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Contemporary Farming and Associated Consequences of Climate Change

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Authors' contributions

This work was carried out in collaboration among all authors. Author NM conducted an in-depth study of previous research, reports, and related literature, and was primarily responsible for writing the initial draft of the manuscript. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Aim: This review aims to synthesize current understanding of the multifaceted impacts of climate change on agriculture, examine adaptive strategies to maintain food security, and offer insights into sustainable farming practices.
Objectives: The objectives are to: (1) identify the potential causes of climate change, (2) assess its effects on agriculture, and (3) discuss mitigation strategies and sustainable farming practice.
Methodology: A systematic review of the literature has been performed. We conducted an in-depth study of previous research, reports, and related literature. Sources were selected based on relevance and credibility to provide a thorough examination of the impacts of climate change on agriculture.
Analysis: The analysis focused on categorizing the direct and indirect effects of climate change on agricultural systems, understanding changes in crop yield, plant physiology and metabolism, and evaluating the effectiveness of various mitigation strategies.

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Result Findings: The findings indicate that the greenhouse effect, driven by gases such as CO_2, CH_4, and H_2O, leads to global temperature increases. The concentration of these gases is rising, with the global average temperature expected to increase by 2°C by 2100, causing significant economic losses. While this increase has boosted plant growth and productivity through enhanced photosynthesis, the associated rise in temperature counteracts these benefits.

Therefore, mitigation strategies such as nutrient management, drip and sprinkler irrigation, and sustainable agricultural practices are essential. Natural farming is a sustainable agricultural practice that offers chemical-free, healthy food while promising to increase farmers' income, improve environmental health, restore soil fertility, and reduce greenhouse gas emissions.

Conclusion: Climate change poses a significant threat to global food and nutritional security by altering agricultural productivity and sustainability. Understanding these impacts and developing effective mitigation strategies is crucial. This review provides valuable insights for policymakers, researchers, and practitioners to address these challenges and ensure resilient agricultural systems capable of sustaining future food security.

Keywords: Climate change; greenhouse gases; greenhouse effect; temperature rise; pest infestation; economic loss.

1. INTRODUCTION

“The steady rise in the human population has historically been accompanied by a number of changes in daily life, culture, science, technology, economy, and agricultural output. Agricultural production has experienced several significant changes-agricultural revolutions which have been influenced by the development of technology, civilization, and general human advancement” [1]. “Nonetheless, the remarkable surge in population over the past century has resulted in numerous unfavorable outcomes that, combined with alterations in the surroundings, affect the stability of the food supply. The growing world population has rising demands for crop production and accordingly, by 2050, global agricultural production will very likely need to be doubled to meet increasing demand” [2]. “Current scientific investigations and agronomic studies are mainly focus on climate change and its associated effects, such as the escalation of global temperatures, heightened levels of atmospheric carbon dioxide, heat waves, floods, severe storms, droughts, and other instances of extreme weather” [1]. Therefore, “when the tendency to reduce yield loss owing to such conditions develops, more attention is paid in agricultural research to the abiotic elements indicated above. Changes in precipitation patterns may be more significant than temperature rise in terms of crop production, particularly in regions where dry seasons present an obstacle to agricultural output” [3].

“A number of controlled and natural systems' properties and distributions, such as hydrology and water resources, cryology, freshwater and marine ecosystems, terrestrial ecosystems, forestry, and agriculture, are significantly influenced by the climate change” [4]. “Due to rising temperatures, elevated levels of CO_2 as well as other greenhouse gases, and changes in precipitation patterns, the sustainability of global food production is seriously threatened. One major issue the world is now experiencing is global warming. The exceptional rates of growth in sea level and atmospheric temperature indicate that it has reached record breaking levels” [5].

Frequently referred to as an "open-air factory," agriculture represents an economic endeavor which greatly depend on the environment and weather conditions for producing food and various other necessities crucial for human survival. Furthermore, “agriculture is most susceptible to climate change, and the effects of this phenomenon are marked by a variety of uncertainties” [6]. “Global agricultural systems are predicted to be impacted by climate change in both good and bad ways, with the negative effects outweighing the positive” [7]. From species to ecosystem levels, temperature rises, changed precipitation patterns, and elevated CO_2 concentrations have a substantial effect on ecosystems [8].

“Weather and climate have a big influence on agriculture. It also depends substantially on water, land, and other naturally occurring resources that are impacted by climate. While fluctuations in temperature, precipitation, and the timing of freezes could expand the growing season or enable the cultivation of alternative crops in some areas. Additionally, it will make farming more challenging. Crops, animals, soil and water resources, rural communities, and agricultural laborers are all susceptible to the effects of climate change. But greenhouse gases released by the agriculture industry into the atmosphere additionally contribute to a part in climate change" [9].

1.1 Literature Review

Over the past few decades, significant global climate changes have been driven by increased human activities that have altered the composition of the atmosphere [10]. Since 1750, concentrations of greenhouse gases such as nitrous oxide (N_2O), carbon dioxide (CO_2), and methane (CH_4) have risen by 20%, 40%, and 150%, respectively [11]. Carbon dioxide, which constitutes the largest share of greenhouse gases [12], saw its emissions increase from 22.15 billion metric tons in 1990 to 36.14 billion metric tons in 2014 [13]. "The increase in greenhouse gases has significant implications for atmospheric warming. The infrared-active gases, primarily ozone (O_3), water vapor (H_2O), and carbon dioxide (CO_2) absorb thermal radiation emitted by the earth's surface and atmosphere, leading to an overall warming effect. Since 1975, the average global temperature has risen at a rate of 0.15–0.20°C per decade [14] and is projected to increase by 2°C by 2100 and 4.2°C by 2400, according to probabilistic estimates of the IPCC's range of climate sensitivity" [15].

"Climate change is expected to intensify in the near future. In Pakistan's province Punjab, projections indicate rising minimum and maximum temperatures during the Kharif and Rabi seasons. By mid-century (2040–2069), simulations predict that the average maximum temperature in the Kharif season will increase by 1–3.3°C, and the average minimum temperature will rise by 2–3°C. Similarly, in the Rabi season, the average maximum temperature is expected to increase by 2.1–3.5°C, and the average minimum temperature by 2–3°C. Projections also indicate variations in regional rainfall, especially during the Kharif season, with increases of 25–35%, while changes during the Rabi season are minimal" [16]. "Temperature and precipitation extremes are expected to become more pronounced in the near future due to global warming. Extreme precipitation events, whether heavy rainfall or drought, will depend on a region's geography. For example, South and East Asia are likely to experience increased average river flows due to prolonged heavy rainfall, whereas droughts in southern Africa and South America are expected to be less severe" [17].

"Precipitation anomalies have detrimental effects on agriculture, particularly in developing nations. These anomalies not only impact crop yields but also significantly affect cropland areas. Evidence suggests that a 9% increase in cropland expansion in the developing world over the past two decades is due to dry anomalies, as farmers expand land to offset yield losses" [18]. "Climate change adversely affects agricultural production and is projected to reduce global cereal yields, with maize and wheat production expected to decline by 3.8% and 5.5%, respectively" [19]. Climatic factors subject plants to various abiotic stresses, including salinity, drought, heat stress, and cold stress [20]. Additionally, water shortages, soil fertility loss, and increased pest infestations are significant negative impacts of climate change on crops [21].

Nowadays, climate change is very crucial topic among people, because world populations are suffering more than past due to speedy change in climate. Reason for choosing this topic is that, human life depends on agriculture, whatever they consume it comes from agriculture. But climate change has its significant impact on agriculture and farmers should adapt to it and everyone has to put effort for mitigating this issue. Consequently, this review paper consolidates current understanding of the diverse effects of climate change on agriculture, examines adaptive strategies to maintain food security, and offers insights into sustainable farming practices. This synthesis aims to assist policymakers, researchers, and practitioners in making informed decisions to tackle these urgent issues.

2. MATERIALS AND METHODS

A systematic review of the literature was conducted, involving an in-depth analysis of previous research, reports, related publications, and websites. We searched Google Scholar using keywords such as "what is climate change," "what is greenhouse effect," "climate change and agriculture," "climate change and economics," "climate change and mitigation strategies," "natural farming," and many more. The search covered publications from 2000 to 2024. Numerous documents were screened, and those deemed most relevant to the study (as listed in the references) were selected for writing this review paper.

3. CAUSES OF CLIMATE CHANGE

The term "climate change" describes notable, protracted variations in the Earth's temperature. The global climate is a result of the interplay between the sun, earth, and seas, wind, rain, and snow, forests, deserts, and savannas, as well as human activity. Climate change, most usually used to refer to anthropogenic or human-caused climate change, is the term used to describe changes in Earth's climates at local, regional, or global scales [22]. “In recent decades, climate change has become the prevailing term to describe alterations in the Earth's climate primarily driven by human activities, notably by the combustion of fossil fuels and deforestation. These activities have led to a rapid increase in atmospheric carbon dioxide levels” [23]. “Since, global warming is one of the most significant indicators of global change, the terms are frequently used interchangeably with climate change. Global warming refers to the rise in average global temperatures, which is linked to significant impacts on humans, wildlife, and ecosystems around the world. The phrase climate change is used to refer to these extra effects since there are other variables and repercussions besides just increasing surface temperatures. Among scientists, who account for 97% of those who write on climate change, there is broad agreement that human activity has been the primary driver of observed warming trends over the 20th century” [24].

Climate change and human activity on the planet generate temperature variations, which in turn start the concentration of greenhouse gases [25]. Anthropogenic activities cause the atmosphere to lose ozone by releasing greenhouse gases including CO_2, methane, and nitrous oxide, among other things [26]. The annual greenhouse emission through different sectors have been shown in Fig. 1. “The increased CO_2 concentration in the atmosphere can affect microbial activities in the soil, along with implications on water content, and therefore increased atmospheric CO_2 (463–780 ppm) can stimulate nitrous oxide and methane emission from upland soil and wetlands, respectively, which nullifies the 16.6% mitigation effect of climate change as predicted by increasing terrestrial carbon sink” [27]. “The agriculture sector contributes 15% of total emissions, primarily methane and nitrous oxide. If dietary choices and food energy consumption remain unchanged from 1995 levels, there will likely be an increase in non-agricultural greenhouse gas emissions worldwide until 2055. But when people's tastes shift toward more expensive goods like milk and meat, emissions are expected to increase even faster. Either technological mitigation, decreased meat consumption, or both can be used to lower emissions” [28]. The main sources of greenhouse-gas emissions by the livestock sectors include enteric fermentation, N_2O emissions, liming, fossil fuels, fertilizer production, etc. [29]. “The utilization of nitrogenous chemical fertilizers is another factor contributing to greenhouse gas emissions. Effective crop management practices could potentially reduce nitrogen fertilizer usage by 38%. Furthermore, enhanced crop management not only leads to a 33% increase in yields but also reduces input energy consumption by 11%, resulting in a 20% decrease in greenhouse gas emissions” [30].

The gases that are present in the Earth’s atmosphere and trap heat and prevent it from escaping to outer space are called "Greenhouse gases". These gases act like a blanket of heat around the Earth. Greenhouse gases are emitted from both man-made sources and naturally occurring sources. Greenhouse gases include carbon dioxide (CO_2), methane, nitrous oxide, etc. [31]. “For humans to survive, the greenhouse effect is essential. In actuality, Earth would be around 30 degrees cooler if greenhouse gasses didn't exist. We could not exist without greenhouse gasses and the warmth they cause. However, ever since the industrial revolution, we’ve been releasing ever-increasing amounts of greenhouse gases (GHGs) into the atmosphere, trapping more heat than ever before. The greenhouse effect isn’t keeping the Earth at a constant temperature. Instead, it’s accelerating the rate at which the planet is warming. This is known as the ‘enhanced greenhouse effect’ and it’s the primary driver of climate change” [31].

The atmosphere contains more carbon dioxide now than it has for at least the last two million years. The amount of carbon dioxide increased by 40% throughout the 20th and 21st centuries. There are several activities through which human generate greenhouse gasses [31]:

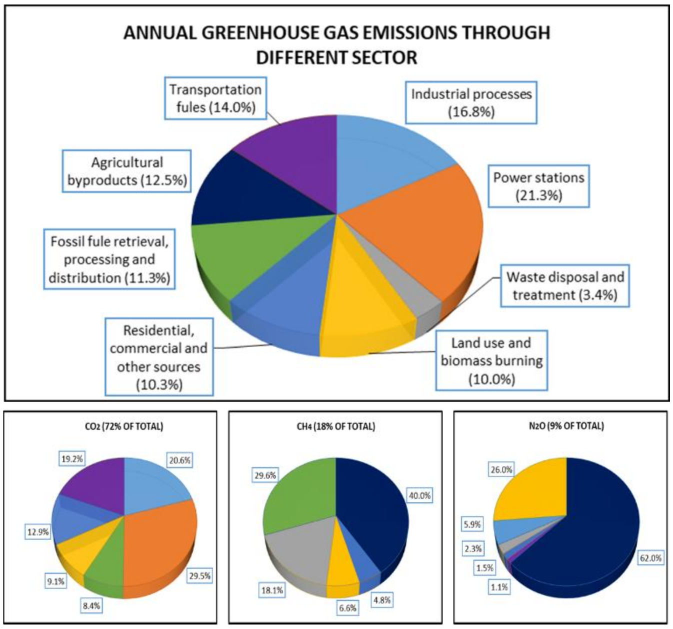

Fig. 1. The annual greenhouse emission through different sectors (https://www.ijirct.org/papers/IJIRCT1201068.pdf)

- **Burning fossil fuels** – Fossil fuels such as oil, gas, and coal contain carbon dioxide that has been 'locked away' in the ground for thousands of years. The carbon dioxide that has been stored is released into the atmosphere when we remove them from the ground and burn them.
- **Deforestation**: Forests absorb and retain atmospheric carbon dioxide. When they are cut down, carbon dioxide accumulates more quickly because there are fewer trees to absorb it. Furthermore, burning trees releases the carbon they have accumulated.
- **Agriculture**: Growing food and raising animals produce a wide variety of greenhouse gas emissions into the atmosphere. Methane, for instance, is produced by animals and is a greenhouse gas that is thirty times more potent than carbon dioxide. The nitrous oxide used for fertilizers is ten times worse and is nearly 300 times more potent than carbon dioxide.
- **Cement** – Producing cement is another contributor to climate change, causing 2% of our entire carbon dioxide emissions.

Asia facing alarming challenges due to climate change and variability all illustrated by various climatic models predicting the global mean temperature will be increased by 1.5 °C between 2030 and 2050 if it continues to increase at the current rate. It is also predicted that there would be a notable rise in temperature in dry regions of western Pakistan, India, and China [32]. "There will be an increase in high-intensity, irregular rainfall over the region throughout the monsoon season. There would be more aridity in South and Southeast Asia as a result of less winter rainfall. Natural disasters are the main reason behind the agricultural productivity (crops and livestock) losses in Asia, including extreme temperature, storms and wildfires (23%), floods (37%), drought (19%), and pest and animal diseases infestation (9%) which accounted for 10 USD billions in amount" [33]. Tropical cyclones have been more frequent and intense in the Pacific during the past several decades. With 262 million people suffering from malnutrition, South Asia was the world's most food insecure area. The lack of natural resources in isolated dry plains and deserts makes the rural people more susceptible to climate change [34].

4. EFFECTS AND IMPACTS OF CLIMATE CHANGE

The impacts of a 1.1-degree Celsius increase in global temperatures are evident today, manifesting in the heightened frequency and severity of extreme weather events such as heatwaves, droughts, floods, winter storms, hurricanes, and wildfires. According to the World Meteorological Organization (WMO), the global average temperature in 2019 was 1.1 degrees

Celsius above pre-industrial levels. This year marked the culmination of a decade characterized by unprecedented global heat, retreating ice, and record sea levels driven by human-induced greenhouse gas emissions. As reported by the United Nations Environment Programme (UNEP) in their 2021 Cooling and Climate Change fact sheet, 30 percent of the global population experiences deadly heatwaves on more than 20 days annually. The periods from 2015-2019 and 2010-2019 have recorded the highest average temperatures in history, with 2019 being the second hottest year ever documented. In 2019, total greenhouse gas emissions, including those from land-use changes, reached a peak of 59.1 gigatons of carbon dioxide equivalent (GtCO2e), as noted in the Emissions Gap Report (EGR 2020). Given the current inadequate global commitments to reducing climate-polluting emissions, a resurgence of high-carbon activities post-pandemic could drive 2030 emissions even higher, potentially reaching 60 GtCO2e [35, 36].

5. CLIMATE CHANGE AND AGRICULTURE

“In the 21st century, agriculture encounters several challenges. These include the imperative to increase food and fiber production to meet the needs of an ever-increasing population with a declining rural workforce, the demand for greater feedstock to sustain a potentially vast bioenergy sector, the necessity to bolster development in numerous developing nations heavily dependent on agriculture, the adoption of more sustainable and efficient production methods, and the adaptation to climate change. Between 2009 and 2050, the world's population is predicted to increase by more than a third, or 2.3 billion people” [37]. The increase in population is expected to occur almost exclusively in the developing world. The world's population is expected to continue to grow faster than ever before, with urban regions expected to house 70% of all people by 2050 (compared to 49% currently), while rural populations are expected to decline after peaking in the following ten years [37].

“By 2050, there will likely be around 3 billion tons of cereal used worldwide for both human consumption and animal feed, up from the current almost 2.1 billion tons. Compared to grains, the demand for other food goods—like dairy and cattle products, vegetable oils—that are more sensitive to rising earnings in emerging nations, would increase far more quickly. Producing these kinds of foods that are lacking to assure nutrition security would also be necessary to feed the world's population enough” [37]. Higher yields and more intense cropping are predicted to account for 90% of the increase in crop output worldwide (or 80% in emerging nations), with land expansion accounting for the remaining 4%. Arable land would increase by around 70 million hectares, or less than 5%, with a decrease of about 50 million hectares, or 8%, in the developed nations to balance the expansion of nearly 120 million hectares, or 12%, in emerging countries. Sub-Saharan Africa and Latin America would account for nearly all of the land growth in emerging nations [37]. “Irrigated land that has been harvested would grow by 17%, while land that is fitted for irrigation would expand by about 32 million hectares (11%). The emerging world would account for the entirety of this rise. The area under rice, which uses a comparatively large amount of water, is shrinking, which means that even while water usage efficiency is gradually improving, water withdrawals for irrigation would still rise by about 11%, or 286 cubic kilometers, by 2050. Irrigation would continue to put a great deal of strain on renewable water supplies, possibly even increasing it significantly in some nations” [37].

Changes in real GDP were often followed by aggregate welfare impacts, which were calculated as the total of the equivalent variation of the households and real investment. However, the distribution of global wellbeing was influenced by international price adjustment losses. The inelastic demand structure of agricultural products was predicted to be reflected in the 16–22% rise in crop product international pricing after accounting for agricultural damage compared to the price of manufacturing exports from high-income nations (Fig. 2) [38].

Depending on the region and irrigation technique, agricultural yields are affected differently by climate change. Extending irrigated regions can boost crop production, but this could be harmful to the ecosystem. Many crops will probably yield less as a result of the temperature rise since they will take longer to mature. The aggregate production of wheat, rice, and maize is expected to decrease if both the temperate and tropical regions experience a warming of 2 °C [39]. “Because tropical crops stay closer to their high-temperature optima and so face high-temperature stress under rising levels of

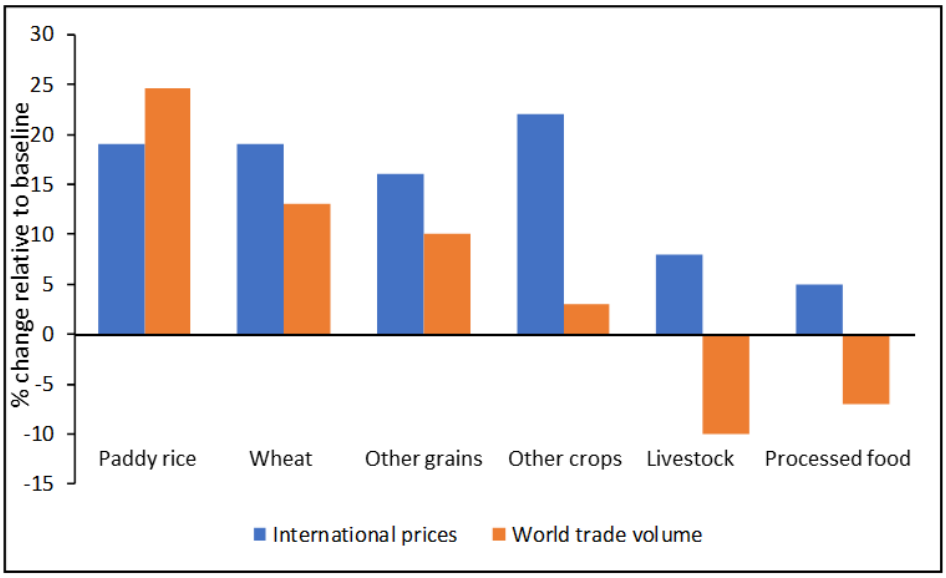

Fig. 2. Effects of Climate Change on Global Agricultural Trade and International Prices, 2080 (https://www.adb.org/sites/default/files/publication/155986/adbi-wp131.pdf)

temperature, climate change generally has a greater impact on tropical regions. Climatic-driven extremes (heat stress, drought, floods, cold waves, and storms) and climatic variability (temperature and rainfall) have a variety of negative consequences on Asia's agriculture industry, especially on the cropping system, which is essential to the food security of the area. As a result, food security in Asia faces problems and difficulties. Climate change threatens the rice-wheat cropping system, a significant agricultural system that provides half of Asia's food needs. Crops of rice and wheat are negatively impacted by climate change in terms of both quantity and quality. For example, the detrimental effects of rising temperatures have resulted in a decrease in wheat's protein content and grain output" [39].

Table 1 shows the macroeconomic implications for six countries in Southeast Asia of the anticipated deceleration in agricultural productivity. With Singapore's tiny agriculture industry and small economy, it is hardly unexpected that the impact on real GDP was so low. But the GDP losses in the Philippines, Vietnam, and Thailand, which ranged from 1.7% to 2.4%, were far more significant. The welfare losses outweighed the GDP declines in most cases, with the exception of Vietnam, where trade would somewhat improve. Compared to the baseline scenario, there would be a decrease in both consumption and investment. Southeast Asian countries' agricultural exports would be hampered by the inclusion of agricultural productivity harm, which would lower their total exports. In order to preserve the current account balance, aggregate imports would therefore also decrease [40].

"Significant drops in crop output are linked in many Asian regions to irregular and strong rainfall patterns during the past few decades, as well as decreased timely availability of water and rainfall. Even with the green revolution's boost in crop yield, maintaining output and enhancing food security for Asia's impoverished rural communities would be difficult in the face of climate change. Damage from climatic shifts may jeopardize national economic output and food security in the least developed nations. Due to differences in climatic trends, yield declines in various crops (such as wheat and rice) vary across areas. In Asia, rice and wheat play a significant role in ensuring food security. There is a big challenge to increase wheat production by 60% by 2050 to meet ever-enhancing food demands" [41]. "Crop yields would increase going forward, although more slowly than in the past. This slowing down of growth has already been going on for an extended period. In general, the projected period's yearly crop production growth rate would be almost half (0.8%) of its historical growth rate (1.7%) (0.9 and 2.1 percent for the emerging nations). Cereal yield growth would slow down to 0.7 percent per annum (0.8 percent in developing countries), and average cereal yield would by 2050 reach some 4.3 tonne/ha, up from 3.2 tonne/ha at present" [42].

Table 1. Macro-economic Impacts of Climate Change on Southeast Countries, 2080 (% change; https://www.adb.org/sites/default/files/publication/155986/adbi-wp131.pdf)

	Indonesia	Malaysia	Philippines	Singapore	Thailand	Vietnam
Real GDP	-1.4	-0.9	-1.7	-0.3	-2.4	-1.7
Welfare	-1.7	-1.6	-1.9	-0.7	-2.7	-1.2
Terms of trade	-0.5	-0.7	-0.9	-0.2	-0.3	0.1
Consumption	-1.9	-1.8	-2.5	-0.8	-3	-1.9
Investment	-0.9	-2.2	-2.4	-0.8	-2.5	-0.9
Exports	-0.9	-0.7	-0.7	0	-2.5	-1.7
Imports	-1.4	-1.5	-1.6	-0.3	-2.7	-1.5
Factor prices						
Capital	-2	0.3	0.2	-0.2	-0.9	-1.5
Unskilled labor	-1.5	-1.6	-2	-1	-4	-1.6
Skilled labor	-2.8	-1.8	-2.6	-1.2	-3.3	-2.3
Land	9.6	4.9	0.9	-8.7	-4.3	3.9

Climate change will exacerbate food insecurity and poverty in South Asian countries by impacting agricultural productivity and natural resources. This will negatively impact the livelihoods of millions of people in the region [43]. It will also cause greater fluctuations in crop production, food supplies, and market prices. According to projections, the impact of climate change on food prices between 2000 and 2050 will be 1.5 times more for animal products (such as cattle, pig, lamb, and chicken) and 2.5 times higher for main food crops (such as rice, wheat, maize, and soybean) [44]. Thus, in the event that climate change adaptation measures are not implemented, South Asia may lose 1.8% of its GDP annually by 2050 and 8.8% by 2100 [45]. On average 9.4% for Bangladesh, 6.6% for Bhutan, 8.7% for India, 12.6% for the Maldives, 9.9% for Nepal, and 6.5% for Sri Lanka are the estimated overall economic losses. Since agriculture provides livelihood to over 70% of the people, employs almost 60% of the labor force, and contributes 22% of the regional gross domestic product (GDP) in SA, communities in the area that depend heavily on agriculture would suffer greatly as a result of these GDP losses [46]. Therefore, to increase agricultural sustainability and create policies that lessen the susceptibility of South Asia poor farmers to climate change, a better knowledge of the effects of climate change on agriculture and the adaptation strategies used to address these effects is crucial.

"Furthermore, humid and warmer climates are more likely to attract diseases and insect pests [47]. Crop yields are also influenced by temperature, rainfall, humidity, and wind speed; in the absence of these factors, there has been a potential for overestimation of the cost of climate change. Most parts of the world have anticipated increased frequency of droughts in the near future as a result of climate change, with a rise in the area impacted by drought from 15.4% to 44.0% by 2100. Africa is listed as the region most at risk. The yield of major crops in drought areas is expected to be reduced by more than 50% by 2050 and by almost 90% by 2100" [48].

"A summary of the economic effects of climate change can be seen in Fig. 3, which shows the total impact on GDP. With its 18% GDP contribution, the agricultural sector has a significant position in the South Asian economy, while its 2.4% worldwide contribution is attributed to all national agricultural sectors combined. That the anticipated impacts of climate change on the agriculture sector have a negative impact on GDP is not unexpected. The countries that the rest of South Asia predicts would be most negatively impacted economically are the Maldives, Bhutan, and Afghanistan, with an average GDP decline of 4.03%. Nepal will be least impacted (2.23% GDP decrease) and Sri Lanka (3.86% GDP decline) the most of the other five South Asian nations. The only two countries in South Asia that are categorized as islands and are both regarded as developing states are Sri Lanka and the Maldives (the rest of the region)" [49, 50, 51].

"Moreover, if the economic consequences of climate change vulnerabilities are broken down by income levels, low-income nations would bear the largest share of the consequences (3.25 GDP reduction), while high-income countries will be the least affected (0.46% GDP loss). Compared to affluent industrialized nations, poor developing countries are more susceptible to the economic effects of climate change" [52].

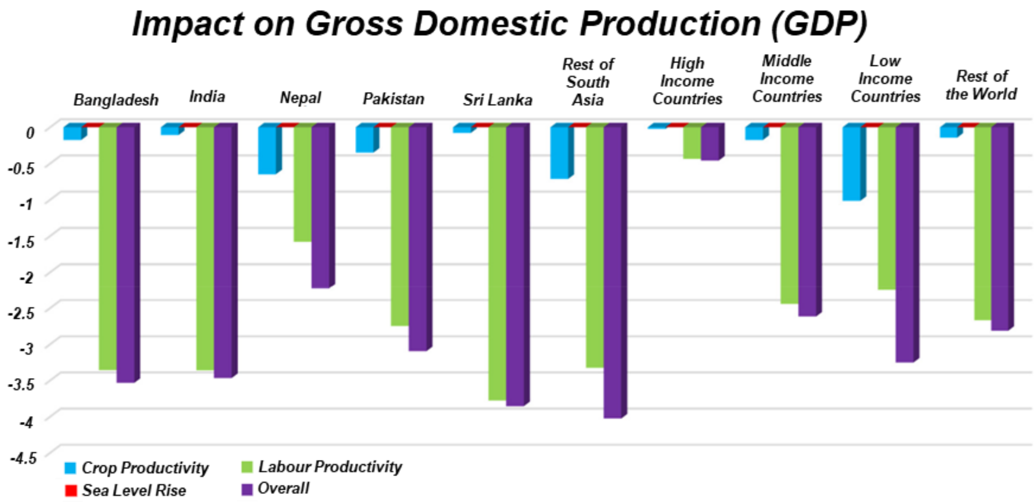

Fig. 3. Climate change impacts on GDP (as a % change from the baseline scenario; https://onlinelibrary.wiley.com/doi/full/10.1111/1467-8489.12541)

"Crop yield declines have the potential to drive up food prices and have a significant impact on agricultural wellbeing worldwide, with a 0.3% annual loss of future global GDP by 2100 [53]. However, it is found that climate change has limited influence on the world food supply, but the developing countries will face severe negative consequences. In India, the temperature is predicted to rise between 2.33 °C and 4.78 °C along with a doubling of CO_2 concentration and longevity of heat waves, which could have a detrimental effect on the agriculture sector" [54]. On the other hand, certain regions have seen a rise in agricultural productivity as a result of climate change. However, neither these regional increases nor declines would cause drastic alterations, and they would only become more noticeable in a few low latitudes. But if the temperature rises over the point when CO_2 is doubled, this might result in significant financial losses [55]. Tropical regions of underdeveloped nations will be severely impacted by climate change, albeit this will mostly depend on the climate scenario in the area. Compared to the cooler central highland area of Sri Lanka, where agricultural output is predicted to stay the same or maybe rise with rising temperatures, the drier north and east of the country would suffer significant losses. The impact of climate change is determined by its pace, which also affects the cost of adaptation. For this reason, environmental policies need to be dynamic and executed with flexibility and adaptation [56].

There are still plenty of land resources with the capacity to produce crops, according to the Global Agro-Ecological Zone research, but this conclusion must be highly qualified. A large portion of the suitable land that is not currently in use is concentrated in a small number of countries in sub-Saharan Africa and Latin America. However, a substantial amount of the available land is only appropriate for cultivating a few numbers of crops that aren't always the most in demand. Many of these nations also have expanding rural populations and are severely land-scarce. A large portion of the land that is not currently in use also has limitations (chemical, physical, endemic illnesses, lack of infrastructure, etc.) that are difficult to overcome or make it unfeasible to do so economically. A portion of the land is protected, forested, or undergoing urbanization [57].

Overall, though, it is reasonable to say that even though a number of nations—particularly in South Asia and the Near East/North Africa—have reached or are on the verge of reaching their land-use limits, there are still enough land resources available globally to feed everyone for the foreseeable future—so long as the necessary investments are made and the decades-long neglect of agricultural research and development is reversed. Similar to the availability of land, fresh water resources are more than sufficient worldwide but are distributed extremely unevenly, with an increasing number of nations or regions within nations experiencing dangerously low water supplies. The same nations in South Asia and the Near East/North Africa that have run out of land resources frequently experience this. The fact that there are still many ways to improve water use efficiency (for example, by offering suitable incentives to use less water) may operate as a mitigating factor [58].

6. TOP CLIMATE CHANGE IMPACTS ON AGRICULTURE

6.1 Changes in Agricultural Productivity

Different regions may experience better or worse growing conditions for crops as a result of climate change. For instance, longer growing seasons are occurring practically everywhere due to changes in temperature, precipitation, and frost-free days [58]. For food production, a prolonged growing season can offer both advantages and disadvantages. While some farmers could be able to plant more crop cycles or longer-maturing crops, others might need to supply more irrigation over a longer, hotter growing season. Additionally, plants, trees, and crops can be harmed by air pollution [59]. For instance, plants that get high levels of ground-level ozone absorb less photosynthesis, develop more slowly, and become more susceptible to disease [60]. Wildfire danger may also rise as a result of climate change. Rangelands, meadows, and farmlands are all highly vulnerable to wildfires. Changes in temperature and precipitation will also probably increase the range and frequency of insects, weeds, and illnesses. This can result in a higher need for pest and weed management [61].

6.2 Impacts to Soil and Water Resources

Climate change is expected to increase the frequency of heavy precipitation everywhere, which can harm crops by eroding soil and depleting soil nutrients. Additionally, agricultural runoff into lakes, streams, and seas can be increased by heavy rainfall. Water quality may be harmed by this discharge [62]. Coastal farming communities face dangers from storms and sea level rise. Agricultural land loss, incursion of seawater that can pollute water supplies, and erosion are some of these hazards. Climate change is expected to worsen these threats [63].

6.3 Health Challenges to Agricultural Workers and Livestock

Many health risks associated to climate change affect agricultural workers. These include being exposed to heat and other harsh weather conditions, being around more pests and hence exposed to more pesticides, being around disease-carrying pests like ticks and mosquitoes, and having poorer air quality [64]. These hazards may be increased by variables such as language problems, limited access to healthcare, and others. The productivity and well-being of animals produced for meat, milk, and eggs can also be impacted by heat and humidity [65].

6.4 Impact of Climate Change on India's Agriculture

Since ancient times, India's agriculture has been mostly depended on the monsoon. A shift in the monsoon pattern has a significant impact on agriculture. Indian agriculture is being impacted even by the rising temperatures. These pre-monsoon changes in the Indo-Gangetic Plain will mainly impact the wheat crop (>0.5°C increase in time slice 2010-2039. In the states of Jharkhand, Odisha and Chhattisgarh alone, rice production losses during severe droughts (about one year in five) average about 40% of total production, with an estimated value of $800 million [66].

Raising CO_2 to 550 ppm boosts oilseed, rice, wheat and legume yields by 10–20%. Temperature increases of 1°C may result in lower yields of groundnut, wheat, soybean, mustard, and potato by 3–7%. Most crops' productivity will only slightly decline by 2020, but it will drop by 10% to 40% by 2100 as a result of rising temperatures, unpredictable rainfall, and less irrigation water. Nearly 60% of farmland is used for rain-fed or un-irrigated crops, which will be the main targets of climate change. In India, it is predicted that a 0.5 °C increase in wintertime temperatures will result in a 0.45 tons per hectare decrease in rain-fed wheat output [67]. The Indian Agricultural Research Institute estimates that for every degree Celsius that the temperature rises during the growing season, 4–5 million tons of wheat might be lost in future wheat output. Rice production is slated to decrease by almost a tonne/hectare if the temperature goes up by 2 °C. It was projected that a 2 °C increase in temperature in Rajasthan would result in a 10-15% decrease in pearl millet yield. If maximum and minimum temperature rises by 3 °C and 3.5 °C respectively, then Soybean yields in M.P. will decline by 5% compared to 1998. The coastal districts of Gujarat and Maharashtra would see the greatest impact on agriculture due to the susceptibility of productive areas to salinization and flooding [66].

7. WATER SCARCITY

Climate change and water are closely related. The world's water is impacted by climate change in a variety of ways. For the most part, the effects of climate change are related to water: decreasing glaciers, rising sea levels, irregular rainfall patterns, floods, and droughts. Water scarcity is the main effect of climate change. Its effects are seen by us in the form of droughts, wildfires, decreasing ice fields, increasing sea levels, and increased floods [67].

Reducing carbon emissions and enhancing the resilience of ecosystems and communities need sustainable water management. Everybody has a part to play, and household and individual acts are crucial. Climate change is making water scarcity and water-related risks (such droughts and floods) worse because it is changing precipitation patterns and the water cycle as a whole [67].

7.1 Global Scarcity of Water

- Currently, around half of the world's population experiences acute water shortage for at least some portion of the year, and about two billion people lack access to safe drinking water. It is anticipated that these figures will raise, made worse by population expansion and climate change [68, 69, 70].
- Freshwater makes up just 0.5% of the Earth's total water volume, and climate change is seriously threatening that supply. Terrestrial water storage, which includes soil moisture, snow, and ice, has decreased at a pace of 1 centimeter per year during the previous 20 years. This has significant implications for water security [70].
- Over the course of the century, it is predicted that the amount of water stored in glaciers and snow cover will further decrease, reducing the amount of water available during warm and dry periods in regions where major mountain ranges supply melt water, which currently houses over one-sixth of the world's population [71].
- It is anticipated that sea level rise would prolong groundwater salinization, reducing freshwater availability for ecosystems and people in coastal locations [71].
- Although there is significant regional variation, limiting global warming to 1.5 °C rather than 2 °C would almost reduce the percentage of the world's population predicted to experience water scarcity [71].
- The effects of climate change extend to water quality, as increased temperatures and more frequent floods and droughts are expected to aggravate a variety of water pollution issues, including sediments, pathogens, and pesticides [71].
- The food supply will be under strain from climate change, population expansion, and growing water shortages since agriculture uses the majority of freshwater, or 70% on average [71, 72].

8. DISCUSSION ON MITIGATION AND ADAPTATION STRATEGIES

Reducing the flow of heat-trapping greenhouse gases into the atmosphere is known as mitigation, and it can be achieved in two ways: either by reducing the sources of these gases (such as the burning of fossil fuels for transportation, electricity, or heat) or by improving the "sinks" that absorb and store these gases (such as the oceans, forests, and soil). In order to "stabilize greenhouse gas levels in a timeframe sufficient to allow ecosystems to adapt naturally to climate change, ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner," mitigation efforts aim to prevent major human interference with Earth's climate [73]. The ability of a system to increase its resilience and decrease its susceptibility is known as adaptation to climate change, and as a result, the ability to adapt will determine how much of an influence climate change really has. Adjusting to the current or anticipated future climate is a necessary part of adaptation, or living in a changing climate. Reducing our exposure to the negative consequences of climate change—such as rising sea levels, more intense extreme weather events, and food insecurity—is the aim. Making the most of any favorable chances brought about by climate change also falls under this category (for example, extended growing seasons or enhanced yields in particular places) [73].

Farmers' views of the severity and threat of climate change are the primary drivers of voluntary mitigation. Nevertheless, the adaption is contingent upon the accessibility of pertinent data [74]. Additionally, fewer people will be exposed to water stress thanks to mitigation techniques; nevertheless, because of their increased stress exposure, the remaining individuals will require adaptation strategies. The usage of traditional management systems and agroecological management systems, namely bio diversification, soil management, and water harvesting, can help farmers adopt climate-resilient technologies [75]. Though most farmers supported adaptations, only a small percentage supported reducing greenhouse gas emissions. This indicates that treatments combining mitigation and adaptation qualities should be the main focus. The primary techniques for adaptation and mitigation fall into three categories: technology for cropping systems, technologies for resource conservation, and socioeconomic or policy interventions [76]. Because they are less aware of the effects of climate change, small and marginal farmers are more vulnerable to losses and are unable to adapt [77].

Modified farming methods are the primary means of adapting to climate change. These practices are heavily influenced by policy decisions that take into account social, political, and economic factors as well as climate extremes and variability [78]. Nutrient management is crucial since improper nutrient management leads to over 80% of the significant economic losses associated with conventional agricultural intensification [79]. One irrigation method that is being advocated to lessen groundwater overdraft and shocks brought on by climate change is drip irrigation. It lessens the need for groundwater for irrigation and has the potential to be climate change resilient. But farmers are using drip irrigation for intensive agriculture, leading to further groundwater over extraction [80]. Sprinkler and drip irrigation are two examples of water-saving irrigation methods that may both reduce and adapt to climate change and offer long-term economic advantages. The most effective climate-smart technologies are those that either promotes soil structure or supply water or nutrients [81].

Among different agriculture practices, natural farming (NF) is one of the sustainable farming methods. In this approach, no chemical fertilizer or pesticides are used however, livestock-based inputs and plant protections are applied [82]. The natural farming is founded on four wheels or pillars such as Beejamrit (a fermented microbial solution used for seed treatment), Jivamrit (a fermented liquid used as fertilizer), Aachhadan or Mulching (a technique for preventing water loss and suppressing weed) and Whapasa (a technique of maintaining 50% air and 50% water vapour in soil) [82]. In India, a localized version of natural farming known as ‘Zero Budget Natural Farming (ZBNF)’ was introduced in the mid-1990s by agricultural scientist and Padma Shri awardee Shri Subhash Palekar [83]. ZBNF utilizes locally available natural resources, such as cow dung, cow urine, and other to cultivate crops without synthetic fertilizers or pesticides. This approach eliminates the need for farmers to buy external inputs from the market, saving them money and potentially reducing farmer suicides. Additionally, it mitigates the harmful environmental impacts of chemical inputs [84, 85, 86, 87].

Studies suggested that natural farming significantly improves crop yield and soil quality. In an experiment conducted by [88], they found significantly higher yield in groundnut and tomato (Table 2 and 3) in comparison with conventional and organic farming. Similarly, [89] observed that natural farming improves soil fertility via increasing bacterial count (28.3×10^6 CFU g^{-1} soil), actinomycetes count (22.0×10^5 CFU g^{-1} soil), and fungal count (8.5×10^3 CFU g^{-1} soil), available nitrogen (275 kg ha^{-1}), dehydrogenase activity (4.81 µg TPF g^{-1} soil hr^{-1}) and seed yield {wheat and gram (1767.3 and 734.1 kg ha^{-1}, respectively)} than that of without natural farming soil [90-92].

Table 2. Comparison of various plant parameters of groundnut across Zero Budget Natural Farming (ZBNF), organic farming, and conventional farming methods

	ZBNF	Organic	Conventional
Mass kernels (kg/plot)	6.90	4.91	5.43
Dry biomass (kg/plot)	6.48	5.00	5.20
Mass pods (kg/plot)	10.03	7.84	8.19
Mass kernels (g/plant)	16.35	15.11	15.57
Dry biomass (g/plant)	51.85	46.63	47.54
Number of pods (/plant)	18.10	16.56	17.00
Mass pod (g/pod)	1.61	1.52	1.57
Proportion mature pods (mature/total pods per plant)	0.81	0.73	0.76
Plant height (cm)	40.89	36.59	37.90
Number of root nodules (/plant)	82.33	81.88	86.35

Table 3. Comparison of various plant parameters of tomato across Zero Budget Natural Farming (ZBNF), organic farming, and conventional farming methods

	ZBNF	Organic	Conventional
Mass fruits (kg/plot)	31.15	23.20	24.71
Dry biomass (kg/plot)	4.70	3.90	4.20
Number of fruits (/plant)	7.33	6.05	6.52
Mass fruits (g/plant)	487.57	364.05	347.59
Fruit mass (g/plant)	69.16	64.66	58.48
Dry biomass (g/plant)	50.99	46.41	47.74
Plant height (cm)	46.43	42.48	42.99

9. CONCLUSION

The burden of maintaining global food and nutritional security due to population growth has placed significant strain on agriculture, a situation that is made worse by climate change. Climate change will reduce agricultural productivity in the coming years, according to a number of studies, notwithstanding the uncertainty surrounding the future climate scenario and its potential effects. The primary determinants of climate, particularly temperature, precipitation, and greenhouse gasses, greatly hindered plant metabolism, physiology, soil fertility, insect infestation, and irrigation supplies. Various solutions for adaptation and mitigation have been devised to counteract the adverse effects of climate change on the sustainability of agriculture. These technologies include weather-smart, carbon-smart, and knowledge-smart practices (agricultural extensions to enhance capacity-building), as well as water-smart practices (laser land leveling, rainwater harvesting, micro-irrigation, crop diversification, raised-bed planting, and direct-seeded rice). Nutrient-smart practices (precision nutrient application, leaf color charts, crop residue management). Farmers and policymakers should focus on sustainable farming approaches such as natural farming. This approach not only guarantees food security but also safeguards our environment from harmful chemical fertilizers and pesticides.

By minimizing the negative consequences, these technologies greatly lessen the effects of climate change on crops and improve their climate suitability. It is anticipated that climate change would result in significant economic losses on both a micro and macro scale, which these measures can help to alleviate. However, in order to increase these interventions' effectiveness, they need to be planned at the local or regional level. Strategies for mitigation and adaptation are anticipated to boost farmers' incomes without jeopardizing the sustainability of agricultural output. The future of climate change and its associated impacts is highly unpredictable, which makes planning for mitigation and adaptation a bit complex. This encourages the development of climate-resilient technology using a regionally specific multifaceted approach. Strategies for planned agronomic management, crop pest control, and the development of suitable cultivars that might adjust to climatic fluctuations are all necessary. To make the usage of various climate-smart technologies easier in the field, farmers should receive training and education on them.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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