues increasing and starts falling very slowly only after 2050 [64].

3.6 Calibration and Validation by NS Approach

The data obtained from MarkSim needs to be checked and validated before using it for simulation. Model data is generated for certain period of known/base period. Some duration of this base period is used for calibration and rest (afterwards) is meant for validation. During the calibration, a factor is determined to validate the result. That factor is then applied in future prediction of model results.

In this method, most adopted method is known as NS (Nash-Sutcliffe) approach [65]. To determine NSE (Nash-Sutcliffe efficiency), an equation is modified [66] below for the precipitation and temperature as eq (3.1) and eq. (3.2) respectively to calibrate the results of GCM in present study.

$$\mathrm{NS}=1-\frac{\sum_{i=1}^{N}\left(\mathrm{Pm(i)}-\mathrm{Po(i)}\right)^2}{\sum_{i=1}^{N}\left(\mathrm{Po(i)}-\mathrm{P`o(i)}\right)^2} \tag*{3.1}$$

where i is time step, N is total number of steps, P_m shows model precipitation, P_o is observed precipitation, P‘$_o$ is mean of P_o over calibration period. NS is Nash-Sutcliffe coefficient.

$$\mathrm{NS}=1-\frac{\sum_{i=1}^{N}\left(\mathrm{Tm(i)}-\mathrm{To(i)}\right)^2}{\sum_{i=1}^{N}\left(\mathrm{To(i)}-\mathrm{T`o(i)}\right)^2} \tag*{3.2}$$

where i is time step, N is total number of steps, Tm shows model temperature, Po is observed temperature, P‘o is mean of To over calibration period. NS is Nash-Sutcliffe coefficient.

Here Nash-Sutcliffe efficiency can range from -$\infty$to 1. An efficiency of 1 (NSE=1) corresponds to a perfect match between model and observed data. An efficiency of 0 (NSE=0) indicates no correlation at all between the model and observed data, whereas an efficiency less than 0 (NSE<0) occurs when the observed mean is a better predictor than the model.

3.6.1 Calibration Approach for Precipitation to Find Factor

For calibration of GFDL-ESM2G, HadGEM2-ES and MRI-CGCM3 models precipitation output data, deficient months (with no rainfall) have been excluded and average of remaining months having rainfall in both observed and model extracted data are considered to find factor. e.g., the GFDL-ESM2G and HadGEM2-ES models data indicated no rainfall in the month of April but observed data shows 4.91mm rainfall. Similarly, the observed data lists 8.75mm and 0.43mm rainfall in September and October, respectively, against zero rainfall produced by the models. So, the mean of the calibration period was taken without considering deficient months of April, September and October for calibration. In calibration of GFDL-ESM2G, the factor 1.10 and 1.40 have been obtained. The average of multiplying factors has been determined to be 1.25 for simulation. Similar steps have been carried out for HadGEM2-ES and MRI-CGCM3 models.

3.7 Future Projections of Precipitation and Temperature

After getting the factors using NS approach, the multiplying factors applied to all three GCMs output data for simulation. Precipitation values are multiplied with the factor mean i.e., 1.25, 1.36 and 1.40 of GFDL-ESM2G, HadGEM2-ES and MRI-CGCM3 mean factors respectively.

The factors of maximum and minimum temperature applied to all three GCMs output data for simulation and further it is used in scenario generation.

Mean Temperature and precipitation of base period i.e., 2010 to 2015, and known Flow rate (Q) was used to calculate the flow for future periods. Three periods, Early Future (2030), Mid Future (2060), and Late Future (2090) were selected as periods to be compared with the baseline and to be used to summarize the results. Moreover, to show future variability in temperature and precipitation. The inter-model differences of GCMs were considered to represent the uncertainty. A range of future climate projections from selected GCMs was studied on monthly and annual scales.

3.8 Discharge Simulation Methodology

The model data after applying multiplying factor used to simulate surface flow using ratio and proportion method. Ratio and proportion method is useful and easy to find only one unknown quantity i.e., simulated flow (Qs). For discharge simulation, the known average values of observed temperature, precipitation, simulated average temperature, precipitation and observed flow value (Qo) during the base period applied to get simulated discharge (Qs) for early, mid and late future.

In ratio and proportion, two ratios are equal. To find out cross product of a proportion, the extremes i.e., observed flow and simulated flow multiplied with means i.e., simulated precipitation and observed precipitation we get equation 4.1, simulated flow (Qs1). To find out simulated flow, an equation as mentioned as equation 4.2 below developed, that can be used to find predicted Q values for any year in the future with simulated precipitation and temperature and observed precipitation and temperature.

Simulated flow is calculated by multiplying observed average flow with simulated precipitation divide by observed precipitation and putting the obtained result

$$Qs_1 = Q \times \left(\frac{Ps}{Po}\right) \tag{4.1}$$

in equation 4.2 as Qs_1 and multiply it with a simulated temperature divide by observed temperature.

$$Qs = Qs_1 \times \left(\frac{Ts}{To}\right) \tag{4.2}$$

Where,

Q_s = simulated flow

T_s= simulated temperature

T_o = observed temperature

Chapter 4

Results and Discussions

4.1 Background

The selected study area is discussed in the previous chapter. Where the method of data analysis, data process, and simulation of the results for the calculation of flow have been discussed. Due to the limited length of data, variation has been observed. The possible ways to calibrate and validate the data have also been discussed. This chapter now discusses the results of the study.

4.2 Model Data Extraction Valuation

For this study, the results of three GCMs as shown in Table 4.1, each with the RCP 8.5 scenario has been applied for predictions of future precipitation and temperature and its effect on the flow of the Mula river by the end of this century.

Table 4.1: List of CMIP5-GCMs used in this study

Model	**Resolution Lat x Long**	**Institution**
GFDL-ESM2G	2.0 x 2.5	Geophysical Fluid Dynamics Laboratory
HadGEM2-ES	1.2414 x 1.875	Met Office Hadley Centre
MRI-CGCM3	1.125 x 1.125	Meteorological Research Institute

The climate change variables adopted in this study are precipitation, maximum, and minimum temperature as per standard practice adopted by many researchers. Calibration and validation of the models for temperature and precipitation are explained in the paragraphs below.

4.2.1 Calibration and Validation of Temperature Model

For calibration and validation of three models mentioned in table 4.1 Nash and Sutcliff efficient coefficient (NSE), coefficient of determination (R) has been applied as explained in section 3.6.

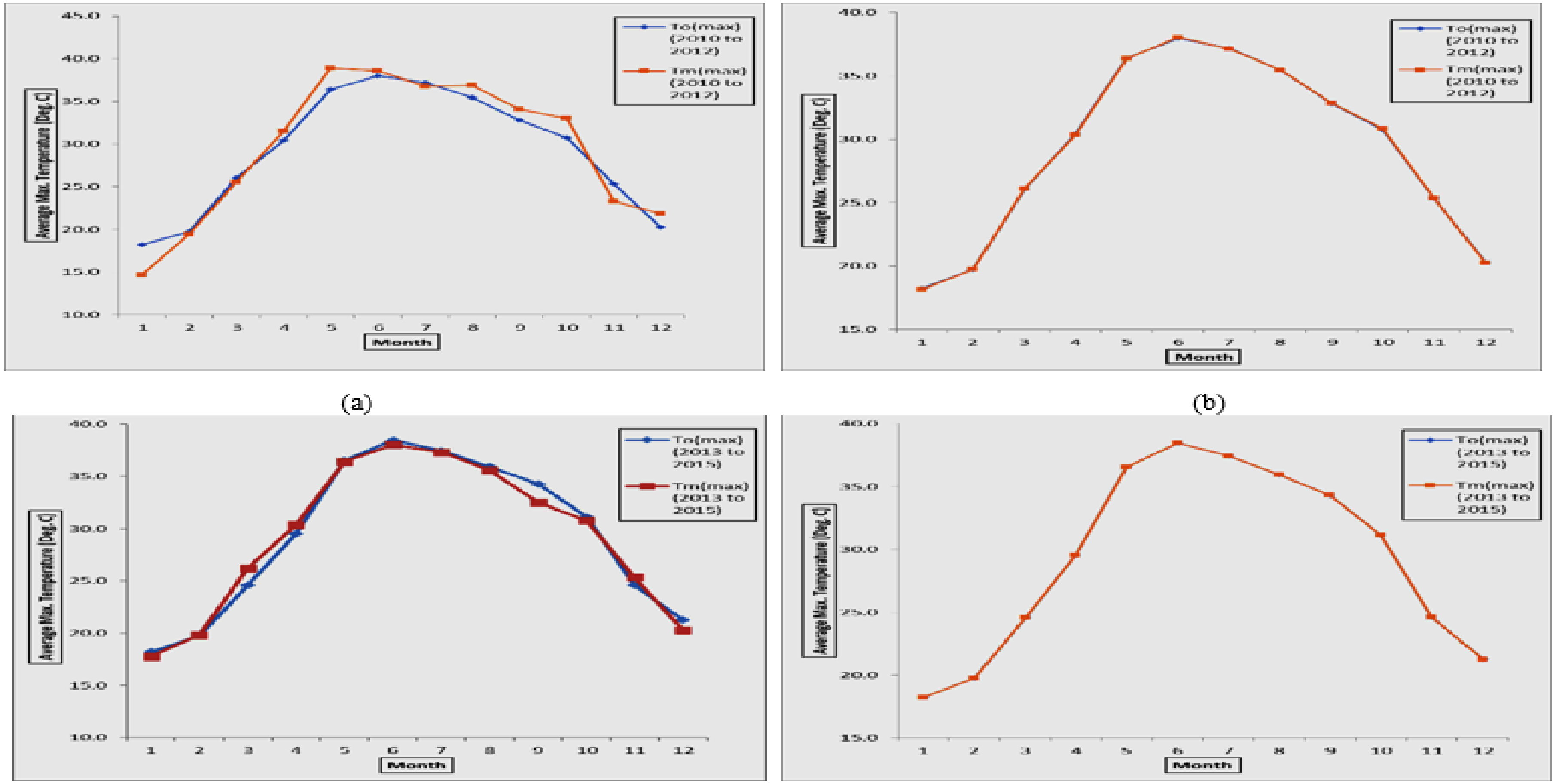
For calibration of maximum, minimum temperature and precipitation, base data for 2010 to 2012 on monthly basis was used. While running GFDL-ESM2G factor range of 0.93 to 1.24 for maximum temperature, -1.64 to 3.42 for minimum temperature and factor of 1.10 for precipitation were determined and then applied to validate the results for years 2013 to 2015. Slight adjustments of factors were further done and factors range of 0.94 to 1.27 for maximum temperature, and -1.48 to 4.09 for minimum temperature and factor of 1.40 for precipitation were finalized. These factors were then applied in model output for simulation years 2030, 2060 and 2090.

A similar approach is executed for HadGEM2-ES and MRI-CGCM3 models. The factors obtained are listed in the table 4.2 below.

Table 4.2: Calibration factor range for different Models and Parameters

Model/ Parameter	**GFDL-ESM2G**	**HadGEM2-ES**	**MRI-CGCM3**
Max. T	0.93 to 1.24	0.96 to 1.22	0.95 to 1.25
Min. T	-1.64 to 3.42	-1.54 to 3.96	-2.02 to 2.87
P	1.1	1.17	1.15

When applied these factors mentioned in table 4.2 to validate the results, it almost compatible and minor adjustment have done. Figure 4.2 (a) and (b) indicate graphical comparison of calibration period data before and after applying factors for minimum temperature using data of GFDL-ESM2G.



(a) (b)

(c) (d)

FIGURE 4.1: Model GFDL-ESM2G Max. Temperature Before and After Calibration and Validation (Calibration a-b; Validation c-d)

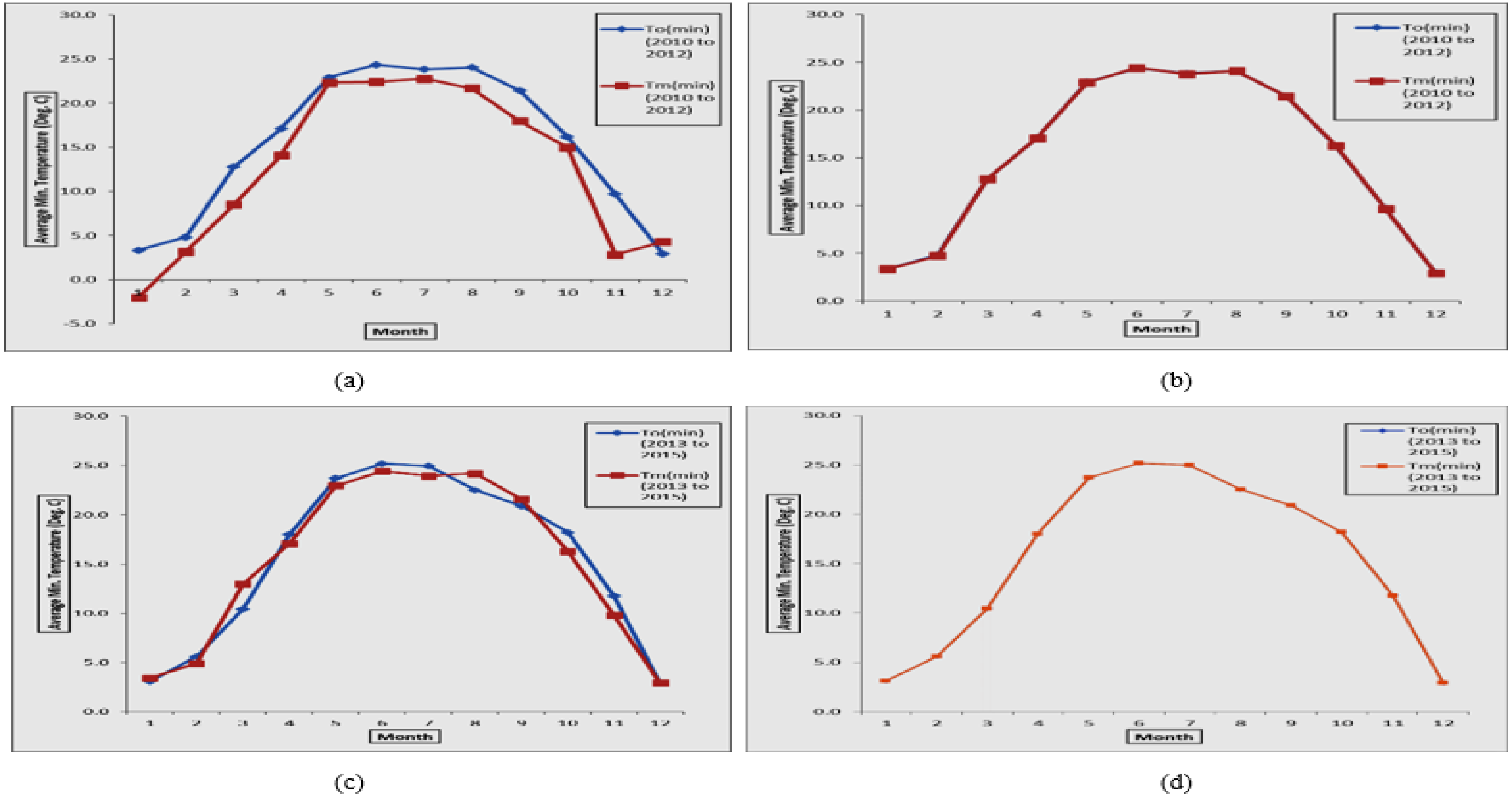
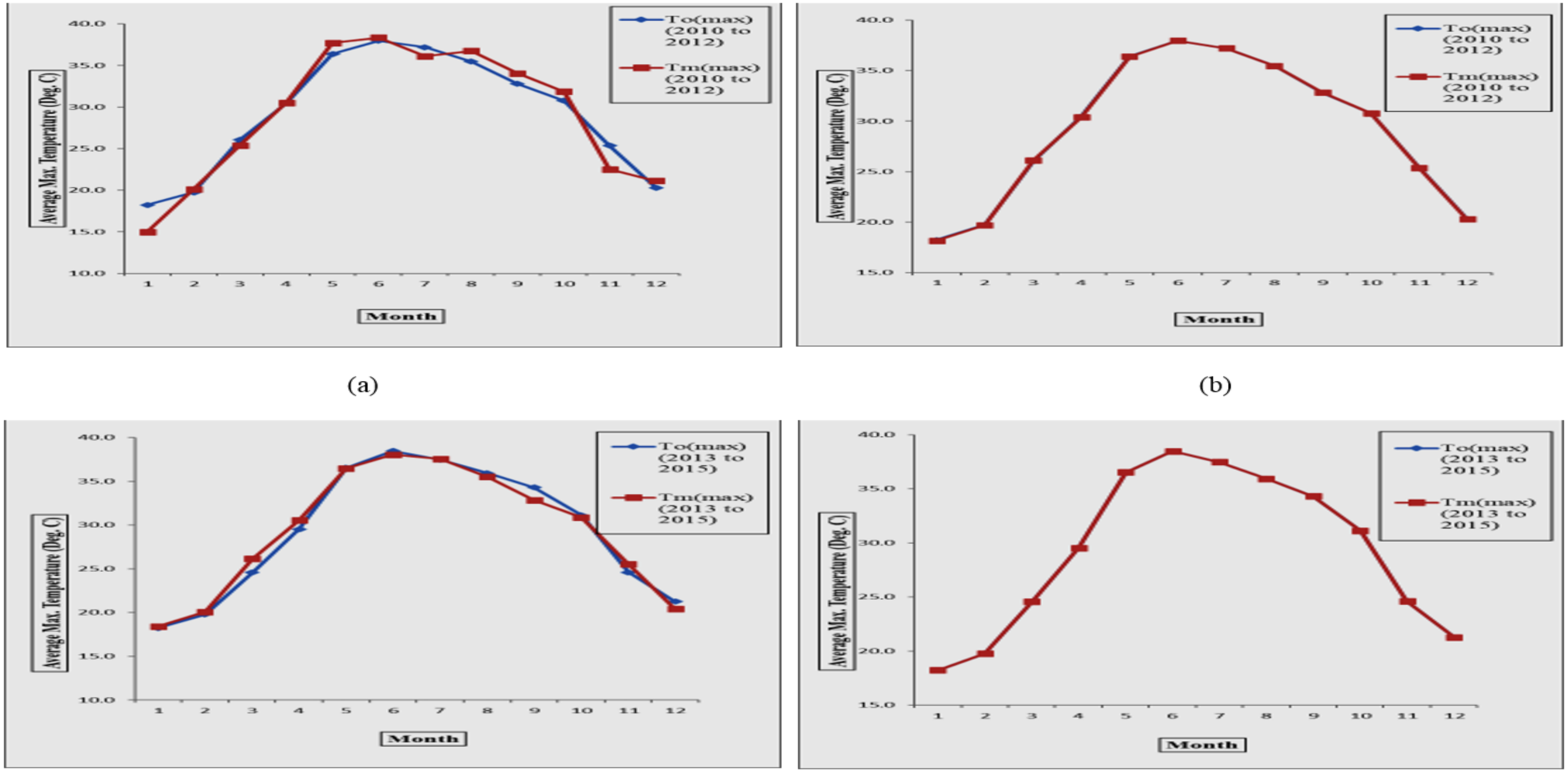


FIGURE 4.2: Model GFDL-ESM2G Min. Temperature Before and After Calibration and Validation (Calibration a-b; Validation c-d)



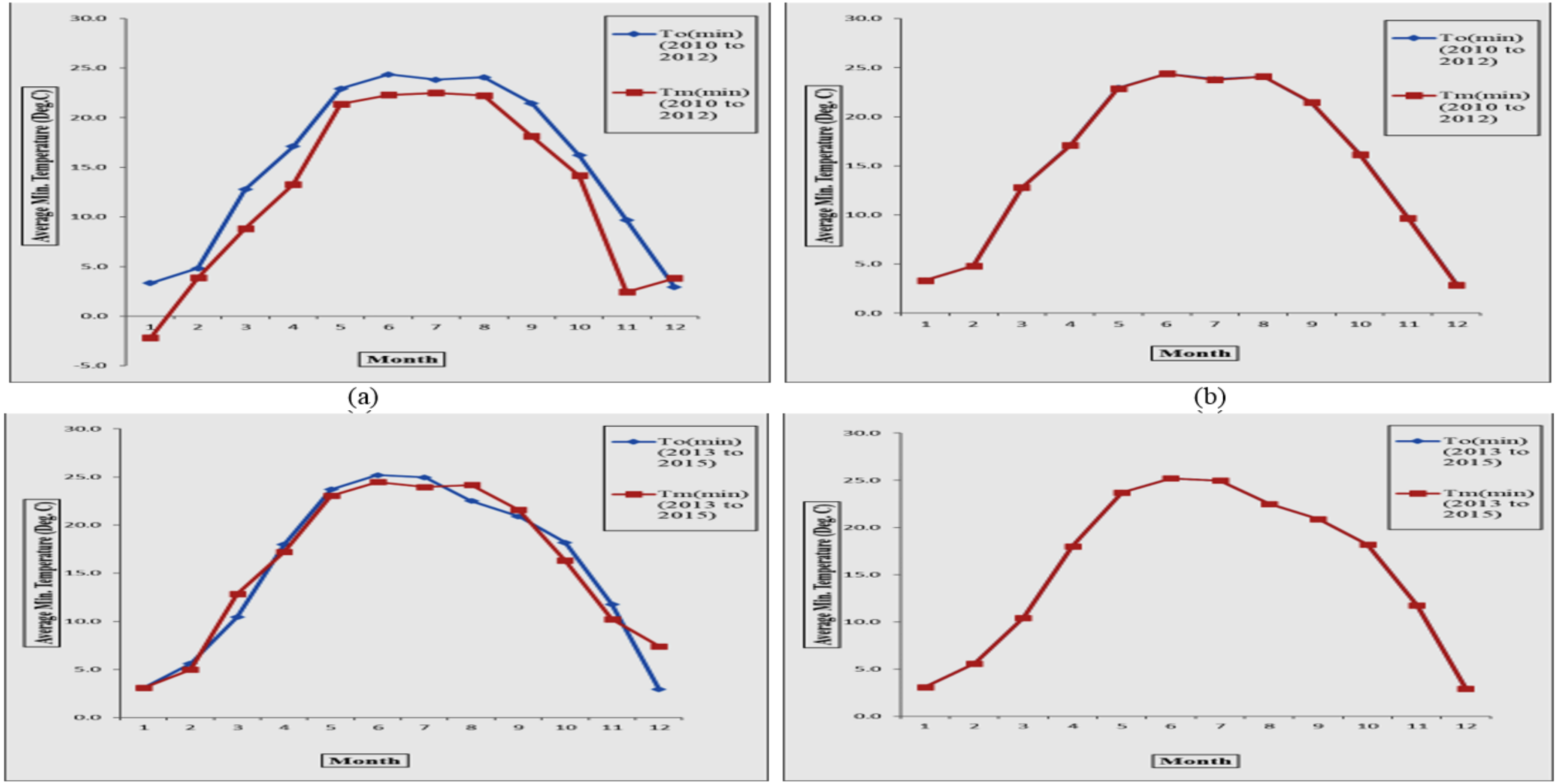
(a)

(b)

(c)

(d)

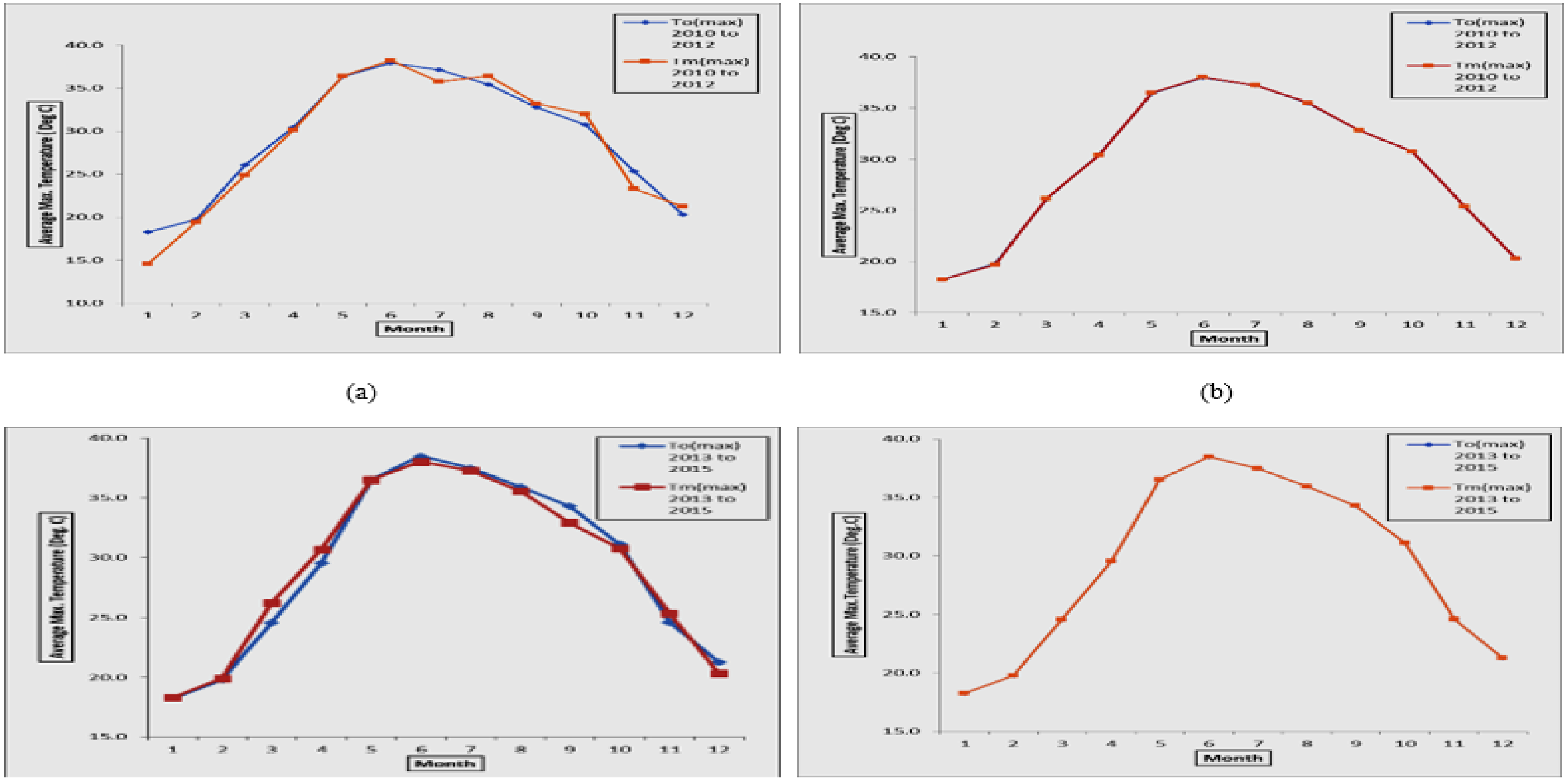
FIGURE 4.3: Model HadGEM2-ES Max. Temperature Before and After Calibration and Validation (Calibration a-b; Validation c-d)



(a) (b)

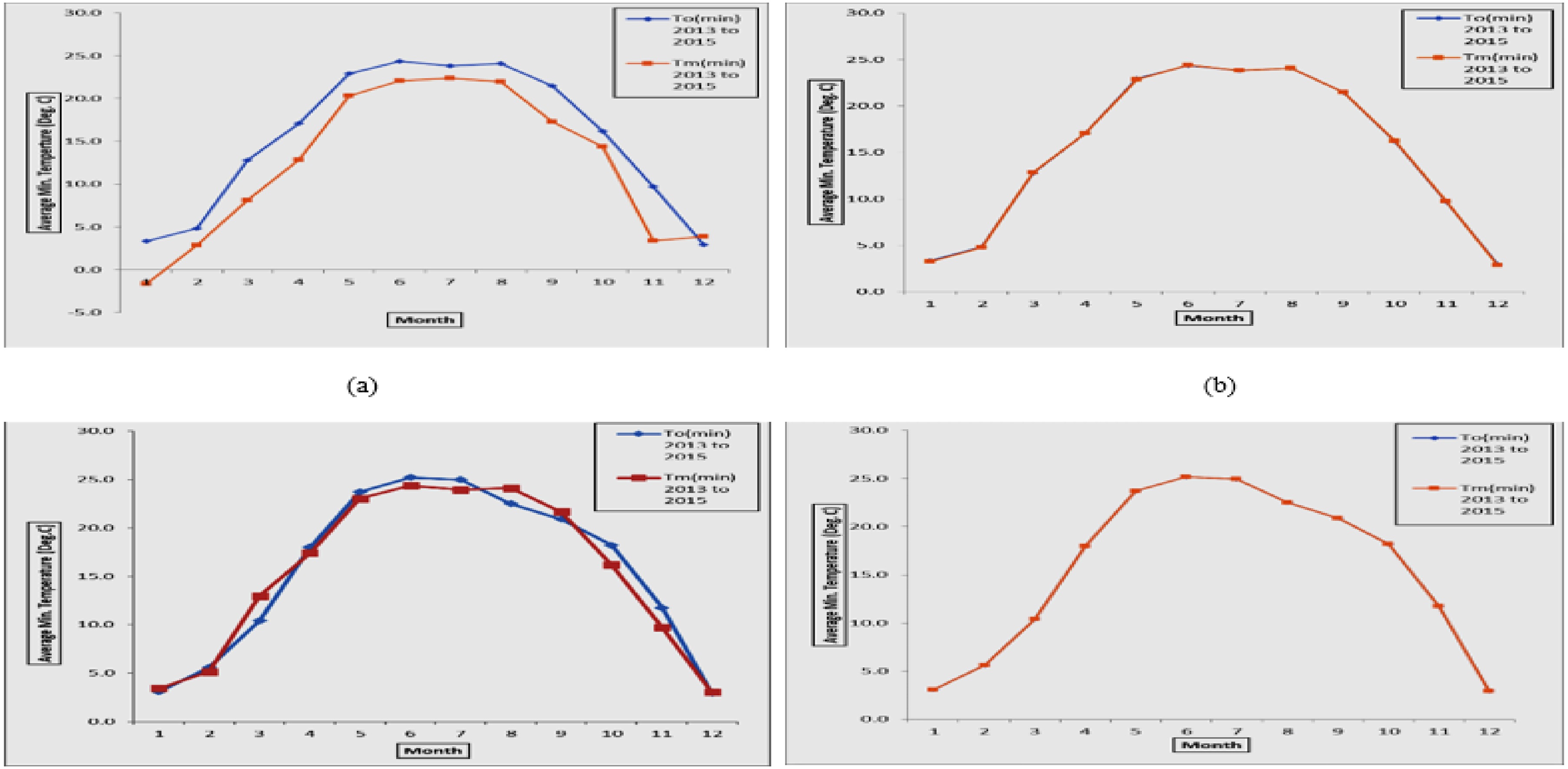
(c) (d)

Figure 4.4: Model HadGEM2-ES Min. Temperature Before and After Calibration and Validation (Calibration a-b; Validation c-d)



(a) (b) (c) (d)

FIGURE 4.5: Model MRI-CGCM3 Max. Temperature Before and After Calibration and Validation (Calibration a-b; Validation c-d)



(a)

(b)

(c)

(d)

FIGURE 4.6: Model MRI-CGCM3 Min. Temperature Before and After Calibration and Validation (Calibration a-b; Validation c-d)

In Figure 4.2 (a), the data shows some variation in some months. The obtained factors then applied and as shown in Figure 4.2 (b) the data is perfectly sat fit on each other. The determined factors then applied to validate the results for years 2013 to 2015 as shown in Figure 4.2 (c). Slight adjustments of factors were further done and the graphs perfectly sat fit on each other as shown in Figure 4.2 (d).

Figure 4.3 (a) and (b) indicate graphical comparison of calibration period data before and after applying factors for maximum temperature using data of HadGEM2-ES. In Figure 4.3 (a), the data shows some variation in some months. The obtained factors then applied and as shown in Figure 4.3 (b) the data is perfectly sat fit on each other. The determined factors then applied to validate the results for years 2013 to 2015 as shown in Figure 4.3 (c). Slight adjustments of factors were further done and the graphs perfectly sat fit on each other as shown in Figure 4.3 (d).

Figure 4.4 (a) and (b) indicate graphical comparison of calibration period data before and after applying factors for minimum temperature using data of HadGEM2-ES. In Figure 4.4 (a), the data shows some variation in some months. The obtained factors then applied and as shown in Figure 4.4 (b) the data is perfectly sat fit on each other. The determined factors then applied to validate the results for years 2013 to 2015 as shown in Figure 4.4 (c). Slight adjustments of factors were further done and the graphs perfectly sat fit on each other as shown in Figure 4.4 (d).

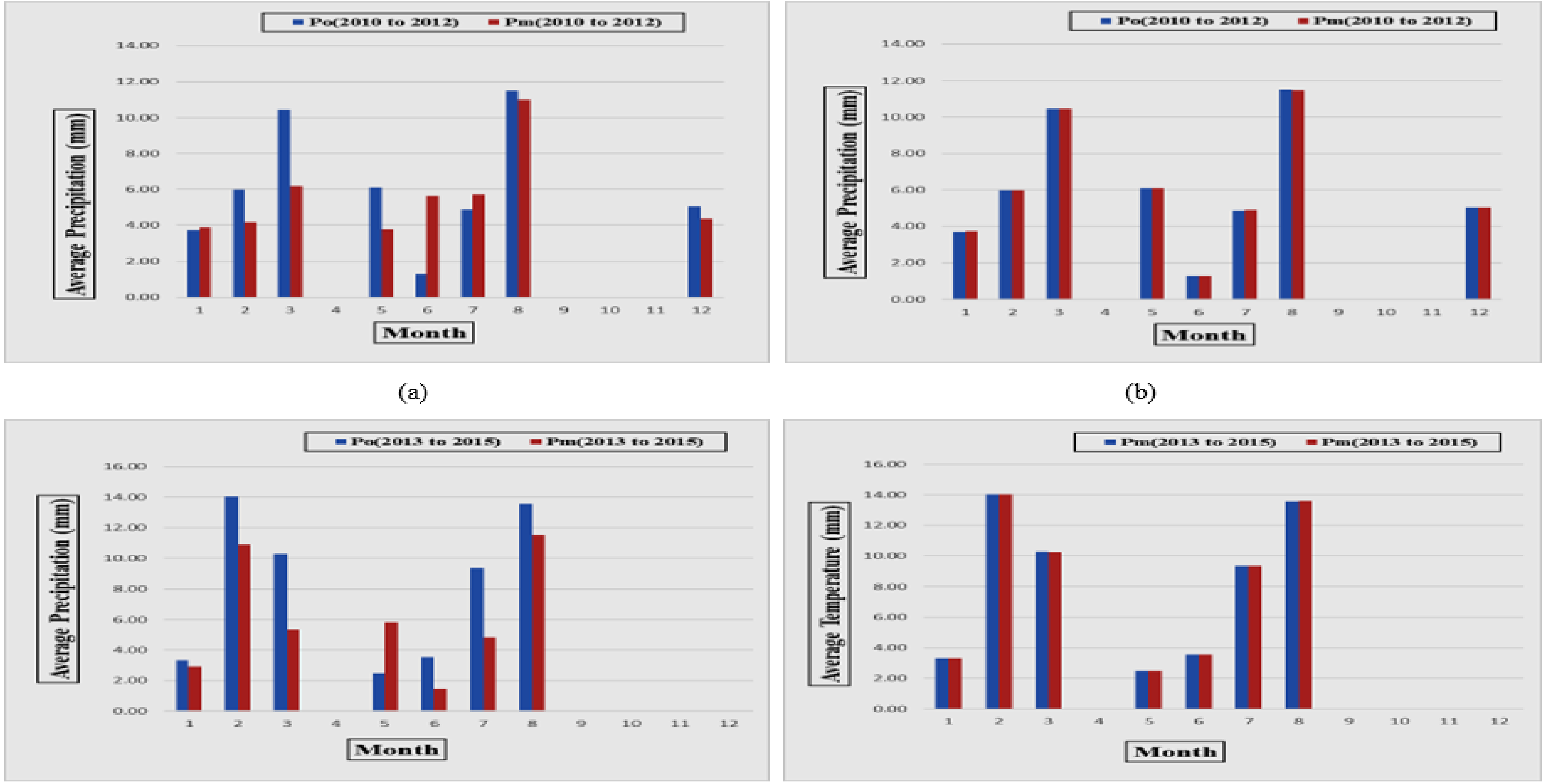
Figure 4.5 (a) and (b) indicate graphical comparison of calibration period data before and after applying factors for maximum temperature using data of MRI-CGCM3. In Figure 4.5 (a), the data shows some variation in some months. The obtained factors then applied and as shown in Figure 4.5 (b) the data is perfectly sat fit on each other. The determined factors then applied to validate the results for years 2013 to 2015 as shown in Figure 4.5 (c). Slight adjustments of factors were further done and the graphs perfectly sat fit on each other as shown in Figure 4.5 (d).

Figure 4.6 (a) and (b) indicate graphical comparison of calibration period data before and after applying factors for minimum temperature using data of MRI-CGCM3. In Figure 4.6 (a), the data shows some variation in some months. The obtained factors then applied and as shown in Figure 4.6 (b) the data is perfectly sat fit on each other. The determined factors then applied to validate the results for years 2013 to 2015 as shown in Figure 4.6 (c). Slight adjustments of factors were further done and the graphs perfectly sat fit on each other as shown in Figure 4.6 (d).

4.2.2 Calibration and Validation of Model for Precipitation

Figure 4.7 (a) and (b) indicate graphical comparison of calibration period data before and after applying factors for precipitation using data of GFDL-ESM2G. In Figure 4.7 (a), the model data shows no rainfall in the month of April, September, October and November. The factors are obtained and then applied as shown in Figure 4.7 (b) the data is perfectly sat fit on each other. The determined factors then applied to validate the results for years 2013 to 2015 as shown in Figure 4.7 (c). Slight adjustments of factors were further done and the graphs perfectly sat fit on each other as shown in Figure 4.7 (d).

Figure 4.8 (a) and (b) indicate graphical comparison of calibration period data before and after applying factors for precipitation using data of HadGEM2-ES. In Figure 4.8 (a), the model data shows no rainfall in the month of April, September, October and November. The average taken from the months having some precipitation value and factors determined. The factors are obtained and then applied as shown in Figure 4.8 (b) the data is perfectly sat fit on each other. The determined factors then applied to validate the results for years 2013 to 2015 as shown in Figure 4.8 (c). Slight adjustments of factors were further done and the graphs perfectly sat fit on each other as shown in Figure 4.8 (d). Figure 4.9 (a) and (b) indicate graphical comparison of calibration period data before and after applying factors for precipitation using data of MRI-CGCM3. In Figure 4.9 (a), the model data shows no rainfall in the month of April, September, October and November. The average taken from the months having some precipitation value and factors determined. The factors are obtained and then applied as shown in Figure 4.9 (b) the data is perfectly sat fit on each other. The determined factors then applied to validate the results for years 2013 to 2015 as shown in Figure 4.9 (c).



(a) (b)

(c) (d)

Figure 4.7: Model GFDL-ESM2G Precipitation Before and After Calibration and Validation (Calibration a-b; Validation c-d)

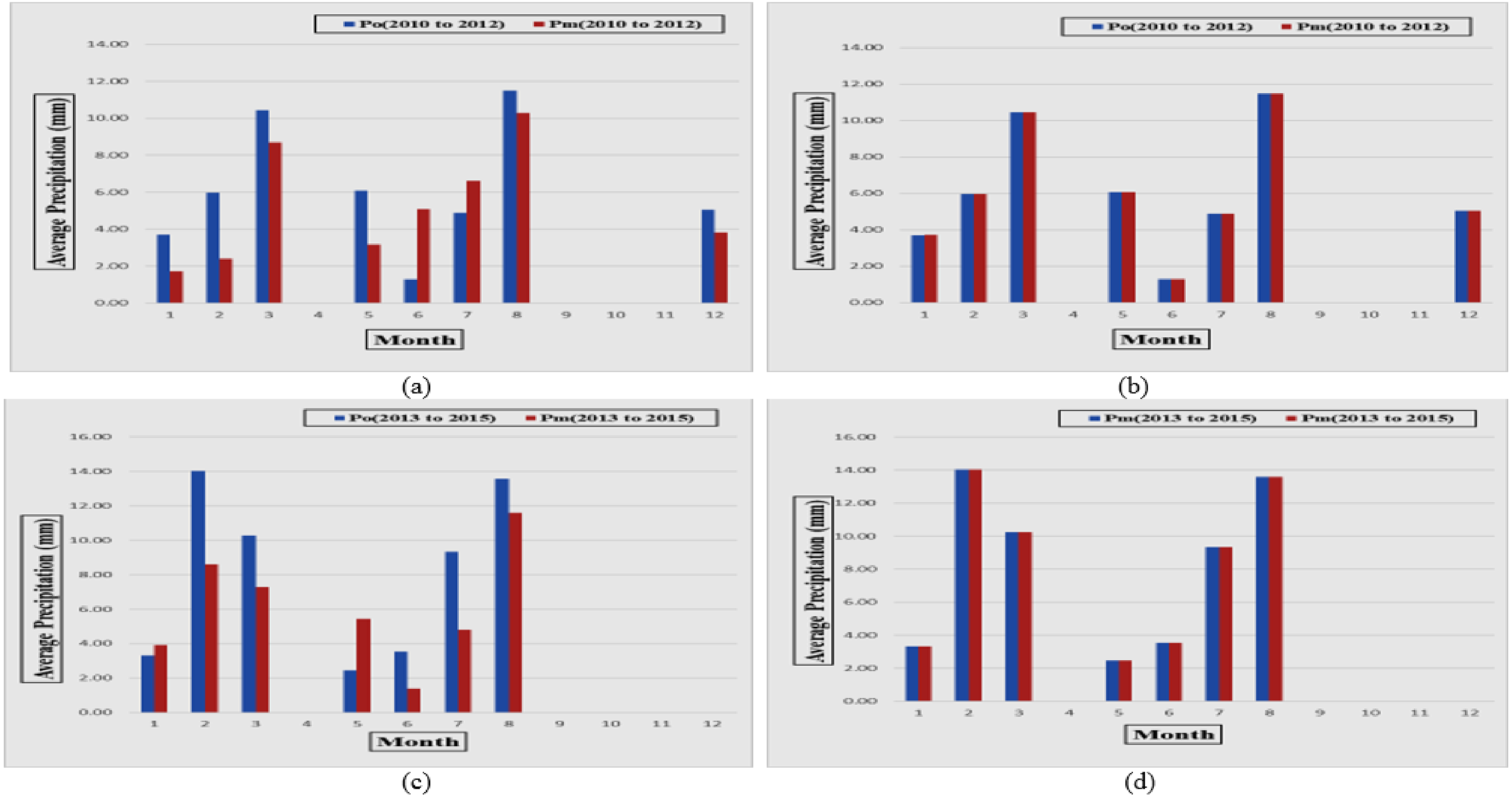
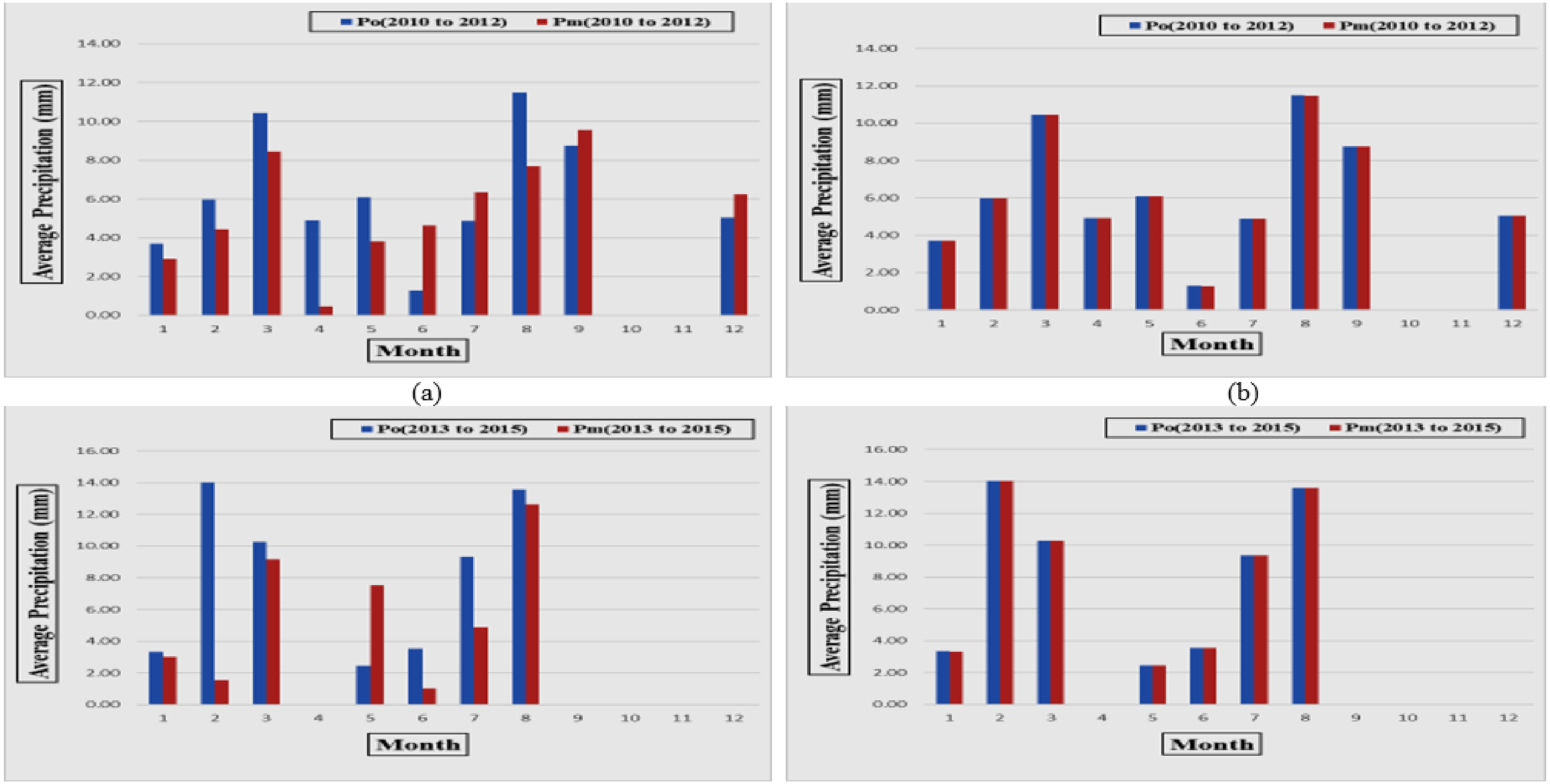


Figure 4.8: Model HadGEM2-ES Precipitation Before and After Calibration and Validation (Calibration a-b; Validation c-d)



(a) (b) (c) (d)

Figure 4.9: Model MRI-CGCM3 Precipitation Before and After Calibration Validation (Calibration a-b; Validation c-d)

Slight adjustments of factors were further done and the graphs perfectly sat fit on each other as shown in Figure 4.9 (d).

4.3 Simulation of Climate Factors

The factors obtained through calibration and validation applied for simulation of maximum temperature, minimum temperature and precipitation. The results of GCMs were compared with the monthly base period data and the changes were calculated for the Mula River. Table 4.3 to 4.5 list the changes in maximum and minimum temperature and precipitation for early future (2030), mid future (2060) and late future (2090) under RCP 8.5.

Table 4.3 lists the simulation results of 3 GCMs by the year of 2030 under RCP 8.5. In GFDL-ESM2G, maximum temperature 35.23^{o}C, minimum temperature 23.21^{o}C and 4.82mm precipitation obtained and change of 5.96^{o}C in max T. 7.86^{o}C in min T and -12.84% in precipitation observed.

In HadGEM2-ES, maximum temperature 35.79^{o}C, minimum temperature 23.69^{o}C and 3.43mm precipitation obtained and change of 6.52^{o}C in max T. 8.24^{o}C in min T. and -37.97% in precipitation observed.

In MRI-CGCM3, maximum temperature 35.74^{o}C, minimum temperature 23.26^{o}C and 4.15mm precipitation obtained and change of 6.47^{o}C in max T. 7.81^{o}C in min T. and -24.95% in precipitation observed.

4.4 Simulation of Discharge

Average flow result is presented in Table 4.6 for the Mula river. The change in the trend of the three models is shown in figure 4.10. The result of the GFDL-ESM2G model as compared to the base period has shown an increase of flow in the early future (2030), then a decreasing trend in mid future (2060) and again increasing trend in the late future (2090). The result of the HadGEM2-ES model has shown a decrease in flow trend in the early future (2030), then increasing trend in mid

Table 4.3: Monthly changes in future maximum and minimum temperature and precipitation for Mula River by the year 2030 under RCP 8.5

S r. No.	**Parameter**	**Observed**	**GFDL-ESM2G**	**Change**	**HadGEM2-ES**	**Change**	**MRI-CGCM3**	**Change**	**Total change**
1	Max T (^{o}C)	29.27	35.23	5.96^{o}C	35.79	6.52^{o}C	35.74	6.47^{o}C	6.32^{o}C
2	Min T (^{o}C)	15.45	23.31	7.86^{o}C	23.69	8.24^{o}C	23.26	7.81^{o}C	7.97^{o}C
3	P (mm)	5.53	4.82	-12.84%	3.43	-37.97 %	4.15	-24.95 %	-25.26 %

Table 4.4: Monthly changes in future maximum and minimum temperature and precipitation for Mula River by the year 2060 under RCP 8.5

S r. No.	**Parameter**	**Observed**	**GFDL-ESM2G**	**Change**	**HadGEM2-ES**	**Change**	**MRI-CGCM3**	**Change**	**Total change**
1	Max T (^{o})	29.27	36.62	7.35(^{o})	37.97	8.70^{o}C	37.22	7.95(^{o})	8.00(^{o})
2	Min T (^{o})	15.45	25.31	9.86(^{o})	26.27	10.82(^{o})	25.34	9.89(^{o})	10.19(^{o})
3	P (^{o})%)	5.53	2.69	-51.36 %	5.48	-0.90 %	2.83	-48.82 %	-33.69%

Table 4.5: Monthly changes in future maximum and minimum temperature and precipitation for Mula River by the year 2090 under RCP 8.5

S r. No.	**Parameter**	**Observed**	**GFDL-ESM2G**	**Change**	**HadGEM2-ES**	**Change**	**MRI-CGCM3**	**Change**	**Total change**
1	Max T (^{o}C)	29.27	39.05	9.78^{o}C	40.65	11.38^{o}C	39.97	10.70^{o}C	10.62^{o}C
2	Min T (^{o}C)	15.45	27.64	12.19^{o}C	29.38	13.93^{o}C	27.76	12.31^{o}C	12.81^{o}C
3	P (%)	5.53	4.85	-12.30%	3.66	-33.82 %	5.4	-2.35 %	-16.15 %

future (2060) contrary to the GFDL-ESM2G flow trend and again increasing trend in the late future (2090) as compared to base period and decrease inflow in the comparison of GFDL-ESM2G.

The result of the MRI-CGCM3 model has shown in some way similar flow trend relates to GFDL-ESM2G. The model has shown a slight decrease of flow in the early future (2030) as compared to the base period, then a decreasing trend in mid future (2060) and again increasing trend in the late future (2090). The results indicate the flows in the Mula river would increase further in the late future (2090) as a result of simulated increases in temperatures and precipitations. The flow remains equal or a slight decrease in flow can be observed in early future 2030 and mid future (2060).

TABLE 4.6: Trend of Average flow for Mula River throughout the 21st century

Period	**GFDL-ESM2G**	**HadGEM2-ES**	**MRI-CGCM3**	**Average (cusec)**
2010-15	4.683	4.683	4.683	4.683
2030	5.335	3.855	4.633	4.608
2060	3.153	6.656	3.351	4.387
2090	6.123	4.853	6.918	5.965

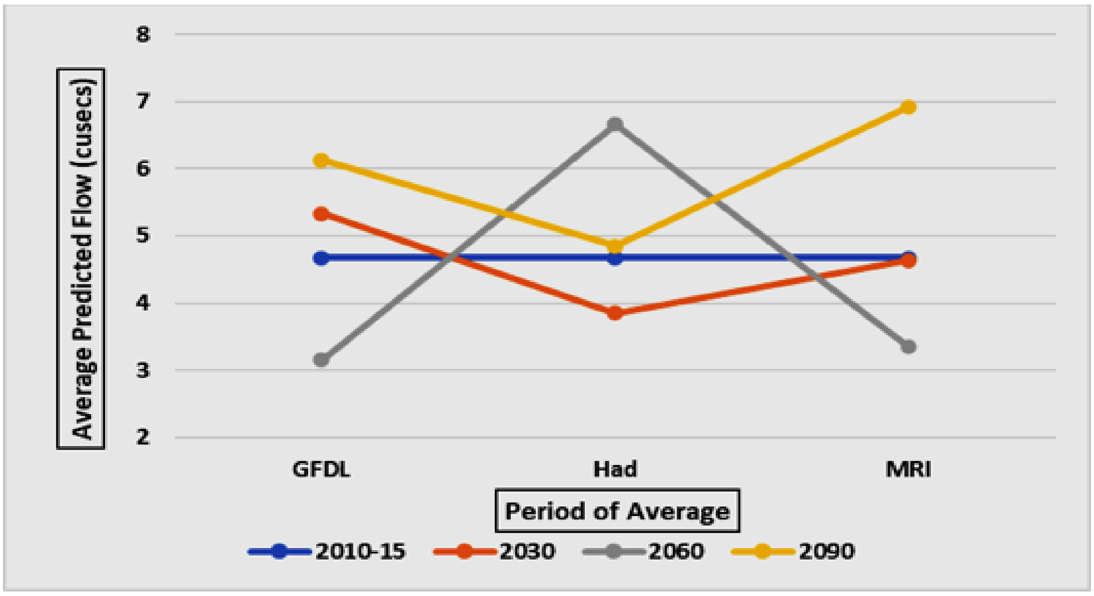


FIGURE 4.10: Trend of Average flow for Mula River throughout the 21st century

4.5 Proposed Remedial Measures

- The simulation of climatic parameters is highly uncertain. Hence, policymakers should consider a range of predictions during decision making process for adaptation of plans and strategies.

- Temperature is projected to increase in the future for the study area. Lack of infrastructures might lead to further difficulties and the possibility of more frequent and extreme floods and droughts possible in the study area.

- Hydro-climatic data collection activities must improve for future research studies on water resources and management of the existing basin of Balochistan. Hence, no gauging stations data quality improvement should be considered and should update the study by latest available observations particularly for higher elevations.

- Due to the increase in population density, the demand for water increases. Due to unavailability of sufficient infrastructures to store surface water, the dependency on groundwater resources affects the underground water balance. There are very few means of recharging underground water. Small, medium or large-scale recharging sources should construct with the available water flows and the government of Balochistan should take serious action on the increasing number of tube wells and Boreholes particularly private borings for most of the houses in Khuzdar and other parts of the Province.

- The construction of watersheds on roofs and in sewerage lines, collecting rainwater in underground tanks, should be encouraged to be carried to utilize maximum water runoff.

- The organization, educational institutes, and the government departments should develop plans to encourage students to carry researches on water resources and make the department up to date with all the required data and information. That would help the government to better plan and manage the water scarcity in the limits.

Chapter 5

Conclusions and Recommendations

5.1 Conclusions

The key conclusions based on the results of this study are as follows:

- Considering the data scarce study area, all three models i.e., GFDL-ESM2G, HadGEM2-ES, and MRI-CGCM3 performed better for temperature and precipitation datasets examined in this study. A slight variation observed due to the insufficient length of the available data.
- The results of GCMs under RCP 8.5 as compared to the base period have shown -1.60%, -6.32% and +2.74% change in flows with respect to the base years average in 2030, 2060 and 2090, respectively.
- The flow changes are mostly in line with the simulated trend of precipitation and temperatures.
- The results indicate the flow trend in the Mula river would increase in the future but the instability of the rainfall pattern will affect the flow of the Mula river.

- The valuation of analysis of climate change on distribution of surface water for the selected study area was done for the first time in district Khuzdar using three GCMs on temperature and precipitation and thus on water availability.
- The trend of precipitation variations over the year shall remain uncertain as it was being experienced during the base period.
- It would be much advantageous for data scarce province Balochistan to develop more water storage reservoirs and dams to minimize the waste of surface water.

5.2 Recommendations for Future Studies

- It is recommended that for future studies, the effects of additional changing factors of climatic parameter such as land use, evapotranspiration, infiltration, transport of sediment with socio-economic must be assessed for extensive range of the study.
- The comparative analysis of different GCMs in data scarce region like Balochistan
- Analysis be carried out for Extreme events i.e., extreme floods and extreme droughts on existing basins of Balochistan.

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