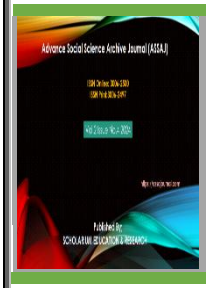

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THE IMPACT OF CLIMATE CHANGE ON PAKISTAN'S AGRICULTURAL ECONOMY

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ABSTRACT

Climate change poses a significant threat to Pakistan's agricultural economy, which is the backbone of the country's GDP and employment. Agriculture contributes approximately 21.2% to the GDP and employs 45% of the labor force, making it crucial for economic stability and poverty alleviation. However, the sector is highly vulnerable to climate-induced variability, including unpredictable rainfall, rising temperatures, and extreme weather events such as floods and droughts. These changes have led to declining crop yields, particularly in major crops like wheat, rice, and cotton, which are essential for food security and export earnings. The increasing frequency of extreme weather events exacerbates water scarcity, soil degradation, and pest outbreaks, further straining agricultural productivity. Smallholder farmers, who form the majority of the agricultural workforce, are particularly at risk due to limited access to resources and climate-resilient technologies. The paper highlights the urgent need for sustainable agricultural practices, technological innovations, and robust policy frameworks to mitigate the adverse impacts of climate change. It emphasizes the importance of adopting climate-resilient crops, improving water management, and enhancing public awareness to ensure long-term food security and economic stability. The study also calls for increased investment in research and development to better understand the regional impacts of climate change and to develop adaptive strategies that can safeguard Pakistan's agricultural sector against future climatic uncertainties.

Keywords: Climate change, Pakistan, agriculture, crop yields, food security, sustainable practices, smallholder farmers, policy frameworks

Introduction

Pakistan is an agro-based economy, as it derives the dominant share of its GDP from agriculture. The key significance of agriculture arises from its strong observed relationship with overall economic growth in the country. In addition to contributions in the form of food supplies, it serves as a feeder industry for the manufacturing sector of the economy. Agriculture also acts as a base for several allied industries that yield processed food products, chemicals, textiles, and leather. The sector provides employment to 45 percent of the country's workforce, however, over the last few decades; it has suffered persistent decline as a source of employment (USMAN, 2015). The historical role and progress of agriculture can be traced back to the era before

Pakistan came into existence in 1947. At the time, agricultural activity in the area showed marvelous growth and development. This progress continued even after the creation of Pakistan and the sector registered a healthy growth of 4.8% in the decade of 1960s. Since the 1970s, however, the establishment of other sectors, particularly the industrial sector, meant agricultural policies were primarily directed towards the promotion of the manufacturing sector at the expense of agriculture. Consequently, shifts occurred in production resources from agriculture to industry. As a result, the agricultural sector performance and growth declined considerably. Recently, a negative growth of 0.3% has been recorded, and the contribution fell from 50% in 1999 to 24% in 2012 (Kaplinsky & Kraemer-Mbula, 2022).

The agricultural and industrial sectors have a close interdependence, and both rely heavily on each other. For example, agriculture depends upon the industrial sector for tractors, fertilizers, pesticides, etc., most of which are produced by the latter. In the same manner, the industrial sector depends upon the agricultural sector for several raw materials, for example, cotton, sugar, oil, etc. Unfortunately, the agricultural sector has been suffering badly due to the influences of the industrial sectors. Another underlying reason is an unfavorable credit policy on agriculture that caused the absence of several agricultural inputs like fertilizers, pesticides, etc. In the long run, it seems as if agriculture is being used as a sacrificial lamb for the industrial sector in order to accelerate industrial growth. Initially, this may prove beneficial, but in the long run, the results would be catastrophic.

Additionally, a number of other factors have also contributed to a decline in the sector. This includes agricultural research, storage, marketing facilities, water shortage, and various other non-compliance practices, leading to low yields. Furthermore, farmers are only concerned with their present earnings, caring little for future growth. Due to such non-compliance practices, it seems as if the land is more of an extractor as opposed to one that nourishes. For example, the average yield of wheat and cotton is 27 and 25 mounds per acre, respectively (Ahmad et al.2021). Moreover, in order to evade additional costs, the practice of applying more water than needed, and taking short-term loans on high interest are in vogue. The susceptibility is further increased when climate changes are examined. Since agriculture depends heavily on weather, the entire sector is at risk. Due to climate change, unpredictability in water (in the form of floods and droughts) and inadequate input resources such as poor seeds, lack of pesticides, etc. are the additional risks that can exacerbate the situation. Rick studies confirm that the lower strata of society will suffer more from environmental degradation and climate change. To help mitigate these obstacles, it is suggested that sustainable agricultural practices should be followed by growth, or else the future will be jeopardized.

Overview of Pakistan's agricultural sector

Pakistan is an agricultural country having the major chunk in its GDP. The agricultural growth is crucial for the economic progress and poverty reduction. The structure of the agricultural sector primarily consists of outputs, such as crops, livestock, fisheries, poultry, farming, and other agriculture-related activities. The country's agricultural

sector contributes about 21.2% of GDP and employs 45% of the entire labor force. The crops are divided into short and long-term crops, and in duration, they are categorized into rabi (autumn) and kharif (spring/summer) crops. The share of agriculture in exports is approximately 60-70%. The major crops are wheat, rice, sugarcane, and maize, while the minor crops include lentils, sorghum, pulses, millet, and barley. The major crops occupy 84.8% of cultivated area and 41% of agricultural value. The agriculture sector also plays a critical role in the growth of other industries (MĂNESCU et al.2024).

In a developing country like Pakistan, the agriculture development is the critical factor for alleviating the problem of poverty. Agriculture is the main source of revenue generation, employment and economic development. The small holder farmers contribute to the most significant part of agro-industry, food security and farmers GDP. These small farmers have some limitations, low yields due to lower could be enhanced through increasing cultivable land and seed market, for the processing, marketing and transportation of agriculture crops. They have not enough money to invest in seeds, fertilizer, and machinery resulting in low yields (Pan et al., 2024). After the brief introduction, the agronomic climate and crop distribution of the study area is presented. Pakistan having fertile soil and several deltas supports the growth of various crops. The geographic location of Pakistan supports a variety of ecosystems which can grow unique and special crops. The weather conditions and soil fertility help cultivate a significant number of different types of crops. The plot provides a distribution of major crops grown across diverse environmental inflows. The major part of Sindh is coastal and share international border with India. The irrigation and fertile land support many crops. Junagadh State before the independence of Pakistan was the agriculturally growing district. Due to construction of different dams on Sindh River the whole irrigation pattern of the Sindh was disturbed and the canals of Sindh dried up.

Climate Change and its Impacts on Agriculture

Climate change is the ongoing rise in Earth's atmospheric temperature, driven primarily by anthropogenic greenhouse gas emissions. Since the 20th century, the Earth's average temperature has increased by 0.6°C, with projections suggesting a rise of 1.4°C to 5.8°C by the century's end. This change impacts crop production by altering crop suitability, increasing competition from weeds, pests, and resource scarcity. Soil fertility degradation can worsen, particularly in already vulnerable regions facing poverty and food insecurity (Nita et al.2022). Developing countries in tropical areas are especially at risk due to projected severe climatic shifts, compounded by intensified tropical cyclones that threaten food security through natural disasters like floods. Conversely, warm ocean temperatures in the northwestern Pacific could lead to increased droughts.

Research has explored the complex climate factors influencing agriculture, yet the connections between environmental shifts and agricultural productivity remain unclear. Understanding these relationships is crucial for effective planning and policymaking. It's important to identify pressing issues for intervention, which can be

categorized into three areas. Firstly, stakeholders must confront the urgent need for action against climate change, as it imposes significant strain on economies and ecosystems. Coastal delta agriculture faces risks from changing salinity and water levels. Secondly, enhancing public discourse is essential to mitigate misconceptions about climate science, as poorly informed policies may overlook long-term consequences. Lastly, focusing on research questions can pave the way for climate resilience strategies within agriculture and other sectors. The objective is to leverage existing research to inform policy and resource management in light of anticipated environmental impacts from climate change.

Concept of climate change

The climate system is a complex interaction of the atmosphere, biosphere, cryosphere, hydrosphere, and lithosphere. Climate change is an alteration in the state of the climate due to changes in the mean and/or variability of its properties, while natural or anthropogenic conditions remain unchanged. Climate change involves changes in long-term conditions, while climate variability describes cyclic fluctuations around long-term averages soils. Climate change variability plays a significant role in agriculture, which might have cascading impacts on food security. The most important factor in climate change is human activities. Activities like agriculture, forestry, and other land use change because of population and growing demands or industrial activities mostly depend on burning of fossil fuels (Muluneh, 2021). Human-induced alterations are adding greenhouse gases to the atmosphere. The greenhouse effect warms the earth's surface, and burning fossil fuels increases greenhouse gases, accelerating the greenhouse effect. Climate changes due to these effects may change the natural environment, cause sea levels to rise, and energy exchange between earth and space, changes solar radiation cheats. The climate model estimates possible future conditions under various scenarios, permitting policy, and effective planning. Recognizing the importance of stocks to address levels, that's how joint collection improves the estimates.

The Paris Agreement was adopted in 2015, recognizing the primary responsibility of large industrialized countries as historical emitters and calls on them to take up their obligations first and foremost. The treaty encourages equitable contributions to the fight against climate change. The potential consequences of climate change, named in other environmental contexts, should mention that global temperatures, sea levels, and large amounts of environmental none-climate change due to the food speed, water-scarcity drought boundary. It should be clear that it is unusual to continue the current scope of emissions and many consequential impacts regarding food security and other resource systems would accelerate sharply (Molotoks et al., 2021). It is important to emphasize the prominence of the food security and poverty aspects of the exposed objects within this consideration, the shift to the desire for preparation and possibly insight into defense actions both at the global and local levels.

Current Climate Change Trends in Pakistan

State of the Climate Change in the World: Climate change is a pressing issue that needs to be sided in its all manifestations: short term and long term. On the one end,

industrial countries by emitting large quantities of greenhouse gases are responsible for the widely reported spatial and temporal changes in climate. On the other end, developing countries often with ecologically fragile resources, are generally more vulnerable to the impacts of meteorological changes. Even within countries and single countries, there is, a large regional variability to the pressure of environment change, due to the presence of geographical and agro-ecological system. State of the Climate Change in Pakistan: One of the most daunting tasks for environmental scientists and policy makers in the 21st century is to understand the effects of global climate change (GCC), if any, on the patterns and dynamics of natural eco-systems and also to devise mechanisms and agricultural practices which may help in adjusting or mitigating such changes. Pakistan is a developing country with a proportionately large agricultural sector and per capita share in greenhouse gas (GHGs) emissions is one of the lowest in the world (Islam et al., 2022).

Nevertheless, the unavoidable impacts of GCC have the potential to severely affect Pakistan. The well-known alteration of the global climate system includes rising average temperature, heating up of the oceans, rising sea levels, recession of glaciers, changing patterns of rainfall with an increase in summer overflow accompanied by an apparent increase in the frequency of extreme events such as cyclones, storms, and surges and a concomitant increase in the intensity of droughts and floods. A large number of studies provide evidence that the frequency and severity of such events are likely to intensify due to GCC. A major part of this research has concentrated on the study of future agricultural water scarcity issues but very little attention has been paid to actual or potential trends in climate. In this paper, we attempt to explore the ongoing trends in climate utilizing data from the past three decades from all weather stations in Pakistan. Specifically, changes in diurnal and seasonal temperature patterns are examined. In the domain of meteorology, the first research of its kind in Pakistan, this investigation provides a rather comprehensive observational database which may be useful for assessing ongoing shifts in the climate system which might have important implications for planning government policies in sectors such as agriculture, transportation and health (Ahmad et al., 2014).

Temperature changes

Pakistan is ranked amongst the top ten countries that are highly prone to disasters caused by climate change. Agriculture is the backbone of its economy and employs over two-thirds of its workforce (USMAN, 2015), till date very scanty research studies are available in the literature on climate change impact on agriculture in Pakistan. There is a dire need to explore the implications of rise in earth's temperature on agri-economy of the country. Significantly low studies are carried out on the subject. The declining agriculture productivity would increase the country's food dependency by augmenting food imports. Realising the extent of the issue, the current review attempts to address the issue by investigating the anticipated climate risks to agriculture of the country.

Between 1960 and 2014, the average temperature of Pakistan increased by about half a degree Celsius. In order to adapt to the changing climate, the onset of the vegetative

phase of the crop should be reserved for later in the year but with rising temperatures the growing season has been predicted to begin earlier which is anticipated to reduce yields and nutritive quality. Extreme heat reduces crop yields and can also affect crop quality. There are significant differences in the heat-resistance of different varieties of important crops. The variability in the region specific temperature alteration needs to be further explored as the frequency of extreme temperatures is likely to augment newly favorable environments for pests and diseases to flourish.

However, at the moment there is little known about how these fluctuations will affect the present and emerging intercropping pest and disease complexes (Ahmad et al., 2014). No statistical research has also been done so far that would elucidate how variable temperature impacts agricultural pest and disease predation at a regional level. With such a large portion of the workforce dependent on agriculture, the present scant understanding of how temperature affects this industry through intercropping pest and disease predation is concerning. There is also not an empirical work on its vulnerability to variable temperature. An awareness of which regions are most at risk to temperature induced increases in these anxieties can inform the administration of where investment is needed. On the basis of the aforementioned considerations, it is vital that further research is conducted to better understand how variable temperature impacts agriculture in Pakistan.

Precipitation patterns

The examination of historical rainfall data indicated that there is a significant shift in the receipt of seasonal rains in studied areas of Pakistan. This is a growing concern in the agricultural community, where the timing of the agricultural operations, such as the time of planting and sowing, is always planned around the arrival of monsoon rains. Streamflows are highly dependent on the variable and unpredictable nature of rainfall and on the whole they are negligible. The reliance on rainfall for crop irrigation is only within the sowing season in kharif, i.e. June to August, and thus a change in the monsoon season is particularly vulnerable for rainfed agriculture. However, with the rapid rise in population in the past few decades, and the steady conversion of the land to other uses such as housing, roads, and factories, there is increased pressure on the available water resources. Evidently, the changes in rainfall have further exacerbated the situation. The occurrence, in a recent 4-year span, in quick succession of such ‘events’ of drastically altered monsoon seasonality is discerned (Hussain et al.2022). Nevertheless, with the looming specter of ongoing global climate change this is a closely studied matter now.

Consequently, modern-day farmers have come to depend on sowing a variety of their crops at different times, to safeguard against a complete failure of their entire sowing. If there are instead three sequential ‘dry’ sowing times in a given year, following the arrival of rains in June, September and December, chances are higher for successful sowing in at least one of these sowing times. Changes in the concentration of seasonal rainfall are consistent with broader climate change phenomena observed at the global scale. Pervasive changes in weather patterns are observed, with particular hydrological consequences locally. Most of the changes occur with a drastic alteration of seasonal

rains, leading to much heavier than usual downpours, which occur over an intensely brief period. Exploitative agricultural practices in response to the changed environment are described.

Vulnerability of Pakistan's Agricultural Sector

Pakistan's economy is primarily agrarian, and smallholder farming plays a crucial role in livelihood and employment opportunities. However, this sector faces various risks and vulnerabilities due to climate change. Smallholder farmers tend to focus on traditional methods because of limited resource accessibility. Uneducated farmers are more likely to resist change and be hesitant to adopt new technologies. The adoption of climate resilient technologies was necessary to cope with climate change threats to ensure food security and sustain the livelihood of smallholder farmers. It is witnessed in the past that land degradation, water scarcity, and outbreak in pest populations have significantly impaired the agricultural economy of smallholder farmers in Pakistan. Livelihood opportunities are at peak through crop production in rural areas. But given the ongoing climatic threats and the less adoption of climate resilient technologies, food security and livelihood opportunities are at risk. Both crop exposure and sensitivity significantly reduce productivity of crops (Habib-ur-Rahman et al., 2022).

Hence, a need is being felt to focus on the study of this relevant issue, and some of it is being addressed in the proposed research. This study will be able to raise awareness among academia, policymakers, and practitioners to address the issues for formulating working policies. Although Pakistan is facing immense challenges posed by the impacts of climate-induced hazards on agriculture, similar challenges are occurring in the face of policies to address the vulnerability of the agricultural economy as resilience cannot be built overnight. On the other hand, the protection of insight from the lens of vulnerability paves the way for appropriate policies to improve the resilience of a climate-prudent agricultural system and ultimately safeguard the livelihood of a burgeoning population through copious and quality food accessibility from the potential. Beneficial impacts of carbon dioxide (CO2) enrichment are limited to a 10% to 15% increase in crop productivity. The impacts are more adverse in the arid and semi-arid agricultural environment of Pakistan, where a large share of the population takes advantage of agriculture for the livelihood. The flood is anticipated to occur much more, with a predominance of 12% to 30%, during the dry period, Kharif (summer) season of the rice crop in Pakistan (Adnan et al.2024). Considering the potential nuisance, this research will contribute to expanding the insight from vulnerability's perspective and welcoming relevant policies that will improve the resilience of an agricultural economy. Contradictory to this scientific consensus, the policy response in Pakistan has been giving inimical regard that stresses the reliance on C3 crops, like wheat and rice that are more sensitive to heat and water scarcity. Another crucial fact revealed is the huge disparities of 53% in monetary terms between the estimated nationwide damage and relief to adaptation to the fragile agricultural economy of the 5th populous country globally in the peril. Moreover, significant

variations among agro-ecological zones are identified, with two most stable adaptation practice arrears seeking the enormous share of the benefit.

Factors contributing to vulnerability

It is widely acknowledged that climate change poses a significant threat to the agricultural economy of developing countries, which is particularly vulnerable to climate-induced variability. Certain regions in the world, such as Sub-Saharan Africa and South Asia, are highly vulnerable to climatic shocks due to an increasing frequency of extreme events like floods, droughts, and cyclones. Of these regions, Pakistan ranks at 7th on the list of most impacted countries by climate change (Habib-ur-Rahman et al., 2022). Agro-based economies mostly prevail in developing countries, severely affecting crop production, a large source of income generation for the rural population. Apart from the aforementioned arid to semiarid conditions, Pakistan is highly vulnerable due to its unique geo-physical conditions. Impacts of climate change are strongly felt since it is under threat of increasing aridity and severity of the climatic events. Pakistan's agricultural economy is highly prone to environmental vulnerabilities, economic vulnerabilities, and social vulnerabilities. Enhanced vulnerability of the agriculture sector to climate change further exacerbates livelihood insecurity. Vulnerabilities in social, environmental, and economic contexts have been viewed as locking farmers and agricultural systems in poverty and maladaptation, thereby undermining progress towards sustainable development.

Environmental vulnerabilities are associated with increasing climatic shocks that are responsible for an increasing frequency of natural disasters, including floods, droughts, and cyclones. Such climatic shocks drastically affect crop production conditions and ultimately decrease agricultural growth in Pakistan. Economic disparities and weak economic conditions play a significant role in limiting the adaptive capacity of people in agriculture. Export and import imbalances in Pakistan are increasing, leading to a fragile and open economic system. The country is heavily dependent on imports, especially machinery, chemicals, and fertilizers. Adaptive capacity can bolster an agriculture-dependent economy in lessening vulnerability. However, the adaptive capacity of the nation is significantly reduced due to a lack of efficient governance, institutional support, and risk management policies for the agriculture sector (Abbas, 2022). Furthermore, vulnerability is exacerbated by low-quality transformation of production goods and services for farmers, lack of innovation, and consultancy services. It is assumed that risks to crops and property can be curtailed by expanding insurance coverage and the early warning system. Considering all these points, the community's resilience appears to be an effective way to decrease the adverse effects of future climatic hazards. This study further highlights that comprehensive assessment of the vulnerability of the sector is needed to target niche interventions in agriculture. The goal is to provide sound evidence for public and private investments in agriculture to fill the gap and strengthen the production system of the farmers.

Adaptation Strategies for Pakistan's Agriculture

Pakistan is considered one of the most vulnerable countries to the adverse impacts of climate change. Pakistan's economy is significantly dependent on the agriculture

sector and is highly sensitive to climate variability. Agriculture in Pakistan is already under serious stress from recurrent and intensive droughts, heat waves and floods. These climate changes directly influence the agricultural economy of Pakistan. The adverse impacts of global climate change are of special concern to food security throughout the world and especially in the developing countries. Therefore, agriculture is prioritized as a main area for the country's adaptation strategy. The focus of this study is to analyse the impacts of global climate change on Pakistan's agricultural economy and presents suitable adaptation strategies that could be effective in reducing these impacts. This study will be helpful for planners, policy makers, researchers, scientists, and farmers to understand and tackle the impacts of global climate change on the agrarian economy of Pakistan in particular and the world in general (Syed et al., 2022).

This research aims to identify the climatic variations and their impacts on agriculture by analyzing long-term time series data. The study is based on agriculture data and the following two methods are employed to understand the impact of climate change on agriculture. The first assessment of the trend analysis using non-parametric statistics. The second is the semi-distributed, grid-based, and parameter calibrated hydrological model, which was used to assess the effects of climate change on water balance components and crops. The model was run for both historical and future periods, under two different scenarios. The nation and lobby engagements and workshops were held involving stakeholders invited from federal, provincial, and district governments, consultancies, related sectors, and NGOs. A conceptual prototype of a water-user association was developed. Two potential sites for the project were selected at the beginning of the study. Part of this study was also focused on creating awareness in academia, by estimating the future water availability potential of the major rivers of the Indus Basin (Adebayo et al.2021). A medium capacity, full-fledged laboratory facility was also developed where faculty and students could be trained in this field.

Technological innovations

Technological innovations play an extremely pivotal role in effectively adapting agriculture in Pakistan to the increasingly severe variants of climate change. These advancements can significantly resolve the ongoing task of minimizing food requirements while simultaneously enhancing the yield of crops from each unit of cultivated area. In recent years, we have witnessed a surge of numerous developments and innovative applications of cutting-edge technology, which have dramatically reshaped production, management, and policy-making agri-systems on a global scale. Biotechnology, in particular, has proven to be highly successful in the development of genetically modified organisms (GMOs), which represent a revolutionary new paradigm for addressing pressing agricultural problems, including the creation of more resilient GMO crops that can withstand pests and diseases more effectively than traditional crops (Chandio et al.2021). It is evident that GMOs have emerged as a highly successful scheme aimed at improving sustainability and productivity within the

agricultural sector, thereby providing solutions that are crucial for food security and environmental resilience in our rapidly changing world.

Information and Communication Technology (ICTs) applications in agriculture are increasingly observed in all parts of the world to meet the challenges imposed by food security and climate change (Habib-ur-Rahman et al., 2022). The interest and enthusiasm of the international community in the ICTs have opened floodgates of innovative research and technological advancements. The effect of these modern technologies on farm practices has been transforming traditional agriculture into precision agriculture, where each crop, or perhaps each plant, can be managed differently from others based on variations in the field. Precision agriculture reduces the cost of inputs, increases crop productivity, reduces environmental hazards, and aims to promote sustainability. Some of the technologies include, (i) precision farming, (ii) use of wireless sensors, (iii) GPS operated drones, (iv) automated farm machinery, (v) solar-powered sensors, and (vi) variable rate technologies like VRT-enabled sprayers. Smart irrigation systems that adapt the rate of watering to match the varying needs of crops in different parts of the same field are also observed to be increasingly popular in many developed agri-economies. Similarly, in Pakistan, these technologies, if widely adopted on a par with other competing regions, can offer daunting improvements, and potentially increase the sole-intensive yield up to double. On the other hand, a rise in temperature and an increase in extreme weather events will substantially reduce crop yield because of sub-optimal growing conditions (Lesk et al.2022).

Thus, the ultimate path to sustainable and prosperous agriculture under a stiffer future climate regime is the adoption of climate-resilient technology. These largely vitally include crop species that are better adapted to predicted future conditions, as well as the development of new technologies or improvements to existing technologies that ameliorate the negative impacts of heat stress on crop growth and performance. Additionally, some evidence for the current characteristics of agricultural technology is also forthcoming, which indirectly reveals the possible effects of climate on this channel. Agricultural technology is produced through the agricultural research and extension systems, which include public sector research and extension institutions as well as private sector actors, and constitutes the physical input manufacturers and suppliers of knowledge and other support services.

Mitigation Strategies for Climate Change in Agriculture

Climate change has posed the emergence of a number of adverse effects on agricultural production that ultimately affect food and livelihood security for the vulnerable segments of society. The rising trends in temperature, combined with erratic monsoons, are contributing significantly to this crisis. These alterations are characterized by continuously changing onset and withdrawal times of the monsoons, which are becoming increasingly unpredictable, resulting in heavy or low rainfall intensities. Additionally, the impacts of increased evapotranspiration are notable, and we are witnessing an increase in snowfall in higher ranges that has unfortunately led to a decline in the availability of water in the form of river or channel flows. Sudden

climatic events, including droughts, floods, frost, hails, and temperatures that either soar above or plummet below average, are all stark signs of the overarching influence of climate change on agricultural practices (Habib-ur-Rahman et al.2022).

These extreme weather events dramatically affect farmers' practices, influencing their production across a variety of crops, particularly in barani areas that heavily depend on rainfall. Climate change generally alters the operating environment of the agricultural industry, as well as the multitude of dangers it faces. These risks include not only physical challenges but also impacts on quantity, quality, biodiversity, regulatory changes, and market fluctuations. Agriculture, being particularly susceptible to these climate risks, has a direct correlation with climatic conditions. The implications of this relationship are profound, especially as they relate to rainfall patterns, crop yields, and overall income for farmers, making the agricultural sector especially sensitive to such climatic shifts. The continuously changing climate acts to limit the choices farmers have regarding what crops to plant and when to plant them, leading to significant ramifications for agricultural output. In contrast, the unpredictable nature of climate change is characterized by increasingly frequent and extreme events such as floods and prolonged dry spells, which pose even greater challenges. Consequently, the traditional reliance of farmers on pre-established planting calendars is diminishing, which holds serious consequences for their long-term planning and food security. Global warming is wreaking havoc on ecosystems around the world, contributing to a reduction in sugarcane crops in areas like Sargodha, placing Sicilian productivity under threat in Narowal, and resulting in significant decreases in available water resources while also lowering aquifer water levels. These cumulative effects underscore the need for urgent adaptations in agricultural practices to mitigate the impacts of climate change. (Habib-ur-Rahman et al., 2022)

Sustainable agricultural practices

This paper looks at how sustainable agricultural practices can contribute to mitigating the impacts of climate change on agriculture, thereby aiming to promote a broader adoption of sustainable agriculture in Pakistan’s agricultural economy. Intensification and expansion of agricultural activities put a lot of pressure on natural resources (water, soil, and vegetation cover). Traditional practices are being replaced by so-called “modern” ones. These practices are highly dependent on external inputs, such as inorganic fertilizers, pesticides, and energy-heavy machines. In the long term, this type of agriculture tends to become unsustainable as it degrades the natural resource base ecosystems rely upon. Despite growing attention to and increasing investments in the improvement of agricultural productivity, nowadays there are still nearly a billion people suffering from undernourishment all over the world. The majority of them are producers. This is a paradox that points out the need for changes in the dominant paradigm of agricultural development (Habib-ur-Rahman et al., 2022). A change in the practices adopted for food production is essential. These practices should be environment friendly and socio-economically and culturally sustainable, that is, ecological.

This paper posits that sustainable agriculture is food production that doesn't degrade the environment. It respects biodiversity and the natural resource base and concentrates on working 'with nature' rather than against it. Agriculture is developed in co-evolution with the local ecosystem to guarantee productivity while protecting the environment. Sustainability can be achieved by preserving and increasing intrinsic soil fertility, thereby maintaining high levels of soil biological activity, as well as high levels of crop diversity. This in turn contributes to the development of a resilient on-farm ecosystem by minimizing the risk associated with pests, diseases, and extreme climatic conditions.

Policy Frameworks and Government Initiatives

Major government policies that address climate adaptation and resilience in agriculture are: the National Climate Change Policy (NCCP) and the Framework for Implementation of Climate Change Policy. A national strategy is being developed regarding climate-resilient agricultural practices. Recently, the Khyber Pakhtunkhwa (KP) government adopted an Agriculture Growth Policy with a sub-strategy for climate change adaptation in the agricultural sector. Another recent initiative is the adoption of a Climate-Smart Agriculture Strategy and Investment Plan (Mumtaz & H. Ali, 2019). Therefore, both the national and provincial governments are in the process of developing strategies and adopting initiatives to effectuate practical steps that address climate change impacts.

Despite these efforts and initiatives, there are various gaps, constraints, and challenges that curb the effective implementation of these schemes and policies. In KP, the biggest conservative party procrastinated implementation of the well-formulated climate change policy, and even after completion of a 6-year term in government (2013–2018) the prepared policy was not adopted. The PTI-led government has adopted the policy but could not effectively implement the proposed strategy because of different considerations that are intricated in nature. Furthermore, the KP government did not maintain a regular question-and-answer session in the KP assembly (Egodage et al.2024). The relevant department did not share complete information regarding adopted initiatives and financial expenditures on behalf of the weathering event in general and of the agriculture sector in particular. In a nutshell, there is no viable mechanism for the demand of question-and-answer session. Finally, in case of the 18th constitutional amendment it is difficult for the federal government to formulate a policy framework encompassing sub-national governments. Last but not least, inclusive policies should be developed after taking all of the stakeholders into confidence. Events and policies formulated far from the farm gate are contingent to failure.

Existing policies and regulations

Policies and regulations can provide a sound basis for actions to address the agricultural sector's vulnerability to climate change. There appear to be no published policy reports or documents available in relation to the wider industry. However, a number of articles have considered the role of regulation and government action in addressing the challenges and opportunities of climate change. (USMAN, 2015) found

a high vulnerability to climatic changes among major crop yields in Pakistan, and highlighted the importance of the National Climate Change Policy (NCCP). The NCCP and the Framework for Policy Implementation on Climate Change and Development (FPICCD) provide an overarching overview of the government's intentions to respond to the challenges posed by climate change. There is, however, a need for any regulatory body to enforce the Climate Change Act and policy instruments of the government.

Regulatory institutions have a key role in the enforcement of compliance and in monitoring the effectiveness of these regulations. The absence of regulation is known to undermine the implementation of sectoral policy decisions. Allegedly, current regulations and process tools are at odds on some levels. There are apparent loopholes and inconsistencies in the current interpretation that hinder an effective response to existing guidelines. Steps should therefore be taken to update and adapt regulations to deal with current concerns invoking the need for continuous review. The effective design of such a framework may involve a combination of size-regulating regulations, such as blending goals, with more flexible, cost-effective economic mechanisms. Further research and stakeholder discussions are needed to refine and explore the potential positions and approaches to government and disperse efforts in this area, in order to ensure close liaison and coherence while minimizing conflicts of interest. If adequate care is not taken, it should also be pointed out, one regulatory policy may end up in opposition to another (Baker et al., 2021). The drawback may come with imposing domestic obligations on industry while government commitments are simultaneously being made at WTO levels. It is implied that a robust regulatory framework is a necessary albeit not sufficient condition if there is to be progress.

Economic Impacts of Climate Change on Agriculture

Climate change has diverse impacts on all aspects of the environment but agriculture, having direct exposure to climatic conditions, suffers more severely than any other sector. Agriculture was, is, and will always be the backbone of the Pakistani economy. Pakistan's economy largely relies on agriculture, since it accounts for about 20.9% of GDP and employs almost 42.3% of the labor force in Pakistan. In time series observance, temperature has increased by 0.7–1.34°C and rainfall has fell by 5-11% over 60 years. It will be the third most vulnerable state due to 1°C increase in mean global temperature (Rehman2023). The substantial changes in climatic parameters affect food security for countries in need of assurance which will have a distressing impact on the national economy.

The agricultural community faces significant challenges due to climate hazards and lack of support facilities. With nearly 60% of the labor force tied to agriculture, negative effects from climate-related incidents impact their socio-economic status. Over 16 years, climate losses have averaged 5-15 billion USD annually, projected to rise to 141 billion USD from 2020 to 2035. Major crops are expected to suffer a loss of 89.94 billion Rs by 2030 due to climate impacts. Wheat yields will be negatively affected by fruit fly settlements, while rice could lose 158 million tons, equating to 5.14% of exports, potentially increasing to 264 million pounds. These losses could lead to severe

economic stress, with disputes over water distribution exacerbating conditions for Rabi crops like wheat and rice. Historical water conflicts in Sindh and Punjab have contributed to political instability, food insecurity, and poverty (Junaid and Gokce2024). There is an urgent need for improved water distribution practices to avert a weakened crop production environment, falling domestic production, and soaring commodity prices, which could lead to global scarcity of agricultural goods. The long-term sustainability and development of the sector are in jeopardy due to ongoing climatic shifts.

Losses in crop yields

Climate change poses significant threats to food security in the developing world, especially in Pakistan. The nation experiences severe weather alterations leading to substantial crop yield losses in groundnut, wheat, cotton, rice, and sugarcane, escalating rapidly. Reports indicate that from 1986-2007, wheat productivity fell by 0.49% per year and cotton by 1.26%. Between 1999-2000 and 2006-07, groundnut yields suffered losses of 60.0-78.0 kg h-1 mm-1 under drought stress and 42.0-76.24 kg h-1 mm-1 from heat stress. Heat stress during spring could drop chickpea yields by 1.573 tonnes per ha–°C over critical temperatures. Agriculture, crucial to Pakistan's economy, contributes 23% of GDP and offers 47% of jobs, with 60-70% of people tied to this sector (Gul et al.2022). However, anticipated declines in arable land and water threaten agricultural growth. Extreme weather can detrimentally impact plant health, significantly lowering crop production. Reports from Sindh highlight that rising temperatures adversely affect crop yields, complicating heat stress management and limiting farmers' capacity to counteract losses. Certain crops show varying levels of vulnerability to climate change, indicating a need for targeted mitigation strategies.

Keeping in view the importance of crop yield losses due to climate change the urgency to study the following broad objectives is elaborated in topic piano-Forte. Economic repercussions and additional importance are also illustrated. Climate change is expected to increase the intensity and decrease the spatial coverage of monsoons in South Asia. Rainfed agriculture provides 80% of food calories to more than 40% of the global population and is particularly prevalent in marginal areas. Rapid shifts in weather patterns threaten the productivity of crops and livestock in rainfed settings. The region, semi-arid areas of Pakistan, are especially vulnerable with respect to the likely impacts of climate change, particularly due to the increasing frequency of extreme events. Supply of irrigation water has become uncertain in many areas of Pakistan and has been reported as a major constraint for crop production. Severe weather changes have manifested nationwide during recent years. On May 23, 2009, temperatures reached 53.5°C in MohenjoDaro, Sindh, breaking the 13-year-old record of the 50.2°C temperature in Larkana. On 15th November 2010, rain and hill torrents in Balakot also broke the record (Yadav2022). Similarly, another disaster hit the country in the form of heavy monsoon floods afflicting provinces across the country.

Environmental Impacts of Climate Change on Agriculture

Climate change has considerable and adverse impacts on agricultural ecosystems through the threaten of loss of biodiversity and deterioration of ecosystems. Increase

in temperature as a result of climate change is a chief cause of changes in ecosystems and agricultural crop distribution. Continued periods of extreme high temperature will reduce crop yields and nutritional quality. Changes in climate conditions leads to alteration in agriculture practices and expansion of pests and diseases (USMAN, 2015). Major direct negative impacts can be tangibly observed in terms of water runoff due to heavy rains, as well as blowing away of top soil that is an outcome of high velocity wind in monsoon period. This implies that problems in relation to soil health are a critical cause of worry, as well as issues related to the management of water resources. This sector is heavily dependent upon suitable terrestrial and aquatic ecosystems, which provides the source of nutrients, a carbon sequestration reservoir and water filtering system critical for human consumption. There is a pressing concern on how to manage agricultural practices by preserving ecological balance.

Another perspective of the environmental impacts of climate change on Pakistan's agriculture sector is the prevention of future environmental degradation of critical natural resource base. The environmental resources required for farming may be jeopardized as a result of the consistent and sustaining severe weather events. The long-term environmental repercussions of climatic variations are a significant worry for general agricultural sustainability, particularly in conditions where it is already under substantial stress because of policies of non-sustainability. Crop yield inflation on water availability leads to exploitation of groundwater resources as an alternative strategy in drought-prone regions which are not only complicating issues of water scarcity for drinking and household purposes but is also causing contamination of water sources from brackish water. Besides environmental impacts, there are also serious concerns about losing fertile agricultural land as 10 hectares per day are becoming hebby perennially due to waterlogging and salinity problem. An advanced research undertaken with coherence to comprehensive analytical and modeling techniques is considered necessary in order to have an exact idea about the magnitude of environmental impacts on the agriculture sector. Efforts are being made in this study to put forward possible complications in preserving ecological balance within agriculture practices and the difficulty of investing in this sector because of a lack of environmental focus.

Biodiversity loss

Biodiversity is a key foundation of ecosystem services and plays a critical role in providing food, fodder, fuel, shelter, medicines, cultural and spiritual heritage, and sustaining livelihoods along with refreshing water, pollination, and nutrient recycling (Abbas et al., 2019). Climate change affects this biodiversity because it alters habitats directly and modifies the distribution of species. Agricultural practices that support biodiversity as well as the importance for conserving traditional crops, wild relatives, and indigenous livestock breeds are linked to food security through agro-ecosystems (USMAN, 2015). Climate homogenization occurs due to global or regional temperature increase and changes in extreme weather events, people have adapted their crops and crop management practices according to environmental factors. Market demands control agricultural practices, and amelioration measures by agrochemicals have

boosted crop yield. Power driven machinery and irrigation practices have risen in a big manner. The homogenization of landscapes has influenced the specialization of farming and deteriorated ecosystem services. This has lead not only to the decline of useful species, traditional crops, and indigenous varieties, but has also created vulnerable farming systems and food supplies. That is, in the continual optimization of farming practices and rising use of monoculture, less adaptable traditional crops have been increasingly replaced by genetically uniform, high-yielding and marketable varieties, thus severely threatening biodiversity as well as ecosystem services.

Approximately 75% of genetic diversity of crops has been lost since the 20th century, and of the 4,000 species of domesticated crops only 20 enter major human diets. Many adults consume large quantities of staple crops, such as rice, wheat, and potatoes. A total of 40,000 different varieties of wheat, 200,000 varieties of rice, and 1,000 varieties of banana are estimated. These varieties have been developed with local practices and are directly linked with cultural adaptation, traditions, and environment. The continuous expansion of intensive crop monocultures has rapidly increased on a global scale, and less than 50 plant species are currently grown, while only 30 of these are cultivated at scales of more than 100,000 km2. In Pakistan, more than 1,000 varieties of wheat existed before the Green Revolution, but due to aggressive breeding and bio-technological applications the available varieties declined to some 65 by 2014. At present, the majority of agricultural land in the Indus Valley is covered by high yielding varieties of wheat and rice, along with Bt and herbicide resistant cotton. Crop breeding practices have caused 75% of indigenous livestock breeds to become extinct due to selection of fast growing, high milk yielding, or good reference qualities.

Conclusion

The agricultural sector in Pakistan is at a critical juncture, facing unprecedented challenges due to climate change. As the backbone of the economy, contributing significantly to GDP and employment, the sector's vulnerability to climatic shifts threatens not only food security but also the livelihoods of millions of smallholder farmers. The increasing frequency of extreme weather events, such as floods, droughts, and heatwaves, has led to declining crop yields, particularly in staple crops like wheat, rice, and cotton. These changes are exacerbated by water scarcity, soil degradation, and the spread of pests and diseases, which further strain agricultural productivity.

The study underscores the urgent need for adaptive strategies to mitigate the impacts of climate change on Pakistan's agricultural economy. Sustainable agricultural practices, such as crop diversification, improved water management, and the adoption of climate-resilient technologies, are essential to enhance the sector's resilience. Technological innovations, including precision agriculture, genetically modified crops, and smart irrigation systems, offer promising solutions to increase yields and reduce environmental degradation. However, the adoption of these technologies requires significant investment and capacity-building, particularly among smallholder farmers who often lack access to resources and information.

Policy frameworks and government initiatives play a crucial role in addressing the challenges posed by climate change. The National Climate Change Policy (NCCP) and

other regional strategies provide a foundation for climate-resilient agricultural practices. However, effective implementation and enforcement of these policies are necessary to ensure their success. Additionally, there is a need for greater collaboration between federal and provincial governments, as well as increased involvement of stakeholders, including farmers, researchers, and private sector actors.

In conclusion, the future of Pakistan's agricultural economy depends on its ability to adapt to the changing climate. By adopting sustainable practices, leveraging technological innovations, and implementing robust policy frameworks, Pakistan can mitigate the adverse impacts of climate change and ensure long-term food security and economic stability. The time to act is now, as the consequences of inaction could be catastrophic for the nation's agricultural sector and the millions of people who depend on it.

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