Chapter 2
Dynamics of Climatic Change and its Impact on Living Organisms

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Abstract: Climate change is a pressing global issue, driven primarily by human activities that release greenhouse gases into the atmosphere. This chapter discusses the dynamic nature of climatic change and its profound effects on the world's ecosystems and living organisms. It emphasizes the interconnectedness of the earth's climate system and the intricate web of life it supports. This chapter evaluates how climate change directly impacts human societies and their relationship with the environment. It also describes the role of climate change in causing diseases and the biological response and physiological changes that occur in the body under changing climate. Furthermore, we have added a section on how climate change affects our agriculture. Understanding the dynamics of climate change and its impact on living organisms is essential for informed decision-making and shaping a more sustainable and resilient future.

Keywords: Climate change, Viruses, Diseases, Agriculture, Resilience

1. Introduction

Climatic change is the ultimate challenge of our time. In 2021, at the Glasgow conference (COP26) of the United Nations Climate Change Conference, world leaders urged policymakers to take necessary actions to counteract the climatic crisis (Atwoli et al., 2021). According to Atwoli et al. (2021) an increase in the global

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temperature above 1.5 °C when compared to 1990 levels directly influences the increase in the rate of infectious diseases globally. A report submitted by the Intergovernmental Panel on Climate Change in 2021 on global warming stated that an increase in 1.5 or 2 °C in overall temperatures globally would cause an increase in vector-borne diseases such as dengue and malaria (Hoegh-Guldberg et al., 2019). The increase in climate change affects both pathogen and vector distributions, which is linked to other ecological challenges leading to loss in biodiversity and ecological loss (Hess et al., 2020).

The human population is highly sensitive to heat wave attributes, leading to higher mortality rates in elderly people, children, and people with pre-existing factors (Basu and Samet, 2002). In 2003 the heat wave death toll was recorded as 70,000 in Europe (Robine et al., 2008). With the help of apparent temperature (AT), Fischer and Schär found the adverse effects of severe heat and health issues on human beings in southern Europe and the Mediterranean (Fischer and Schär, 2010). Two factors that lead to the mortality rate in humans are thermal stress and thermal strain (Jendritzky and Tinz, 2009). Thermo-physiological factors also play an important role in determining the impact of heat stress on human health. The production of heat inside the human body results from mental and physical activities, so the heat is dissipated through convection, conduction, radiation, respiration, and evaporation (Koppe et al., 2004). Heat extremes in Europe in the years 2015, 2017, 2018, and 2019 are because of anthropogenic climate change (Vautard et al. 2020). The populated and agricultural areas located at 30° latitude show more than 90% varied temperatures due to climatic change (Vogel et al., 2019).

The environment and other pathogens indirectly affect pathogens' life cycle and reproduction rate (Guerra et al., 2008). The survival of the mosquitoes completely depends on the temperature. The range between 22-23°C is highly vulnerable to the development of mosquitoes as temperature ranging from 25-26°C helps the spread of Japanese Encephalitis virus (JEV) (Tian et al., 2015). The temperature rise enhances the extrinsic incubation period EIP for a pathogen like *Plasmodouium falciparum,* where the incubation gets reduced from 26 days at 20°C to 13 days at 25°C (Harvell et al., 2002). Some factors increase the 'stochastic chains of transmission of the diseases' and enhance the pathogen's adaptation to the host, thus leading to faster emergence of diseases (Antia et al., 2003).

2. Climate and Diseases

Temperature plays a major role in spreading diseases with varied timing and intensities (Dobson and Carper, 1993). Prolonged exposure to high temperatures in various parts of the geographical location tends to spawn various infections (Epstein et al., 1998). The deadliest heat waves recorded during 2015-2019 have new temperature records. The transmission of dengue *Aedes aegypti* has increased to 8.9 and 15% for *Aedes albopictus* (Watts et al., 2021). Compared to the year1950, malaria transmission in Africa increased to 38.7% and 149% in the Western Pacific region by 2015-2019. Malaria and Dengue are just two examples among several other diseases, expected to be altered due to climate change (Schaffner and Mathis, 2014). Not all cascading diseases are linked to climate change. The heightened spread of *Anopheles stephensi* from Asia into Africa is due to migration and not climate change (Sinka et al., 2020).

Extended high-temperature exposure to water bodies favours algal bloom and microorganisms' cell cycle. The bacterium *Vibrio* sps*,* commonly seen in the Baltic and North Sea, showed a higher growth rate during 2006 hot summers (Frank et al., 2006). In *Salmonella* sps based food-borne infections, the bacterial growth increases if the temperature rises between 7 and 37°C. The rise in temperature doesn't favor the growth of all the microorganisms, especially *Campylobacter* spp, a food-borne bacterial pathogen, concentrated on the surface of the water bodies during the winter season when the temperature is low (Jones, 2001). The UV (Ultra Violet) prohibits the growth and survival of *Campylobacter* spp (Obiri-Danso et al., 2001). Precipitation plays an important role in water-borne pathogen survival and development. During the rainy season, there is an increase in sedimentation stirring, leading to fecal microorganism accumulation (Jofre et al., 2009). When the precipitation happens after a prolonged drought, this leads to disease outbreaks (Wilby et al., 2005).

The change in humidity also impacts the pattern of waterborne diseases. According to Lowen et al. (2007), the spread of the influenza virus is high during cold temperatures and low humidity levels. The survival of water-borne viruses near the surface is reduced due to the drying effect (Gerba, 1999). Thu et al. (1998) found that humidity during the rainy season helps in dengue virus propagation leading to the outbreak of dengue hemorrhagic fever in Yangon and Singapore. Sunlight also favors pathogen development, where it synergistically helps multiply *Vibrio cholerae* in aquatic environments (Islam et al., 2009).

The presence of dust particles in the wind during Asian Dust Storms (ADSs) increases the chances of cultivable bacteria, fungi, and fungal spores (Griffin, 2007). The concentration of influenza virus in the air is higher during ADS days than on normal days (Chen et al., 2010). The infectious virus particles present in the air can be transported across the ocean by the help of dust particles (Griffin, 2007). In India, there is a sudden increase in rainfall and glacier lake outburst floods (GLOF), especially in mountain regions. After the flood in 1988 in West Bengal, there was an outbreak of diarrhea that killed 276 people and respiratory infections. During flooding, there is an increased vector, rodent-borne infections, and malaria (Ahern et al., 2005). At the time of the flood in Bangladesh, there was a reported outbreak of rotavirus and leptospirosis (Fun et al., 1991). It is found that one-quarter of the reported childhood deaths in South Asia are due to diarrheal diseases. It is mostly due to unsafe drinking water and less availability of fresh water (Ezzati et al., 2004). During the winter season in China, the parasite *Schistosoma japonicum* found in the host *Oncomelania hupensis* has extended its range into Northern China (Zhou et al., 2010).

3. Malaria, Zoonotic Diseases and Disease Transmission

Malaria is a serious public health problem. More than 1 million deaths occur due to malarial infection worldwide, with 400-500 reported cases yearly (Hales et al., 2003). Drastic change in temperature, rainfall, humidity, use of insecticide, and drug resistance has a deteriorating effect on human health and the malaria transmission rate. In South Asia, malarial disease forms the major vector-borne disease among all (Hales et al., 2003).

In India, malarial infection has higher latitudes and altitudes due to complex climatic distribution and disease patterns. Reduced transmission rate leads to immunity loss in the population, which causes epidemic in the upcoming years (Gage et al., 2008). The first early warning for malarial infection was implemented in India (Kiszewsk et al., 2004). The month of rainfall accounted for 45% of the malarial transmission (Kiszewsk et al. 2004). It is predicted that by 2050s, the range of malaria vectors can shift geographically toward southwestern and northern States (Kiszewsk et al., 2004). They have a larger transmission window period in northern and western states when compared to the southern states. In the Indian sub-continent, malaria persistence can be seen in Orissa, West Bengal, and Southern parts of Assam, which can get shifted toward Coastal states of Southwestern India like Maharashtra, Kerala and Karnataka (Bhattacharya et al., 2006).

Climate change affects other vector-borne diseases such as Chikungunya, Dengue, Leishmaniasis, Lymphatic filariasis, onchocerciasis, and tick-borne diseases due to their geographical range and vector population shift. Vector-borne diseases caused by rodents were found to be higher during the rainy season due to their population abundance and distribution (Gage et al., 2008). Temperature and humidity greatly influence the survival and development of fleas, which directly influence the plague incidence (Gage et al., 2008). *Rickettsia typhi* caused murine typhus disease is transmitted through fleas, which exhibit similar climatic sensitivity (Gage et al., 2008). The mosquito vector *Aedes aegypti* carries arboviral diseases such as chikungunya and dengue. The first outbreak of chikungunya reported in 1963 in Calcutta continued till 1973 (Mavalankar et al., 2007). In 2005 the virus remerged with a rapid spreading rate affecting one million people (Epstein, 2007). Dengue outbreaks (50 times) were also reported in India since 1960 (Majra and Gur, 2009). The vector's activity and the virus's transmission rate depend highly on temperature and rainfall (Gage et al., 2008).

The transmission of disease can be either direct or indirect. Direct transmission is from human to human, whereas indirect transmission is through any vector source. In African highlands, there is an association between malarial transmission and temperature variability (Bouma, 2003). In the highlands of Kenya, the highest malarial infection was recorded during the highest rainfall

(Githeko and Ndegwa, 2001). Certain meteorological factors that can lead to hemorrhagic fever with renal syndrome are temperature, rainfall, and humidity (Xiao et al., 2014). The Human influenza virus is transported from Asia to America during winter months over the Pacific (Hamnett et al., 1999). The influenza outbreak can be seen in downwind regions of South Korea and Japan during the dust storm season (Chen et al., 2010).

The persistence of influenza infection during the winter season in Europe is correlated to the long hours in indoors (Lofgren et al., 2007). H5N1 outbreaks follow major bird migration flyways, confirming wild birds' key role in dispersing the virus across continents (Tian et al., 2015). During the holiday season, poultry markets are affected by human-infected avian influenza, which can transmit to migratory birds and lead to disease transmission (Wang et al., 2014). By the 1980s and 1990s, there was reported re-emergence of visceral leishmaniasis in the northeastern part of Brazil caused by rural-urban farmer migration. A cross-sectional study of diarrheal incidence in children under 5 is due to unprotected water sources and unhygienic practices during water scarcity (Lloyd et al., 2007). Due to water scarcity, the cases of diarrhea were increasing worldwide (Lloyd et al., 2007). In Southern Europe, territorial expansion has increased the risk of malaria and other tropical diseases (Semenza and Menne, 2009).

4. Extreme Weather

When the value of the recorded weather or climate variable goes beyond the observed value (upper or lower), such an event is noted as extreme. Some global extreme events were El Nino, La Nina, and Quasi-Biennial Oscillation (QBO); meteorological hazards include drought, heatwaves, and floods. These events occur only 5% of the time (Zhou et al., 2010). In 1983, the malaria outbreak was reported in Ecuador, Peru, and Bolivia, accompanied by the El Nino event (Nicholls, 1993). By 1988 El Nino winter and 1999 La Nina winter, there was a 10% increase in diarrhea for each 2.5 h water exposure weekly (Dwight et al., 2004). Extreme weather has varied magnitude effects on health. Hemorrhagic Fever with Renal Syndrome (HFRS) was high during the 1954, 1975, and 1991 floods. By 1998 floods, the symptoms of HFRS decreased; when there is an increased population of rodents, there is a sudden increase in the disease outbreak, and declines when the rodent population is reduced (Huaxin et al., 1999).

The Severe Acute Respiratory Syndrome amplifies during global travel. As in human pathogenic avian influenza (HPAI) tends to be heightened during bird migration. However, the poultry trade plays a major role in the spread (Wei et al., 2015). The use of mitigators helps in the reduction of the disease, eg. Smallpox and rinderpest have been eradicated with the help of vaccine development (Mariner et al., 2012). According to Lubchenco and Karl (2012), the impact of extreme weather can be predicted based on the frequency of the climatic variables. The increase in the ultraviolet-B radiation disrupts the ozone at the stratospheric layer.

This happens when the reaction occurs between the ozone layer and the free radicals from chlorofluorocarbons (Molina and Rowland, 1974). Extreme UV causes skin cancer, cataracts, and immune suppression in humans and animals. It also impairs the antigen presentation by Langerhans cells (Cruz and Bergstresser, 1988). It also lowers lymphokine production, reducing the secretion of T-helper cells and T-suppressor cells at a systemic level. Exposure to UV can alter the course of infectious diseases like onchocerciasis and dermatophytosis, where skin acts as the first way of entry.

Extreme UV impairs the defense against intracellular pathogens to leprosy antigens (Daynes, 1990) (Table 1).

Table 1. Extreme weather events and its adverse effect on humans

S. No	Events	Disease	Findings	References
1	El Nino	Vector Diseases	Malaria outbreak, Hantavirus Cardiopulmonary syndrome Colorado Plateau	Haines and Patz, 2004, Hjelle and Glass, 2000
2	El Nino	Water-borne disease	Exposure to California coastal waters during an El Nino winter increases the risk of diarrhea.	Dwight et al., 2004
3	La Nina	Vector-borne disease	La Nina caused drought connected to the Chikungunya fever epidemic, West Nile fever, and Japanese encephalitis.	Chretien et al., 2007, Nicholls, 1993.
4	Heat waves	Vector-borne and Air-borne disease.	West Nile fever in Israel by 2000 also increases the risk for respiratory diseases.	Paz, 2006
5	Drought	Vector and Water borne diseases.	The diarrheal disease commonly affects the refugee camps. It is also associated with hantavirus pulmonary syndrome. Heightened risk of West Nile fever and St. Louis Encephalitis virus.	Shaman et al., 2002, Wang et al., 2010
6	Flood	Water-borne disease. Vector-borne disease	High water favors *Cryptosporidium* infection. In Lewes in Southern England, high floods cause gastroenteritis. Mozambique flood spreads malaria, typhoid, and cholera. Heavy rain leads to the Ross River fever outbreak. Malarial infection was observred in 1988 in Khartoum, Sudan. Diseases such as lymphatic filariasis, arbovirus disease, Hemorrhagic Fever with Renal Syndrome	Reacher et al., 2004, Mackenzie et al., 2000 Ahern et al., 2005. Woodruff et al., 1990. Huaxin et al., 1999, Cordova et al., 2000, Nielsen et al., 2002.

5. Human factor and social response

The risk of infectious disease can also rely upon social and economic factors. Certain populations and places are more vulnerable to risks associated with climatic changes (Wei et al., 2012). Malaria (*Plasmodium vivax*) and dengue spread due to urbanization (Shah et al., 2004). At times of water scarcity, the morbidity rate of diarrhea increases, especially when a population is restricted to water access. After a tropical cyclone, there is an increase in disease outbreaks (Balantidias outbreak in Turkey and typhoid fever in Mauritius) in developing countries than in developed nations (Guill and Shandera, 2001). In the developed nations, there is no increase in infection after the hurricane (Toole, 1997).

Climate change-induced health risk also depends upon the healthcare infrastructure and public health system. After Hurricane Flora in 1963, 75,000 cases of *Plasmodium falciparum* were reported in Haiti (Bissell, 1983). Similarly high frequency of dengue morbidity has been reported in Guatemala and Honduras after Hurricane Mitch in 1998 and malaria in Nicaragua. Furthermore, poor public health caused by severe earthquakes and hurricanes led to the spread of *Vibrio cholera* (Kouadio et al., 2012). The outbreak of mosquito-borne vectorial disease is due to inadequate measures in mosquito breeding sites. Improved extreme weather forecasts and meteorological hazards can reduce the health risks related to climatic change. Syndemics are the afflictions (two or more) that synergistically contribute to excess disease in a population (Rock et al., 2009). Public awareness campaigns help to reduce diarrheal and vector-borne diseases (Hamnett et al., 1999). In Botswana, a successful weather forecast system and an ocean-climate animal model helps monitor the malarial disease (Thomson et al., 2006). An early warning system is not always possible due to the less knowledge about climatic change (Cestari et al., 1995).

6. **Biological response**

Climatic change can influence pathogens, vectors, and defensive mechanisms of the host and habitat. The spread of vector-borne diseases by mosquitos is sensitive to meteorological agents, first said in the 1920s (Gill, 1920) and quantified in the 1950s. Extreme heat kills mosquitos, whereas warmer climatic conditions increase their production rate and biting activity (Leeson, 1939). The malarial protozoa take about 26 days for incubation at 20°C and 13 days at 25°C (Gill, 1920). Freezing temperature kills *Aedes aegypti* egg, larva, and adult. Changing weather and volatile conditions disrupt co-evolved insect species that prevent the spreading of ‘nuisance’ species (Epstein, 2007). The northern latitude part is subjected to regular seasonal changes. Repeated freezing and thawing in winter disrupt the forests, increasing their vulnerability to pest attacks (Lindgren, 2000). The pattern of global warming is seen at high altitudes in winter and nighttime above the earth's surface.

The warmer winters in the United States (US) facilitate the migration of ticks from the northern part bringing up tick-borne encephalitis and Lyme disease (Easterling et al., 1997). During global warming, the atmosphere holds 6% of water vapor for each 1°C warming, preventing the heat escape resulting in greenhouse warming. The higher rate of evaporation results in more intense tropical-like downpour. Repeated parching and warming of the earth results in intensified pressure changes drawing in tornadoes and larger weather systems (Karl et al., 1995). When atmospheric CO_2 increases, mosquito transmission rates increase from 45 to 60% (Martens et al., 1997), and the CO_2 change in the atmosphere is outside the bounds compared to the last

10,000 years. By the 1980s, malaria transmission was limited to California by vector control programs, whereas minor outbreaks were reported in Texas, Florida, New York, and New Jersey (Zucker, 1996). Malaria also came into South Korea, Southern Europe, and the Soviet Union. They are found to recolonize in the Indian Ocean, South African coastal areas and Dengue was found to be spread in Australia and Argentina (Epstein et al., 1998). Figure 1 depict impact of climatic change and its consequences on Nature.

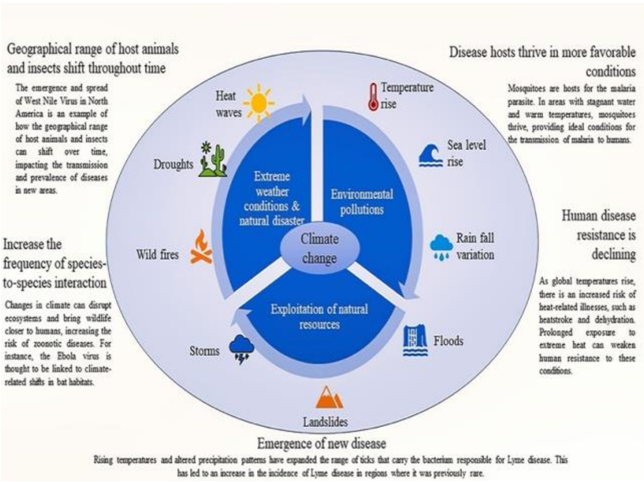

Figure 1. Impact of climatic change and its consequences on nature

7. Physiological changes

The human body responds to higher temperatures in two ways: by redirecting the blood flow to the skin to facilitate heat transfer from muscles to skin and by secretion of sweat to release excess body heat as the brain carries out the regulatory mechanism with additional inputs from the nerve cells (Kenny and Jay, 2011). They help the human body limit the rise in core temperature to avoid the negative effect on the body with a rise in a heartbeat. People with pre-existing cardiac conditions can experience compromised cardiac oxygen delivery, leading to cardiovascular collapse (Boyette and Manna, 2021).

Extreme sweating leads to dehydration, and if the water is not properly restored, it can decrease the blood volume, which strains the cardiovascular system. Finally, it leads to kidney fibrosis, chronic kidney disease, and acute kidney failure (Glaser et al. 2016). Sequential effects like oxidative stress and cardiovascular problems arise due to higher internal temperature. Also, people with a pre-history of respiratory conditions are known to show pulmonary edema and acute respiratory distress syndrome (Zanobetti et al., 2012). Air pollution during heat waves causes the second largest death after cardiovascular disease. The misfunctioning of organs can persist for years even after the injury period making them three times vulnerable to death from the injury compared to normal human beings (Wallace et al., 2007).

8. Morbidity and mortality

The severity of climate-related death and disease highly depends on the growth, age, adaptation, and developmental process choices (Russo et al., 2019). The mean surface temperature value rise has been noticed since 1950. In certain regions, instead of once in 20 years, an extremely hot day could become once in two years. The mean peak temperature at the Artic part will be 5·04 to 6·29°C whereas the border shared by the USA is ranged between 2·57 to 3·09°C, which is higher than the suggested one (Schewe et al. 2019). Accepting the Paris Agreement to limit the temperature below 2·0°C increase could avoid from 70 to 1980 deaths per city related to extreme heat among fifteen cities in the USA. If the temperature is below 1·5°C increase from the projected temperature, the annual heat-related deaths can be reduced from 110 to 2720 (Lo et al., 2019).

The number of people exposed and in the vulnerable category increases with the additional warming unit. Climatic change can also have other heat-related hazards like wildfire and thinning of the ozone layer. Another major concern is the increasing urban population from 751 million in 1950 to 4.2 billion in 2018. By the year 2030 the total population living in urban areas is expected to reach 60% higher from 31 megacities to 43 megacities (DESA, 2018). By the end of 2050, the world population can reach from 6·9–12·6 billion to 8·5–10·0 billion. Older people are at high risk of dying from heart-related effects.

9. Emergence of new viral variants

The pathogen emergence from wild animals or domesticated animals to the human population has been seen in recent decades, from flu, Human Immuno Deficiency Virus (HIV-1, HIV-2), Middle East respiratory syndrome virus (MERS), to Severe Acute Respiratory Syndrome (SARS-CoV-2) (Karesh et al., 2012). To enter the human population, the pathogen must cross the human-animal barrier or evolve into human-human transmission. The contact between human and animal reservoirs happens when humans move into unoccupied regions. Nipah virus was identified in bats, particularly in flying foxes, which caused an outbreak among pig farmers in Malaysia by 1999 (Parashar et al., 2000). There are three main factors related to the outbreak in the pig farm expansion of farm area into bat-infested lands, overpopulation of the pig farm, and trading internationally leads to the spread of infection to other parts of the world (Malaysia and Singapore) (Field et al., 2001).

Intensification of meat consumption and application of antibiotics over domesticated animals carrying antibiotic-resistant strains can affect human health. Climate change alters species density and range, increasing the risk of zoonotic diseases. Some factors, like prolonged drought during climate change followed by heavy precipitation, led to the outbreak of pulmonary hanta virus due to the rodent population in 1993 (Patz et al., 1996). Similarly, due to climate change, Australia's black flying fox (reservoir of Hendra virus) population has moved southwards 100 km in the past 100 years. This affected the horse population and entered into humans (Martin et al., 2018). The spread of Zika virus (through the vector *Aedes aegypti*) and chikungunya (through the vector *Aedes albopictus*) due to urbanization has increased. *Aedes aegypti* has the strongest attraction for human odor and is involved in the transmission of arboviral diseases (Rose et al., 2020). A dense population with highly connected urban areas is a hot spot for the spread of COVID-19 and SARS.

The outbreak of Influenza can be seen in more populated and denser regions as well as in the case of the COVID-19 pandemic (Rader et al., 2020). Climate change can affect the pathogen environment (bacteria and fungi); the causative agent for coccidioidomycosis (*Coccidioides* spp) increases with increased sporulation upon favorable conditions. Climate change also produces drug-resistant strains like *Candida auris,* which has heat tolerance gained during climate change compared to other closely related species (Du et al., 2020). The causative agent for cholera is *Vibrio cholerae,* commonly found in aquatic environments. The rise in global temperature (El Niño) and sea level, led to the multiplication of bacteria causing an epidemic locally. With proper sanitation, the disease can be lowered in many places (Colwell, 1996). The population's susceptibility to a particular disease increased when the vaccine was not properly administered. The measles outbreak in 2018 in Madagascar affected 100,000 individuals. Improving vaccination and serological surveys enhances the immunity of a population.

10. Climate change impact on agriculture.

Farming depends on the climate and its long-term effects. In order to maintain productivity on par with current climate change, optimum farming changes must be made (Gornall et al., 2016). Extreme temperatures during the growing season affect income, productivity, and security. The seed crops of the cooler season and cereals show an increase in productivity towards north latitudes (Maracchi et al., 2005). By 2050s, there will be a 30% increase in crop yields, such as maize, sunflower, and soybeans in southern Europe (Ewert et al., 2005). Also, wheat production increases from 37–101% by 2050. Moderate climate change doesn't affect crop production, but an increase in climatic conditions affects the temperature. The increase of 2^{o}C in mid-latitudes increases wheat production by 10%. In contrast, in the low latitudes, wheat production decreases by 80% of the total agriculture depending on the annual rainfall. The rate and magnitude of the climate change affect the crop production (Reilly et al., 2003). The difference in the precipitation depends on the warming effects at different places globally.

11. Climate change and drought

Major places where crops like barley, rice, maize, sorghum, soybean, and wheat grow have experienced drought, based on the PDSI index (Palmer Drought Severity Index). The mean value of PDSI globally has also increased, according to IPCC (2007). Data suggest that greenhouse gas increases due to anthropogenic activity, along with the increase in the aerosol concentration in the air, which are some of the major causes for drought to occur (Burke et al., 2006). Climate modeling studies found that the places where drought is experienced have increased from 20-28% in the twentieth century (Burke et al., 2006). By applying national scale data for four crops (barley, maize, rice, wheat), the drought index can explain

75% of the Based on PDSI yield reduction (Li et al., 2009). The yield reduction values for rice are 5.82 and 11.98% for maize. The yield reduction for major crops can be more than 50% by the year 2050 (Li et al., 2009). In the mid and high latitudes, the impacts of droughts can be seen as long seasons and higher temperatures.

The models of global climate crop production and water resources show that reduced crop production in Russian regions can be overcome by increasing the production of other crops. In the end, it has only very small changes. The food system globally is responsible for 37% of the annual CO_2, CH_4, and N_2O emissions (Lynch et al., 2021). Half of the anthropogenic methane and three-quarters of anthropogenic N_2O were released by the agricultural sector. Overall decarbonization rather than specified agricultural practices can cut off these gases.

12. Heavy Rainfall and Storms

Heavy rainfall or less rainfall affects food and crop production. During flooding, water logging causes anaerobicity, affecting crop growth and leading to delayed farming (Falloon and Betts, 2010). Due to heavy rainfalls in August 1999, the quality of the crops worsened, followed by the fungal attack on grains (Kettlewell et al., 1999). The amount of rainfall is heavy when the temperature and CO_2 are doubled. When the wind speed reaches 74 mph, they are termed “hurricanes” in the Pacific (North) and Atlantic (North). The same wind speed is called a “typhoon” in the westernmost North Pacific. Cyclones appear throughout the year in the Western North Pacific region (Gornall et al., 2016).

Places having higher population rate is more vulnerable to these cyclone attacks, especially in North Indian Ocean parts like Myanmar, Bangladesh, India, and Pakistan, where unprecedented flooding takes place.

Cyclone Sidr cost 3500 lives in Bangladesh (2007), and cyclone Nargis cost 130,000 in Myanmar (2008). Cyclones also contribute to 20% of South Florida's annual rainfall, which helps relieve drought conditions. Hurricane Gabrielle (2001) and Fay (2008) ended the drought from 2000-2001 and 2006-2009, respectively (Abtew, 2019). The storm Fay brought 15 inches of rainfall, saving the region from water shortages and wildfires and preventing the entry of salt water into freshwater aquifers (Abtew, 2019).

13. Disease by Pests

Atmospheric change in carbon dioxide concentration indirectly affects the crops through pest infestation. Pests such as aphids and weevil larvae thrive well under elevated CO_2 conditions (Staley and Johnson, 2008). Global warming directly impacts the reduced overwintering mortality of the aphids making them more widespread. In the African continent, the change in rainfall affects the locust migration pattern in the sub-Saharan desert. Decreased rainfall and drought increase external stress causing mutation and increasing resistance to specific diseases in plants (Schmitt-Olabisi et al., 2020). The constant change in overall temperature causes unpredictable outbreaks of pests with higher magnitude. Elevated CO_2 level impacts C_3 and C_4 plants differently. CO_2 level affects the C_4 plants less when compared to C_3 plants (Tubiello et al., 2002). As the temperature rises, the metabolic rate of the insects doubles for each 10^oC.

The increased metabolic rate results in more food consumption, the population's size, and the time taken for a generation. Elevated temperature increases the herbivory nature of insects (DeLucia et al., 2008). Heavy rainfall also affects the insect's diapause stage, and the insect's eggs will be washed away in highly flooded areas. The impaired rainy seasons have effects on some insects like soil-dwelling wireworms (*Agriotes lineatus* L.), which affect underground crops such as potato, sugar beet, and corn, especially in grassland areas. They can become a serious threat during climate change (Johnson et al., 2008).

Insect distribution solely depends upon agricultural practices, climate, distribution of crops, and cultural practices. Low temperature plays major part than high temperature in their distribution pattern (Hills, 1987). Along with climatic condition, soil properties, and environmental structure also has greater importance in pest survival. Drought condition affects insects in various ways (I) dry climate influence the growth of insects; (II) certain plants that are stressed by drought condition attracts insects like bark beetles; (III) plants' secondary metabolites decrease during drought condition, which makes it vulnerable to insects attack (Yihdego et al., 2019). As a result of global warming, by the year 2055, the insect pests are expected to shift to greater altitudes.

European corn borer (*Ostrinia nubilalis* Hubner) has shifted 1000 km northward. About 97 species of non-native Lepidoptera (74%) have been established in Europe, 88 species have expanded their range (Lopez-Vaamonde et al., 2010). Elevated temperatures affect insects on the ground's surface more than those living inside the soil, where soil acts as an insulating medium (Bale et al., 2002). Aphids release pheromones at the time of elevated temperatures or are threatened by predators and parasitoids, which makes them vulnerable to attracting more predators. There is a chance of an increase in the whitefly population at higher humidity and temperature (Pathania et al., 2020). If a taxon is introduced into a particular region intentionally or unintentionally apart from its natural habitat, it is termed an invasive alien species (IAS) (Shine et al., 2000). Only a small proportion of this becomes economic pests, referred to as the “rule of 10,” where one in 10 becomes economic pests (van der

Zanden, 2005). The change in climatic conditions can influence the invasive pathway either positively or negatively. Based on the thermal limit of each living being, the increase in temperature affects each species and the ecosystem. Varied climatic conditions like storms, cyclones, and heavy winds transport the pest to newer locations where they are established (Skendžić et al., 2021). The hurricane of 2005 shifted the Cactus moth (*Cactoblastis cactorum* Berg) from a Caribbean island to Mexico, which resulted in an economic threat to 104 *Opuntia* species, among which 38 were endemic (Burgiel and Muir, 2010).

14. Increased Carbon dioxide concentration

The population of herbivore insects can be altered by increased atmospheric CO_2 levels which directly affects the feeding rate and growth rate of the pests (Fuhrer, 2003). Increased CO_2 level has a major impact on particular insect pest-host plant systems. Which affects wheat, rice, and cotton (C_3 crops) than corn and sorghum (C_4 crops). There will be a noticeable change in the chemical composition (high in starch and sugar) in the plant leaf, affecting the insects that feed on leaf parts by altering the carbon and nitrogen ratio (Lincoln, 1993).

A study conducted by Hamilton et al. (2005) on soybeans under elevated CO_2 shows that there was 57% more damage to the crop by Potato leafhopper (*Empoasca fabae* Harris), Mexican bean beetle (*Epilachna varivestis* Mulsant), and Western corn rootworm (*Diabrotica virgifera virgifera* LeConte), Japanese beetle (*Popilia japonica* Newman) compared to normal CO_2 conditions. Under such conditions, the herbivore insects consume more plant materials leading to a wider range of damage. A study by Stiling and Cornelissen (2007) demonstrated the adverse effect of elevated CO_2 on the biological parameters of herbivore insects, 17% increase in feeding rate, 22% lower in pest abundance, 4% increase in development time, and 9% decrease in growth rate.

15. Varied Precipitation Pattern and Increased Generations

Climate change has a higher impact on annual precipitation patterns resulting in lesser frequency and higher intensity. Such drastic changes in precipitation lead to sudden floods and droughts. Flooding leads to water stagnation which risks insects' survival, such as (aphids, mites, jassids, and whiteflies) (Pathak et al., 2012). Staley and Johnson (2008) stated that increased rainfall and drought condition affects (*Agriotes lineatus* L.) soil-dwelling wireworm, which affects potato, corn, and sugar beet. Drought conditions affect most herbivorous insects. Drought-induced stress attracts certain insect species by the disintegration of xylem, which attracts bark beetles. There will be less secondary metabolites production, which acts as a defensive mechanism (Yihdego et al., 2019). The generation time shortens with an increase in temperatures resulting in a greater number of species. Growing degree days (GDD) measure thermal tolerance developed during climate change. GDD is the minimum and maximum temperature threshold measure widely used in agriculture to assess insect phenology (Cayton et al., 2015). Increasing 2^{o}C leads to one to five additional life cycles a year, like in white butterflies (*Pieris brassicae* L.) (Bale et al., 2002).

Aphids indicate temperature changes with a lesser developmental threshold and shorter generation period (Menéndez, 2007). High temperatures tend to shorten the larval and nymphal stages making it to attain adult much sooner (Menéndez, 2007). This results in the faster reproduction rate of particular individuals until favorable conditions exist. The suction trap data shows an increase of 1^{o}C from January and February induces the flight of potato aphids (*Myzus persicae* Sulzer) two weeks earlier (Shrestha, 2019).

Phenological changes have a greater impact on Lepidoptera, where 36 species showed advanced their first appearance in the UK (Menéndez, 2007). In Spain, 17 species have advanced their generations within 7 weeks in the past 15 years, also seen in the European grapevine moth (*Lobesia botrana* Denis and Schiff.) (Menéndez, 2007). After 1980, the generation timeline for Lepidoptera species in Europe decreased. Species with bivoltine (partially) or multivoltine tend to advance into second or third subsequent generations (Roff, 1980).

16. Conclusion

To sum up, the dynamics of climate change, mostly caused by man-made factors like greenhouse gas emissions, have far-reaching and significant effects on living things and the ecosystems they inhabit. Temperature, precipitation patterns, and the frequency and severity of extreme weather events have all changed as a result of these changes, which have been happening at an unprecedented rate. The effects of climatic change on living things are numerous and varied. A rise in the incidence of illnesses, changing habitats, and interrupted migration patterns are challenges facing species. Some ecosystems may even break under the pressure as they struggle to adjust to these quick changes. Human cultures are also not immune to the effects of climate change, which affects public health, water supplies, and food security.

Addressing the issue of climate change urgently is essential for individuals, communities, governments, and international organizations. The main goals of mitigation strategies should be to cut greenhouse gas emissions, switch to cleaner energy sources, and encourage sustainable land and resource management. To assist societies, adapt to the changes already taking place, adaptation measures are also crucial. Climate change ultimately acts as a stark reminder of our interdependence with the natural world. The effects on living things serve as a wake-up call for us to reconsider how we interact with the environment and to work together to secure a sustainable and resilient future for all life forms on Earth. We can only expect to lessen the effects of climate change and save the variety of life on our planet via international collaboration and a dedication to sustainability.

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