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CLIMATE CHANGE INDUCED EXTREME WEATHER EVENTS AND FOOD SECURITY

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Abstract

Climate change has come to be recognized as one of the key issues affecting food security globally in recent times, especially in the context of the exacerbation of extreme weather events like heat waves, droughts, floods, and cyclones. These extreme events affect agricultural productivity, the quantity of food produced, the health of animals, and the sustainability of fisheries and aquaculture, thereby affecting the food security status of nations in terms of availability, accessibility, utilization, and stability. Studies have shown that even the slightest rise in the average temperature of the earth leads to the reduction of the quantity of staple foods like wheat, maize, rice, and soybean, with yields falling by 3-7% for every 1°C rise in the average earth temperature. Heat waves and rainfall variability affect the health of animals, thereby reducing the quantity of milk and meat produced, as well as the mortality rate of animals. Flooding and rainfall variability affect the quantity of food produced, while marine heat waves reduce the quantity of fish produced. Moreover, regional studies suggest that South Asia, Sub-Saharan Africa, Southeast Asia, and Latin America are the vulnerable regions, and the loss in the crop yield is estimated to vary between 5 and 60%, depending on the crop and the local climatic conditions. Though the adaptation techniques are effective, there are limitations in the institutional, technological, and socio-economic limitations in the mitigation and adaptation techniques. However, this review highlights the importance of addressing the mitigation and adaptation techniques in a manner that would help to strengthen the agricultural sector, addressing the concerns of food security in a changing climate. This is a critical issue that needs to be understood by the policymakers, researchers, and stakeholders who wish to address the concerns of food security in a changing climate.

INTRODUCTION

Climate change is becoming worse, and its impacts have already been seen globally, with extreme weather changes such as heavy rainfall and floods becoming major threats to our lives, agriculture, and food security. Temperature increase has intensified the water cycle, leading to heavy rainfall and floods, which affect our agriculture, leading to reduced crop yields and posing a threat to food security globally (Tabari, 2020). The effects of anthropogenic climate change are already being felt in the global agricultural productivity of crops due to rising temperatures and changes in precipitation patterns. A global study of the major crops

revealed that the warming trends have already impacted the production of wheat and maize and are expected to continue doing so in the future climate scenarios (Zhao, Liu, Piao, Wang, Lobell, Huang, Huang, Yao, Bassu, & Ciais, 2017). Besides impacting food yields, climate change also impacts the nutritional content of food crops. For instance, an increase in CO_2 levels in the atmosphere was found to lead to a decline in protein content of food crops (Myers et al., 2014).

Extreme heat events are also very destructive in the context of agriculture. The increase in rising temperature extremes has led to an increase in the frequency and duration of heat waves across the globe, and this has the effect of reducing the productivity of agriculture (Perkins-Kirkpatrick & Lewis, 2020). The heat waves also reduce the productivity and mortality rates of cattle (Myers et al., 2017).

World Health Organization notes that agricultural disruptions caused by the climate issues can undo achievements made in achieving malnutrition reduction unless proper adaptation strategies are put in place. The climate change is gradually compromising food systems and causing food and nutrition insecurity Climate change poses a threat to food security through decreased crop yields and increased variability in crop production (Lin et al., 2022). According to the global monitoring reports, food insecurity is one of the challenges facing the world. In 2023, it is estimated that 2.33 billion individuals were facing moderate and severe food insecurity, which shows that there is still pressure on food systems due to climate variability, conflicts, and economic shocks (UNICEF, 2024). Another factor that affects market stability is the volatility of yields caused by climate change. It has been observed that climate variability affects the availability of food and price volatility, and it is responsible for a large part of the annual variation in agricultural yields (Ray et al., 2019).

Climate change as a major driver of global food insecurity, although literature strongly highlights but this relationship is not completely linear. Climatic factors not only shapes food systems but also socio economic conditions, agricultural management, technology, and governance. Several studies depend on broad forecasts, which might ignore adaptive capability and local variability. The impact of climate change on food security is therefore a serious matter that needs to be considered in the context of a complex system of interrelated components.

1. Climate Change and Extreme Weather Events

1.1. Rising Global Temperatures

Temperature increase directly affects agricultural productivity by accelerating crop growth and reducing grain filling duration (Table 01). According to the 2025 Lancet Countdown on Health and Climate Change report, jointly prepared with the World Health Organization, the health hazards of heat and other climate-related issues have reached unprecedented levels, with major indicators such as deaths due to heat rising rapidly with the increase in temperature globally (Romanello et al., 2025). A global multi model analysis showed that warming leads to a substantial decrease in crop yields (Zhao, Liu, Piao, Wang, Lobell, Huang, Huang, Yao, Bassu, & Ciais, 2017). In addition, increasing global temperature will heighten water stress. As a result, there will be an increase in rates of evaporation and cause the increase in drought (Scheff & Frierson, 2014). Higher temperatures also cause more evapotranspiration and soil moisture loss, that decreases crop water availability (Jägermeyr et al., 2021).

1.2. Heatwaves and Their Frequency

Heatwaves are increasing in intensity and frequency due to human induced global warming (Perkins-Kirkpatrick & Lewis, 2020). Recent findings suggest that the occurrence of heatwaves is becoming more frequent and spatially extensive with the progression of climate change. In this regard, a study conducted at the global level revealed that the number of instances of large-scale heatwave occurrences has increased almost eight times since 2000, while the number of regions that are simultaneously affected by heatwaves has increased substantially. This is particularly detrimental to agricultural

productivity; as extreme temperatures often occur at critical growth stages in the development of agricultural products (ul Hassan et al., 2024). This is because extreme heat affects the fertility of crops, especially when they are in the flowering stage. Livestock are also susceptible to heat wave, which affects production, fertilization, and death rates. Heat extremes are projected to become one of the most important risks to global agriculture (Table 01). This is particularly the case for tropical and subtropical areas (Perkins-Kirkpatrick & Lewis, 2020).

1.3. Flooding and Heavy Rainfall Events

Climate change is the main cause of increasing the intensity and frequency of heavy rainfall, which is also cause the increasing the chances of flood across the globe (Table 01). The extreme rainfall is causing flooding globally (Hettiarachchi et al., 2018). Based on the 2025 report of the Lancet Countdown on Health and Climate Change, which was developed with the strategic support of the World Health Organization (WHO), the occurrence of extreme precipitation days, which may lead to flash floods and landslides, has significantly increased in the global land area and is attributed to the effect of climate change in the frequency and intensity of heavy rainfall events associated with adverse health outcomes (Romanello et al., 2025). Hydrological extreme events, which include flooding, can also disrupt the food supply chain, damage agricultural land, and cause economic losses. The effect of extreme events can be more devastating in regions where social or economic vulnerabilities already exist (Galli et al., 2025).

Geography and farming system varies the impact of extreme weather events, existing research consistently ties them to agricultural losses and volatility in the food supply. Infrastructure, farmers' capacity, and resource availability for adaptation determine how severe effects are. Some studies give less emphasis to resilience strategies like improved irrigation, technological innovation, or agricultural diversification while put more concentrate on harm. Extreme weather at affects human adaptation and system readiness, therefore be viewed as a challenge as well as a threat. The various pathways through which global temperature rise affects environmental degradation, weather events, and socio-economic impacts such as food insecurity are shown in Figure 01.

2. Impacts on Agricultural Production

When weather gets more unpredictable because of global heating, farms feel it fast in form of scorching heat waves, dry spells, sudden floods, or shaky rain trend. Yields decline, livestock productivity suffers, fish populations decline, soil fertility deteriorates, and water reservoirs dry up, ultimately resulting in significant productivity loss. Food on tables everywhere starts to wobble as a result (Table 01).

2.1. Effects on crop yields

Studies show hot spells at key moments - like pollen set or grain loading, cut output across staples like wheat, corn, and rice. When temperatures rise, plants become stressed, especially under dry conditions. Climate change-related heat stress and extreme weather conditions are also impacting crop yields around the world. According to the joint report on "Extreme Heat and Agriculture" published by the FAO and the WMO, with every rise in temperature by 1 °C, the yield of staple crops like maize and wheat is set to decline by 4–10% (Fao, 2018).

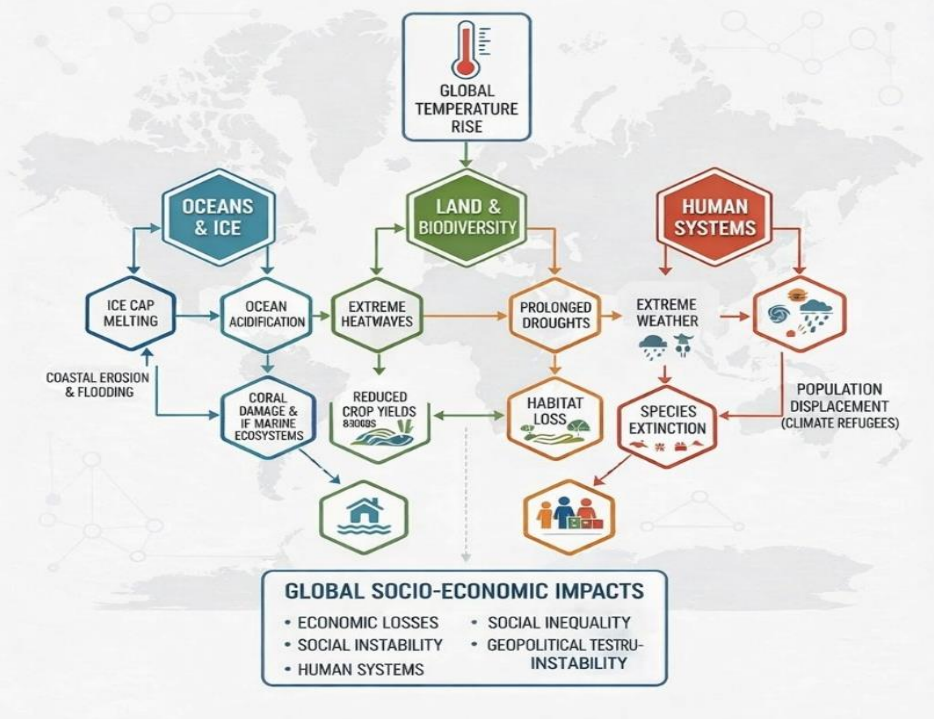

Fig. 01. Interconnected global impacts of climate change on biosphere

Data presented in Table 01 demonstrate that for every one degree increase in temperature, crop yields decrease by 6 % in wheat, 7.4 % in corn and just under 3 % in rice (Zhao, et al., 2017). During droughts, soil dries out, limiting water availability, resulting in impaired plant growth, which reduces photosynthetic energy production, and leads to overall crop shortfalls. Across southern Africa, intense dry runs have slashed maize output between one fifth and half, research indicates, based on how long such spells last and their severity (Leng & Hall, 2019). On the flip side, torrential rains that soak fields too deep bring damage through soggy ground conditions, oxygen starved roots, along with heightened risk from insects and illnesses (Lesk et al., 2016a).

2.2. Livestock Productivity and Health

Climate change has been seen to have a significant impact on livestock productivity and health. To exemplify, climate change, which is characterized by rising temperatures and the increase in heatwaves, has been seen to impact the growth rate, milk and meat production, reproduction, and disease incidence in cattle, sheep, goats, and poultry. According to the FAO, extreme weather conditions and changes in rainfall patterns have been cited as a threat to global livestock, hence the need to come up with climate-smart approaches to adaptation (Anuta et al., 2025). Heat makes cows eat less, grow slower, lose calves, and stop making milk. As summarized in Table 01, in different parts of the world, herds that faced long stretches of high heat gave less milk - by as much as one quarter and some did not survive (Thornton et al., 2021). When storms hit, grazing areas often shrink fast. Without green patches year-round, animals eat less nutritious grass mixes. Research shows dry spells bring poor feeding times plus weaker defenses against illness (Rojas-Downing et al., 2017).

2.3. Fisheries and Aquaculture Impacts

When climate shifts happen, they often shake up how fishery and farm aquatic life operations run. Warmer ocean water, sudden spikes in sea heat, or intense weather shifts mess with where fish move, when they spawn, and if they live through

shocks. Data presented in Table 01 demonstrates what actually occurs shows some areas losing key fish populations, sometimes cutting annual catches by between 15 and 35 percent (Smale et al., 2019).

When it rains heavily, aquaculture faces trouble because flooding brings heavy sediment and extra nutrients into ponds. Poorer water conditions then create low oxygen levels while making fish more susceptible to illness. Evidence shows major fish stock losses happen after such events, especially where people earn less along coastlines and river deltas (Ahmed et al., 2019).

2.4. Soil Fertility and Land Quality

When storms hit hard, dirt wears away faster under fierce skies. Water rushing across fields washes away what plants need, tearing down structure and fading richness over time. Dry spells that last too long silence underground helpers who normally trade nutrients between roots and air. When dry spells follow heavy rains again and again, the amount of carbon and nitrogen in soil tends to drop steadily, data from recent field research show (Panagos et al., 2020).

2.5. Water Availability for Irrigation

When rainfall shifts because of global heating, it alters where water gathers above or below ground. Rivers flow less when dry spells happen more often, dragging down how much crops can soak up during key growing moments. Table 01 shows scientists expect irrigation needs to climb between 4 and 18 % within decades simply because heat pushes up moisture loss from soil and plants (Elliott et al., 2014).

Current research demonstrated that climate change badly impacts livestock productivity, agricultural yields, and fisheries output, ultimately resulting in economic losses across various agro-ecological systems. The data is largely driven from observational experiments which does not fully explain farmer reactions and climate extremes. The scientific evidence is still biased, cereal producing crops are more focused than mixed farming systems and substantial crops. Future research should integrate biophysical and socioeconomic indicators to accurately measure the cumulative and cascading effects of climatic extremes on agricultural production systems.

3. Food Security Dimensions Affected by Climate Extremes

Climate change-induced extreme weather events impact food security by compromising all four key attributes of food security, namely, food availability, access, utilization, and stability. Droughts, floods, heatwaves, and storms affect both food security and socio-economic conditions, thereby raising vulnerabilities to food security globally (Table 01).

3.1. Food Availability

The impact of droughts and heatwaves on crop yields is quite high, as empirical evidence reveals that droughts and heatwaves reduce crop yields by 30-40%, thereby reducing food availability (Table 01). The global impact of disasters revealed that extreme weather events associated with climate change resulted in an average annual loss of 3-5% of cereal crop production in developing countries during 1964-2007 (Lesk et al., 2016a). Climate change is also posing threats to food security at the global level, as climate change affects food production. According to Wheeler & von Braun, climate change is expected to have negative impacts on food production, including lower yields of major food crops such as wheat, rice, and maize, especially in the tropics (Wheeler & Von Braun, 2013). Floods reduce food availability by damaging crops, grains, and infrastructure. Floods resulted in post-harvest loss of more than 20% of total crops in South and Southeast Asia. Floods restricted food availability during post-recovery periods (Dottori et al., 2018). The impact of climate-induced marine heatwaves and extreme weather events on fish populations resulted in a decline of fish biomass, thereby reducing animal-based food sources required for nutrition (Free et al., 2019).

3.2. Food Access

Climate change has a negative impact on food access through extreme weather conditions,

which increase the prices of food, reduce household incomes, and disrupt the food system. As summarized in Table 01 studies from the Sub-Saharan region of Africa indicate that drought impacts the prices of food, causing them to rise by 10-30%, thus reducing economic access to food (Brown et al., 2015). Extreme weather conditions also reduce physical access to food. For example, floods and cyclones often isolate communities, thus preventing the movement of food to markets. Household studies indicate that extreme weather conditions reduce income opportunities, thus causing people to reduce the quantity of food they consume (Hertel et al., 2010).

3.3. Food Utilization and Nutrition

Climate extremes have a major impact on the nutrition of populations. Climate-related impacts on the availability and accessibility of nutritious foods lead to a decrease in the variety of consumer foods. As a result, the population is forced to consume more calorie-dense foods. Studies have shown that the prevalence of wasting and stunting among children increases after drought and flood events (Stanke et al., 2013). Climate related impacts such as extreme temperatures and flooding events lead to a decrease in the quality of food and water. As a result, the population is more susceptible to water-borne diseases. Studies have shown that the risk of diarrheal diseases is high among populations affected by flooding events. Diarrheal diseases have a major impact on the nutrition of children (Phalkey et al., 2015).

3.4. Food Stability over Time

Food stability is threatened by the impacts of climate extremes that cause repeated disruptions to the supply and access of food. This makes it difficult for people to recover from the effects of these disasters. As a result, the prevalence of food insecurity is high. Table 01 shows according to panel analyses conducted in different countries, repeated climate related disasters cause high variability in the production and consumption of food from one year to another (Bellemare et al., 2010). Recent research has reaffirmed that climate change is affecting food systems over time by weakening crop productivity. A scientific reports finds that climate change have a direct impact on crop productivity through changes in temperature, precipitation, CO_2, and pest and disease pressure, which have implications for food security under projected climate change scenarios (Li et al., 2025).

Climate extremes also reduce the coping mechanisms of the affected populations. According to research findings, repeated climate-related disasters cause high levels of dependence on external food support for the affected populations (Brück & d'Errico, 2019). This is a major challenge to the achievement of sustainable food security in the face of climate change.

Empirical research shows that climate change disrupts food availability through production losses and price volatility. Long term data shows connection between climate shocks and quality of food, however food stability characteristics are still missing. The use of proxy indicators in research limits the ability to draw reliable conclusions about causality. By using integrated food system methodologies, a more thorough understanding of food security during climate extremes can be obtained.

4. Socio-Economic Implications

The socio economic implications of climate change-induced extreme weather events transcend biophysical effects on food systems. The adverse impacts of extreme weather events on socio economic factors are felt by vulnerable groups, especially smallholder farmers, rural populations, and other social groups (Table 01).

4.1. Impact on Smallholder Farmers

Smallholder farmers are highly susceptible to the adverse effects of extreme weather events. They are more likely to be impacted by climate extremes because of their dependency on rain fed farming, lack of access to financial resources, and low adaptive capacity.

Table 01: Quantitative impacts of climate change–induced extreme weather events on agricultural production, food security, and socio-economic outcomes

Climate extreme	Affected system	Quantitative impact	Impact	Implication	Source
Temperature increase (+1 °C)	Major cereal crops (wheat, maize, rice)	Yield reduction: wheat −6%, maize −7.4%, rice −3.2%	Food availability, stability	Reduced farm income; higher market prices	Zhao et al., 2017
Heatwaves	Dairy livestock	Milk production decline: 10–25%	Food availability, utilization	Income loss for livestock-dependent households	(Thornton et al., 2021)
Severe drought	Rain-fed maize systems	Yield loss: 20–40%	Food availability, access	Smallholder income decline: 15–30%	(Leng & Hall, 2019; Oyekale, 2009)
Flooding & extreme rainfall	Cropland & post-harvest systems	Post-harvest losses >20%	Food availability, stability	Infrastructure damage; market disruption	(Dottori et al., 2018; Lesk et al., 2016a)
Marine heatwaves	Capture fisheries	Catch reduction: 15–35%	Food availability, utilization	Protein supply loss in coastal communities	(Smale et al., 2019)
Climate variability	Staple food markets	Food price increase: 10–30%	Food access	Increased vulnerability of poor households	(Brown et al., 2015)
Recurrent climate extremes	Rural households	26 million people pushed into poverty annually	Food access, stability	Chronic food insecurity	(Hallegatte et al., 2015)
Repeated droughts & floods	Food systems over time	High year-to-year production variability	Food stability	Dependence on external food aid	(Bellemare et al., 2010; Brück & d'Errico, 2019)
Climate shocks	Female-headed households	Higher income losses than male-headed households	Food access, utilization	Widening gender inequality	(Doss et al., 2017)

Empirical evidence indicates that droughts and floods negatively impact crop yields and farm incomes of smallholder farmers. According to reports listed in Table 01 for instance, a multi country empirical analysis of smallholder farmers in low- and middle-income countries revealed that severe drought negatively impacted farm incomes of smallholder farmers by 15-30%, depending on crop types and duration of drought exposure (Oyekale, 2009).

Extreme weather events also contribute to increased indebtedness of smallholder farmers. They often rely on credit to recover from the adverse effects of climate extremes. The recurrence of extreme weather events reduces farm savings and asset ownership of smallholder farmers (Dercon et al., 2012).

4.2. Rural Livelihood Vulnerability

Rural livelihoods are very vulnerable to climate extremes, particularly to climate related disasters like drought and floods, which usually affect livelihoods that depend on agriculture, pastoralism, fishing, and natural resource utilization. From empirical research, it has been evident that drought and flood impacts lead to a reduction in employment and wage opportunities and food availability in rural areas. From longitudinal research conducted in Africa and South Asia, it is evident that climate extremes lead to increased livelihood instability, particularly due to a reduction in labor demand and non-agricultural sources of income (Mueller et al., 2014).

Climate extremes also lead to distress migration, particularly in rural areas that seek alternative sources of livelihood to replace income sources that were affected by climate extremes. From empirical research, it is evident that rural-urban migration increases with increased drought impacts, which may affect rural labor availability (Gray & Mueller, 2012).

4.3. Market Price Fluctuations

Severe weather conditions cause price volatility in the food market due to the effects on the production and supply of food. Droughts and floods lead to a reduction in the yield of crops and cause uncertainty. This causes price volatility in the market for food products. According to the studies conducted on the market for food products, it is found that severe weather conditions cause a high surge in the prices of staple foods, especially in import dependent countries (Puma et al., 2015).

Price volatility mainly affects the poor segment of the population because they spend a larger proportion of their income on the purchase of food products. Table 01 shows according to the studies conducted on the global market for food products, it is found that extreme weather conditions cause a 20 percent surge in the volatility of prices for cereals (Hertel & Rosch, 2010).

4.4. Poverty and Food Insecurity

Climate extremes contribute to poverty through the loss of assets, reduced income, and higher food prices. Micro level analyses have found that exposure to droughts and floods increases the probability of falling into poverty. The global empirical study estimated that 26 million people are pushed further into poverty each year owing to climate-related extreme events, mainly through the impact of climate extremes on agriculture and food prices (Hallegatte et al., 2015).

The food insecurity dimension is also related to the poverty dimension. Repeated climate-related extreme events limit households' capacity to attain food security. The panel data analyses have revealed that households experiencing repeated climate-related extreme events suffer from food consumption deficits (Brück & d'Errico, 2019).

4.5. Gender and Social Inequalities

Extreme weather events associated with climate change have significant impacts on gender and social inequalities. Empirical evidence suggests that female farmers experience more constraints in accessing resources such as land, credit, extension services, and climate information. Research findings suggest that there are significant differences in income loss between male and female headed households due to climate change. As discussed in Table 01 the findings suggest that female headed households experience more loss in income compared to male headed households (Doss et al., 2017).

Extreme weather events have significant impacts on increasing the workload of women in collecting water, providing care to family members, and preparing food. The increased workload reduces the time allocated to income generating activities. The socially marginalized sections of society, such as landless laborers and indigenous people, experience similar impacts due to their limited access to resources and social protection services (Rao et al., 2019).

Literature revealed that climate extremes increase poverty, food insecurity, and gender inequality by affecting smallholder farmers and rural livelihoods. The empirical research pays little attention to long-term resilience, adaptive ability

and social protection systems for concentrating on the immediate economic effects. Gender specific analyses are rare, especially in climate change vulnerable areas. In future, gender-sensitive techniques should be used in research to understand how policy initiatives can reduce socioeconomic vulnerabilities caused by climate induced extreme weather events.

5. Regional Case Studies

Different regions are affected by climate change in different ways, necessitating locally specific solutions. Food security for smallholders who depend on rain-fed fields is at risk in South Asia due to rising temperatures and unpredictable rains that reduce rice and wheat harvests (Aryal et al., 2020). Frequent heat waves and droughts in Sub-Saharan Africa weaken household food supplies by reducing the production of maize and sorghum. Floods and cyclones that destroy crops and interfere with trade networks are common in Southeast Asia. Long dry spells in South America and the Central American Dry Corridor reduce staple yields and put stress on water supplies in Latin America. These examples demonstrate how climate change related extreme weather is already harming food systems around the world, highlighting the urgent need for strategies like drought-tolerant crops, effective irrigation, and early warning systems (Rehman et al., 2024).

5.1. South Asia

Increasing warming, erratic rainfall, devastating floods, and prolonged droughts associated with climate change are all impacting agricultural production in South Asia and threatening the food security of millions of people (Behera et al., 2024). Monsoon variability reduces the production of staple foods, increases the chances of crop failure, and puts rural areas at risk of starvation and economic loss due to the high dependence of the region on rain-aided agriculture (Sainath et al., 2025). For example, events such as the floods in Pakistan in 2022, which destroyed agricultural land and livelihoods, illustrate this vulnerability (Mushtaq et al., 2022), while the heat waves in India, which seriously affected food systems and agricultural productivity (Kroeger & Reeves, 2022). Collectively, these climate change extremes demonstrate how environmental shocks can disturb food systems and increase vulnerability in South Asian countries (Rehman et al., 2024).

5.2. Sub Saharan Africa (Climate Change & Crop Yields)

In Sub-Saharan Africa climate change makes extreme weather worse. This especially causes heat waves, droughts and irregular rainfall. These conditions hurt the production of crops like maize, rice and soybeans. Climate change affects maize, rice and soybeans production in a way. It causes problems for maize, rice and soybeans farmers in Sub-Saharan Africa. The heat waves and droughts are bad, for maize, rice and soybeans. The irregular rainfall also affects maize and rice and soybeans crops (Parmesan et al., 2022). The studies compiled in Table 02 indicate in the future if we keep releasing a lot of things into the air maize yields will probably go down a lot in some parts of Southern Africa. We are talking about losses of 30 to 60 percent when the earth gets 3 to 4 degrees and this will be especially true during years when we do not get enough rain (Table 02). Maize yields will be affected by this warming and maize yields will be a problem, during these dry (Simanjuntak et al., 2023). Meanwhile rice and wheat might get some benefits from CO_2 but they will still have problems because of not enough water and too much heat. Research shows that we need to find ways to grow rice that can handle the changing climate and get better at growing wheat. These changes are making it harder for the region to have food. We need climate- rice varieties and better ways to grow wheat (Benjamin et al., 2025). These changes hurt the regions food stability. Detailed modeling shows that agriculture here is still very sensitive to changes in climate and extreme weather conditions. The regions farming depends on weather. Bad weather can cause problems. Changes in climate make it hard to grow food (Table 02). This makes the regions food stability weak. Agriculture in this area is at risk because of weather. The regions food stability is at risk. Climatic variability and extreme

weather affect agriculture here a lot. The regions food and agriculture are not stable. These changes affect farming and food. The regions agriculture remains highly sensitive, to variability and extreme (Liu et al., 2025).

5.3. Southeast Asia (Extreme Events & Food Systems)

Southeast Asia is getting hit hard by crazy weather because of climate change. This includes floods, cyclones and weird changes in the monsoon season. All of these things can really hurt the farms. Mess up the way we grow and get food (Table 02). If you look at what's happening in Southeast Asia you can see that when it rains way too much or when it is really dry it can ruin the crops flood the fields and make it hard to grow basic foods, like rice (Venkatappa et al., 2021). These extremes are a problem for the food that farmers grow and, for the people who live in the countryside. The extremes make it harder for people to get the food they need which means that food is not always available when people need it and it can be very hard to get to this affects the food availability and access of the populations and the agricultural output (Taniushkina et al., 2024).

6.4 Latin America (Case Study)

In Latin America and the Caribbean climate change is really affecting agriculture. Climate change is causing bad weather like super long droughts and too much heat, which hurts the crops that people grow like maize and beans and rice and coffee. This means that people are not getting much food from their farms so they are making less money from their farms and there is not enough food for everyone to eat which is a big problem, with food. Climate change is making it harder for people to grow maize and beans and rice and coffee (Fernandes et al., 2012). These impacts are clear in crops like maize and beans (Table 02). They are very sensitive to temperature and rainfall changes. This makes farmers, who grow these crops very vulnerable. They are hit hard by changes in weather. Maize and beans are crops for many small farmers. They depend on them for food and income. Changes, in temperature and rainfall affect their harvest. This in turn affects their livelihood (Benjamin et al., 2025). Coffee production is in trouble because of the weather. The temperature is going up. The rain is coming at different times. This is a problem for people who make a living from coffee. It also affects the money they get from selling coffee to countries. People in communities are really going to feel the effects of this. Coffee production is very important, to them (Vignola et al., 2022). Climate-induced losses hurt food production and worker productivity, which in turn threaten food availability. This also impacts the economy. Makes food systems less resilient in the long run across the region, where climate change affects yield and labor capacity. Stability and food systems are, at risk (Banerjee et al., 2021).

Climate change is an issue for small farmers. It hurts them in ways and in many different places. No matter where small farmers are they always seem to get hurt. In countries like Pakistan and India floods and heat waves are really bad for crops that need rain to grow. In Sub-Saharan Africa droughts are a problem because maize and sorghum crops do not grow like they should. In Southeast Asia floods and storms make it hard to get food to people who need it. In Latin America long droughts hurt crops like coffee.

The main thing to remember is that we need to help farmers in each region with solutions that work for them. We need to plan and give small farmers the assistance they need so that everyone has enough food. Climate change is still a problem, for farmers and we need to help them. We need to help farmers so that they can grow food for everyone.

6. Adaptation Strategies

Farmers and communities are coming up with ways to deal with climate change. Climate change is a problem for agriculture. It brings droughts and weird weather patterns like heavy rains or really hot temperatures. All these things hurt the crops. Make it hard for people to get food. So farmers are trying things to make their farms stronger. One thing that works is planting different kinds of crops in the same field. This is

called crop diversification. Crop diversification is an idea because it helps the farm survive when the weather is bad. It also helps make sure the farmers get a harvest even when the weather is really hot or really dry. Climate change is a threat to agriculture but crop diversification and other adaptation strategies, in agriculture can really help (Sridhar et al., 2025). Using seed types that can handle dry spells and hot weather is very important. These seed varieties help crops grow more and make them less likely to be hurt by bad weather conditions, like droughts and heatwaves. They make farming more productive. Help farmers deal with water stress and heat (Belmin et al., 2023). Changing the way we do farming like planting at times helps farmers make sure their crops grow at the right time when the rain falls (Grigorieva et al., 2023). Using water-saving irrigation techniques, like precision irrigation really helps to save water. This way we can conserve our resources. Still get a good crop output from the fields. Adopting water-saving irrigation techniques is a good idea because it helps us to save water and maintain crop output at the same time. Water-saving irrigation techniques, such as precision irrigation are very useful, for our crops (Lakhiar et al., 2024). Combining soil and water management approaches makes the soil stronger. This helps the soil stay fertile and keep water**.** It is like a protection against weather. Research shows that using these methods together really helps. They make it less likely that people will not have food. This is because they make the land produce more and keep the farming system stable. The soil and water management approaches are very important. They help the soil and water work. This makes the land better, at growing crops.

Table 02: Global Impacts on Food Security and adaptation Strategies

Region	Major Impacts on Food Security	Estimated Yield	Adaptation Strategies	References
Asia	Heatwaves, floods reduce rice & wheat	–5% to –15% crop yield by 2050	Climate-resilient crops, irrigation, agroforestry	(Lobell et al., 2011); (Challinor et al., 2014)
Southeast Asia	Floods, cyclones and heavy rains	–10% to –20% rice yield	Salt-tolerant rice, mangrove restoration, early warning systems	(Wassmann et al., 2009); (Hirabayashi et al., 2013)
Sub-Saharan Africa	Severe drought & heat stress	–10% to –30% maize yield by 2050	Drought-tolerant crops, soil carbon sequestration, rainwater harvesting	(Challinor et al., 2014); (Wheeler et al., 2013)
Latin America	Droughts & hurricanes increase hunger risk	–10% to –25% maize & soybean yields	Agroforestry, crop diversification, watershed management	(Lesk et al., 2016b); (Ray et al., 2015)

Soil and water management approaches are a way to deal with the problems caused by the weather. They help the farmers grow food. This means that people will have food to eat (Begashaw et al., 2024).

6.1. Climate-Smart Agriculture

Climate Smart Agriculture is a set of farming practices and technologies that help make farming better. It makes farming more productive and stronger, against weather. This way farming

uses water and keeps the soil healthy. Climate Smart Agriculture helps farmers deal with problems. For example, it uses seeds that grow well in different weather and it uses good ways to keep the soil fertile. It also uses watering systems (Figure 02). All this helps farming keep feeding people even when there are droughts, floods and heat waves. Climate Smart Agriculture is important because it helps farmers grow food even when the weather is bad (Awais et al., 2026).

6.2. Crop Diversification

Crop diversification is when a farmer grows different crops instead of just one. This is an idea because it helps keep the farm producing food even when the weather is bad. For example, some crops can handle heat. Some can handle drought and some can handle pests. When a farmer grows different crops they can help the soil stay healthy use water wisely and make sure that if one crop does not do well the farmer will still have others to sell. Crop diversification really helps the farmer because it spreads out the risk so if one crop fails the farmer will not lose everything. This is important for the farmer. It is good, for the earth too because crop diversification helps keep the soil healthy and the water clean and it makes sure that the farmer can keep growing food even when the weather is bad which is what happens with climate change as we can see in Figure 02. Crop diversification is a strategy that farmers can use to keep their farms strong. It is something that farmers should think about because it can really help them and it can help the earth too by keeping the soil healthy and the water clean and by making sure that the farmer can keep growing many different crops like we said before crop diversification (Grigorieva et al., 2023).

6.3. Drought-Resistant and Heat-Tolerant Varieties

Farmers need crops that can handle weather and high temperatures. Crops that can resist drought and tolerate heat are really helpful. They help farmers keep growing food when it is extremely hot and dry outside. These special crops are made using plant breeding and biotechnology. They can survive when there is no water and can handle the heat when they are growing. They can even produce food when things are really tough. For-example some kinds of wheat can handle the heat and some kinds of maize can handle weather (Figure 02). Drought resistant and heat-tolerant crops are better than kinds of crops. They make food plants have roots and use water more wisely. Drought-resistant and heat tolerant crop varieties, like these are very useful. They reduce the risk of crops failing and help keep food production steady. This means that drought-resistant and heat-tolerant crops make sure people have food to eat, especially in areas that often have heat waves and droughts (Cairns et al., 2013).

6.4. Improved Irrigation Systems

Climate change is a problem for farmers because it makes it hard to get water when they need it. Improved irrigation systems are very important for farmers to deal with this problem. These systems help farmers use water in a way and keep their crops healthy even when it does not rain much. Farmers are moving away from the way of flooding their fields with water. Now they use ways like precision irrigation and smart scheduling. This means they use computers to decide when to water their plants based on the weather and how wet the soil. They also use technologies like drip irrigation that gives water directly to the roots of the plants. This way of doing things is really good because it stops water from being wasted (Figure 02). When farmers flood their fields a lot of water is lost because it evaporates or runs off the field. With these new systems water goes straight to the roots of the plants so none of it is wasted. This helps farmers grow their crops even when it is hard to get water. So improved irrigation systems are very important for farmers. They help farmers keep their crops healthy and strong even when there is not water. This is good for everyone because it means we will have food to eat for a time. It also helps keep our water clean and safe which is very important, for people and the Earth (Ahmed et al., 2023).

6.5. Early Warning Systems

Early warning systems give farmers information ahead of time about weather conditions like droughts, heat waves or storms. This helps them to adjust when they plant, how they water, and how they manage their crops before weather hits. They can prepare ahead of time. Farmers can reduce losses. Protect their crops (Figure 02). This makes their livelihood more resilient to changes, in the climate caused by impending droughts, heat waves or storms. Farmers can prepare for weather events and improve their livelihood resilience against sudden climate impacts by using early warning systems (Awais et al., 2026).

Farmers can really make a difference with climate change. They can keep food production going by using Climate Smart Agriculture. This means farmers will grow crops and use special seeds that can handle drought and heat. Farmers can also make irrigation better. Farmers will set up warning systems for weather. These Climate Smart Agriculture ideas sound good when you think about them. Climate Smart Agriculture does not always work in real life. The problem with Climate-Smart Agriculture is that things like technology and knowledge can be expensive and hard to get. The roads and other infrastructure in the area where farmers live can also be a problem for Climate Smart Agriculture. Sometimes farmers just do not know how to use these Climate Smart Agriculture things. So even though Climate Smart Agriculture strategies are very important they only work well if the local area is ready, for Climate Smart Agriculture and if farmers can get the help they need with Climate Smart Agriculture.

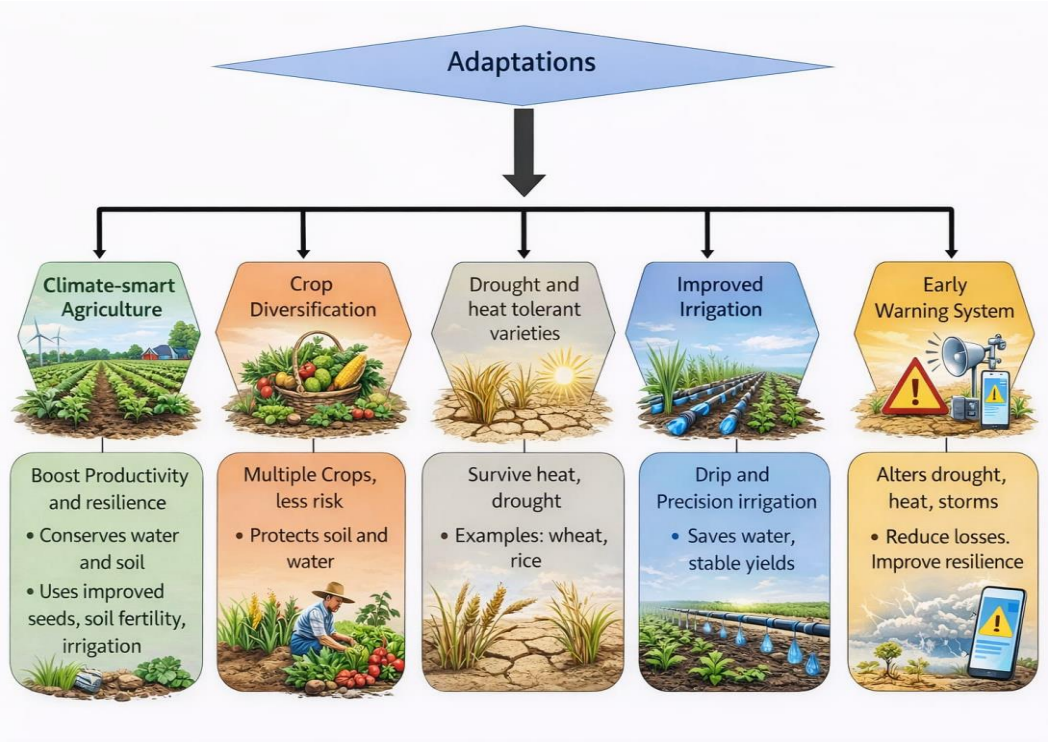

Fig.02. Adaptation to protect crops and food security

7. Mitigation Strategies in Agriculture

Agriculture is a part of the problem when it comes to global greenhouse gas emissions. There are things we can do to make a difference (Table 03). We can reduce these emissions and make farming better at the same time (Table 03). One of the things we can do is manage nutrients better so that the soil does not produce as much nitrous oxide (Yezheng et al., 2026). We can also change the way we feed livestock and handle manure to reduce the amount of methane that gets released (Hodge et al., 2024). Agricultural

systems can be made sustainable by doing things like reducing tillage and planting cover crops (Javed et al., 2024). We can also use trees in our farming to store carbon in the air and in the ground (Hussain et al., 2024). Finally, we can make the soil healthier by adding organic matter and changing up the crops we plant, which will help the soil store carbon (Khaqan et al., 2025). Agriculture can be better for the environment, with these things. Agriculture will be more sustainable (Table 03). It will produce greenhouse gas emissions as you can see in Table 03. When we use these approaches together agriculture systems can reduce their climate footprint. Agriculture systems can also make the soil healthier. Keep more water in the ground. This will help us have food for a time even when the climate is changing. Agriculture will be better for the environment and agriculture will be more sustainable (Smith et al., 2014).

7.1. Reducing Greenhouse Gas Emissions in Agriculture

Reducing greenhouse gas emissions in agriculture is important. Farms have to take action. They need to make sure less methane, nitrous oxide and carbon dioxide get into the air. They still have to grow food for people. Here are some things farms can do. They can manage nutrients and fertilizer better. This helps crops use nitrogen well. They can use conservation tillage. This means they do not dig up the soil much (Smith et al., 2008). Managing manure helps reduce methane, Farms should use energy wisely. These practices help emissions. They also improve soil health. They increase productivity. Farming becomes more environmentally friendly. This is good as climate change pressures grow (Figure 03). A recent review shows that some field practices help. These include: Form of nitrogen supply, Use of slow release fertilizers, Application of soil amendments like biochar, integrated nutrient management. These can reduce oxide and other greenhouse gas emissions from agricultural soils. Reducing greenhouse gas emissions, in agriculture is a goal. It helps farms grow food and care for the environment (Hassan et al., 2022).

7.2. Sustainable Land Management

Sustainable land management integrates economic and social dimensions to make sure land resources are used in a good way without hurting them in the long run. It is about doing things like saving the soil and protecting plants and animals and planning how we use the land.

This helps with problems like cities getting bigger and the weather changing and more people growing food. These things help keep the soil healthy they stop it from washing and they help the soil hold water better and they make the soil richer (Figure 03). This is good for the crops. It also helps with climate change by keeping carbon in the soil. Sustainable land management is really important for taking care of the land and the earth. By balancing how food we grow with keeping the earth healthy Sustainable land management makes sure that farms can keep going for a long time and can deal with changes, in the weather (Montgomery, 2007).

7.3. Agroforestry Practices in Agriculture

People do something called agroforestry when they farm. This is a way of farming where people grow trees or shrubs with crops and animals. Agroforestry is really, about growing things. So people will grow trees and shrubs and crops and animals at the same time. This is what agroforestry is. This helps create landscapes that are good for growing things and can handle tough conditions. When farmers put trees into their fields they can store carbon make the soil better and stop it from getting washed or blown away. The trees also help keep the air and water clean and make sure there are lots of plants and animals around. Agroforestry is good for farmers because the trees give them things to sell, like food, animal food, firewood or lumber (Figure 03). This means farmers can make money in ways and do not have to worry as much, about money problems. As a nature based mitigation strategy, agroforestry helps remove carbon dioxide from the atmosphere while making farmland more sustainable, productive, and climate resilience (Garrity, 2004).

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Table 03: Agricultural Mitigation Strategies and Their Impact

Mitigation Strategy	Examples	Estimated Impact on GHG Emissions / Yield	Benefits	References
Reduce Greenhouse Gases	Precision fertilizer use, manure management, conservation tillage	10–30% reduction in nitrous oxide & methane emissions	Lower pollution, improved soil fertility	(Smith et al., 2008); (Hassan et al., 2022)
Sustainable Land Management	Soil conservation, balanced land use, erosion control	5–15% emission reduction	Prevent soil erosion, long-term productivity	(Montgomery, 2007)
Agroforestry	Trees with crops/livestock, mixed farming	20–50% increase in carbon storage	Extra farmer income, biodiversity protection	(Garrity, 2004)
Soil Carbon Sequestration	Compost, crop rotation, reduced tillage, cover crops	Yield increase 5–20%; carbon storage increase	Higher soil fertility, water retention	(Zhang et al., 2024)
Improved Livestock Management	Feed additives, improved manure storage	10–25% methane reduction	Better animal productivity	(Hodge et al., 2024)

7.5. Carbon Sequestration in Soils in Agriculture

Carbon sequestration in soils is something that happens naturally. This is when the air takes in carbon dioxide and it gets stored in the soil. The soil stores this carbon because of the way we take care of the land. We can do things like not tilling the soil much leaving the leftover crops on the field planting extra crops adding natural things like compost or manure to the soil and changing

up the types of crops we plant (Figure 03). All these things help the soil store carbon (Figure 03). Carbon sequestration, in soils is really important because it helps the soil store more carbon dioxide from the air. This helps to get rid of carbon dioxide from the air and makes climate change a little better. It also makes the soil better which means it can hold water and is stronger when there is no rain or it is very hot. This is good, for growing crops in a way that's sustainable and helps to make sure people have food to eat (Zhang et al., 2024).

Farming can be better for the earth. We can do this by using soil to store carbon and other ways like planting trees with crops and taking care of the land. These ways of farming also help to reduce the things we release into the air. The goal is to make farming good for the earth without reducing the amount of food we grow. Soil and trees in farming like soil carbon sequestration and agroforestry show that farming and taking care of the earth can work together. Farming and the earth are connected so we should use methods, like soil carbon sequestration and agroforestry to help the earth and still have a farm. This way of farming is good for the earth because it helps animals and plants to live, stores carbon makes the soil healthy and helps to keep water in the ground.

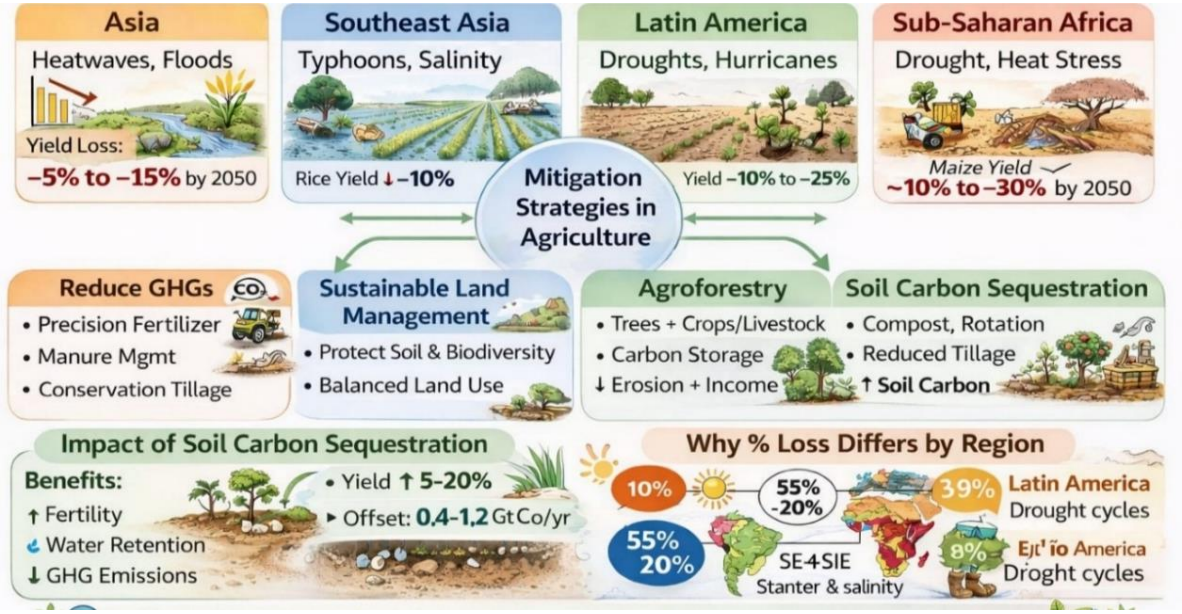

Fig.03. The picture shows methods that boost crops and food in different regions

The good things about soil carbon sequestration and agroforestry are clear. But using these methods can be hard because they can be expensive farmers need to learn about them we do not have all the tools we need. We have to balance what we want now with what is good for the earth in the long run. Agroforestry work differently depending on the place the type of soil the weather and the people who live there. Soil carbon sequestration and agroforestry are ideas and are important, for farming in a way that is sustainable. They just need to be planned have the right tools and have people to help the farmers then they can be very successful.

8. Policy and Governance Framework

Extreme weather occurrences (floods, droughts, heat waves, and cyclones) brought about by climate change have ensured that food security, which was previously an agricultural concern, is now a governance concern that requires multi-level planning. Governance and policy structures influence the ability of countries to prepare for, absorb, and respond to climate change shocks.

8.1. International Climate Agreements

International frameworks of climate governance are key to informing global responses to food insecurity triggered by climate change. The United Nations Framework Convention on Climate Change (UNFCCC) and its supporting agreements, such as the Paris Agreement, are focused on adaptation, resilience, and sustainable food systems as core elements of climate action. While food security is not considered as a sector in its own right in initial climate change agreements, more recent cycles of assessment by the Intergovernmental Panel on Climate Change (IPCC) have placed increasing emphasis on the susceptibility of agro food systems to climate extremes such as floods, droughts, and heatwaves. IPCC Sixth Assessment Report (AR6) points to climate extremes as a primary cause of reduced crop production, supply chain disruptions, and increased food prices, especially in developing countries (Pörtner et al., 2022). Nevertheless, the key weakness of international agreements is their lack of bindingness on adaptation goals, leading to inconsistent national level implementation. While global agreements set out strategic guidance, they are often lacking in operational specificity on how climate risk assessment can be implemented in food security-oriented interventions, especially in the case of small scale farmers and informal food systems (Campbell et al., 2014).

8.2. National Food Security Policies

National food security policies have increasingly recognized climate change as a systemic risk, especially in areas that are vulnerable to climate-related extreme weather events. Climate Smart Agriculture (CSA) approaches have been widely used in national adaptation plans to address productivity, resilience, and mitigation objectives. Systematic reviews have shown that countries that assess climate risks in their food security policies are better equipped to mitigate risks associated with climate change (Lipper et al., 2014).

Nonetheless, critical assessments have shown that most national policies are still reactive and not preventive, with a focus on post disaster relief and response rather than resilience. In addition, there is a lack of coherence between agricultural, water, disaster, and climate change ministries in addressing climate related extremes (Aggarwal et al., 2018). Evidence from developing countries has shown that food security policies are often focused on yield rather than diversification of livelihoods, nutrition, and gender perspectives of climate change vulnerability (Fanzo et al., 2018).

8.3. Climate Financing Mechanisms

Climate finance instruments such as the Green Climate Fund (GCF), adaptation funds, and multilateral development financing instruments play a vital role in facilitating the adaptation of food systems to extreme weather events. The review of CSA and adaptation policies indicates that focused climate finance enhances agricultural resilience through the development of irrigation systems, climate resilient crop varieties, and early warning systems (Taylor, 2018).

Although there has been a rise in global climate finance commitments, the distribution is grossly unequal. Small-scale farmers and grassroots institutions are often hampered by red tape when accessing climate finance, which undermines the success of adaptation initiatives at the grassroots level (Barnard et al., 2014). In addition, a large proportion of climate finance is dedicated to mitigation initiatives, while adaptation, especially food security adaptation, is grossly underfunded. This is a key issue, as food systems are among the most urgent and climate-sensitive sectors impacted by extreme weather events.

8.4. Role of community based organizations

Non-governmental organizations (NGOs) and local institutions are critical in ensuring the implementation of climate policies through food security interventions. Adaptation studies have shown that community based organizations are more effective than government institutions in dealing with localized climate change, especially in the case of floods and droughts (Ensor et al., 2018).

NGOs are important in ensuring climate resilient livelihoods, access to climate information, and improving local governance structures. But at the

same time, the dependence on NGOs also reveals the weakness of governance, as the interventions of NGOs are project-specific and time-bound. Without integrating successful local adaptation experiences into national policy structures, effective adaptation at the local level can remain in isolation (Adger et al., 2018).

9. Research Gaps and Future Directions

Climate change and food security studies have shown a sharp rise in publications over the last decade, with major themes centered on the effects of crop yield, climate modeling, and vulnerability studies (Abid et al., 2016). However, major gaps continue to exist. First, there is a lack of interdisciplinary studies on climate science, nutrition, economics, and social equity. Second, the effects of extreme weather events on food access and utilization, apart from food production, are unexplored.

Systematic reviews of flood- and drought-affected areas, such as Nepal and South Asia, have shown limitations in methodology, including short-term studies, a lack of longitudinal studies, and inadequate focus on informal food systems (Tome et al., 2022). Future studies should focus on adaptation strategies, indigenous knowledge systems, and the effectiveness of policies in the context of compound climate extremes. Furthermore, there is a need for more empirical evidence on the effects of climate finance and governance reforms on food security outcomes.

Conclusion

This review synthesizes evidence to demonstrate that climate change, through the occurrence of extreme weather events, is a profound and multidimensional threat to food security on a global perspective. Climate change agreements are of the utmost importance in normative support but have no applicability in terms of food security adaptation. Governments are becoming increasingly cognizant of the risks associated with climate change but have no implementation, investment, or governance coherence. Climate change financing and sectoral interventions by NGOs have promising roles in building resilience but need institutionalization and equity-focused design. The future of food security in the context of climate extremes requires a governance approach, adaptation financing, and research that bridges the divide between disciplines and policies. Resilience in the food system is a high priority in climate change adaptation and a fundamental imperative in sustainable development.

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