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The Nexus of Climate Change and Land-use in Kenya

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Land as a resource remains a useful in alleviating human risks through provision of food, water, energy and environmental goods/services. There appears to be intertwined relationship between land and climate change, where climate change is perceived as a threat to land, while land and land use remains a major factor in climate change. There are however, few studies that have explored these intricate interrelationships between climate change and land as a nexus approach especially at the local levels. Therefore, the aim of this paper is to bring to light the interconnectedness between land and climate change and land, as well as assesses land impacts on climate change, in Kenya, and further suggests strategies needed to address these issues from a multidimensional perspective in the policy-making process. Scoping review was used to gather data from academic journal articles, book chapters, global databases, national database and conference papers. The objective of scoping reviews is to provide a broad overview of the literature on a specific topic and identify patterns, trends, knowledge clusters, and gaps. The study also obtained secondary data from various sources in the study. The study established that land-use influence climate change through agricultural expansion, urbanization, activities in catchment areas, large scale settlements, deforestation, manufacturing and industrial activities. Climate change then impact the land through reduction in agricultural activities and production, negatives on the forest ecosystems, reducing water resources, as well as detriment to quality of human,

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animal and plants life. The study concludes that land use change is a major driver of climate change and climate change drives land use activities in a nexus. To further this research, the study recommends ways of exploring land-sensitive approaches to climate change and land use management in a nexus approach. The nexus approach that allows for the inter-linkages, trade-offs, and synergies existing between climate and land resources need to be developed.

Keywords: Land; land-climate nexus; Kenya; climate adaptation; climate change impacts.

1. INTRODUCTION

The world has experienced massive changes in the land use patterns over the last 100 years [1]. Currently the global land use change is estimated to be greater than four times than previously estimated [2]. Over the same period of time, there have been increased global warming of the environment resulting from the long term sporadic increase in emissions of Greenhouse Gases (GHGs) resulting in changes to the normal weather conditions clearly manifest climate change [3]. Climate change has been reported over the last 100 years following records of 0.74°C increase in the global average temperatures with a likelihood of further increase by 1.6–2.6°C by the end of the 21st Century relative to the 1980 baseline [4]. At the continental level, there has been massive changes of land use patterns over the last century [5,6] concurrent with the warming in the African continent that has always been greater than the global average [7] with an increased average temperature expected to be 3–4°C by the 21st Century [8]. These impacts are more severe in dryland areas of the continent [9]. The land use changes have been shown to drive the climate change in the continent [10]. “Meanwhile the climate change cause differences in precipitation differentially across different regions of Africa where, high latitudes and the equatorial Pacific region have witnessed an increase in annual precipitation while regions in the dry mid-latitude and subtropics had reduced precipitation” [11]. “Sub-Saharan Africa is highly susceptible to climate change due to majority of the land lying across the warming tropics” [12].

In Kenya, there have been substantial reports of land use changes in the last century [13,14]. Land-use patterns in Kenya has been changing since the beginning of the 1900s aiming mostly for economic or environmental benefits such as food production, energy, building materials, and industrial production etc [15,16]. Meanwhile climate change has been widely reported in the country [17,18], which is caused by increasing

GHGs, leading to high ambient temperature, reduced rainfall, and increasing extreme events such as floods, droughts, strong winds and storms, with subtle gradual change in sea-level [19, 20]. Land-use is one of the current drivers of climate change in Kenya [21,22]. It is also projected that ambient temperature will most likely increase by 2.5°C by the year 2050 leading to increasing frequency of extreme events such as flooding and droughts [23]. The climate change events appear more intense in the hot and dry regions of the Arid and Semi-Arid Lands (ASALs) which has seen massive reduction in levels of precipitation as well as a significant increases in frequency and severity of drought and floods [24]. In arable regions of the Kenyan Rift Valley, the temperature seems to have increased then values reported decades ago due to massive land use changes [25,26]. At the same time, the adverse climate change affects land and land resources [21,27,28].

“During the past few decades, land-use and climate changes are two major global issues [29], and proper research highly demands finding their relationships and impacts for the future”. Forest and agricultural land are the main factors in the path of land-use affecting climate change, so they have become the focus of previous researches. However, the nexus of land and climate change have rarely been studied in a cause-consequences criterion especially for many local regions. From the foregoing, it is evident that land and climate interact in a complex ways that is not unidimensional but multidimensional through multiple feedbacks. This situation therefore calls for a nexus approach that addresses the interconnectedness, synergies, and trade-offs existing between climate change and land resources. Interesting studies on the nexus between climate change and land in Kenya are rather scarce. Therefore, the aim of this paper is to highlight the interconnectedness between land and climate change with emphasis on Kenya, and the need to address these issues from a multidimensional perspective.

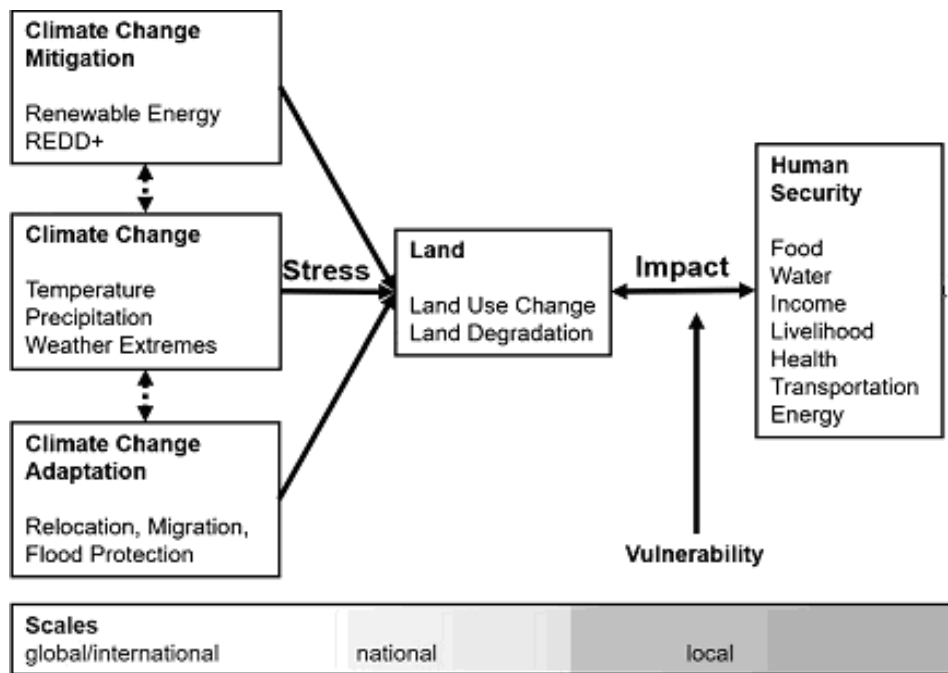


Fig. 1. Conceptual framework of effects of climate change on land resource dynamics
Source: modified from Schefran et al. [30]

The key conceptual framework that describes the pathways in research on climate change and land are impacts and vulnerability. This study relied on the conceptual framework of effects of climate change on land resource dynamics which has been previously described [30] (Fig. 1). The summary of the relationships in Fig. 1 shows the connections between climate change, including impacts and vulnerability on land and human security [30]. The purpose of Fig. 1 is to illustrate the complexity of links within the nexus of climate change and land.

2. METHODS

Scoping review [31] was used to gather data from of the nexus of climate change and land in academic journal articles, global databases, national database, book chapters, and conference papers. Scoping reviews are an established method for evidence synthesis, and are also increasingly applied in climate change research. The objective of scoping reviews is to provide a broad overview of the literature on a specific topic and identify patterns, trends, knowledge clusters, and gaps. While a scoping review approach usually does not include a critical appraisal of individual studies' results and their impacts, it is 'particularly valuable for broad, multi-faceted questions', and provides the basis for in-depth follow-up research on specific

subsets of the identified evidence. The study also obtained secondary data from various sources in the study.

3. RESULTS AND DISCUSSION

3.1 Land-Use as Driver of Climate Change

At the global, regional and local scale, there has been an increase in human activities on land that often results in the increase in emission of GHGs causing localized changes in weather related events [32,33]. Aggregated over large areas, these changes have the potential to influence climate change at the regional and global levels. The activities on land that drive climate change are therefore discussed on this section.

3.1.1 Expansion of agricultural activities

"Climate change is driven by multiple climate pollutants consisting of carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) which are largely associated with agriculture" [34]. "Cropland and livestock based agriculture, contributes to climate change by releasing CO₂, CH₄ and N₂O" [35]. "In this regard agriculture emitted 5.5–6.5 billion tons of CO₂ equivalent in 2021 (10–12% of all GHGs in that year). Its share of CH₄ and N₂O emissions was much greater: agriculture contributes about 47% of

global CH₄ and 58% of N₂O. These figures are devoid of GHGs from electricity and fuel used in agriculture for machinery, processing, and transport. Also, emissions vary widely among countries, with more industrialized countries producing more GHGs than developing countries but deriving much less of their GHGs from agriculture” [35].

In Kenya, agriculture was the leading source of GHG emissions, contributing 62.8% of total 80,000 kT of GHG emissions, followed by emission from energy (31.2%) [36,37]. Agriculture is also one the main reason for a change in land-use that take up and store carbon dioxide (CO₂) from the atmosphere, to farmland.

3.1.2 Urbanization/urban development

“There is rapid increase in urban areas together with urban populations [38] leading to numerous activities in the urban areas that tend to increase warming. Urbanization is related to the climate change issue in two ways. Firstly, a significant amount of energy is used in urban areas which is, a major source of greenhouse gases” [39]. “Secondly, the increase in population of the urban areas result into more use of marginal land, thereby which exacerbate the potential impacts of climate change” [40]. Cities are usually 2-3°C warmer than their surrounding environments a phenomenon known as Urban Heat Islands (UHI) [41]. UHI is a localized climate phenomenon whereby urban areas

experience warmer temperatures than their surrounding non-urban areas (Fig. 2). The magnitude or intensity of this so-called urban heat island (UHI) depends on various factors, such as the size and morphology of the city.

“The rapid urbanization in Kenya over the past decades seems to have been accompanied by extensive land-use and land cover changes, which potentially affect local or regional climate” [42]. “One of the major consequences of these modifications is the increase in land surface temperature in urban areas, such as those reported in Nairobi City, which strengthens the urban heat island (UHI) effect” [43,44]. “Land-use changes in urbanization, creating an urban heat island (UHI), have been implicated for the observed warming in Kenya urban areas during the last few decades” [45,46].

3.1.3 Large scale settlements and climate change

“A great variety of settlements exist today reflecting human needs, abilities, and aspirations, as well as social, political, and economic relations” [47]. The conundrum of large scale settlements comes with forest clearing for agricultural production, city expansion causing clearance of land, water abstraction, pollution of the land, energy use and transport which are the main drivers of greenhouse gas emissions.

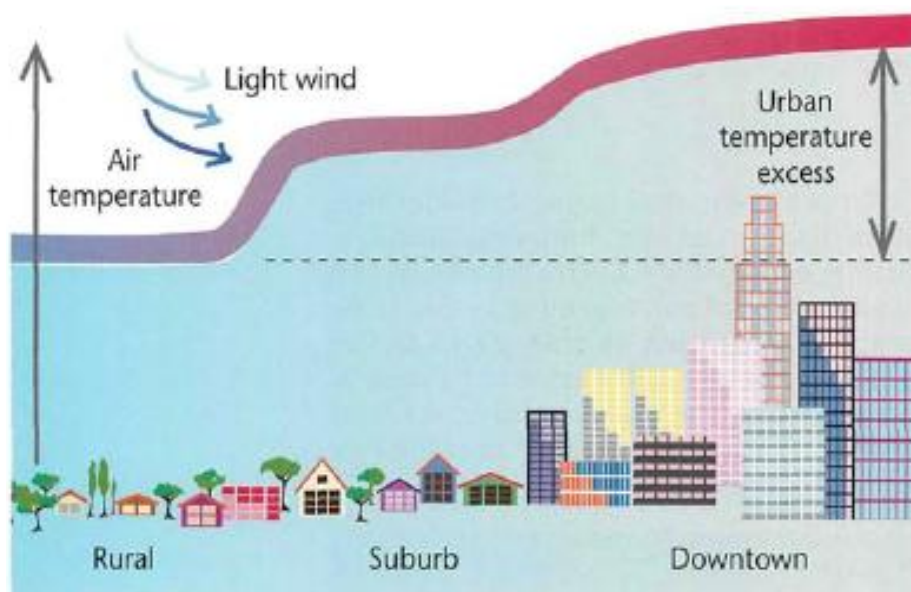


Fig. 2. Generalized cross-section of a typical urban heat island (UHI)

In Kenya, since the onset of missionary evangelism and colonization, human settlements have taken two distinct patterns: the rural and urban settlements. After independence saw Kenya give back much of forest and densely vegetated lands to the locals which earmarked the onset of land-use change followed by large scale settlement of people [48,49]. Each of these patterns has been greatly influenced by politics, administrative and the socio-economic development of the time. There are scenarios where large parts of forest ecosystems is hived off and given to the people for settlement. Settlements schemes have also been established in forested areas by authorities in a bid to settle landless people, reduce population in highly populated area, increase food production and settle people displaced by different disasters [50,51]. Perhaps one of the most controversial settlements is in the Mau Forest in the last 20 years [52]. Over the past 20 years, this forest has faced destruction from illegal loggers and encroachers who have extended their farming and grazing lands deep into the forest.

3.1.4 Deforestation and climate change

There has been large scale clearance of forests to allow for humans settlement, agriculture, mining, road construction or industrial development in the past especially in the tropics [53,54]. In Kenya, closed forests are crucial water catchments. Among these forests, the five largest blocks are Mt. Kenya, the Aberdare Range, the Mau Complex, Mt. Elgon and the Cherangani Hills. These montane forests are surrounded by the most densely populated areas of Kenya. Notwithstanding the services they provide to the people of Kenya, these forests have been and remain the target of uncontrolled and unplanned development activities that has led to massive deforestation which tend to cause climate change concern. There are also settlement schemes that were hived off from forested areas in Kenya that have led to massive deforestation in Kenya [50]. As people clear forests to pave way for settlements, deforestation and land degradation sets in which further leads to negative impacts on climate change.

Efforts to increase afforestation and reforestation activities have been observed since 2002 (average of 326,794 ha/year from 2002-2018 as outlined in the 2019 FRL), these can be attributed largely to the establishment of private commercial plantations and Government-led initiatives. However, deforestation and forest

degradation (average 338,863ha/year) still occur at slightly higher rates: there is therefore a net loss of forest in Kenya [55]. Kenya is one of the countries which has documented reduction forests cover the past 30 years within the gazetted forest, trust lands as well as in the private land [56] including in gazetted and protected water towers [52,57]. Loss of forests through excision, population pressures and climate change is estimated at close to 5,000 ha per year. Kenyan forest cover during independence was over 10% of the land mass [58]. The Kenya forest cover in 2020 was 6.2% of the total land area which is a reduction from 6.9% in 1990 [59]. Therefore it is clear that Kenya has lost 0.8% of forest cover over the same period of time. Forest cover in Kenya including the area of publicly owned plantations, which has been the backbone of Kenya's once thriving wood based industry, has progressively reduced over the years and currently some of the drivers of climate change [60].

3.2 Climate Change Impacts on Land and Land-use

Analysts of climate impacts identified three main land based sectors that are impacted by climate change: agriculture, forestry, water, and indirectly human life [61-63]. Agriculture and forestry are key land-uses. Water is important to land because its availability affects the viability of agriculture through irrigation. The impacts are discussed in this section.

3.2.1 Impacts on agriculture and food production

Agriculture is one of the largest climate-sensitive sector due to response to increasing temperature and precipitation on crop yields and livestock production [64]. In regions of where temperature are low, increasing temperatures lead to improved crop growth due to temperature optima being higher in cold environments. However, in region where there is high temperature then warming may have little impact or adverse impacts. The temperature and precipitation variations due to climate change also affect crops and livestock more depending on aridity of the area. Indirect effect of climate change on land is also probable where such as arable land being left fallow or abandoned completely when there is severe drought or converted to open water during periods of extremely high precipitation, that may negatively affect the land production or production capacity.

“Agriculture is an important sector in Kenya due to its significant contribution to the economy, livelihoods and food security” [65]. “The sector is constantly affected by climate change causing seasonal alterations in rainfall and temperature of varying magnitude and duration over the years” [19,66]. Erratic weather events characterized by frequent droughts were experienced in 1951, 1952–1955, 1957–1958, 1974–1976, 1980–1981, 1983–1985, 1987, 1992–1993, 1995–1996, 1999–2001, 2004–2006

and 2008–2009 [67,68]. Agricultural production during the years of droughts has always been low (Fig. 3).

Production trends of major crops produced in Kenya show high variability between 1980 and 2016 (Fig. 3) and crop yields in the agricultural sector over the same time (Fig. 3) are also provided. Based on the information of these graphs, drop in crop production appears to echo with drought conditions.

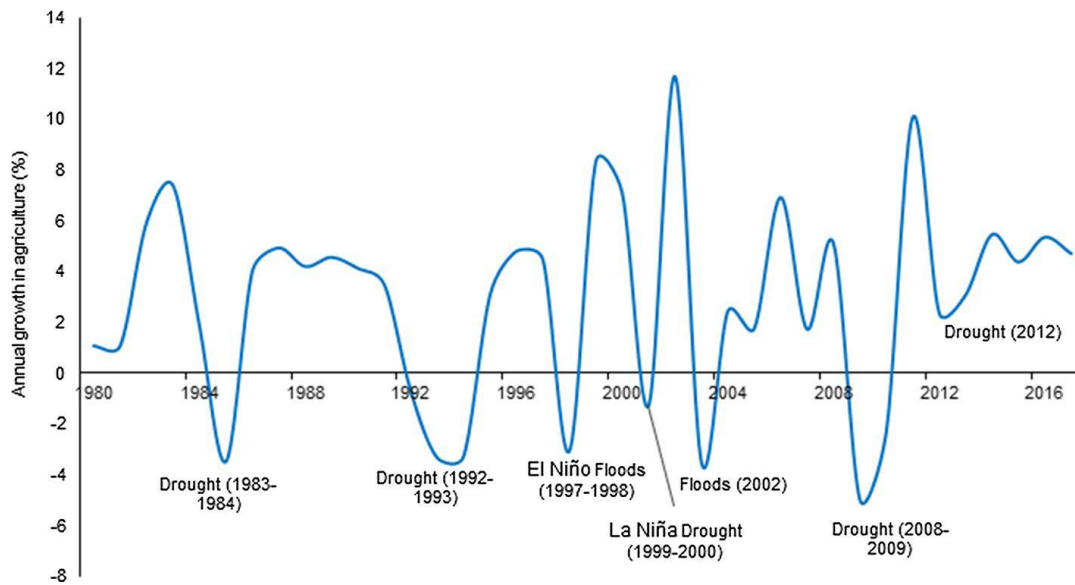


Fig. 3. Climate extreme events and agricultural growth trends in Kenya from 1980 to 2016
Source [19]

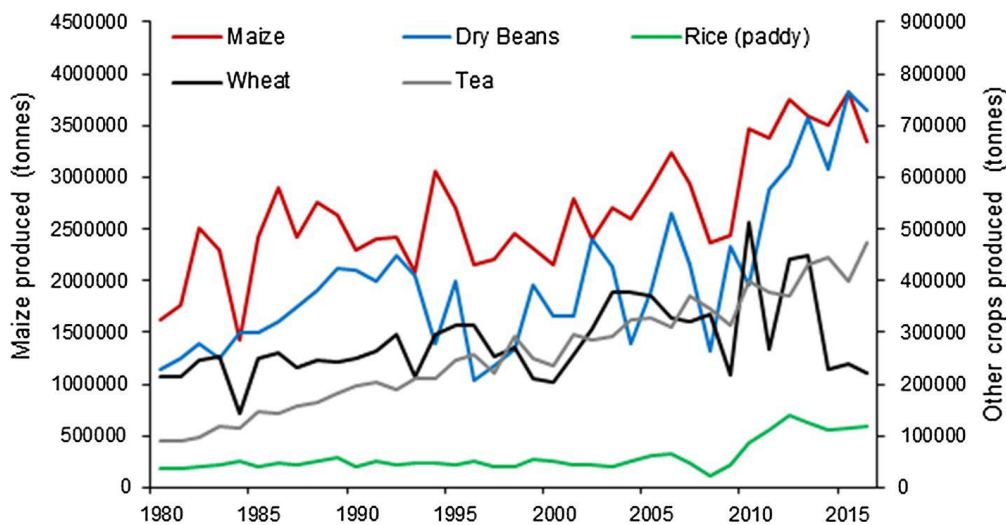


Fig. 4. Production trends of various selected crops in Kenya over time. Adapted from FAOSTAT database

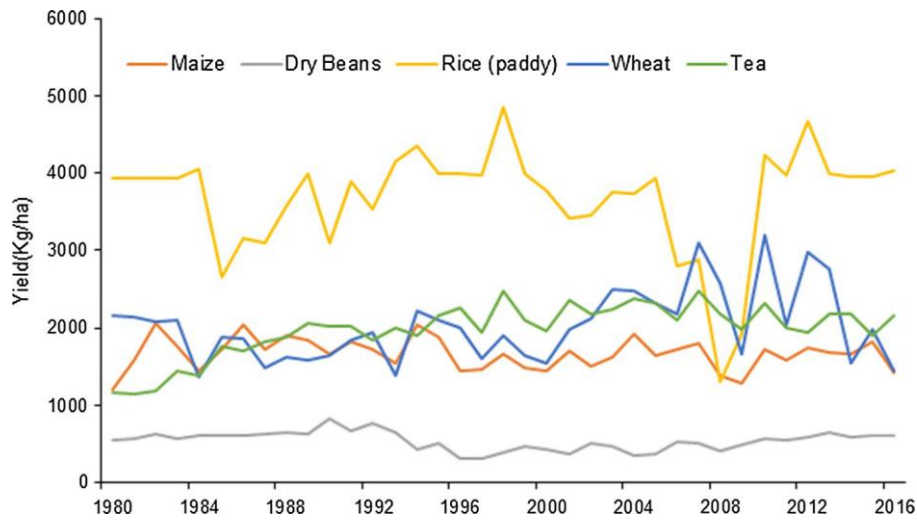


Fig. 5. Yield of selected crops in Kenya. Adapted from FAOSTAT database

Other factors that affect agricultural productivity in Kenya that are related to climate change are pests and diseases, declining soil fertility, land cover changes, and inadequate climate change preparedness and responses well as over-reliance on rain-fed agriculture which is constantly affected by climate variations [69, 70].

Simulated impacts of climate change on agricultural production in Kenya suggest that between 2010 to 2050, there will be losses in yield of some crops such as maize, wheat, rice and groundnuts due to climate change [71, 72]. Whereas accurate prediction of crop yield remains difficult for a number of crop due to other anthropogenic influences, the yield of maize is expected to decline by almost 50% or an equivalent decrease by approximately 200 kg/ha for every rise in temperature by 1°C above the optimum temperature [73]. This is mainly due to dependence of rain-fed water availability for maize production, which makes it apparent candidate to be affected by erratic weather events including droughts—a negative outcome of climate change.

3.2.2 Impacts on forest ecosystems

Climate change may affect forest ecosystems through alteration of the growth, mortality and reproduction of trees [74, 75]. There is also the climate change risks to global forest health which may accelerate tree mortality [76]. “Climate change affects forest vegetation physiology, their relationships with pests, competitors and mutualism. Warmer temperatures change the timing of life cycle events (phenology), with earlier bud burst, leafing and flowering in trees,

although there is much year-to-year and regional variation. It will affect forests also indirectly by increasing the risk of infestation” [77]. “Also climate change may affect nutrient cycling directly through its impact on temperature and precipitation” [78]. The productivity and integrity of forest ecosystems is linked to the supply of nutrients and climate change can influence nutrient dynamics by altering the rate of litter decomposition.

“Effects of climate change on forest ecosystems also alter the frequency and/or severity of natural disturbances in some forests, particularly fire and insect disturbances” [79]. Climate change is driving disturbance regimes in several forest ecosystems. In case there is increases in disturbance there will be massive effects on forest ecosystem structures such as species richness, composition, their overall functioning [80]. There is evidence resulting in increased forest damage, erosion and landslides, with wetter soils and flooding over the last century.

In addition, forest growth including undergrowth will be affected by elevated levels of carbon dioxide. The combination of rising temperatures and higher CO₂ levels is expected to have several major effects on trees. This dynamic process is expected to cause dieback in some places and the disappearance of entire forests in others.

3.2.3 Impact on water resources

“Climate change impacts the world’s water in complex ways. Climate change will affect water

resources through its impact on the quantity, variability, timing, form, and intensity of precipitation” [81]. “Climate change may threatens the quality of source water through increased runoff of pollutants and sediment, decreased water availability from drought and saltwater intrusion, as well as adversely affecting overall efforts to maintain water quality” [82]. “Extreme weather events are making water scarce, more unpredictable, more polluted or all three. Additional effects of global climate change that have important implications for water resources include increased evaporation rates, increased water temperatures, and decreased water quality in both inland and coastal areas” [83].

“Climate change is expected to affect water quality in both inland and coastal areas. Specifically, precipitation is expected to occur more frequently via high-intensity rainfall events, causing increased runoff and erosion” [84]. “More sediments and chemical runoff will therefore be transported into streams and groundwater systems, impairing water quality. Water quality may be further impaired if decreases in water supply cause nutrients and contaminants to become more concentrated. Rising air and water temperatures will also impact water quality by increasing primary production, organic matter decomposition, and nutrient cycling rates in lakes and streams, resulting in lower dissolved oxygen levels” [85]. “This suite of water quality effects will increase the number of water bodies in violation of today’s water quality standards, worsen the quality of water bodies that are currently in violation, and ultimately increase the cost of meeting current water quality goals for both consumptive and environmental purposes”. [85]

“Radical changes to the freshwater hydrology of coastal areas, caused by saltwater intrusion, would threaten many coastal regions’ freshwater supplies” [86]. “Rising sea levels could also affect water availability in coastal areas indirectly by causing water tables in groundwater aquifers to rise, which could increase surface runoff at the expense of aquifer recharge” [87].

“Climate change projections on water resources indicate that Kenya, will suffer from water scarcity” [88]. “Climate change impacts on water availability are a consequence of the rising global temperatures which change the water cycle by influencing when, where and how much precipitation falls and evaporate, and such water

is not always available when and where people need it. Furthermore, the impact of climate change on water would result in increased demand on a reduced resource. Climate change impacts in the water sector in Kenya have been manifested through severe flooding, droughts, rising water levels in lakes, water scarcity, invasion of alien species in water bodies such as water hyacinth in Lake Victoria and other water bodies” [88].

“Most of the lakes in the Rift Valley in Kenya have been experiencing rise in water levels including Lake Victoria, Lake Nakuru, Lake Baringo, Lake Bogoria and Lake Turkana” [89]. “The rise has been attributed to climate change impacts such as severe rainfall, flooding and land-use degradation. The rise in water levels in these lakes have affected businesses, schools, and homes, led to pollution of fresh water while bringing crocodiles and hippos dangerously close to homesteads. Scientists and officials are concerned that the freshwater Lake Baringo and alkaline Lake Bogoria could merge which would cause cross-contamination and threaten aquatic species” [89].

3.2.4 Impacts on quality of human, animal and plants life

“In addition to impacts on the economy, climate change is likely to affect people’s quality of human, animal and plants life” [90]. “For instance, as ecosystems shift, some plants and animals may be lost as species endemic to a specific location find it hard to move to new locations. Some scientists warn that there could be massive losses of species associated with even relatively modest warming. The Intergovernmental Panel on Climate Change (IPCC) argues that 20–30 percent of species are likely to be at risk of extinction if warming exceeds 1.5–2.5°C (2.7–4.5°F)” [91]. The shifting of ecosystems also may bring disease, as some vector-borne pathogens may move into new territory causing health risk to human an animal life (IPCC 2007).

Heat stress might increase as a result of more intense or more frequent heat waves. It is difficult to place a value on the damages resulting from such changes. Valuing the loss of human and other species of animals is quite difficult. One strategy to value endangered species is to determine what it would cost to protect them. The same strategy could be used to value desired species in the face of climate change. The protection cost would then be the damages

resulting from climate change. Similar strategies could be used to value the potential loss of life from disease or heat stress. The cost of the public health response needed to address these problems could be a measure of the damages.

4. CONCLUSIONS

In this review paper, the nexus of climate change and land-use are explored. First the paper describe land-use and their influence on climate change such as agricultural expansion, urbanization, activities, large scale settlements, deforestation, manufacturing and industrial activities. The paper then looks at the impacts of climate change on land including: primary effects such as changes in land surface air temperature, GHG emissions, occurrence of extreme events, forest cover change, water resources, drought and desertification. The paper also looks at the indirect effects such as food production, and socio-economic impacts on the population. On one hand, it examines the relationship between climate change and the components of the land nexus independently, and on the other hand, it provides an overview of how interconnected the components of the land nexus are, and how when climate change impacts one of them, the others can also directly or indirectly suffer the consequences. Initiatives supporting these measures draw on leading policy developments such as the Paris Agreement and concomitant available financing to take action but often lack the recognition of the negative externalities and conflict implications of adaptation and mitigation measures.

5. RECOMMENDATIONS

The nexus approach that allows for the inter-linkages, trade-offs, and synergies existing between climate and land resources suggest the need for developing mitigation and adaptation strategies toward climate change in a comprehensive manner. This is a very complex system, and therefore calls for a trans-disciplinary team which is a diverse group of professionals and experts from the sectors of climate change, water resource management, natural resource management, biodiversity and ecosystem conservation, sustainable agricultural production, environmental protection, economics, sociology, and local communities, working together across their disciplines to tackle the issues relating to climate change and the land nexus.

Most African governments have initiated governance systems for adaptation, such as disaster risk management, modifications of technologies and infrastructure, ecosystem-based approaches and livelihood diversification strategies. Similarly, the IPCC special report of 2018 identifies a range of adaptation options to reduce risks to livelihood, water and economic growth, among these are efficient irrigation, disaster risk management, risk spreading and sharing and community adaptation. The 5th Assessment Report of the IPCC therefore recommends the need for collaborative and participatory research, and improved communication systems on climate change and flexibility of livelihood options could be potential mechanisms to improve adaptive capacities for climate change.

Drastic measures should be taken to seize and maximize on viable adaptation and mitigation strategies in order to strengthen the agricultural sector and increase food production and access for the growing population. The Kenyan government can play a vital role by promoting appropriate farm-level adaptation measures, providing timely early warning information on seasonal climate forecasts, development of supportive policies and investments geared towards uptake of climate-smart agriculture in order to improve crop production and achieve food security, while contributing to reduction in challenges posed by climate change.

Kenya like many other developing countries lacks adequate participatory farmer-led extension activities to drive successful uptake of locally feasible adaptation strategies towards climate change adaptation. There is therefore need to strengthen community-based approaches and recognize adaptation strategies that are informed by indigenous, local knowledge and scientific research in order to help the farmers to cope with climate change.

To achieve the land nexus in a changing climate, sufficient attention must be given to both national and international organizations/institutions in SSA. They must be able to integrate the outcomes land nexus generated from the multidisciplinary teams into adaptation and mitigation plans toward climate change. Considering the novelty of the land nexus approach in the policymaking process of SSA region, efforts must be taken to deepen the knowledge hub of the stakeholders which will help to foster the ease of interactions between

them. Finally, governments and private institutions must be ready to invest or provide institutional support to attract investments for promoting the land-climate nexus.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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