Chapter

A Novel Assessment of the Impacts, Vulnerability, and Adaptation of Climate Change in Eastern Africa

Msafiri Yusuph Mkonda

Abstract

The evidences that climate change (CC) is a real situation have been established by different scholars and international organizations. However, much of the vast and burgeoning literature on CC has indicated spatial differences on the impacts, vulnerability, and adaptation among different communities. On that basis, various studies have grouped Eastern Africa as the most affected region by CC and has the weakest capacity to adapt or/and mitigate the dreadful conditions posed by CC. This chapter attempts to indicate the socioeconomic vulnerability in eastern Africa that has been coupled by climate impacts. In doing so, a wide range of studies reflecting the region has been reviewed. The results exhibit that there has been a cause-effect relationship between anthropogenic activities and climate impacts. Although both natural and anthropogenic factors cause climate change, the latter is more pronounced in local conditions. The level of deforestation and degradation in most eastern Africa is exceedingly high and this has subsequently increased the emission of the top green greenhouse gases (CO_2, CH_4, and N_2O) into the atmosphere. Thus, the resolutions of various conference of parties on CC need to adhere by both developed and developing countries for the betterment of the planet.

Keywords: agricultural production, adaptation policy, CC, eastern Africa, vulnerability

1. Introduction

Numerous international agreements on climate change, natural resources utilization, and development from the 2000s have made various calls to embolden scientific writing that would establish the concepts and good methodological approaches on climate vulnerability [1–3]. As a result, thousands of citable papers have been published in various reputable international journals (including *Environment, Development and Sustainability*) as responses to these calls [4]. However, due to increased vulnerability coupled with climate challenges in most developing countries, there have been increasing needs to establish more studies that give empirical evidences of the current climatic situation [4–6]. This aims to

come up with tangible and scientific information relevant for discussion in various national and international dialogs to shape the future prospects. This is a basis for the Fifth Assessment Report (AR5) on the Intergovernmental Panel on Climate Change (IPCC) to convene a call for papers to elicit rigorous climatic finding in most developing countries especially the sub-Saharan Africa which is the most vulnerable region on Earth to climate change impacts [4].

Although the whole sub-Saharan Africa experiences unprecedented impacts of climate change, some regions face the worst compared to others [5–7]. Among the regions are Eastern Africa and the Horn of Africa [8, 9]. According to FAOSTAT [10], the Eastern African economy is highly dependent on agriculture, which is dominated by traditional rain-fed small-scale production, and thus, any further erratic weather tends to underpin crop failure in the region.

On the other hand, excessive droughts have ruthlessly affected animal husbandry in the region, and much of this effect happens in the already stressed areas like Central Tanzania, Northeastern Kenya, and the driest parts of the Horn of Africa. The vulnerability of the developing countries has been coupled by lack of strong institutions to deal with calamities and environmental disasters (**Table 1**). This has even increased the level of pollution and degradation as a search of alternative livelihoods. The Conference of the Parties (COP) on climate change, i.e., COP15 (Copenhagen in 2009), COP16 (Cancun in 2010), COP17 (Durban in 2011), COP18 (Doha in 2012), COP19 (Warsaw in 2013), and COP20 (Lima in 2014), realized this problem and, thus, proposes measures to reduce environment problem, more particularly the emission of greenhouse gases.

While various climate models from individual authors and the recent IPCC reports have confirmed that global climate change is real and that it is occurring more rapidly [4], there has been a need to establish empirical evidences that indicate the level of vulnerability and adaption especially in developing countries. This is particularly important as it is recognizable that over 66% of the global population is starving, whereas most of this population is in developing countries especially sub-Saharan Africa [3]. Thus, the understanding of actual climate scenarios in the region will inform the discussion for coping and mitigating the climate impacts.

As a response to the call of the Fifth Assessment Report of the IPCC regarding climate change [4], this paper attempts to discuss the causes, vulnerability, and adaptation and mitigation measures that exist in Eastern Africa in order to unveil the real climatic situation to various stakeholders at both local and global levels. This will enable climate practitioners to intensify the curbing of the top greenhouse gases such as carbon dioxide (CO_2), methane gas (CH_4), nitrous oxide (N_2O), and

Institutional factors	Economic factors	Environmental factors
i. Informal skills	i. Labor	i. Risk environment
ii. Local knowledge	ii. Health	ii. Degraded environment
iii. Formal education, skills, and technology	iii. Access to natural resources	iii. High dependence of climate-sensitive sectors and natural resources
iv. Informal network	iv. Access to communal resources	iv. Communal lands and resources
v. Formal security network	v. Access to alternative economic opportunities	
vi. Strength of local institutions		

Source: Modified from Eriksen and Noes [11].

Table 1.
Examples of factors that influence vulnerability in the region.

chlorofluorocarbons (CFCs) through proper mitigation strategies for the sustainability of the planet [3]. Similarly, at the local level, the improved understanding among the farmers on the influence of climate on agricultural production is desirable for coping with actual and expected variations in both temperature and precipitation [12]. This will again curb an increasing number of undernourished people in the region.

Therefore, climate resilience at the local level is potentially optimized by proper adaptation measures coupled by appropriate and affordable mitigation measures. This underpins the effects posed by the temporal changing weather and climate in the region. Thus, proper adaptation measures that mainly focus on the agro-ecosystems are particularly useful to meet the demands of the increasing population in the region rather than using the "slash and burn" practices [13]. Eventually, the majority of the population lack livelihood option due to entitlement failure [14].

2. Location

Eastern Africa regions mostly cover Kenya, Uganda, Tanzania, Rwanda, Burundi, South Sudan, and other parts of the Horn of Africa that entail Eritrea, Ethiopia, Somalia, and Djibouti. This ecological region covers approximately 4,000,000 km^2, where Tanzania is the largest country and the smallest ones are Burundi and Djibouti. The region has a population of over 200 million. The region is bordered with two big water bodies, the Indian Ocean and the Red Sea. Tanzania, Kenya, Eritrea, Djibouti, and Somalia are bordered with the Indian Ocean and the Red Sea, while Ethiopia, Rwanda, Burundi, and Uganda are the landlocked

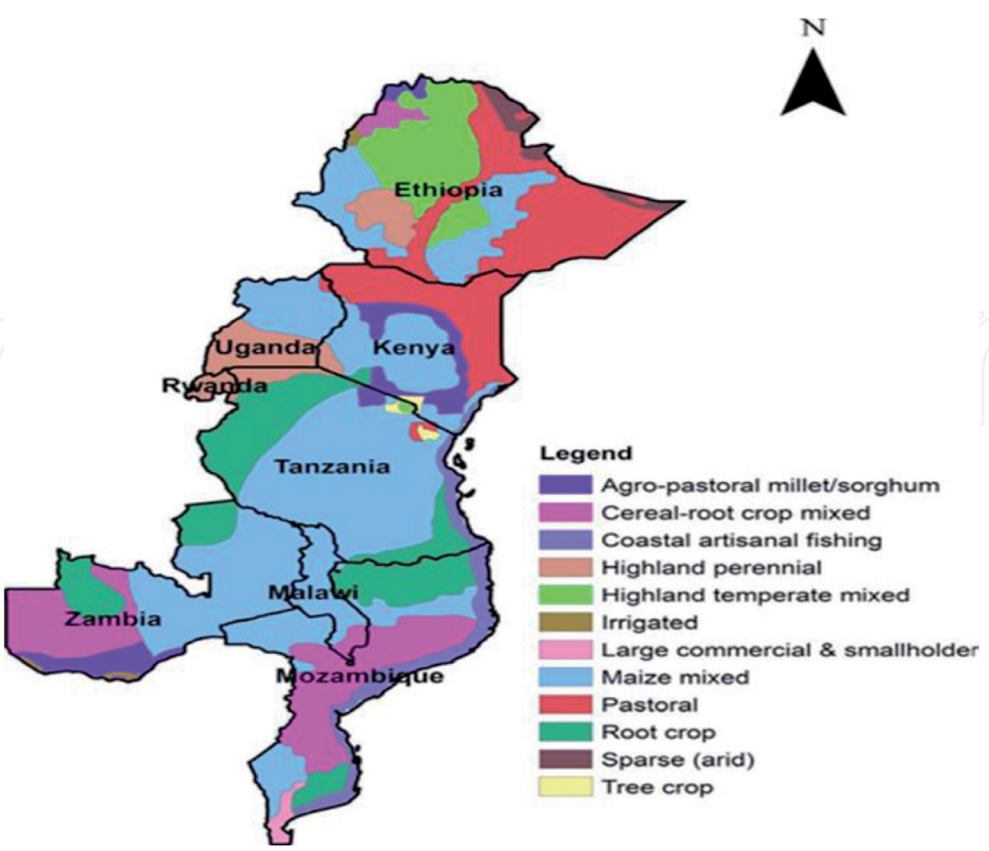

Figure 1.
Land use map of the study area. Source: [21].

countries in the region. Topographically, the Eastern African region is very complex, including mountains, valleys, rifts, rivers, ridges, and lakes.

The greatest rift in the world (Eastern Great Rift) is located in this region, and earthquake and a volcanic eruption are active [15]; the volcanic eruption of 2010 that occurred in the Danakil Depression of Ethiopia and Eritrea is a good example [16]. The elevation of the region ranges from the highlands of Ethiopia to the Danakil Depression below sea level; the Danakil Depression (local name Dallol) is the hottest place on the surface of the Earth (>60°C). Lakes Victoria, Tana, Abaya, and Turkana are the biggest surface water located along the rift valley [17–19]. The Lake Tana in Ethiopia is the source of Blue Nile River, which is a tributary of the Nile River [20]. Drought due to climate change and land gradation is the major environmental concern of this region (**Figure 1**).

3. Climate situation

Various studies from both local and international level indicate that climate change is a major agenda in the area [1]. This is important because Eastern Africa is among the worst vulnerable regions to climate change impacts [2, 3]. Although the region has been hit by this change, there are spatial differences on the magnitude of the impacts. The areas experiencing semiarid climates (especially Central Tanzania, Northeastern Kenya, and Uganda) suffer the most than those experiencing equatorial (Southern Uganda and Kenya and parts of Northern Tanzania) and tropical climates [12, 15, 22]. Overall, climate variability has been a critical driver of year-to-year impacts on both managed and unmanaged ecosystems in the area.

In order to properly understand its ecological impacts, it is essential to quantify how various ecosystems have historically responded to climate variability and to characterize the uncertainty in projected impacts. In this aspect, the general understanding dynamics of farmer adaptation and decision-making is particularly important. Now, the present study explores the major causes, vulnerability, impacts, and adaptations and mitigation measures. Rigorous literature has been significantly consulted to meet the objectives.

4. Major economic livelihoods

The major economic livelihood in the region is crop production, livestock keeping, and mixed crop-livestock production. In the latter agroecosystem, the crop residues are useful in supporting the feeding of livestock in addition to meadows and pastures. Likewise, animal manure is useful in fertilizing the farms. FAOSTAT [10] shows that crop production accounts for about 70%, while livestock accounts for about 30% of the total worth of agricultural production in the region. Despite being dominant among the pastoral communities only, the latter plays a key role both as a source of animal products and as a key input to production in the region. Among the dominant pastoral societies are the Maasai (Tanzania and Kenya), Turkana, Kalenjin, Kisii, Embu (Kenya), and Karamojong and Banyankole (Uganda) who mainly herd cattle, sheep, goats, and donkey for various purposes. Agricultural practices in the region are traditional, dominated by small-scale farms mainly under 2 ha per each household, and are characterized by low inputs of physical capital, fertilizers, and pesticides [23]. FAOSTAT [10] further observed that more than 90% of the agricultural production is rain-fed, thus making the practice not a dependable one on the face of the changing climate [3, 5, 12]. The

self-sufficient ration is under 70% in most areas [24], therefore needing more food support from external sources.

5. Causes of climate

Despite the monotony of explaining the causes of climate change, it is fairly pretty to highlight these causes especially those with anthropogenic characteristics. Apart from natural causes that seem to have natural balance, anthropogenic activities in both developed and developing countries have been observed by various studies to have increased greenhouse gases in the atmosphere [3, 4]. In developing countries, deforestation and other forms of environmental degradation release thousands of tons of carbon in the atmosphere [18]. Subsequently, animal husbandry has been observed to emit lots of CH4 in the atmosphere. In addition, since most developing countries are dumpsite of various fabricated industrial goods, e.g., refrigerators which in turns emit CFCs, it is realizable that this system contributes significantly to the emission of this dangerous greenhouse gas. While that happens in developing countries, their counterparts (i.e., developed countries) emit more greenhouse gases through the pollution from industries. Since the focus of the present study is on developing countries, much of the examples and discussion will be recapped from the study area.

One can ask how the developing countries have significant contribution to greenhouse gases. The answer can be difficult especially on the quantification; however, the ways of doing so are obvious. The dominant agricultural systems and other livelihoods reflect the level of greenhouse emission from the case study area [3]. Since agriculture and animal husbandry are the major socioeconomic livelihoods in the areas, it is understandable that the expansion of agricultural farm and intensification of umber herds have significant contribution to greenhouse emission.

On the aspect of whether climate is changing or not, even most lobbyists and pessimists to climate change agree on the changes; however, they pose a zest for inquiry on whether the change is significant or needs to be ranked higher than other challenging factors.

6. Vulnerability of eastern Africa region to climate change

According to Adger [25], vulnerability is the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt. There are theories and conditions that subject a person or community into the state of vulnerability. Among the conditions that best explain this situation is entitlement failure [14]. Thus, the poor or weak people develop more vulnerability than rich people. Despite of being understandable, the challenges for vulnerability research are to develop robust and credible measures, to incorporate diverse methods that include perceptions of risk and vulnerability, and to incorporate governance research on the mechanisms that mediate vulnerability and promote adaptive action and resilience [25, 26].

We explore the state of vulnerability in the Eastern African region in order to propose synergies between vulnerability and on resilience of social ecological systems. This review will not only show the real contexts of the area but also optimize the adoption of suitable mitigation measures that would serve the purpose of both regional and international level. It provides evidence-based investigation to inform the discussion in the international arena and more particularly in the Conference of

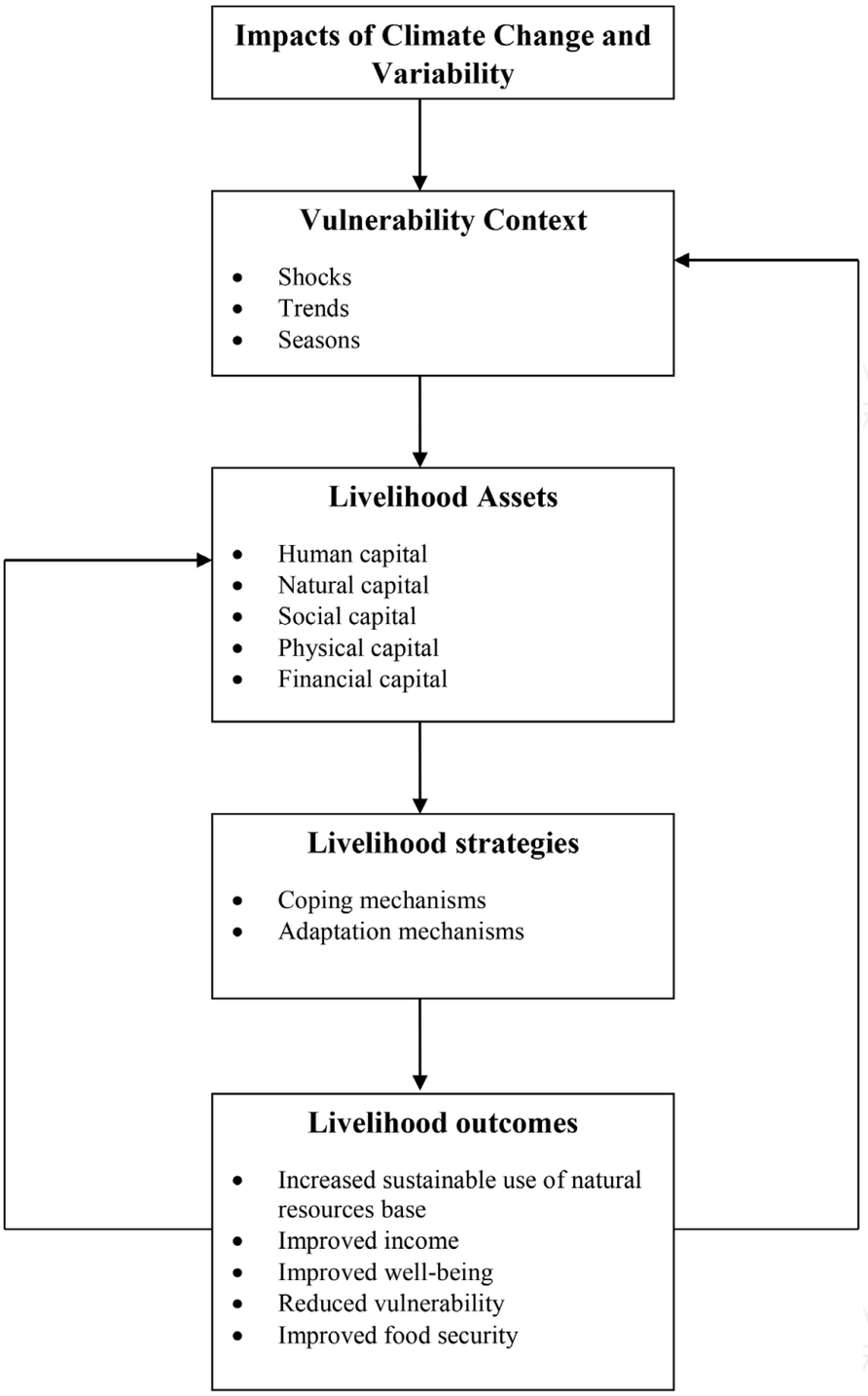

Figure 2.
Climate variability, vulnerability and adaptation, and its livelihood outcome. Source: Modified from the Sustainable Livelihood Framework [27].

the Parties on climate change and the subsequent reports by the Intergovernmental Panel on Climate Change [1–3]. **Figure 2** explores the overall concept of vulnerability to reduce it for best outcomes [27].

However, the measurement of vulnerability can be complicated by the fact that it emerges through complex interactions between biophysical and social dimensions across multiple scales, all of which vary across time, location, the nature of biophysical stressors, and outcomes of interest [28]. Therefore a combined theoretical and practical approach should be adopted in doing the same.

Further conceptualization reveals that in most developing countries, there have been factors that influence vulnerability for decades. These factors need to be

controlled in order to increase the resilience of the farmers, thus increasing their capability in the production process.

Crane et al. [28] coined that for the vulnerability to be well assessed, there is a need to assess the systems of vulnerability, how this system is vulnerable, what are the causes of vulnerability, how vulnerability distributed in the system, and what are the causes of this distribution. Therefore, on the basis of the study area, it is confirmed by various authors that poverty, weak agrosystems, weak technology, inadequate knowledge, and over dependency on rain-fed agriculture are among the key reasons for increased vulnerability [5, 12, 25, 29, 30]. Rain-fed agriculture that takes over 70% of the population has become a risk business in the area [3].

The situation has destroyed the production systems; thus, even the drought-resistant crops cannot further withstand [31]. Thus far, food shortage and poverty have increased in the region [24, 32–34]. This has mainly happened due to crop failure. In addition, thousands of animals have died due to drought. This has been more pronounced in Tanzania, Kenya, and Ethiopia which experience semiarid climates [35]. The vulnerability has been more pronounced during critical areas due to limited livelihood options [36]. For example, the government can have capacity to help a bearable number of people, however, if the number of people elapses beyond its controlling capacity, it is obviously that the excess number of people will be helpless and thus, conceding intensive impacts.

7. Impacts of climate change

Despite the arguments of some pessimists and lobbyists on climate change, it is obvious that climate impacts and vulnerability have ruined the livelihoods of many people [6]. This has been more pronounced to the already affected agro-ecosystems [4, 24, 31, 34, 37]. In most cases, climate impacts have been measured in different contexts. Farmers do so during crop growing season, while livestock keepers measure it during drought season when pasture and water for their herds are inadequate. Various studies have modeled climate trends to depict the general alterations [5, 12, 22, 32].

Further, Mkonda [38] analyzed the temporal wet spells in Tanzania during the growing season and found that in most years there were seven to nine wet spells in January and March, while below seven wet spells were recorded during February. Recently, the study by Ghebrezgabher et al. [8] had almost similar variation of wet spells when it analyzed the dry and wet condition in the Horn of Africa (Eastern Africa). Similar trend was observed by Stern et al. [39] some decades back. These wet spells are always high in the equatorial climatic region. However, despite the ubiquitous of wet spells in these areas, there have been insignificant impacts to crop production if they are highly unevenly distributed in a particular month because prolonged dry spells may take over to affect crop production. Therefore, this scenario can be curbed by improving the forecasting methods to determine the real climatic situation.

The study by Kahsay and Hansen [9] observed that temperature and rainfall have been varying over space and time in the region (Eastern Africa). It revealed that during spring, the mean rainfall has been kept at 266 mm, while during fall and summer, it has been kept at 201 and 133 mm, respectively. On the other hand, the mean temperature for spring, fall, and summer has been kept at 24.58, 24.02, and 24.28°C, respectively. Our review implies that there has been a modest association between the variation of rainfall and temperature. Therefore, the alteration of these climate variables during the growing seasons has been bringing significant impacts to agricultural output while being largely irrelevant outside the growing season.

Although the impact of climate change can affect both the managed and unmanaged ecosystems and the livelihood of the majority, it rather hits most the vulnerable people as soundly stipulated in Section 4 of this paper. Livestock keepers lack optional livelihoods when thousands of their cattle die due to extreme drought [16, 18]. In due course, the climate affects livestock in a number of ways; an increase in heat affects the health of animals and reduces their food intake. The situation also affects the dairy and meat and production as a result from impacts on grass and rangeland [40]. Apart from that, the situation deprives animals from access to plenty of water due to drought [40, 41]. However, pastoralist with some financial muscles shift from one place to another using transport systems while those with weak economy were severely affected with their herds [14].

For instance, since 2000, Tanzania has experienced massive movements of pastoral communities (especially the Maasai) with their herds in thousands. In most cases the movement has been from areas with low potentials, e.g., semiarid, to high-potential zones, e.g., in floodplains [31], in search for pastures and water. This has been an adaptation strategy of these societies to get rid from extreme droughts. However, this has not been a sustainable option since they have further been degrading the area of destination and, thus, limiting more livelihood options and increasing poverty [28, 41]. IPCC reports have already specified that poor people with less socioeconomic instruments have been the most victims of climate impacts [1, 2]. The study by Agrawala et al. [29] that was conducted in Tanzania had similar observations. This, therefore, shows the degree of magnitudes of climate impacts to vulnerable livelihoods. Despite the direct impacts of climate to various livelihoods and ecosystems, there is a wide range of indirect impacts that also hits the same ecosystems and living organisms. And this poses accumulative impacts to the same.

8. Existing adaptation strategies

According to UN Framework Convention on Climate Change, adaptation and mitigation are very important practices for the sustainability of the planet. Despite the fact that these two practices are credible in both developed and developing countries, IPCC reports [1–3] have affirmed that developing countries, especially the sub-Saharan Africa, need to devote more time and resources to significantly embody these practices into all sectors that determine the peoples' livelihoods. Eastern Africa is among the regions with rapid population increase (growth rate 3%); thus, the demands of food and other environmental resources are increasing rapidly [42]. So far, if the increasing food demand due to human population growth is not well curbed, more degradation or the misuse of environmental assets and natural resources can be enormous. This situation has progressively compelled the region to adapt and cope with the changing climate to meet the necessary environmental resources even though this has been done with little success.

Various studies such as Alqudah et al. [43], Burney and Naylor [44], Cole [45], Eriksen et al. [46], Kilembe et al. [47], Lobell and Gourdji [48], and Rickards and Howden [49] have observed that the existing adaptation practices in Eastern Africa have widely been incremental, or transformational and have been basing on the severity of the climate impacts. Incremental adaptation refers to the fine-tuning of the existing system to minimize impacts, which includes changing planting dates, crop varieties, plant density, and nutrient and water management practices, while transformational involves the opting of alternative income generation methods [49, 50].

The increment adaptation has been the most important aspect as many people remain in agricultural production as their major livelihoods. These adaptations

have significantly involved irrigation (i.e., groundwater or from rainwater harvest), fertilization, and adoption of drought and tolerant seeds. This is dominant in the countries like Tanzania, Uganda, Rwanda, and Burundi where agriculture contributes over 50% of the GDP [10]. Even in countries like Kenya and Ethiopia where agriculture contributes to less than 30% of the GDP, adoption of suitable adaptation measures has been unavoidable.

9. Potential trajectories to improve adaptation and mitigation strategies

The current situation shows that despite having numerous strategies, practices, and programs to address climate change impacts, the level of vulnerability is still high in most developing countries [51]. This is because there are other factors that affect negatively the efforts of increasing resilience to climate impacts. Therefore, to improve adaptation to climate impacts, we need to have a clear exploration of what we have been doing for couple of time. In most Eastern African countries, the National Adaptation Plan of Action (NAPA) was adopted in the 2000s [31]. NAPA reviewed the level of vulnerability of economic, social, and ecological factors, among others, to climate change. Thus, it is better to review the NAPA if it still captures the most current challenges. If not, we need to revise it and mainstream the new important aspects in plans, programs, and policies. This will serve the widest audience of victims in the region, more particularly the small-holder farmers.

Again, the study on local condition should be done to explore the actual climate impacts that emanate in the locality. It was found that there have been intra-variations of climate variables within the local condition [12]. This now necessitates the follow-up from that level and progresses onward. However, this should be accompanied by authentic meteorological stations installed in villages. This will be the source of climate data and information.

Besides, various international and local reports have realized that since rain-fed agriculture is not reliable, there is a need to develop irrigation systems from groundwater and rainfall harvest sources [1]. In semiarid zones such as Central Tanzania and Northeastern Kenya and Uganda, intensive transformation to serve the livelihoods in these areas is needed. It will improve the agricultural systems for food crops and animal husbandry. This is because, currently, there has been a massive crop failure and death of a huge number of animals.

The improvement of agricultural systems needs to be given high priority in the region. This is because most poor agricultural systems have significant contribution to the emission of greenhouse gases. This is influenced by limited knowledge and technology to overcome the environmental changes that have been progressing over time. The implementation of various plans, projects, and programs needs to have effectiveness to the majority and not business as usual. This involves the best addressing of the climate challenge to the targeted group. Despite the increasing number of needy people, however, there is still a possibility to advance the methods of solving the challenges as related to the magnitude of the problem. This will bring more positive results to the social, economic, and ecological development to the majority.

10. Conclusions and potential policy implications

In this review, we assess and estimate the causes, vulnerability, impact, and adaptation strategies of climate change on the livelihoods in Eastern Africa. This was to respond the call for the Fifth Assessment Report of the IPCC regarding

climate change in developing countries to curb the dominant greenhouse gases for the sustainability of the planet. Our main contribution is to indicate the level of climate impacts by giving evidences from various robust and scientific researches that have been done in favor of the scope of the present study.

Here we find that a wide range of anthropogenic activities in most developing countries involve deforestation, degradation, and pollution of the environment and, thus, emit tons of greenhouse gases (i.e., CO_2, CH_4, N_2O, and CFCs) into the atmosphere. This is the claim of various climate stakeholders especially in international conferences (i.e., COP). Despite being less polluters than their counterpart, i.e., developed countries, the developing countries need to improve and stabilize their adaptation and mitigation measures because they suffer the most and are least equipped to cope. The variation of mean season temperature and precipitation within growing season has had a significant impact to agricultural production in the region. This in turn poses more vulnerability to farmers especially the poor, thus depriving the tool to either heal or cope with the dreadful condition.

Our estimation results appear to be economically viable, environmentally friendly, and communality acceptable as they consider the actual situation of the majority farmers and their socioeconomic dynamics. In addition, they can help to plan, prepare, and implement sound climate policies in the regions and/or international level. This will help in attributing farmer responses to climate variability with respect to socioeconomic and ecological circumstances.

The study has also viewed that there is substantial potential adaptation and mitigating measures of climate change which possibly can even increase agricultural output through conventional technologies such as flexible planting and rainwater harvesting, conservational agriculture (i.e., agroforestry), afforestation, and sustainable utilization of the Earth's resources. It also realized the need to improve forecasting methods at relevant scales for understanding ecosystem response and translating forecasts into useful decision support for natural resource managers and farmers. Therefore, there is a need to document all sound adaptation and mitigation measures that have proved to be helpful in the region. This should go with good governance in the region as some countries have political stiffness due to allegation of being dictatorial regimes.

Practically, adaptation strategies should be significantly mainstreamed into the country's planning frameworks, but how? By conducting vulnerability assessments for critical sectors to enhance understanding of the potential impacts of climate change. Developing a national climate change strategy that clearly lays out priority sector and ecosystem vulnerabilities and means for addressing them. Overall, this will improve the resilience of the people in developing countries and make the planet free from excessive concentration of greenhouse gases that are increasingly disturbing the destiny of the planet.

Conflict of interest

The author declares no conflict of interest.

IntechOpen

Author details

Msafiri Yusuph Mkonda
Department of Geography and Environmental Studies, Solomon Mahlangu College of Science and Education, Sokoine University of Agriculture, Morogoro, Tanzania

*Address all correspondence to: msamkonda81@yahoo.co.uk

IntechOpen

References

[1] IPCC. Climate Change 2007: Impacts, Adaptation and Vulnerability—Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom/New York, NY, USA: Cambridge University Press; 2007

[2] IPCC. Climate Change 2007: The Physical Science Basis Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom/New York, NY, USA: Cambridge University Press; 2007

[3] IPCC. Summary for policymakers. In: Field CB, Barros VR, et al., editors. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press; 2014. pp. 1-32

[4] Hens L. An evidence based data set on climate changes for developing countries. Environment, Development and Sustainability. 2014;**16**(2):255-256. DOI: 10.1007/s10668-013-9504-7

[5] Ahmed S, Deffenbaugh N, Hertel T, Lobell D, Ramankutty N, Rios A, et al. Climate volatility and poverty vulnerability in Tanzania. Global Environmental Change. 2011;**21**(2011):46-55

[6] Blanc E. The impact of climate change on crop yields in sub-Saharan Africa. American Journal of Climate Change. 2012;**1**:1-13

[7] Hertel T, Burke M, Lobell D. The poverty implications of climate-induced crop yield changes by 2030. Global Environmental Change. 2010;**20**:577-585

[8] Ghebrezgabher M, Yang T, Yang X. Long-term trend of climate change and drought assessment in the horn of Africa. Advances in Meteorology. 2016;**2016**:12. Article ID: 8057641. DOI: 10.1155/2016/8057641

[9] Kahsay G, Hansen L. The effect of climate change and adaptation policy on agricultural production in eastern Africa. Ecological Economics. 2016;**121**:54-64

[10] FAOSTAT. FAO Statistical Database. 2014. Available from: http://faostat3.fao.org/home/E [Accessed: March 2017]

[11] Eriksen S, Noess L. Pro-Poor Climate Adaptation: Norwegian Development Cooperation and Climate Change Adaptation. Oslo: Norwegian Agency for Development Cooperation; 2003

[12] Rowhani P, Lobell DB, Linderman M, Ramankutty N. Climate variability and crop production in Tanzania. Agricultural and Forest Meteorology. 2011;**151**(2011):449-460

[13] Kleinman P, Bryant R, Pimentel D. Assessing ecological sustainability of slash-and-burn agriculture through soil fertility indicators. Agronomy Journal. 1996;**88**(2):122-127. DOI: 10.2134/agronj1996.00021962008800020002x

[14] Sen A. Food, Economics and Entitlements. WIDER Working Papers (1986-2000) 1986/001. Helsinki: UNU-WIDER; 1986

[15] Maslin M, Brierley C, Milner A, Shultz S, Trauth M, Wilson K. East African climate pulses and early human evolution. Quaternary Science Reviews. 2014;**101**:1-17

[16] Nyssen J, Poesen J, Moeyersons J, Deckers J, Haile M, Lang A. Human impact on the environment in the

Ethiopian and Eritrean highlands—A state of the art. Earth-Science Reviews. 2004;**64**(3-4):273-320

[17] Kiage L, Liu K. Palynological evidence of climate change and land degradation in the Lake Baringo area, Kenya, East Africa, since AD 1650. Palaeogeography, Palaeoclimatology, Palaeoecology. 2009;**279**(1-2):60-72

[18] Pricope N, Husak G, Lopez-Carr D, Funk C, Michaelsen J. The climate-population nexus in the east African horn: Emerging degradation trends in rangeland and pastoral livelihood zones. Global Environmental Change. 2013;**23**(6):1525-1541

[19] Romahn S, Mackensen A, Kuhlmann H, P¨atzold J. Benthic foraminiferal response to late glacial and Holocene Sea level rise and rainfall variability off East Africa. Marine Micropaleontology. 2015;**119**:34-48

[20] Frankl A, Poesen J, Haile M, Deckers J, Nyssen J. Quantifying long-term changes in gully networks and volumes in dryland environments: The case of northern Ethiopia. Geomorphology. 2013;**201**:254-263

[21] FAO. FAO-Geonetwork. Rome, Italy: Food and Agriculture Organization of the United Nations; 2002

[22] Lobell DB, Burke MB. Why are agricultural impacts of climate change so uncertain? The importance of temperature relative to precipitation. Environmental Research Letters. 2008;**3**:034007

[23] Eriksen S, O'Brien K, Rosentrater L. Climate change in eastern and southern Africa: Impacts, vulnerability and adaptation. In: Global Environmental Change and Human Security, Report. Vol. 2008. 2008. p. 2

[24] URT. Review of food and agricultural policies in the United Republic of Tanzania. In: MAFAP Country Report Series. Rome, Italy: FAO; 2014

[25] Adger N. Vulnerability, global environmental change. Journal of Environment. 2006;**16**:268-281

[26] Mahoo HF, Young MDB, Mzirai OB. Rainfall variability and its implications for the transferability of experimental results in the semi-arid areas of Tanzania. Special issue: Rain water harvesting for crop production in semi-arid Tanzania. Tanzania Journal of Agricultural Sciences. 1999;**2**(2):127-140

[27] Baumann F. Improving Access to Natural Resources for the Rural Poor: A Critical Analysis of Central Concepts and Emerging Trends from a Sustainable Livelihoods Perspectives. Working Paper I. Rome: Livelihood Support Programme; 2002

[28] Crane T, Delaney A, Tamás P, Chesterman S, Ericksen P. A Systematic Review of Local Vulnerability to Climate Change in Developing Country Agriculture; 2007. DOI: 10.1002/wcc.464

[29] Agrawala SA, Moehner A, Hemp M, Van Aalst S, Hitz J, Smith H, et al. Development and Climate Change in Tanzania: Focus on Kilimanjaro. Paris: Organisation for Economic Co-operation and Development; 2003

[30] Burke M, Lobell D. Food security and adaptation to climate change: What do we know? Climate Change and Food Security. 2009;**37**:133-153

[31] URT. United Republic of Tanzania, National Adaptation Programme of Action (NAPA). Dar es Salaam: Division of Environment, Vice President's Office; 2007

[32] Lobell DB, Burke MB. On the use of statistical models to predict crop

yield responses to climate change. Agricultural and Forest Meteorology. 2010;**150**:1443-1452

[33] Mbilinyi BP, Tumbo SD, Mahoo HF, Senkondo EM, Hatibu N. Indigenous knowledge as decision support tool in rainwater harvesting. Physics and Chemistry of the Earth, Parts A/B/C. 2005;**30**:792-798

[34] URT. Poverty and Human Development Report Research and Analysis Working Group; 2009

[35] Mkonda MY, He XH. Are rainfall and temperature really changing? Farmer's perceptions, meteorological data, and policy implications in the Tanzanian semi-arid zone. Sustainability. 2017;**9**(8):1412. DOI: 10.3390/su9081412

[36] Mkonda MY, He XH, Festin ES. Comparing smallholder farmers' perception of climate change with meteorological data: Experiences from seven agro-ecological zones of Tanzania. Weather, Climate, and Society. 2018;**10**(3):435-452. DOI: 10.1175/WCAS-D-17-0036.1

[37] Mkonda MY, He XH. Yields of the major food crops: Implications to food security and policy in Tanzania's semi-arid agro-ecological zone. Sustainability. 2017;**9**(8):1490. DOI: 10.3390/su9081490

[38] Mkonda MY. Temporal rainfall and temperature trends, impacts in agriculture and adaptations that respond to local conditions. A case of Mvomero District, Tanzania. Research on Humanities and Social Sciences. 2014;**4**(12):36-49

[39] Stern RD, Dennett MD, Dale IC. Analyzing rainfall measurements to give agronomically useful results. II. Modelling approach. Experimental Agriculture. 1982;**18**:237-253

[40] Tietjen B, Jeltsch F. Semi-arid grazing systems and climate change: A survey of present modelling potential and future needs. Journal of Applied Ecology. 2007;**44**:425-434

[41] Thornton P, Herrero M, Freeman A, Mwai O, Rege E, Jones P, et al. Vulnerability, Climate Change and Livestock—Research Opportunities and Challenges for Poverty Alleviation. Kenya: ILRI; 2008

[42] FAO. Adapting to Climate Change through Land and Water Management in Eastern Africa: Results of Pilot Projects in Ethiopia, Kenya and Tanzania. Rome: Food and Agricultural Organization of the United Nations; 2014

[43] Alqudah AM, Samarah NH, Mullen RE. Drought stress effect on crop pollination, seed set, yield and quality. In: Lichtfouse E, editor. Alternative Farming Systems, Biotechnology, Drought Stress and Ecological Fertilization. Dordrecht, The Netherlands: Springer; 2011. pp. 193-213

[44] Burney JA, Naylor RL. Smallholder irrigation as a poverty alleviation tool in sub-Saharan Africa. World Development. 2012;**40**:110-123

[45] Cole M. Rwanda's Climate: Observations and Projections. Oxford, United Kingdom: Smith School of Enterprise and the Environment, University of Oxford; 2011

[46] Eriksen S, Klein RJT, Ulsrud K, Næss LO, Brien KO. Climate Change Adaptation and Poverty Reduction: Key Interactions and Critical Measures. GECHS Report 2007:1. Norway: Global Environmental Change and Human Security, University of Oslo; 2007

[47] Kilembe C, Thomas TS, Waithaka M, Kyotalimye M, Tumbo S. East African Agriculture and

Climate Change: A Comprehensive Analysis-Tanzania. Washington, DC: International Food Policy Research Institute; 2012

[48] Lobell DB, Gourdji SM. The influence of climate change on global crop productivity. Plant Physiology. 2012;**160**:1686-1697

[49] Rickards L, Howden SM. Transformational adaptation: Agriculture and climate change. Crop & Pasture Science. 2012;**63**:240-250

[50] Paavola J. Livelihoods, vulnerability and adaptation to climate change in Morogoro, Tanzania. Environmental Science & Policy. 2008;**11**:642-654

[51] Mkonda MY, He XH. Climate variability, crop yields and ecosystems synergies in Tanzania's semi-arid agro-ecological zone. Ecosystem Health and Sustainability. 2018;**4**(3):1-14. DOI: 10.1080/20964129.2018.1459868