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Chapter

# Climate Change and Food Safety

*Suneeta Chandorkar*

## Abstract

Climate change causes an increase in global temperatures and a shift in weather patterns. Increased carbon emissions are one of the leading causes of climate change. Temperature and humidity increases are conducive to the growth of potentially toxin-producing microorganisms and may favor invasive alien species detrimental to the health of plants and animals. This is causing foodborne illness outbreaks. The acidification of ocean and sea water, the proliferation of toxic phytoplankton, and the contamination of seafood are all caused by rising ocean temperature. The degradation of water and soil quality has led to over 600 million cases of waterborne and infectious diseases. Extreme temperatures and increased precipitation also result in decreased fodder, overcrowded livestock accommodation, an increase in morbidity, and an increase in the use of pharmaceuticals, specifically antibiotics. Pathogens from effluent and heavy metals contaminate the water and soil, and the increased absorption of heavy metals by fish is correlated with ocean warming, hypoxia, and increased salinity. Bioaccumulation of heavy metals higher up the food chain poses a larger threat to human health. The threat of climate change can be mitigated by reducing greenhouse gas emissions or by modifying human behaviour to account for inevitable climatic changes.

**Keywords:** climate change, food safety, heavy metals, pesticide residue, antimicrobials, mycotoxins

## 1. Introduction

Climate change has been defined as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability, observed over comparable time periods" [1]. Climate change is a global phenomenon that extends beyond environmental and ecological concerns, impacting all natural systems and posing a threat to global development goals. Climate change refers to the increased severity and frequency of meteorological phenomena such as extreme temperatures, heavy precipitation, intense cyclones, drought, and flooding, as well as global warming. Floods, droughts, and cyclones are estimated to have caused 15 times more damage in regions with high vulnerability than in regions with low vulnerability over the past decade. Moreover, socioeconomic disparities within a region or nation can have a disproportionately negative effect on vulnerable groups [2]. Climate change has an impact on every aspect of our environment, including the air, water, soil, food systems, and livelihoods. According to the Sixth Assessment Report of the

Intergovernmental Panel on Climate Change (IPCC), up to 3.6 billion people reside in areas that are extremely vulnerable to the effects of climate change. Foodborne and waterborne illnesses are brought on by the degradation of soil and water quality. Worldwide, there are reportedly more than 600 million cases of infectious disease. Additionally, foodborne illnesses cause 125,000 child deaths annually, with children under the age of five bearing 40% of the burden [3]. Climate change has led to the loss of agriculture and marine productivity, loss of biodiversity, disruption in food supplies, and food price volatility, thereby affecting the quantity and quality of food consumed, thus jeopardizing food and nutrition security. In 2020, between 720 and 811 million people faced hunger, primarily in Africa and Asia [4]. Although the effects of climate change on the availability and production of food are extensively studied yet the effects on food safety have received little attention. The scientific method or discipline of food safety describes the handling, preparation, and storage of food to prevent foodborne illness [5].

Changes in climate have multiple effects on food safety. Temperature rise and increased precipitation are conducive to the occurrence, persistence, and virulence of several microorganisms associated with foodborne diseases. Additionally, it promotes the growth of plant parasites and weeds. This leads to an increase in the use of hazardous compounds in the form of pesticides, which endangers food safety. Parasites related to livestock diseases are also affected by climate change [6]. Temperature extremes and increased precipitation may result in decreased fodder, crowded livestock lodging, an increase in morbidity due to heat stress, and an increase in the use of drugs, particularly antibiotics, leading to drug and antibiotic resistance among consumers. Water and soil are contaminated by pathogens from effluent and heavy metals because of flooding. Increased heavy metal absorption in fish is correlated with ocean warming, hypoxia, and increased salinity. Bioaccumulation of heavy metals up the food chain poses a larger threat to human health. The various pathways through which climate change affects food safety, adaptation, and mitigation are discussed in detail herewith [7, 8].

## 2. Causes and impact of climate change on food systems

Climate change is a complicated phenomenon involving long-term alterations in temperature and weather patterns. The changes may be natural or caused by human activities. Since the 1800s, these changes have been largely caused by human activities, such as the burning of fossil fuels, rapid industrialization, modern transportation methods, and extensive food supply chains, to mention a few. These human activities have increased the production and presence of greenhouse gases (GHGs), such as carbon dioxide, methane, hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), nitrous oxide, and ozone, in the lower atmosphere layers. These gases capture the sun's energy, resulting in higher global temperatures than would otherwise be the case, or the greenhouse effect. Carbon dioxide (79.4%) is the most significant contributor to GHGs, followed by methane (11.5%), nitrous oxide (6.2%), and chlorofluorocarbons (3.0%) [9]. In 1990, the first Intergovernmental Panel on Climate Change (IPCC) report stressed the need to control climate change, which was emerging as the greatest problem of the twenty-first century. The challenge is to limit global warming to 1.5°C above preindustrial era. The presence of GHGs has affected the food system, i.e., life on land and water through various pathways [10].

Increased atmospheric carbon dioxide levels have caused the acidification of water bodies. Ocean acidification diminishes its capacity to retain oxygen, resulting in hypoxia. It is estimated that over the past 50 years, the open oceans have lost 77 billion tons (2%) of their dissolved oxygen stock, which has grave consequences for the survival of marine life. Numerous marine species, such as the commercially valuable Atlantic Cod, become extinct, or species, such as krill, migrate to the Polar Regions. The rising ocean temperature is conducive to the development and proliferation of algal species that cause ciguatera [11].

As temperatures and $CO_2$ levels rise, glaciers are melting. Between 1961 and 2016, a period of over four and a half decades 19,000 glaciers across the globe lost about 9000 billion tons of ice, with losses accelerating over the past three decades [12]. The risk of flooding is increasing as sea levels rise due to melting glaciers, warming oceans, and increased unseasonal precipitation with insufficient snowfall. The melting of glaciers and permafrost (frozen water in the subsoil layers) is releasing into the environment once-buried chemicals such as pesticides, heavy metals such as mercury, dormant ancient strains of harmful bacteria and viruses, and micro-plastics [13]. Algae are found in both salt and fresh water. Algae can rapidly develop and multiply under ideal conditions such as enough light availability, warm seas, and high nutrition levels, resulting in "blooms." Algae blooms can harm aquatic environments by blocking sunlight and depleting oxygen, limiting the growth and survival of other aquatic creatures. Certain algae species, such as golden and red algae and certain forms of cyanobacteria, can create strong toxins that can harm wildlife and humans by causing liver and nervous system damage. Harmful algal blooms (HABs) are those that damage aquatic ecosystems or have the potential to impact human health. Climate change may promote the growth and dominance of harmful algal blooms through a variety of mechanisms including:

- Warmer water temperatures
- Increased salinity
- Increases in atmospheric carbon dioxide concentrations
- Changes in rainfall patterns
- Intensifying of coastal upwelling
- Sea level rise

Ocean acidification may increase phytoplankton methyl mercury (MeHg) assimilation by promoting the growth of a small species that accumulates MeHg efficiently. Human activities, namely, waste disposal through incineration and industrial processes, are predicted to raise atmospheric mercury levels over the coming centuries. The ability of deeper waters to sequester mercury may be overwhelmed as a result of these human activities and ocean warming, resulting in higher concentrations of the neurotoxin in surface waters and, thereby, in the food chain [14, 15].

Animals produce greenhouse gases and are therefore both contributors to and victims of climate change. In some regions, increased temperatures will lengthen the grass-growing season, allowing for more extensive livestock grazing and greater exposure to vectors and wildlife [16]. It has been hypothesized that high temperatures caused by climate change could contribute to heat stress in livestock, resulting in an increase in the release of enteric pathogens that could overwhelm food control systems and enter the food supply [17, 18]. To avoid excessive exposure and stress, more animals may be brought indoors in some regions, thereby increasing the likelihood of disease transmission.

Climate change has had significant effects on both biotic and abiotic factors that contribute to agriculture. Climate change influences the prevalence of microorganisms such as fungi and viruses, as well as the populations of insects, parasites, and other vectors. Abiotic factors, such as air pollution, nutrient deficiencies, and extreme temperature, have an impact on soil quality, plant health, and crop yield [19].

Thus, climate change poses a threat to food safety via both biotic and abiotic routes or sources. These factors operate through the food system both plant and animal-based foods and feeds. The biotic sources include algal blooms, mycotoxins, insects, and pathogens, while the abiotic sources include increased exposure to heavy metals, pesticide residues, and drug residues. The impact of human activities on climate change and methods for mitigating their negative effects to promote food safety are discussed.

### 2.1 Climate change agriculture and food safety

By 2050, the global population is projected to reach 9.3 billion, necessitating a 50–60% increase in food production to sustain it. (FAO) The increased food demand necessitates intensifying agriculture by increasing the use of fertilizers and pesticides to prevent food loss due to the increased presence of parasites caused by climate change [20].

Agricultural production has witnessed a ninefold increase in the use of synthetic nitrogen fertilizers and a threefold increase in the use of phosphorus fertilizers over the last four and a half decades, and this usage is estimated to increase by 40–50% over the next four decades [21]. Only 42–47% of nitrogenous fertilizers are assimilated by plant vegetation, while the remainder escapes into the atmosphere or enters water bodies, where it promotes the initiation and persistence of harmful algal blooms (HAB). Algal blooms are associated with phosphorus accumulation in freshwater sources. Blooms of *Prorocentrum* spp., *Karenia mikimotoi*, and others are not only spread over a larger area but are present longer because of China's increased fertilizer use. Between 2008 and 2012, the total economic cost of HABs in China was approximately USD 364 million [22]. Increased frequency and intensity of extreme events, such as hurricanes, can cause enormous release of nutrients and organic matter from watersheds into coastal waters, thereby fostering algal blooms. The Chesapeake Bay region of the United States experienced a massive bloom in 2003 as a result of conditions caused by Hurricane Isabel. Deep-water upwelling, which brings nutrients from deeper waters to the surface and causes algal blooms days after the passing of a hurricane, also contributes to a phytoplankton bloom caused by a hurricane. In 2007, a phytoplankton bloom was caused by Hurricane Gonu in the Arabian Sea [23]. Several HAB-forming species have expanded their geographic distributions over time. In the 1970s, *Alexandrium tamarense* and *A. catenella*, the organisms responsible for paralytic shellfish poisoning (PSP), were found in temperate coastal regions of Europe, Japan, and North America. They have since migrated to the Southern Hemisphere, where they have caused toxic blooms along the coastlines of Australia, New Zealand, Papua New Guinea, and South Africa. In addition, new PSP-causing species (*A. fundyense*, *A. minutum*, and *A. cohorticula*) have been identified off the coasts of Brunei, India, Thailand, and the Philippines [24]. In 2012, PSP-causing Alexandrium species were discovered in subpolar regions off the coast of Greenland for the first time. Globally, approximately 2000 cases of PSP are reported annually, with a mortality rate between 15% and 50% [25]. Consequently, the inhabitants of these regions are either exposed to mycotoxins or face food insecurity due to restrictions on fishing.

Mycotoxins, which are metabolites of fungi that thrive on starch and oil seed crops, pose an important threat to food safety [26]. *Aspergillus*, *Fusarium*, *Penicillium*, and *Claviceps* contain the vast majority of toxigenic food and forage species. Agriculture is concerned with five mycotoxins: aflatoxins, ochratoxin A, fumonisins, deoxynivalenol, and zearalenone. According to data collected between 2006 and 2016, these mycotoxins accounted for 55, 29, 61, 58, and 46% of occurrences in cereal grains. Similar outcomes emerged from the analysis of submitted feed samples [27]. There is an insignificant reduction in the mycotoxin content on processing of food, except through dilution; hence they pose a major challenge to food safety. As reported by the Foodborne Diseases Burden Epidemiology Reference Group of WHO, aflatoxins are associated with the highest number of global DALYs (636889) attributable to liver cancer [28]. Concomitant exposure to aflatoxins and hepatitis B virus infection is responsible for about 5–28% of all cases of hepatocellular carcinoma in the world. Other mycotoxins have harmful effects on the kidneys, reproductive system, immune system, and gastrointestinal system [29]. Animal feed is frequently contaminated with multiple toxins, in addition to human food. Recent reports indicate that 64% of the feed samples submitted for analysis, primarily from sub-Saharan Africa, Southeast Asia, and South Asia, contained two or more mycotoxins. When mycotoxin concentrations exceed the regulated or recommended levels, animal protein losses and contamination of animal products such as milk occur leading to a negative impact on human health and nutrition [27]. Alterations in the prevalence patterns of various mycotoxins have also been caused by the introduction of novel feed sources, such as food refuse. Due to a shift toward more plant-based feed, mycotoxins are also becoming a developing concern for the global aquaculture industry [29].

Mycotoxin mitigation calls for good agricultural practices, Pre- and postharvest measures, such as biological and chemical procedures and the choice of suitable packaging materials for storage such as Purdue Improved Crop Storage (PICs) bags. Biological control agents can be used as one of the mitigating strategies. Commercial crops like groundnuts, maize, pistachios, and cottonseed are sprayed with nontoxigenic *Aspergillus flavus* fungal strains that out compete toxic strains during preharvest. Enzymes have fewer safety concerns, are easier to use, and are more specific than bacteria when it comes to biocontrol [30].

### 2.2 Climate change human behavior and food safety

Indirect threats to food safety occur due to climate change. Prolonged warmer seasons influence consumers' behavior and practices associated with food. Climate change presents indirect dangers to food safety. Prolonged milder seasons influence consumer behavior and food handling and storage practices, which can increase the risk of human exposure to foodborne pathogens [24]. During the summer, outdoor cooking and picnics can pose difficulties in terms of temperature-safe food storage and cross-contamination of cooked and uncooked foods. There is a correlation between environmental stressors and an increase in food safety violations due to a decrease in food safety inspections [31]. Water scarcity can affect the transmission of foodborne pathogens such as Listeria monocytogenes by compromising hygienic conditions in food processing facilities, hand hygiene of food handlers, and equipment sanitation. A lack of water may compel farmers to irrigate their crops with surface water containing pathogens that cause foodborne illness [32]. A rise in ambient temperatures affects the entire food cold chain, from the initial refrigeration or freezing of food to its transportation, storage, and retail display. Increasing ambient temperatures and elevated food storage temperatures will increase the probability that humans will consume unsafe food [33].

According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the average increase in global surface temperature will range between 1.7 and 4.8 degrees Celsius by the end of the twenty-first century [34]. This projected increase in temperature as a result of climate change could impact the microbiological stability of nonrefrigerated food products by increasing the growth potential of spoilage microorganisms during transportation and storage (on retail and domestic levels), thereby increasing the risk of spoilage and resulting in significant economic and material losses. Increased temperature, humidity, and precipitation promote the proliferation of fungi. *Aspergillus* and *Fusarium* species are the predominant fungi responsible for contaminating cereal grains. Maize is the most susceptible crop to *Fusarium* spp. contamination, while maize is the most susceptible crop to Aspergillus spp. Temperature and water activity (aw) have been found to affect the growth of both fungi, with the latter being the most significant growth factor [35].

### 2.3 Climate change livestock and food safety

There is substantial evidence that climate change will impact the entire livestock food supply chain, from farm production to processing operations, storage, transportation, retailing, and human consumption. As has been stated previously, pests and pathogens are expanding their geographic presence due to climate change, resulting in an increase in antimicrobial use. Natural selection has led to the emergence of antimicrobial-resistant pathogens due to the rampant and indiscriminate use of antimicrobials in humans and the extensive use of medically important antimicrobials in terrestrial livestock production, aquaculture, and crop production. Approximately 73% of global antimicrobial use is in meat production, and antimicrobial resistance in food-producing animals is growing. According to research, 40% of chickens and 30% of pigs raised for human consumption in LMIC failed to respond to antibiotics used to treat disease more than 50% of the time [36]. Antimicrobial resistance has grave consequences for public health, with an estimated 700,000 people dying annually from drug-resistant diseases (including nonfoodborne diseases). Extreme weather that causes flooding, such as hurricanes, increases the likelihood that areas containing animal farm waste containing antibiotics will be flooded. This increases the spread of antibiotic-resistant bacteria in the surrounding environment [37].

Climate change and the lengthening of food chains increase the likelihood of contamination issues arising from foodborne pathogens and parasites, so it is crucial to raise awareness of this in order to mitigate public health risks. When national and regional health authorities in different sectors, medical and scientific research communities, and the agri-food industry collaborate, more effective regulations and guidelines can be developed to improve public health.

Heavy metal contamination of animal feeds is yet another major food safety concern. The two most common routes for entry of heavy metals in animal feeds are the natural route through metal corrosion and atmospheric deposition in soil and water, and through the anthropogenic activities such as the application of fertilizer, pesticides, and mining. The animal feeds grown in the contaminated soil and/or by application of contaminated water lead to entry of heavy metals into feeds and animal foods. Not only do heavy metals in animal feed endanger animal health and reduce animal productivity, but they also contaminate animal products, posing risks to humans [38].

The heavy metals of concern are cadmium, chromium, arsenic, lead, and mercury. Based on the morbidity and mortality of humans, mercury is regarded as one of the most toxic materials. Heavy metals are nonbiodegradable (they are excreted at much slower rates than they are absorbed), and as a result, their concentration within an organism builds over time (bioaccumulation). Bio-magnification causes their concentration to increase as we ascend the food chain. Cadmium and mercury are two examples. Once heavy metals enter living organisms, they undergo transformation and are converted into more reactive or toxic forms, such as mercury being converted in vivo to methyl mercury [39]. Once they enter the human system, all the heavy metals get stored in the liver and are excreted through the kidneys. Cadmium overexposure has been linked to renal dysfunction, lung insufficiency, and osteomalacia. The primary target of mercury is the kidney. Necrosis of the tubular epithelium following acute poisoning can lead to renal failure within 24 hours. After prolonged exposure, tubular necrosis in the kidney and glomerulonephritis are the most prominent toxic effects of mercury. Chromium is required for the normal metabolism of carbohydrates, lipids, and proteins in animals and humans. However, elevated chromium levels can lead to a variety of diseases, including liver cancer. Chromium enters the food system from soil or metal contact during harvesting and processing. Arsenic is a metalloid element and carcinogen associated with increased risks of numerous noncancer endpoints, such as diabetes, cardiovascular disease, and neuropathy. Reviews on the presence of heavy metals in animal feeds, vitamins, minerals, or supplements for livestock revealed that cadmium, chromium, arsenic, lead, and mercury are among the heavy metals present. However, because heavy metals have a propensity to bioaccumulate, they present a risk to both livestock and people even though the levels were below the tolerance limits set by the regulatory body. Although it is challenging to completely eradicate them, monitoring the presence of heavy metals in feeds and feed ingredients and implementing feed management and bioremediation strategies to lessen exposure can help reduce the risk of heavy metal toxicity throughout the food system [40].

### 2.4 Climate change adaptation and mitigation

Dealing with the threat of climate change can be done in one of two ways:

i. Mitigation, which involves reducing GHG emissions, and

ii. Adaptation, which entails changing human behavior to account for the unavoidable changes in the climate.

In order to track greenhouse global warming, the level of $CO_2$ emissions should be reduced by 50% over the next 50 years, according to documented scientific evidence. As a result, taking quick action is crucial to avoiding the worst-case scenarios. Major climate change adaptation measures include, among other things, the development of rainwater storage systems and the strengthening of protective levees along coastlines. Major climate change mitigation actions include increased energy efficiency, expanded use of renewable energy, and slower deforestation. One of the biggest consumers of energy worldwide is transportation. Therefore, it is necessary to address fuel efficiency. Good agricultural practices should be taught in schools. For instance, methods to extract $CH_4$ from animal waste or landfills and convert it into electricity can be developed. Alternative energy sources include geothermal energy from rocks for the production of electricity, biofuels, and nuclear power, as well as solar energy, which can be used in photovoltaic cells, hydropower to create hydroelectricity, wind energy, which is captured by wind turbines and wind farms, and hydropower. Other approaches are carbon sequestration in natural systems, such as the soil, through large-scale reforestation, the increase of organic matter in the soil, and farming techniques, such as no-till farming and crop rotation and research [41]. Other approaches include the promotion of minimally processed foods, short food supply chains through the promotion of local and indigenous food systems. Empowerment of the different actors in the food chain to implement food safety management programs in the production systems is also key. In addition to law enforcement, a critical review of existing food laws and standards is also needed in order to adapt to emerging risks and threats. Hence, developing food safety preparedness plans in the event of natural disasters should also be a national priority for every country. Finally, education and awareness campaigns on food safety, sustainable production, and consumption of foods with due emphasis on curbing food loss and waste, a major source of GHGs [42].

Transport is one of the most significant energy consumers in the world. Consequently, fuel efficiency must be addressed. Good agricultural practices must be inculcated in the field of agriculture. For instance, techniques can be developed to capture $CH_4$ from landfills or animal waste for the production of electricity. Alternative energy sources include solar energy, which can be utilized in photovoltaic cells, hydropower to produce hydroelectricity; wind energy captured by wind turbines and wind farms, geothermal energy from rocks for the production of electricity, biofuels, and nuclear energy [43]. Other strategies include carbon sequestration in natural systems, such as the soil, via large-scale reforestation, the increase of organic matter in the soil, and farming techniques, such as no-till farming and crop rotation, as well as research. Other strategies include promoting minimally processed foods and short food supply chains by promoting local and indigenous food systems. Key is also the empowerment of the various food chain actors to implement food safety management programs in production systems. In addition to law enforcement, a critical review of existing food laws and standards is necessary to adapt to new risks and threats. Consequently, the development of food safety preparedness plans in the event of natural disasters should be a national priority across the globe. Education and awareness campaigns on food safety, sustainable food production, and consumption, with an emphasis on reducing food loss and waste, can help in reducing greenhouse gas emissions [44].

Existing greenhouse gases will continue to contribute to global warming; accordingly, parallel adaptive measures are required. Building of rainwater storage systems to alleviate damage caused by floods, with the water being reused during drier periods, development of crop strains that require less water and soil moisture, precision agriculture to manage resources, namely water, and use of fertilizers and pesticides can reduce GHG emissions considerably. Precision application of fertilizer decreased methane and nitrous oxide emissions by 1% and 16%, respectively, over conventional methods. Direct-seeded rice (DSR) produces fewer GHG emissions than transplanted rice. Dry DSR and wet DSR have 76.2% and 60.4% less global warming potential than transplanted rice, respectively. In addition, wet DSR produced a 10.8% greater yield than transplanted rice. Aerobic rice has enormous potential for mitigating future climate change, as it conserves 73% of irrigation water used in land preparation and 56% of irrigation water used during crop growth. Utilizing micro-irrigation technologies to cultivate aerobic rice is an appropriate method for sustainable rice production. It also aids in reducing rice field methane emissions [45].

## 3. Conclusions

Climate change has impacted food safety through multiple pathways, which could lead to an increase in the risk of foodborne illness and impact millions of people's access to safe, nutritious food around the world. The food contamination issues also threaten the Sustainable Development Goals (SDGs), particularly SDG 2 (zero hunger), SDG 3 (good health and well-being), SDG 6 (clean water and sanitation), SDG 8 (decent work and economic growth), SDG 10 (reduced inequalities), SDG 12 (responsible consumption and production), and SDG 13 (reduced inequalities) (climate change). Timely measures to adapt and mitigate the effects of climate change are required to promote human and planet health.

## Conflict of interest

None.

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