CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Comparative Assessment of Climate Scenario Projection using Global Climate Models for Peshawar, Pakistan

by

Malik Ahsan Gulzar

A thesis submitted in partial fulfillment for the degree of Master of Science

in the

Faculty of Engineering

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This work is dedicated to all my valuable treasures in life, to my

Respected Family

Which is my love and strength

Thank you for always helping me through every difficult time of my life and for

Encouraging me to move forward. You have been always a sign of love and happiness for me.

CERTIFICATE OF APPROVAL

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Abstract

Climate change is one of the most critical issues of our time, affecting various regions worldwide, including Peshawar, Pakistan. This MSc thesis presents a comprehensive analysis titled "Comparative Assessment of Climate Scenario Projection using Global Climate Models for Peshawar, Pakistan." Its objective is to offer valuable insights into the potential future climatic conditions in the region. The research begins by collecting and scrutinizing historical climate data spanning 30 years (1989 - 2018) to establish a robust baseline. Global Climate Models (GCMs) are then employed to project future climate scenarios for Peshawar. The assessment focuses on climate variables like temperature and precipitation to evaluate the likelihood of local climate changes. The research significantly relies on the MarkSim statistical tool, known for its effectiveness in evaluating the performance of multiple GCMs in projecting climate scenarios. For generating future weather data, three GCM models (MRI-CGCM3, MIRCO5, and HadGEM2-ES) are used in combination with different Representative Concentration Pathways (RCPs) - RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5. This approach covers a comprehensive range of climate scenarios, enabling a robust analysis of potential future climate conditions in Peshawar. The MarkSim tool data is then compared with the observed data from the Met Department Khyber Pakhtunkhwa for the years 2011 to 2018. Using the Nash-Sutcliffe technique, commonly applied to evaluate hydrological models, the calibration and validation of temperature and precipitation data for Peshawar are performed. The calibration process involves adjusting and fine-tuning the models and projections based on a comparison with the observed data from 2011 to 2014. Following the calibration phase, the subsequent validation phase utilizes data from 2015 to 2018. The research focused on three specific time horizons, namely 2030, 2060, and 2090. For Peshawar, temperature is expected to variate from 0.06 °C (MRI-CGCM3, RCP 2.6) to 4.68 °C (MIROC5, RCP 8.5) and precipitation is expected from -16.46% (MIROC5, RCP 8.5) to 37.18% (HadGEM2, RCP 8.5). These projected changes do not significantly impact local agriculture, water supplies, and public health. However, considering Peshawar's geographic location and socioeconomic circumstances, it may be vulnerable to the

effects of climate change. This emphasizes the importance of taking proactive measures to adapt to and mitigate these changes. The study's conclusions and recommendations contribute valuable data on climate change in Peshawar, providing a foundation for informed decision-making and the development of effective adaptation strategies.

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Abbreviations

ACZs	Agro-Climatic Zones
AI	Artificial Intelligence
ANNs	Artificial Neural Networks
AR	Assessment Report
ARDL	Autoregressive Distributed Lag
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station Data
CMIP	Coupled Model Intercomparison Project
CO2	Carbon Dioxide
DIK	Dera Ismail Khan
DSSAT	Decision Support System for Agro Technology Transfer
EKC	Environment Kuznets Curve
ENSO	EI Nino Southern Oscillation
EU	Europe
FAO	Food and Agriculture Organization
GB	Gilgil Baltistan
GB	Great Britian
GCMs	General Circulation Models
GHG	Greenhouse Gases
GM	Global Warming
GWP	Global Warming Potentials
HH	Household
ICT	Information and Communication Technology
ICZ	Intertropical Convergence Zone

IN	Inch
IPCC	Intergovernmental Panel on Climate Change
IR	Industrial Revolution
ISO	International Organization for Standardization
KPK	Khyber Pakhtunkhwa
LCA	Life Cycle Assessment
LWM	Land and Water Management
Met	Meteorological
MM	Millimetre
MODIS	Moderate Resolution Imaging Spectroradiometer
NCEP	National Centers for Environmental Prediction
NIES	National Institute for Environmental Studies Nash
NS	Sutcliffe
NSE	Nash Sutcliffe Efficiency
O3	Ozone
ODP	Ozone Depletion Potentials
PC	Personal Computer
RCPs	Representative Concentrated Pathways
RE	Residual Error
RMSE	Root Means Square Error
SF6	Sulphur Hexafluori
SO2	Sulphur Dioxide
SPCZ	South Pacific Convergence Zone
SRM	Snowmelt Runoff Model
SSP2	Shared Socioeconomic Pathway 2
SWAT	Soil and Water Assessment Tool
SWMM	Storm Water Management Model
US$	United States Dollar
US	United States
WDP	Water Depletion Potentials
WE R	Water & Environment Research Group

WEB World Wide Web

WUE Water Use Efficiency

Chapter 1

Introduction

1.1 General

The Industrial Revolution (IR) was the shift to new industrial techniques that took place in Great Britain (GB), continental Europe, and the United States (US) from around 1760 to 1820.

The current increase in the global average temperature of the oceans and atmosphere is referred to as global warming. Carbon dioxide (CO2) as well as other air pollutants capture sunlight and solar rays that have already been reflected off the earth's surface as they accumulate in the atmosphere. The most recent example of climate change is often referred to as global warming.

Climate change is the long-term alteration of temperature and weather patterns. Despite the fact that some of these changes may be natural, since the 1800s, human activity has been the main driver of climate change. Climate change is the long-term alteration of temperature and weather patterns. Despite the fact that some of these changes may be natural, since the 1800s, human activity has been the main driver of climate change.

This is primarily due to the gases released by the burning of fossil fuels like coal, oil, and gas, which retain heat. Due to this, floods are occurring in one part of the world and droughts in other parts. Even the weather condition & trends at a particular location are changing. General-circulation-models (GCMs) are effective tools for conducting research on climate change but should be carefully selected along with Representative Concentrated Pathways (RCPs).

1.2 Industrial Revolutions- A Turning Moment for Climate Change

The Industrial transformation has been referred to as the most significant transformation in human history because of its huge impact on people's daily lives. The term "industrial revolution" refers to a period of history that got its start in Great Britain in the 18th century. As technical innovation processes accelerated, a range of new tools and equipment were produced [1]. Three industrial revolutions (IRs) have already had a significant outcome on the global. In first IR, water & steam were used in mechanical processes for the mass manufacture of metals and textiles.

The second IR focused on the idea of industries; during this time, electricity, gas, and oil were used; in addition, the steel and synthetic industries were formed along with new communication and transportation networks. The third IR included automation and new nuclear energy. The majority of these revolutions, meanwhile, had significant negative effects on the environment. Both the environment and human lives were severely damaged and harmed by them. As a result, the IR 4.0 is a practical, long-term, and ecologically beneficial method of production that makes use of recyclable bio-based components and renewable resources [2].

Similar to the previous industrial revolutions, the Fourth Industrial Revolution has the potential to both increase global income levels and enhance the standard of living. It will effect and have a significant impact on government, business, and people's lives. From an evolutionary perspective, the Fourth Industrial Revolution is based on the Third Industrial Revolution and built upon it. It is frequently referred to as the Digital Revolution since it supports digital technologies [3]. Industrial revolution triggered climate change win the form of global warming.

1.3 Global Warming and Climate Change

The overall annual increase in world temperature during the industrial revolution has been little more than 1 degree Celsius, or over 2 degrees Fahrenheit. It climbed on average by 0.07 °C (0.13 °F) per 10 years between 1880, the year that precise data gathering had begun, and 1980. However, since 1981, the rate of increase has more than doubled. The annual global temperature has risen by 0.18 °C, or 0.32 °F, per decade during the previous 40 years. Now, climate scientists have determined that we must limit global warming to 1.5 °C by 2040 if we want to avoid an event in which regular life throughout the world is marked by its worst, most devastating effects, the life-threating droughts-floods- tropical storms- wildfires, and other mishaps that we refer to collectively as climate change [4].

The main source of greenhouse gas emissions and contributors to global warming worldwide is energy production and consumption. Climate change, commonly known as global warming, is one of the most challenging problems the world is now dealing with. Global warming is the rise in the aggregate land surface, air, and sea surface temperatures, according to the Intergovernmental Panel on Climate Change (IPCC) [5]. The overall negative economic effects of climate change, including slow-onset and extreme weather events, have been documented more frequently [6].

The phenomenon of global warming raises the temperature. This rise in temperature causes more evaporation ultimately leading to more precipitation [7]. The hydrological cycle has become more intense as a result of global warming, which has increased the rate of both precipitation and evaporation. The size, intensity, frequency, and spatial distribution of climatic extremes have significantly increased as a result of the subsequent changes in the mean and distribution of temperature and rainfall [8]. Pakistan has been dealing with drought and flooding. The La Nina phase of the EI Nino Southern Oscillation (ENSO), which is associated with rainfall during the summer monsoon that is above average, causes flooding [9]. Climate change studies are using circulation models which could be general circulation or regional circulation models.

1.4 Research Motivation and Problem Statement

Water is life and its importance can't be denied. Early settlements were also made besides water bodies. Due to the industrial revolution, another factor has been badly affecting water resources and that is climate change. Due to this, floods are occurring in one part of the world and droughts in other parts. Even the weather condition & trends at a particular location are changing [10]. Pakistan, being an agricultural country, has also been suffering from the negative effects of climate change. Due to climate change, rapid population growth, and inadequate infrastructure development, the Pakistan is becoming water scarce. Per-capita water availability has already gone much below the threshold value of 1000 m3 per capita and it is expected to down up to 500 m3 per capita by 2050 if not managed well [11]. More than 150 extreme weather events reported in Pakistan between 1998 and 2018. Extremely high and low temperatures, the worst rains, and flooding were among them [12]. To do a study related to climate change, GCMs are powerful tools, however, there is a need to carefully select the GCMs and intelligently opt RCPs. The current research aims to also study climate change in Peshawar and will give a scientific approach on how to select appropriate GCMs out of available GCMs.

Thus, the problem statement is as:

"Peshawar is one of the major cities of Pakistan. Being the provincial capital, the majority of the population of Khyber Pakhtunkhwa either has shifted or plans to shift to Peshawar or its vicinity. As a result of population densification, increased transportation, and the establishment of various small and large industries, the city has been experiencing the impacts of extreme weather events, such as heavy rains causing floods and rising temperatures. Therefore, the present study selects and utilizes three GCMs and will focus on changes across all four scenarios"

1.5 Overall Objective and Specific Aim

The overall objective, being part of "WE R" a research group of the Civil Engineering Department, Capital University of Science and Technology, this study will evaluate variations and analysis of different scenarios for the specific GCM(s) to simulate climate change for the study area.

"This MS research work's specific aim is to examine and compare 03 GCMs for RCPs with observed weather data for future projections to choose the most effective configuration of climate change models for the target site."

1.6 Scope of Work and Study Limitations

The scope of work includes the collection and analysis of observed data, selection of suitable climate change models in regional contexts, analysis of simulated data, and comparison of the results of both simulated and observed data.

Study limitation includes;

- Use of a maximum of 03 GCMs.
- The scope of this research primarily centered around climate science, with a specific emphasis on investigating climate change and its effects on temperature and precipitation patterns. Given this focus, the study did not necessitate an in-depth exploration of detailed socioeconomic scenarios (SSPs) and only relied on RCPs for modeling future climate scenarios.
- Despite our multiple requests to the Meteorological Department, we have only been provided with data up to the year 2018. Therefore, the study utilized observed data until 2018.
- The study relied on IPCC AR5 since AR6 was not available for download during the research period.

1.7 Thesis-Outline

The structure of this research work has been thoughtfully organized to offer readers a comprehensive roadmap and a crystal-clear sense of direction in their exploration of climate scenario projections. Through a detailed examination of this thesis, researchers and professionals hailing from diverse disciplines, with a special focus on civil engineers and water resource engineers, will gain invaluable insights into the intricate methodologies employed for selecting global-climate-models or general circulation models.

Moreover, they will gain a profound understanding of the significance of representative-concentration-pathways, along with the sophisticated techniques utilized for calibration and validation. The thesis serves as an illuminating guide, illustrating the step-by-step approach used to conduct the research, analyze the intricate climate projections, and carry out a meticulous assessment.

The thesis is thought fully divided into five major chapters, each one representing a pivotal aspect of this research journey. Through these chapters, readers will be guided on a logical and systematic exploration, starting from the fundamental principles of the climate change and the role of global or general climate models to the detailed examination of the region of interest - Peshawar, Pakistan.

Chapter 1 lays the foundation for this research by encompassing various key elements, including the background and significance of global-warming and the climate change, the impact of the industrial revolution, the motivation driving this research, the problem statement, the overall objective, specific aims, scope of work, and study limitations. This chapter serves to enlighten the readers about the necessity of conducting research in this area, the crucial importance of the present study, the boundaries within which the research operates, and the objectives that guide the research endeavors. The problem statement, the overall objective, specific aims, scope of work, and study limitations

Chapter 2 presents a comprehensive literature review, delving into crucial aspects that form the backdrop of this research. The literature review encompasses in-depth discussions on the industrial revolution, global warming, and climate change, and specific insights into the climate change scenario in Pakistan and Khyber Pakhtunkhwa. Additionally, it explores the intricacies of general circulation or global-climate-models (GCMs) and representative- concentration-pathways (RCPs), while also delving into the application of the Nash Sutcliffe technique for calibration and validation.

Chapter 3 describe the specifics of the study area & the overall methodology adopted for the research work. It includes comprehensive information on data collection from the meteorological department, data downloaded from online tools, data analysis techniques, key considerations for selecting general circulation models, the selection process of various representative-concentration-pathways , and the method used for calibration and validation.

In this chapter, the study area is thoroughly described, shedding light on its geographical and climatic characteristics, providing readers with a clear understanding of the region under investigation. The methodology section outlines the step-by-step approach used throughout the research, ensuring transparency and reproducibility of the findings.

Chapter 4 provides result, analysis and discussion, captures a thorough and detailed analysis and interpretation of the precipitation and temperature data collected for Peshawar city, covering the period from 1989 to 2018. To gain insight into potential future climate scenarios, the study utilized three Global-climate-models (GCMs), namely HadGEM2, MIROC5, and MRI-CGCM3. These GCMs were applied across four distinct Representative-Concentration- Pathways (RCPs) - 2.6, 4.5, 6, and 8. The analysis was focused on three specific time horizons: 2030, 2060, and 2090. By employing these GCMs and RCPs, the research aimed to offer a detailed understanding of the potential variations in precipitation patterns and temperature trends in Peshawar city over the selected periods.

Chapter 5, the comparative assessment of climate scenario projections conducted for Peshawar, Pakistan, utilizing global climate models, has illuminated and concluded the potential outcomes and impacts of climate change on the region along with the recommendations.

Chapter 2

Literature Review

2.1 General

There is a growing set of study on climate change & its impact on many locations of the world, according to the literature analysis of the comparative evaluation of climatic scenario prediction using global-climate-models for Peshawar. Studies have been done specifically on how Pakistan and South Asia may be affected by climate change.

The region's future climate has been projected using a variety of global climate models, and it is generally concluded that in the decades to come the region will face raise temperatures, varying precipitation patterns, and more repeated worst weather events. In addition, there is considerable worry about how climate change may affect local agriculture, water supplies, and public health.

2.2 Industrial Revolutions

The Industrial Revolution (IR) 4.0's key theme is the trend of digitization, automation, and wider usage information and communications technology [13]. Rapid advancements in digital technology have triggered a new industrial revolution phenomena known as Industry 4.0. This revolution supported the interconnection across all industry components by introducing modern technologies [14]. Declining environmental quality poses a severe threat to the continuation of life on

Earth. Like other countries, China has been working to lessen its reliance on non-renewable energy sources by introducing innovative energy-efficient technologies that support the growth of a more sustainable industrial structure [15]. There is no arguing that the IR-4.0 has changed how we interact, live, and work. The interaction between people, businesses, and governments, as well as the environment in which they operate, have undergone drastic economic changes as a result of the information and technology (IT) age [16]. The results show that the industrial revolution in activities has an impact both globally and locally. We have observed an increase in the share of top firms, particularly in small markets, as a result of their tendency to expand by entering new, smaller markets. The increased presence of top firms has reduced local focus on local markets as fresh establishments of leading firms take market share away from local incumbents [17]. The industrialization happened in locations with lower salaries but higher mechanical skills, but other parameters i.e. literacy, banks, and proximity to coal, have little explanatory power. Contrary to popular belief, living standards did not remain stagnant during the Industrial Revolution [18]. The current study analyzed, discussed, and synthesized the applications, opportunities, and problems of artificial intelligence (AI), robots, and block chain at 26 selected higher education institutions (HEIs) between 2013 and 2019 [19]. Economic history is full of technical disruptive inventions that have altered markets, lifestyles, and corporate practices. Starting with steam power, electricity, telegraphs, and internal combustion engines, and continuing by means of mainframes, PCs, the internet, and mobile/social networking, advances have transformed the business sector. Even so, new disruptive technologies and innovations continue to emerge [20]. The relevance of adopting a circular economy, as well as current technical breakthroughs, and their role in decreasing climate risk and dependency on existing resources, were examined in detail. This evaluation also emphasized the improvement of environmental feasibility through the use of IR 4.0 technology and other approaches such as LCA and decentralized treatment systems [21]. It is believed that the industrial revolution significantly accelerated climate change. The effects of climate change offer serious problems for societies all around the world, including threats to infrastructure, food security, and human health. In the era of the Industrial Revolution, resources appeared limitless, and humanity regarded nature as a force to conquer and control. However, a major challenge confronting us today is the obsolete infrastructure and methodologies from the initial Industrial Revolution, which continue to pose significant problems for humankind [22]. The term "Industrial Revolution" refers to the economic and technological advancements that gained momentum and pace during the eighteenth century, ultimately giving rise to modern industrialism. Blanqui asserted in 1837 that this revolution had brought about more profound changes to England's industrial conditions than any other period in human history. Toynbee categorized the industrial revolution as one of the key historical phases. The swift modernization of Japan makes the term "industrial revolution" particularly fitting for its case. However, it is noteworthy that the commercial and financial transformations in Japan have had a more extensive impact than strictly industrial changes [23]. Numerous theories vie for explaining the Industrial Revolution, yet none have undergone econometric evaluation. This research delves into the diverse growth patterns observed in the English counties from the 1760s to the 1830s, aiming to elucidate the factors behind these disparities. Our findings reveal that industrialization took root in regions characterized by initially lower wages but abundant mechanical skills. On the other hand, parameters such as literacy, the presence of banks, and proximity to coal held little influence in explaining these variations [18]. Due to the predicted disruptions, the adoption of 4th industrial revolution practices globally has been a hot topic of discussion. Education is recognized as a crucial instrument for empowering individuals with the essential abilities to effectively embrace and adapt to the challenges posed by the 4th Industrial Revolution (4IR) [24]. Numerous writings have explored the role and influence of the Fourth Industrial Revolution (4IR) on higher education (HE). Additionally, several review studies have examined how 4IR technologies contribute to and affect HE. However, it is noteworthy that the mainly of these works have concentrated on individual 4IR technologies in isolation, as evidenced by the review studies cited in this current research [25]. The results indicated that the adoption of Fourth Industrial Revolution (4IR) principles is shaped not only by perceptions but also by tangible challenges such as divergent global perspectives on 4IR, complexities in conceptualizing its scope, and the existence of a technological skills break in higher education institutions, among further elements. In order to overawed these problems and fully leverage the potential of 4th Industrial Revolution in higher education institutions, institutions must gain a comprehensive understanding of its educational implications. Achieving this entails conducting further empirical research work on the effects of 4IR on the education sector [26]. Environmental sustainability has emerged as a paramount concern in the realm of industrial development. This study seeks to perform a systematic literature review, with the objective of offering diverse research avenues for future scholars to explore. Additionally, the review aims to shed light on the intersection of Industry 4.0 and environmental sustainability, providing valuable insights into this crucial domain [27]. The agricultural sector's industrial revolution is confronted with demographic challenges, particularly related to an ageing workforce. Intelligent technology, artificial intelligence, big data, and augmented reality are being adopted as strategic options to meet these difficulties. The use of information technology in Indonesia's agricultural sector has addressed these issues and promoted growth in the sector, demonstrating a direct or indirect positive impact [28].

2.3 Global Warming and Climate Change

[29] analysed that global warming continues to occur as a output of the usage of fossil-fuels, with less marks of the focus of greenhouse gases reducing. The climate of a given region has a significant impact on the environment. Any variation may have a negative impact and outcome on the ecosystem's proper working and processes. Global warming and its consequences pose a serious challenge to every industry. Decreased agricultural output, forest degradation, biodiversity loss, species shift, increase sea level, habitat loss, intensified land degradation, and higher possibilities of cyclones, floods, and heat waves are among the impacts.

According to [30], A lot of scientific disciplines, particularly atmospheric research, oceanography, and ecology, must work together to address the serious global issue of climate change. To comprehend, model, and predict future climate conditions, specialised tools and approaches are needed due to the complexity of the issue and size. Our comprehension of climate change and the precision of climate projections can be considerably improved by ChatGPT along with other artificial intelligence and natural language processing technologies. [31] investigated that radical environmental change will be witnessed if fossil fuel use continues to release greenhouse gas emissions. Therefore, it is crucial to focus efforts in orthography policy to support climate-change goals at the local and international level.

[32] used the MarkSim GCM-DSSAT weather file generator, forecasts of rainfall, maximum temperature, and lowest temperature are included as weather parameters for climate change scenarios. Although the rainfall kept the same with significant variations, the solar radiation demonstrated an increasing tendency. [33] investigated the impact of climate change using weather data produced by the MarkSim GCM of the IPCC's RCP scenario for the anticipated years. According to the study's findings, climate change may eventually cause decrease in all reference genotype yields in several pigeon pea maturity groups. [34] researched how Rajshahi's temperature will vary in the years 2030, 2050, and 2080 as a output of climate-change.

According to the findings, there will be average temperature increases in 2030, 2050, and 2080 compared to the current climate. Four global climate or general circulation models from the Coupled-Model-Intercomparison-Project were downscaled by [35] using the Eta regional climate model, which is utilized by the Brazilian National Institute for Space Research (CMIP-5). Marksim GCM-DSSAT weather file generator and weather parameters for climate change scenarios are used by [36] to investigate the study. [37] concluded that in all scenarios, the influence of climate change accelerated generative stages, and lowered production. [38] analysed that the kandi region will experience more rainfall as well as continuous warming over the 21st century.

According to [39] under RCP 6.0, the average annual minimum and maximum temperatures will rise by 1.79 °C and 2.89 °C, respectively, while the mean annual rainfall will decrease by 16.15% and 22.94% for two future periods. The study by [40] revealed variations in the frequency, duration, and intensities of hydrological droughts under dry and wet GCM conditions, and that future precipitation changes will be the main determinant of the likelihood of drought characteristics. [41] analysed that an unequal raise in precipitation and an disproportionate raise in temperature limits, which pointed to hazards corresponded to managing climate-change and the requirement for policy-level decisions in this situation. GCMs can help informing policy positions aimed at reducing the effects of climate change by offering insights into the manner in which climate may change in the future.

[42] assessed climatic characteristics like the South-Pacific- Convergence-Zone (SPCZ) and the Intertropical-Convergence-Zone (ICZ), including variables that influence natural climate variability throughout time. A summary of the main climate processes and parameters that affect the Pacific, together with an analysis of how anthropogenic global warming will likely affect these processes and drivers in the future, is expected to assist relevant local agencies (such as Meteorological-Services-and-National Disaster-Management-Offices) in clearly communicating new knowledge to sector based specific key stakeholders and the wider range of community using awareness raising. [43] explored the presumptions and data inadequacies that affect conventional life-cycle analysis approaches in assessments of methane emissions from livestock globally. These issues include a lack of data resulting from a concentration on industrial rather than widespread systems, mistakes brought on by the use of improper emission factors, uncertainties over how the potential for global warming for various greenhouse gases is estimated, and disagreements regarding the proper baselines.

According to [44] , the bulk of the currently appropriate habitats are unaffected by climate change, and there is little to no impact on the theoretically ideal planting area for P. chinensis. The potential planting area will somewhat expand in the north and slightly shrink in the south as a result of rising temperatures. According to [45], the effects of global warming on biodiversity are exacerbated by the increasing frequency and intensity of extreme weather. Concerns regarding irreparable ecological damage have been raised as a result of local extinctions and communal collapses caused by the global effects of a number of climate change components. [46] forecast the period before crucial global warming thresholds are achieved by using the spatial pattern of historical temperature observations. Despite the fact that no observations were used during training, validation, or testing, the ANNs correctly predicted the timing of historical global warming from maps of historical annual temperatures. The primary estimate for the 1.5 °C global warming threshold, according to earlier studies, is between 2033 and 2035, with a 1 range of 2028 to 2039 in the Intermediate (SSP2-4.5) climate forcing scenario. The occurrence of global warming, climate change, and environmental pollution brings forth distinctive combinations of abiotic and biotic stresses for plants to contend with [47].

The phenomenon of global warming is exerting its influence on animal populations across the globe, primarily due to prolonged rises in temperature and a surge in the occurrence of extreme heatwave events. Among the impacted creatures, fishes, being ectotherms, are projected to be especially susceptible to the effects of global warming. While there is little information on how global warming affects stress physiology in the wild, numerous studies have investigated how temperature rises affect stress physiology in carefully controlled laboratory settings. These studies offer valuable insights into the potential effects that can be anticipated in the wild as well [48].

After analyzing 118 countries spanning the period from 1960 to 2016, it has been observed that higher temperatures are positively correlated with higher urbanization rates in the long run. This connection is considerably more significant than any short-term associations between these variables. Moreover, the long-term relationship between global warming and urbanization is influenced by country-specific conditions, suggesting that the impact varies depending on individual country characteristics [49]. This review examines and compares the global-warming potential of various renewable hydrogen manufacture technologies. These technologies include wind- and solar PV-powered water electrolysis, biomass gasification, and biogas reforming. The analysis is grounded on a compilation of 64 hydrogen production cases sourced from the existing literature [50]. A.I and natural language processing technologies, like ChatGPT, hold immense promise in the realm of climate change research, offering opportunities to enhance our comprehension of the phenomenon and refine climate-projections. ChatGPT can be harnessed in multiple methods to support climate research, such as facilitating model parameterization, analyzing and interpreting data, generating various climate scenarios, and evaluating models. By leveraging this innovative technology, researchers & policy makers gain a potent tool to create & analyze diverse climate scenarios using a vast array of data inputs, thereby leading to more accurate climate projections [51]. The impact of global-warming is anticipated to output in an increase in wildland fires, but there is a dearth of information concerning the future changes to fire regimes in Europe [52].

2.4 Climate Change in Pakistan

[53] As a result of climate change, Pakistan has been shown to be among the most vulnerable countries, particularly in Southeast Asia in which it frequently faces floods and droughts. Climate change has a detrimental effect on the agricultural sector, groundwater, soil quality, nutrition, health condition, soil organic matter and poverty. According to [54], Pakistan is experiencing the most rapid urbanization rate in South Asia. If this urbanization process remains unplanned, it could lead to detrimental consequences. Not only would it diminish the adaptive ability of the inhabitants to handle with the variations, but it could also lead to chaotic living conditions for the population. [55] assessed the impact of financial development, technological advancement (fertilizer consumption, enhanced seed distribution), and global climatic change (CO2 emissions) on Pakistan's cereal production from 1977 to 2014.

According to [56], Pakistan is among the regions of the developing world that are most vulnerable to catastrophic weather occurrences, particularly in Southeast Asia. Due to its significant vulnerability to extreme weather occurrences, Pakistan has been negatively impacted by climatic changes. Numerous studies have examined how farm households perceive, adapt to, and mitigate climate change, but there is insufficient information on farm households' awareness of climate change in Pakistan. The findings by [57] indicated a significant rise in climate change coverage in Pakistan throughout the years. Nevertheless, the predominant emphasis has been on areas such as climate politics, climate governance, policy and climate change and society. The study delves into the development of these diverse themes and their potential effects on the populace.[58] Investigated that drought, an extreme climatic occurrence primarily triggered by insufficient rainfall, results in water scarcity across diverse agro-ecological regions of Pakistan. The situation can be worsened by the prevailing dry weather conditions. Hence, it becomes imperative to have precise, timely, and effective drought monitoring to mitigate its adverse impacts. In this research, a combination of Moderate- Resolution-Imaging-Spectroradiometer (M-O-D-I-S) and TRMM-based data, along with remote sensing techniques, were employed to enhance drought mitigation and bolster disaster risk reduction strategies. [59] investigated the relationship between rice output in Pakistan and carbon dioxide (CO2) emissions, average temperature, planted area, and fertilizer consumption.

According to [10], Pakistan's per capita contribution to climate change is unusually significant compared to the rest of the world since indigenous species of animals like lions, vultures, dolphins, and tortoises are in danger of going extinct despite creating and contributing minuscule amounts to global GHG emissions.with local animal species like lions, vultures, dolphins, and tortoises facing extinction despite producing and making a negligible contribution to global GHG emissions. The review's conclusions revealed that GHG emissions are responsible for climate change, which has an effect on Pakistan's society as well as agriculture, forestry, livestock, and weather patterns. In both RCP scenarios performed by [60], there was a linear positive relationship between air temperature and precipitation across Pakistan. Cities with hotspots, or those with the hottest, driest, and wettest climates, were also found. By the end of the century, Hyderabad is predicted to overtake Jacobabad, Bahawalnagar, and Bahawalpur as the warmest cities in Pakistan, with average temperatures reaching 29.9°C under RCP4.5 and 32.0°C under RCP8.5. The majority of Pakistan's hottest cities are found in regions near its southern border. On the other side, the three wettest cities, Murree, Balakot, and Muzaffarabad are placed in the monsoon region.

[61] Studied that Pakistan ranks among the top ten countries profoundly impacted by global warming. Presently, the nation is grappling with severe repercussions of this phenomenon, exemplified by an extreme flood event. This catastrophic flood has left an astonishing toll, affecting 33 million individuals, obliterating 1.5 million homes, and causing extensive damage to crops amounting to $2.3 billion. The flood's devastating impact extends to infrastructure, damaging over 2000 km of roads, disrupting connectivity to provinces and major cities. Consequently,

Pakistan is facing an economic crisis, with inflation reaching an alarming high of 26% to 27%, and a looming severe food crisis. Adding to the distressing situation, several regions in Pakistan recently recorded unprecedented temperatures, with Jacobabad registering a scorching 51 °C, while various territories saw the mercury soar to 40 °C. [62] conducted a study to investigate the primary challenges faced by Intergovernmental Relations (IGRs) concerning effective climate adaptation governance, focusing on the Pakistani agriculture sector as a good study. The outcomes revealed that the principal cause of weak IGRs in this context is the unstable political situation prevailing in the country. [63] studied the Environment-Kuznets-Curve (EKC) theory's viability for the country of Pakistan. An autoregressive-distributed-lag (ARDL) model was used in the analysis, and it was discovered that using ICT has a negative effect on CO2 emissions. Additionally, the long-term outcomes showed that Pakistan's environment would benefit more from ICT equipment imports. However, the lack of use of green technology in ICT equipment made in Pakistan may result in electronic waste. Through an eclectic production model, [64] examined the dynamic relationship between shifting annual temperatures and production of important crops like wheat, rice, bajra, jowar, maize, barley, sugar cane, mastered oil, and cotton in Pakistan from 2000 to 2019. A panel econometric analysis' predicted results showed that, while the short-term effects of rising temperatures on certain crop output were negligible, the long-term effects were significantly detrimental. According to the [65], the results of the vector autoregressive model's long-run dynamics demonstrated that while temperature, rainfall, and livestock production all have positive effects on carbon dioxide emissions. Similarly, crops production, energy use, and population growth have negative effects. The results of a short-run analysis also showed that carbon dioxide emissions in Pakistan are positively impacted by forestry production, crop production, animal production, population increase, rainfall, and temperature, while carbon dioxide emission has negatively impacted by energy usage. According to the [66], Pakistan's high population growth has led to studies showing that the country is particularly vulnerable to climate change., location, and old technological production practices. History demonstrates that floods and the detrimental effects of the climate on crops have caused Pakistan to suffer. According to research, it might cost up to US$14 billion to address the current climate's effects on crop productivity. Due to the severe weather conditions, which include natural droughts, floods, and heat waves, agricultural production is reduced in Pakistan.

According to the [67] , in developing nations like Pakistan, agriculture provides the bulk of the rural and surrounding urban populations with their primary means of survival. Despite its enormous economic contribution, it confronts serious problems imposed due to climate change, including increased temperatures, floods, droughts, and yield losses. The second-most important food crop and source of income for millions of farm households in Pakistan, rice, is seeing a severe yield decline as a result of climate change. Results by [68] indicated that by 2050, climate change-related losses in wheat and rice crop output will cost Pakistan's real gross domestic product $19.5 billion. This loss will also be accompanied by a rise in commodity prices, which will cause a significant drop in domestic private consumption. [69] studied how the Punjab province of Pakistan's cotton farmers were reacting to the impacts of climate-change on higher cotton yields and overall cotton income. In three districts of Punjab, Pakistan's primary cotton-producing province, 480 cotton growers were surveyed using a well-designed and pretested questionnaire. Propensity score matching was employed in this study to ascertain the association between the impacts of adaptability on the productivity of cotton and cotton income. Logistic regression analysis was carried out to find the adaptation-related components.

According to [70], the management of river basins and watersheds, agriculture and irrigation, urban and domestic water concerns, floods, droughts and disaster management, groundwater management, and transboundary management are the main climate-water governance domains in Pakistan. [71] studied the potential effects of changing land use and climate on the flow of streams in the Pakistani Mohmand Dam catchment. The Soil, and Water Assessment Tool (SWAT), a semi-distributed hydrological model, was used to do this. The most recent dataset from Coupled-Model-Intercomparison-Project phase 6, which contains information from multiple global-climate-models (GCMs), was also used. By integrating these tools and datasets, the researcher aimed to apprehend how alterations in land cover and, potential climate shifts could impact the stream flows in the specific catchment area of Mohmand Dam in Pakistan

2.5 Climate Change in Khyber Pakhtunkhwa

[72] researched that KP is split into three climatic zones: the northern, central, and southern climatic zones. [56] studied the level of awareness of climate change and its associated aspects among Pakistani agricultural households. A household survey was used to collect data from 400 research participants from 4 districts in the Khyber-Pakhtunkhwa (KPK), province of Pakistan. [73] is carried out research in the Pakistani province of Khyber Pakhtunkhwa to find out how smallholder farmers feel about climate change. 400 smallholder farmers in Khyber Pakhtunkhwa's Malakand, Mardan, and Swabi districts provided information.[74] investigated that the overwhelming floods of 2010 and, 2011 in Pakistan discovered serious climatic shifts, especially in the District Charsadda of Khyber Pakhtunkhwa. These national floods washed fertile soil in the study region, causing agricultural production losses and a rise in vector-borne illnesses in crops of the district Charsadda. [75] estimated the effect of climate change on maize productivity in Khyber Pakhtunkhwa, Pakistan. The districts of Chitral, Swat, Mansehra, Peshawar, and D.I. Khan were chosen among Khyber Pakhtunkhwa's various agro-ecological zones. The meteorological and non-climatic variables used in the study were maize area, maximum temperature, minimum temperature, and precipitation. The influence of climate- change on wheat producers in Khyber Pakhtunkhwa, Pakistan, was investigated by [76].

A comprehensive farm survey of 150 farms was planned. Three districts from the study area were chosen through a multistage sample process: Chitral, D.I. Khan, and Peshawar. The possible effects of climate change on wheat output in several agro-ecological zones of Khyber Pakhtunkhwa (KPK), Pakistan, were investigated by [77]. Using experimental dataset, the CERES-Wheat model was calibrated and evaluated. 50 farms' survey data were obtained from the study districts of Chitral, Dera Ismail (D.I.) Khan, and Peshawar. Climate change scenarios for the mid-century (2040-2069) were developed using 05 selected general circulation or global-climate-models (GCMs) and representative-concentration-paths (RCPs 4.5 and 8.5). In order to investigate the socioeconomic and demographic factors linked with climate change in the four districts of Khyber Pakhtunkhwa, the [56] employed a probit model technique. According to the findings, 73% of farm households were aware of the impacts of climate-change. Farm communities' awareness of climate change was found to be substantially correlated with socioeconomic and demographic factors including farm household age, education level, agricultural knowledge, ownership of land status, extension, as well as access to information sources. Data is gathered by [73] from 400 smallholder farmers in Khyber Pakhtunkhwa's Malakand, Mardan, and Swabi districts. The study elaborated on farmers' perceptions and farming adaptations to climatic fluctuations. Binary logistic regression was used to identify the factors that influence smallholder farmers' adaption tactics. The findings showed that responsiveness and farm household adaptation measures for climate change were widespread during the course of the research work. 116 agricultural households were surveyed as part of [74] extensive field surveys in the Charsadda area of Pakistan's Khyber-Pakhtunkhwa province. The agriculture industry and the livelihoods of the local peasants are under threat due to climate change factors like shifting temperatures, signs of ongoing droughts, and a constant shift in rainfall patterns. [78] examined a dataset of 600 agricultural households from four regions in Khyber Pakhtunkhwa (KPK), Pakistan province collected through a standardised questionnaire. Flood (60%) was cited by farm households as a climate issue at the farm level, along with crop pests (56%) and insect attacks (55), extreme temperatures (54), human diseases (54), and livestock diseases (46%). [75] concluded that the highest temperature had an adverse effect on maize yield. The impact of precipitation on maize yield is favorable and large. High temperatures are harmful to maize productivity. As a result, policy efforts should be concentrated on the effect of change in climate on maize productivity. The climate scenarios were examined by [76] selecting 05 GCMs from the most recent CMIP-5 family with 02 RCPs of 8.5 and 4.5, respectively, at two carbon concentrations of 499 ppm and 571 ppm. For each GCM, yield simulations were run. Crop model results show that wheat yields would increase in Chitral, whereas yields will decrease in D-I-Khan and Peshawar owing to climate change. In the northern Hindukush-Himalayan area of Pakistan, [79] investigated an existing research vacuum addressing public knowledge of climate risks and associated adaptation measures. Stratified sampling was used to choose 25 union councils from the study area's nine tehsils (sub-districts). The statistical technique was utilized to gather information from 396 respondents utilizing structured questionnaires. The loss of forests, waste from industry, manmade contaminants environmental factors, and the use of fossil fuels are the main contributors to climate change, which is exacerbated by population growth. A few of the effects noted over the years include temperature fluctuations, unexpected rainfall, floods, droughts, and retreating glaciers, which are extreme weather occurrences. Farmers' decisions about climate change adaptation strategies and their socioeconomic circumstances, were studied by [80], a total of 200 farmers in Nowshehra, Khyber Pakhtunkhwa, were surveyed at random. To examine the relationship between independent factors and farmers' decisions to choose a particular adaptation approach, the study used a multivariate probit model. The survey discovered that rainfall collection, soil conservation, adjusting cultivation dates, water bodies, and hillsides with spillways were the most often used drought management strategies. The elements influencing farm household adaptation to climatic change and the restrictions to adapt techniques in Pakistan's Khyber Pakhtunkhwa area were investigated by [81], the multinomial logit model was used to categorise farmers' adaption techniques to climate change for this aim. [72] concluded that climate factors' effects increase from southern to northern climate zones. The study also showed that increasing maize planting areas can reduce any adverse shock to crop productivity. In all climatic regions of KP, it is known that variations in environmental factors have substantial short- and long-term impacts on maize productivity. [82] conducted a study to assess the influence of climatic variations on tomato productivity in different agro-ecological zones of Khyber Pakhtunkhwa, Pakistan. The outcomes of the study highlighted that both the average maximum temperature and its square value exhibited a significant impact on tomato yield. This suggests that the productivity of tomatoes is sensitive to variations in maximum temperature, and the relationship between temperature and yield may not be linear, as indicated by the significant influence of the squared temperature term. According to [83], due to its substantial corn production, Khyber Pakhtunkhwa (KP) may experience a decrease in corn productivity. While crop yields tend to rise under moderate temperatures, temperatures surpassing 30 degrees Celsius can lead to a reduction in corn yield. Consequently, KP might encounter a shortage of cereal crops in the near future as a consequence of climate change. According to [84], meteorological stations in Peshawar, Dir, Chitral, Drosh, Kakul, and Saidu have shown a positive trend in rainfall. On the other hand, stations in Cherat, Bannu, and Balakot have exhibited a moderate rainfall trend. However, for the remaining stations, no clear trend could be discerned, likely because of the limited duration of available data. The study by [85] , a novel approach is presented, It entails linking the Sustainable Livelihoods Framework and the Vulnerability Framework of the Intergovernmental-Panel on Climate Change. The purpose of this expanded framework is to assess how ecological measures, community susceptibility, and change in climate mitigation affect each other. This study will concentrate on a sizable ecological region in northwest Pakistan because it exhibits a range of geographic and climatic characteristics.

The Swat region of Matta-Kharari was examined by [86] to record the floristic diversity and biological range of plant species. Ecological research had not before been done in this area. To do this, plant species were sampled using quantitative ecology methodologies. Specifically, sixty-seven quadrats were established, each measuring 1x1 m^2 for herbs, 5×5 m^2 for shrubs, and 10x10 m^2 for trees. These quadrats served as systematic sampling units to gather data on the plant diversity and distribution within the study area. According to [87] , at present, climate change stands as one of the most crucial global issues. This study delved into the effects of climate change on rice production in distinct rice-production agro-ecological regions within 4 districts of Khyber Pakhtunkhwa province: Swat (region A), Mansehra (region B), Mardan (region C), and D.I. Khan (region D). The research aimed to assess how climate change impacts rice production across these diverse agro-climatic regions in the specified districts.

2.6 General-circulation-models and Representative Concentrated Pathways

Computer-driven models for predicting climate changes are called general-circulation-models (GCMs), also referred to as global-climate-models. GCM is regarded as a crucial informational tool for analysing future climate [88]. The selection of general-circulation-models (GCMs) must be done carefully if the effects of climate change on a region's hydrology are to be accurately assessed [89]. The shifting climate has led to changes in precipitation and temperature patterns worldwide, elevating the vulnerability to natural and social calamities, particularly in transitional coastal zones like the Huaihe river basin (HRB). To address this, the study employed the Empirical Quantile Mapping (EQM) method for bias correction and conducts a comprehensive evluation of the presentation of 30 global-climate-models (GCMs) from the Coupled-Model-Intercomparison Project-phase 6 (CMIP6). Assessment focused on how well these models simulate precipitation and temperature over the Huaihe river basin (HRB) during the period from 1979 to 2014 [90].

To accurately estimate the effects of climate change in a region, it is essential to use an adequate ensemble of general-circulation-models (GCMs). There are numerous techniques for ranking and choosing GCMs [91]. The performance of six global- climate-models (GCMs) from the Coupled-Model-Intercomparison-Project Phase 6 (CMIP-6) was evaluated. The examination centered on their capacity to reproduce weather conditions in 29 Indonesian cities, including precipitation, wind speed, temperature, and relative humidity. The database served as a standard for evaluating the working of the CMIP-6 GCMs' simulations of surface air temperature, precipitation, wind speed, and relative humidity for cities between 1980 and 2014 [92].

2.6.1 HadGEM2

The study's primary objective was to assess the performance of CMIP5 models, specifically focusing on CORDEX and Verdai dynamics Seasonal pressure anomalies in Iran. Among the CMIP5 models based on CORDEX project dynamic models, BCC-CSM, HadGEM2-ES, GFDL, and MIROC, it was found that HADGEM2-ES exhibited a higher level of correlation and efficiency compared to the other models [93]. The study employed dynamic downscaling to analyze the regional climate of the Korean Peninsula (KP) using a high-resolution regional climate model (RCM). The RCM was driven by multi-representative-concentration-pathways (RCP) scenarios of HadGEM2-AO to investigate changes in summer precipitation. Looking ahead to future projections, all RCP experiments, including different RCP radiative forcings (RCP2.6, RCP4.5, RCP6.0, and RCP8.5 runs), demonstrated an increase in summer precipitation over the Korean Peninsula [94]. The future scenarios were constructed using Representative-concentration-pathways (RCPs) 2.6 and 8.5, on the basis of MIROC-5 and HadGEM2-ES models. The Random Forest model demonstrated the best performance statistics among the evaluated methods. According to these climate change scenarios, there is a projected increase in the average Net Primary Productivity (NPP) for the Amazon forest, especially with a higher magnification under RCP 2.6. The HadGEM2-ES and MIROC5 models suggest an increase of 10% and 12% in NPP, respectively [95].

The study assessed the future climate susceptibility to vector proliferation using 02 models, HadGEM2-ES and MIROC5, under two scenarios: RCP 4.5 (stabilization level) and RCP 8.5 (high level). The assessment covered two time frames, 2011-2040 and 2041-2070. The variables considered for evaluation were relative humidity (RH), the annual percentage of days with the minimum temperature higher than the 90th percentile (TN90p), and the number of days in a year with precipitation higher than 10mm (R10) [96]. The findings from the HadGEM2-ES model indicate a decrease in precipitation, maximum temperature, and minimum temperature across all upcoming periods under RCP4.5. As for the review of the HadGEM2-ES model results under RCP8.5, it predicts a decline in precipitation throughout all upcoming periods, while the maximum temperature is expected to increase during the periods of 2051–2075 and 2076–2100 [97]. Model performance metrics demonstrate that RCA4-GFDL-ESM2M outperforms all other models with a correlation coefficient of 0.5, a root mean square error of 0.4 m s- 1, an RSR (Root Sum of Squares Ratio) value of 7.7, and a bias of 19.9%. Following in performance, RCA4-HadGEM2 and RCA4-CM5A-MR rank second and third, respectively [98].

In the July sea ice cover, during its maximum extent, the marginal ice zone (MIZ) fraction experiences a significant increase, approximately 2 to 3 times, from 14% (20%) in the 1980s to 46% (50%) in the 2010s, based on NCEP (National-Centers-for-Environmental-Prediction) and HadGEM2-ES atmosphere-forced simulations, respectively. In a HadGEM2-ES forced projection for the 2040s, the July sea ice cover is projected to consist almost entirely of MIZ, accounting for 93% of the total coverage [99].

This study utilized low (RCP2.6) and high (RCP8.5) greenhouse gas emissions scenarios from the Intergovernmental Panel on Climate Change (IPCC). The general circulation model HadGEM2-ES, part of the Coupled Model Intercomparison Project Phase 5 (CMIP5), was employed to drive the regional climate model RegCM4.7. The main objective of the study was to evaluate the performance of both models in simulating the spatio-temporal characteristics of extreme indices over tropical South America (TSA) during two periods: the historical period from 1986 to 2005 and the projection period from 2080 to 2099 [100]. meteorological data for the 2020–2050 interval were downscaled using the model HadGEM2 under 03 scenarios, namely RCP 2.6, RCP 4.5 and RCP 8.5 . Then, using the calibrated and validated SWAT model for investigating the effects of climate change on runoff and sediment in the basin. The results show a decrease in rainfall, an increase in temperature and a decrease in runoff in the 2050 horizon [101]. The simulations were generated using boundary conditions from simulations driven by the general circulation model HadGEM2-ES. The main objective was to assess the added value (AV) of RegCM4.7, by effectively reproducing regional aspects during the historical period (1986–2005) and evaluating its performance in simulating regional aspects for far-future change projections (2080–2099) [102].

In this study, a hydrological model was used to predict regional rainfall using a high resolution (HR) climate-model (HadGEM2-ES downscaled to a 5 km resolution) and the Representative-Concentration-Pathways, or (RCP8.5) scenario. The simulation of alternative combinations of rainfall events took into account both spatial and temporal factors, such as concentrated and scattered rainfall trends across the watershed, as well as temporal factors like varying durations and return times. [103]. Climate simulations were conducted using downscaling techniques to refine the RegCM4.3.5 model resolution to 50 km, considering RCP 8.5 and RCP 4.5 scenarios with MPI-ESM-MR and HadGEM2-ES models. The outcomes reveal that the Central Asian domain is expected to undergo warmer and more extreme temperatures due to the rise in radiative forcing. Notably, the annual lowest value of minimum daily temperature is projected to increase remarkably by up to 8 degrees, particularly in high latitudes. Over Siberia, an even more significant increase of more than 12 degrees is anticipated [104]. The objective of this study was to identify suitable areas for candelilla conservation in Coahuila under future climate change conditions. To achieve this, we utilized records of candelilla presence, as well as current and projected bioclimatic layers obtained from the MPIESM-LR and HadGEM2-ES climate models, using two scenarios - RCP 4.5 and RCP 8.5. These data were combined with soil and topographical variables to create species distribution models, allowing us to propose potential areas for candelilla conservation considering changing climatic conditions [105].

The future climate data used in this study were obtained from the Multivariate Adaptive Constructed Analogs method, using the Global Climate Model HadGEM2 under the representative-concentration-pathways 8.5 [106]. For this study, the GFDL-ESM2M and HadGEM2-ES global models were employed, and their output was downscaled by WRF under the RCP4.5 scenario. The details of the various datasets used are provided. Following a comparison of historical climatic variables simulated by each GCM-RCM with observed climate data, it was observed that GCMs, RCM inclined to overestimate annual precipitation and incorrectly represent the timing of the rainy season [107].

In this study, we utilized Mean monthly temperature and rainfall data in GeoTiff raster format from the Coupled-Model-Intercomparison-Phase 5 (CMIP5). We employed two global circulation models, namely CCSM4 and HadGEM2-ES, to explore RCPs - representative comparison pathways, RCP 8.5 and RCP 4.5. The global-climate-models (GCMs) were freely downloaded from WorldClim at a spatial resolution of 1-km for the analysis [108]. In this study, two representative-concentration-pathway scenarios (RCP4.5 and RCP8.5) were used to investigate potential changes in the flow of streams and reservoir storage from 2021 to 2098. These scenarios were created using the GFDL-ESM2M, HadGEM2-ES, and MPI-ESM-MR global-circulation-models. Used a physically based model called SWAT (Soil and, Water-Assessment Tool) to understand the hydrologic response of the basin to climatic variations [109]. The simulations were performed for two distinct periods: the historical period spanning from 1996 to 2005 and the future period between 2021 and 2032. Using AERONET and MISR statistics, the HadGEM2 model was evaluated, and the results showed that the simulation could replicate the aerosol characteristics with a high degree of confidence. [110].

2.6.2 MIROC5

The forthcoming scenarios were derived from RCPs 8.5 and 2.6, utilizing the models, HadGEM2 and MIROC5. Among the statistical models used, Random Forest exhibited the most favorable performance (with $R^2 = 0.71$ in training and 0.68 in the holdout-test). The scenarios for climate change foresee a rise in the average Net Primary Productivity (NPP) for the Amazon forest, particularly more higher intensification in RCP 2.6. The NPP increase is projected to be 10% for the HadGEM2-ES model and 12% for the MIROC5 model under RCP 2.6. These findings indicate the potential for an enhanced NPP in the Amazon forest under these climate change scenarios [95]. The SUFI-2 technique was used to calibrate the SWAT model, and validation findings for a 20-year forecast period (2020–2040) showed the model to be highly accurate at simulating runoffs. For predicting the basin's temperature and rainfall, CMIP5 models were utilized, with the Miroc5 scenario showing the best performance. The outcomes indicated basin's forthcoming climate situations are characterized by an increase in temperature and a decrease in rainfall, which were found to be consistent with appropriate changes in the climate outlook [111].

The researchers employed the model to simulate the long-term impacts of climate change by evaluating two representative-concentration-pathways (RCPs) - RCP4.5 and RCP8.5. These pathways represent two extreme scenarios and were assessed using global circulation models available in the region: MIROC5 for wetter conditions and CSIRO-Mk3 for drier conditions [112]. The main objective of this study was to evaluate the future trends and intensity of climatic factors, namely temperature and rainfall, in the Dechatu catchment, Ethiopia. To achieve this, different representative-concentration-pathways (RCP4.5 and RCP8.5) were considered. Additionally, the study aimed to identify existing climatic adaptation practices in the region.To understand the changes in temperature and rainfall from 2025 to 2075, four global/derived regional climatic models (GCMs/RCMs) - CanESM2, CNRM-CM5, EC-EARTH, and MIROC5 - were utilized. The research focused on analyzing the trends in these climatic variables under the specified RCP scenarios over the mentioned time frame [113].

The water level of the source was examined using 02 greenhouse gas emission scenarios, RCP4.5 and RCP8.5, together with the GCMs MIROC-5 and HADGEM2-ES, which were linked with the RCM eta (regional-climate-model). The Gompertz model was also used to forecast the city's population until the year 2100.The results showed that the amount of precipitation from August to November decreased significantly. [114]. To evaluate the prejudice in the predicted results of global & regional circulation models, data from 17 GCMs was downscaled for Ludhiana. The observed annual mean maximum temperature (Tmax) was recorded as 30.35°C. However, the GCMs overestimated this value, with estimates ranging from 32.11°C (MIROC-ESM) to 33.08°C (IPSL-CM5A-LR). Consequently, the overestimation range fell between 1.76°C to 2.73°C [115]. The study aimed to project the future climate's susceptibility to vector proliferation under two scenarios: RCP 4.5 (stabilization level) and RCP 8.5 (high level) for two time periods: 2011-2040 and 2041-2070. Two models, Eta HadGEM2-ES and Eta MIROC5, were used for the assessment. The factors considered included relative humidity (RH), the annual percentage of days with a minimum temperature higher than the 90th percentile (TN90p), and the number of days in the year with precipitation higher than 10mm (R10). These factors were analyzed for different seasons to understand their impact on vector proliferation in the specified climate scenarios and time frames [96].

Addressing the challenges of climate change necessitates a deeper understanding of its potential impacts to develop effective climate change approaches adaptation. In this study, the researchers explored climate projections from two distinct global-climate-models (GCMs): a wet scenario using MIROC5 and a dry scenario using CSIRO. The focus was on quantifying the potential resultss in terms of hydrological modules within the Upper Blue Nile Basin [116]. The global vegetation Leaf Area Index (LAI) estimated by the three models during the period 2016-2018 was contrasted against the simulated results from the CanESM2, MIROC5, and CanMIR models. These models exhibit diverse spatiotemporal variations in global vegetation LAI, as depicted in Figure 8. Moreover, the disparities between the average LAI from 2016 to 2018 and the average vegetation LAI from 1981 to 2000 were carefully recorded [117]. The GCMs were ranked based on computed performance measures using the procedure for order inclinations by resemblance to best Solution (TOPSIS), with the objective of determining their skill levels. As a result, MRI ESM2 of CMIP6 and MIROC5 of CMIP5 were identified as the utmost skilful models and were selected for projecting future extremes. To assess the relative performance of the CMIP5 and CMIP6 models, the Taylor skill score was employed [118]. The study involved conducting five hundrad-member ensemble simulations using chemistry-climate-models (CCMs) based on both Model for Interdisciplinary-Research on Climate (MIROC) two versions 1) 3.2 and 2) 5. These CCMs were developed collaboratively by Japan's-National-Institute-for-Environmental-Studies (NIES) and the University of Tokyo. The research aimed to analyze the relationships between column ozone, polar cap temperature, and zonal mean zonal wind with concentrations of ozone-depleting substances (ODS) and greenhouse gases (GHG) [119]. The climatic classification has been looked at using DMI values. Four AOGCM's (CanESM-2, GFDL-CM-3, MIROC-5, and NorESM-1) used yearly ensemble precipitation totals and mean temperature data to generate the Drought Moisture Index (DMI) for every grid covering the whole Thailand domain [120]. The ensemble of downscaled GCMs models (ACCESS-1.3, MIROC-5, and CNRM.CM-5) predicted that the mean annual temperature will rise by around 0.4 °C over the previous 30 years, from 21.8 °C in 1990 to roughly 22.2 °C by the end of 2019. Under RCPs 4.5, 6.0, and 8.5, it is predicted that temperatures will increase from 22.6 °C in 2030 to 23.2 °C in 2060, a rise of 0.6 °C. Increasing greenhouse-gas (GHG) emissions and less rainfall are also blamed for this increase [121]. The hazard likelihood of waterborne illnesses resulting from floods was assessed using the quantitative-microbiological-risk-assessment (QMRA) approach. To investigate the upcoming forecast of waterborne diseases using the flood scenario with a 50-year return period in 2030, we utilized the 4.5 RCP climate scenario and day-to-day precipitation data from HadGEM, MIROC5 and MRI CGCM 3 models. The study focused on two major municipalities in Indonesia, Medan and Surabaya, and considered norovirus as the nastiest-case scenario for aquatic diseases [122]. The mechanism is thoroughly investigated, with specific attention to area averages across five oceanic regions marked by black rectangles. These regions were selected due to the prominent positive low cloud feedback observed in MIROC6 and also because they align with the low cloud regions identified in observational data [123]. In the historical period, the mean annual maximum temperature recorded by Daymet was 26 °C while the mean annual minimum temperature was 13 °C. On the other hand, the CCSM4, MIROC5, and MPI-ESM-LR models simulated mean annual maximum temperatures of 27 °C, 28 °C, and 27 °C, respectively. For the mean annual minimum temperatures, the models simulated 17 °C, 16 °C, and 18 °C, respectively [124]. According to the ReefMod-GBR projections under the MIROC RCP2.6 scenario of heat stress, the number of reefs with sufficient coral cover to sustain high densities of outbreaking Crown-of-Thorns starfish (CoTS) is expected to decrease over the course of three decades. The yearly average of nearly 1980 reefs between 2020 and 2041 is projected to decrease to less than 800 reefs between 2041 and 2050 [125]. Six factors affecting rice production and quality were taken into account, together with mean monthly precipitation and temperature statistics from two global climate models (MIROC-5 and MPI-ESM-LR), when estimating the climate appropriateness for two harvesting seasons. The study examined scenarios for both the present and the future climate. The findings showed that within the VTCS zone, actual and anticipated climate changes significantly deviated from anticipated patterns in rainfall and temperature. [126]. In order to accurately resolve the oceanic heating patterns linked to eastern vs central Pacific El Nio episodes, five climate models were chosen: GISS-E2-R, GFDL-ESM-2M, CCSM-4, CESM-1-WACCM, and MIROC-5. HadGEM2-ES, a sixth model that has been used often in future estimates of coral bleaching due to climate change, was also picked for comparison reasons [127].

2.6.3 MRI-CGCM3

Within the Mahi River basin (MRB), India, the precipitation and temperature forecasts made by the INMCM-4, MRI-CGCM3, and its ensemble mean showed good performance. In order to examine the potential effects of global warming on the flow of MRB, we combined the climatic data using the SWAT model in this study. The results show that comparable to the baseline period (1981 to 2010), the annual mean streamflow is predicted to grow by 76.74% in the coming future (2011-2040) based on the outputs of the INMCM-4, 25% based on the outputs of the MRI-CGCM3, and 24.53% based on the ensemble mean [128]. According to the RCP2.6 and RCP8.5 forecasts, future climate conditions anticipated by the HadGEM-2-ES and MRI-CGCM-3 climate models are expected to cause L. striatellus' range to expand and its emergence timing to advance. However, different models and estimates differ in how much these changes will occur [129]. The MRI-CGCM-3 model and RCP 4.5 scenario are found to pay less to vulnerability compared to the MIROC-ESM model and RCP 8.5 scenario. However, since not possible to determine with certainty which release scenario or GCM is more possible to occur, it is essential to consider that all predicted climate futures are likely to result in high plant and vegetation stress [130]. The results show good agreement between the Standardised Precipitation Index (SPI) obtained from synoptic stations throughout the historical period (1990–2005) and the SPI estimated by the Meteorological-Research-Institute-Coupled Global- Climate-Model version 3 (MRI-CGCM-3). In 77% of the synoptic stations, the Root Mean Square Error (RMSE) value is not more than 0.75, indicating substantial agreement entre the model and observed data [131]. The annual mean air temperature increased by approximately 4°C across all sites, regardless of the Global Circulation Model (GCM) used. The seasonal average air temperature showed significant increases during the fall and slight decreases during the other seasons when using the MIROC5 model. However, with the MRI-CGCM3 model, the maximum raise in temperature was noted during the winter weather [132]. Calculating the discrepancy between the abrupt-4 CO2 experiment's most recent 30 years (20 years for MRI-CGCM3) and the 30 years of the before industrialization control simulation for CMIP5 yields the change. For CMIP6, the change is calculated based on the 30 years over the period 1850 –1880 of the historical simulation. It is important to note that results obtained using simulations with gradual CO2 increase instead of abrupt 4 $\times$ CO2 show very similar outcomes [133]. CCSM4 and MPI models demonstrate better performance in simulating the Atlantic Multidecadal Oscillation (A-M-O) forced upper-level circulation responses across Eurasia. On the other hand, CSIRO, GISS, and MRI-CGCM-3 models show good ability in simulating the A-M-O modulation of the sea-surface-temperature (SST) gradient for the extra-tropical and tropical regions over the Pacific Ocean [134]. In this research, the forecast of potential wheat yield changes in China was carried out using three crop models (APSIM, EPIC, WheatGrow) and 03 General-circulation-models (GCMs) (ACCESS-1-0,BCC-CSM-1-1-M, MRI-CGCM-3) [135].

The area experiencing bimodal growing seasons exhibited an increase in all scenarios, involving various combinations of Representative-concentration-pathways (RCP) and Global-climate-models (GCM), both in the mid of the 21st century (2040–2069) and the late 21st century (2070–2099). The magnitude of this increase ranged from 13% to 212%, resulting in an areal expansion of 49,000 to 792,000 km2. Specifically, late-century RCP 4.5 MRI-CGCM-3 and late-century RCP 8.5 HadGEM-2-CC-365 projections observed the highest areal raises [136]. To accomplish this, we first used hydrological models to drive temperature and precipitation readings from 04 Global-climate-models (GCMs), MRI CGCM3, BCC-CSM1.1and MIROC. As a result, we were able to model daily flow for the upstream range of the Yangtze River over three different time periods: the previous millennium (850–1849), the historical era (1850–2005), and the future era (2006–2099) [137].

When compared to other scenarios, the MRI-CGCM-3.0 RCP 2.6 scenario's observed ecosystem-relevant impacts were very different. The relationships among flood damage, landslide risk, and other future effects were relatively low, suggesting less direct association between these variables. Furthermore, in the RCP 8.5 scenarios, the correlations among impact indicators were stronger compared to those in the RCP 2.6 scenarios, indicating a more pronounced interconnectedness among the impact indicators in the higher emission scenario [138]. Taking into account the residual sum of the squares error, the models were scored from 1 to 16, with 1 having the smallest error and 16 possessing the highest. For instance, the models such as IPSL-CM5A-MR, BCC-CSM-1-1-M, MRI-CGCM-3, and MIROC-5 were selected as the first, second, fifteenth, and sixteenth models, respectively, at the Vicksburg site, taking into account their respective lowest and greatest error sums. [139]. Two global climate models (GCMs), CCSM-4 and MRI-CGCM-3, were employed in this study to forecast the species' adaptability in the past and future. Under current conditions and Last Interglacial (LIG) conditions, the potential range of the species occupied 15.8% and 14.1% of the studied area, respectively. While at the Last Glacial Maximum (LGM), it dramatically decreased to 3.8%. [140]. Future climate scenarios were derived from a database of monthly anomalies of maximum temperature, minimum temperature, and average monthly precipitation. These anomalies were obtained from an ensemble model consisting of 11 reduced-scale and calibrated general-circulation-models (GCMs) selected specifically for Mexico. Among the multiple GCMs used, the MRI-CGCM3 model was employed to represent two representative concentration trajectories (RCPs) of greenhouse gases (GHG), namely RCP 8.5 and RCP 4.5 [141].

For the duration from 1950 - 2099, an examination of the 90th percentile exceedance of the modeled results in relation to the observed flow revealed that two climate models (GFDL-CM3 and MRI-CGCM3) surpassed the observed flow in the RCP 4.5 scenario. On the other hand, for the RCP 8.5 scenario, as many as 12 climate models exceeded the observed flow [142]. The MRI-CGCM3 model, being the least warm among the models considered, exhibited the lowest mid-century exposure under both RCPs, standing at 18.7%. However, this value was still higher than the average exposure during the recent period (11.0%) across the 10 scenarios. For all 10 scenarios, the range of monthly drought exposure values increased over time, moving from the recent period to the mid-century period [143].

2.6.4 Representative Concentration Pathway

Climate scenarios such as the carbon radiation scenario referred to as "Representative Concentration Pathway (RCP)" gives an understanding of how climate may change in the future. The recently released IPCC 5th Assessment Report (AR5) is based on RCP 8.5, 6, 4.5, and 2.6 W/m2 radiative forcing scenarios, which represent the range from pessimistic to optimistic emission scenarios [144]. To create next-generation emission scenarios, four representative concentration paths (RCPs), named RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 were created [145]. [32] studied four Representative-concentration-pathways (RCPs) scenarios 2.6, 4.5, 6.0, and 8.5 to project three future scenarios, namely 2030, 2050, and 2070. [34] used Google Earth, a spreadsheet with the MarkSim-DSSAT Weather Generator, In this work, an ensemble of 17 GCM models using a new MarkSim web version for IPCC-AR5 data and four RCP scenarios (2.6, 4.5, 6.0, and 8.5) were used to assess the effects of climate change on Rajshahi city's temperature in the years 2030, 2050, and 2080. The findings indicated that the current climate has an impact on average temperature changes. [146] studied four Representative-concentration-pathways (RCPs) scenarios, temperature data for eleven Agro-Climatic Zones (ACZs) of India were acquired in various climate years (2010, 2030, 2050, 2070, 2090), the MakSim tool was used. [147] used Maksim to assess how climate change will affect the production of winter wheat and the need for water for different representative concentration route (RCP) scenarios (RCP 8.5, RCP 6.0, RCP 4.5, and RCP 2.6) as well as time slices (the 2040s, 2060s, and 2080s). The findings captured that under all RCP scenarios and time slices, wheat yield and water use efficiency (WUE) will rise. [148] studied seven General-circulation-models (GCMs) and their ensemble, four representative-concentration-pathways scenarios (RCP 2.6-RCP 4.5-RCP 6.0 and RCP 8.5), and three time periods (2020, 2050, and 2080) generated from MarkSim-DSSAT weather file tool were used to generate daily maximum and minimum temperature data. [36] studied four Representative-Concentration- Pathway (RCPs) scenarios, namely 2.6, 4.5, 6.0, and 8.5, for the years 2030, 2050, and 2070. [149] examined the HAD GEM2-ES global climate model for RCPs 4.5 and 8.5. Weather data for Varanasi, Uttar Pradesh, for the periods of 2010, 2035, 2065, and 2095, precisely RCP 2.6, 4.5, 6.0, and 8.5, were produced by [37] using the GFLD-CM3 model. Under RCP 8.5, the impact was the greatest. [38] used Marksim weather generator to extract the temperature and rainfall data from the HadGEM2-ES model for the Kandi region of Punjab under various climate change scenarios (RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5). [39] studied the Snowmelt -Runoff -Model (SRM) and 20 Coupled-Model-Inter-comparison Project phase 5 for representative concentration pathway 6.0 for 5th assessment report (AR5) of the Intergovernmental Panel on Climate Change using Marksim to investigate the effects of climate change in the Beheshtabad Watershed, Iran.. [150] examined the 17 general-circulation- models ensemble forecasts under four representative-concentration-paths (RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5), the data for the calibrated, CERES Maize model was used. The results showed a negative relation between temperature and yield. [151] downscaled the information from four GCMs (CSIRO-Mk3-6-0, FIO-ESM, GISS-E2-R, and IPSL-CM5A-MR) under 04 representative-concentration-route (RCP) scenarios for Ludhiana during the 21st century, the variations in temperature and precipitation on a monthly basis were evaluated. [152] used ensemble of 17 General-circulation-models from the Coupled-Model-Inter comparison-Project Phase-5 for the examination of soil temperature at three meteorological stations. Based on the RCP scenarios RCP 8.5, RCP 6, and RCP 4.5, analysis of the data from the three sites produced soil temperature rises of 2.4 to 4.4 °C, 1.2 to 2.3 °C and 0.8 to1.5 °C. According to [40], for the forecasted duration 2021 to 2050 (2050s) and 2051 to 2080 (2080s), the CERES-maize model evaluated sowing dates by estimating the maize yield using various Representative-concentration-pathways 8.5, 4.5, 6.0 and 2.6 W/m2 from the seventeen Global Circulation Models (GCM) of CMIP5 (Coupled-Model-Inter comparison Project Phase-5) climate projection scenario. [7] investigated a baseline of observed precipitation average for the years 1980 to 2014 against the two GCMs (GFCM and MPEH) data from 2001 to 2010. For various seasons, it was discovered that the Nash-Sutcliffe coefficient value varied from 0.49 to 0.98. Results were averaged over the last ten years i.e. 2091 to 2100, and then compared to the average for the base period, or 1980 to 2014, to determine the results. [41] analysed an ensemble of 40 GCMs for three RCPs (i.e. RCP 4.5, 6.0, and 8.5) for the future climate projections 2025 and 2050, and studied observed weather data (1980–2011) for South Punjab. 06 of the 36 GCMs used in a study by [153], utilized Coupled-Model-Inter-comparison Phase- 5 (CMIP-5) GCMs over South Asia performed exceptionally well, recreating low biases over the region for the temperature variable. The average temperature is predicted to rise up to 5 oC under RCP 8.5 (the worst scenario) by 2100, according to future estimates under four RCPs assessed in the same study over Pakistan for temperature and precipitation variables of climate. When it comes to precipitation, northern Pakistan (GB, AJK) appears to become warmer than southern Pakistan (Sindh, Punjab). Another study by [154], used a statistical downscaling climate projection model (SimCLIM-2013) for the projection of maximum and minimum temperatures for 2030 and 2060 in different parts of Pakistan, ensemble 40 GCMS and used RCP 6 (a median RCP) for future projection in SimCLIM model. Study found challenges for agricultural practices and water resources due to varying trends of temperatures in different months of the year as compared to current pattern, study also recommended to focus in evaluation and application of GCMs for other agro-climatic regions for climate adaption to cope with the varying pattern of temperature and its effects on different aspects of society or environment. [35] selected GCMs and two emission scenarios (RCP 4.5, RCP 8.5) for the Weihe River Basin in China. The goal of this research was to predict rainfall erosivity in the Tocantins-Araguaia river basin, a significant Brazilian watershed, for the 21st century under two different RCP 4.5 and RCP 8.5 scenarios. According to [77], According to the effects of climate change, wheat yield in Chitral will grow by 10% and by 14% in RCP-4.5 and RCP-8.5, respectively, whereas it will decline by 7.9% and by 11% in D.I. Khan. The yield in Peshawar will decline by 5.5% in RCP -4.5 and 8.4% in RCP-8.5. After conducting an extensive literature review encompassing 20 papers published within the last five years, a comprehensive analysis was carried out. The review revealed that among the selected papers, a majority of 14 studies employed MarkSim as their primary data source for General-circulation-models (GCMs). Additionally, six studies relied on data sourced from the Intergovernmental Panel on Climate Change (IPCC).

2.7 Nash-Sutcliffe Efficiency

[155] proposed an innovative diagnosis method that is well adapted to analysing simulation findings from large watershed samples. It is a variation on the traditional Taylor diagram that shows multiple failure elements (based on partiality, deviation from the mean, or squared errors) which are frequently used in efficiency standards to assess the performance of hydrological model.i.e. Nash-Sutcliffe efficiency. According to [156] NASH model program needs a calibration stage to ensure that it accurately simulates the behaviour of the hydrological system. The model was calibrated using 13 rainfall-runoff events. A precise calibration was achieved by iteratively adjusting the k-parameter till an acceptable match was found between the observed and modelled runoff. The mathematical definition of NSE by [157] illustrates why, in practise, it is appropriate to use NSE=0 as a distinction between skilled and unskilled forecasts, and this has nothing to do

with the standard forecast, which is equivalent to the average of observations. According to the results [158], the SWAT model often performed well in modelling runoff based on the Nash Sutcliffe Efficiency & Coefficient of Determination (R2) numbers. During the simulation period, the NSE & R2 values for monthly stream flow were 0.827 and 0.957, respectively. According to the study's findings, land use patterns have shifted, with a rise in agricultural, built-up, and aquatic land and a decline in forest and desert areas. The hydrological effectiveness of satellite based precipitation data is assessed by [159] over a 10-year period (2008–2017) by applying GR2M monthly hydrological simulation. The effectiveness of the CHIRPS system is assessed by [160] across the entire territory of Kerala. System rain gauge information collected from 67 gauge stations was utilized to evaluate this climatic hazard group. For the evaluation, validation data such as Nash-Sutcliffe efficiency (NSE) was used. The results reveal that this satellite rainfall calculation is quite efficient, with 0.72 value of NSE. According to [161], 32 rainfall-runoff events were used to calibrate the model parameters, and the calibrations were assessed using four metrics: Nash-Sutcliffe efficiency, % bias, continuity errors for runoff, and flow. 32 Nash-Sutcliffe efficiency calibrations, 30 percentage bias calibrations, 32 continuity error runoff calibrations, and 4 continuity error flow calibrations were all successful. The hydrological and hydraulic dynamics of the basin can be precisely replicated by SWMM. The 124 validations had a success rate of 88 applying Nash-Sutcliffe efficiency, 35 using percentage bias, 124 employing continuity errors for runoff, and 62 using continuity error for flow. The root means square error (RMSE) and the Nash-Sutcliffe criterion are calculated by [162] to determine the best-fit model after statistically controlling the goodness of fit test and identifying the admissible distributions. As a suitable distribution, each of the fitted distributions with the highest Nash-Sutcliffe (NS) criteria and the lowest RMSE is picked. Following the sensitivity analysis by [163] , the Nash-Sutcliffe model's efficiency coefficient was 0.512, which was satisfactory. The Index of Agreement and the calibration coefficient both show good results, with values of 0.848 and 0.743, respectively. Using the following formula, calculate the Nash Sutcliffe coefficient:

$$NS = 1 - (\Sigma \text{ (observed - modeled) }^{2} / \Sigma \text{ (observed - mean observed)}^{2})$$

Chapter 3

Research Methodology

3.1 General

The environment, the economy, and society are all significantly impacted by the global phenomena known as climate change. Peshawar, a city in Pakistan's Khyber Pakhtunkhwa province, due to its geographical location and socioeconomic status, is susceptible to the negative effects of climate change. Projecting future climate related scenarios for Peshawar has been possible due to the usage of general-circulation-models (GCMs). The results of different GCMs, however, may range greatly from one another. An effective statistical approach that may be used to assess how well various GCMs perform when projecting is called Marksim. Overall, the methodology specified for the MSc thesis "Comparative Assessment of Climate Scenario Projection using Global-climate-models for Peshawar, Pakistan" is intended to provide a rigorous and systematic approach to assess the working of GCMs in projecting climate change scenarios for the research area and to evalute the potential impacts of climate change.

3.2 Study-Area

The study-area for this research is situated in Peshawar, the capital of Khyber Pakhtunkhwa, Pakistan. Peshawar holds the distinction of being not only the largest city in KPK but also one of the most significant cities in the country.

Situated in the broad and picturesque Valley of Peshawar, the city finds itself embraced by majestic mountain ranges on three sides, while the fourth side opens up to the vast plains of Punjab. With an elevation of approx. 1132 feet above mean sea-level, Peshawar can be geographically pinpointed at coordinates 34.01°N and 71.52°E.

FIGURE 3.1: Peshawar Map [164]

The climate of Peshawar is characterized by distinct weather patterns, reflecting the diverse terrain that envelops it. The region experiences an average annual precipitation level of about 400 mm (16 in) based on a comprehensive 30-year record. As the seasons transform, Peshawar reveals its climatic variations. During winters, the mercury descends to a minimum temperature of around 4 °C, while in the scorching summers, it soars to a maximum of approximately 40 °C.

One notable aspect that sets Peshawar apart from many other areas in Pakistan is its unique rainfall pattern. Unlike regions that are deeply affected by monsoons, Peshawar experiences seasonal rainfall both in winter and summer. The winter season, in particular, witnesses a higher rainfall record, particularly during the months of February to April, influenced by western disturbances. As for the summer season, the city witnessed its most substantial rainfall in July 2010, an impressive 402 mm (15.8 in), while the highest winter rainfall was recorded in February 2007, measuring an astounding 236 mm (9.3 in).[164]

3.3 Methodology

The Comparative Assessment of Climate Scenario Projection Using Global-climate-models for Peshawar employed the MarkSim tool as an integral component of its methodology. MarkSim, a statistical tool renowned for its ability to assess the working of multiple GCMs in projecting climate related scenarios, played a crucial role in this research endeavour.

To generate future weather data, 03 GCM models, MRI-CGCM3, MIRCO5, and HadGEM2-ES, were employed. These models were utilized in combination with different Representative-concentration-pathways (RCPs), including RCP 2.6-RCP 4.5-RCP 6.0 and RCP 8.5. By employing these models and RCPs, a comprehensive range of climate scenarios was encompassed, allowing for a robust analysis of potential future climate conditions in Peshawar.

The data from the MarkSim tool was then compared with the observed data from the Met Department Khyber Pakhtunkhwa from 2011 to 2018. The Nash-Sutcliffe efficiency coefficient, commonly known as the Nash-Sutcliffe technique, is a measure of statistics used to evaluate the efficiency of hydrological models. It is frequently used to calibrate and validate hydrological models but may also be used to analyze data related to temperature and precipitation. Using Nash Sutcliffe technique, the calibration and validation of temperature and precipitation data for Peshawar was performed.

The calibration process utilized the data from the initial four-year period, spanning from 2011 to 2014. During this phase, the models and projections were adjusted and fine-tuned based on a comparison with the observed data from the Met Department Khyber Pakhtunkhwa.

Once the calibration phase was completed, the subsequent validation phase commenced. For validation, the data from the period between 2015 and 2018 was utilized. Following that, analysis was performed to provide the results and conclusion that are summarised in the pertinent section of this document. The flow chart of methodology is shown in **Fig. 3.2**.

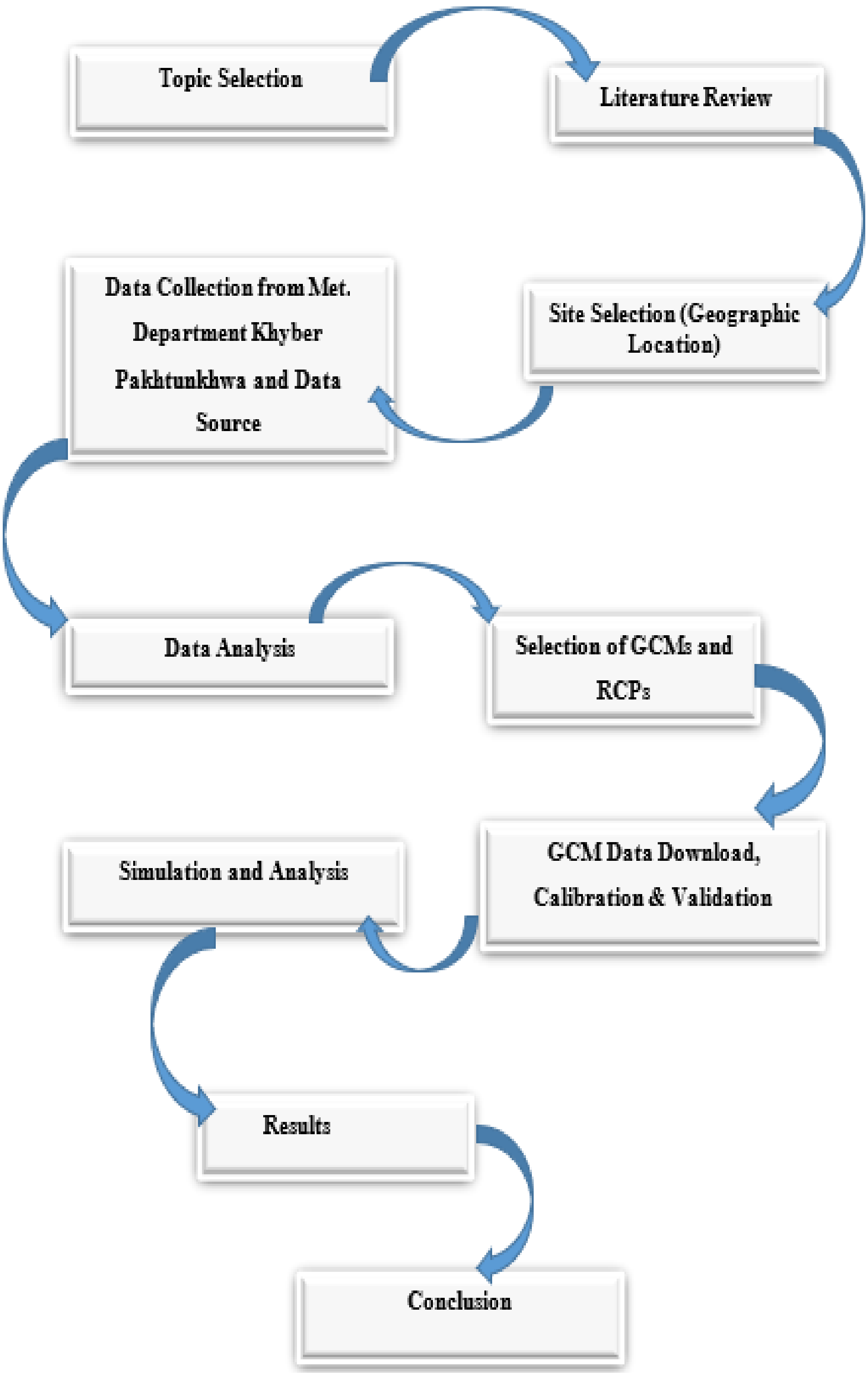

FIGURE 3.2: Flow Chart of Methodology

3.3.1 Data Collection

3.3.1.1 Introduction

A data set is a group of data that is used to support research findings, analysis, and conclusions. Any type of information that is pertinent to the study topic can be included in the data set, including survey replies, experimental results, and historical records. Because it serves as the foundation for research and conclusions, the choice and utilization of an acceptable data set are essential to the success of an MSc thesis project. A well-defined data collection also ensures that research findings are transparent and repeatable. The historical records of monthly temperature and precipitation readings for a time frame of 30 years from 1989 to 2018 were gathered from a meteorological station situated within Peshawar city. Similarly, the precipitation and temperature data for the period 2011 to 2018 were downloaded from MarkSim online tool.

3.3.1.2 Data Collection from Metrological Department KPK

3.1.1.1.1 Temperature Data

As per meteorological department data of the monthly mean temperature for Peshawar over the 30-year period from 1989 to 2018, the summer months were usually June, July, and August, with average temperatures varying between 29.5 to 33.5 degrees Celsius. The coldest months usually had average temperatures between 10 and 15 degrees Celsius, and these were December, January, and February. The city's annual mean temperature during that time was nearly 22.67 degrees Celsius. Please refer to the **Table 3.1**.

3.1.1.1.2 Precipitation Data

As per meteorological department data of the monthly total precipitation for Peshawar over the 30-year period from 1989 to 2018, the summer months were usually June, July, and August, with total precipitation around 5000 mm. The coldest months usually had total precipitation of 4000 mm, and these were December, January, and February. The city's annual mean precipitation during that time was nearly 528 mm. Refer to the **Table 3.2**.

Table 3.1: Annual Mean Temperature in Degrees Celsius Collected from Met. Department

Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
1989	10.7	11.8	17.4	21.5	29.0	32.3	32.2	30.0	28.0	24.0	17.3	13.2	
1990	12.8	12.4	17.0	21.8	31.5	32.5	33.0	30.8	29.2	22.7	17.6	11.9	
1991	10.4	11.7	16.8	20.5	26.5	31.1	33.1	31.2	27.7	23.0	16.7	13.5	
1992	11.4	11.9	16.5	20.8	26.3	31.5	31.7	31.1	27.4	23.4	17.0	14.1	
1993	10.5	14.8	15.7	23.1	30.2	31.3	31.5	32.4	28.1	23.4	17.8	14.1	
1994	12.2	11.5	19.1	21.1	28.7	32.6	31.0	30.7	26.5	22.0	17.4	12.2	
1995	11.0	12.7	16.5	20.0	28.9	32.9	32.2	30.4	27.3	24.2	17.2	12.1	
1996	11.2	14.0	18.7	23.7	28.4	31.8	32.7	31.0	29.3	23.0	16.5	12.3	
1997	11.0	12.7	17.4	0.0	26.3	30.5	33.0	31.1	28.9	22.1	16.2	11.9	
1998	10.7	12.1	17.0	23.9	29.6	31.4	32.4	31.4	28.7	24.9	18.0	12.6	
1999	11.6	13.7	18.4	24.9	31.1	32.9	33.2	31.5	29.6	25.0	17.7	14.2	
2000	11.4	11.8	17.8	25.7	33.2	32.2	32.1	31.2	27.4	24.4	17.3	13.9	
2001	11.3	14.3	20.0	23.8	32.2	32.3	31.4	31.5	27.8	24.7	17.1	14.2	
2002	11.5	12.3	19.6	24.9	32.0	31.9	33.6	30.3	26.5	24.2	17.7	13.3	22.67
2003	12.0	12.6	18.1	23.5	28.1	32.8	31.4	30.5	28.1	23.3	16.4	13.6	
2004	11.8	13.8	22.5	25.3	30.5	31.1	32.5	30.8	28.2	22.1	17.8	14.1	

Continued Table 3.1 Annual Mean Temperature in Degrees Celsius Collected from Met. Department

Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
2005	10.4	10.8	18.5	22.5	26.2	32.5	31.7	31.4	28.5	24.1	16.8	12.5	
2006	11.1	16.7	18.7	24.2	32.5	31.1	31.9	30.3	28.1	25.2	17.5	12.5	
2007	12.0	13.0	17.3	26.0	29.5	31.7	31.4	31.4	28.1	23.8	17.6	12.9	
2008	9.3	12.3	21.8	22.4	30.0	31.3	31.3	30.0	27.6	25.6	18.0	11.6	
2009	13.1	13.8	18.8	21.7	29.9	30.7	32.7	32.0	28.6	24.5	16.8	13.7	
2010	13.2	13.3	22.2	25.6	29.8	30.3	31.9	29.6	27.9	25.2	17.9	11.8	
2011	10.9	12.4	19.4	22.7	31.9	32.9	31.0	30.7	28.0	24.3	18.5	12.9	
2012	10.2	10.5	18.3	22.9	28.3	31.6	33.5	31.4	27.0	23.4	17.4	13.5	
2013	11.2	12.4	19.1	22.5	29.7	31.6	31.8	30.4	28.6	25.3	16.5	13.7	
2014	12.4	12.6	16.4	22.0	27.6	32.6	32.0	30.9	28.5	23.5	17.1	12.8	
2015	12.0	13.9	17.2	23.0	28.8	31.7	30.5	29.4	27.0	20.6	17.0	13.0	
2016	11.7	14.7	18.8	23.2	31.1	33.2	32.1	31.0	29.1	25.9	18.3	15.1	
2017	11.4	14.4	18.8	24.8	31.0	32.2	31.6	30.6	28.2	25.8	16.9	13.9	
2018	12.4	14.3	20.7	24.0	28.1	33.2	30.9	31.2	28.3	22.8	17.2	12.5	

Table 3.2: Annual Mean Precipitation in Millimeter Collected from Met. Department

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1989	37.1	11.0	45.5	19.3	9.3	1.0	50.9	18.4	16.2	9.0	3.0	31.6	
1990	49.7	67.8	54.2	26.2	17.0	2.4	9.4	74.5	45.0	52.2	8.5	46.9	
1991	9.7	54.3	141.4	58.5	71.4	1.0	13.0	20.0	5.0	2.0	3.0	5.0	
1992	84.8	61.8	114.2	73.0	59.4	2.0	4.0	102.9	26.7	18.0	0.0	33.0	
1993	35.7	14.5	178.5	34.4	12.3	55.4	58.4	0.0	56.0	11.0	10.2	0.0	
1994	17.0	77.5	60.0	80.0	25.5	14.0	162.3	37.5	55.1	55.7	1.0	56.7	
1995	0.0	49.0	126.8	130.4	25.3	1.0	92.5	99.0	65.0	13.0	13.0	3.0	
1996	29.0	74.0	75.8	38.0	14.5	12.0	17.8	110.0	51.0	203.0	42.0	0.0	
1997	16.0	27.0	23.5	0.0	29.0	38.0	45.5	13.0	12.0	63.8	4.0	28.5	
1998	44.6	144.0	67.0	69.0	31.5	25.5	97.0	65.0	21.5	7.5	0.0	0.0	
1999	150.3	28.0	73.5	10.5	6.5	48.0	24.5	36.5	15.0	1.0	24.0	0.0	
2000	57.0	28.5	41.0	5.0	10.0	12.5	11.0	16.0	46.8	9.0	0.0	22.0	528
2001	0.0	1.6	37.5	37.5	19.0	36.5	50.0	39.0	18.0	0.0	24.0	0.0	
2002	2.0	76.0	73.0	21.0	8.0	53.0	0.0	87.0	20.0	2.0	8.0	38.0	
2003	33.0	131.5	66.0	129.0	23.0	10.0	156.0	114.0	111.0	70.0	42.0	19.0	

Continue Table 3.2: Annual Mean Precipitation in Millimeter Collected from Met. Department

Years	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
2004	109.0	93.0	0.0	60.0	1.0	0.0	14.0	57.0	35.0	44.0	15.0	26.0	
2005	128.0	132.0	149.0	27.0	51.0	0.0	21.0	25.0	67.0	5.0	20.0	0.0	
2006	68.5	26.0	60.0	15.0	6.0	14.0	95.0	49.0	15.0	34.0	24.0	91.0	
2007	0.0	236.0	128.0	22.0	23.0	77.0	105.0	22.0	59.0	0.0	12.0	1.0	
2008	92.0	9.0	11.0	267.0	4.0	42.0	37.0	274.0	38.0	1.0	0.0	4.0	
2009	50.0	75.0	85.0	187.0	57.0	20.0	18.0	92.0	19.0	0.0	19.0	1.0	
2010	21.0	119.0	17.0	32.0	21.0	81.0	409.0	125.0	4.0	0.0	0.0	10.0	
2011	8.0	112.0	34.0	49.0	52.0	14.0	58.0	122.0	38.0	52.0	29.0	0.0	
2012	51.0	20.0	18.0	66.0	51.0	0.0	2.0	27.0	127.0	16.0	4.0	76.0	
2013	3.0	197.0	116.0	85.0	15.0	18.0	13.0	63.0	1.0	48.0	36.0	1.0	
2014	3.0	28.0	111.0	0.0	20.0	35.0	54.0	58.4	4.0	46.0	1.0	0.0	
2015	42.0	72.0	111.0	110.5	21.0	0.0	187.0	169.0	25.0	55.0	25.0	8.0	
2016	8.0	23.0	120.0	60.0	8.0	55.0	37.5	45.0	3.0	1.0	0.0	0.0	
2017	70.0	60.0	24.0	35.0	5.0	42.0	77.0	66.0	36.0	0.0	69.0	19.0	
2018	0.0	37.0	31.0	92.0	89.0	14.0	152.0	23.5	18.0	27.0	6.0	14.0	

3.3.1.3 Data Collection from Data Source (MarkSim)

The MarkSim Global Climate Model (GCM) data used in this study is available from 2010 onwards. To ensure consistency and comparability with the observed Meteorological (Met.) Data, the overlapping data for the period 2011 to 2018 was selected. The precipitation and temperature data for three GCMs, namely HadGEM2, MIROC5, and MRI-CGCM3, under different Representative-concentration-pathways (RCPs) 2.6, 4.5, 6.0, and 8.5, were obtained from the data source.

The analysis in this study focused on three specific time horizons: 2030, 2060, and 2090. Accordingly, the precipitation and temperature data for these particular years were also downloaded from the MarkSim online tool. This allowed for a comprehensive assessment of the projected climate scenarios for Peshawar, Pakistan, under different GCMs and RCPs.

3.3.2 Data Analysis

This Master's thesis offers a thorough examination of temperature and precipitation data for Peshawar City over the course of 30 years (1989–2018), with the goal of identifying long-term trends in the climate and examining any potential consequences of the climate change. The research makes use of a substantial dataset gathered from meteorological records and applies advanced statistical methods and tools for data visualization for in-depth analysis. The study focuses on analysing trends, variations, and possible temperature and precipitation shifts, providing essential data on the local climate dynamics.

3.3.3 General-Circulation-Models (GCMs)

3.3.3.1 Introduction

The study of climate change relies heavily on general-circulation-models (GCMs). These models shed light on the climate of the future by predicting regional climate change, identifying climate hazards, and developing adaption strategies [165].

General-circulation-models are extensively used in the research of the climate change (GCMs). Through the prediction of regional climate change, the identification of climate risks, and the expansion of the adaptation plans, these models provide insight into the climate of the future [166].

3.3.3.2 Selection Key Considerations

The level of detail or the spatial and temporal scale at which the model simulates the Earth's atmosphere, oceans, and land surface is referred to as resolution in the context of general-circulation-models (GCMs). The size of the grid cells affects a GCM's resolution, with smaller grid cells enabling better resolution simulations that capture more precise aspects of the Earth's climate system. Two methods are generally preferred for the selection of Global-climate-models (GCMs). Firstly, GCMs are chosen based on their frequency of usage by researchers, as indicated by the literature review. This approach ensures that widely recognized and extensively studied GCMs are included in the analysis, considering their relevance and established credibility in the scientific community. In addition, the selection of GCMs is also guided by their resolution. Higher resolution models are preferred due to their capability to more accurately represent regional climate patterns and capture finer-scale variability. This is particularly important for capturing the impacts of topography and local weather phenomena that play a significant role in shaping the climate of a specific region.

It is important to mention that researchers who rely on GCMs selected based on their frequency of usage, as determined by the literature review, also take into account the resolution of the models. The finer the resolution of a GCM, the more accurate and detailed the resulting climate projections are likely to be.

For this research work following three GCMs are selected on the basis of finer resolution presented in the above **Table 3.3**.

1. MRI-CGCM3
2. MIRCO5
3. HadGEM2-ES

It is important to note that there is no data bias since Marksim (online data tool), which is aligned and an outcome of IPCC. It provides data directly at the point of interest. This results in point data rather than data presented in grid form. [168, 169].

TABLE 3.3: Resolution of General-circulation-models [167]

No.	**Model**	**Resolution (Lat x Long°)**	**Ranking**
1	BCC-CSM-1.1	2.8125 x 2.8125	13
2	CSIRO-Mk3.6.0	1.875 x 1.875	16
3	GFDL-CM-3	2.0 x 2.5	9
4	GFDL-ESM-2M	2.0 x 2.5	10
5	GISS-E2-R	2.0 x 2.5	8
6	IPSL-CM5A-LR	1.875 x 3.75	6
7	MIROC-ESM	2.8125 x 2.8125	12
8	MIROC-5	1.4063 x 1.4063	**2**
9	NorESM1-M	1.875 x 2.5	5
10	BCC-CSM-1.1(m)	2.8125 x 2.8125	14
11	FIO-ESM	2.812 x 2.812	17
12	GFDL-ESM-2G	2.0 x 2.5	11
13	GISS-E2-H	2.0 x 2.5	7
14	HadGEM2-ES	1.2414 x 1.875	3
15	IPSL-CM5A-MR	1.2587 x 2.5	4
16	MIROC-ESM-CHEM	2.8125 x 2.8125	15
17	MRI-CGCM3	1.125 x 1.125	**1**

3.3.4 Representative-Concentration-Pathways (RCP's)

3.3.4.1 Introduction

The IPCC AR5 use concentration paths known as RCPs. These are predetermined trajectories for changes in land use, greenhouse gas concentrations, and aerosol concentrations that are in line with a variety of generic climate outcomes used by the general public of climate modellers. The routes are defined by the radiative forcing brought about by the close of the twenty-first century. The extra heat that the cooler atmosphere would keep as a consequence of the release of more greenhouse gases is measured in Watts per square metre (W/m2). Each RCP in the academic literature reflects a wider variety of possible outcomes. The full range of emissions scenarios, with as well as without climate policy, are covered by the RCPs. There are three medium stabilized scenarios (RCP4.5, RCP6, and RCP8.5), one scenario with extremely high baseline emissions (RCP8.5), and one mitigating scenario (RCP2.6) resulting in a very low forcing level [168].

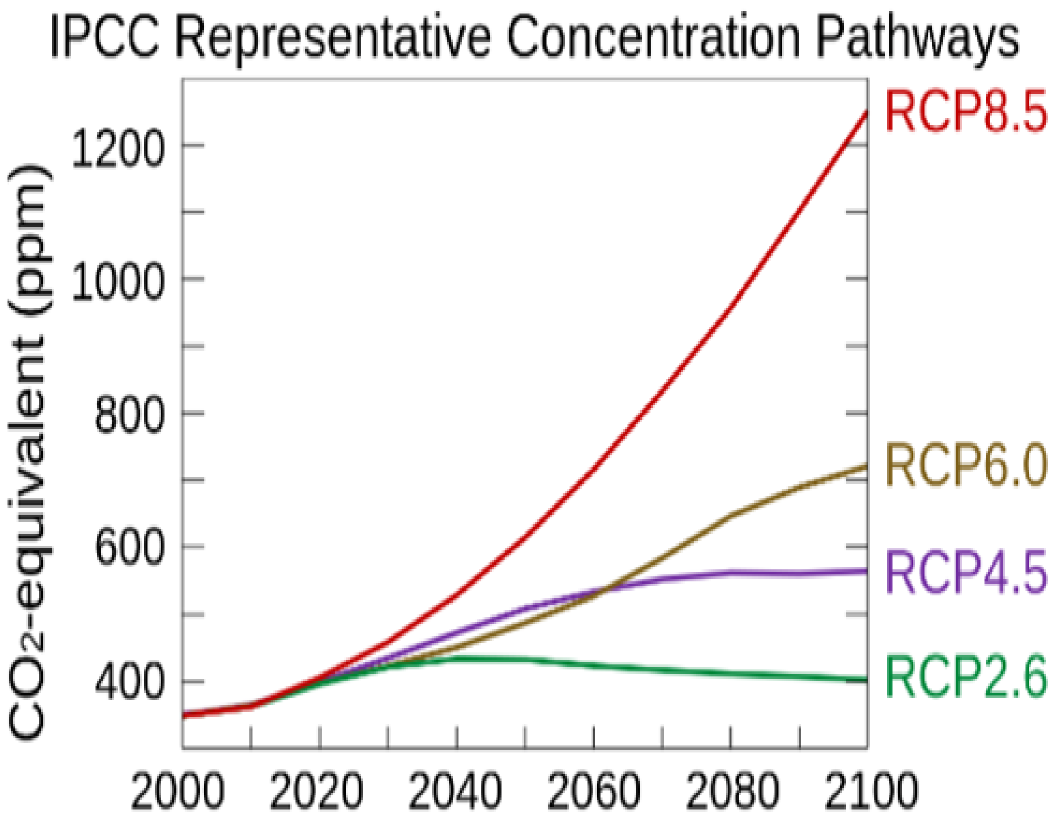

FIGURE 3.3: RCPs Representation [171]

TABLE 3.4: Frequency Analysis for RCPs

				RCPs			
S.No	**Title**	**Author**	**Year**	**2.6**	**4.5**	**6**	**8.5**
1	Impact assessment of seasonal climate change on kharif rice under various future scenarios	Priyadarshini et al.,	2022	√	√	√	√
2	Development of the Indian FutureWeather File Generator Based on Representative-concentration-pathways	Manapragada et al.,	2022	√	√		√
3	Modelling climate change impact on soil loss and erosion vulnerability in a watershed of Shiwalik Himalayas	Raj et al.,	2022		√		√
4	Impact of climate change in Rajshahi City based on Marksim weather generator, temperature projections	Tauhid Ur Rahman et al.,	2021	√	√	√	√
5	Evaluating the effects of climate change on precipitation and Temperature for Iran using RCP	Doulabian et al.,	2021	√	√		√
6	Assessing mean climate change signals in the global CORDEX-CORE ensemble	Teichmann et al.,	2021	√			√
7	Modeling climate change impacts on crop water demand, middle Awash River basin, case study of Berehet woreda	Tessema et al.,	2021		√		√
8	Modeling Snowmelt Runoff Under CMIP5 Scenarios in the Beheshtabad Watershed	Raisi et al.,	2021	√		√	√
9	Assessment of climate change impact on different pigeon-pea maturity groups innorth Indian condition	Yadav et al.,	2021	√	√	√	√
10	Selection of general-circulation-models for the projections of spatio-temporal changes in temperature of Borneo Island based on CMIP5	Saadi et at.,	2020	√	√	√	√
11	Statistical Analysis of Projected Climate Data under Diverse Scenarios for Kandi Region of Punjab	Kaur et al.,	2020	√	√	√	√

Continued Table 3.4 Frequency Analysis for RCPs

				RCPs			
S.No	**Title**	**Author**	**Year**	**2.6**	**4.5**	**6**	**8.5**
12	Effects of Elevated Air Temperature and CO2 on Maize Production and Water Use Efficiency under Future Climate Change Scenarios in Shaanxi Province, China	Saddique et al.,	2020	√	√	√	√
13	Quantitative assessment of precipitation changes under CMIP5 RCP scenarios over the northern sub-Himalayan region of Pakistan	Ahmad et al.,	2019	√	√	√	√
14	Uncertainty in hydrological analysis of climate change: multi parameter vs. multi-GCM ensemble predictions	Younggu et al.,	2019		√		√
15	Spatio-temporal temperature variations in Marksim multimodel data and their impact on voltinism of fruit fly, Bactroceraspecies on mango	Singh Choudhary et al.,	2019	√	√	√	√
16	Climate change is expected to increase yield and water use efficiency of wheat in the North China Plain	Rashid et al.,	2019	√	√	√	√
17	Projections of future soil temperature in northeast Iran	Araghi et al.,	2019		√	√	√
18	Assessment of seasonal climatic variability and its impact on kharif rice yield of Ganjam, Odisha, India	Paikaray et al.,	2019	√	√	√	√
19	Climate predictions for Ludhiana District of Indian Punjab under RCP 4.5 and RCP 8.5	Dar et al.,	2019		√		√
20	Assessment of climate change impact on wheat crop using MarkSim GCM in Varanasi, Uttar Pradesh	Patel et al.,	2018	√	√	√	√

3.3.4.2 Selection Key Considerations

Since each RCP (Representative Concentration Pathway) represents a different scenario of greenhouse gas emissions and socio-economic development, they all offer a range of potential future greenhouse gas concentration trajectories and associated climate outcomes. The analysis of a variety of potential climatic futures and the evaluation of the effects of various greenhouse gas emission scenarios on climate variables like temperature, precipitation, sea level rise, and extreme events are made possible by the use of multiple RCPs. It also offers a tool to assess the prospective advantages and disadvantages of various degrees of reducing greenhouse gas emissions and preparing for climate change.

Overall, using multiple RCPs allows for a more thorough and robust understanding of the potential climate futures, as well as the hazards and opportunities that go along with them. Therefore, this research work exercised all RCPs (2.5, 4.6, 5 & 8.5) for simulation purposes.

Table 3.4 outlines the review of 20 literature papers in the past five years. This indicates that researchers utilized RCPs (2.4, 4.5, 6, and 8.5). Out of 20 researchers, 15 selected RCP 2.6, 18 used RCP 4.5, 13 utilized 6, and all researchers used 8.5.

3.3.5 GCMs Data Download

3.3.5.1 MarkSim DSSAT Weather File Generator

3.3.5.2 Introduction

According to [167], MarkSim was developed to simulate weather in the 1980s and 1990s utilizing global monthly climate data sources. The precipitation data are transformed into a third order-Markov model, which splits the planet into 720 distinct climatic groupings. SIMMETEO is used to generate the temperature data simulation. For each of the almost 9,200 locations, a third order-Markov chains model of rainfall was developed. After results were grouped by climatic cluster, regression equations were created employing the average monthly rainfall and temperature data collected from each station inside the cluster for every single of the Markov parameters. Thus, by identifying to which cluster the data record belongs and applying the appropriate regression equations, the model may be fitted to any monthly climate data record. The new MarkSim Standalone uses 17 models from the CMIP5 range that were taken into account in the latest IPCC report, compared to the original MarkSim Standalone's six GCMs from the IPCC's fourth approximation.

FIGURE 3.4: MarkSim DSSAT [169]

3.3.5.3 Selection Key Considerations

The Intergovernmental Panel on Climate Change (IPCC) recognizes a pool of 40 General Circulation Models (GCMs). However, this research is bounded by the functionality of the MarkSim online weather tool, a pivotal element in this study. This tool is tailored to process and assess data from a subset of 17 GCMs, shaping the parameters of our climate analysis. Based on a review of the literature, it has been observed that researchers preference to use GCMs data from Marksim rather than downloading data directly from the Intergovernmental-Panel-on-Climate-Change (IPCC). The primary reason behind this inclination is that GCMs from Marksim eliminate the need for downscaling procedures. Instead, researchers can obtain data directly from Google Maps, which provides information specific to their point of interest. This approach offers convenience and efficiency in accessing relevant data, contributing to the growing popularity of Marksim GCMs in recent research endeavours.

3.3.6 Calibration and Validation Dataset

The process of calibrating a measuring equipment or system involves comparing its measurements to established standards in order to correct or confirm its accuracy. The purpose of calibration is to eliminate or minimize any systematic errors or biases in the measurements and ensure that the instrument provides accurate and consistent results.

On the other hand validation is the procedure of evaluating and assessing the performance, accuracy, and suitability of a model, system, or experiment for its intended purpose. It includes comparing the result or predictions of the model OR system against independent data or established criteria.

Considering that Marksim GCMs data is available from 2010 onwards, we selected the overlapping data for the period 2011 to 2018 between the observed Meteorological (Met.) Data and MarkSim GCM data. The first four years, from 2011 to 2014, were used for calibration, while the latter four years, from 2015 to 2018, were used for validation.

3.3.6.1 Nash-Sutcliffe Technique

The Nash-Sutcliffe efficiency coefficient, commonly known as the Nash-Sutcliffe technique, is a measure of statistics used to evaluate the efficiency of hydrological models. It is frequently used to calibrate and validate hydrological models but may also be used to analyze data related to temperature and precipitation.

The following procedures were performed to calibrate precipitation and temperature data for Peshawar using the Nash Sutcliffe technique:

1. Data Collection: Gather temperature and precipitation data from Met Department, Peshawar Khyber Pakhtunkhwa.

2. Data Organization: Separate data sets for calibration as well as validation, the model is calibrated using the calibration data set, and the model performs better when using the validation data.

3. Define the known/observed and modeled data: The observed data consists of the temperature & precipitation data gathered from the met department, while the modeled data consists of the values predicted by the Marksim.

4. Determine the Nash Sutcliffe coefficient: Using the following equation 3.1, calculate the Nash Sutcliffe coefficient:

$$NS = 1 - \frac{\Sigma_i^n (O_i - P_i)^2}{\Sigma_i^n (O_i - \overline{O})^2} \tag{3.1}$$

   NS = 1 - (Σ (observed - modeled) 2 / Σ (observed - mean observed)^2)s

   Where Σ is the total sum of the data, "observed "is the known data, "modeled" is the Marksim data, and "mean observed" is the observed/known data's mean value. The NS coefficient varies from -infinity to 1, with 1 indicating ideal model performance and less than zero indicating that the model performs worse than the mean observed value [157].

5. Evaluate model performance: Use the NS coefficient to evaluate model performance. A coefficient value of 0.6 or greater is often seen as indicating good model performance, whilst a coefficient of below 0.4 is regarded as poor model performance.

6. If the model's performance is unsatisfactory, tweak it by modifying the parameters and repeating the calibration and validation process until an acceptable level of performance is obtained.

Chapter 4

Results and Analysis

4.1 General

The selected study area is discussed in previous chapter. The GCMs data is downloaded and their performance in projecting climate scenarios is assessed using the statistical tool MarkSim. The data received from the MarkSim tool is then compared with the observed data obtained from the Met Department Khyber Pakhtunkhwa. Analysis was then carried out to get the results.

The findings and outcomes derived from this study shed light on the effectiveness of the GCMs in projecting climate scenarios within the selected study area. Furthermore, they subsidize to the overall knowledge of the climate dynamics in the region and serve as a foundation for subsequent discussions and recommendations.

4.2 Calibration and Validation

There are 40 GCMs available, and it is very problematic to obtain and download their information from IPCC. On the other hand, MarkSim is a user-friendly online data tool that adheres to the IPCC standards. MarkSim utilizes the same data as the IPCC, which means that MarkSim data is equally reliable. Since MarkSim GCMs data is available from 2010 onward, we selected the overlapping data for the period 2011 to 2018 between the observed Meteorological (Met.) Data and MarkSim GCM data. The first four years, from 2011 to 2014, were employed for calibration purposes, and for validation, the data informtion from 2015 to 2018 was utilized.

The Nash-Sutcliffe method is used to calibrate and validate temperature and precipitation data. For example, in RCP 8.5 for GCM-MIROC5, **Table 4.3** shows how calibration was performed on precipitation data. Before calibration, the value of NS is not equal to 1, ranging from -5.79 to 0.18. Similarly, the value of RE is not equal to 0, ranging from -0.33 to 0.15. After calibration, different factors are applied to achieve NS = 1 and RE = 0. As a result, the obtained NS value is almost equal to 1, while the RE value is nearly equal to 0. After this analysis, it has been concluded that for RCP 8.5 with GCM-MIROC5, the precipitation data should be multiplied by a factor of 1.21 to get the results that are acceptable.

Table 4.1: Calibrated Factors for Precipitation Using Nash-Sutcliffe Method

RCP	**HadGEM2**	**MIROC5**	**MRI-CGCM3**
2.6	1.32	1.31	1.44
4.5	1.21	1.22	1.16
6	1.25	1.31	1.23
8.5	1.36	1.21	1.29

Table 4.2: Calibrated Factors for Temperature Using Nash-Sutcliffe Method

RCP	**HadGEM2**	**MIROC5**	**MRI-CGCM3**
2.6	0.96	0.94	0.96
4.5	0.97	0.97	0.97
6	0.97	0.95	0.97
8.5	0.96	0.96	0.97

TABLE 4.3: Nash-Sutcliffe Method Used for RCP 8.5 and GCM-MIROC5 (Precipitation)

Before Calibration	**Year**	**Po**	**Pm**	**(Po-Pm)2̂**	**(Po-Po*)2̂**	**NS=1-((Po-Pm)2̂/(Po-Po*)2̂)**	**RE=(Po-Pm)/Po**
	2011	379.4	568	35569.96	5241.76	-5.79	-0.33
	2012	423.9	458	1162.81	1413.76	0.18	-0.07
	2013	419.4	596	31187.56	10080.16	-2.09	-0.3
	2014	414.9	360.4	2970.25	18279.04	0.84	0.15
	Avg.	409.4	**495.6**				
After Calibration							
Factor for Correction of P	**Year**	**Po**	**Pm**	**(Po-Pm)2̂**	**(Po-Po*)2̂**	**NS=1-((Po-Pm)2̂/(Po-Po*)2̂)**	**RE=(Po-Pm)/Po**
1.5	2011	568	568	0	5241.76	1	0
1.08	2012	457.81	458	0.04	1413.76	1	0
1.4	2013	587.16	596	78.15	10080.16	0.99	-0.01
0.86	2014	356.81	360.4	12.86	18279.04	1	-0.01
1.21	**Avg.**	492.45	**495.6**				

A related method has been implemented for the rest of the calculations of precipitation (refer to the table 4.1) and temperature (refer to the table 4.2) data that were downloaded for this GCM (MIROC5) as well as the other two GCMs (HadGEM2 & MRI-CGCM3). After the calibration, calibrated factors for both precipitation and temperatures were used for validation purposes.

Discussion:

Calibration factors, when applied during the validation period, resulted in followings; HadGEM2 - All RCP's.

i. For precipitation, the results were within 87% acceptability/closeness to observed ones.

ii. For temperature, the results were within 98% to 99% acceptability/closeness to observed ones.

MIROC5 - All RCP's

i. For precipitation, the results were within 87% acceptability/closeness to observed ones.

ii. For temperature, the results were within 99% to 100% acceptability/closeness to observed ones.

MRI-CGCM3 - All RCP's

i. For precipitation, the results were within 89% acceptability/closeness to observed ones.

ii. For temperature, the results were within 98% to 99% acceptability/closeness to observed ones.

4.3 General Circulation Model - HadGEM2

4.3.1 Precipitation Results and Analysis

4.3.1.1 Precipitation Under RCP 2.6

The baseline annual average rainfall is 495.60 mm, which is expected to increase to 512.16 mm in 2030, 521 mm in 2060 and 556.12 mm in 2090. These results capture that in 2030 the increase in rainfall would be 16.56 mm (3.23%), in 2060 by 25.40 mm (4.88%) and in 2090 by 60.52 mm (10.88%) respectively. Please refer to the **Figure 4.1** which shows the bar chart reflecting the precipitation results for HadGEM2 by applying RCP 2.6 for 2030, 2060 and 2090.

4.3.1.2 Precipitation Under RCP 4.5

The baseline annual average rainfall is 495.60 mm, which is expected to increase to 502.36 mm in 2030, 499.23 mm in 2060 and 511.88 mm in 2090. These results capture that in 2030 the increase in rainfall would be 6.76 mm (1.35%), in 2060 by 3.63 mm (0.73%) and in 2090 by 16.28 mm (3.18%) respectively. Please refer to the **Figure 4.1** which shows the bar chart reflecting the precipitation results for HadGEM2 by applying RCP 4.5 for 2030, 2060 and 2090.

4.3.1.3 Precipitation Under RCP 6

The baseline annual average rainfall is 495.60 mm, which is expected to increase to 499.38 mm in 2030, 517.88 mm in 2060 and 750 mm in 2090. These results capture that in 2030 the increase in rainfall would be 3.78 mm (0.76%), in 2060 by 22.28 mm (4.30%) and in 2090 by 245.40mm (33.92%) respectively.

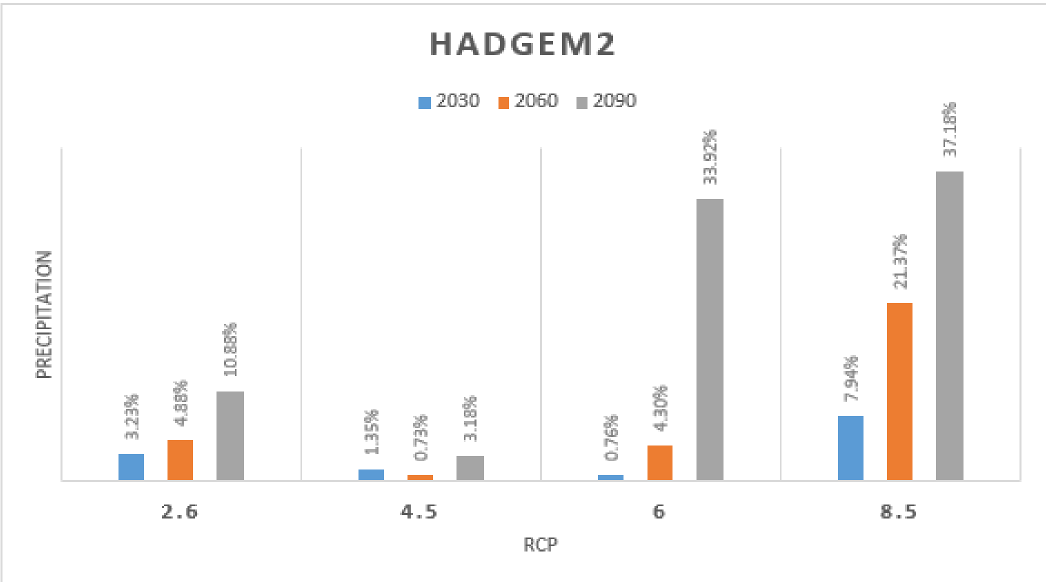

FIGURE 4.1: Bar Chart Reflecting the Precipitation Results for HadGEM2 by Applying Different Scenarios for 2030, 2060 and 2090

4.3.1.4 Precipitation under RCP 8.5

The baseline annual average rainfall is 495.60 mm, which is expected to increase to 538.32 mm in 2030, 630.29 mm in 2060 and 788.89 mm in 2090. These results capture that in 2030 the increase in rainfall would be 42.72 mm (7.94%), in 2060 by 134.69 mm (21.37%) and in 2090 by 293.29 mm (37.18%) respectively. Please refer to the **Figure 4.1** which shows the bar chart reflecting the precipitation results for HadGEM2 by applying RCP 6 for 2030, 2060 and 2090.

4.3.2 Temperature Results and Analysis

4.3.2.1 Temperature under RCP 2.5

The baseline annual average temperature of 22.60 °C would rise to 24.02 °C in 2030, 24.45 °C in 2060 and 24.43 °C in 2090. These results forecast that raise in average temperature would be 1.42 °C (5.90%), 1.85 °C (7.58%) and 1.83 °C (7.50%) in 2030, 2060 and 2090 respectively in future. Please refer to the **Figure 4.2** which shows the bar chart reflecting the temperature results for HadGEM2 by applying RCP 2.6 for 2030, 2060 and 2090.

4.3.2.2 Temperature under RCP 4.5

The baseline annual average temperature of 22.60 °C would rise to 24.00 °C in 2030, 25.23 °C in 2060 and 25.85 °C in 2090. These results forecast that raise in average temperature would be 1.40 °C (5.83%), 2.63 °C (10.44%) and 3.25 °C (12.57%) in 2030, 2060 and 2090 respectively in future. Please refer to the **Figure 4.2** which shows the bar chart reflecting the temperature results for HadGEM2 by applying RCP 4.5 for 2030, 2060 and 2090.

4.3.2.3 Temperature under RCP 6

The baseline annual average temperature of 22.60 °C would rise to 23.78 °C in 2030, 24.93 °C in 2060 and 26.44 °C in 2090. These results forecast that raise in average temperature would be 1.18 °C (4.94%), 2.33 °C (9.34%) and 3.84 °C

(14.52%) in 2030, 2060 and 2090 respectively in future. Please refer to the **Figure 4.2** which shows the bar chart reflecting the temperature results for HadGEM2 by applying RCP 6 for 2030, 2060 and 2090.

4.3.2.4 Temperature under RCP 8.5

The baseline annual average temperature of 22.60 °C would rise to 24.15 °C in 2030, 26.14 °C in 2060 and 28.52 °C in 2090. These results forecast that raise in average temperature would be 1.55 °C (6.40%), 3.54 °C (13.55%) and 5.92 °C (20.76%) in 2030, 2060 and 2090 respectively in future. The 5.92 °C value is abnormal as compared to one which is reported by IPCC. Please refer to the **Figure 4.1** which shows the bar chart reflecting the precipitation results for HadGEM2 by applying RCP 8.5 for 2030, 2060 and 2090. Please refer to the **Figure 4.2** which shows the bar chart reflecting the temperature results for HadGEM2 by applying RCP 8.5 for 2030, 2060 and 2090.

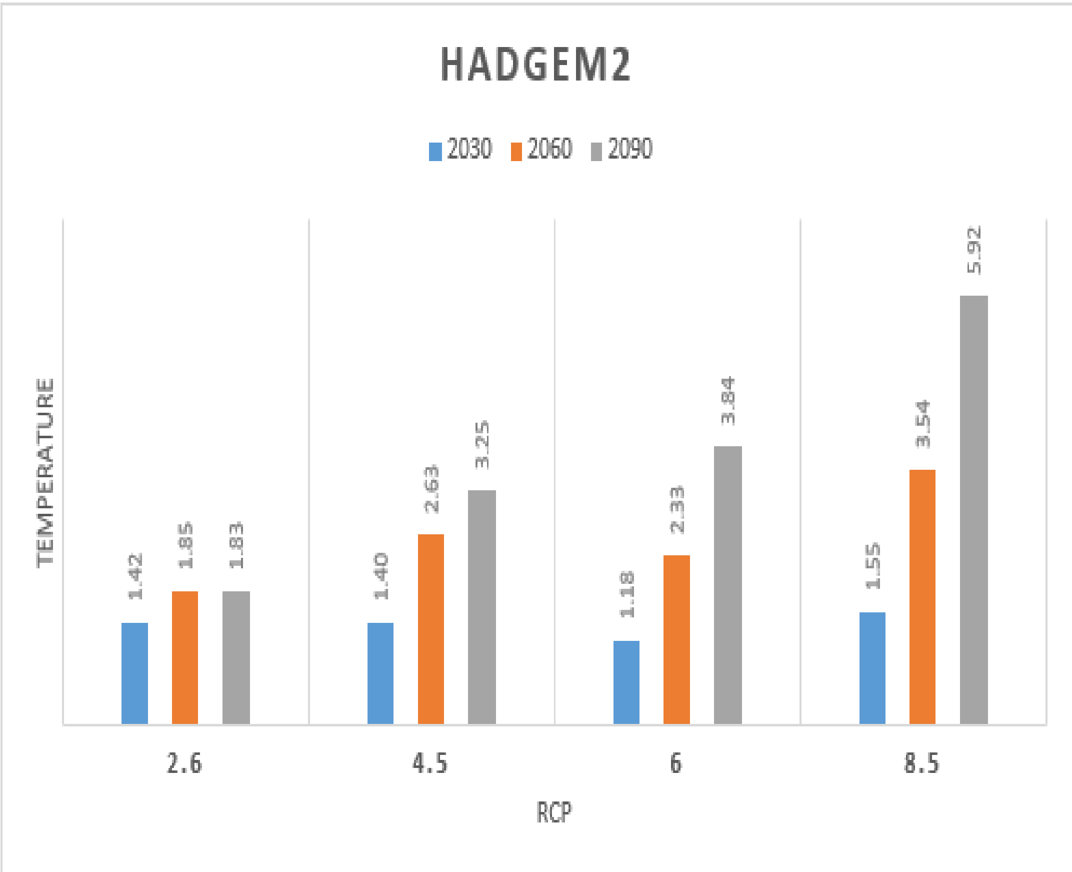

FIGURE 4.2: Bar Chart Reflecting the Temperature Results for HadGEM2 by Applying Different Scenarios for 2030, 2060 and 2090

4.4 General Circulation Model - MIROC5

4.4.1 Precipitation Results and Analysis

4.4.1.1 Precipitation under RCP 2.6

The baseline annual average rainfall is 495.60 mm, which is expected to decrease to 478.54 mm in 2030, 488.85 mm in 2060 and increase to 549.80 mm in 2090. These results capture that in 2030 the decrease in rainfall would be 17.06 mm (3.56%), in 2060 by 6.75 mm (1.38%) and increase in 2090 by 54.20 mm (9.86%) respectively. Please refer to the **Figure 4.3** which shows the bar chart reflecting the precipitation results for MIROC5 by applying RCP 2.6 for 2030, 2060 and 2090.

4.4.1.2 Precipitation under RCP 4.5

The baseline annual average rainfall is 495.60 mm, which is expected to increase to 500.27 mm in 2030, 499.66 mm in 2060 and 517.19 mm in 2090. These results capture that in 2030 the increase in rainfall would be 4.67 mm (0.93%), in 2060 by 4.06 mm (0.81%) and in 2090 by 21.59 mm (4.18%) respectively. RCP 4.5 for 2030, 2060 and 2090.

4.4.1.3 Precipitation under RCP 6

The baseline annual average rainfall is 495.60 mm, which is expected to increase to 500.19 mm in 2030, decrease to 485.36 mm in 2060 and increase to 787.50 mm in 2090. These results capture that in 2030 the increase in rainfall would be 4.59 mm (0.92%), in 2060 decrease by 10.24 mm (2.11%) and in 2090 increase by 291.90 mm (37.07%) respectively.

4.4.1.4 Precipitation under RCP 8.5

The baseline annual average rainfall is 495.60 mm, which is expected to decrease to 425.51 mm in 2030, 448.40 mm in 2060 and increase to 700.17 mm in 2090.

These results capture that in 2030 the decrease in rainfall would be 70.06 mm (16.46%), in 2060 by 47.20 mm (10.53%) and increase in 2090 by 204.57 mm (29.22%) respectively. Please refer to the **Figure 4.3** which shows the bar chart reflecting the precipitation results for MIROC5 by applying RCP 8.5 for 2030, 2060 and 2090.

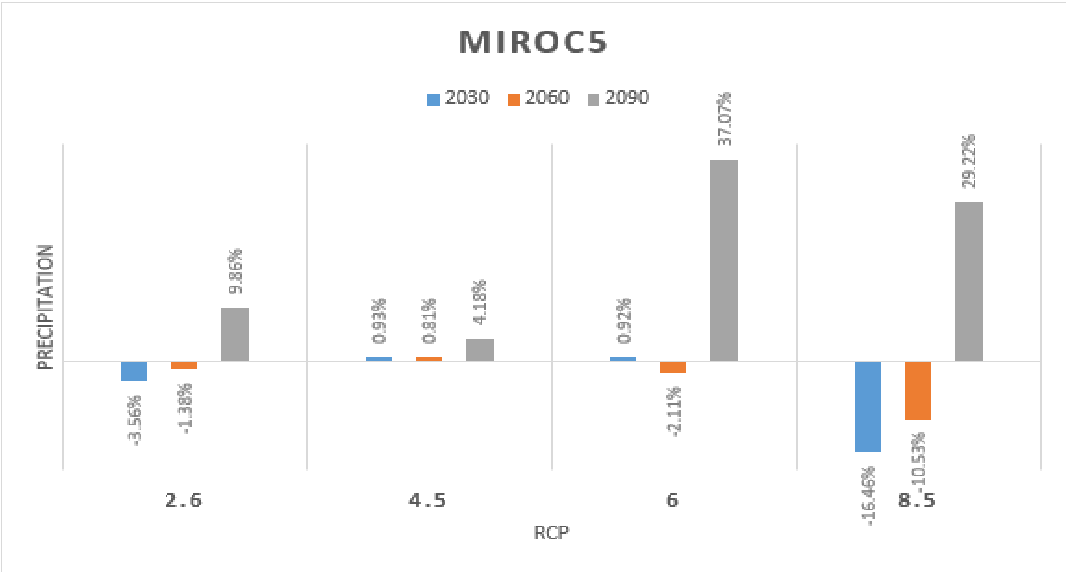

FIGURE 4.3: Bar Chart Reflecting the Precipitation Results for MIROC5 by Applying Different Scenarios for 2030, 2060 and 2090

4.4.2 Temperature Results and Analysis

4.4.2.1 Temperature under RCP 2.6

The baseline annual average temperature of 22.60 °C would rise to 22.99 °C in 2030, 23.25 °C in 2060 and 22.97 °C in 2090. These results forecast that raise in average temperature would be 0.39 °C (1.70%), 0.65 °C (2.78%) and 0.37 °C (1.60%) in 2030, 2060 and 2090 respectively in future. Please refer to the **Figure 4.4** which shows the bar chart reflecting the temperature results for MIROC5 by applying RCP 2.6 for 2030, 2060 and 2090.

4.4.2.2 Temperature under RCP 4.5

The baseline annual average temperature of 22.60 °C would rise to 24.15 °C in 2030, 26.06 °C in 2060 and 25.00 °C in 2090. These results forecast that raise in average temperature would be 1.55 °C (6.44%), 3.46 °C (13.29%) and 2.40 °C (9.59%) in 2030, 2060 and 2090 respectively in future. Please refer to the **Figure 4.4** which shows the bar chart reflecting the temperature results for MIROC5 by applying RCP 4.5 for 2030, 2060 and 2090.

4.4.2.3 Temperature under RCP 6

The baseline annual average temperature of 22.60 °C would rise to 23.41 °C in 2030, 25.10 °C in 2060 and 25.16 °C in 2090. These results forecast that raise in average temperature would be 0.81 °C (3.45%), 2.50 °C (9.96%) and 2.56 °C (10.16%) in 2030, 2060 and 2090 respectively in future. Please refer to the **Figure 4.4** which shows the bar chart reflecting the temperature results for MIROC5 by applying RCP 6 for 2030, 2060 and 2090.

4.4.2.4 Temperature under RCP 8.5

The baseline annual average temperature of 22.60 °C would rise to 24.39 °C in 2030, 27.22 °C in 2060 and 27.28 °C in 2090. These results forecast that raise in average temperature would be 1.79 °C (7.33%), 4.62 °C (16.97%) and 4.68 °C (17.16%) in 2030, 2060 and 2090 respectively in future. Please refer to the **Figure 4.4** which shows the bar chart reflecting the temperature results for MIROC5 by applying RCP 8.5 for 2030, 2060 and 2090.

4.5 General Circulation Model - MRI-CGCM3

4.5.1 Precipitation Results and Analysis

4.5.1.1 Precipitation under RCP 2.6

The baseline annual average rainfall is 495.60 mm, which is expected to increase to 570.67 mm in 2030, 599.90 mm in 2060 and 597.30 mm in 2090. These results capture that in 2030 the increase in rainfall would be 75.07 mm (13.16%), in 2060 by 104.30 mm (17.39%) and in 2090 by 101.71 mm (17.03%) respectively. Please

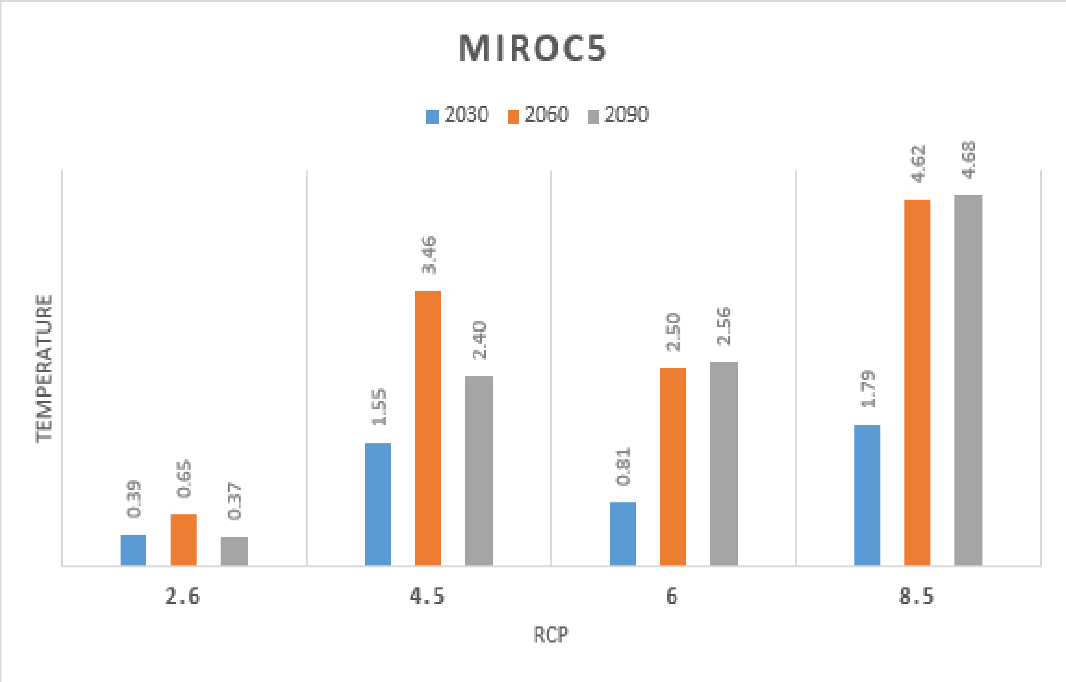

FIGURE 4.4: Bar Chart Reflecting the Temperature Results for MIROC5 by Applying Different Scenarios for 2030, 2060 and 2090

refer to the Figure 5.5 which shows the bar chart reflecting the precipitation results for MRI-CGCM3 by applying RCP 2.6 for 2030, 2060 and 2090.

4.5.1.2 Precipitation under RCP 4.5

The baseline annual average rainfall is 495.60 mm, which is expected to decrease to 489.80 mm in 2030, 453.45 mm in 2060 and 460.74 mm in 2090. These results capture that in 2030 the decrease in rainfall would be 5.80 mm (1.18%), in 2060 by 42.15 mm (9.30%) and in 2090 by 34.86 mm (7.75%) respectively. Please refer to the **Figure 4.5** which shows the bar chart reflecting the precipitation results for MRI-CGCM3 by applying RCP 4.5 for 2030, 2060 and 2090.

4.5.1.3 Precipitation under RCP 6

The baseline annual average rainfall is 495.60 mm, which is expected to increase to 529.39 mm in 2030, 505.78 mm in 2060 and 543.29 mm in 2090. These results capture that in 2030 the increase in rainfall would be 33.79 mm (6.38%), in 2060 by 10.18 mm (2.01%) and in 2090 by 47.69 mm (8.78%) respectively. Please refer to the **Figure 4.5** which shows the bar chart reflecting the precipitation results for MRI-CGCM3 by applying RCP 6 for 2030, 2060 and 2090.

4.5.1.4 Precipitation under RCP 8.5

The baseline annual average rainfall is 495.60 mm, which is expected to increase to 517.83 mm in 2030, 576.85 mm in 2060 and 574.65 mm in 2090. These results capture that in 2030 the increase in rainfall would be 22.23 mm (4.29%), in 2060 by 81.25 mm (14.08%) and in 2090 by 79.05 mm (13.76%) respectively. Please refer to the **Figure 4.5** which shows the bar chart reflecting the precipitation results for MRI-CGCM3 by applying RCP 8.5 for 2030, 2060 and 2090.

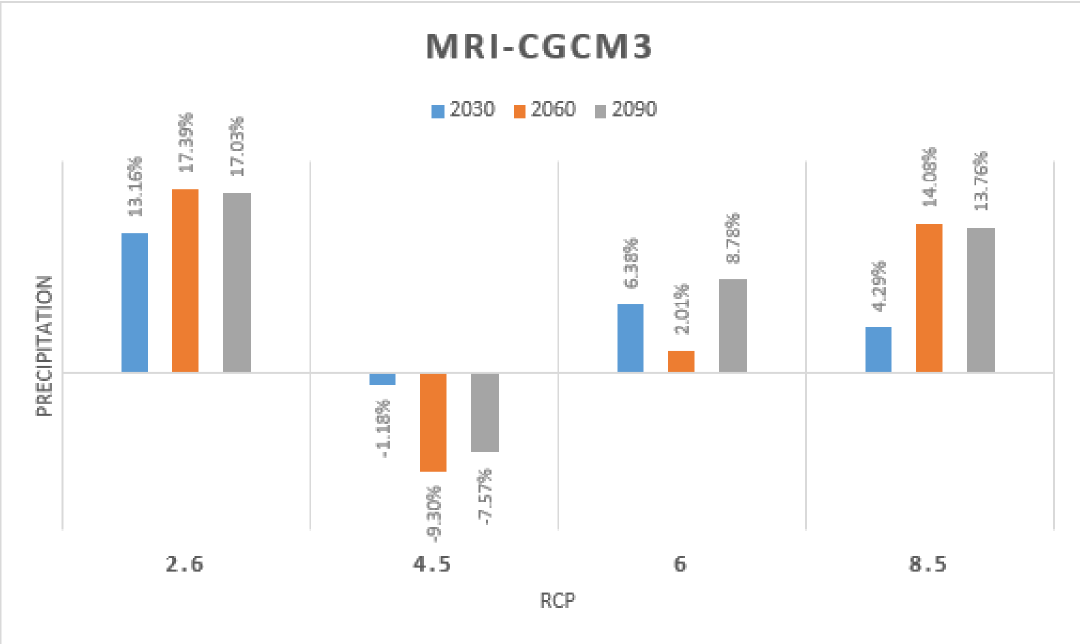

FIGURE 4.5: Bar Chart Reflecting the Precipitation Results for MRI-CGCM3 by Applying Different Scenarios for 2030, 2060 and 2090

4.5.2 Temperature Results and Analysis

4.5.2.1 Temperature under RCP 2.5

The baseline annual average temperature of 22.60 °C would remain same 22.66 °C in 2030, 24.84 C in 2060 and 22.95 °C in 2090. These results forecast that raise in average temperature would be 0.06 °C (0.24%), 0.24 °C (1.07%) and 0.35 °C

(1.52%) in 2030, 2060 and 2090 respectively in future. Please refer to the **Figure 4.6** which shows the bar chart reflecting the temperature results for MRI-CGCM3 by applying RCP 2.6 for 2030, 2060 and 2090.

4.5.2.2 Temperature under RCP 4.5

The baseline annual average temperature of 22.60 °C would rise to 23.12 °C in 2030, 24.02 °C in 2060 and 24.54 °C in 2090. These results forecast that raise in average temperature would be 0.52 °C (2.27%), 1.42 °C (5.92%) and 1.94 °C (7.90%) in 2030, 2060 and 2090 respectively in future. Please refer to the **Figure 4.6** which shows the bar chart reflecting the temperature results for MRI-CGCM3 by applying RCP 4.5 for 2030, 2060 and 2090.

4.5.2.3 Temperature under RCP 6

The baseline annual average temperature of 22.60 °C would slight rise to 22.82 °C in 2030, 23.82 °C in 2060 and 24.69 °C in 2090. These results forecast that raise in average temperature would be 0.22 °C (0.94%), 1.22 °C (5.14%) and 2.09 °C (8.47%) in 2030, 2060 and 2090 respectively in future. Please refer to the **Figure 4.6** which shows the bar chart reflecting the temperature results for MRI-CGCM3 by applying RCP 6 for 2030, 2060 and 2090.

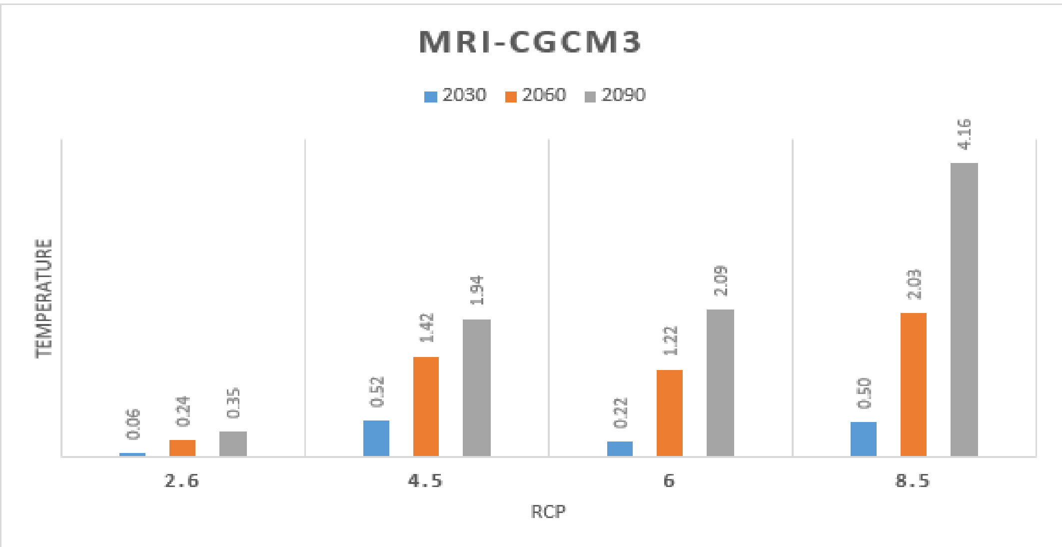

FIGURE 4.6: Bar Chart Reflecting the Temperature Results for MRI-CGCM3 by Applying Different Scenarios for 2030, 2060 and 2090

4.5.2.4 Temperature under RCP 8.5

The baseline annual average temperature of 22.60 °C would rise to 23.10 °C in 2030, 24.63 °C in 2060 and 26.76 °C in 2090. These results forecast that raise in average temperature would be 0.50 °C (2.16%), 2.03 °C (8.25%) and 4.16 °C (15.54%) in 2030, 2060 and 2090 respectively in future. Please refer to the **Figure 4.6** which shows the bar chart reflecting the temperature results for MRI-CGCM3 by applying RCP 8.5 for 2030, 2060 and 2090.

4.6 Discussion

4.6.1 General

The section presents an in-depth analysis and interpretation of the precipitation and temperature data collected for Peshawar city from 1989 to 2018. In order to understand the potential pridicted climate scenarios, three global-climate-models (GCMs), namely HadGEM2, MIROC5, and MRI-CGCM3, were utilized. These models were applied under four different representative-concentration-pathways (RCPs), namely 2.6, 4.5, 6, and 8. The analysis focused on three specific time horizons, namely 2030, 2060, and 2090. By employing these GCMs and RCPs, the study aimed to offer a comprehensive understanding of the potential variations in precipitation patterns and temperature trends in Peshawar city throughout the selected time frames. The findings from this analysis hold significant importance as they subsidize to enhancing understanding about the potential impacts and effects of change in the climate on Peshawar's climate system

4.6.2 General Circulation Model - HadGEM2

4.6.2.1 Precipitation

The discussion in this section focuses on the observed data regarding annual average precipitation for the period 1989 to 2018 in Peshawar, as well as the projected changes in precipitation under different Representative-concentration-pathways

(RCPs). The observed data reveals an annual average precipitation of 528 mm during this period. However, the simulation results indicate potential changes in precipitation patterns for future years under various RCP scenarios. According to the projections, under RCP 2.6, the annual average precipitation is expected to reduce to

512.16 mm in 2030, 521 mm in 2060, and then increase to 556.12 mm in 2090. Similarly, under RCP 4.5, the annual average precipitation is projected to decrease to 502.36 mm in 2030, 499.23 mm in 2060, and 511.88 mm in 2090. Under RCP 6, the annual average precipitation is expected to decline to 499.38 mm in 2030, 517.88 mm in 2060, and increase to 750 mm in 2090. Lastly, under RCP 8.5, the annual average precipitation is likely to increase to 538.32 mm in 2030, 630.29 mm in 2060, and 788.89 mm in 2090. These findings indicate potential fluctuations in precipitation patterns, with some scenarios showing a decreasing trend while others suggesting an increase.

4.6.2.2 Temperature

The discussion revolves around the observed data on annual average temperatures for the 30-year period from 1989 to 2018, as well as the simulation results under different Representative-concentration-pathways (RCPs). The observed data shows that the annual average temperature for this period was 22.67 °C, with a standard deviation of 0.70 °C, indicating minimal variation over the 30-year span. These findings suggest a relatively stable climate trend during this period. However, the simulation results project slight increases in annual average temperatures for future years under different RCP scenarios. For RCP 2.6, the projected temperatures are 24.02 °C in 2030, 24.45 °C in 2060, and 24.43 °C in 2090. Similarly, under RCP 4.5, the projected temperatures are 24.00 °C in 2030, 25.23 °C in 2060, and 25.85 °C in 2090. Under RCP 6, the projected temperatures are 23.78 °C in 2030, 24.93 °C in 2060, and 26.44 °C in 2090. Lastly, under RCP 8.5, the projected temperatures are 24.15 °C in 2030, 26.14 °C in 2060, and 28.52 °C in 2090. These results indicate a minor upward trend in temperatures over the coming decades. Overall discussion shows that there is no significant variation in the temperature of Peshawar.

4.6.3 General Circulation Model - MIROC5

4.6.3.1 Precipitation

The discussion in this section revolves around the observed data and projected changes in annual average precipitation for the period 1989 to 2018 in Peshawar, Pakistan, under different Representative-concentration-pathways (RCPs). The observed data reveals that the annual average precipitation during this period was 528 mm. However, the simulation results indicate potential changes in precipitation patterns for future years under various RCP scenarios. Under RCP-2.6, the average annual precipitation is anticipated to reduce to 478.54 mm in 2030, 488.85 mm in 2060, and increase to 549.80 mm in 2090. Similarly, under RCP 4.5, the mean annual precipitation is forecasted to decrease to 500.27 mm in 2030, 499.66 mm in 2060, and 517.19 mm in 2090. Under RCP 6, the annual average precipitation is expected to decrease to 500.19 mm in 2030, 485.36 mm in 2060, and increase to 6787.50 mm in 2090. Lastly, under RCP 8.5, the average annual precipitation is anticipated to decrease to 425.54 mm in 2030, 448.40 mm in 2060, and increase to 700.17 mm in 2090. These findings highlight slight shifts in precipitation patterns, with some scenarios indicating a decreasing trend while others suggest an increase.

4.6.3.2 Temperature

The discussion in this section focuses on the observed data regarding annual average temperatures for the 30-year period from 1989 to 2018, as well as the simulation results under different Representative-concentration-pathways (RCPs). The observed data indicates that the annual average temperature during this period was 22.67 °C, with a relatively low standard deviation of 0.70 °C, suggesting a stable climate trend over the 30-year span. However, the simulation results using various RCP scenarios project potential changes in average annual temperatures for future years. Under RCP 2.6, the average annual temperature is predictable to stable at 22.99 °C in 2030, increase to 23.25 °C in 2060, and stable at 22.97 °C in 2090. Similarly, under RCP 4.5, the average annual temperature is likely to increase to 24.15 °C in 2030, 26.06 °C in 2060, and 25.00 °C in 2090. Under

RCP 6, the average annual temperature is anticipated to raise to 23.41 °C in 2030, 25.10 °C in 2060, and 25.16 °C in 2090. Lastly, under RCP 8.5, the average annual temperature is anticipated to raise to 24.39 °C in 2030, 27.22 °C in 2060, and further increase to 27.28 °C in 2090. These findings suggest potential changes in temperature patterns, with some scenarios indicating a steady increase while others demonstrate a slight decrease over time.

4.6.4 General Circulation Model - MRI-CGCM3

4.6.4.1 Precipitation

This section focuses on the observed annual average precipitation statistics for Peshawar from 1989 to 2018 as well as the anticipated changes in precipitation under various Representative-concentration-pathways (RCPs).The observed data reveals an annual average precipitation of 44 mm during this period. However, the simulation results indicate potential changes in precipitation patterns for future years under various RCP scenarios. Under RCP 2.6, the annual average precipitation is predicted to rasie to 570.67 mm in 2030, 599.90 mm in 2060, and 597.31 mm in 2090. On the other hand, under RCP 4.5, the annual average precipitation is projected to decrease to 489.80 mm in 2030, 453.45 mm in 2060, and 460.74 mm in 2090. Under RCP 6, the annual average precipitation is anticipated to slightly raise to 529.39 mm in 2030, then decrease to 505.78 mm in 2060, and then increase to 543.29 mm in 2090. Similarly, under RCP 8, the annual average precipitation is projected to decrease to 517.83 mm in 2030, increase to 576.85 mm in 2060, and 574.65 mm in 2090. These findings suggest potential fluctuations in precipitation patterns, different scenarios show growth with time, while others show a drop.

4.6.4.2 Temperature

The discussion in this section focuses on the observed data regarding annual average temperatures for the 30-year period from 1989 to 2018, as well as the simulation results under different Representative-concentration-pathways (RCPs). The observed data reveals a stable climate trend with an annual average temperature of 22.67 °C and a low standard deviation of 0.70 °C. However, the simulation results using various RCP scenarios project potential changes in average annual temperatures for future years. Under RCP 2.6, the annual average temperature is anticipated to remain stable at 22.66 °C in 2030, increase to 24.84 °C in 2060, and then stable to 22.95 °C in 2090. Similarly, under RCP 4.5, the annual average temperature is projected to increase to 23.12 °C in 2030, 24.02 °C in 2060, and 24.54 °C in 2090. Under RCP 6, the average annual temperature is expected to stable at 22.82 °C in 2030, increase to 23.82 °C in 2060, and 24.69 °C in 2090. Lastly, under RCP 8.5, the annual average temperature is predicted to increase to 23.10 °C in 2030, 24.63 °C in 2060, and 26.76 °C in 2090. These findings suggest potential fluctuations in temperature patterns, with some scenarios indicating stability, while others demonstrate an increase or decrease over time.

Chapter 5

Conclusion and Recommendations

5.1 Conclusion

In conclusion, the comparative assessment of climatic scenario projections made for Peshawar, Pakistan, using global-climate-models has shed light on the potential effects and impacts of climate change on the region. A thorough understanding of the potential future climate scenarios for Peshawar has been attained through the assessment and evaluation of temperature and precipitation observed data from 1989 to 2018 and includes the use of four representative concentrationpPathways (RCPs) and three global climate models (HadGEM2, MIROC5, and MRI-CGCM3). This study used MarkSim, a statistical tool, to evaluate the effectiveness of the GCMs. Such a method enables a thorough and organized assessment of GCMs' capability to forecast potential climate change scenarios for Peshawar. Since MarkSim GCMs data is available from 2010 onward, the overlapping data for the period 2011 to 2018 between the observed Meteorological (Met.) Data and MarkSim GCM data is used. The first four years, from 2011 to 2014, were utilized for calibration purposes, and for validation, the data set from 2015 to 2018 was utilized. The Nash-Sutcliffe method is used to calibrate and validate temperature and precipitation data. This methodology can act as a useful framework for upcoming investigations into and discussions about climate change in the area.

5.1.1 Precipitation

The comparative assessment of precipitation data involves the use of three Global Climate Models (GCMs) - HadGEM2, MIROC5, and MRI-CGCM3. These models were applied with Representative Concentration Pathways (RCPs) 2.6, 4.5, 6, and 8.5 for the years 2030, 2060, and 2090. The results are summarized in Table 5.1. Upon comparison, it appears that HadGEM2 and MIROC5 exhibit similar trends among the three GCMs.

Table 5.1: Comparative Assessment of Precipitation Using Three GCMs by Applying Four RCPs for 2030, 2060 and 2090

		Precipitation		
RCP	**Year**	**HadGEM2**	**MIROC5**	**MRI-CGCM3**
2.6	2030	3.23%	-3.56%	13.16%
	2060	4.88%	-1.38%	17.39%
	2090	10.88%	9.86%	17.03%
4.5	2030	1.35%	0.93%	-1.18%
	2060	0.73%	0.81%	-9.30%
	2090	3.18%	4.18%	-7.57%
6	2030	0.76%	0.92%	6.38%
	2060	4.30%	-2.11%	2.01%
	2090	33.92%	37.07%	8.78%
8.5	2030	7.94%	-16.46%	4.29%
	2060	21.37%	-10.53%	14.08%
	2090	37.18%	29.22%	13.76%

5.1.2 Temperature

The comparative assessment of temperature data involves the use of three Global Climate Models (GCMs) - HadGEM2, MIROC5, and MRI-CGCM3. These models were applied with Representative Concentration Pathways (RCPs) 2.6, 4.5, 6, and 8.5 for the years 2030, 2060, and 2090. The results are summarized in Table 5.2. Upon comparison, it appears that MRI-CGCM3 and MIROC5 exhibit similar trends among the three GCMs.

Table 5.2: Comparative Assessment of Temperature Using Three GCMs by Applying Four RCPs for 2030, 2060 and 2090

		Temperature		
RCP	**Year**	**HadGEM2**	**MIROC5**	**MRI-CGCM3**
	2030	1.42	0.39	0.06
2.6	2060	1.85	0.65	0.24
	2090	1.83	0.37	0.35
	2030	1.4	1.55	0.52
4.5	2060	2.63	3.46	1.42
	2090	3.25	2.4	1.94
	2030	1.18	0.81	0.22
6	2060	2.33	2.5	1.22
	2090	3.84	2.56	2.09
	2030	1.55	1.79	0.5
8.5	2060	3.54	4.62	2.03
	2090	5.92	4.68	4.16

5.1.3 General Circulation Model - HadGEM2

Under RCP 2.6, the annual average precipitation is expected to raise to 512.16 mm in 2030, 521 mm in 2060, and 556.12 mm in 2090. Similarly, under RCP 4.5, the annual average precipitation is anticipated to raise to 502.36 mm in 2030, 499.23 mm in 2060, and 511.88 mm in 2090. Under RCP 6, the annual average precipitation is anticipated to raise to 499.38 mm in 2030, 517.88 mm in 2060, and 750 mm in 2090. Lastly, under RCP 8.5, the annual average precipitation is anticipated to raise to 538.32 mm in 2030, 630.29 mm in 2060, and 788.89 mm in 2090.

For RCP 2.6, the projected temperatures are 24.02 °C in 2030, 24.45 °C in 2060, and 24.43 °C in 2090. Similarly, under RCP 4.5, the projected temperatures are 24.00 °C in 2030, 25.23 °C in 2060, and 25.85 °C in 2090. Under RCP 6, the projected temperatures are 23.78 °C in 2030, 24.93 °C in 2060, and 26.44 °C in 2090. Lastly, under RCP 8.5, the projected temperatures are 24.15 °C in 2030, 26.14 °C in 2060, and 28.52 °C in 2090.

5.1.4 General Circulation Model - MIROC5

Under RCP-2.6, the average annual precipitation is anticipated to decline to 478.54 mm in 2030, 488.85 mm in 2060, and increase to 549.80 mm in 2090. Similarly, under RCP-4.5, the mean annual precipitation is anticipated to incline to 500.27 mm in 2030, 499.67 mm in 2060, and 517.19 mm in 2090. Under RCP 6, the annual average precipitation is expected to increase to 500.19 mm in 2030, decrease to 485.36 mm in 2060, and increase to 787.50 mm in 2090. Lastly, under RCP 8.5, the average annual precipitation is anticipated to decline to 425.54 mm in 2030, 448.40 mm in 2060, and increase to 700.17 mm in 2090.

Under RCP 2.6, the average annual temperature is anticipated to stable at 22.99 °C in 2030, increase to 23.25 °C in 2060, and stable at 22.97 °C in 2090. Similarly, under RCP 4.5, the average annual temperature is anticipated to raise to 24.15 °C in 2030, 26.06 °C in 2060, and 25.00 °C in 2090. Under RCP 6, the average annual temperature is estimated to raise to 23.41 °C in 2030, 25.10 °C in 2060, and 25.16 °C in 2090. Lastly, under RCP 8.5, the average annual temperature is estimated to raise to 24.39 °C in 2030, 27.22 °C in 2060, and further increase to 27.28 °C in 2090.

5.1.5 General Circulation Model - MRI-CGCM3

Under RCP 2.6, the annual average precipitation is predicted to raise to 570.67 mm in 2030, 599.90 mm in 2060, and 597.31 mm in 2090. On the other hand by analyzing RCP 4.5, the annual average precipitation is anticipated to decline to 489.80 mm in 2030, 453.45 mm in 2060, and 460.74 mm in 2090. Under RCP 6, the annual average precipitation is estimated to raise to 529.39 mm in 2030, 505.78 mm in 2060, and to 543.29 mm in 2090. Similarly, under RCP 8, the annual average precipitation is anticipated to raise to 517.83 mm in 2030, increase to 576.85 mm in 2060, and 574.65 mm in 2090.

Under RCP 2.6, the annual average temperature is predicted to remain stable at 22.66 °C in 2030, increase to 24.84 °C in 2060, and then stable to 22.95 °C in 2090. Similarly, under RCP 4.5, the annual average temperature is predicted to raise to 23.12 °C in 2030, 24.02 °C in 2060, and 24.54 °C in 2090. Under RCP 6, the average annual temperature is expected to stable at 22.82 °C in 2030, increase to 23.82 °C in 2060, and 24.69 °C in 2090. Lastly, under RCP 8.5, the annual average temperature is anticipated to raise to 23.10 °C in 2030, 24.63 °C in 2060, and 26.76 °C in 2090.

According to the study's conclusions, Peshawar is anticipated to experience stable temperatures and different patterns of precipitation over the next few decades. These projected changes have no major significant implications for local agriculture, water supplies, and public health. However, considering its geographic location and socioeconomic circumstances, Peshawar may be susceptible to the impacts of climate change. This emphasizes the significance of taking proactive steps to adapt to and mitigate these changes.

5.2 Recommendations

- The main emphasis of this study revolves around climate variables, specifically temperature and precipitation, utilizing the RCPs. It is recommended for future researchers to investigate changes by considering SSPs in latest IPC report, as this integration will offer a deeper comprehension of the complex relationship between climatic shifts and socioeconomic dynamics.

- This study extensively utilizes observed data of temperature and precipitation obtained from the meteorological department, specifically up until the year 2018. In order to ensure the most current and accurate analysis, it is strongly recommended that future research endeavors consider incorporating observed data from the year 2019 and onwards. This updated dataset will provide a more comprehensive and reliable basis for climate-related analyses and predictions.

- Furthermore, it is advised that future research endeavors incorporate the insights and findings from the latest IPCC report, AR6. This updated information will provide a more current and comprehensive foundation for climate-related studies.

- A comprehensive re-evaluation of the projected temperature increase to 5.92 °C by 2090, based on the General Circulation Model - HadGEM2 using RCP 8.5, is strongly advised. This value appears notably higher compared to the estimates provided by the IPCC.
- The study's recommendations add to the database of information on climate change in Peshawar and provide the foundation for scientific decision-making and the development of effective adaptation strategies
- The analysis of this research will help to combat the potential consequences of climate change, to build public health systems, promote sustainable water management practices, and strengthen the agricultural sector's resilience.

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