



Effects of Climate Change and Variability in Africa: A Review of Concepts and Evidence

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ABSTRACT

Global climate has been changing for many thousands of years and will continue to do so in the future. While it is acknowledged that the entire climate change has always been happening even before the start of anthropogenic activities, this is perhaps the most serious problem that the civilized world is facing today. Key important phrases such as 'climate change' and 'global warming' now form part of our lives and rarely a day goes without being mentioned. There is a serious concern for the state of climate because of the strong consensus that climate change has implications on rainfall, temperature, agriculture and food security and human life styles, although climate change projections are quite diverse and vary widely across the globe. While industrialization has always been viewed as the key to wealth and better living (technological innovations, economic and social transformations of the human society), it has also been acknowledged that it affects the environment and ultimately contributes to climate change. This paper presents a review of the state of climate change and variability in Africa. We describe some common aspects on the African climate system and discuss related factors triggering its dynamics, aiming to determine social and demographic sectors vulnerable to climate change and whether there is evidence of critical thresholds beyond which climate drastically changes. With projected high temperature rise than the rest of the world, increase in the occurrence of droughts, floods and other natural disasters, Africa's economy, its people and ecosystems are vulnerable to climate change. Immediate changes also impact on global energy budget, water resources, air quality and consequently influence changes in human lifestyles and philosophies, habitat quality and distribution of wildlife and other natural resources.

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1. INTRODUCTION

No other continent is as symmetrically located with respect to latitude as Africa, for its northern and southern extremities extend almost equally from the equator [1,2]. Africa is sometimes described as a continental plateau [3] and it is true that much of its area is moderately elevated above sea level so that altitude plays a key role in reducing the otherwise tropical temperatures over very extensive areas. Only the extreme northern and southern subtropical parts reaching far enough poleward experience winter rainfall and feel the effects of the mid-latitude westerlies [3,4] and their disturbances in the cooler seasons. Africa has a wide variety of climate regimes [5,6,7,8]. Particularly the climate is distinguished by seven climatic zones: tropical rainforest, tropical wet- and dry, mountain, Mediterranean, mid-latitude dry and humid subtropical [9]. A large part of the continent also has a warm or hot climate with humidity and rainfall varying dramatically from area to area. Hulme et al. [7,8] describe Africa's climates as both varied and varying: varied because they range from humid equatorial regimes through seasonally arid tropical regimes to sub-tropical Mediterranean-type of climate, and varying because they exhibit differing degree of temporal variability, particularly with regard to rainfall. The most important climatic differences are due to variations in rainfall amount, duration and seasonality [4,6]. For example, the poleward extremes of the continent experience winter rainfall associated with the passage of mid-latitude air masses [3,10]. The northern and southern ends experience extra-tropical climate regimes flanked by Sahara and Kalahari deserts in the north and south respectively, and dominated by the sub-tropical anticyclones. Across the deserts, precipitation is inhibited by subsidence virtually throughout the year [4,10]. Rainfall maxima are controlled primarily by the seasonal migration of the Intertropical Convergence Zone (ITCZ) between summer (October–April) and winter (May–August). Contrastingly, moderate to heavy precipitation characterizes the equatorial and tropical areas [4]. Because the ITCZ movement follows the position of maximum surface heating associated with meridional displacement of the overhead position of the sun, near-equatorial regions experience two rain seasons, whereas regions further poleward experience one distinct rainfall season.

Like the rest of the world, Africa is highly sensitive to climatic conditions, in which its location, size and shape play key roles. Due to the wide variety of climate regimes and the complexity of the key factors, climatic fluctuations can have influence over land and the entire earth for several centuries. The continental climate system is also controlled by a complex mixture of large-scale weather systems, many from distant parts of the globe. This indicates that the earth climate system is constantly changing, therefore capable of all sorts of surprises. Varying climatic conditions would define patterns that would otherwise favour new species and/or ecosystem evolution. A serious issue pertaining to this is the nature of change triggered by events combined with climate change and variability. It is now apparent that new threats to coastal and/or previously unaffected areas have emerged as a consequence of climate change. Notwithstanding, climate change is one of the most spoken topics today. This is an effect resulting from many interacting factors; there is no one distinct causing factor of climate change. Climate change can be defined as 'any change in climate over time, be it due to natural variability or human activity' [11]. However, this definition differs from that given by the United Nations Framework Convention on Climate Change (UNFCCC), given as:

"Change in climate attributed directly or indirectly to human activity that alters global atmospheric composition and which is in addition to natural variability observed over comparable time periods" [12].

However, climate change is generally described as a persistent change in the weather triggered by anthropogenic activities, mostly linked to industrialization and manifests into a long-term shift in the statistics of weather [13]. This could show up as a deviation from the 'normal climate' (e.g. expected average temperature and precipitation values) for a given place and time of the year from one decade to the next [14] -one of the major drivers being 'global warming.' Connolly-Boutin and Smit [15] also describe climate change as an emerging stressor experienced over longer time frames via changes in climatic norms and over shorter periods via changes in the frequency and severity of extreme weather events. It is widely agreed by the scientific community today that climate change is a reality [11,16], and so is the case in Africa [17].

Substantial inter-annual precipitation variations are observed throughout the continent [18, 19]. In some cases, extreme events lead to too much flooding or prolonged droughts with far reaching physical, environmental and socio-economic impacts [20]. The Intergovernmental Panel on Climate Change (IPCC) predicted that temperatures across Africa are expected to increase by 2–6 °C within the next 100 years, with rainfall amount expected to increase and result in frequent flooding [7]. For example, observed surface air temperatures have shown an accelerating warming trend since 1960s. Consequently, there has been an increase in the number of warm spells; trends in precipitation over Africa are less coherent, with large spatial and temporal variability and declining rainfall in some areas [21, and references therein]. Such climate extremes are also linked to (global) large-scale events such as El Niño Southern Oscillation (ENSO), sea surface temperatures (SSTs) and dipole systems; Indian Ocean dipole and the Quasi-Biennial Oscillation (QBO), including the monsoon flows.

While Africa is highly vulnerable to climate change, her vulnerability is not only caused by climate change, it is also due to a combination of several other stresses that characterise it, all of which contribute to weaken her adaptive capacity [22]. This fluctuation is governed by factors such as marine and continental interactions [23] and human and natural influences that impact economic development, agriculture, water resources, food security, livelihoods etc. It is quite clear that climate change is no longer a hypothesis; there is no doubt about it, for it has been changing over many years [9]. The IPCC Fourth Assessment Report (FAR₄) also indicates that climate change is real and that pollution from human socio-economic development activities are responsible for the observed anthropogenic climate changes. Africa is widely recognised as one of the world's most vulnerable regions [24] due to widespread poverty, limited coping capacity and highly variable climate [25], and references therein]. Impacts of climate change are so worrisome [26]. Vulnerability is an important term commonly associated with climate change and variability. The IPCC FAR₄ defines vulnerability in the context of climate change as:

“The degree to which a system is susceptible to, and unable to cope with adverse effects of climate change, including climate variability and extremes. In a broader sense, this is a function of the character, magnitude

and rate of climate change and variation to which a system is exposed, its sensitivity and its adaptive capacity” [24].

Meanwhile, the IPCC Fifth Assessment Report (FAR₅) defines vulnerability as: *“the propensity or predisposition to be adversely affected”* [27]. Vulnerability increases over time if systems face repeated shocks that steadily erode their base [28]. This is a dynamic concept, varying across temporal and spatial dimensions and often depends on socio-economic, peoples' livelihoods, capacity and access to knowledge, information, services and support, including geographic and environmental factors [29, 30]. Generally, three components of vulnerability are often highlighted in climate change context: exposure, sensitivity and adaptive capacity [31]. Although vulnerability definitions differ across research communities, in this review, we limit ourselves to the context of climate change focusing on the African continent.

Africa is particularly vulnerable because its economies are largely dependent on weather-sensitive production systems [24, 32]. This is also due to the fact that current climate is already severe, poor information and slow technological change, particularly over sub-Saharan Africa [33]. As highlighted in some global reports, droughts and floods have increased in frequency and severity in recent years are projected to increase in many areas around the world. However, Africa's vulnerability is not only limited to its high exposure to climate change; many African communities also lack the capacity to respond or adapt to the impacts [34]. Impacts such as rising temperature and precipitation change are undeniably clear and are already affecting ecosystems, biodiversity and humankind. The continent is anticipated to experience more than its fair share of climate change's negative impacts, despite consuming just a fraction of the world's fossil fuels [35]. Understanding and predicting these inter-annual, inter-decadal and multi-decadal climatic variations has become a major challenge facing Africa and African climate specialists [7, 36]. The implication is that climate change, with all associated problems will continue to affect Africa and the world. This is also highlighted by global assessment reports, confirming Africa's high vulnerability. For example, the IPCC Third Assessment Report (TAR) stated that:

“Africa is the most vulnerable region to climate change, due to extreme poverty of many Africans, frequent natural disasters

such as droughts and floods, and agricultural systems heavily dependent on rainfall” [12].

1.1 Significance of the Study

Humanitarian crisis associated with environmental conditions over Africa such as severe and persistent droughts, floods and other extreme weather events exemplify the risk and/or vulnerability of people and ecosystems associated with climate change. These shocks affect vulnerable communities battling with poverty, weak institutional and financial support etc. and can have devastating consequences on their livelihoods and economic development. This paper aims to develop a conceptual framework of the relationships among climate factors, how they relate to multiple stress capacities and provide a structure for understanding their implications. Recognizing these interconnections can help improve our understanding of the relationships between climate, food production, health and livelihoods. It is also very imperative and necessary to help guide practical initiatives and/or action plans (including adaptation and mitigation) intended to improve and sustain peoples' life styles as the climate continues to change.

2. MATERIALS AND METHODS

2.1 Study area

This study focuses on Africa, the second largest continent after Asia, covering about one-fifth (about 6%) of the total land surface. The continent is bounded by the Atlantic Ocean on the west, Mediterranean Sea in the north, Red Sea and Indian Ocean on the east and the waters of both the Atlantic and Indian oceans in the south [37]. It is cut almost equally into two by the equator (0° latitude) and most of the landmass lies within the tropical region bounded by the Tropics of Cancer and Capricorn in the north and south respectively. It is also crossed from north to south by the Prime Meridian (0° longitude). The total land area is approximately 11,724,000 square miles (30,365,000 km²) and measures approximately 5,000 miles (8,000 km) from north to south and about 4,600 miles (7,400 km) from east to west [37]. Much of the land area is considered as a vast plateau, rising steeply from narrow coastal strips and consists of ancient crystalline rocks. Africa is sometimes nicknamed the “mother continent” due to its being the oldest inhabited continent on earth [38]. Several other islands off the coasts (e.g. Mozambique, Seychelles, Cape Verde, São

Tomé and Príncipe and Canary) are associated with the main land.

Africa comprise of countries that are highly fragmented in terms of variety of natural resources, sustainable development goals, and poverty levels. The continent is also home to several natural disasters such as droughts, famine, floods and other attendant disaster-related epidemics [22]. According to the United Nations Population Division (UNDP) report, Africa is home to 1.2 billion people (an increase from 477 million in 1980). This is about 15% of the world's human population [2]. Annual population increases are estimated to exceed 42 million people per year and total population will double, reaching 2.4 billion by 2050 (about 3.5 million people per month, or 80 people per minute). However, this population profile will have influence on global demography in the 21st century. For example, the United Nations report of 2016 stated that:

“African countries are concurrently countries of origin, transit and destination. The most prominent form of migration being labour followed by forced migration, besides irregular and transit migration” [39].

2.2 Data and Methodology

The primary source of data for this study was electronic literature collection. This was conducted through the Google search engine using the key word “effects of climate change and variability in Africa.” Furthermore, electronic search for ‘climate change’, ‘impacts of climate change’, ‘vulnerability’ and ‘socio-economic impact of climate change in Africa’ was conducted with Google and other search engines. Results from these searches also encompassed findings from the UN and IPCC reports, peer reviewed scientific journals, conference/workshop proceedings and other high-quality grey literature. Additional data was also collected from the cited literature used in this study. Overall, the study is purely qualitative, but employs a blend of quantitative and qualitative evidence to assess effects of climate change and variability in Africa.

3. RESULTS

3.1 Evidence of Climate Change and Variability in Africa

In this section, we review literature on evidence of differential climate change and variability on

various climate components. Following this evidence, we discuss it in terms of threats on human socio-economic and livelihoods, agriculture and food security, health and water resources. Similarly, we discuss potential thresholds of deleterious climate change on the well-being and socio-economic challenges in Africa. There is scientific consensus based on the overwhelming evidence that global climate is changing, and that it is caused largely by human activities [11, 40]. Predominantly, the influence of anthropogenic activities to global climate has become so apparent to influence climate change [41]. Warming of the climate system is unequivocal and since the beginning of the Industrial Revolution period, many of the observed changes are unprecedented over decades to millennia. The atmosphere and oceans have warmed; amount of snow cover and ice have diminished; sea levels have risen and greenhouse gas (GHG) concentrations have increased [42]. The IPCC FAR₅ also indicates that there is high confidence that changes are occurring in the distribution and dynamics of all types of terrestrial ecosystems in Africa. There is substantial evidence of African climate variability and change derived from instrumental, geological, remote sensing and proxies of other climate sensitive parameters in literature [20]. Similarly, climate modelling provides vital tools that can be used to address various aspects of climate variability.

Modern era of anthropogenic climate forcing is variably defined as having started around 1750 with the Industrial Revolution and its adaptation of fossil fuels as a dominant energy source; beginning of the first standardized observations of climate change around 1850, and the enormous acceleration of economic activity and emissions following World War 2 [43]. However, the author also argues that very little actual data is available prior 1960s to quantify Africa's role in the global trends, although the general consensus is that global African contribution has been small (~1%) up to the start of the period of contemporary climate concern. Africa's contribution mainly comes from increasing human population, accompanied by increasing pollutant emissions as a result of technological development and urbanization. This is also exacerbated by widespread land use change that currently dominate pollutant emissions. Although Africa has been the lowest source of GHG emission owing to its lack of industrial development [44], the continent is believed to be the most vulnerable to climate change impacts

[45]. Nevertheless, Africa's role in carbon emission is believed to be atypically minor, for its past economic activity has not contributed to the accumulated global carbon stock; its current activity accounts for only a trivial proportion of global emissions [45]. However, it must be acknowledged that in addition to three main pollutant sources in Africa (biomass burning, aeolian dust and anthropogenic), there are other significant sources that also contribute to the overall pollution and hence climate dynamics.

Biomass burning (BB) is one example mostly induced by humans as part of their agricultural and related practices [46, and references therein]. Burning affects most vegetated land-cover types, especially in tropical and savannah regions of Africa, resulting in the darkening of the upper atmosphere, thereby reducing its albedo that contributes to the absorption of solar radiation and surface heating. Immediate burning results in heat release and smoke emission (containing particulates and gases) that affect atmospheric composition and interact with solar radiation, cloud microphysics and hence atmospheric heating and cloud modification [46, 47, 48]. Besides anthropogenic, other continental-scale and sub-continental climate anomalies also play substantial role in determining inter-annual and longer climate variability time-scales [19]. These climate-forcing agents also impact on the global energy budget.

Indeed climate change is one of the most spoken topics today, resulting from many interacting factors [49]. This may occur from external or internal factors [50] or through a complex of interactions leading to changes in the overall state of the earth's climate system. Fig. 1 highlights some of the main factors that can potentially alter global climate system. These involve variation in the sun's output leading to variation in the global radiation budget; oceanic and land systems; changes in atmospheric gas concentrations; volcanic activities; surface and atmospheric albedo etc. One of the major drivers of climate change is global warming –a term described as an average increase in the temperature of the atmosphere near the earth surface [13]. Consequently, global warming is generally agreed to be caused primarily by emission of GHGs and other chemicals in the atmosphere. However, past evidence suggest that only a limited number of factors are responsible for climate change [13, 49], such as variations in the earth's orbital characteristics, volcanic eruptions, solar output and activity;

cosmic rays, carbon dioxide (CO₂) variations, asteroids and earth's climate. Meanwhile, it is worth noting that all factors that influence the climate system do not work in the same direction to cause climate change, but the change is due to their complex interactions. Overall, climate change can impact on almost all components of the atmosphere -including water and air quality demand, with potentially devastating socio-economic consequences.

3.1.1 Rainfall patterns

Rainfall continues to vary across Africa from time to time, with declining amounts in some areas. Most of the African continent is semi-arid and prone to extreme rainfall variations from year to year [51]. Below-normal rainfalls are characterized by recurrent droughts (sometimes more severe) where frequent increases and intensification of ENSO episodes have been observed. ENSO is a large-scale air-sea phenomenon that consists of warming (El Niño) or cooling (La Niña) in the equatorial Pacific and is primarily linked with climatic variability in Africa due to atmospheric teleconnections [32]. Although ENSO impacts are strongest in the Pacific, past records show that some severe droughts and floods observed over some parts of the continent have been associated with ENSO events [52]. Current records indicate that rainfall pattern across Africa varies extremely and exhibits different scales of temporal and spatial

variability [53, 54]. Particularly, ENSO is a major driving force to climate variability in southern Africa, affecting rainfall patterns [55]. One of the stronger relationships of ENSO is between the El Niño cycle and drought over southern Africa [3, 56]. However, although the influence of ENSO over southern African climate is well documented, the impacts are highly variable as SST anomalies in the Tropical Pacific Ocean vary considerably between ENSO events. These anomalies are compounded by different modes of variability within the Indian- and Atlantic Oceans respectively, which also modulate regional circulation and rainfall over the subcontinent [57, 58]. Most studies in literature agree that El Niño (La Niña) typically reduces (intensifies) precipitation over southeastern Africa and result in dry (wet) conditions, while increasing (decreasing) it over northeastern tropical Africa [59, 60, 61]. Inter-annual rainfall variability is large over most of Africa; for example, in regions such as the Sahel, multi-decadal rainfall variability has been substantial. For example, the nature of rainfall variability for three regions (Sahel, East- and Southeast Africa) was showed by Hulme et al. [8] to exhibit contrasting patterns of variability. Sahel exhibited large multi-decadal variability with drying while East Africa displayed a relatively steady regime with some evidence of long-term wetting, and Southeast Africa displayed a stable regime, but with noticeable inter-decadal variability.

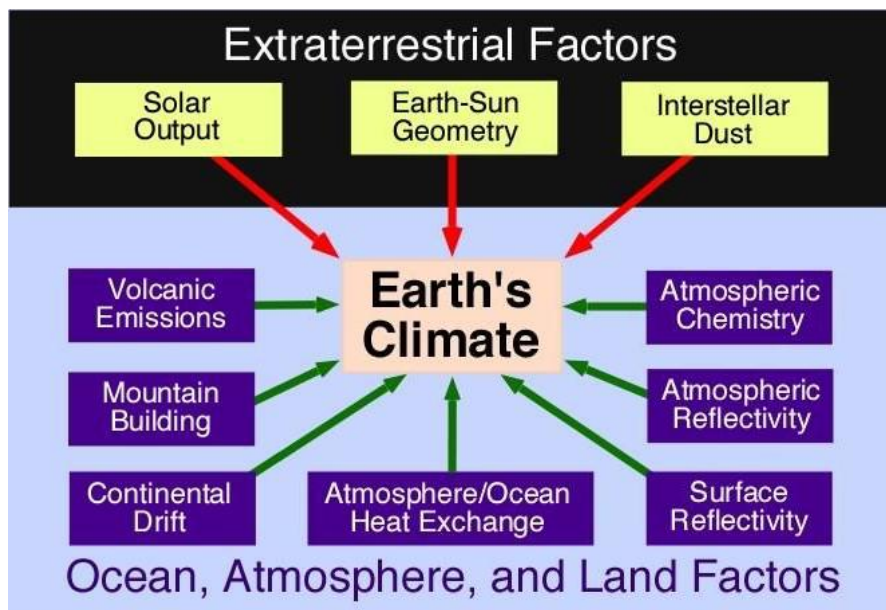


Fig. 1. Factors influencing global climate change [48]

The long-term precipitation changes from both northern and southern regions of Africa are also linked to the monsoon circulations and controlled by precessional variations in summer insolation [62]. Southern Africa has experienced an increase in inter-annual variability over the past 40 years, with more intense widespread droughts [63]. The Southern Oscillation effect is also coupled with a number of changes in different parts of the continent and global environment. For example, increased frequency of extreme El Niño and La Niña events due to climate change allows greater locust breeding during winter in the Horn of Africa during summer in the Sahel of West Africa respectively [28]. Any change in wind circulation flow could allow locusts and swarms to reach previously unaffected areas and/or spread to other global regions. Besides ENSO, the North Atlantic Oscillation (NAO) and the West African climate anomaly patterns, other continental scale and sub-continental climate anomalies also play vital roles in determining inter-annual and longer climate variability time scales [19]. For instance the decade 1950–1959 was characterised by above-normal precipitation over most of the continent –with deficiencies prevailing over equatorial Africa, whereas the period 1960–1969 showed the rainfall pattern dramatically reversing in sign, much deficits were observed in most parts and equatorial Africa received abundance of rain.

3.1.2 Temperature changes

Climate change impact is already putting a massive strain on the continental resources and landscape. As alluded in literature, Africa is already set to bear the most economic burden due to rising temperatures over the next decades. For example, temperatures are projected to rise faster than the global average during the 21st century. Extreme temperatures are expected to breach today's levels by 2°C by 2050 [64]. Studies also indicate variations across the continent. On regional scales, observations showed increase in temperatures over the Sahel, tropical forests, southern-, eastern- and North Africa [53]. Temperature increase over tropical Africa was shown to increase by 0.29°C since 1960, while over the Sahel it increased by 0.2–0.3°C during the 1990s [8, 54]. Fig. 2 shows observed temperature changes over Africa (1990–2000). As shown, observational records indicate that Africa has been warming throughout the 20th century at the rate of 0.05°C per decade, with slightly larger warming in June–November than December–May [7]. Significant warming

occurred in the early 1980s (1988 and 1995 being the two warmest years) prior to 2000. However, the observed warming trend is consistent with global climate changes and is likely to be a signal of the anthropogenic effect. At the root of climate change is global warming caused by anthropogenic emissions (e.g. CO₂, methane [CH₄] and other GHGs). Since Industrial Revolution, humans have always played a major role in anthropogenic emissions that can directly and indirectly affect both climate and atmospheric composition.

While it is acknowledged that warming occurs worldwide, temperatures are rising on the African landmass and surrounding oceans [45]. According to the authors, Africa is distinctive in the combination of climate-change effects: (i) first, it is evident that Africa is warming faster than the global average temperature and this is likely to continue, (ii) secondly, Africa is such an enormous landmass and the climatic effects differ according to location. The authors also argue that some African regions will become drier while others become wetter; some may derive economic benefit and most would be adversely affected.

Also shown in Fig. 3 are associations between inter-annual climate variations over Africa with respect to ENSO and NAO. As observed, different regions across the continent display similar responses to climate change due to these weather events. As acknowledged, temperatures have soared across the globe and will continue to rise. For example, global trends in temperature rise have increased by about 0.5°C over the last 100 years [3, 43] while SSTs have also risen by more than 1°C since the 1950s. Recent research also suggests that the southern hemisphere (SH) climate will continue to change and temperatures are expected to rise higher than they are today. Annual average temperatures are expected to rise by about 1.5–2.5°C by 2050 in the SH and about 2.5–3.0°C in the northern hemisphere (NH), compared to the time before the 1990s [65]. Globally, average temperatures are projected to increase between 0.15 and 0.3 °C per decade. Model-based predictions of future GHG-induced climate change for Africa also suggest that warming will continue, and in most scenarios accelerate [7]. The IPCC FAR₄ had also projected surface temperature rise over the 21st century under all assessed emission scenarios. Also, the frequency and intensity of heat waves are likely to be more frequent and prolonged.

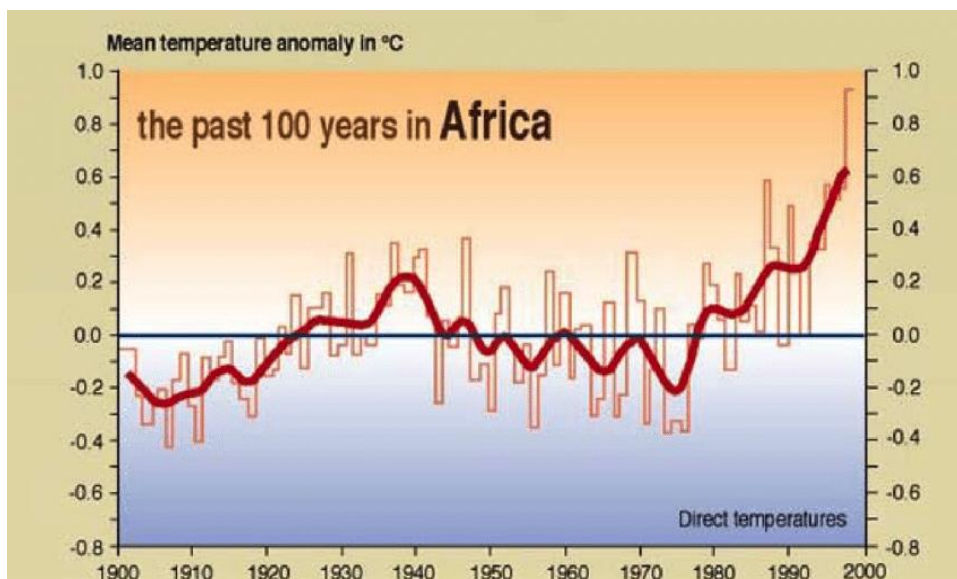


Fig. 2. Observed temperature changes in Africa
 (Adapted from Nyong [22], IPCC TAR, 2001: Impacts, Adaptation and Vulnerability)

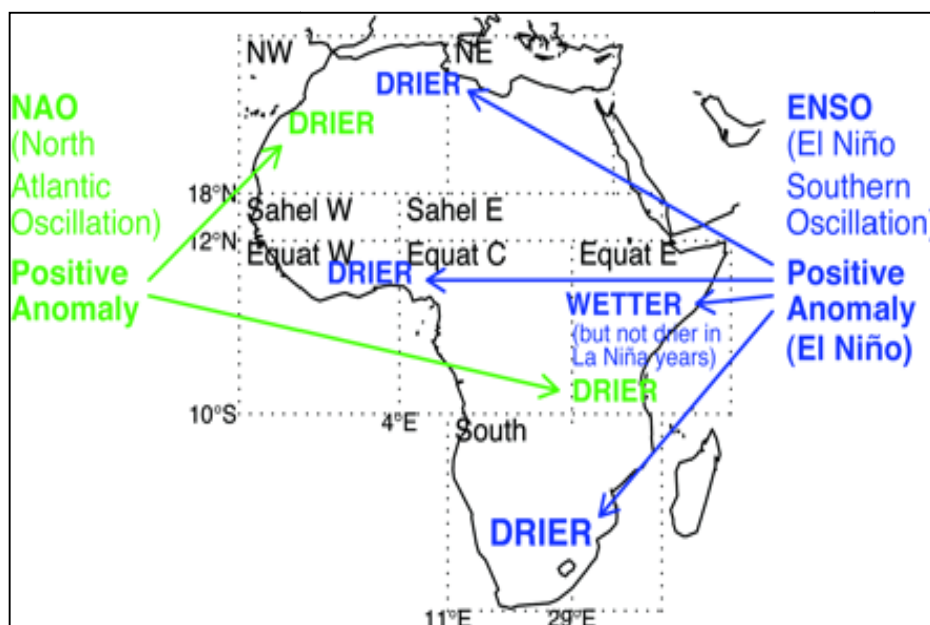


Fig. 3. Inter-annual variation in climatic variability and association with large-scale aspects. Different regions within the continent display similar responses to climate change and variability

(Adapted from Stige et al. [32])

3.1.3 Extreme and synoptic events

Quite often, natural disasters (e.g. floods, droughts and heat waves) occur in many parts of Africa. Impacts of these extreme events are felt in different magnitudes; some regions already

experience costly impacts in terms of loss of lives, economic damage to infrastructure and property, agriculture, tourism, food security and health [66, 67]. Consequential effects occur through weather events such as ENSO episodes (El Niño and La Niña), tropical storms, forest fires

etc. and result in very catastrophic effects to the ecosystem, humankind and infrastructure. For example, south-eastern Africa is prone to frequent extreme events [68] that unleash large wave events over land [69]. Elevated temperature and the unpredictability of rainfall (both temporally and spatially) are projected to increase both frequency and intensity of extreme weather events for sub-Saharan Africa, including droughts, heavy rain storms, flooding, forest fires and ENSO events [16]. In semi-arid ecosystems, climate change frequency and drought severity are likely to exacerbate effects of drought on food supply which can feed back to limiting production [24]. For example, West African Sahel is infamous for the extreme droughts that began in the late 1960s and took a toll on food production. Also, the world's attention has been recently focused on the extreme droughts in eastern Africa [51].

Climate-related events coupled with other anthropogenic stressors interact to influence changes in abundance and distribution of wildlife resources [70]. There is likelihood of climate-related extremes such as heat waves, droughts, floods, cyclones and wildfires will expose some ecosystems rendering them vulnerable to climate variability [42]. For example, heavy rainfall events increasing over southern Africa, along with changes in seasonality and weather extremes [53]. However, there is considerable uncertainty regarding projected extreme changes to the end of the current century and confidence in projecting them in the direction and magnitude of climate change [71]. Given the current limits of understanding the underlying processes of climate change in many regions [71], it may appear that low-probability, high-impact extremes will still persist in the future. At the global scale, science implies that further increases in GHG temperatures will continue to rise and as a result, so will global average precipitation. This could lead to an increase in heavy rainfall events in general [72]. Also, there is a considerable literature on the economic costs of climate variability and extremes. A strong upward trend in the overall losses due to climate change is projected, despite the uncertainties on how the changes will unfold in the future.

3.2 Effects of Climate Change and Variability

3.2.1 Water resources

Climate change has a multitude of immediate and long-term impacts on water resources in

Africa. These include flooding, drought, sea-level rise, drying up of rivers, poor water quality in surface and groundwater systems, precipitation changes, water vapour pattern distortions, snow and land ice distribution [73]. The continent has some of the world driest deserts, largest tropical basin forests, highest equatorial mountains and key natural resources that are unevenly distributed [73]. That being said, Africa is at the forefront of the regions affected by climate fluctuations on water resources [74]. When compounded together, these effects can have devastating impacts on ecosystems and communities -ranging from economic and social impacts to health and food insecurity, all of which threaten the continued existence of many living organisms. About 25% of the contemporary African population experiences water stress, while 69% live under conditions of relative water abundance [75]. The United Nation Environmental Programme [76] also indicated that about 1100 million people do not have access to clean drinking water, and contaminated water is the cause of 5 million deaths annually -majority of which occurs in sub-Saharan Africa. Since the late 1960s, droughts have caused a lot of suffering in Africa, particularly affecting people in the Great Horn, Sahel and southern Africa [77]. A lot of literature show that there has been a decrease in surface and groundwater flow as a result of declining rainfall. Other studies also highlight the evolution of river flows and impacts on the natural and human territorial systems in recent periods, the extent and reality of which depends on the regions' hydro-climatic conditions [78].

Climate change is also projected to increase the risk of drought over much of Africa in the 21st century. The most affected regions seem to be largely determined by changes in SSTs, especially in the tropics through associated changes in atmospheric circulation and precipitation. Worldwide, climate-related warming of oceans, lakes and rivers has been observed in recent decades with implications for freshwater ecosystems such as changes in water salinity, water nutrient content, pesticide concentrations and other pollutants, salinization of groundwater, water chemistry and pH balance [79]. While lake levels in other parts of the world have risen in response to increased snow- and ice melt, lake levels in Africa have declined due to the combined effects of drought, warming and human activities [73]. According to the authors, climate change is anticipated to increase conflicts between people as a result of struggle

for water use if increasing supply to meet the growing demand cannot be assured, including other pressures on natural human resources. Water resource use for domestic, commercial or industrial is also known to trigger numerous conflicts across Africa. By critically affecting crop productivity and food production, and on the other hand being a necessity in human life, water plays a critical role in food security.

3.2.2 Agriculture and food security

Agriculture is an important sector to the African economy [73], which on average accounts for 70% of the labour force [15] and over 25% of the gross domestic product [80]. It is central to the food security and economic growth of developing nations, providing the main source of livelihood for the poor. Globally, agriculture is accepted as one of the sectors most vulnerable to climate change impact [81] due to increased temperatures, reduced rainfall and increased frequency of variation in extreme events especially in the tropics [82]. Third world countries, particularly Africa are threatened by the predicted effects of climate change because of their economic dependence on climate for development whose backbone is agriculture. Climate change profoundly impacts the conditions in which agricultural activities are conducted. Sufficient evidence shows that average temperature rise in Africa is faster than the global average and is likely to persist in the future [7]. The warming is definitely hazardous for agricultural activities as many of the crops grow close to the thermal tolerance limits [45]. Consequential effects may include: reduced agricultural land use due to submergence of coastal regions and increased aridity in tropical

high agricultural potential regions, shortened or disrupted growing seasons, declining agricultural yields, increased incidences of pests and diseases, food insecurity and poverty.

Throughout the world, plants, animals and ecosystems adapt to the prevailing climatic conditions [28]. Particularly, Africa is the region with the greatest risk of increased hunger; there is looming food crisis in many African countries in addition to hard-core poverty, public health problems and changes in human settlement patterns [82, and references therein]. While food security is a fundamental requirement for human sustenance and well-being, it is also influenced by other aspects of their livelihoods such as income, health and assets [83]. This is also attributed to Africa's low adaptive capacity, economic importance of climate-sensitive sectors in many countries and their limited human, institutional- and financial capability to respond and anticipate to direct and indirect climate change effects and variability [45]. It is widely accepted that the continent is already experiencing the devastating impacts evidenced through frequent floods, droughts and shift in marginal agricultural systems. These additional risks would directly translate further into risks for food security and nutrition for citizens who directly depend on agriculture for their livelihoods [28]. The table below shows climate change impacts on crop production value associated with a range of climate shocks over Africa. Given the level of dependency of poor and food-insecure on agriculture, the potential impacts of climate change on agriculture is of great concern. Quite clearly, these impacts translate from climate to the environment, population, economic and social dimensions.

Table 1. Analysis of the actual crop yield impacts (FAO, [28])

| Country | Weather/climate variable shock | Impact on the value of crop production |
|----------|----------------------------------|---|
| Ethiopia | Rainfall-growing season | + (7–8)% |
| | Temperature-growing season | + (10–60)% |
| Malawi | Rainfall-growing season | + (16–20)% |
| | Dry-spells-growing season | – (10)% |
| Niger | Rainfall-growing season | + (64–84)% |
| | Late rainfall onset | – (42–51)% |
| Tanzania | Within season rainfall variation | – (8–15)% |
| | Too hot growing season (>30°C) | – (14–25)% |
| Zambia | Rainfall-growing season | + (5–10)% |
| | Late/false rainfall onset | Decreases the +impact of inorganic fertilizers by 50% |
| | Too hot growing season (>28°C) | Nullifies the +impact of improved seed |

Africa's agricultural activities are mainly controlled by rainfall amounts and distribution [84], a factor highly dependent on the climate. Most countries rely on rain-fed agriculture [85], which is the source of food, fibre and income on primary sectors such as fisheries. However, many African farmers are particularly vulnerable since they rely on rain-fed agriculture rather than irrigation. On the other hand, Africa's vulnerability to climate change lies in the fact that climate change affects two most important direct inputs: precipitation and temperature [86]. Climate change continues to play an increasingly important role on humankind and food security in Africa as in any other part of the world. For example, increasing temperatures and CO₂ concentration affect crop yields in some places, prominent amongst them being changes in growing season and soil moisture conditions suitable for crop growth [82]. This pose challenges to farmers and threaten food security. Evidence is also emerging that high-value perennial crops are negatively impacted by rising temperatures since suitable agro-climatic zones will become marginal for plants by the 2050s [87]. Furthermore, crops' wild relatives provide an important source of genetic diversity for crop improvement, but their survival is threatened by climate change [88].

Overall, climate change could make it difficult to grow crops, raise animals and produce food in many areas. Rising temperatures, extreme precipitation variability would negatively impact on population distribution, food security, livestock and crop production –particularly in sub-Saharan Africa. One demanding key factor therefore, would be population change. For example, the UN projected that African population will continue to grow rapidly throughout the 21st century and is expected to exceed that of East Asia by 2030s and South America by mid-century. The Africa Center for strategic studies report of 2016 indicate that Africa's population is growing rapidly and is estimated to balloon from the current 1.2 billion to 2.8 billion by 2060. Consequently, this growth will have direct effects on the demand for agricultural commodities –particularly staple food crops [89]. The continental development is projected to experience a continuing increase in per capita income and a demographic shift from rural to urban areas by 2050. However, food production per capita continues to fail to keep up with population growth rate, with rural population almost trembling in sub-Saharan Africa [82]. Demands for traditional staple food is likely to slow in per capita as the demand for purchased

and processed food increases. Food security is an important commodity for human survival. For example, in a region characterized by competition for land, coupled with climate change, there is high demand for food supply to feed the growing population. Thus, climate change can pose an impediment to food security, owing to the fact that Africa lags the world in agricultural research, partly a legacy of colonial and Green Revolution era neglect and exacerbated and continued by the choices of most African governments [90].

3.2.3 Health and livelihoods

Climate change affects the main determinants of human health [91]. As highlighted earlier, human beings are exposed to climate change directly through weather patterns (e.g. intense and frequent extreme events) and indirectly through changes in water resources, air- and food quality, ecosystems, agriculture and lifestyles. Climate change induces health-related problems due to hunger and starvation, water stress, pests and diseases, resource conflicts as well as consequential stress from extreme weather events [92]. Furthermore, scientists argue that climate change can negatively affect human health by modifying the transmission of diseases such as cholera, malaria and meningitis. A number of diseases are sensitive to changing climate conditions such as temperature and precipitation. Dirty or contaminated water supply can increase the prevalence of certain diseases and/or intensify disease outbreaks [26]. For example, vector-borne diseases (e.g. malaria and fever) increases dramatically during periods of above-normal temperature and rainfall. Malaria increases frequently during higher (nocturnal) temperature and it has been found to enhance in areas where it has not previously been a serious threat [22]. For example, high temperatures and severe rainfall events were thought to be precarious factors initiating malaria epidemics in East Africa and Madagascar [26, and references therein]. The frequency and sternness of malaria in East Africa also appears to be correlated with increasing occurrence, magnitude and perseverance of the Niño phenomenon throughout the past 20–30 decades [11]. Cholera has also been known to cause large-scale severe epidemics during periods of strong El Niño [22].

Other water-related aspects of health include cases of cataracts in the arid and semi-arid regions of Africa due to low cloud cover and

greater intensity of solar radiation; malaria and typhoid fever due to increased rainfall and temperature; cholera and dysentery due to urban flooding and improper waste disposal [93]. Also, warmer and more humid conditions could enhance bacterial growth and mould on stored food, thus increasing food spoilage and creating some specific toxicological health hazards [92] and threatens to change the prevalence of those associated with air pollutants and aeroallergens. Climate change could alter or disrupt natural systems thereby bringing new challenges to the control of infectious diseases, as a changing climate makes it possible for diseases to spread or emerge in areas where they had been limited or had not even existed before [2]. Recently, it has also become clear that climate change and variability will have direct and indirect impacts on diseases that are endemic in Africa [22]. Notwithstanding however, vulnerability of many African countries is not only due to climate parameters. Anthropogenic actions (e.g. deforestation, irrigation, conflicts and migrations) and low capacity to tackle issues; insufficient health services and low access to water and sanitation also play vital roles [22].

Owing to the above-mentioned facts, it is therefore imperative to understand the actual dynamics of climate change impact at the lowest levels of the society, such as households, communities and surroundings. Additionally, climate change is associated with changes in human livelihoods (e.g. domestic, industrial, power generation and navigation activities). These impacts depend on the baseline condition of water supply, access to water resources and management systems, population growth, energy demand and supply, technological change, economic and social conditions. For example, meteorological disasters (floods, droughts etc.) have major impacts on food production and supply, human health, economic and environmental losses [94]. This also invites questions such as 'what is the trend of climate change, what is the impact on livelihood, who is vulnerable to the impact and how, what other constraints that exacerbate societal or environmental vulnerability, and what are the existing local and institutional coping mechanisms and what are the possible adaptation and mitigation mechanisms?'

The extent and complexity of climate change impacts can directly and indirectly threaten human life and sustainable development. Changes can also affect many important sectors

of the economy and influence food demand and supply, energy, goods/services and other commodities. For example, an increase in surface temperature will affect the livelihoods of many Africans depending on rain-fed agriculture. This can lead to low productivity, income and the standard of living, thus completing the vicious poverty cycle [73]. At national level, climate change impacts can trigger an increase in agricultural commodities such as food price and hence directly impacts on the economic and social status of the whole population. This triggers macro-economic effects for agriculture-dependent countries where agriculture is an important part of the gross domestic product (GDP) and constitutes an important part of employment [28] and human development.

4. DISCUSSION

It is important to study the variability and dynamics of climate under varying external forcing (e.g. the features, processes and modulators of weather patterns) with global trends. Their variability can independently and/or interactively play pivotal roles in the global climate change –be it in the past, present or future. Interactions between these systems sometimes result in large variations in weather and/or climate regime spanning to seasons, decades or centuries. However, the interplay between the atmosphere, land and oceans driving the climate is extremely complex. One of the key challenges also is to understand and predict periodic or seasonal characteristics of large-scale atmospheric and land-oceanic interactions and flows. Climate change impacts (including changes in the patterns of the extreme events) can potentially destabilize livelihood systems and future development activities [63]. For example, the threats posed by climate change increase the urgency of promoting adaptation strategies for sustainable management of the available water and other human resources. It is expected that if society can cope with the current climate variability shocks, there would be a high probability of adapting to the impacts of future climate change [20].

Fig. 4 summarises effects of climate change across Africa, as reported by Africa Center for Strategic Studies. Highlighted are some ways in which climate change is straining Africa, evidenced through rainfall, temperature, agriculture and food security, health and diseases, water resources, environment and

health. As highlighted, different regions within the continent are affected to different degrees due to climate change; the most affected sectors being agriculture, food security, wildlife and vegetation. As a result, migration from affected areas causes population inflows into fragile areas and often leads to conflicts over resources, political instability etc.

High temperatures and changes in rainfall patterns are likely to negatively reduce crop production and would have strong adverse effects on food security. On the other hand, pests, weeds and diseases are expected to increase and will have detrimental effects on crops, wildlife species and/or humankind. As acknowledged, much of Africa's food security is largely dependent on rain-fed agriculture and that majority of African farmers are small-scale farmers with limited financial resources and access to infrastructure. Particularly, agriculture

is expected to pay a significant cost of the damage caused by climate change [95]. Given the continent's considerable carbon stocks [96] and the high direct dependency of a fast-growing population [97] on natural resources as well as major changes driven by urbanization [98] and the continental development agenda [99], Africa's role in global climate forcing is growing. Overall, the combination of climatic and non-climatic drivers and stressors will exacerbate the vulnerability of Africa's economic system to climate change. However, to understand these climatic dynamics and/or produce resulting effects, climate specialists need to better understand the fundamental basis of how climate changes as well as the associated land-ocean influences and modifications on factors such as rainfall, temperature and pressure patterns. This involves analysis of the variability at inter-annual and longer-time scales, and that of various trends and relationships with teleconnections.

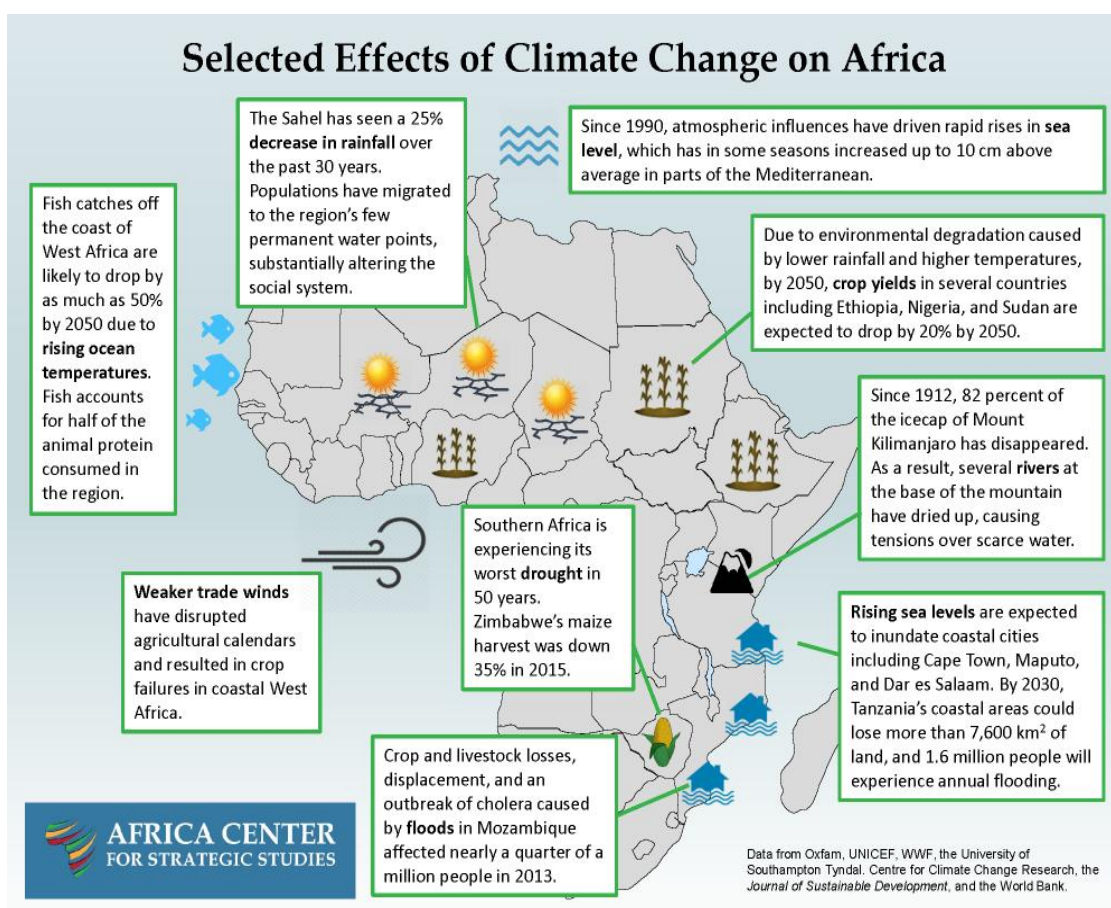


Fig. 4. Current and possible future impacts and vulnerabilities associated with climate change in Africa

(<https://africacenter.org/spotlight/selected-effects-climate-change-africa/>)

5. SOCIO-ECONOMIC SUSTAINABILITY CHALLENGES IN AFRICA

- i) There is an awakening fact that the world's food crops are vulnerable to rapid changes in environmental parameters, combined with diminishing and degrading land and water resources. This places food supplies in a precarious condition [82]. There will be serious food insecurity problems resulting from disruption of natural ecosystems with grassland and deserts expanding, coastal regions being sub-merged while most perennial rivers will probably dry up, thus inhibiting irrigation. Rising food cost will make it harder for those living close to poverty line to survive.
- ii) Combined with excessive GHG emissions from around the world, deforestation in Africa is still rampant. Forests have the ability to absorb and sequester tonnes of gases such as CO₂, which would otherwise trap heat in the atmosphere and are one of the primary tools for climate change mitigation. Consequently, huge tracts of the continent's rich forests are destroyed for industrial and infrastructural development. Large tracks of land are rapidly being cleared for settlement and subsistence farming; the overall shift in land-use will fragment wildlife habitats and restricts the movement of certain species.
- iii) While Africa faces more exposure to climate change as well as broader socio-economic and political challenges, many of its diverse agricultural systems remain resilient [34]. As the adverse impacts become more frequent and severe, the already fragile socio-economic activity is more likely to exacerbate [81, and references therein). With the high population growth rate, rapid urbanization trends and rising GDP in many African countries, the agricultural system still needs to become adaptive to climate change as the uncertainties continue to unfold.
- iv) Overall, human population will definitely be affected. For example, people living along the coast in arid and semi-arid regions will be forced to migrate to climatically habitable regions. Increasing peak temperatures and heat waves will likely reduce the habitability of some cities/towns, causing outright migration to other centers [90]

6. CONCLUSION

Global climate change has been occurring from the glacial-interglacial transition to present, and will continue into the foreseeable future. The resulting effects already noticed demonstrate that the earth's climate was- and will possibly never be in equilibrium. Climate change affects all aspects of human life, ecosystems, atmospheric and environmental aspects. Even without past climate change, Africa is vulnerable to current climate change. However, a thorough understanding of climate variability is one of the challenging tasks with important applications for geophysical efforts to quantify dynamical issues and predictability as well as developing efficient methods. Adaptation mechanisms need to be strengthened by making progress in areas such as governance, human resources, institutional structures, public finance and natural resource management. Such progress builds the resilience of countries and vulnerable communities to all types of shocks and can help abate climate change impacts.

From the review, there are some conclusions common to many studies: climate in sub-Saharan Africa is already exhibiting significant changes; this is evidenced through changes in average temperature, amount- and seasonality of rainfall; patterns, prevalence and intensity of weather extremes such as droughts and floods as well as soaring temperatures. This can negatively affect agricultural production (and hence increase risk of food supply), initiate health-related problems and influence peoples' lifestyles. While there is uncertainty in climate change projections with regard to the exact magnitude, rate and regional patterns, the consequences are likely to affect the destiny of many generations to come, particularly the poor societies if no appropriate measures are taken. Long-term aspects ought to be considered since the length of time for which climate change prediction is sought is very long, compared to the natural time attached to the physical parameters. It is also prudent that anthropogenic remedial measures be employed to limit further changes in climate. While it might not be very practical to reverse the state of pollutant load in the atmosphere, it is possible to minimise and/or halt future excess gas production. Massive afforestation and agro-forestry farming programmes should be encouraged to provide enough vegetation to take up the excess gases such as CO₂ –since vegetation is one of the major CO₂ sinks on earth. It is also high time that

selective breeding is done for crops and animals specifically adapted to Africa's agro-climatic conditions, with idiosyncrasies in soil, pest, disease and rainfall profiles, in addition to common farming practices. Further research is also needed on the degree to which the continental climatic seasons are homogeneous with respect to characteristics of variability and causal factors. There should be a culture of systems thinking throughout Africa, engaging the quadruple helix –scientific community and technological innovation experts, policy makers, private sector and civil society organizations. Overall, it should be acknowledged that climate change is a global challenge that does not have borders and is a worldwide concern.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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