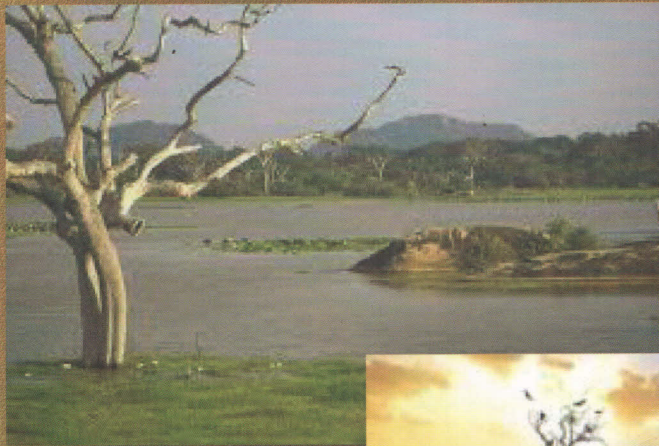


Water, Land and People in Climate Change



S. L. Tilakasiri

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Chapter 01

GLOBAL WARMING AND CLIMATE CHANGE:

PAST, PRESENT AND FUTURE

S. L. Tilakasiri, R. M. Olanrewaju and A. A. Salami

Introduction

Global Warming and Climate Change constitute two terms used in describing the observed rise in average temperature of all components of climate system over a long period of time. The effects of both are reciprocal in nature. For instance, the current change in climate has been blamed on anthropogenic/human activities that have resulted from overloading the atmosphere with greenhouse gases particularly carbon dioxide (CO₂), which has resulted in unprecedented rise in the temperature of the earth's climate system with its attendant problems threatening the sustenance of man and his environment.

The severity of the impacts of Global Warming and Climate Change differ over space. The worse affected areas are the developing countries of the world because of their economies mostly depend on natural resources, which are particularly vulnerable to climate change. The review of the past climate changes and global warming provides us an insight into paleo-environment which is vital to the understanding of the present and future climate of the earth.

The world's climate was/is changing, and it will continue to change throughout the 21st Century and beyond. Considering the magnitude of the impacts of climate change on man and his environment through global warming, it becomes necessary to trace the trends in the changes of the earth's climate over time. Human actions have been a primary cause of the climate change observed today, but humans are capable of changing their behaviours

in ways that can modify the rate of future climate change. The understanding of these will enable man to be better equipped in his strategies to outsmart the negative influences of climate change on man and his environment for livable and sustainable future.

Many studies have been undertaken on climate change primarily on climate and physical aspects of the anticipated changes such as prediction, modeling, physical disaster risk reduction strategies and infrastructural adaptation plans etc. This book seeks to bring some of these issues and perspectives forward and explore the challenges, impacts and potential responses to a changing climate, especially for the natural environment, livelihoods and development. The concepts of natural environment, livelihood and development are very important in sustainability. The term "Environment" is used to describe the collective of the surrounding external conditions within which an object, usually an organism, exists. A distinction can be made between the natural (or physical) environment and the man-made (socio-economic) environment.

Development as a concept is a victim of definitional pluralism because of the multifarious contextual usage. But in its simplest reductionism, the term means improvement or to become more advanced, more mature, more complete, more organized, more transformed etc. Mabogunje (1977) viewed development as a process of moving the whole social system upward so as to enhance the capacity of each member of a society to realize his or her inherent potential and to effectively cope with the changing circumstances of his or her life. Livelihoods have become increasingly popular in development studies and practice in the recent years. A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base (Carney, 1998).

Developing an understanding of what comprises a livelihood, what strategies are pursued to ensure food security, human health, governance, environmental and sustainable development, what resources are needed to make them viable, and how these resources are accessed and bring sustainable development has been the focus of much of this book. Through combining the potential consequences of climate change with an understanding of natural environment, development and livelihoods, this book explores how we can help respond to the challenges of the future. This chapter intends to provide some background information and preamble for forthcoming discussions in the subsequent chapters.

History of Earth's Climate

The Earth is the third planet from the Sun, the densest planet in the solar system, the largest of the solar system's four terrestrial planets, and the only astronomical object known to harbor life (Wikipedia, 2016). It was formed around 4.6 billion years ago and it was originally very hot (Dalrymple, 2001). However, the output of sun's energy was only 70

per cent of what it is presently while liquid water was present on the surface around 4.3 billion years ago. The earliest undisputed life on earth appeared around 3.8 billion years ago and photosynthesis began between 3.5-2.5 billion years ago which produced oxygen and removed carbon dioxide and methane, which are greenhouse gases, from the atmosphere (Bell *et al.*, 2015). As a result, the earth went through periods of cooling, commonly referred to as "Snowball Earth" and subsequent warming. Earth began its current cycles of glacial and interglacial periods around 3 million years ago.

The study of the history of the earth climate cannot be undermined considering the fact that the past has a lot of implications for both the present and the future. The above is corroborated by Hansen and Sato (2012) who described the past as the key to future and also acknowledged that our most precise knowledge of assessing man-made climate effects is not only traceable to Earth's Paleo-climate but to its ancient climate and how it responded to past changes of climate forcings including atmospheric composition. Though the causal factors of the ancient and modern climate vary (in that one is natural and the other anthropogenic in nature) the effects are similar but mild and unnoticeable during the Paleo-climate. Global temperature changes in responses to specified climate forcing has been mean of assessing changes of both the paleo-climate and present day climate. However, Hansen and Sato (2012) noticed that the glacial – interglacial oscillations that characterized the ancient climate were driven by much weaker natural forcings than man-made forcings consequent of increasing atmospheric carbon dioxide. Though weak, it had a long time to operate and this has resulted in growing and melting of ice over time and space.

Based on Ayoade (2011), past climate can be grouped in to two broad epochs namely the past climate during the geological period before recorded history and the period during recorded history. This was the era before recorded history hence nobody can say with precision what the earth's climate was. According to Ayoade (2011), knowledge about climate during this period is obtained from indirect sources of evidences in the earth crust. These indicators of past climate are grouped into three broad classes of biological which include fossils, pollens and tree rings. Lithogenetic indicators which are varves silt deposits, weathering phenomena and morphological indicators such as inselbergs, river terraces, glacial features, fossil dunes and relict landforms.

The various clues discussed above reveal that the climate of the earth has been undergoing continuous changes from time immemorial. According to United State Environmental Protection Agency EPA (2014), these evidences reveal the cyclical pattern of rising and falling of both temperatures and carbon dioxide levels mostly over the last 650,000 years. These changes in climate are associated more with both astronomical and extra-terrestrial causes than with terrestrial causes.

The changes in global surface temperature for the past 5.3 million years as inferred from cores of ocean sediments taken all around the global oceans. Hansen and Sato (2012) reveled global temperature about 1 – 2°C warmer than today with a sea level rise of 15 – 25 meters higher during the early Pliocene. However, the period that followed (Pleistocene)

witnessed a downward trend in temperature and so described as ice age. The last 800,000 years of this 5.3 million years are expanded into three eras of Holsteinian, Eemian and Holocene. The periods of Eemian (about 130,000 years ago) and Holsteinian (about 400,000 years ago) are two prior interglacial periods that were warmer than Holocene – and witnessed sea level rise that reached the heights of at least 4 – 6 meters than today. However global temperature has been described stable during the Holocene interglacial period of the past 10,000 years which marked the development of civilization.

The causes of present climate change are different from those of the past climate as previously discussed. IPCC (2014) reported that scientists were more than 95 per cent certain that global warming is mostly being caused by anthropogenic activities, mainly increasing concentrations of greenhouse gases such as carbon dioxide (CO_2). Man is overloading the atmosphere with greenhouse gases mainly CO_2 through his various activities. Currently, about half of CO_2 released from the burning of fossil fuel is not absorbed by the vegetation and the oceans hence, the rest resides in the atmosphere.

Global Warming and Climate Change: An Overview

The two terms “Global Warming” and “Climate Change” mean different things to different people and activate different sets of beliefs, feelings, and behaviors, as well as different degrees of urgency about the need to respond (Leiserowitz *et al.*, 2014). According to Micheal (2009), some of the scientists who revealed two long-term changes and the processes that cause climate change include Jean-Pierre Perraudin (1767-1858), Jean de Charpentier (1786-1855), Ignatz Venetz (1788-1859), Louis Agassiz (1807-1873) among others. Studies have shown that after the end of the Little Ice Age in about 1940, a period of climatic warming began in the middle of the 19th Century. After 1940 global average temperatures fell very slightly until about 1976, after which they began rising once more.

The concept of global warming came to use in 1827 when the French mathematician and physicist Jean-Baptiste Joseph Fourier (1768-1830) published an article in the *Mémoires de l'Académie Royale des Sciences de l'Institut de France* (Memos of the Royal Academy of Sciences of the Institute of France) in which he discussed the temperatures of the Earth and other planets. The term climate change appeared in the scientific literature before the term global warming, and has been used more frequently in peer-reviewed articles for more than forty years (<http://bit.ly/1j7d4PV>). For example, the closely-related term climatic change was first used in a seminar paper by Gilbert N. Plass in 1956, whereas the term global warming wasn't used until 1975 by author Wallace Broecker (Micheal, 2009). Global warming and climate change have different technical definitions, although they are often used interchangeably in popular media (Wilson, 2000).

Leiserowitz *et al.*, (2014) refer to global warming as the increase in the earth's average surface temperature since the Industrial Revolution, primarily due to the emission of greenhouse gases from the burning of fossil fuels and land use change, whereas

climate change refers to the long-term change of the earth's climate including changes in temperature, precipitation, and wind patterns over a period of several decades or longer (IPCC, 2007). Salami (2016) defined global warming as the average increase of the earth's surface temperature and oceans as compared to previous centuries. This is resulted from anthropogenic activities which increase the level of CO₂ and other greenhouse gases in the atmosphere. Scientists have used both terms in the peer-reviewed literature for decades, but the scientific community generally prefers the term climate change, which refers to a wider range of phenomena than just the increase in global surface temperatures (People's Bank, 2008).

Global warming is causing climate patterns to change. However, global warming itself represents only an aspect of climate change. Climate change refers to any significant change in the measures of climate lasting for an extended period of time. In other words, climate change includes major changes in temperature, precipitation, or wind patterns, among other effects, that occur over several decades or longer (<https://www3.epa.gov/climatechange/>). Climate Change is a measurable increase in the average temperature of the earth's atmosphere, oceans and landmasses. This temperature difference over the years has now become rapid due to industrialization and man's activities which more often than none are not environment friendly. Such activities result in the release of various gases or emissions (Green House Gases) which contribute significantly to global warming. Examples of these include Carbon Dioxide, Methane; Nitrous Oxide; Ozone; Synthetic Chemicals; aerosols etc.

Climate change may be limited to a specific region, or may occur across the whole Earth. United Nations on Environmental Programme (UNEP) (2008) defines climate change as extreme reactions of the weather phenomenon which creates negative impact on agricultural resources, water resources, human health, and depletions of ozone layer, vegetation, soil and doubling of CO₂ in the ecosphere. Scientists have intensified the greenhouse effect by increasing the concentration of greenhouse gases in the atmosphere.

There is growing evidence that climate change, particularly increasing temperatures, is already having significant impacts on the world's physical, biological and human systems, and it is expected that these impacts will become more severe. The IPCC reports that the average global surface temperature increased by 0.6°C during the 20th Century (Houghton *et al.* 2002). This temperature increase has been linked to a number of observed changes in the global climate, including: a 0.1–0.2 metre rise in global average sea level; a 10 per cent decrease in snow cover since the late 1960s; more frequent, persistent and intense El Niño episodes since the 1970s; and more frequent and severe droughts in parts of Africa and Asia (Houghton *et al.*, 2002).

The last decade of the 20th Century and the beginning of the 21st Century witness the warmest period in the entire global instrumental temperature record, starting from the mid-19th century (NOAA, 2007). Global warming and climate change are terms for the observed century-scale rise in the average temperature of the Earth's climate system and

its related effects (Gillis, 2015). Multiple lines of scientific evidence show that the climate system is warming (Borenstein, 2015). Figure 1 shows global mean surface temperature change from 1880 to 2015, relative to the 1951–1980 mean.

Climate Change is a “Global Commons” problem that requires a collective action. Studies have shown that there are disjointed efforts to combat this problem. The most vulnerable are generally those who have contributed the least to the problem (Tilakasiri, 2008). These are poor countries that have very low adaptive capacity and least infrastructure to cope.

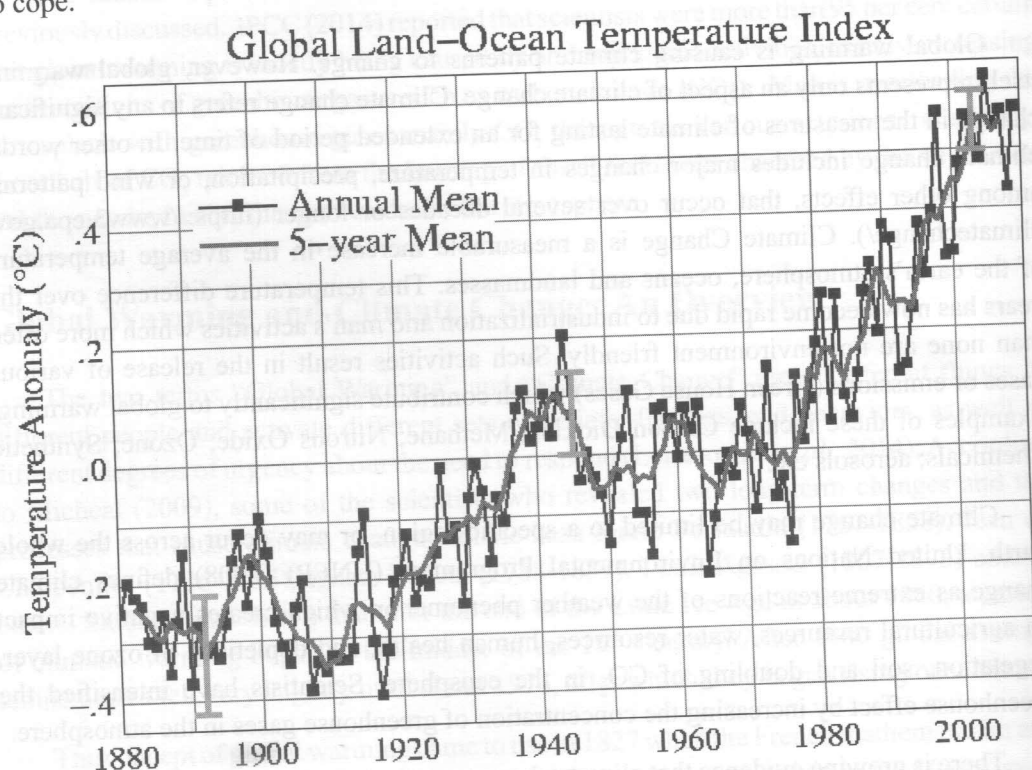


Figure 1: Global Mean Surface Temperature Change from 1880 to 2015 Relative to the 1951–1980 Mean

Source: National Aeronautics and Space Administration (2015).

Evidence of Global Warming

The global air temperature change is a primary measure of global climate change while an increasing abundance of infrared-absorbing trace gases in the earth's atmosphere would bring about a global warming. Since the beginning of the century, there has been a rise in global mean temperatures of about 0.5°C (Kemp, 1998). Micheal (2002) stated that fossil fuels (such as coal, oil, and natural gas) provide about 85 per cent of the world's energy, sustaining the world's standard-of-living and providing much of the power for

transportation, generation of electricity, home heating, and food production. Compared to other sources of energy, fossil fuels are relatively inexpensive, transportable, safe, and abundant. At the same time, their use contribute to environmental problems such as air pollution and acid rain, which are being addressed through various control efforts, and to long-term climate change, which governments have begun to address through adoption of the UN Framework Convention on Climate Change negotiated in 1992.

By the mid-1980s, it was estimated that a doubling of CO_2 would cause an average warming of $1.3\text{--}4^\circ\text{C}$ (Hansen and Lebedeff, 1988). Based on the first assessment of IPCC (1990), the value of $1.5\text{--}4.5^\circ\text{C}$ with a best estimate of 2.5°C was produced. By the time of the second assessment in 1995, their best estimate had been reduced to 2°C with a maximum of 3.5°C , to be reached by 2100. Although the estimated temperature is not particularly high - mainly because the global averages - evidence from past world temperature changes indicates that they are of a magnitude which could lead to significant changes in climate and climate-related activities. The Third Assessment Report of IPCC (2001) indicated that the magnitude and timing of the warming during the 20th Century, especially during the last 50 years, quite closely matches what would be expected from the combined influences of human and known natural influences.

According to Kemp (1991), the basic cause of this warming is seen as the enhancement of the greenhouse effect over the same period brought on by rising levels of anthropogenically produced greenhouse gases. Flavin (1989) stated that observed warming is what might be expected from the rising level of greenhouse gases, but the change has not been consistent. According to Hansen and Lebedeff, (1988), the main increase took place between 1910 and 1940 and again after 1975. Between 1940 and 1975, despite rising greenhouse levels, global temperatures declined. However, the warming between the 1960s and 1980s was more rapid than that between the 1880s and 1940, and James Hansen (1988) of the Goddard Institute for Space Studies (GISS) claimed that the global greenhouse signal is sufficiently strong for a causal effect relationship between the anthropogenically produced carbon dioxide increase and global warming to be inferred.

During the Climatic Optimum some 5000 to 7000 years ago, temperatures in North America and Europe were only $2\text{--}3^\circ\text{C}$ higher than the present average, but they produced major environmental changes (Kemp, 1998). Evidence from that time and from another warm spell in the early Middle Ages 800 to 1000 years ago also suggests that the greatest impact of any change will be felt in mid- to high latitudes in the northern hemisphere. Using a combination of investigative techniques - ranging from laboratory experiments with plants to the creation of computer generated models of the atmosphere and the analysis of past climate anomalies - researchers have produced results which provide a general indication that warming would bring about changes in the length and intensity of the growing season which, coupled with new moisture regimes would disrupt existing vegetation patterns, both natural and cultivated (IPCC, 1996b).

Higher temperature might threaten the forests indirectly through an increase in the frequency of forest fires and insect infestations, and if the rate of change takes place more rapidly than the forest can respond, rapid die-off of large numbers of trees is a possibility. Whatever the final outcome, it appears likely that global warming in the northern forest would disrupt the northern ecosystems, and in turn have a significant impact on those countries, such as Canada, Sweden, Finland and Russia, where national and regional economies depend very much on the harvesting of softwoods from the boreal forest (Pearce, 1992).

Studies have indicated that in lower latitudes where the temperature element is less dominant, the impact of global warming would be felt through changes in the amount and distribution of moisture (Parry and Duncan, 1994). In Northern Australia, for example, the increased poleward penetration of monsoon rains would allow the expansion of tropical and subtropical vegetation. Studies further posited that in China, agricultural output is expected to rise as a result of the northward spread of crops such as rice, corn and cotton, and the increase in the area in which tropical and subtropical fruits can be cultivated (Kemp, 1998).

Of major concern to many agriculturists is the expected decline in precipitation in the world's grain-producing areas, which along with higher temperatures, could increase the frequency and severity of drought in the grain belts of North America, Russia and Ukraine, leading to more frequent crop failures. Parry (1990) predicted a decline in grain yields of 15-20 per cent in Africa, tropical Latin America and much of India and south-east Asia by the middle of the 21st Century. Another major concern associated with water is a rising sea level brought about by the thermal expansion of the oceans and the additional water added to the sea by the melting of snow and ice as warming progresses. Technology, politics, socioeconomic conditions and even demography can influence warming, for example, through their contribution to changes in greenhouse gas concentrations, yet the nature and magnitude of the variations in such elements is almost impossible to forecast.

Despite such uncertainties and a certain degree of dissension among scientists and politicians, the international view as expressed by the Framework Convention on Climate Change is to see global warming as a serious threat to the environment and society in the future, which must be dealt with now. Attempts to arrest continued warming have centered mainly on the control and reduction of greenhouse gas emissions, but the degree of success is as yet limited. This led to Paris 2015 summits on climate change of heads of States and governments and their representatives to discuss ways of tackling climate change.

Evidence of Climate Change in the Past

Over the past few hundred years, there has been a steady increase in the numbers of sunspots, at the time when the earth has been getting warmer. The data suggests solar activity is influencing the global climate causing the world to get warmer (BBC, 2004). An

analysis shows that the Sun is more active now than it has been at any time in the previous 1,000 years. Scientists based at the Institute for Astronomy in Zurich used ice cores from Greenland to construct a picture of star's activity in the past and stated that over the last century the number of sunspots rose and at the same time that the earth's climate became steadily warmer.

According to Richard (2009), ice ages have occurred in a hundred thousand year cycle for the last 700 thousand years, and there have been previous periods that appear to have been warmer than the present despite CO_2 levels being lower than they are now. Recently, there have been the medieval warm period and the little ice age. Greenhouse gasses – mainly CO_2 , but also methane – were involved in most of the climate changes in earth's past. When they were reduced, the global climate became colder.

When they were increased, the global climate became warmer. When CO_2 levels jumped rapidly, the global warming that resulted was highly disruptive and sometimes caused mass extinctions. Because of the integrated nature of the earth/atmosphere system, climatic conditions are inherently variable.

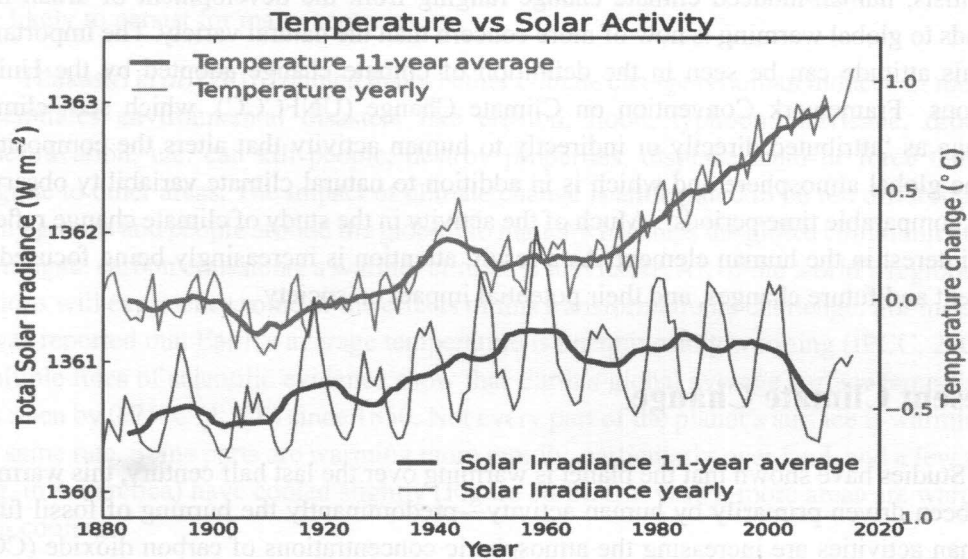


Figure 2: Annual Global Temperature Change (ThinLight) with 11 Year Moving Average of Temperature (Thick Dark).

Source: <https://www.skepticalscience.com/solar-activity-sunspots-global-warming.htm>

Variations in such meteorological conditions as temperature, precipitation and atmospheric pressure from season to season and from year to year are common, for example. If the variations continue in one direction for a number of years, they can be seen as an expression of climate change. According to Lamb (1977), evidence of past change is available in many forms: for example, biological, stratigraphical, archaeological, agricultural, glaciological or historical. All these sources provide proxy data, but change is also indicated in the instrumental record that began to take a more reliable form in the 19th

Century (Bradley, 1992). Modern research methods also make use of computerized climate models to look forward as well as back. IPCC (1996) stressed that the earth's climate appears to have fluctuated over a wide range in the past, with most areas being, at some time or other, warmer or drier or wetter or colder than they are now.

Kemp (1998) and Micheal (2009) posited that during the Pleistocene, for example, higher latitudes experienced a series of ice ages, separated by periods of amelioration. Over the past 10,000 years, since the end of the ice ages, variations have continued, with periods of improvement such as the Climatic Optimum and periods of deterioration as represented by the Little Ice Age. Climatic Optimum is a period of major warming during the immediate post-glacial period between 5000 and 7000 years ago, which is also referred to as the altithermal or hypsithermal. Temperature was perhaps 1-3°C higher than at present and changes in precipitation amounts and distribution also occurred. As a result of recent global warming, current world temperature is approaching those of the Optimum.

All these changes were generated by natural processes, but in recent years, there are growing indications that human activities have also contributed to change. For many scientists, human-induced climate change ranging from the development of urban heat islands to global warming is now of more concern than the natural variety. The importance of this attitude can be seen in the definition of climate change adopted by the United Nations Framework Convention on Climate Change (UNFCCC), which sees climate change as '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'. Much of the activity in the study of climate change reflects this interest in the human element. As a result, attention is increasingly being focused on present and future changes, and their potential impact on society.

Present Climate Change

Studies have shown that the planet is warming over the last half century, this warming has been driven primarily by human activity—predominantly the burning of fossil fuels. Human activities are increasing the atmospheric concentrations of carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and of various halocarbons (HCFCs and, until very recently, CFCs). These gases collectively are referred to as greenhouse gases because they act as a glass in greenhouse. These gases are transparent to the incoming solar energy (short wave length) but translucent to the infrared out going terrestrial radiation. Some of this energy is absorbed by these gases, some is re-radiated towards the earth surface while some is tracked down towards the surface, thus warming up the earth and its environment. Although natural processes such as volcanic eruption can also affect the atmospheric composition through production of aerosols, observations indicate that this has not been an important cause of changes over the past 10,000 years (Michael, 2002). It is well-established that human activities are the major cause of the dramatic changes in atmospheric composition since the start of the Industrial Revolution about 200 years ago.

The buildup of greenhouse gases in the atmosphere has changed Earth's climate and this has endangered man and his economic activities, health, and environment. While these gases occur naturally, records going back many thousands of years indicate that the present concentrations are well above natural levels. For example, the CO_2 concentration is currently about 370 parts per million by volume (ppmv), which is about 30 per cent above its preindustrial value of about 280 ppmv (Micheal, 2002). This increase has been due primarily to the combustion of fossil fuels and secondarily to the release of carbon occurring in the clearing of forested land and the plowing of soils for agriculture.

Presently, methane concentration is well above 150 per cent and its increase is due primarily to emissions from rice agriculture, ruminant livestock, biomass burning, landfills, and fossil fuel development, transmission, and combustion. The concentrations of many halocarbons are entirely new to the atmosphere—many of these compounds are solely a result of human activities. The persistence (or lifetimes) of the excess contributions of these gases in the atmosphere range from decades (for CH_4) to centuries (for CO_2 and some halocarbons) to thousands of years (for some per fluorocarbons). Thus, with ongoing emissions, the excesses of their concentrations above natural levels with these consequences are likely to persist for many centuries.

Tilakasiri *et al.* (2016) opined that whether climate change is human induced or natural, precipitates environmental disasters like erosion, flood, typhoon, hurricane, drought, desertification, etc. can kill people, destroy properties, displace them or force them to migrate to other areas. The impact of climate change is anticipated to be felt differently by many groups and people around the globe. No matter what steps the global community takes to mitigate carbon emissions, a warmer climate is inevitable. All of the world's regions and nations will experience some of the effects of this transformational challenge. For instance, it was reported that Earth's average temperature is unequivocally warming (IPCC, 2007b). Multiple lines of scientific evidence show that Earth's global average surface temperature has risen by 0.75°C (1.3°F) since 1850. Not every part of the planet's surface is warming at the same rate. Some parts are warming more rapidly, particularly over land, and a few parts (e.g. in Antarctica) have cooled slightly (Figure 3a-b). But vastly, more areas are warming than cooling.

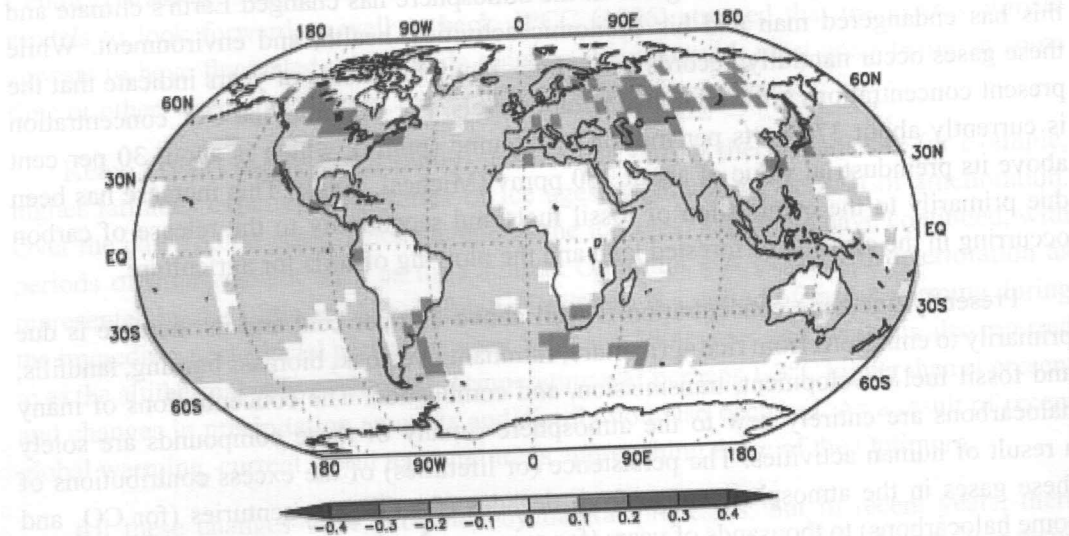


Figure 3a: Global Trends in Temperature per Decade from 1870 to 2005.

Source: Adapted from NAS (2008).

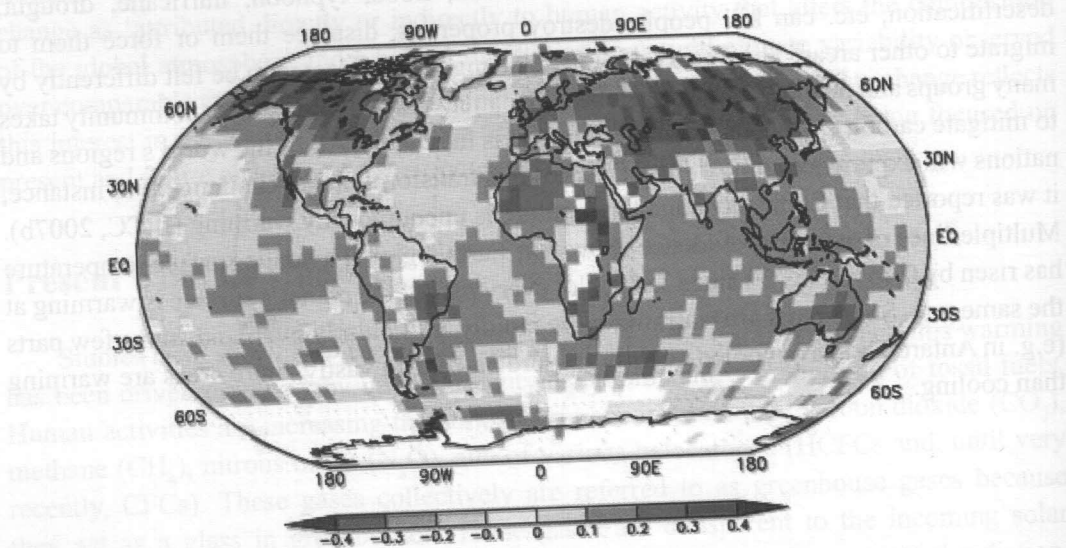


Figure 3b: Global Average Change in Temperature per Decade from 1950 to 2005.

Source: Adapted from NAS (2008).

Climate change will cause scarcity of the basic resources like food, fresh-water supplies, arable land for agricultural activities and habitations that sustain life for people around the world, especially in African countries which are already vulnerable to climate variability and have least capacity to respond (Tilakasiri *et al.*, 2016). Similarly, findings have concluded that African states are likely to be the most vulnerable to multiple stresses

of climate change, with up to 250 million people projected to suffer from water and food insecurity and, in low-lying areas, a rising sea level (IPCC, 2007). Only one per cent of Africa's land is located in low-lying coastal zones but this land supports 12 per cent of its urban population. These developments may well be exacerbated by the lack of state and regional capacity to manage the effects of climate change. These same dynamics haunt many nations in Asia and the Americas, too, and the implications for developed countries such as the United States and much of Europe will be profound.

Similarly, an entire African continent was responsible for only 3.7 per cent of the world's annual CO₂ emissions, compared to China with 21.5 per cent, the United States with 20 per cent, and the European Union with 14 per cent. This is in spite of the fact that African forests take in 20 per cent of carbon absorbed by trees across the world (Minter and Wheeler, 2009). From 1980 to 2005, sub-Saharan Africa had 18.5 per cent of the world's population growth but its share in the growth of CO₂ emissions was just 2.5 per cent. During the same time the United States and Canada had 4 per cent of the world's population growth but its share in the growth of CO₂ emissions was 13.9 per cent. China had 15.3 per cent of the world's population growth and 44.5 per cent of the growth in CO₂ emissions. This actually understates the contributions of high-income nations (Satterthwaite, 2009).

Presently warmer temperature cause glaciers and land ice to melt. This additional water resulted in the expansion in the volume of sea water as it warms. The global average sea level rose by 1.7 mm/yr (0.07in/yr) during the 20th Century, but since satellite measurements began in 1992, the rate has been 3.1 mm/year (0.12in/yr) (IPCC, 2007a). As sea level rises, shoreline retreat has been taking place along most of the nation's sandy or muddy shorelines, and substantial coastal wetlands have been lost due to the combined effects of sea-level rise and direct human activities. Higher sea levels has been noted to have the tendency of changing the salinity and water circulation patterns of coastal estuaries and bays, with varying consequences for the mix of species that can thrive there. Climate change is also linked to a number of other changes that can be seen around the world (IPCC, 2007b). These include earlier spring snowmelt and peak stream flow, melting mountain glaciers, a dramatic decrease in sea ice during the arctic summer, and increasing frequency of extreme weather events, including the most intense hurricanes.

At present, climate change has produced complicated effects on water balances, supply, demand, and quality. The complex interaction between temperature and water demand and availability means that climate change can have many different kinds of effects on ecosystems. Changes in evapotranspiration and precipitation will affect the amount and the distribution, spatially and temporally, of surface runoff. Climate change affects water quality in three ways. First, reduction in hydrologic resources may leave less dilution flow in the stream, leading to degraded water quality or increased investments in wastewater treatment. Second, higher temperature reduces the dissolved oxygen content in water bodies. Third, in response to climate change, water uses, especially those for agriculture, may increase the concentration of pollution being released to the streams. Olanrewaju (2003a) explained that the regional shift on livestock grazing currently experienced in Niger Republic has a lot

of bearing with a change of climate towards severe aridity and emphasised on the invasion of pollutants on both Nigeria inland water system and deep seas this can cause. Together, these pose a threat to water quality and the integrity of the aquatic ecosystem.

Climate change is transforming ecosystems at extraordinary rates and scales. As each species responds to its changing environment, its interactions with the physical world and the creatures around it change—triggering a cascade of impacts throughout the ecosystem, such as expansion into new areas, the intermingling of formerly non-overlapping species, and even species extinctions. Studies show that with rapid climate change, one-fourth of earth's species could be headed for extinction by 2050 (<http://www.nature.org/ourinitiatives/urgentissues/global-warming-climate-change/threats-impacts/index.htm>).

Global warming is also causing shifts in the reproductive cycles and growing seasons of certain species. For example, higher temperatures have led to an increase in the number of eggs laid by the spruce budworm, already one of the most devastating pests in North America's boreal forests (Gitay *et al.*, 2002). Again, Olanrewaju (2003b) observed a shift from normal to late onset of rain led to a shift in melon crop cultivation in Kwara State, Nigeria. The ecological impacts of climate change are typically local and vary from place to place and region to region. The most rapid changes in climate are expected in the far north and south of the planet, and in mountainous regions.

Just as climate change affects biodiversity, so changes in biodiversity can also affect the global climate. Land use changes that lead to biodiversity losses can cause increased greenhouse gas emissions. Forests are a major store of carbon, and when forests are cut down or burnt, CO₂ is released into the atmosphere. Continuing deforestation, mainly in tropical regions, is currently thought to be responsible for annual emissions of 1.1 to 1.7 billion tonnes of carbon per year, or approximately one-fifth of human CO₂ emissions (Brown *et al.*, 1996).

The World Conservation Union (IUCN), (2003) stressed that climate change and associated ecological changes also pose threats to the viability of many economic and social structures, even where people are not displaced or in serious physical risk. This is particularly true where they will lead to decline in the availability or quality of natural resources such as water or land on which the livelihoods of many poor people are based.

Other noticeable features of climate change include changing in the character of extreme weather and climate events on a global scale and ocean acidification as a result of taken up of carbon dioxide emitted by human activities by the oceans.

In Nigeria, for instance, Adebola (2011) stated that observed climate variability and changes in Nigeria as reported by the Nigerian Meteorological Agency include some of the following:

- ♦ Warmer hot season throughout Nigeria. March – May has had hot episodes of heat waves as temperature increases of about an average of 0.4-1.5°C with extreme ranges of 2.0 – 3.3°C are being observed across the country. The result is warmer and more frequent hot days and nights over most places.

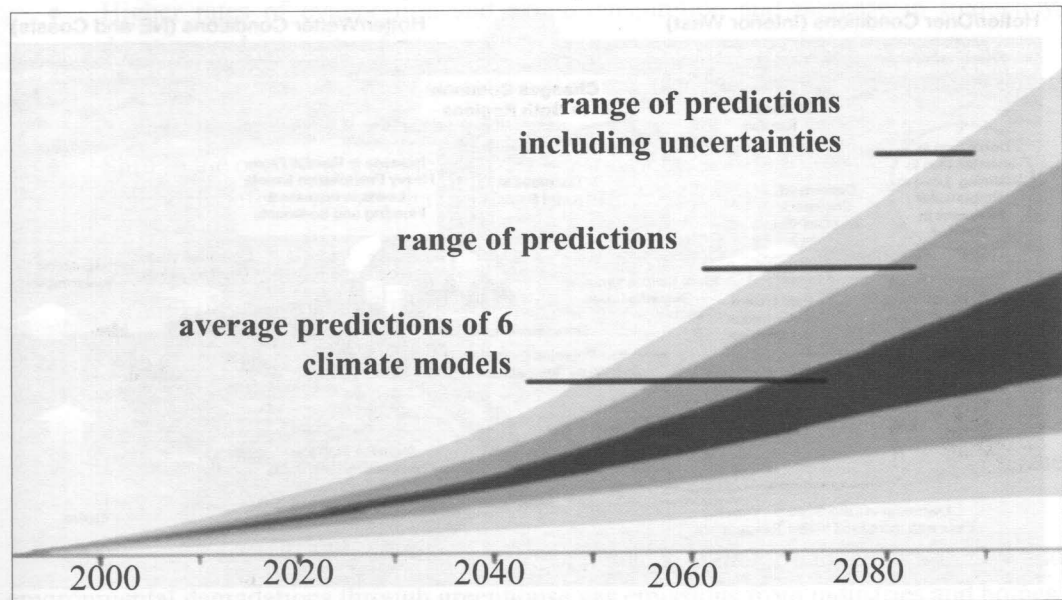


Figure 6: Global Average Sea Level Rise 1990 to 2100.

Source: IPCC, 2001.

Based on the results of models, a warmer world will experience more precipitation at the global scale, but the changes will not be the same everywhere. In general, the projections indicate that dry areas, especially in the latitude band just outside the tropics, will tend to get drier on average (IPCC, 2007b). Areas that are already wet, especially in the tropics and closer to the poles, will tend to get wetter on average. Increased climate variability and increased evaporation in a warmer world could both increase the risk and likely intensity of future droughts.

According to Cao *et al.* (2007), emissions through 2100 would likely lead to oceans with surface temperatures that are 2-4°C (3.6-7.2°F) higher than now and surface waters so acidified that only a few isolated locations would support the growth of corals. Most marine animals, especially sedentary ones, and plants are expected to be significantly stressed by these changes. Some may be able to cope with either increased temperatures or more acidic waters, but adjusting to both may not be feasible for many species.

United States Global Change Research Programme (2009) posited that the amount of water available for on earth might be reduced as Earth warms, and if competition for water resources increase. This is because as temperatures rise, people and animals would need more water to maintain their health and thrive. Many important economic activities, like producing energy at power plants, raising livestock, and growing food crops, also require water. According to IPCC assessment reports, while the African continent contributes less than 4 per cent of the global GHG, about 70 million Africans will be exposed to water shortage by 2020. This is a clear example of the inequitable exposure to the impacts of climate change.

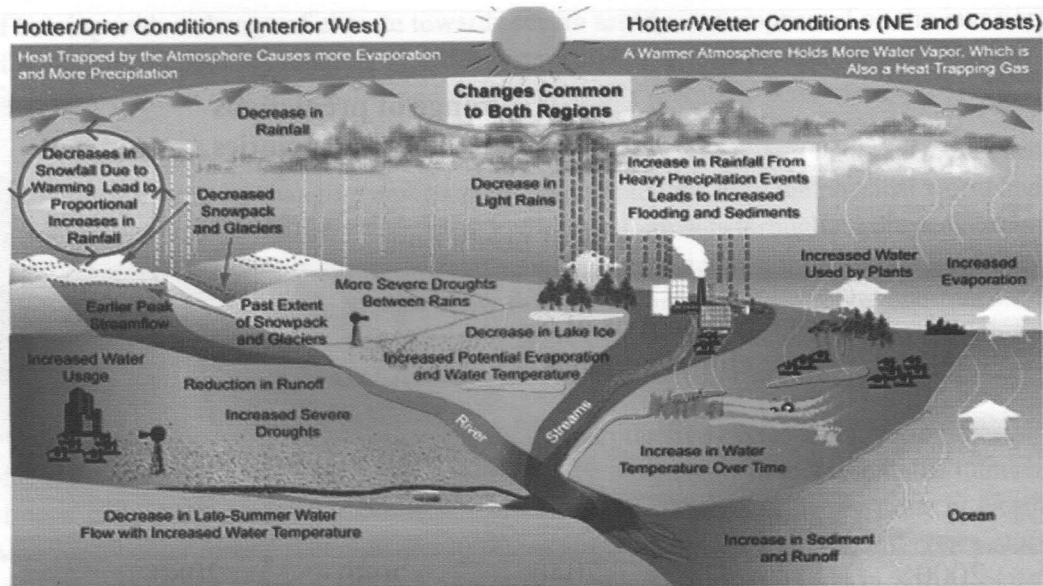


Figure 7: Projected Changes in the Water Cycle.

Source: USGCEP (2009).

Different factors—temperature, precipitation patterns, sea-level rise and extreme events—both the magnitude and speed of change are important. For both ecosystems and human activities, a rapid *rate* of climate change presents challenges that are different from, but no less serious than, the challenges from a large *amount* of change (Schneider and Root, 2001). Studies of the past temperature trends have shown that for future temperature trends combine with different factors that influence atmosphere and surface temperature will change in this century. The factors include population growth, economic development, urbanization and technological change as well as cultural and social interaction among groups and countries.

Predictions of future climates for all the countries in the world will vary. But in Africa without adequate adaptation measures, most of the region is likely to be deleteriously affected by rising temperatures leading to increasing rates of evaporation and transpiration, changes in the timing and reliability of rains, and, in many areas, an increase in the intensity of rainfall events and in the frequency and duration of droughts. Some of these changes are already being experienced across the region, others are predicted in the near future (GoE, 2007; FAO, 2010; World Bank, 2013).

- ◆ Higher rates of evaporation and evapotranspiration and increase in frequency, duration and intensity of dry spell.
- ◆ Late onset of rain and early cessation of rain with wider spread since 1911, leading to shortened length of the rainy season.
- ◆ Shift in the occurrence of the little dry season (August break) from August to a long time well before August, that is, mostly in mid-July and also shift in the harmattan haze season.
- ◆ Pronounced reduction in annual rain by about 15-20 per cent in some places (drought); while a few others maintained high values within the shortened season resulting in floods in such places.
- ◆ Drought and desertification literally blowing away the north and the desert now covers over 35 per cent of the nation's landmass; and
- ◆ Floods, storm surges and gully erosions (washing away the coastal zone) e.g. the Lagos Bar Beach.

Studies have revealed that man has contributed in no small ways to climate change and environmental degradations through greenhouse gas emissions from industries and homes, especially Carbon dioxide (CO_2), which causes global warming (Tilakasiri *et al.*, 2016). In general, present climate change is affecting people in far-reaching ways. Impacts related to climate change are evident across regions and in many sectors important to society—such as human health, agriculture and food security, water supply, transportation, energy, ecosystems, and others—and are expected to become increasingly disruptive throughout this century and beyond.

Future Climate Change Expectation

Global concern over future climate change and its potential impact on society has placed a focus on understanding the relationship between climate and human activity. Studies have shown that human-induced climate change is projected to continue, and it will accelerate significantly if global emissions of heat-trapping gases continue to increase. One of the most important and widely discussed outcomes of the IPCC's reports in 1990, 1995, 2001, 2010 and 2013 were the estimates that, in the future, the world would warm at a rate of 0.2°C per decade on average due to greenhouse gas forcing. Since those predictions were made, it has become clear that the world has not been warming at that rate, leading to the question of whether the lack of warming seen in the past years is just a temporary departure from the stated average rate of warming, or whether it is indicative of something else.

According to United Nations Environmental Protection Agency (EPA) (2016), continued emissions of greenhouse gases will lead to further climate changes. The study of Olanrewaju (2009) corroborated this for the developing city. Future changes are expected to include a warmer atmosphere, a warmer and more acidic ocean, higher sea levels, and larger changes in precipitation patterns. The extent of future climate change depends on what humans do to reduce greenhouse gas emissions. The more humans emit gases, the

larger future changes will be. Definitely, these changes will have impacts on food supply, water resources, infrastructure, ecosystems, and human health.

The magnitude and rate of future climate change will primarily depend on some factors such as the rate at which levels of greenhouse gas concentrations in the atmosphere continue to increase, how strongly features of the climate (e.g., temperature, precipitation, and sea level) respond to the expected increase in greenhouse gas concentrations and natural influences on climate (e.g., from volcanic activity and changes in the sun's intensity) and natural processes within the climate system (e.g., changes in ocean circulation patterns). Studies have shown that Future Carbon Emissions will probably increase, especially in China and developing countries.

The IPCC (2007) assessment refines how global temperature might change in the future. The predictions are based on greenhouse gas emission scenarios and a link between greenhouse gas concentration and temperature through modeling. A climate model is a representation of certain aspects of the climate system. One of the simplest climate models is an energy-balance model, which treats the earth as a flat surface with one layer of atmosphere above it. It is based on the simple principle that in equilibrium the incoming and outgoing radiation must be equal (Dessler, 2011). Despite their simplicity, these models provide a good qualitative understanding of the greenhouse effect.

Simulation results from models can be used either to develop physical insight about the system by means of comparison with reality, or to make projections of future climate (Held, 2005). 'Projection' is a technical term in the climate modelling literature and refers to a forecast that is conditional on a certain forcing scenario. The forcing scenario is specified by the amount of greenhouse gas emissions and aerosols added to the atmosphere, and these in turn depend on number of other factors such as changes in land use as well as future socioeconomic and technological developments. Figure 4 shows a projected greenhouse gas concentrations for four different emissions pathways. The top pathway assumes that greenhouse gas emissions will continue to rise throughout the current century. The bottom pathway assumes that emissions reach a peak between 2010 and 2020, declining thereafter.

Evidence of rising atmospheric and ocean temperatures, changing precipitation patterns, rising sea levels, and decreasing sea ice is undeniable. Future temperatures are expected to change further. The amount of future climate change depends on human actions. A large number of experiments with climate models indicate that if the world continues to emphasize rapid economic development powered by fossil fuels, it will probably experience dramatic warming during the 21st Century. The projected greenhouse gas (mainly CO₂) concentrations for four different emissions pathways – between 2000 and 2100 – is reflected in Figure 4. The highest emission pathway of RCP 8.5 is expected during this period. The range is between RCP 2.6 – RCP 8.5. As shown in Figure 5, it is observed and projected that the changes in global average temperature under four emissions pathways. The vertical bars at right show likely ranges in temperature by the end of the century, while the lines show projections averaged across a range of climate models. Changes are relative to the 1986-2005 average.

Projected Atmospheric Greenhouse Gas Concentrations

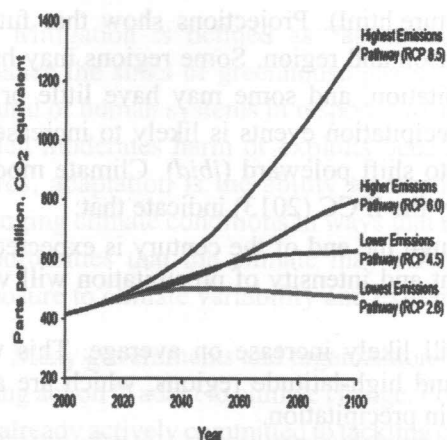


Figure 4: Projected Greenhouse Gas Concentrations for Four Different Emissions Pathways

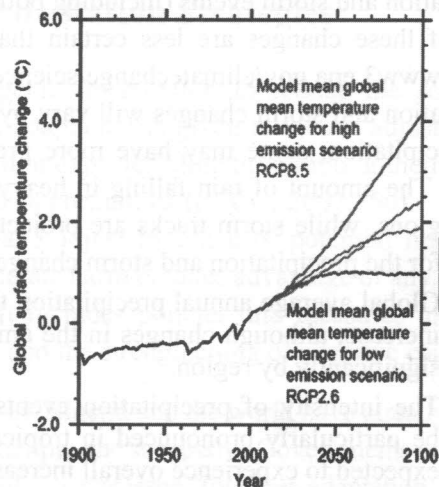
Source: <https://www.epa.gov/climatechange/science/future.html>

Figure 5: Observed and Projected Changes in Global Average Temperature under Four Emissions Pathways.

Source: IPCC, 2013

For this kind of future temperature (Figure 5), the IPCC (2007b) projected a likely range of global warming over 1990 levels of 2.4–6.4°C (4.3–11.5°F) by 2100. If greenhouse gas emissions grow more slowly, peak around the year 2050, and then fall, scientists project a likely warming over 1990 levels of 1.1–2.9°C (2.0–5.2°F) by 2100. Similarly, IPCC (2013) summarized that climate models project the following key temperature-related changes.

- ◆ Increases in average global temperatures are expected to be within the range of 0.5°F to 8.6°F by 2100, with a likely increase of at least 2.7°F for all scenarios except the one representing the most aggressive mitigation of greenhouse gas emissions.
- ◆ Except under the most aggressive mitigation scenario studied, global average temperature is expected to warm at least twice as much in the next 100 years as it has during the last 100 years.
- ◆ Ground-level air temperatures are expected to continue to warm more rapidly over land than oceans.
- ◆ Some parts of the world are projected to see larger temperature increases than the global average.

Temperature increases at the high end of the range of possibilities are very likely to exceed many climate thresholds. Warming of 6°C (10.8°F) or more would probably have catastrophic consequences for lifestyles, ecosystems, agriculture, and other livelihoods, especially in the regions and populations with the least resources to invest in adaptation—that is, the strategies and infrastructure for coping with the climate changes. Warming to the high end of the range would also entail a global average rate of temperature change that, for the next century or two, would dramatically exceed the average rates of the last 20,000 years, and possibly much further into the past.

Climate change affects more than just temperature. The location, timing, and amounts of precipitation will also change as temperatures rise. IPCC (2013) stated that patterns of

precipitation and storm events (including both rain and snowfall) are also likely to change. Some of these changes are less certain than the changes associated with temperature (<https://www3.epa.gov/climatechange/science/future.html>). Projections show that future precipitation and storm changes will vary by season and region. Some regions may have less precipitation, some may have more precipitation, and some may have little or no change. The amount of rain falling in heavy precipitation events is likely to increase in most regions, while storm tracks are projected to shift poleward (*ibid*). Climate models project for the precipitation and storm changes by the IPCC (2013) indicate that:

- ◆ Global average annual precipitation through the end of the century is expected to increase, although changes in the amount and intensity of precipitation will vary significantly by region.
- ◆ The intensity of precipitation events will likely increase on average. This will be particularly pronounced in tropical and high-latitude regions, which are also expected to experience overall increases in precipitation.
- ◆ The strength of the winds associated with tropical storms is likely to increase. The amount of precipitation falling in tropical storms is also likely to increase.
- ◆ Annual average precipitation is projected to increase in some areas and decrease in others.

Continued emissions could lead by 2100 to 0.6 m (2 ft) or more of sea-level rise. According to National Research Council (2011), warming temperature contribute to sea level rise by: expanding ocean water; melting mountain glaciers and ice caps; and causing portions of the Greenland and Antarctic ice sheets to melt or flow into the ocean. Continuation of recent increases in loss of the ice caps that cover Greenland and West Antarctica could eventually escalate the rate of sea-level rise by a factor of 2 (Overpeck *et al.*, 2006; Rahmstorf, 2007). There will also be hotter extreme temperature and fewer extreme cold events.

According to Melillo, Jerry, Terese, Richmond and Gary (2014), global sea level has risen by about 7.5 inches since 1870. IPCC (2013) estimates that future sea level rise vary for different regions, but global sea level for the next century is expected to rise at a greater rate than during the past 50 years. Melillo *et al.* (2014) project global sea level to rise by another 1 to 4 feet by 2100, with an uncertainty range of 0.66 to 6.6 feet. Changes in ice sheets are currently expected to account for 1.2 to 8 inches of sea level rise by the end of this century (NRC, 2011).

Scientists use climate models to estimate changes in future sea level rise, one of the expected effects of global warming. Figure 6 predicted by six climate models, each of which ran 35 different greenhouse gas emission scenarios. The center dark region shows the predicted sea level rise for the models averaged over the 35 emission scenarios. The lighter blue region shows the range of the maximum and minimum model predictions. The outer, lightest blue section includes the uncertainties of land-ice changes, permafrost changes and sediment deposition (not including the possibility of melting of the West Antarctic Ice Sheet). The top curve is the extreme worst case scenario and the bottom curve shows the least expected change.

Climate Change Mitigation and Adaptation Strategies

Mitigation is defined as “as anthropogenic intervention to reduce the source or enhance the sinks of greenhouse gases” and adaptation is given to mean “adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities ((IPCC, 2007:750). In other words, adaptation is the ability to respond and adjust to actual or potential impacts of changing climate conditions in ways that moderate harm or takes advantage of any positive opportunities that the climate may afford. It includes policies and measures to reduce exposure to climate variability and extremes, and the strengthening of adaptive capacity.

Many governments and organizations across Nigeria and the world have already started taking action to adapt to climate change. For example, the successive Governments in Nigeria are already actively committed to tackling climate change issue. Together, adaptation, coupled with actions to reduce greenhouse gas emissions, are essential to limiting the damages from future climate change. Salami (2016) posited mitigation actions have predominated so far in every major urban centre in the country (particularly Lagos, Nigeria) and the need for adaptation also is recognized, through mitigation and adaptation policies.

Adaptation strategies should be based on these three general properties—wealth, controllability and adaptive capacity—as they relate to different scales and contexts (The World Conservation Union (TUCN, 2003). They should include local actions taken by the poor themselves in response to changing market or environmental conditions supported by larger-scale, planned responses by government or other institutions that provided adaptation measures that are beyond the control or capabilities of local communities. IUCN (2003) stated three stages to approach adaptation which include planning, measures and measures to facilitate adequate adaptation, including insurance and other adaptation measures. A three-stage process that were identified as the basis for developing adaptation strategies include understanding vulnerability-livelihood interactions; establishing the legal, policy and institutional framework and develop a climate change adaptation strategy.

The devastating effects of climate change can be reduced if appropriate adaptation measures are employed. The range of actions as put forward by the First National Communication (2003) and Canada-Nigeria Climate Change Capacity Development Project reports (2004) as likely adaptation actions to be adopted in response to the current and anticipated climate change impacts on the various sectors of Nigeria's economy. These include:

- i. Physical and Ecological Adaptation (such as degradation of soils and Land resources; saltwater intrusion; drought and desertification);
- ii. Agriculture (such as crop production, livestock and fisheries);
- iii. Water Resources;
- iv. Socio-economic sector (such as economic base, energy, industry, transport and health); and
- v. Coastal Area which could be technical, engineering and structural; biophysical and ecological and non-structural.

In combating climate change effects at the national level, the launching of the Nigeria Sat – X satellite in August, 2011, has the ability to aid Nigeria in effective monitoring of key environmental issues such as flooding, gaseous emissions, agriculture, forestry and environmental mapping while it also provides satellite imagery for humanitarian use in the event of major international disasters such as the tsunamis, hurricanes, fires and flooding.

At the State level, the government of Lagos State has contributed in no small way to ensuring that on every front of the battle the menace of Climate Change and threats to Lagos' emergence as a successful Mega City are strategically addressed (Adegbola, 2011). In Nigeria for instance, some of the remarkable strides of the Lagos State Government in creating a viable environment and initiatives for sustainable development are illustrated in Table 1.

Table 1: Stride of the Lagos State Government in Creating a Viable Environment and Few Initiatives for Sustainable Development for the Attainment of the Millennium Development Goals.

S/N	Some Strides in Creating a Viable Environment	Initiatives for Sustainable Development for the Attainment of the Millennium Development Goals
i	The Launching of School Advocacy Programme on Climate Change	Aggressive Public Enlightenment Campaign
ii	Annual Tree Planting Campaign Exercise	Duplicating State Programme Initiatives on Sustainable Development
iii	Climate Change Summit	Establishing Environmental Stations
iv	Landscaping and Beautification Projects	Efficient Energy Use
v	Bus Rapid Transit (BRT) Scheme	Promoting Research Initiatives
vi	Construction of Walkways and Bicycle Paths	Improvement on Aesthetic Environment
vii	Efficient Waste Management System	Tax Reduction for Environment Friendly Outfits
viii	The Use of Pollution Abatement Technology in Industries	Local Initiatives for Biodiversity
ix	Regulation and Management of E-Waste in the State	
x	Vehicular Emission Monitoring and Regulation	
xi	Waste to Wealth and Waste to Energy Projects in order to Reduce Release of Carbon Dioxide into the Atmosphere	

Source: Adapted from Adegbola, (2011)

The Way Forward

In December 2015, a summit on climate change was held in Paris due to the future effects of climate change. The Paris Agreement requires all countries—developed and developing—to make significant commitments to address climate change. Countries responsible for more than 80 per cent of global greenhouse gas emissions made specific commitments to reduce their emissions by 2020 and ideally, strengthen their emissions reduction targets for 2030 as a part of the Copenhagen and Cancun agreements.

According to UNFCCC (2014) as cited in NRDC (2015), this agreement was made to reflect a greater level of ambition than in the previous commitment. For example, the United States and European Union have committed to economy-wide emissions reduction targets (e.g., cuts below 2005 levels), whereas developing countries and emerging economies have committed to targets that reflect their level of development and historic contribution to climate change (e.g., greenhouse gas intensity targets). The Paris agreement calls for zero net anthropogenic greenhouse gas emissions to be reached during the second half of the 21st Century.

All of the emissions scenarios considered by the IPCC yield global warming in the 21st Century that dwarfs warming seen in the past millennium. Immediate change to near zero CO₂ emissions is required to restrict global temperature increases to less than the constant composition commitment, C3 (Matthews and Weaver, 2010).

For the nation to achieve its ambition of improving environmental management, and accelerated development, it needs to redouble efforts to scale up climate change mitigation initiative which would drive a carbon neutral society for and ensure socially equitable climate resilient. Slow growth of world population for reducing anthropogenic activities as well as adoption of climate resilient crops and farming systems to achieve global security.

There should be a number of strategies for developing and integrating Green Infrastructure (GI) in human settlement which should include green spaces in new development, green roofs on new buildings, urban agriculture, tree planting and replanting among others. Efforts should also be made to enhance the use of technology options in managing climate variability risks (Salami, 2016). This is because Green Infrastructure (GI) can help to improve thermal comfort in urban heat islands and can help to alleviate flood risk by providing water absorption and flood storage space.

An institutional mechanism such as climate innovation centre should be established for developing countries that will adopt technologies and products for climate mitigation and adaptation purposes. Monitoring on deforestation, universal carbon tax and International Cooperation as most three efficient solutions for solving global warming are essential.

A participatory approach to water management, forest management and rural development for carbon sink enhancement and promotion of sustainable development need to be adopted while using innovative renewable new technologies that maximize

the production and the use of carbon-free energy while minimizing cost and optimizing communions.

Community participation is essential of adaptation and mitigation strategies. For this, members of the communities should be given training for skill development to manage weather vulnerabilities as climate risk managers of each local level. Finally, in order to reconcile climate change and economic growth, there is need to have good governance, strong institution along with economic and political stability.

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