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Review Article

Climate change and its Impact on Agriculture

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ABSTRACT

Global agriculture is facing serious problems from climate change, which will affect agricultural productivity, water availability, and rural lives. This study looks at the many effects of climate change on agriculture, emphasizing important patterns, weak points, and mitigation techniques. An rise in the severity of extreme weather events, altered precipitation patterns, and rising temperatures all cause disruptions to agricultural systems, which has an impact on animal production and crop yields. Problems with irrigation management and food security are made worse by changes in water supply and quality. Socioeconomic ramifications of vulnerable areas include decreased farmer earnings, food insecurity, and rural poverty, especially in emerging nations. Adaptation methods are critical for strengthening agricultural systems' resilience in the context of climate change. Adoption of agricultural types resistant to climate change, better water management techniques, and encouragement of sustainable land-use practices are some of these tactics. In order to promote international collaboration, integrate climate adaptation into national development objectives, and support climate-smart agriculture, policy interventions and institutional frameworks are essential. In order to adopt adaptive measures and maintain sustainable food production systems, policymakers, researchers, farmers, and stakeholders must work together to address the implications of climate change on agriculture.

Keywords: Climate, Crop production, Environment, Agriculture.

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INTRODUCTION

Over the past 65 years, significant global changes, including observed and anticipated climatic shifts and global warming, have emerged as critical issues for the twenty-first century. Climate change (CC) poses a complex challenge that affects various ecological, environmental, socio-political, and socio-economic aspects worldwide (Barnett et al., 2008; Stewart et al., 2005; Warziniack et al., 2018). Long-term patterns in temperature and precipitation, as well as variations in humidity and air pressure, are characteristics of climate change. Rising sea levels, the disappearance of the world's ice sheets, and erratic weather patterns are some of the most notable consequences of climate change (Gowda et al., 2018; Zhao et al., 2017). Prior to the Industrial Revolution, the main producers of greenhouse gases (GHGs) including CO2, CH4, N2O, and H2O in the atmosphere were natural occurrences like volcanic eruptions, wildfires and seismic activity (Vose et al., 2015). Climate change is the phrase used to describe long-term changes in Earth's temperature and weather patterns that are largely brought on

by human activity, such as the burning of fossil fuels, deforestation, and industrial processes. Increased greenhouse gas emissions cause global temperatures to rise, precipitation patterns to change, and extreme weather events like hurricanes, droughts, and floods to occur more frequently (Ingram et al., 2005). Globally, climate change has profound and far-reaching repercussions. Global economics, human health, water supplies, and natural ecosystems are all impacted. While shifting weather patterns cause disruptions to agricultural and food production, sea levels are rising which pose a major threat to coastal populations. In addition to making already-existing environmental problems worse, climate change presents serious threats to world stability and sustainable development (Iqbal and Arif, 2010; Schichting and Ahmadi, 2004). Comprehending the global context of climate change is vital to apprehend its effects on particular areas and industries, including Pakistani agriculture. Researchers can contextualize local manifestations of climate change and create effective adaptation and mitigation plans by looking at larger trends and scientific evidence of the phenomenon (Tariq et al., 2014**)**. Climate change effects following aspects:

Climate change impacts on biodiversity

The primary cause of species extinction and a major influence on global biodiversity is climate change (CC). Most climatic events have been proven to be associated with large-scale species dynamics (Wear and Coulston, 2015; Davis et al., 2015). Because of the pace and scope of CC, species' suitable habitat ranges in freshwater, marine, and terrestrial habitats are shifting. Changes in general climatic regimes have a range of effects on ecosystems, such as altered species abundance, shifting ranges, altered activity timing, and altered use of microhabitats (Arkema et al., 2013). The ability to tolerate biological interactions, environmental stresses, and dispersion constraints often determines the global range of any species. As a result, in response to CC, local species must move, adapt, or face extinction (Corvalan et al., 2005). The species that can best adapt have a better chance of surviving by adjusting to new ecosystems or by enduring in their current habitats. Inadequate access to microclimates and habitat connectivity are significant factors that increase vulnerability to intense heat wave occurrences and climate change. For instance, variations in carbon sequestration rates are being brought about by climate-driven shifts in the global distribution of mangroves (Ebi and Nealon, 2016).

Human health and Climate change

It is widely believed that CC has a substantial impact on the health of human (Davidson and Janssens, 2006). The WHO estimates that from 2030 to 2050, CC might cause an extra 250,000 deaths annually (Crowther et al., 2011). These deaths are ascribed to the global expansion of vector-borne diseases and the mortality and morbidity brought on by extreme weather events (Galloway et al., 2008). Here is a quick overview of some of the new health concerns related to this worldwide issue.

Economic costs associated with antimicrobial resistance and Climate change

AMR (Antimicrobial resistance) is a rapidly escalating global health challenge Galloway et al., 2008;Hilborn and Beasley, 2015). Health professionals worldwide are extremely concerned about this problem, which has the prospective to converse nearly all the development made in the health sector (Runting et al., 2017). Pharmaceutical industries globally produce massive quantities of antibiotics, but Resistance to harmful germs is progressively growing.. This resistance has significant implications for both national and global economies (Maynard, 2002). AMR is not confined to any specific region; it is booming on every continent (Sandifer et al., 2015). This growing resistance is pushing humanity toward a post-antibiotic era, where pathogens currently susceptible to antibiotics could become resistant, leading to new endemics and pandemics (Sandifer et al., 2015). If this scenario becomes a reality, there will be increased risks associated with complex medical procedures such as chemotherapy, joint replacements, and organ transplants (Bell et al., 2016). Nowadays, it is considerably harder and more expensive to treat common illnesses including pneumonia, post-surgical infections, HIV/AIDS, TB, and malaria because of the increase in drug-resistant cases (Sandifer et al., 2015).

Relationship vector-borne-diseases with climate change

Regardless of an environment, temperature is essential to the survival of living things. Therefore, a particular living organism, particularly a disease, needs a complex temperature range in order to survive on Earth. Precipitation is the second crucial element of CC and affects the transit and dissemination patterns of many pathogenic pathogens. A major contributing factor to the extinction of many species is the global warming. While some new organisms may thrive as a result of the warmer temperature, other species may be becoming extinct as a result of the changing ambient temperature. Here, it was clear that some infections might potentially reappear after being reported or not seen (Rasul et al., 2008). Here are some examples that how environmental changes affect various infectious diseases in humans seen in Table 1.

Table 1. Environmental changes affect various infectious diseases in humans (Shen and Aydin, 2014).

Environmental modifications	Potential diseases	The causative organisms and pathway of effect
Construction of canals, dams, and irrigation pathways	Schistosomiasis	Snail host locale, human contact
	Malaria	Upbringing places for mosquitoes
	Helminthiases	Larval contact due to moist soil
	River blindness	Blackfly upbringing
Agro-strengthening	Malaria	Crop pesticides
Suburbanization	Cholera	deprived hygiene, asepsis; augmented water municipal assembling pollution
Deforestation and new tenancy	Malaria	Upbringing sites and trajectories, migration of vulnerable people
Agriculture	Lyme disease	Tick hosts, outside revelation
Ocean heating	Red tide	Poisonous algal blooms

Psychological effects of climate change

Certain pandemics and diseases have intensified and spread quickly due to climate change (CC). In adding to its evident special effects on agriculture, forestry, and health, CC also has psychological repercussions for civilizations that are already at risk. The recent COVID-19 epidemic in several nations worldwide serves as one example of this (Rasul and Ahmad, 2012). Healthy people have also been impacted by the fear and panic that the sufferers of this viral virus have experienced. Even those who have a fever or the ordinary cold are scared during such outbreaks and are required to follow certain regulations. The population is constantly terrified by living in such conditions, which normalise stress and ultimately result in psychological frailty.

CC raises the frequency of mental health difficulties by exacerbating worry, anguish, and other problems in the general population. Post-traumatic stress disorder (PTSD) can result from frequent exposure to catastrophic climatic disasters, including geological disasters, and persistent psychological dysfunction is facilitated by their recurrent nature. Furthermore, stress levels are raised by ongoing media coverage of such incidents (Amir et al., 2020). In a similar vein, populations in flood-prone locations live in continual fear of famine and drowning. These communities are further strained by the devastation of physical infrastructure brought on by floods (Raza et al., 2020).

Influence of Climate change in economic sector:

Climatic change influences productivity and economic growth. Climate change is one of the most important issues for which environmental authorities have to care since it affects the economy (Mustafa et al., 2021). Considering adverse effects of climate change on agriculture productivity is very essential so that climate policies and local adaptations would be workable. The current research indicates that CC will affect the global agriculture system. It will affect agricultural productivity in various regions. Experts are now studying the impacts of CC on agriculture in the different regions and developing antidotes (Ali and Erenstein, 2017). Global warming grew during the 1980s, which increased temperatures and modified patterns of precipitation and evaporation. Agricultural growth in most countries is sensitive to variations of climate that affect crops and yields and total factor productivity (Rahman et al., 2020). Natural catastrophes and food security are challenges that are quickly becoming more urgent on a worldwide scale. In afflicted nations, local crop production has been harmed by a number of significant climatic and natural disasters. Human life may be impacted as well since emerging economies and communities have not adequately controlled the repercussions of these calamities. For instance, China, one of the most impacted nations on earth, is vulnerable to natural calamities due to its large population, harsh weather, and rapid climate change, unstable environment, and catastrophe vulnerability. Approximately 137 million Chinese citizens were negatively impacted by different natural disasters, and a statistical survey conducted in January 2016 found that China suffered an loss of 298.3 billion Yuan (Abid et al., 2015).

INTRODUCTION TO PAKISTAN'S AGRICULTURAL SECTOR AND ITS SIGNIFICANCE

For the economy of least-developed nations (LDCs), such as Pakistan, agriculture is vital. With an annual growth rate of 2.7% and a 21% contribution to the GDP, it is an essential component of Pakistan's economy (Rahman et al., 2017). 44 % of labour force finds work in this sector; while in rural areas 62 % population are rely on agriculture for their livelihood. One important area where corporate developments and our lifestyles meet is agriculture. Assuring food security, lowering poverty, igniting the industrial revolution, and promoting economic growth—particularly in emerging nations—are just a few of its many functions in any country's economy (Khan et al., 2020). In agriculture, the processes of economic and basic reproduction are intertwined. Three factors can be considered its economic importance: generating foreign exchange, providing the country with food and raw materials for regional businesses, and supplying goods and services to both internal and international markets. The entire area of Pakistan is 796,095 km², of which around 22 million hectares are arable and 8.3 million hectares are uncultivated. Pakistan is rich in natural resources and has a diverse range of climates and ecosystems. Water and fertile land are Pakistan's two main natural resources (Gul et al., 2019). This industry employs 42.3% of the labour force (36.2% of men and 74.5% of women), sustains three-quarters of the nation's population, and contributes significantly to foreign exchange profits, according to the Federal Bureau of Statistics 2015-2016. In order to reduce poverty and boost a nation's economy, agriculture is essential. Food production is highly reliant on land and water, which are vital resources for agriculture. Food demand rises in tandem with Pakistan's annual population growth. The demand for essential economic resources like food, fibre, and housing increases yearly as the population grows. Approximately 90% of all the world's crop of rice as well as 43% of the global wheat are produced and consumed in Asia. These are natural disasters, conflicts, climate change, and population growth. It is evident that 70% of Pakistan's foreign reserve is generated from agriculture while 47% of its workforce is engaged in it. The economy, revenue, and food security all go hand in hand with the agricultural sector. These features are prone to natural hazards and disasters (Gorst et al., 2018). The agriculture sector is the main sector for most of Pakistan's working population, which constitutes a backbone of the economy and the GDP, primarily in rural areas. Livelihoods and food security, fisheries, livestock, and crop production are all vital to this sector (Tariq et al., 2014; Janjua et al., 2010). Crops like wheat, rice, sugarcane, cotton, and maize are some of the crops that Pakistani agriculture produces, and it amounts to 24% of the total agricultural value and 4.67% of GDP. Bajra, Jowar, mash, gramme and other minor crops contribute 11.36% in agricultural value and 2.25% in the GDP. Livestock accounts for 11.61% of GDP and 58.55% of agricultural value added. Forestry accounts for 0.41% of GDP and 2.06% of agricultural value added. Fishing contributes 0.43% to the GDP and 2.17% to total agriculture (Gorst et al., 2018). Since livestock farming produces dairy, meat, and other items, it is essential to rural economies. The agriculture industry contributes to exports and foreign exchange profits in addition to maintaining the nation's food supply (Jamil et al., 2021). Pakistan's economy and way of life depend heavily on agriculture, thus any disruptions brought on by climate change might have a significant impact. Crops (Potato, Tomato, Citrus etc,) yields (Hameed et al., 2024; Hameed et al., 2023; Ali et al., 2023a; Ali et al., 2023b), animal production, and total agricultural productivity are all directly impacted by variations in temperature, precipitation patterns, and water availability. Comprehending these effects is crucial for formulating efficacious policies and tactics to guarantee sustenance security and adaptability to climatic fluctuations (Ahmad et al., 2011).

IMPORTANCE OF UNDERSTANDING CLIMATE CHANGE IMPACTS ON PAKISTANI AGRICULTURE

Studying and comprehending the precise effects of climate change on Pakistani agriculture is essential for several reasons:

• Food Security: Depending on the purpose, food security can be defined in a variety of ways. The most comprehensive and appropriate definition is provided by the FAO. To meet their dietary requirements and food choices for a healthy and active life, "food security exists when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food." Climate change is expected to have a negative impact on the four pillars of food security: availability, access, utilisation, and stability, as well as their interactions. As seen in Figure. 1.

Figure 1. The three components of food systems with their main elements are shown in italics

Farmers' capacity to fulfill domestic food demand and maintain exports is impacted by climate change's hazards to food production and availability (Iqbal and Arif , 2010). Numerous studies have analyzed food security in Pakistan at the national level. Pakistan's food security situation and found that population growth, uneven income distribution, and urbanization have increased the demand for food. Additionally, deficiencies in agricultural machinery and rising irrigation costs contribute to low agricultural production. Schichting et al., (2004) used household-level data to examine the connection between income and food security in northern Pakistan. Their findings indicated that nutrient demand is heavily influenced by income levels; low income prevents people from affording adequate food. (Tariq et al., 2014) investigated the relationship between food security and climate change in Pakistan, focusing on wheat production in Punjab. They divided the region into irrigated and non-irrigated areas, using time-series data from 1980-2012 and employing the OLS method to assess climate change's impact on food security. Their analysis revealed that minimum temperatures in November and February positively affect wheat production. They also noted that Pakistan's average temperature is rising annually. By projecting a 3-degree Celsius increase by 2050, they estimated that per capita wheat availability would drop to 84 kg per annum from 198 kg per annum in 2012. (Janjua et al., 2010) highlighted that wheat is Pakistan's staple food crop, and heavy rainfall during the harvesting period can significantly damage wheat production, exacerbating food insecurity.

Economic Stability: Climate change's impact on economic growth is no longer a secret; rather, it is quickly becoming a sobering fact. Pakistan's economy depends heavily on agriculture. Agriculture plays a significant role in Pakistan's economy, contributing up to 18.9% of the country's annual GDP and employing 42.3% of the labor force(Jamil et al., 2021). Despite its importance, the sector faces numerous challenges, with climate change-related disasters like floods and droughts posing major difficulties for agricultural development (Jamil et al., 2021). Disruptions brought on by the climate may cause rural areas to become more impoverished, lose revenue, and have fewer job options. Temperature and precipitation are crucial inputs in agricultural production, and many believe that climate change will significantly impact agriculture. In higher latitudes, production may increase due to an expansion of arable land, whereas in the tropics, production is likely to decrease due to reduced water availability. Variations in temperature can modify the duration of the growing season, and changes in rainfall can result in droughts or floods. These are only two of the ways that climate change can directly impact crop productivity. Climate change also affects supply chain infrastructure, markets, and food pricing. **(**Gregory et al., 2005; Akram et al., 2010) emphasize the critical role of climate change in food security. Higher temperatures will be particularly detrimental to most developing countries, which already face inadequate water supplies and high temperatures (Reilly, 1995; Rosenzweig, 1994). As a result, many agricultural regions will become less productive or unfit for cultivation due to rising temperatures. (Mendelsohn and Dinar, 1999) concluded that warming in traditionally cool wheat-growing regions will reduce grain yields due to higher temperatures.

Water Resources: Pakistan's economy is based on agriculture. Over 80% of agricultural produce is produced using the mostly irrigated production technique, which also consumes 90% of the river water that is available. Land and water, the productive resources that form the basis of food production, are becoming increasingly limited due to

climate change, among other factors. These resources are under pressure from climate change in two ways: directly (through increased land degradation, evapotranspiration, and glacier melt) and indirectly (through improved soil processes like denitrification, which releases greenhouse gases, and the absence of plant nutrients, which raises the water requirements of crops, etc. Furthermore, in addition to the incalculable harm to life and property, the frequency and severity of extreme climatic events such as floods, droughts, cyclones, etc., are increasing, with major repercussions for standing crops (Schichting and Ahmadi, 2004).

Environmental Sustainability: The impacts of climate change on biodiversity, ecosystem services, and soil health have implications for natural resource management and long-term agricultural sustainability (Gregory et al., 2005). A major worldwide danger to ecosystems and biodiversity is climate change. It affects the products and services that natural systems offer to civilization, as well as the interactions that individual species have with other creatures and their environments, changing the structure and function of ecosystems (Diaz et al., 2019).

ECOSYSTEM

Direct effects of shifting climatic drivers and the combined impacts of specie and population-level responses account for the observed changes in ecosystems at the ecosystem level in response to climate change.

Primary productivity

Photosynthetic organisms known as primary producers provide the basis of the majority of food webs, provide oxygen for the planet, and control essential elements of carbon cycling and sequestration, are essential to almost all life on Earth. The consequences of climate change on primary production have been diverse, spanning many temporal and geographical ranges (Lipton et al., 2018). Higher trophic levels are probably going to magnify these shifts in primary output (Chust et al., 2014) potentially leading to significant alterations in ecosystem function and even entire ecosystems. The impact of climate-driven changes on forest primary productivity varies by forest type and elevation. Primary output is anticipated to decline in forests with low soil water availability during the growing season. On the other hand, primary output is anticipated to rise in energy-constrained forests where the growth season is constrained by snow and freezing temperatures (Latta et al., 2010). However, even in these energy-limited forests, growth increases could be constrained by drought and extreme temperatures. Additionally, it remains uncertain whether the effects of fertilization will persist as forests age (Norby et al., 2010).

Extreme events and ecosystem resilience

Climate change has altered the duration, magnitude, and frequency of extreme events such as droughts, forest fires, and heatwaves (Kc et al., 2020). These events significantly impact ecosystems and interact with other climate-driven changes, diminishing ecological resilience. Rising temperatures and altered precipitation patterns have led to more extreme droughts and wildfires, which affect ecosystem structure and function, particularly in forested areas. Over the past two decades, warming and more variable precipitation have increased forest drought severity in the West, Southeast, and the Lake States (Clark et al., 2021), reducing tree growth and increasing mortality. However, responses to these changes vary (Choat et al., 2012) and can be delayed in long-lived species. Drought weakens tree defenses, making them more susceptible to other disturbances such as insects, pathogens, invasive species (Choat et al., 2012) and wildfires (Littell et al., 2016). While drought impacts have long-term consequences, drought-facilitated disturbances can result in more immediate changes to forest ecosystem structure and functions.

Ecosystem services

Ecosystem services that promote human well-being depend on diverse biological groups and healthy ecosystems (Diaz et al., 2016). Thus, changes in the providing, regulating, sustaining, and cultural services are among the ecosystem services that are impacted by climate change, as are the effects on species, populations, and ecosystems. Figure 2 makes it evident how ecosystem services are being impacted by climate change.

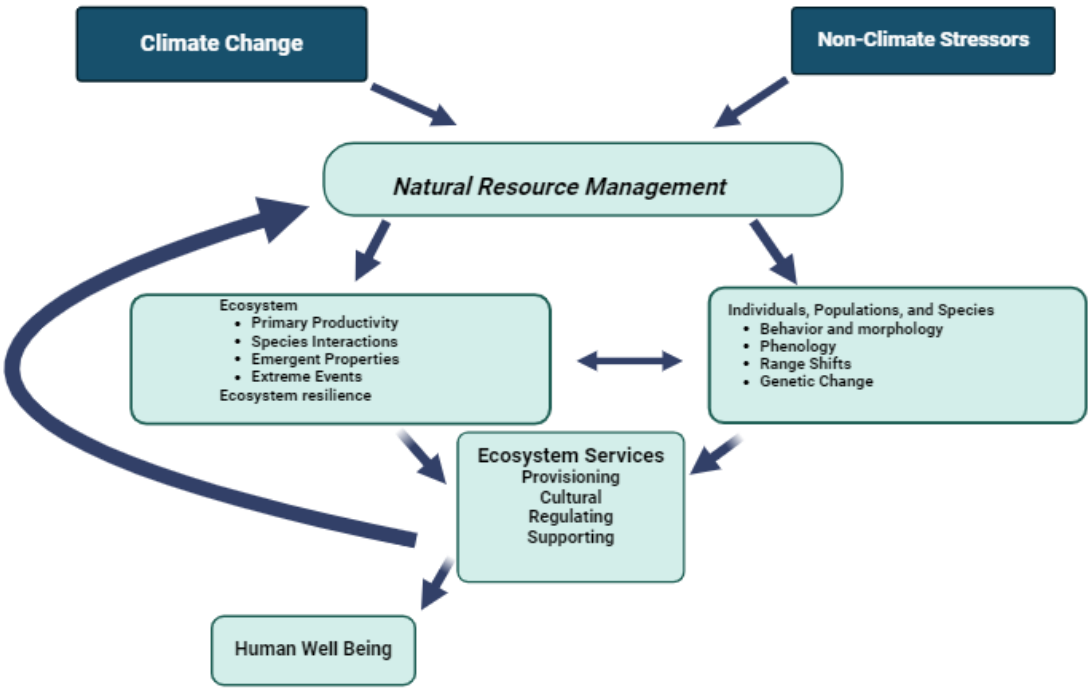

Figure 2. Ecological systems are impacted at various scales by the interaction of climate change and non-climate stresses. Individuals, populations, and species are all impacted by these combined stresses, as are the functions and characteristics of ecosystems. Depending on the species or environment, climate change has a different proportional influence than other stressors. Ecosystem services that promote human well-being depend on diverse biological groups and healthy ecosystems (Diaz et al., 2019). In addition to having an impact on ecosystems, biodiversity, and the services they provide, natural resource management may also mitigate or worsen non-climate stresses and climate change.

Provisioning services

Climate-induced changes in provisioning services, which include the material goods people obtain from ecosystems and biodiversity, can significantly impact human economies and well-being. For instance, climate impacts on forested watersheds—such as increased temperatures, changes in precipitation and snowfall, and disturbances like wildfires—are altering freshwater supplies for municipalities, agriculture, and power generation (Stewart et al., 2005). Surface water shortages are likely during dry years in some locations, and rising stream temperatures can degrade water quality (Warziniack et al., 2018). Wildfires also contribute to increased sediment deposition and debris in streams, lakes, and reservoirs, further stressing water supplies and potentially raising water treatment costs. These changes in water supply, coupled with other climate change impacts, can alter agricultural production. Droughts and other extreme events can decrease crop yield and quality (Gowda et al., 2018), with projected production declines for several important crop species as temperatures rise (Zhao et al., 2017).

Regulating services

Important regulatory functions, including carbon sequestration, mitigating the effects of severe events, preserving soil and air quality, and halting the spread of disease, are provided by biodiversity and ecosystems. Carbon storage is becoming more and more crucial as climate change picks up speed. Despite the fact that the country's forest acreage has grown since 2000, (Oswalt et al., 2014), It's still unclear if carbon storage from afforestation will surpass emissions from deforestation (Vose et al., 2015). Furthermore, ageing forests have lower rates of CO2 absorption than regrowth forests after previous disturbances, and increasing temperatures, increased water stress, and disturbances are predicted to reduce carbon storage in many forests (Wear and Coulston, 2015). Coastal wetlands, which are highly productive ecosystems, store carbon (Davis et al., 2015) and provide natural defenses against erosion, waves, flooding, and storm surges (Arkema et al., 2013). However, if coastal wetlands are deteriorated by human development or sea level rise, their ability to offer these functions declines. Additionally, ecosystems control the life cycles, quantity, and spread of pathogenic organisms (Corvalan et al., 2005). As species ranges, abundances, and habitat conditions change due to climate change, ecosystems' capacity to deliver this function is

impacted. For instance, Aedes mosquitoes, which spread diseases like dengue, are becoming more widespread in the southern United States, which raises the chance of contracting the disease (Ebi and Nealon, 2016).

Maintaining ecosystem services, such as primary productivity, nutrient cycling, and genetic diversity, is essential to ecosystem function. Decomposition of soil organic matter often increases with temperature, which may result in increased soil carbon losses and changed carbon-to-nitrogen ratios Davidson and Janssens, 2006). Biologic interactions, such as indirect impacts on the makeup of the soil microbial population, affect these changes (Crowther et al., 2011). The burning of fossil fuels and other activities that contribute to climate change also increase nitrogen deposition, which has a major effect on terrestrial and aquatic ecosystems through eutrophication and other processes (Galloway et al., 2008). Rising temperatures and increased nutrient loading are causing cyanobacteria that cause hazardous algal blooms to occur more frequently, last longer, and spread farther, which can have a detrimental impact on the health of people and animals (Hilborn and Beasley, 2015).

Cultural services

The term "cultural services" describes the intangible advantages that people obtain from ecosystems and biodiversity, including enjoyment, cultural identity, and mental and physical well-being. Compared to other ecosystem services, cultural services have received less research attention, despite their significance to human well-being (Runting et al., 2017). Among the first to use science, scholarship, and other means of expression to connect culture and environmental change were indigenous peoples (Maynard, 2003). There is mounting proof that humans benefit from being in natural environments (sandifer et al., 2015). On the other hand, climate-related extremes like storms and rising temperatures can have a detrimental effect on both physical and mental health (Bell et al., 2016). Indirect economic losses, such as loss of livelihoods, can have negative sociopsychological impacts (Shen and Aydin, 2014). Knowledge of the specific challenges that Pakistani agriculture faces from climate change helps policymakers and other stakeholders devise specific adaptation measures. Such information is very crucial in helping Pakistan's agricultural sector stay alive under climatic adversity.

CLIMATE TRENDS AND VARIABILITY OBSERVED IN PAKISTAN

Pakistan's terrain and geographic position result in a variety of climatic variations, from lush plains and hilly places to desert regions. Pakistan has seen distinct patterns and unpredictability in its climate during the last few decades, which have been linked to global climate change (Akram, 2010). Important climatic patterns seen in Pakistan consist of:

Temperature Rise: Over the years, Pakistan has seen a notable increase in average temperatures, with both daytime and nighttime highs. Heatwaves have increased in frequency and severity, especially in cities. Heat waves, a consequence of climate extremes, have become more frequent and intense during summer across most parts of the world. These events not only cause fatalities among living beings but also affect evapotranspiration rates and soil moisture, ultimately leading to crop failure. Asian mountain glaciers are under severe threat from global warming and accelerated recession. Elevated temperatures are expected to increase the frequency of heat waves in the future. The duration of heat waves is crucial to their harmful impacts, as they can disrupt the water cycle by enhancing convection, evapotranspiration, condensation, and precipitation rates. Heat waves are a major threat to plant, animal, and human health. The temperature starts to disrupt the biological development of living things over a particular degree, and if it continues for a long period, it can seriously damage plants (flower/fruit fall and leaf burn) and humans and animals (sunburn and sunstrokes). Heat waves cause significant harm that cannot be undone. Because of their increased need, crops, animals, and people frequently experience water shortages as a result of persistent heat waves (Rasul et al., 2008).

Changing Precipitation Patterns: Pakistan's precipitation patterns have grown more unpredictable, resulting in longer stretches of dry weather interspersed with heavy downpours. Water management and rain-fed agriculture are challenged by this fluctuation. Regions that typically experience active precipitation zones used to enjoy up to 200mm of rainfall regularly, but such amounts now appear as disastrous events in areas where they make up the annual total. The lower half of Pakistan, encompassing Balochistan and Sindh, represents this latter zone, with annual rainfall amounts of only a few hundred millimeters occurring mainly during 15-20 days in summer. Occasionally, a few heavy precipitation events during the active monsoon period result in significant rainfall, leading to devastation rather than benefits. Although the extent of the rise will differ by location, the IPCC's 4th Assessment Report (2007) makes it abundantly evident that there is a greater than 90% chance that climate change will cause

severe events to occur more frequently and with greater severity in the twenty-first century. These shifts are now clearly seen in Pakistan (Rasul and Ahmad, 2012).

Sea Level Rise: Water has been expanding, seasonal snow and glaciers have been melting more quickly, and weather patterns have been changing as a result of the warming of the atmospheric, land, and ocean thermal regimes. Sea level rise, both temporary and permanent, is associated with these changes. Sea level rise is evident along Pakistan's coastline, just like it is elsewhere in the world. Prior to the widespread worry over climate change and global warming in the 1990s, sea level monitoring was not regarded as a crucial problem. The whole community is keeping an eye on sea level rise because of the effects of global warming on glacier melting and thermal water expansion, which might drown tiny islands. According to even the most optimistic projections, infrastructure and coastal areas will be significantly impacted by increasing sea levels. Coastal erosion, flooding of coastal plains and wetlands, inundation of deltaic plains, salinisation of aquifers and soils, and loss of fish, bird, and other wildlife and plant habitats are some of the possible consequences (Rasul and Ahmad, 2012).

Rapid Glaciers Retreat: The Himalaya-Karakoram-Hindukush range forms the largest mountain chain on Earth and holds the third-largest ice reserves after the Polar Regions. These mountains, which run nearly east-west from north to south and are hard to tell apart, delineate the boundary between China and South Asian countries including Pakistan, India, Nepal, and Bhutan. They provide a vital water source for South Asia by containing monsoon precipitation and protecting the area from chilly winter surges brought on by northerly winds. Additionally, these mountains contain vast reserves of solid water, which melt during the summer, supplying rivers with precious water during critical times. These glaciers provide runoff for major rivers like the Indus, Ganges, and Yangtze, which are vital to more than a billion people in Asia. Heat waves, defined as prolonged periods of maximum temperatures above a certain threshold, are becoming more common with rising temperatures. These thermal extremes, once rare, are now frequent, contributing to the thinning of ice and the alarming retreat of glaciers. As temperature maxima continue to increase, the simultaneous thinning of ice and glacial retreat poses a significant threat (Rasul and Ahmad, 2012).

Monsoon Dynamics: The South Asian monsoon plays a crucial role in Pakistan's climate, affecting rainfall patterns across the country. Changes in monsoon dynamics, such as altered onset and withdrawal dates, impact agricultural seasons and water availability (Akram, 2010).

RESULTS AND DISCUSSION

Analysis of Temperature Rise, Changing Precipitation Patterns, and Extreme Weather Events

The climate of Pakistan, diverse and ranging from continental in the northern regions to tropical in the southeast, has been significantly impacted by climate change, with data indicating a consistent rise in average annual temperatures across the country. Growing crops, the availability of water, and human health are all impacted by rising temperatures. Heat stress increases the risk of health for vulnerable people, it reduces crop yields, and increases the demand for irrigation of water. The effects of changes in rainfall impact on agriculture and the provision of water. Heavy down pour causes soil erosion and flooding as it interferes with farming activities. Extreme weather events like cyclones, floods, and droughts occur frequently in Pakistan. Such incidents hence lead to severe destruction and negatively affect the livelihood and agricultural infrastructure (Amir et al., 2020).

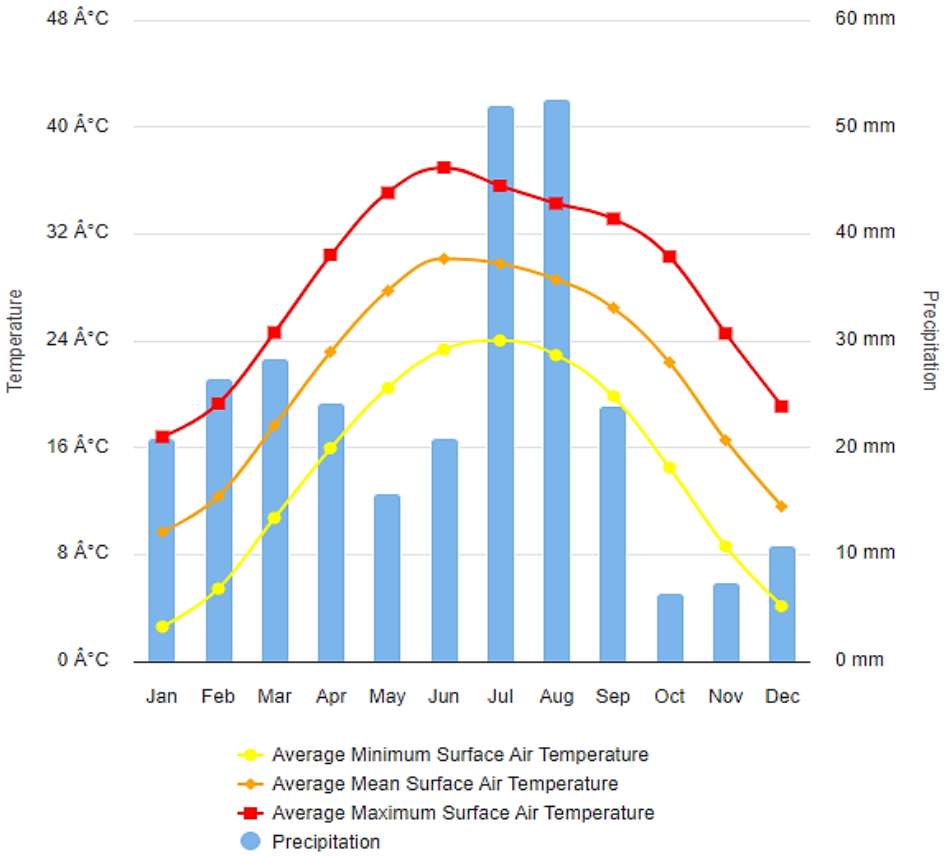

Figure 3. Monthly climatology of average minimum surface air temperature, average mean surface air temperature, average maximum surface temperature & precipitation 1991-2020; Pakistan (World Bank Climate Change historical data for Pakistan)

This is the average monthly temperature and precipitation in Pakistan. This shows the minimum temperatures on a yellow line. Minimum temperature goes from as low as 8°C in January and December and rises as high as 24°C in June. Average temperature goes up to a yellow orange line starting at 16°C in January and rises up to as high as 32°C in June. The red line graph shows the average max temperatures where in January it reaches about 24°C and reaches 40°C in June. The blue bars refer to the highest rainfall content in July and August approximately at 50 mm and less in November approximately at 10 mm. The data shows clear seasonal patterns: from December to February, it is cool and dry; from March to May, it is a slow warming up and increase in rainfall; from June to August, it is hot and wet; and from September to November, it cools down with a decrease in temperature and rainfall. This graph shows the temperature and precipitation fluctuations during the seasons of Pakistan.

The Pakistan Meteorological Department reported anomalies in rising temperatures, which have increased and projected above-normal temperatures for 2024. The urban heat island effect has been exacerbated by urbanization and deforestation. Historical data from 2000 to 2024 shows erratic precipitation patterns, complicating water resource management and agriculture. According to the PMD report, it was a season of scarce snowfall and rain. This has challenged summer 2023-2024 with drought and heavy rainfall causing water shortages and distribution issues. Flooding and heatwaves are on the rise. The PMD has issued a flash flood warning to northern areas after stating that the melting of the glacier is taking place at a rapid pace and most areas witnessed rainfall above average in some months of 2024. These extreme weather events devastate infrastructure, agriculture, and human health. For instance, the recent flood in 2022 caused nearly $30 billion in damages, severely affecting Pakistan's agriculture, a major contributor to its GDP. The PMD's seasonal forecasts for 2024 indicate that while some regions may experience above-normal rainfall, others may face below-normal precipitation, exacerbating the risk of water shortages. One of the top 10 countries in the world for climate change and natural disasters, Pakistan faces additional warming from its already hot climate at a rate significantly higher than the global average. Climate change is a risk multiplier, with potentially extremely detrimental outcomes that can have repercussions.

Anthropogenic carbon (BC) deposits and climate change will hasten the melting of the Himalaya, Hindu Kush, and Karakorum (HKHK) glaciers, altering the flow of the crucial Indus River system and having a major impact on Pakistan's environment and economy. Floods and landslides will be caused by a more unpredictable monsoon regime and probably more powerful storm and cyclone occurrences. Low-lying coastal ecosystems will be subject to loss and submersion as a result of the ocean's continued encroachment on infrastructure and coastal towns. Figure 4 provides a detailed overview of flood occurrences that have occurred in Pakistan up to this point.

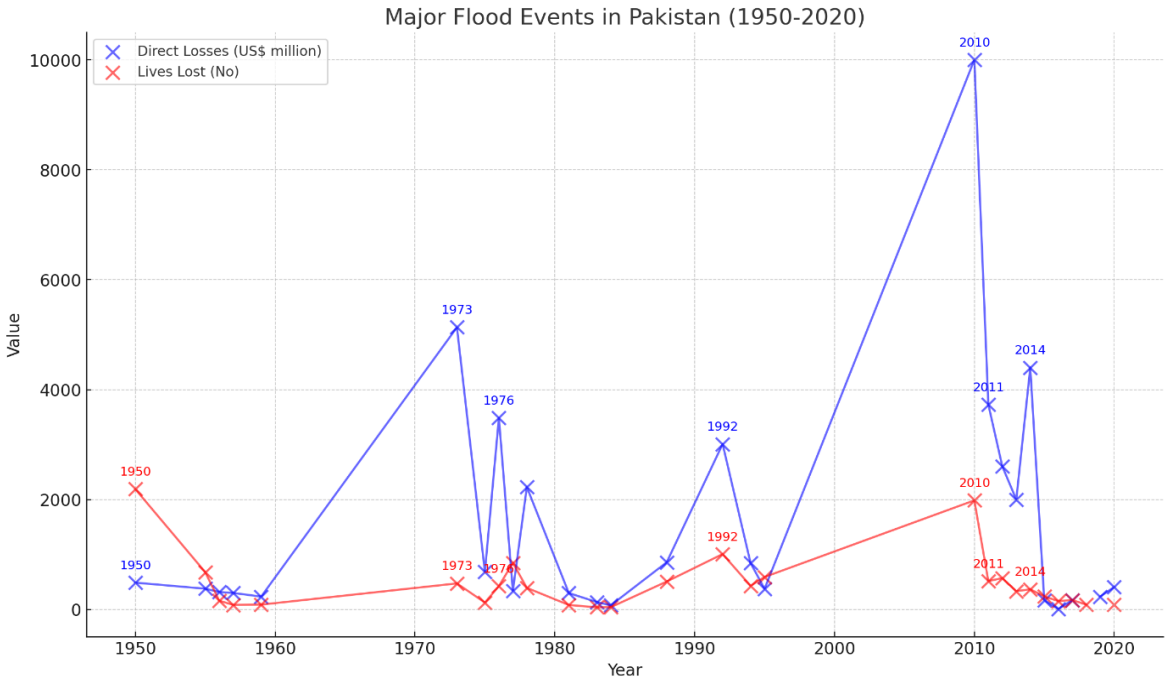

Figure 4. Major flood events occurred in Pakistan (1950-2020)

Impact of Climate Change on Water Resources, Glaciers, and Ecosystems in Pakistan

Pakistan's ecosystems, glaciers, and water supplies are all significantly impacted by climate change, which has important ramifications for agriculture:

Water Resources: River flows and groundwater recharge are impacted by shifting precipitation patterns and glacier melting, which has an effect on irrigation accessibility and water quality. Resource competition and water shortages increase in dry seasons.

Glacial Retreat: The major rivers of Pakistan depend on glaciers for their irrigation and hydroelectric powers. The rate at which the glaciers are retreating influences river flows and boosts runoff, making water management even more complicated.

Ecosystems: Climate change impacts biodiversity, affecting crop-essential plants and animals, thereby disrupting pollination and soil fertility and insect dynamics which impact crop resilience and productivity (Raza et al., 2020).

VULNERABILITY OF PAKISTANI AGRICULTURE TO CLIMATE CHANGE

Evaluation of the Vulnerabilities That Various Agricultural Regions Face

Varieties of climate change impacts prevail because of fluctuating temperatures and differing soil types, water supplies, and cropping patterns prevalent over different agricultural areas of Pakistan. Over many areas of arid regions in Pakistan, water deficiency causes stress due to heat in addition to causing damage to agriculture and livestock. Other hazards to crops and fisheries prevail in coastal areas. Mountainous terrain is also affected by river flow changes, glacier melts, and landslides to water supply and soil stability (Mustafa et al., 2021).

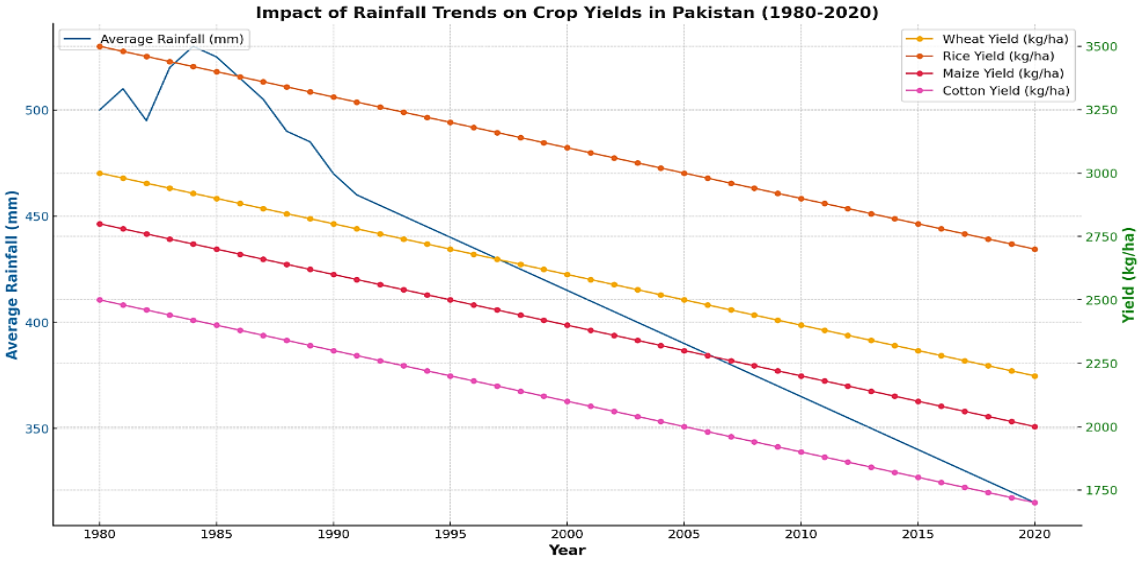

Figure 5. Impacts of rainfall trends on crop yields in Pakistan (1980-2020)

This graph displays the average rainfall in Pakistan from 1980-2020 and crop yields of wheat, rice, maize, and cotton. While 500 mm was rainfall in 1980, it went all the way to 315 mm in 2020. Sources for this graph include World Bank Climate Change Knowledge Portal, NASA GISS, and Pakistan Meteorological Department.

Identification of Climate-Sensitive Crops and Livestock

Certain crops and livestock species exhibit higher sensitivity to climate variability and extremes. Climate-sensitive crops include wheat, rice, maize, cotton, and sugarcane, which require specific temperature and water conditions for optimal growth. Livestock species such as dairy cattle, goats, and poultry are affected by heat stress, water scarcity, and changes in forage availability (Ali and Erenstein, 2017).

By cultivating and distributing heat-tolerant crop varieties, harvest yields can be less negatively impacted by rising temperatures. Both endeavors to cultivate heat-resistant crop varieties and employ genetic modification to enhance agricultural resilience and productivity in response to climate change are commendable. Despite the rising temperatures, many species can grow and produce large yields. As seen in Table 2.

Table 2. Heat-tolerant crop varieties

Crop	Variety	Developed By	Characteristics	Suitable Regions
Wheat	Sehar-2006	Wheat Research Institute, Faisalabad	High yield potential, heat tolerance	Punjab, Sindh
Wheat	Inqlab-91	Wheat Research Institute, Faisalabad	Adaptable to different climates, including heat	Punjab, Khyber Pakhtunkhwa
Wheat	Sassi	Nuclear Institute for Agriculture and Biology (NIAB)	Heat and drought resistance	Semi-arid regions of Punjab
Rice	Super Basmati	Rice Research Institute, Kala Shah Kaku	Excellent grain quality, heat tolerance, aromatic	Punjab
Rice	IRRI-6	International Rice Research Institute (IRRI)	Heat and saline tolerance	Sindh, Balochistan
Rice	KS-282	Rice Research Institute, Kala Shah Kaku	Heat tolerance, high yield potential	Punjab
Cotton	NIAB-999	NIAB	Heat and drought resistance	Punjab, Sindh
Cotton	CIM-599	Central Cotton Research Institute, Multan	Heat tolerance, high yield	Southern Punjab
Cotton	FH-142	Cotton Research Institute, Faisalabad	Heat and drought resistance	Punjab, Sindh

Drought-Resistant Crop Varieties

An essential solution to the issues arising from less precipitation in agriculture especially in Barani areas in Pakistan is the development of crop varieties that are resistant to drought. Scientists employ breeding programs and genetic engineering techniques to develop crops that possess enhanced resilience to extended drought conditions and exhibit improved water utilization capabilities [52]. These innovative crops enhance the resilience of our food supply to climate change by enabling farmers to maintain production even under water scarcity conditions.
Drought-tolerant crop varieties can be seen in Table 3.

Table 3. Drought-tolerant crop varieties

Crop	Variety	Developed By	Characteristics	Suitable Regions
Wheat	Chakwal-50	Barani Agricultural Research Institute, Chakwal	High yield potential, drought tolerance	Rainfed areas of Punjab
Wheat	NARC-2009	National Agricultural Research Centre (NARC)	Drought resistance, high yield	Punjab, Sindh
Wheat	Dharabi-11	Barani Agricultural Research Institute, Chakwal	Adaptable to dry conditions, drought resistance	Rainfed areas of Punjab
Rice	DR-92	Rice Research Institute, Dokri	Drought tolerance, high yield potential	Sindh
Rice	Shaheen Basmati	Rice Research Institute, Kala Shah Kaku	Drought resistance, aromatic, good grain quality	Punjab
Rice	NIAB-IR9	NIAB	Drought tolerance, improved yield	Punjab, Sindh
Cotton	CIM-573	Central Cotton Research Institute, Multan	Drought tolerance, high yield	Southern Punjab
Cotton	NIAB-78	NIAB	Drought resistance, early maturity	Punjab, Sindh
Cotton	FH-113	Cotton Research Institute, Faisalabad	Drought tolerance, good fiber quality	Punjab, Sindh

Socio-economic Factors Influencing Agricultural Vulnerability

Socio-economic factors play a crucial role in determining agricultural vulnerability to climate change. Smallholder farmers with limited resources and access to technology are more vulnerable to climate risks. Land tenure systems, market access, and institutional support influence farmers' ability to adapt to climate change. Gender dynamics and social inequalities intersect with agricultural vulnerability, affecting women farmers' resilience and livelihoods (Ali and Erenstein, 2017).

IMPACT OF CLIMATE CHANGE ON CROP PRODUCTION

Effects of Rising Temperatures on Crop Growth, Phenology, and Yields

Rising temperatures accelerate crop development and alter phonological stages, affecting flowering, fruiting, and maturation. Heat stress reduces photosynthesis and negatively impacts crop yields, particularly during critical growth stages. Shifts in temperature regimes influence the geographic distribution of crops and their suitability in different regions (Rahman et al., 2020).

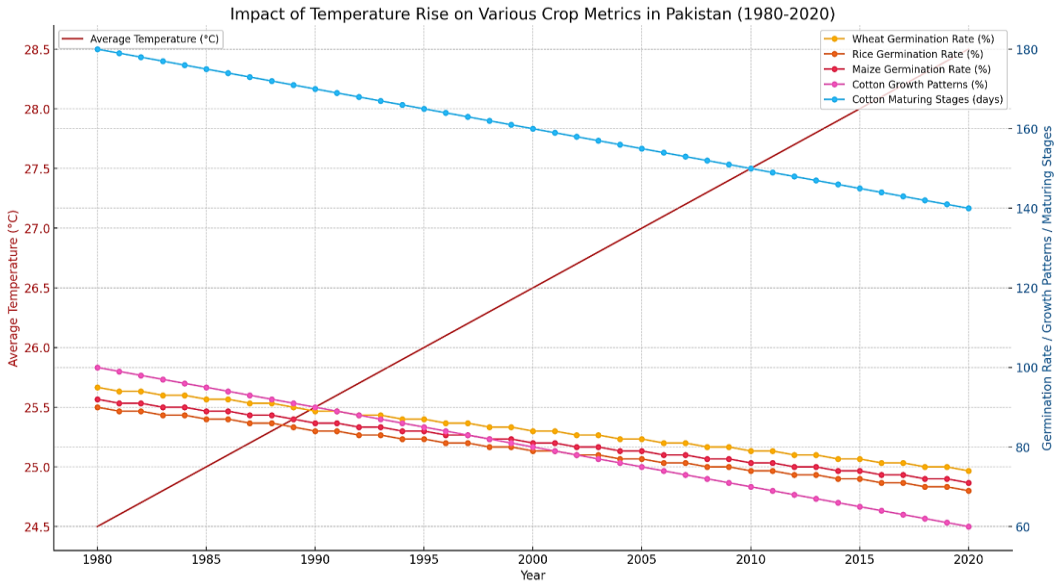

Figure 6. Impact of temperature rise on various crop

The graph depicts the correlation between the increase in average temperature in Pakistan from 1980 to 2020 and the crop yields of wheat, rice, maize, and cotton. This led to the average annual temperature of Pakistan to increase from 24.5°C in 1980 and 28.5°C in 2020. Data are taken from World Bank Climate Change Knowledge Portal, NASA GISS, and the Pakistan Meteorological Department.

Crop yield data reveals a steady decline over FAO FAOSTAT, Pakistan Bureau of Statistics and IFPRI. Yield on wheat decreased from 1980's 3000kg/ha to the low of 2020 standing at 2200 kg/ha, which further suggests that increasing temperatures have devastating effects on wheat production productivity. Rice yields declined from 3500 kg/ha in 1980 to 2700 kg/ha in 2020, meaning higher temperatures affect production. Similarly, maize yields decreased from 2800 kg/ha in 1980 to 2000 kg/ha in 2020, which also signifies that temperature increases affect crop productivity. This reduces the yield from as low as 2500 kg/ha in 1980 to just about 1700 kg/ha in 2020, that shows how it is going backwards; up the scales of production is reducing it as higher temperature yields produce more biomass and yield.

Changes in Precipitation Patterns and Implications for Irrigation and Rainfed Agriculture

Erratic precipitation patterns disrupt planting schedules, triggers water stress, and also reduces crop yields. This increased frequency of drought hits rainfed agriculture with a pressing need for improved water management techniques and drought-tolerant crops. Changes in snowmelt impact the availability of irrigation, hence influencing crop irrigation timing and efficiency (Rahman et al., 2017).

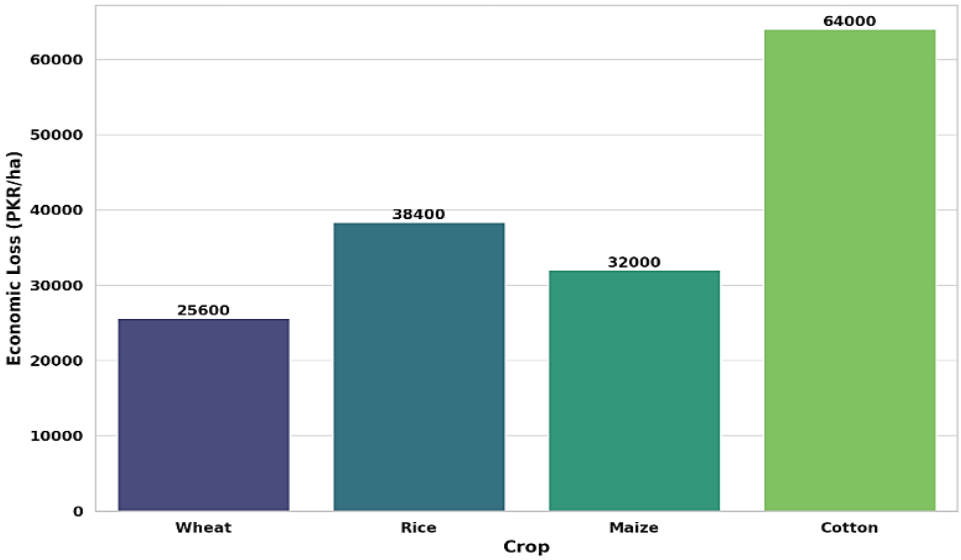

Figure 7. The average economic losses from 1980-2020

During the climate change from 1980 to 2020, cropping yield of Pakistan had to bear enormous economic losses. Wheat caused a loss of about 17,280 PKR ha-1, which represented 13.5 percent of total losses. In rice, the losses were around 25,920 PKR ha-1, accounting for a share of 20.3 percent to total losses. Maize incurred a loss 21,600 PKR ha-1, the total losses were 16.9%. The cotton crop suffered heavily and accounted for 40.3% of the entire losses by facing a value loss of 43,200 PKR/ha. The above figures thus portray a picture of an economically catastrophic effect of global warming on agriculture.

Case Studies on Specific Crops and Their Response to Climate Change

Climate change impacts wheat productivity due to temperature sensitivity during flowering and grain filling. Altered precipitation affects rice cultivation and water management. Rising temperatures and water scarcity reduce cotton fiber quality and yield. Climate change would adversely affect the agriculture of Pakistan as cited by the "A Case Study of Pakistan." Reduced production in wheat and rice will eventually cut the GDP at $19.5 billion for the year 2050. It would increase the commodity price with decreasing domestic demand (Khan et al., 2020). Wheat yield is likely to be higher in Chitral, whereas D.I. Khan and Peshawar is likely to record lower yields. The majority of the farmers of D.I. Khan and Peshawar will lose their economic status (Gul et al., 2019). The study underlines policies in governments toward climate-adaptive agriculture, economic stability, and food security and the nexus of agriculture-industry. With vulnerabilities identified in agricultural areas, specifying climate-sensitive crops and livestock, and reviewing socio-economic factors, adaptation strategies in Pakistani agriculture can be prepared specifically. Climate change has been affecting crop production, thus necessitating adaptive measures and investments in resilient agriculture to ensure food security and livelihoods in Pakistan (Gorst et al., 2018).

WATER RESOURCES AND IRRIGATION MANAGEMENT

Impact of Climate Change on Water Availability and Quality

Climate change impacts the water resources through changed precipitation, melting of glaciers, and altered river flows. The variability in snowmelt and monsoon patterns reduces the seasonal water supply for irrigation and agriculture. Higher temperatures and evaporation worsen the water scarcity, and this competition heightens for the resources (Khan et al., 2023).

The altering flow of Indus basin surface waters, which changes from 120 to 230 km3 annually with rainfall and snowfall patterns, affects Pakistan's water resources. The summer inflow averages 160 km3, and that of winter is 30 km3. There is a need for summer water storage. In Pakistan, annual withdrawal from surface water and groundwater is about 122 km3 and 62 km3 (Young et al., 2019). Annually, the surface water is adding up to 1.0 to 1.5 tons of salt each year (Bhutta and Smedema, 2007).

Research shows that global warming can raise sea levels by more than a meter at the end of the 21st century (Hansen and Sato 2011; Vermeer and Rahmstorf 2007). Such increase may cause salinization in coastal areas due to saltwater intrusion. Saltwater contaminates freshwaters, and hence their use for drinking or farming is impossible. It therefore likely to salinize freshwater around 600 million population living in the coastal region (Wheeler 2011; CIESIN 2010).

Challenges in Water Management and Irrigation Efficiency

Pakistan is dealing with severe issues in water resource management due to the old irrigation system, inefficient use, and losses during transport. Water supply varies with the times and demand, which increases difficulty in fair distribution and sustainability. Poor drainage leads to salinity and waterlogging, reducing soil fertility and crop yield (Shahid and Piracha, 2010).

Adaptation Strategies for Sustainable Water Use in Agriculture

Improving irrigation means is one way of reducing the adverse effects that result from higher temperatures. Water is utilised in an effective way hence water wastage becomes a minor thing and the crop stays hydrated during the hot temperatures. Rainwater harvesting systems capture and store rainfall for use in irrigation during drought to increase the availability of water for agriculture (Khan et al., 2022). These methods help ensure soil moisture, which can be crucial for plant life in hot conditions.

ADAPTATION AND MITIGATION STRATEGIES

Review of Adaptation Measures Adopted by Farmers and Policymakers

Farmers in Pakistan adapt to the new situation by altering crops, selecting drought-tolerant crop varieties, and conserving water. Governments also benefit from climate-resilient agriculture through incentives in policy, extension

services, and climate information. So the long-term economic and social ability of Pakistan is directly attached to its capability to accommodate the effects of recent climatic change. The Ministry of Climate Change has implemented several measures to align the general population with the country's climate policies regarding adaptation and mitigation activities. To mitigate the impacts of climate change, it is imperative to act in several areas such as transportation, agriculture, livestock, energy, forestry, urban planning, and industry (Lin and Ahmad, 2017). The Intended National Determined Contributions (INDC) suggest that Pakistan requires from 7 to 14 billion US dollars yearly to carry out these mitigating measures. Under the Green Pakistan Program, around 100 million trees have been planted all around to help to mitigate climate change effects (GOP, 2017).

Pakistan's greenhouse gas (GHG) emissions may increase dominantly due to the growing and demanding use of coal-based electricity, industrial production, and agricultural output. In 2011, the total amount of emissions was 347 million tons of CO_2 eq. According to the National Economic and Environmental Development Study (NEEDS), if current trends continue, the emissions are projected to rise to 4621 million tons CO_2 eq. by the year 2050. The energy industry is expected to account for over 60% of emissions, with agriculture being a close second. Vision 2030's carbon reduction objectives are based on three key principles: the use of renewable energy, improved efficiency, and the use of co-generation in industry (GOP, 2014). Other crucial concerns are the cessation of deforestation, enhancing the efficiency of buildings, and transitioning to alternative transportation fuels. Further measures are necessary, notwithstanding the reduction of transmission and distribution losses from 25% in 2000-01 to 21% in 2008-09. The NEEDS estimates that low carbon development, which seeks to decrease emissions by 40% via the use of cleaner technologies, would require significant financial resources. These resources are expected to range from $8 billion to $17 billion by the year 2050. The agriculture industry must focus on many areas such as implementing innovative rice cultivation methods, reducing nitrous oxide emissions from soil, enhancing cow breeding practices to minimize methane emissions, and providing cost-effective animal diets that can reduce methane production Bezirtzoglou et al., 2011).

Role of Agricultural Technologies in Climate Resilience

Agricultural technologies such as drought-resistant crops, precision agriculture, and remote sensing help optimize resource use and enhance productivity under changing climatic conditions. Sustainable land management practices such as conservation agriculture and agroforestry improve soil health and resilience to climate stress.

Policy Interventions and Institutional Frameworks for Climate-Smart Agriculture

Policy interventions focus on enhancing agricultural resilience through climate-smart practices, resource-efficient technologies, and capacity building. Institutional frameworks support partnership, knowledge sharing, innovation, and agricultural approaches with the objective of helping fight climate change. Among its elements is the inclusion of climate strategies in national planning and agricultural policies towards enhancing resilient food systems. Agricultural planning must incorporate adaptation as well as mitigation practices, for sustainable food production in Pakistan. Farmers, policymakers, and stakeholders must work together to increase productivity, conserve resources, and improve livelihoods (Fahad et al., 2020; Malhi et al., 2021).

SOCIO-ECONOMIC IMPACTS AND LIVELIHOODS

Socio-economic Consequences of Climate Change on Rural Communities

Climate change affects rural Pakistan more severely, as agriculture is a significant sector of the economy. Lower crop production, insufficient water supply, and loss of livestock directly reduce income and increase food insecurity risk. Displacement and migration occur as a result of climate-related disasters, affecting social cohesion and community resilience (Ahmad et al., 2020).

Impacts on Farmer Livelihoods, Food Security, and Rural Poverty

Climate change undermines farmer livelihoods by reducing agricultural productivity and income (Abd-alla et al., 2014). Food security is compromised due to fluctuations in crop yields, disruptions in supply chains, and rising food prices. Rural poverty increases as farmers face greater economic risks and limited access to alternative livelihood opportunities. Almost 9 billion world population will face food security in 2050. Pakistan has almost 212 million people, of which 20% suffer from food insecurity and 58% suffer from malnutrition. Due to climate change, the livelihood of Pakistan’s people is in danger (Abbas et al., 2022). It was reported that with increase of 3 degree temperature until in 2050 would decrease the wheat availability per person would drop from 198 kg per year in 2012 to 84 kg per year until 2050. By the mid-century, up to 20$ billion lose due to climate change effects on wheat and

rice (Ali et al., 2017). Pakistan has high poverty rate, so their sustainable agriculture adaptive capacity for different climate events is low (Ali and Erenstein, 2017).

Gender Dimensions and Equity Considerations in Climate Adaptation

Gender roles and norms influence vulnerability and adaptive capacity within rural communities. Women farmers often face greater challenges due to limited access to resources, land tenure issues, and unequal decision-making power. Gender-sensitive adaptation strategies promote women's empowerment, equitable access to resources, and inclusive decision-making processes (Ahmad et al., 2020).

Future Outlook and Recommendations

The approach presents the socio-economic impacts of climate change on Pakistani agriculture, hence making a call for evidence-based policies to develop resilience. This research shall therefore take on an interdisciplinary nature-climate science, agriculture, economics, and social sciences-in conceptualizing its framework. In light of the above conclusions, policymakers should make the adaptation to climate change form agricultural policies, engage relevant stakeholders, and seek cooperation from other nations and appropriate funding for adaptation initiatives (Ali et al., 2021, Ali, 2018).

CONCLUSION

The review is aimed to address the impact of climate change on agriculture in Pakistan, based on the grounds of its relation with the socio-economic determinants. Its urgency is underlined together with proactive measures, evidence-based policies, and additional investments in research and technology. It ends up listing the key messages that point at policy coherence, stakeholder engagement, and international cooperation as well. Recommendations should be the integration of climate adaptation into national plans, agricultural policies, and disaster risk strategies. This shall be promoted by intergovernmental, NGOs, research institutions, and the private sector. The review also hints at areas of future research and innovation in improving the adaptation and mitigation of agriculture to climate.

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AUTHOR CONTRIBUTIONS

All authors contributed equally to this research.

COMPETING OF INTEREST

The authors declare no competing interest.

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