Global Perspectives on Climate-induced Food Security Risks

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Abstract

Climate change has been receiving extensive attention due to its effect on livelihood and food production. Climate change has the ability to intersperse with global strategies in reducing hunger and malnutrition. It is hypothesized that climate shifts bring significant detrimental effects on food production systems, thereby endangering food security. The agriculture sector faces severe challenges in reaching the Sustainable Development Goals because of the direct and indirect consequences inflicted by ongoing climate change. Although many industries are greatly impacted by climate change, the impact on the agricultural industry is subsequently huge. Irrational weather changes have raised public concerns, as sufficient output and food supplies are under a continuous threat. The growing population has increased the need for food, putting pressure on food production systems. Furthermore, the potential climate change implications are yet uncertain, particularly at regional scales. Climate change is likely to enhance food insecurity concerns in areas already sensitive to climate change. Human-induced climate change is anticipated to alter food quantity, quality, and potentially to distribute it equitably. It can be apprehended that all food security components (primarily food access and utilization) likely be under indirect influence through pledged consequences on menage, earnings and health damages. The corroboration supports the crucial need for massive, focused investments in mitigation and adaptation measures to establish sustainable, climate-smart, eco-friendly, and climate-stress-robust food production systems. This chapter will cover the primary paths of which climate change affects food security, leading to disturbances in agricultural productivity and food supply chains. It points out how climate variabilities affect vulnerable populations especially smallholder farmers, women and children. Through concerted efforts and focused interventions, it is possible to reduce the harmful effects of climate change on agricultural systems and pave the path for a more sustainable and food-secure future.

Keyword: Climate change, environmental stresses, food security, adaptive strategies, implementation challenges

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Introduction

Climate change has become one of the most pressing concerns of our era (El-Sayed and Kamel, 2020). It is characterized as a prolonged alteration in the statistical features of the climate system, evidenced by an atypical distribution surrounding the observed mean during an average duration of 30 years (Fakana, 2020). Climate change is mainly caused due to human activities such as the fossil fuels, the destruction of forests, and industrial operations. These activities release greenhouse gases into the surrounding environment, which entrap heat and induce modifications in the climate system of the Earth. The ramifications of climatic change are complex, including elevated sea levels and an escalation in the number and severity of climatic phenomena, changes in precipitation patterns, and alteration sin ecosystems, thus resulting in climatic variability (Kumar et al., 2021). From altering agricultural productivity to exacerbating water scarcity and increasing the frequency of natural disasters, climate change poses a fundamental challenge to global stability (Toromade et al., 2024).

Climate change presents substantial risks to food availability, accessibility, and use, thus impacting the entire food supply chain from production to consumption (Godde et al., 2021). Alterations in temperature and precipitation patterns can impede agricultural output, resulting in reductions in crop yields, livestock productivity, and fish stocks. The emergence of scientific evidence highlighting the links between climate change and agricultural efficiency (Ortiz-Bobea et al., 2021). As a result, vulnerable groups, such as children, women, and the elderly, are more susceptible to malnutrition and food insecurity, undermining their health, well-being and adaptability to upcoming climate-related hazards (Toromade et al., 2024).

Climate-related disasters and agricultural failures can result in diminished income and asset loss for farmers, intensifying destitution and disparity in remote villages. Moreover, interruptions in food supply chains can influence food costs, commerce, and stability of the market, affecting consumers, businesses and industries globally (Enthoven & Van den Broeck, 2021). The natural resources including water and land utilized in agricultural production are highly influenced by climate change (Ekechukwu & Simpa, 2024).

Food security is attained when persons consistently possess financial, social, and physical access to sufficient food that fulfills the dietary needs preferences as well as needs of healthy and active lifestyle (Godde et al., 2021). Addressing the problems of food security and climate change necessitates synchronized efforts and investment across all tiers, from local adaption strategies to global collaboration and governance structures (Vincent et al., 2021).

1. Causes of Climate Change

Climate change can be the result of any factor that alters the amount of solar radiation; absorbed or sent into outer space or has an impact on how energy is redistributed within the atmosphere and between the atmosphere. Changes in the amounts of solar radiations that come to the surface of Earth, fluctuations in of the Earth's reflectivity of the atmosphere and changes in greenhouse gases effect, that affect how much heat is retained in the atmosphere, are just a few examples of the many man-made and natural factors that can affect Earth's energy balance and cause climate change (Fakana, 2020).

1.1. Anthropogenic Causes

The use of fossil fuels, deforestation, and land development are among the anthropogenic activities that contribute to climate change. for agriculture, urbanization, and infrastructure. These activities emit greenhouse gases into the atmosphere (Fawzy et al., 2020).

1.1.1. Deforestation

When trees are incinerated or deforested for purposes in terms of agriculture, grazing or urban development, the amount of carbon emission from the atmosphere to the forest ceases, both currently and for the anticipated lifespan of the trees. The present pace of deforestation causes an extreme rise in CO_2 levels of the atmosphere in the last few decades. Changes in biodiversity directly influence Earth's surface temperature via the exchange of water and energy. The loss of forest cover modifies worldwide and local climate patterns, leading to devastating rainfall events succeeded by prolonged periods of drought (Tahir et al., 2011).

2.1.2. Land-use shifts

Alterations in land usage and intensified land utilization have resulted in desertification and land degradation. Land use is a major net contributor to greenhouse gas emissions. Alterations in land utilization—such as for forests, agriculture, urban areas, etc.—can induce both cooling and warming impacts regionally by modifying the reflectivity of Earth's surfaces (influencing the amount of sunlight reflected back into space) and by adjusting regional moisture levels. Unsustainable land management and usage have resulted in adverse economic consequences, further intensified by climate change. Land-use change, specifically the conversion of forests and wetlands to crop production, releases carbon sequestered in biomass and soil, contributing an additional 10 to 15 percent of global CO_2 emissions (Tubiello et al., 2015).

2.1.3. Emission of Greenhouse Gases

Since the pre-industrial era, temperature of the atmosphere has increased approximately twice as much as the world mean temperature due to greenhouse gas emissions. Over the past 25 years, there has been a rise in average temperatures across many regions of the globe. The ongoing release of greenhouse gases from developed countries is causing hydro-meteorological phenomena, rising sea levels, and seasonal variability (Tahir et al., 2011). Worldwide, economic and population expansion remained the primary catalysts for the rise in CO_2 emissions through fossil fuel use. The increase in CO_2 emission is the primary contributor to global warming (Fakana, 2020).

2.1.4. Urbanization

Unplanned urbanization can lead to detrimental effects that negatively damage the economy, cause deforestation, contribute to environmental degradation, and exacerbate global warming by increasing GHG emission and climate change. Urbanization affects local temperature patterns, modifying temperature gradients and perhaps altering regional climatic dynamics. Urban growth can exacerbate temperature in cities and surrounding areas resulting in heat island effect, such as heat waves. Enhanced urbanization may exacerbate severe rainfall occurrences within the city or in areas downwind of metropolitan locales, hence increasing threats to the flood management system (Hao et al., 2023).

Natural Causes

Anthropogenic activities are the primary reasons of climate change although, several significant natural elements also cause a great effect on the climate system (Fakana, 2020).

Sun's Intensity

The climate is affected by natural variations that determine the rate of solar radiations that reaches the surface of Earth. Variations of the sun can influence the intensity of sunlight which extend to the Earth's surface. The quantity of heat energy received at any point on Earth is directly influenced by the solar angle, which changes by position, duration of day, and season due to the Earth's rotation around the sun and its axial tilt. Variations in solar energy production may affect our climate—directly, by altering the pace of solar heating of the Earth's atmosphere, and informally, by modifying clouds forming processes (Khavrus & Shelevytsky, 2010).

2.2.2. Changes in ocean current circulation

Since the 1950s, geologists and marine biologists have amassed compelling proof that disturbances in ocean current circulation are a crucial factor in climate change. Climate change is induced by modifications in ocean current circulation. An ocean current is a persistent, directed flow of seawater produced by several causes, in terms of breaking waves, wind and disparities in salinity and temperature. The increase in Earth's surface temperature will occur at a slower rate than anticipated by climate models, owing to the absorption of CO_2 by the seas. Ocean current circulation is crucial in managing global climate and sustaining primary productivity and marine environment (Duteil et al., 2014).

Sea-level Rise

Average sea level increase is anticipated due to the thermal expansion of seas and the melting of glaciers. One of the contributors of increase in sea-level is melting of terrestrial ice due to increase in heat. Thermal expansion can be occurred due to water hence; warmer oceans occupy a greater volume. The reduction of terrestrial ice, including glaciers and ice sheets, resulting from heightened melting. Global average sea levels have increased around 17 cm since 1900 due to the ocean water's thermal expansion and the melting of glacial ice. The principal factors influencing variations in ocean water volume are the expansion of seawater (Fischer & Knutti, 2015).

3. Effects of Climate Change on Food Security Dimensions

3.1. Food availability

Food availability refers to the sufficiency of food to satisfy individuals' nutritional needs, encompassing the food chain's supply. Climate change influences availability of food by negatively affecting crop yields, as well as the productivity of fish and cattle. In the non-availability of suitable solutions, Agricultural productivity will be impacted by climate change and fluctuation., food security, and exacerbate the currently intolerable levels of poverty.The agriculture industry, encompassing crops and cattle, is negatively impacted by climate change and is at threat because of vulnerabilities, especially in areas with restricted adaptation ability (Zougmoré et al., 2018).

The results of changes in climate on crop production and animals are interconnected; for example, diminished fodder growth leads to reduced weight gains in livestock. Subsequent research examines the possible detrimental influence of climate change on fisheries sector (Ding et al., 2017). Moreover, the effects on biodiversity results in a decrease in the number of pollinators which are useful in the production of various food items, resulting in food insecurity (Pilling et al., 2020).

3.2. Food Access (affordability, functioning markets and policies)

Food accessibility refers to a household's capacity to obtain adequate quality food to satisfy dietary needs. Obtaining an adequate quantity of nutritious food is feasible only when households have sufficient financial means to purchase food necessary for maintaining optimal nutrition levels (Fisher et al., 2012). The destruction of ecosystem resulting from climate change adversely impacts agricultural production. For example, climatic variabilities cause loss of pollinators and soil biodiversity, decreasing agricultural productivity, resulting in less crop yield (Muluneh, 2021). This will diminish food accessibility due to adverse effects on food prices and rural economies. Rising food prices will impact millions of marginalized individuals residing in regions already plagued by elevated levels of hunger and poverty. The situation is especially concerning for populations reliant on agriculture for their lives and income, particularly small-scale farmers (Akinseye et al., 2020).

Climate change impact gesographical areas of production on a massive scale, resulting in alterations in the appropriateness of regions for crop or livestock production, which could have effects on the prices and access to food (Jones et al., 2017). Climate change also effects households' access to the food by influencing transportation, infrastructure of road, and economic conditions (Farooq et al., 2022).

3.3. Food Utilization

The utilization of food to meet dietary and nutritional needs is significantly influenced by even minor climatic changes, as well as secondary factors such as accessibility to water and sanitation facilities (Hughes, 2020). The nutritional behavior of indigenous communities will be significantly impacted (Smith et al., 2019). Climate change will additionally impact food utilization by diminishing the nutritious content of main crops and heightening the risk of food infection. Climate change will significantly affect food use, encompassing nutrition and food safety. All of these factors have ramifications for the safety and the nutritional quality of food. The decline of biodiversity attributable to climate change effects the nutritional quality of food making it less diverse and it increases the risks of diseases (Lake et al., 2012).

3.4. Food Quality and Diversity

Food utilization is affected mainly by two aspects: food safety and health implications due to climate change that affect dietary values, which then impact the food security (McDonald et al., 2011). Climate change can cause an increase in severity of events, including droughts, floods, heat stress and cold stress. In general, climate change, characterized by both elevated and diminished temperature stresses, is anticipated to compromise food safety owing to heightened microbial proliferation at rising temperatures, particularly within fresh vegetables and fruits (Alegbeleye et al., 2022) and fisheries supply (Marques et al., 2010).

The health is affected via various ways, including vector-borne diseases, natural catastrophes, that ultimately effect food and feed safety, plant and animal health, nutrition and their ability to provide care for children (Connor et al., 2010). There are concerns that increasing disease prevalence would result in the over application of pesticides and veterinary pharmaceuticals, particularly in fisheries, so jeopardizing human health (Hayes et al., 2018).

3.5. Food System Stability

The stability of food is significantly associated with climatic variations, as climate influences food price patterns, affecting both long-term and short-term price fluctuation. Over the past decade, minor disruptions in the food chain, have affected pricing, frequently resulting in an increase in food costs. Food insecurity is particularly prevalent in impoverished cultures; as economically disadvantaged populations allocate the majority of their resources to procure expensive principal food items. Climate change renders the need as well as supply of food items by amplifying food prices. Certain secondary hazards associated with food destabilization emerge primarily from climate change, including the political and economic risks that contribute to food insecurity for poor populations (Berazneva & Lee, 2013).. It also jeopardizes the ongoing socio-economic aspects of the food chain. Deprived groups are particularly susceptible to this change in climate, exacerbating their economical insecurities and other socio-economic problems (Panpakdee & Limnirankul, 2018).

Table 1: Environmental stressors on ecosystem: A triple threat to biodiversity, vector-borne diseases, and food security

Environmental factor	Impacts on biodiversity	Impacts on vector-borne diseases	Impacts on food security	References
Temperature	Decline of pollinator species leading to a decrease in crop yield. Allow harmful pests to thrive, resulting in crop damage Causes coral bleaching, thus reducing marine biodiversity.	Increase spreading of vectors like mosquitoes and ticks and disease transmission seasons (e.g., dengue seasons)	Increases drought stress on temperature-sensitive crops like maize and wheat as well as reduces fruit quality like strawberries and cherries	Muluneh, 2021; Rocklov & Dubrow, 2020
pH	Dangerous to shell-forming species like Pacific oyster and blue mussel in the Pacific Ocean. Reduces fish populations like coral trout.	Acidic waters increase the survival of pathogens like *Vibrio cholerae*.	Decreased yield of marine species such as oysters and salmon, thus impacting food supply.	Zhu et al., 2020
Precipitation	Flood destroys habitats, while droughts reduce freshwater availability and increase wildfire risk, threatening species.	Enhanced stagnant water that boosts mosquito-borne diseases like malaria and dengue.	Flooding waterlogs crops and promotes fungal infections (e.g., rice crop). Drought leads to crop failure.	Kumar et al., 2018; Souza and Weaver, 2024
Humidity	Increase in fungal diseases like chytridiomycosis - damage *Shorea robusta* in the Amazon.	High survival rates of mosquitoes, particularly *Aedes aegypti*, increasing dengue and malaria transmission in humid regions.	Crop diseases such as *Phytophthora infestans* causing potato blight.	Kumar et al., 2018; Souza and Weaver, 2024
Salinity	Reduction in salt-sensitive freshwater species like *Oncorhynchus mykiss* (rainbow trout). Salt stress affects *Rhizophora mangle* (red mangrove)	Affect mosquito breeding grounds. High salinity impacts pathogens (e.g., cholera bacteria thrive in brackish water)	Decreases crop yield and quality, as many staple crops like rice, wheat. Lowers arable land	Mukhopadhyay et al., 2021; Ramasamy & Surendran, 2011

3.6. Food Productivity

Climate forecasts have suggested with considerable reliability that globally, food production will diminish owing to irregular and unpredictable variations in climate. Agriculture is the primary source for meeting nutritional requirements, although seafood also holds significance in the global food chain. Significant food crops, like wheat and rice, are affected by temperature fluctuations, alterations in precipitation patterns, global warming resulting from elevated greenhouse gas release, and abiotic stress induced by various heavy metals. Climate change modifies temperature as well as precipitation patterns, resulting in alterations to growing seasons, water availability, and agricultural viability. Intense weather conditions in terms of droughts, floods, and storms result in a diminished yield of crops and cattle. A projected decrease in fish output of 5–10% is anticipated by the year 2050, particularly within tropical marine habitats (Raza at al., 2022)Fungal infestations diminish global sanitary availability of food by 8.5% (Fisher et al., 2012). Recent incursions of both established and novel infections and illnesses in agricultural, animal, aquacultural, and forestry systems have prompted an increased application of pesticides and pharmaceuticals, hence posing a risk to human health (Tirado et al., 2010).

3.7. Health and Nutritional Balance

Elevated CO_2 concentrations in the atmosphere lead to a decrease in amino acid synthesis, consequently diminishing protein content in the edible portions of crop items and adversely affecting the dietary quality of the vegetables. Comparative investigations of various legume and cereal indicated a decrease in protein content in the former owing to elevated CO_2 concentrations of 7 to 10%, whereas the drop in the latter was negligible. If alterations in protein composition in the plant persist, over 200 million individuals are expected to experience protein deficiency, particularly exacerbating conditions in impoverished regions and increasing their health risks (Figure 1) (Smith & Myers, 2019).

Thermal stress Both cold and heat stress adversely affect the meat and milk output in livestock. The quantity and quality of cattle products are potentially adversely affected by temperature stressors. In case of milk production, temperature variations, particularly heat stress, significantly affect the quality of milk byproducts. These alterations may lead to adverse economic consequences for producers and consumers. Consequently, it is determined that temperature fluctuations, particularly those above thermoneutral ability of animal, can substantially affect live weight gain, milk and meat output, as well as animal fertility (Thornton et al., 2022).

4. Strategies and Solutions for Addressing Climate Change-Induced Food Security Challenges

Climate change presents substantial risks to the food security, endangering the accessibility, availability and stability of food systems globally. This comprehensive review explores a range of strategies and solutions to address climate change-induced food security challenges, mitigation efforts to minimize greenhouse gas emissions from agriculture, encompassing adaptation measures for agricultural resilience, policy interventions and institutional frameworks, and international cooperation and partnerships (Cheng et al.,2021).

4.1. Joint Mitigation and Adaptation Approaches

Sustainable agroforestry practices augment output, improve input-use efficiency, minimize food waste, and guarantee environmental safety by decreasing carbon emissions, primarily in the form of greenhouse gases (GHGs). Mitigation and adaptation strategies as a result of changes in climate should reduce the disparity in greenhouse gas emissions by enhancing crop and livestock output while simultaneously decrease the emissions to ensure the food security within the sustainable food production units. A variety of technical modifications exist for gradual improvement, encompassing greenhouse gas emissions in agricultural systems and livestock production, as well as mitigating emissions from excessive fertilizer use. Aerobic rice represents an environmentally efficient alternative to conventional rice cultivation, enhancing production sustainability through improved input usage efficiency in the context of anticipated climate change and resource shortages (Fukai & Mitchell, 2022).

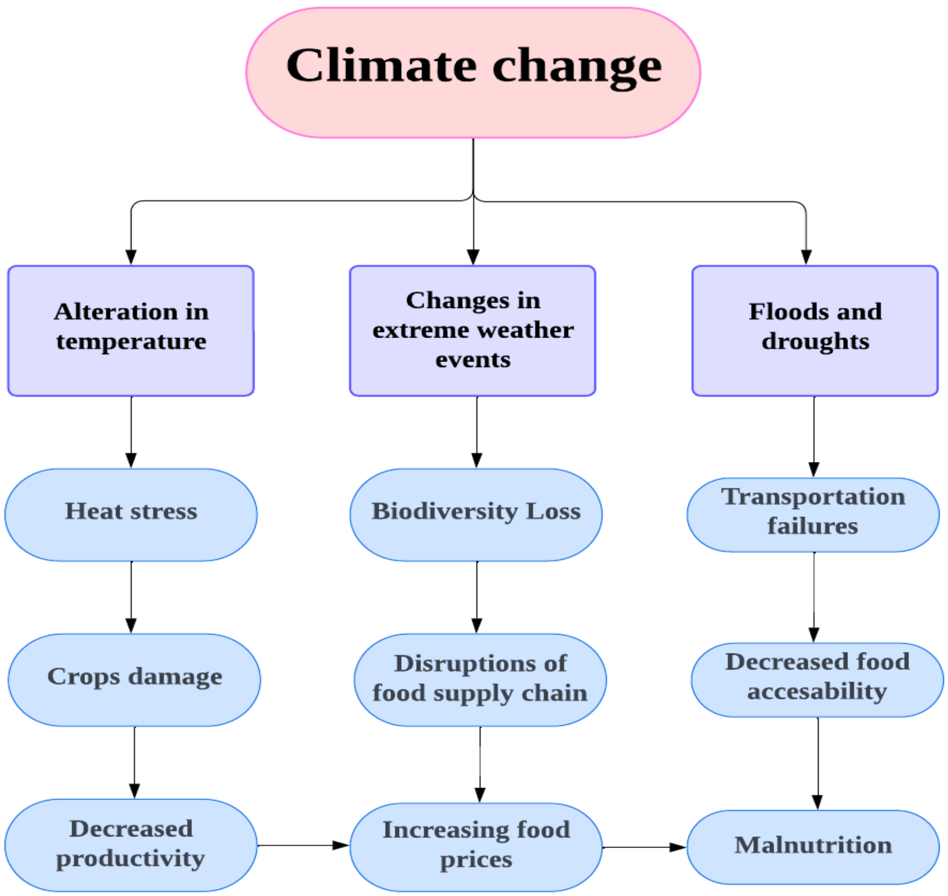

Fig. 1: Climate change impacts on global food security and nutrition

Sustainable land management strategies are essential for improving the adaptability of agricultural systems to climate change while promoting soil health, biodiversity, and ecosystem services (De Corato, 2020). Specific policy measures, motivating strategies, information and implementation targets should be established to promote political investments aimed at enhancing adaptation and mitigation efforts in response to climate change, hence ensuring the food security. Developing as well as developed nations are now aligning on shared adaptation priorities, including addressing threats to the agricultural sector, safeguarding water resources, mitigating climate change influence on the health, assessing threats in energy sector, ensuring security of local people, and implementing strategies to minimize climate change problems (Farooq et al., 2022).

Crop diversification entails the cultivation of a diverse array of crops, each possessing distinct qualities and growth requirements, to mitigate risk and bolster resilience against climate fluctuation. By planting diverse crops, farmers can mitigate the impacts of extreme weather events, pests, and diseases, ensuring a more stable and secure food supply. Additionally, producing resilient crops via traditional breeding and biotechnology can augment resistance due to heat, floods, droughts and other climate-induced stresses, hence enhancing yields and food security during climate change. Sustainable intensification is proposed as a mutually beneficial approach to integrate food security and climate change mitigation (Descheemaeker et al., 2016).

Innovative Approaches

Water conservation and efficient irrigation techniques are essential for optimizing water use efficiency and reducing the vulnerability of agricultural systems to water scarcity and drought. Drip irrigation, sprinkler irrigation, and precision irrigation technologies provide water directly to the crop root zone, reducing evaporation and runoff while enhancing water absorption. Additionally, rainwater harvesting, soil moisture conservation, and wastewater reuse can augment water supplies and buffer against climate-related fluctuations in precipitation, ensuring a reliable and sustainable water source for agriculture. Investment in agricultural research and extension services is critical for developing and propagating climate-resilient technologies and providing knowledge to farmers and rural populations (Khan et al., 2021).

Research institutions, universities, and extension agencies play a crucial role in conducting applied research, testing innovative solutions, and providing technical assistance and capacity-building support to farmers. By investing in research and extension services, governments can empower farmers with the information, skills, and resources they require to adjust to climate change, improve productivity and enhance food security (Osumba ,2021). Remote sensing is essential for forecasting the influence of climate-induced factors on agricultural productivity. It helps in improving our comprehension of environmental alterations, facilitate decision-making, and allow for proactive strategies to ensure food availability and sustainable farming practices in relation to climate change (Khanal et al., 2020).

4.3. Collaborative Approaches

Smallholder farmers and rural communities are severely impacted by climate change and food insecurity due to their limited resources, access to markets, and capacity to adapt (Figure 2). Providing targeted support and investments to smallholder farmers and rural communities is essential for enhancing their resilience and livelihoods in the face of climate related risks. Additionally, empowering women and marginalized groups with access to resources and decision-making opportunities can enhance their adaptive capacity and contribute to more inclusive and equitable development outcomes. Various studies have aimed to alleviate the fluctuations in smallholders' income by engaging stakeholders at all levels during periods of stress and hunger (Bonuedi et al., 2022).

Numerous developing nations have established various climate change legislation, national strategies of climate change action plans that delineate the goals for mitigating climate-induced risks. Several nations, notably those in South Asia, have established climate change funds and climate change resilience funds to finance initiatives related to riverbank management, environmental conservation, and disaster mitigation. Numerous impoverished nations, with the assistance of wealthy countries, have revised their development plans, extending to grassroots as well as district and municipal levels, as locally climate-induced adaptation means to support prototype adaption initiatives (Farooq et al., 2022).

Multi-stakeholder platforms serve as essential vehicles for involvement, dialogue, and collaborative learning. Engagements involving several stakeholders are essential for formulating public-benefit policies aimed at fostering innovation in response to the multifaceted and complicated problems posed by climatic changes on the food security (Saint Ville et al., 2017). The significance of multi-stakeholder interactions, encompassing both informal and formal stakeholders, is paramount in the design, implementation, and effective monitoring of policy frameworks aimed at enhancing food security. In addition to grassroots campaigns, awareness seminars, training workshops, talk shows and the integration of climate-induced impacts on the food security into the curriculum are several strategies deserving of governmental attention. Finally, interdepartmental cooperation is essential to expedite implementation strategies, enhance knowledge-driven decision-making, promote climate change and food security research, and develop climatic policies (Saina et al., 2013).

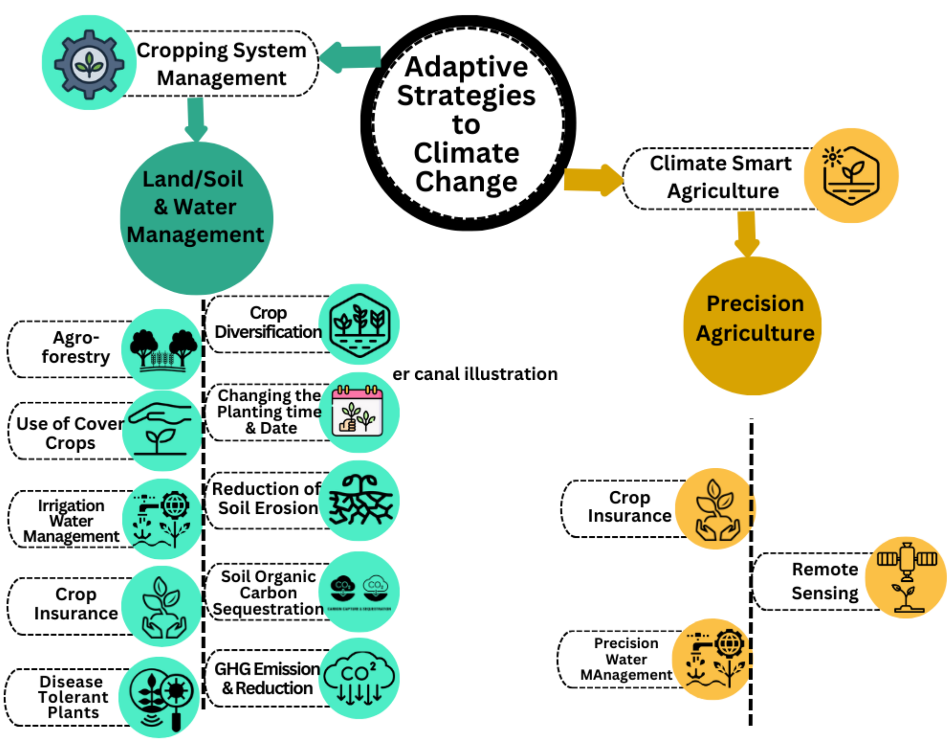

Fig. 2: Adaptive strategies to climate change

Conclusion

Climate change presents a substantial risk to worldwide food security, with its impacts on all dimensions of food system. Changing climate in terms of high temperature, changes in precipitation patterns and extreme weather events, disrupts agricultural production, causes yield loss, leading to food shortages. Loss of biodiversity combined with climate-induced shifts in ecosystem, further lessens the agricultural productivity, resulting in food insecurity. Vulnerable populations, especially smallholder farmers, women and children are at higher risk due to climatic variabilities. Addressing these challenges require coordinated efforts at local, national and global levels. This includes supporting smallholder farmers, enhancing agricultural research and extension services, and integrating climate adaptation into food security policies and programs. Moreover, providing education and technology access to vulnerable population are essential elements for these adaptation strategies.

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