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Climate Change Perspective in Pakistan

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Abstract
The study aims to assess historical climate variations and forecast changes within various agro-climatic regions of Pakistan over the next half-century, employing both Regional and Global Climate Models. The primary objective is to evaluate the vulnerabilities specific to different regions and propose suitable coping mechanisms and adaptation strategies. An examination of historical climate data underscores the undeniable reality that climate change is an ongoing process in Pakistan. The rate and nature of these changes are expected to fluctuate across time and geographical regions, exerting profound effects on various aspects of society. In parallel with endeavors to curtail greenhouse gas emissions, preparing for and adapting to the consequences of a shifting climate is imperative. Comprehending the implications of climate change for Pakistan constitutes a vital initial step in this endeavor. Should future climate changes materialize to the extent projected by the majority of global climate models, it is anticipated that Pakistan's water resources will undergo substantial alterations. This, in turn, will have ripple effects on food production, public health, industrial processes, transportation systems, and the long-term sustainability of ecosystems. Particularly, regions in the southern part of the country, already grappling with resource stress, are poised to face exacerbated challenges due to supply or demand shifts driven by climate change. Historical records and projections from General Circulation Models and Regional Climate Models converge on the prediction that extreme climatic events, such as droughts and floods, will intensify in frequency and magnitude across different parts of Pakistan. These extreme events are expected to exert substantial pressure on existing infrastructure and institutional capacities, potentially precipitating significant economic, social, and environmental repercussions. Consequently, it is imperative to place specific emphasis on understanding, mitigating, and adapting to these extreme climatic events.

Keywords: GCMs , RCMs, Emissions Ripple effect, Food production

1 Introduction

Throughout the course of Earth's geological history, its climate has undergone continuous evolution spanning millennia. However, the past two centuries have witnessed the emergence of a pressing concern, known as the greenhouse problem, which poses an unprecedented threat to the stability of the climate system. This climatic evolution is shaped by a multitude of factors, encompassing both internal and external sources of variation. The El Nio-Southern Oscillation (ENSO), changes in atmospheric composition as revealed by isotopic analyses of ice cores, variations in the extent and volume of terrestrial and marine ice, and the innate variability of the biosphere are among these variables. These various components emphasise the intricate relationships between various Earth system components and the wide range of responses they elicit. Over the course of the past century, there has been a notable and sustained increase in the average annual surface air temperature, registering an approximate rise of 2.9°C in boreal Asia. This trend has raised significant concerns among nations in the Asiatic region. They are especially concerned since the buildup of greenhouse gases in the atmosphere has the potential to alter the climate dynamics of the area. Changes in storm patterns, variations in the frequency and severity of floods and droughts, and a corresponding rise in sea levels can all be signs of this

metamorphosis. The Asiatic region has historically struggled with its susceptibility to changes in monsoonal patterns, the effects of El Nio Southern Oscillations, and the potential destruction caused by tropical storms. These weaknesses highlight the area's extreme sensitivity to phenomena connected to climate change.

1.1 Country Profile

The geographical makeup of this nation spans a vast latitudinal range, stretching from the southern shores of the Arabian Sea to the towering Himalayan Mountains in the north. Situated within the realms of the sub-tropics while also encompassing portions within the temperate zone, this diverse landscape provides a home to approximately 180 million inhabitants. A substantial proportion of this population is highly susceptible to the impacts of climate change. Of notable concern is the significant number of residents who dwell in low- lying coastal regions and river deltas. These areas, characterized by their proximity to water bodies, are particularly vulnerable to the far-reaching consequences of global temperature increases and the ensuing shifts in climate patterns. Among the most formidable challenges faced by these communities are the rising sea levels and the concomitant threat of inundation caused by flooding events. As the climate continues to evolve, these vulnerabilities are poised to take a heavy toll on the populace and necessitate robust adaptation measures to safeguard their well-being. Climatologically, Pakistan exhibits a predominantly arid to semi-arid climate, characterized by considerable spatial and temporal variations in various climatic parameters. Notably, approximately 59% of the annual precipitation in the country can be attributed to the monsoon rains, which serve as a pivotal hydro-meteorological resource for Pakistan's diverse ecosystems. In the Greater Himalayan region situated above the 35th parallel north, the primary source of moisture during the winter season predominantly takes the form of snow and ice. The annual maintenance of river flow is made possible by the gradual melting of this stored snow, which also adds to the perennial nature of these important water bodies. A coastal climate can be found on the southern and eastern edges of the nation; it is distinguished by its presence along a short stretch of the coastline. In contrast, the northern parts of Pakistan are mostly affected by mountainous climates, with a range of extremes from humid to arid. In between these two extremes, the climate changes into one that is primarily tropical and continental.

The core objective of this study is to delve into the historical patterns of climate change within Pakistan and to project potential changes that may transpire over the next half-century. This projection relies on the utilization of both Regional and Global Climate Models. By gaining a comprehensive understanding of these changes, the study aims to identify the vulnerabilities specific to different agro-climatic regions across the country. Furthermore, it endeavours to formulate and propose effective coping mechanisms and adaptation strategies, thus contributing to the nation's resilience in the face of a dynamically evolving climate landscape.

2 Data and Methodology

The study relied on a comprehensive dataset spanning the previous five decades, from 1951 to 2000, to conduct an in-depth analysis of past climate variations. Various climatic parameters were examined, and graphical representations were generated for mean annual and seasonal rainfall, as well as maximum, minimum, and mean temperature values. These data were collected from 60 meteorological stations strategically located across diverse agro-climatic regions within the country. The temperature data encompassed both mean and seasonal temperature measurements, accounting for variations during both the monsoon and winter periods. Precipitation data, encompassing annual and seasonal totals, were also subjected to rigorous analysis. This comprehensive examination facilitated the identification of trends within the dataset, with trend lines plotted and changes elucidated through the fitting of curves to the data. In order to spatially visualize these climatic changes, contour lines were drawn onto maps of the country. These contour maps enabled the delineation of regions exhibiting positive and negative changes in climatic parameters, providing a valuable geographical perspective on the shifts occurring within Pakistan's climate. To project future climate scenarios, the study harnessed the Climate Scenario generator MAGIC, alongside the Regional Climate Model RegCM2. These models utilized data derived from the 1961- 1990 period as a baseline, aiding in the generation of forecasts for both rainfall and temperature patterns. This forward-looking approach forms an integral

component of the research, as it assists in anticipating potential future climatic shifts and their implications for Pakistan's agro- climatic regions.

3 Analysis of Results & Conclusions

The study emphasises the critical significance of the total stock of greenhouse gases (GHGs) in the atmosphere as the primary driver of climate change rather than concentrating solely on annual GHG emissions. It's interesting to note that historically, the combined contribution of developed and transitional economies to the global stock of GHGs has accounted for roughly 75%. Additionally, when annual contributions are taken into consideration, significant variations across various countries are seen in both the absolute and per capita emissions. Pakistan stands out as a nation that is particularly sensitive to the consequences of climate change because of a number of crucial factors. It is especially vulnerable to environmental disruptions because of its heavy reliance on climate-sensitive industries like agriculture and forestry. Significant trends can be seen when historical Pakistani climatic data is analyzed. Since the beginning of the 20th century, the annual mean surface temperature has shown a steady rising pattern. Particularly arid coastal regions, arid mountain ranges, and hyper-arid plains all see an increase in temperature. In addition, there has been a noticeable decline in winter and summer rainfall, with the coastal belt and hyper-arid plains experiencing drops of 10% to 15%. In contrast, the monsoon zone has had a notable increase in rainfall, ranging from 18% to 32%, with a focus on the more humid regions. The southern half of the country has seen an increase in solar radiation of 0.5% to 0.7%, whereas Baluchistan has seen a 5% fall in relative humidity. With more sunshine hours and a 3-5% increase in ETo because of a 0.9°C temperature increase, there is a 3-5% drop in cloud cover in central Pakistan. With no change in rainfall, the net irrigation water needs increased by 5%. increasing aridity in northern regions outside of the monsoon season and in arid areas. There have been seven powerful, ten moderate, and seven mild El Ninos over the past 100 years. Rainfall variations between 17 and 64% of the mean during intense events.

Table 1: Temperature Change during 1951 - 2000

S.No Region	Trend Over the last century	Range (°C)
Above the Thermal Low Region	Increased	0.2 to 1.0°C
Coastal regions in Baluchistan	Decreased	- 0.5 to -1.5°C
Monsoon climate belt	Generally decreased	- 2.0 to 0.0°C
Mountains in the northern (Greater Himalayan) region	Generally increased	-1.5 to 1.5°C
Thar region	Increased	0.3 to 1.0°c
Sindh Coast	Generally Increased	0.0 to 0.5°c

Tropical cyclones are a significant meteorological phenomenon that has a big impact on the weather and climate in numerous tropical Asian locations. Cyclones often develop in the northern Indian Ocean and have a major effect on countries like Bangladesh, India, Pakistan, and Sri Lanka. Over the past fifty years, there has been a discernible increase in the frequency of depressions and cyclones in the Arabian Sea and the Bay of Bengal. Intensity of these cyclonic systems has also increased, particularly in the latter half of the 20th century. This heightened activity of tropical cyclones in the region underscores the growing significance of understanding and managing these weather events. It necessitates proactive measures, such as improved early warning systems, enhanced disaster preparedness, and climate-resilient infrastructure, to mitigate the potential impact on vulnerable coastal populations and economies in the affected countries.

The observed changes in cyclone behaviour also warrant ongoing research and monitoring to gain deeper insights into the underlying climatic drivers and their implications for the future. Extreme weather occurs frequently in Pakistan, including low-temperature winds from the northwest that notably strike the southern plains of the nation in January. Furthermore, heat waves and high temperatures frequently occur in megacities with dense populations and extensive urban areas. These incidents regularly become worse due to the urban heat island effect and air pollution, posing major risks to the public's health and wellbeing.

The El Nio-Southern Oscillation (ENSO) phenomenon has a significant impact on Pakistan's weather patterns and interannual climate variability on a global scale. Extensive research has demonstrated the significant impact of ENSO events on the country's climate. El Niño events, for instance, tend to suppress monsoon rainfall activity over Pakistan, as evidenced by previous studies (Chaudhry, 1995). Conversely, La Niña events have been associated with reduced winter precipitation in Pakistan, as observed in research by Azmat (2002).

Table 2: Changes in precipitation from 1951 to 2000.

Geographical Region	**Annual Basis**	**Monsoon Climate**	**Winter Season**
Coastal areas/oceans	Negative	Negative	
Positive Quetta & Sindh	Positive	Positive	Positive
Southeastern region Western Balochistan and	Negative	Negative	Negative
Monsoon Geographical belt	positive	positive	Mostly
positive Northern Mountains	positive	positive	Negative
Nokkundi			

Notably, the severe drought that afflicted Pakistan and large parts of South Asia during the years 1998-2001 is linked to the La Niña phenomena, as established in studies by Hoerling and Kumar (2003). These findings underscore the importance of understanding and monitoring ENSO events, as they hold considerable sway over Pakistan's climate patterns and can have far-reaching consequences for agriculture, water resources, and overall societal well- being. Effective management and adaptation strategies are essential to address the challenges posed by these extreme weather events and their impacts on both urban and rural communities. Results show that due to windy conditions, temperature change over seasonal lows is comparatively sluggish during monsoons compared to other dry and hyper-arid regions.

i. RCMs Projections

The analysis conducted using Regional Climate Models (RCMs) has yielded somewhat distinct findings, particularly concerning precipitation patterns. Notably, Southeast Sindh and Cholistan exhibit a positive change in projected precipitation over the next half-century. However, the temperature trend remains relatively consistent with previous observations.

ii. Possible effects of climate change

An already resource-constrained nation is made much more complex and difficult by the effects of climate change. The predicted climate changes in the area affect many significant facets. These include an increase in surface temperatures, a strengthening of the monsoon circulation, and both the frequency and intensity of intense rainfall events have increased. Climate change also has an impact on sea level rise. The cumulative effects of these anticipated changes may have significant repercussions on the nation's ecosystems, biodiversity, hydrology, and water supplies. The crucial economic sectors of agriculture, forestry, and fishing will also likely suffer many difficulties. Mountainous and coastal environments could undergo changes that have a wide-ranging impact.. Moreover, human settlements and human health could be significantly affected.

Addressing these multifaceted impacts of climate change in Pakistan necessitates comprehensive strategies and actions, encompassing mitigation efforts, adaptation measures, and policy interventions. It underscores the urgency of managing climate risks and fostering resilience across various sectors of the nation's economy and society. Marine life and forestry: Mangrove forests are just beginning to feel the effects. Pakistan, which is the nation least impacted by sea level rise, would suffer from the loss of its mangrove forests, which supply inhabitants with food and fuel and are the source of 90% of Pakistan's prawn exports. Rising sea levels present another imminent concern, leading to the inundation of extensive coastal areas across Asia and the subsequent recession of flat sandy beaches. The delicate ecosystems of mangroves and coral reefs in the region are also expected to face severe repercussions.

El Nio-Southern Oscillation (ENSO) occurrences are also anticipated to intensify and occur more frequently in a warming world. This increased activity could have a significant impact on the Asian monsoon system and lead to greater inter-annual changes in rainfall patterns. Food production and the sustainability of the region's water resources could face extra issues as a result of these variations in the monsoon's characteristics. As such, the impacts of climate change in Asia are multifaceted and interconnected, necessitating comprehensive strategies and international cooperation to address these complex challenges effectively. The intensification of tropical cyclones, coupled with rising sea levels, poses an escalated risk of both human casualties and property damage in low-lying coastal areas, particularly those susceptible to cyclones, such as Southeast Sindh. As temperatures warm and precipitation levels increase, the likelihood of heat-related illnesses and the transmission of infectious vector-borne diseases like malaria and dengue is expected to rise. Additionally, climate change exacerbates threats to biodiversity through changes in land use, land cover, and population pressure. Climate change has significant effects on the water industry because both water and agriculture are extremely vulnerable to its effects. Due to expected climate change, freshwater availability is predicted to become extremely sensitive. In river deltas, flooding is predicted to become more frequent and severe, which could have negative effects on the local economies of these areas. On the other hand, arid and

semi-arid regions may experience significant water stress as a result of changing climatic patterns that worsen current problems with water scarcity. Effective management of these issues is essential for maintaining agriculture, guaranteeing water security, and preserving the well-being of populations affected by these changes.

Water Flow at Qilla Bisham in Years

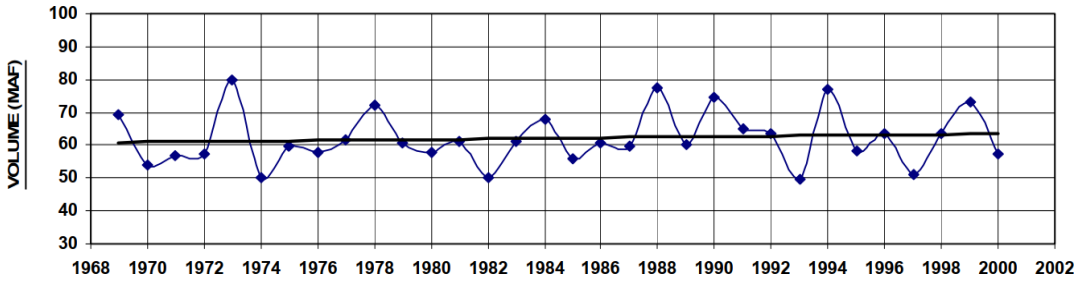

Figure 1

Concerning the evidence of the ongoing effects of climate change on the Himalayan glaciers is the Gangorti glacier's rapid retreat at a pace of 98 feet per year. By 2035, all of the central and eastern Himalayan glaciers may have disappeared, according to scientific predictions if this rend continues. There is a commensurate decrease in downstream flow volumes as these glaciers thaw. A direct correlation between precipitation and inflow data analysis suggests that, despite higher temperatures in the upper watersheds, inflows are reduced in dry years. This conclusion appears to be at odds with the IPCC's predictions, which predict that larger river flows will result from enhanced glacial melt as a result of warmer temperatures. This apparent contradiction underscores the complexity of climate change impacts in specific regions and highlights the need for more comprehensive research to understand the intricate interplay of various factors influencing glacier behaviour and river flow dynamics in the Himalayan region. Additionally, it emphasizes the urgency of addressing the environmental and water resource challenges associated with glacier retreats in this critical part of the world.

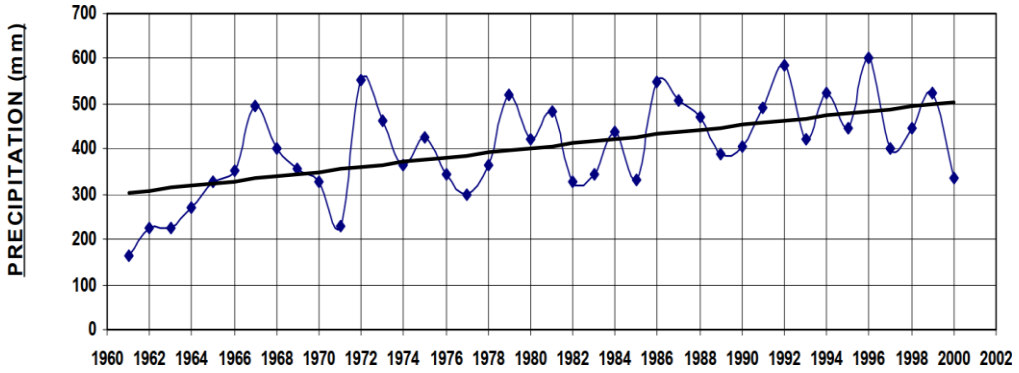

Figure 2

Although downstream flow regimes may first increase as a result of glacier melt contributions, historical stream flow data suggests that this phase of heightened flow has already happened. In fact, the basins are presently undergoing a trend of diminishing flows that could last for a while, which has important consequences for water supplies. Water shortages, already present in the nation, especially during recent severe droughts, could get worse if this decreasing trend continues. The rise in temperature has also been a steady tendency throughout the previous few decades, whether or not it was accompanied by variations in the amount of precipitation. This rise in temperature has caused glaciers to melt more

quickly, increasing the amount of glacier sliding and the amount of silt in the upper watershed. These processes can further compound the challenges associated with managing water resources in the affected areas. It underscores the intricate relationship between climate change, glacier behaviour, and downstream water availability, highlighting the need for adaptive measures to address the evolving water resource dynamics. While downstream flow regimes may first increase as a result of glacier melt contributions, historical stream flow data suggests that this phase of heightened flow has already happened. In fact, a current trend of diminishing flows in basins has important ramifications for water resources and the ability to last for a while. Water shortages, already present in the nation, especially during recent severe droughts, could get worse if this decreasing trend continues. In addition, whether or not there are variations in precipitation, the rise in temperatures has been a steady pattern over the previous few decades. This rise in temperature has hastened glacier melting, which has raised glacier sliding levels and increased sediment loads in the upper watershed. These processes can further compound the challenges associated with managing water resources in the affected areas. It underscores the intricate relationship between climate change, glacier behaviour, and downstream water availability, highlighting the need for adaptive measures to address the evolving water resource dynamics. Because of the anticipated effects of climate change, it is anticipated that freshwater quality would decline. The availability of safe and potable water is decreasing as a result of the water quality decline, and the expenses of treating and purifying the water to make it appropriate for diverse uses are rising at the same time. It's critical to understand how changes in water quantity and quality are connected. Pollutant concentrations have a propensity to increase when water levels are decreased, raising worries about contamination. In contrast, high-flow situations and flooding can increase turbidity and flush contaminants into the water system, further lowering the quality of the water. These complex dynamics underscore the critical importance of comprehensive water resource management and the need for strategies to safeguard both water quantity and quality in the face of climate change impacts. When it comes to the presence and dispersion of our natural ecosystems, water is a crucial and limiting element. Particularly important natural systems that have a big impact on the quality of the water are wetlands. The consequences of climate change can have a significant impact on these ecosystems. Metals, nutrients, and sulphates are frequently filtered out and neutralised through the natural process of water passing through a wetland, improving the water quality. However, wetlands' capacity for assimilation and purification is negatively impacted by the effects of climate change, especially decreased water table levels. Addressing these challenges requires a multifaceted approach that considers the preservation and restoration of wetlands and the mitigation of water quality issues as crucial components of ecological conservation efforts in the face of climate change.

a. Water Demand

The impact of climate change on water resources depends on changes in demand, which considers both environmental and human variables, as well as potential changes in the resource base, or the amount of water that is available. The demand for water in the future is anticipated to change as a result of a number of factors, including population growth, economic development, and wealth distribution. Between 500 million and over 2 billion people, or a significant portion of the world's population, are reportedly already experiencing acute water stress. This figure is predicted to rise dramatically by 2025. This increase is being caused by many reasons, including population growth and the amplified effects of climate change. A deeper knowledge of water stress is also made possible by improved groundwater resource monitoring. These dynamics underscore the pressing need for sustainable water resource management, equitable distribution, and effective conservation efforts to address the growing challenges associated with water demand, especially in the context of a changing climate.

b. Recommendations

Developing countries in Asia, such as Pakistan, which are likely to bear the brunt of climate change impacts due to resource and infrastructure limitations, should prioritize the development and implementation of incremental adaptation strategies and policies. These tactics should emphasize "no-regret" actions and stress how crucial it is to take climate change into account while planning, designing,

and carrying out development operations. Implement a macro strategy for sustainable development that focuses on quick, equitable, and sustainable growth. This strategy should work to improve public food distribution systems, income levels, education and technical skill levels, disaster preparedness and management, and healthcare systems. Together, these initiatives ought to lessen society's general susceptibility to the effects of climate change. Micro Strategy for Climate Change- Related Sectors: Make a micro- level strategy with the industries that are most susceptible to climate change as its focal point. Encouragement of climate change adaptation requires the creation of new institutions or the modification of existing ones. It also calls for the modification of existing planned or implemented climate-sensitive infrastructures as well as other long-term choices that are subject to climate variability and change. These suggestions highlight how urgent it is to have comprehensive and multifaceted measures in place to deal with the problems that climate change is posing in nations like Pakistan. To increase resilience and decrease vulnerability to the effects of a changing climate while promoting sustainable growth and fair development, a combination of broad-based development and focused sector-specific interventions is required. It is crucial to keep track of these trends and fluctuations in important climate factors. It is essential to improve weather forecasting systems in the area to face the changing problems brought on by climate change. This entails putting new land-use planning policies into place to ensure resilience against climatic uncertainties. The adoption of cutting-edge methods for reliable regional climate change projections and assessments of variability, particularly regarding extreme events, is crucial in the quest for successful climate change mitigation and adaptation. It is also crucial to improve cooperation and coordination among the regional nations. Facilitating collaboration during climate change adaptation efforts may result in more thorough and effective plans. It is essential to involve local communities, non-governmental organizations (NGOs), and the general public. Ensuring awareness of climate change risks and involving these stakeholders in the planning, implementation, and monitoring of adaptation and mitigation strategies is key to fostering collective action and building resilience. These recommendations underscore the importance of a multi-pronged approach to address climate change in the region effectively. They emphasize the need for continuous research, improved infrastructure, international cooperation, and inclusive community engagement to mitigate the adverse effects of climate change and promote sustainable development. In conclusion, the findings of this study emphasize the pressing need for concerted efforts to mitigate the effects of climate change, particularly in a nation as vulnerable as Pakistan. Effective policies and adaptation strategies must be devised and implemented to safeguard critical sectors of the economy and protect the livelihoods of millions of people threatened by climate- induced shifts, including rising temperatures, altered rainfall patterns, and changing humidity levels.

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