# Retracing Economic Impact of Climate Change Disasters in Africa: Case Study of Drought Episodes and Adaptation in Kenya

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## Contents

**Abstract**

Valuation studies have shown that drought occurrences have more severe economic impact compared to other natural disasters such as floods. In Kenya, drought has presented complex negative effects on farming communities. The main objective of this chapter is to analyze the economic impacts of drought and

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identify appropriate climate change adaptation measures in Kenya. To achieve this objective, an empirical approach, combined with secondary data mined from World Bank Climate Knowledge Portal and FAOSTAT databases, has been used in three main steps. First, historical links between population size and land degradation, temperature and rainfall changes with drought events were established. Second, economic impacts of drought on selected economic indicators such as quantities of staple food crop, average food value production, number of undernourished people, gross domestic product, agriculture value added growth, and renewable water resources per annum in Kenya were evaluated. Third, different climate change adaptation measures among farmers in Makueni county were identified using focused group discussions and in-depth interviews, for which the use of bottom-up approach was used to elicit responses. Findings from the binary logistic regression model show a statistical relationship between drought events and a selected set of economic indicators. More specifically, drought events have led to increased use of pesticides, reduced access to credit for agriculture and the annual growth of gross domestic product. One of the main recommendations of this chapter is to involve farmers in designing and implementing community-based climate change adaptation measures, with support from other relevant stakeholders.

## Introduction

The agriculture sector in sub-Saharan Africa accounts for about 30% of the gross domestic product (GDP) and 40% exports in the region (Calzadilla et al. 2013). The sector is characterized by rainfed extensive crop and pastoral systems with low yields below potential (Amjath-Babu et al. 2016). The overreliance on rainfed systems has made the region prone to impacts of increasing temperatures, declining precipitation, changes in surface water run-off, and increased carbon dioxide ($CO_2$) (World Bank 2008). Low precipitation and high temperatures have reduced surface moisture content and increased evapotranspiration rates respectively causing soil degradation. Frequent weather-related disasters such as floods, droughts, tropical cyclones, and landslides have led to deaths and loss of livelihoods (Lumbroso 2017).

Drought is one of the most recurring climate change disasters for countries on the horn of Africa. This extreme weather event has occurred due to lack or inadequate precipitation leading to water shortage for plants, human, and animal consumption (Muller 2014; Maity et al. 2016). Its occurrence has been associated with global climate change, as there exist scientific evidence associating increased human activities with global climate change shocks such as floods and droughts (IPCC 2007). There are four types of droughts: meteorological (shortage in rainfall),
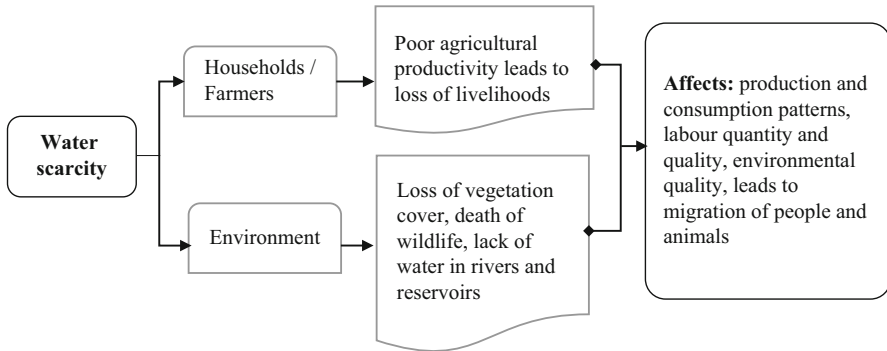
**Fig. 1** Impacts of water scarcity caused by drought on households and environment (Adapted from Freire-González et al. 2017)

hydrological (insufficient water in rivers and reservoirs), agricultural (inadequate soil moisture), and socioeconomic droughts (Maity et al. 2016).

In sub-Saharan Africa, droughts are common and their economic impacts in general have not been adequately studied. The reason behind this could be the complex nature of drought as it presents complex effects to lives on earth (Wang et al. 2014). Drought accounts for about 5% of the natural disasters but the losses that it causes account for about 30% of what is caused by other natural disasters (Wang et al. 2014). It aggravates water scarcity problem by affecting both surface and groundwater resources leading to reduced water supply, quality, and disruption of wetlands (Mishra and Singh 2011). When it persists for months or years, it causes conflicts between pastoral communities due to competition for the diminishing water and pasture resources (Uexkull 2014; Martin et al. 2016).

To demonstrate the economic impacts of drought, this chapter follows the framework by Freire-González et al. (2017). The authors establish many pathways and the drivers that contribute to the economic impacts of drought, which they classify into two categories: primary and secondary. The primary impacts of drought are those that affect economic agents such as industries, households, government, and the environment, while the secondary impacts lead to fires, desertification, and migration of people, as well as animals (Freire-González et al. 2017). Further, drought affects tangible assets such as land and vegetation cover differently from other natural disasters such as earthquakes, storms, or floods that affect buildings, machines, and other assets. In the long term, drought leads to soil degradation, damages to buildings due to soil sagging, as well as the ecosystems due to excessive groundwater abstractions without enough rainfall to replenish it (Freire-González et al. 2017). Drought leads to an increase in temperature causing excessive loss of water through evapotranspiration thus reducing water availability and quality. People are affected differently by drought depending on their geographical location (Freire-González et al. 2017). For example, the impact of drought on people in developing countries is more pronounced due to limited financial capacity to cope with effects such as malnutrition, starvation, increased pests and disease vectors such as malaria and

**Table 1** Impacts of drought on agricultural productivity and resulting socioeconomic impacts

| Description | Impacts on productivity | Socio-economic effects |
| --- | --- | --- |
| Cropping systems | Shift planting and harvesting dates | High market food prices |
| | Partial or total crop failure | Starvation and malnutrition |
| | Decreased crop yields | Decrease in farmers' income |
| Livestock | Decrease in forage from grasslands | Conflicts over pasture |
| | Increased livestock deaths | Decrease in household income |
| | Decrease in the quality of meat and milk | From livestock sales |
| Soil properties and soil health | Insufficient soil moisture for plant growth | Loss of vegetation cover |
| | Death of soil micro-organisms | Desertification |
| Hydrological cycle | Reduced water levels in rivers and reservoirs or no water at all | Increase in water prices |
| | Water scarcity | Conflict over scarce water and pasture resources |

dengue fever-causing mosquitoes (Freire-González et al. 2017), economic burden, and in extreme cases, death. Freire-González et al. (2017) framework focuses on how water scarcity caused by drought affects the households and the environment (Fig. 1).

It is important to focus on drought because it exacerbates the water scarcity situation, coupled with the fact that Africa is one of the driest continents in the world (Mishra 2014). Drought severely affects the water sector in many parts of SSA region, and the impact of the drought on the sector negatively affects the economy.

Some of the effects of drought on the agricultural productivity are also tabulated (Table 1), and the resulting socioeconomic impacts. The analysis gives a broad picture of the effects of drought on the agricultural productivity and the social aspects of the farmers. In some regions of America, the costs relating the effects of drought on the crop and livestock sectors among households have been quantified. For instance, Craft et al. (2017) carried out a study in Kentucky, USA, and reported a reduction in livestocks and hay produced, estimated at a cost of $143.4 due to water shortage caused by drought. However, the quantitative analysis of the impacts of drought on livestock and crop production in SSA has not yet been estimated due to paucity of available data and research capacity. In the context of SSA, a general qualitative analysis based on previous studies such as Wang et al. (2014), Kusangaya et al. (2014), and Adams et al. (1998) is used in this chapter to draw a close context.

## Climate Change Adaptation Measures in the Agriculture Sector of Sub-Saharan Africa

Climate change adaptation is one of the coping strategies supported by the United Nations Framework Convention on Climate Change (UNFCCC) to help developing countries, to reduce the negative effects of climate change (UNFCC 2015;

Deressa et al. 2009). Countries in sub-Saharan Africa express their adaptation needs in a policy document known as the Intended Nationally Determined Contributions (INDCs) (UNFCC 2015). The implementation of the INDCs is supported by several stakeholders such as government institutions, non-governmental organizations (NGOs), donor organizations, the World Bank, and the United Nations Environmental Programs involved in environment and climate change adaptation implementation in SSA region. These organizations have so far supported adaptation strategies in the agriculture sector such as small-scale irrigation of crop in areas where rains have failed, crop and livestock diversification, changes in planting dates, use of soil and water conservation techniques, namely terracing, mulching, and organic manure application (Nthambi et al. 2021; Bryan et al. 2013; Calzadilla et al. 2013; Francisco et al. 2010). Previous research has treated climate change adaptation measures in agriculture as a private good because this only involves individual farmers' adapting to the situation to reduce the local impacts of climate change (Lavoro 2010; Hasson et al. 2010). The effectiveness of these adaptation measures depends on the amount of resources available to support the adaptation process. Adaptation measures can, however, be categorized into two classes: autonomous and anticipatory (public). Autonomous adaptation measures are adjustments to respond to climate variability such as (rainfall) by individual farmers. This could be adopting suitable cropping types, changes in planting dates, and investment in irrigation technologies among other strategies (Calzadilla et al. 2013).

Anticipatory (public) adaptation is a planned measure to respond to climate change which is based on a public policy characterized by acceptability, flexibility, and net benefits (Dinar et al. 2008, c.f. Calzadilla et al. 2013). There are already existing studies from different countries in SSA region that have suggested autonomous adaptation measures (Alemayehu and Bewket (2017); Gebrehiwot and van der Veen (2013); Tessema et al. (2013); Deressa et al. (2011); Amdu (2010)). However, there are limited studies that have sought to address the anticipatory (public) climate change adaptation approach from both a scientific and public policy perspective.

## Methodology

### Study Area

Kenya is one of the SSA countries in the East African region. It covers an area of 581,309 km$^2$, which consists of 98.1% land and 1.9% water mass (GoK 2010). The agro-ecological zone distribution map of Kenya is shown in Fig. 2a, and this map identifies four main climate zones including humid, subhumid, semi-arid, and arid regions within the administrative map of Kenya. About 82% of the land mass represents arid and semi-arid areas (ASALs) (Kabubo-Mariara 2009; Rosenzweig et al. 2004), which are naturally prone to drought events. In Kenya, most
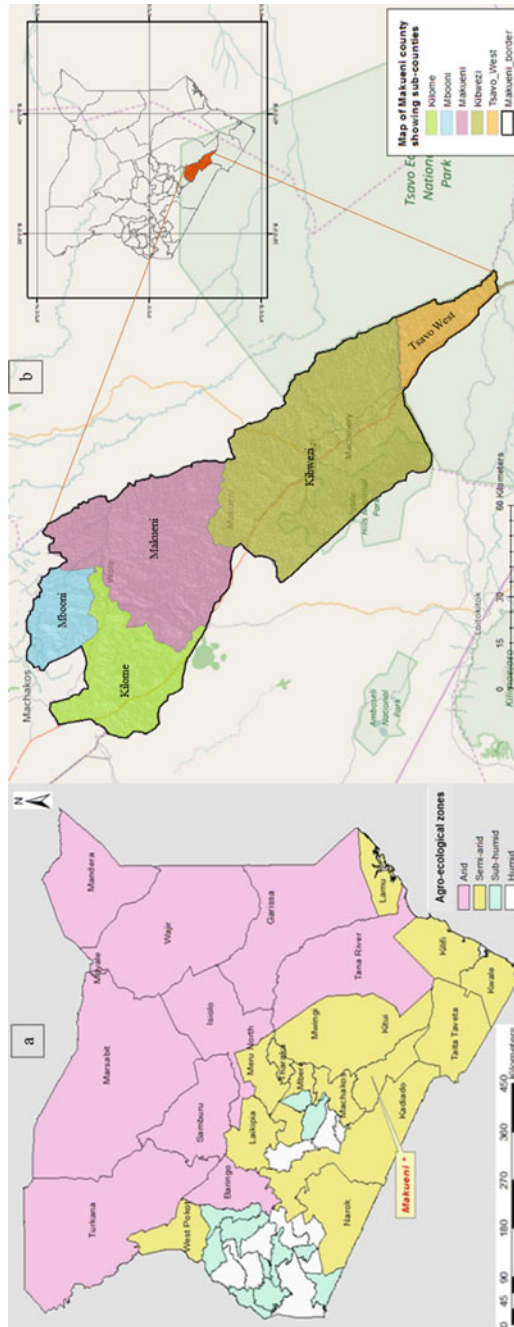
**Fig. 2** Map of Kenya showing (**a**) the distribution of agro-ecological zones across the counties and (**b**) the sub-counties in Makueni, the case area in Kenya
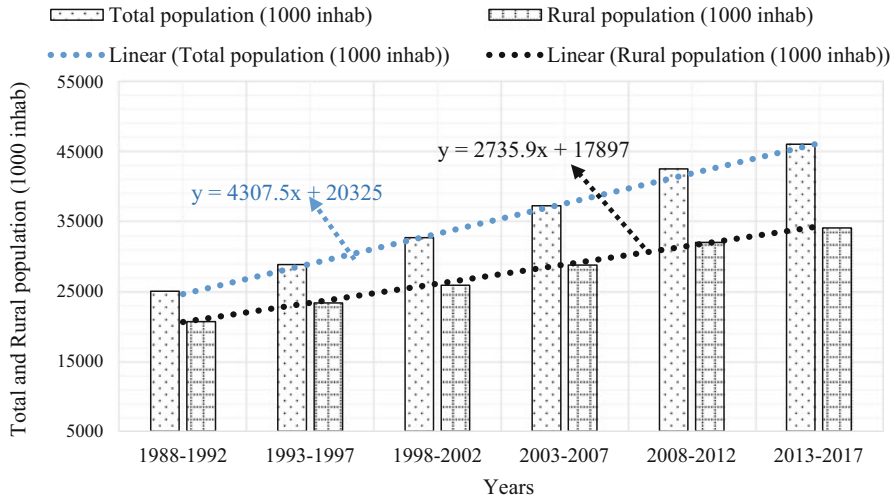
**Fig. 3** Total and rural population (1000 inhabitants) between 1988 and 2017 in Kenya (Data source: FAOSTAT 2017)

households found in the ASAL region have limited financial capability to respond to weather shocks such as the severe drought events (Ng'ang'a et al. 2016).

One of the counties in the ASALs region of Kenya in focus is Makueni County. It is situated in the eastern part of Kenya and lies between Latitudes 1° 35′ and 3° 00″ South and Longitudes 37° 10′ E and 38° 30′ E. It covers an area of 8034.7 km$^2$ (GoK 2013) I has four sub-counties (Fig. 2b). Households in Makueni County hold a base area of 1.58 hectares which is more in comparison to the national household land holding size of 0.97 hectares. The area experiences a bimodal rainfall pattern of between 300 mm and 1200 mm/annum (GoK 2013). The County's average temperature ranges between 20.2 °C and 35.8 °C (SACRED AFRICA 2011). It is prone to frequent droughts which are caused by inadequate rainfall leading to loss of fodder and food crop productivity. The drought events affect crop farming in the lower areas of the County making the communities living there to take a shift from crop production to animal production (GoK 2013).

One of the main drivers of climate change in Kenya is land degradation resulting from unsustainable land use practices due to a growing population. Land degradation occurs mainly due to the excessive conversion of woodlands into agricultural and settlement areas to cater for the increasing demand for food and shelter among households (Shadeed and Lange 2010). The estimated population in Kenya is approximately 46 million people out of which 34 million people live in rural areas (FAOSTAT 2017). Since the late 1980s, there has been an increasing population trend in the rural areas and the total number of inhabitants in Kenya (Fig. 3). The increase in rural population (Fig. 3) means an increasing dependence on agricultural activities to sustain the daily livelihood of the rural populace.

Muriuki et al. (2011) argue that the population growth in Kenya over the years has led to the massive movement of people from humid and sub-humid areas to arid and semi-arid areas. Resulting land degradation from these migrations has partly contributed to increased temperature and drought frequencies in Kenya since has potential to cause an interruption to the hydrological and ecosystem cycles.

## Methods

The selected data mined from databases of the World Bank and the UN FAO websites to evaluate the impact of drought consisted of climate indicators (temperature and rainfall values), population size, average food value, number of undernourished persons, renewable water resources, agriculture value added annual percentage growth, pesticide use, producer prices (US dollars), credit to agriculture (US dollars), and annual % growth of GDP for a period of over 20 years. The time series trend analyses of rainfall, temperature, population size, average food value, number of undernourished persons, renewable water resources, and agriculture value added annual percentage growth were done. Logistic regression model of the economic indicators (pesticide use, producer prices (US dollars), credit to agriculture (US dollars), and annual percentage growth of GDP) datasets were implemented in STATA to demonstrate the relationship between drought events and the selected variables. A binary coding approach was adopted to separate the years when drought events occurred which were coded as 1 and 0 otherwise. The binary logit model estimates the relationship between drought and several other independent variables. The model is applied to variables which are within $(0...1)$ and $(-\infty...\infty)$ and is expressed in eqs. 1, 2 and 3 as specified in Bera et al. (2020).

$$c = \beta_0 + \beta_k x_k \tag{1}$$

$$c = log_e\left[\frac{P}{1-P}\right] = logit(P) \tag{2}$$

where $P$ represents the probability of a drought event causing an impact to the agriculture sector. c represents the logit(P) and it is related to the independent variables. $\beta_0$ denotes the constant value, $\beta_k$ represents the coeficient estimates for the x factors. $x_k$ represents selected indicators that explain the dependent variable. In terms of the probability that drought events influence the independent variables, the model can be formulated as follows:

$$P = \frac{\exp(\beta_0 + \beta_k x_k)}{(1 + \exp(\beta_0 + \beta_k x_k))} \tag{3}$$

To demonstrate the willingness of smallholder farmers to be involved in an appropriate anticipatory climate change adaptation strategy, focused group discussions were conducted among three population groups in Makueni County. The population consisted of farmer groups, NGOs dealing with agriculture and

environmental issues in each of the agro-ecological zones, and government institutions charged with the responsibility of food security and environmental protection. The selection of these three populations was guided by the Agricultural Sector Development Strategy (ASDS) 2009–2020. Six focused group discussions were conducted with six registered farmer groups (a total of 190 farmers; 60 males and 130 females) between February and March 2015. The semi-structured interviews consisted of 17 key informants from the NGOs and government institutions which were used to supplement the information obtained from the smallholder farmers in the focus group discussions. In both cases, farmers and officials of NGOs and government institutions were asked to identify different adaptation measures based on the status quo then.

## Results and Discussion

## Drought Identification and Historical Trend Analysis

### Drought Episodes

The meteorological drought is responsible for hydrological and agricultural droughts types in Kenya. However, a successful integrated water resources management can help prevent the socioeconomic drought caused by the two droughts types. The socioeconomic drought is driven by factors of demand and supply of crop and livestock products (AMS 1997). The meteorological drought events in Kenya recorded were experienced between 1991–2, 1992–3, 1995–6, 1998–2000, 2004, 2006, 2008–9 (Ochieng et al. 2016), 2010–11, 2014–15, and 2016–17 (Reliefweb 2017). These episodes affected the agriculture sector and posed a risk on the food production systems. They caused an imbalance in the production and consumption patterns, which are very important components of food security (Kogan et al. 2013; Li et al. 2009; Tubiello et al. 2007). Previous studies in Kenya show that the agriculture sector is adversely affected by drought events leading to water scarcity, food insecurity, and conflict among pastoral communities (Muriuki et al. 2011). In some cases, people, livestock, and wildlife have lost their lives through starvation (Ombis 2013). The most recent instances occurred on February 10, 2017, and the government of Kenya responded by declaring drought a national disaster. This is because 2.7 million people faced the risk of starvation and about 23 out of a total of its 47 Counties were alarm areas, requiring urgent food and water aid (Reliefweb 2017). The declaration simply means high opportunity costs of other sectoral developments would be lost in pursuing food and cash transfers to the affected people in areas such as the Southeast, coastal lowlands, and the northern parts of the country. Although these impacts of drought are real in Kenya, there are limited scientific documentation to evaluate the impact of drought due to paucity of data. Moreso, there is limited literature which have studied the frequent droughts and linked them to the historical changes in the rainfall and temperature trends in the area.
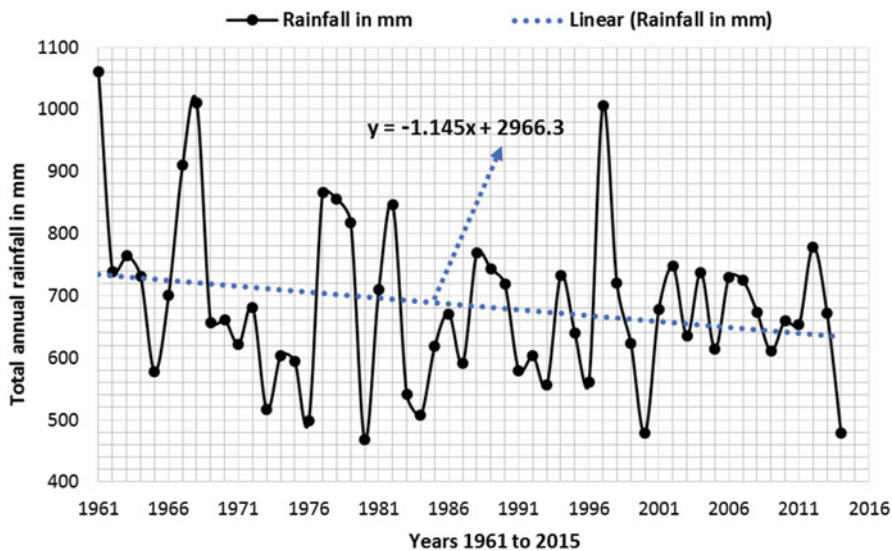
**Fig. 4** Total annual rainfall in mm between 1961 and 2014 in Kenya (Data source: World Bank 2017)

## Rainfall Trends

Over the past decades, scientists have carried out studies demonstrating how rainfall variability and increase in temperature have affected the agriculture sector and/or have a likelihood of causing catastrophes in the future. In East Africa, the annual rainfall amounts have declined considerably since the 1990s thus marking the region with frequent severe droughts between 2004–2005, 2009–2011 (Bloszies and Forman 2015) and 2014–2017 (Reliefweb 2017). The severe droughts have caused failures in rainfed crop production systems leading to food insecurity, famine, and political instability in most parts of northern Kenya, and other countries on the horn of Africa such as Ethiopia, southern Sudan (Bloszies and Forman 2015), and Somalia. Kenya has two main rainy seasons between January to May and October to December and a dry season from June to August. However, since the 1960s the amounts of rainfall received have reduced and are expected to reduce in the coming years. Trend analysis of data from World Bank (2017) database demonstrates a declining trend of precipitation and a high variability of rainfall characterized by extreme highs and lows over the past 55 years (Fig. 4).

A Kolmogorov-Smirnov (K-S) on the rainfall data from 1961 to 2016 indicates a normal distribution of rainfall. However, a Mann-Kendall (MK) statistic test at 95% and 99% indicate significant annual and seasonal variations of rainfall. The changes in seasonal and annual variations represent a reducing rainfall trend (Fig. 4). The trendline in the illustration indicates decreasing rainfall trend (see blue dotted linear) over time. A further decline may be expected if the diagram does not take into account the years of El Niño/Southern Oscillation (ENSO) rains which represent a climate change shock. For instance, the El Niño rains caused massive flooding and
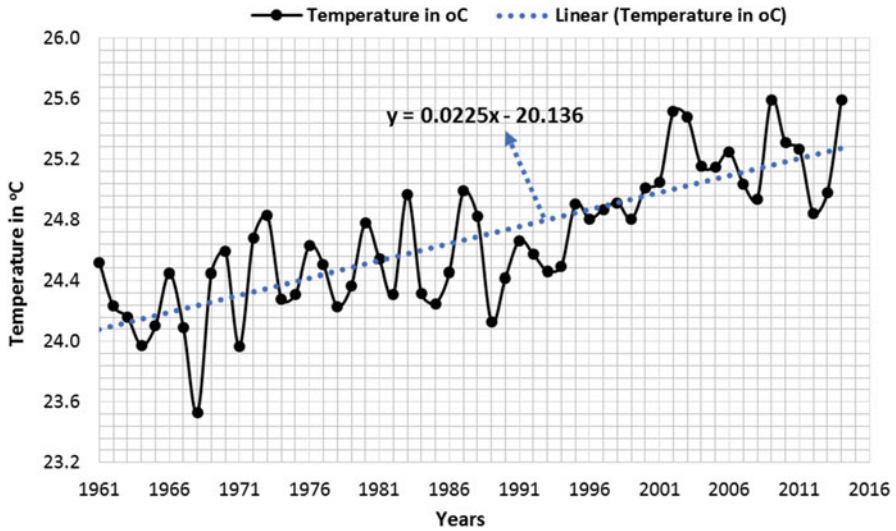
**Fig. 5** Mean annual temperature between 1961 and 2014 in Kenya (Data source: World Bank 2017)

mudslides in 1998 (Bloszies and Forman 2015). The severe floods in 1998 caused deaths, extensive damage to infrastructure leaving many households isolated and displaced (FAO 1998). If the years of El Niño rains are excluded from Fig. 4, the rainfall trend would probably be expected to decrease further.

### Temperature Trends

Since the 1960s the mean annual temperature in Kenya has increased by 1.0 °C at a mean rate 0.21 °C per decade. The increase is higher between March and May (0.29 °C) and low between June and September (0.19 °C) per decade (World Bank 2017). In the last 55 years, trend analysis of temperature data from the World Bank (2017) has increased by 1.1 °C. The increase in temperature affect the agriculture sector as the soil organic matter is depleted leading to degradation (Kirschbaum 1995). Soil degradation affects crop growth, and causes poor production yield. This is because there is a high correlation between soil organic carbon pool and climate (Kirschbaum 1995). The increase in temperature leads to an increase in humidity in the atmosphere due to high evapotranspiration rates (Tian and Yang 2017). The analysis of the temperature time series of Kenya is illustrated in Fig. 5. The result of the trend in the temperature changes is expected to increase further as shown by the trend (blue dotted linear line) line. The temperature increase in Kenya explains the local warming and drying of the country which has manifested in the form of frequent severe drought events since the 1990s.

Global warming has been associated with increased drought frequencies over the last five decades in Kenya. Yin et al. (2014) argue that the dry to very dry areas have doubled in the world due to effect of rising temperature. In Kenya, it is evident that

the temperature increase has led to further drying in many parts of the arid and semi-arid region, for example, in the south-east, coastal areas, and northern parts of the country. This has increased the cases of land-related conflicts, as viable agricultural crop lands encroach into meadows meant for animals of pastoralists who graze in these areas (Reliefweb 2017).

## Evaluation of Economic Impacts of Drought on the Agriculture Sector in Kenya

### Impact of Drought on Maize Production

The impact of the global climate change has been linked to the negative effects of economies, governance structures, and communities (Linke et al. 2015). Therefore, many developing economies and poor communities that depend on the agricultural produce can be badly affected due to the change. For instance, maize is one of the staple food crop in Kenya and contributes significantly toward food security (MALF 2017). The dwindling trend in its production since the 1990s can be attributed to severe droughts, especially during periods of drought episodes. To illustrate this, the trend in the annual percent change of maize yields corresponding to periods of drought between 1991 and 2014 declined (blue dotted trend line) (Fig. 6). The annual percentage changes in maize production were positive for the years when the drought events of 1991, 1993, 1998, 2008, and 2011 occurred. They became negative in 1992, 1995, 2004, 2010, and 2014 and zero for drought event of 1996.
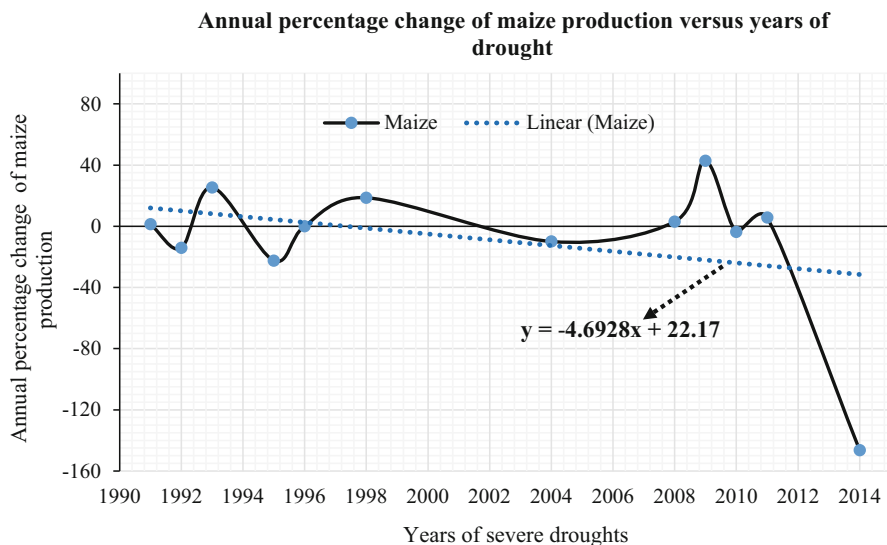


**Annual percentage change of maize production versus years of drought**

$y = -4.6928x + 22.17$

**Fig. 6** Annual percentage change in maize production between 1991 and 2014 in Kenya (Data source: FAOSTAT 2017)
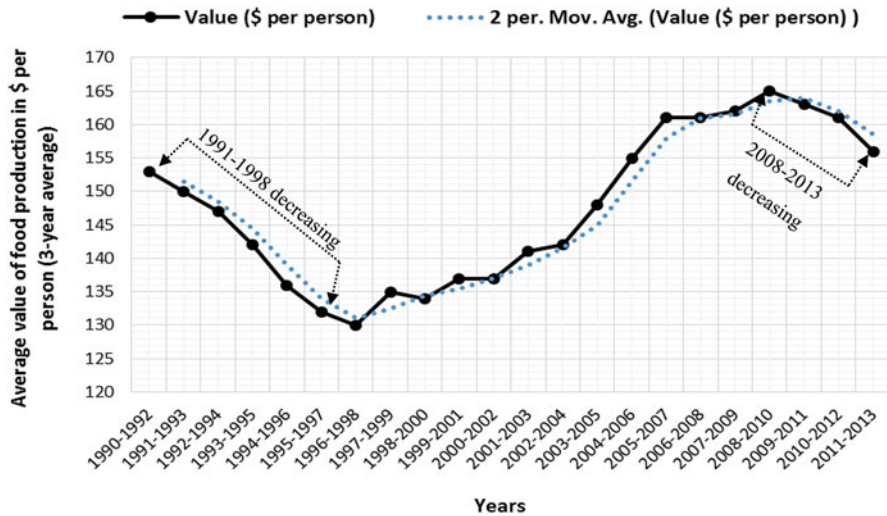
**Fig. 7** Average value of food production in dollars per person (3 – year average) in Kenya (Data source: FAOSTAT 2017)

During these drought events there were low maize yields and this led to increase in maize prices and higher demand for substitute food types such as rice, wheat, and root crops among others. The increased demand in the substitute food crop for the staple maize, forced the prices of these crop to go higher.

## Impact of Drought on the Average Food Value Production

Drought affects the average value of food production expressed in dollars per capita. Average value of food production is a country-wide measure of the absolute economic size of the food production sector (Land Portal 2018). The relationship between rainfalls and average food value revealed that there were drought events between 1991–1998 and 2008–2013. During this period, the average food value in dollars per capita followed a declining trend (Fig. 7). The average food value indicator is estimated over 3 years moving average to reduce the impacts of production errors resulting from complexities that occur due to disparities in major food stocks (Land Portal 2018). The two-person moving average curve (blue dotted curve) in Fig. 7 smoothens the short-term fluctuations in the average food value and shows an increasing or decreasing trend in the long term.

## Impact of Drought on the Number of Undernourished People

The agriculture sector in Kenya provides means of livelihood to more than 80% of the population (Faostat 2019). The population of undernourished people between 1990 and 2016 remained relatively high corresponding to the period of drought episodes in the country. These numbers of people are estimated to be in danger of calorie inadequacy and are under hunger threat (World Hunger Education Service 2016). They are thus at a risk of malnourishment. The analysis of the data revealed
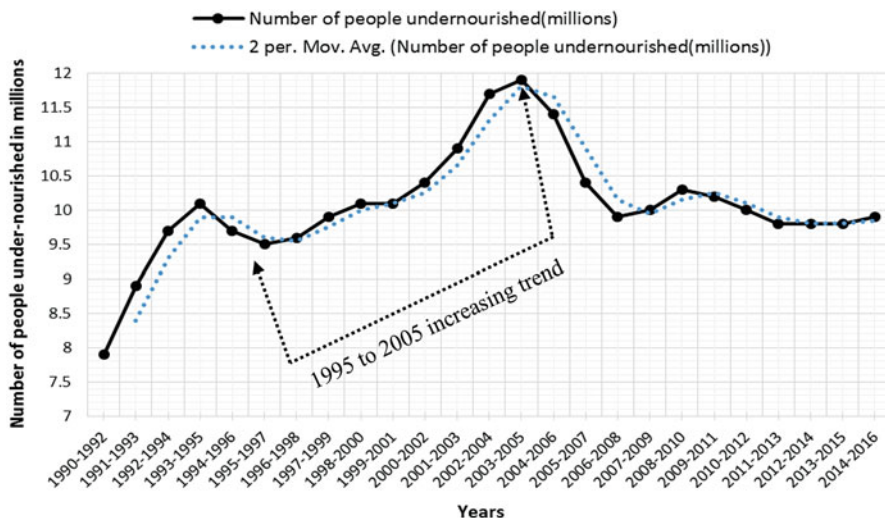
**Fig. 8** Number of undernourished people in millions (three-years average) in Kenya (Data source: FAOSTAT 2017)

that the number of undernourished people has been fluctuating, but relatively increasing in number, as shown in the trend plot (Fig. 8). For instance, between 1995 and 2005 there is a noticeable increase in the number of people under the threat of hunger in Kenya due to the 11 drought events that occurred between 1995 and 2005. The implication of this fact is that frequent severe drought events can be a threat to the Sustainable Development Goal (SDG 2) of the United Nations on the eradication of hunger and malnourishment because drought limits food availability to the people.

Thus, the number of undernourished people in Kenya have remained high regardless of efforts to meet SDG 2 of ensuring zero (0) hunger. Ensuring zero (0) means ending hunger by achieving food security through access to the right amounts and quality of food from sustainable agricultural practices. To understand the relationship between food and drought, or hunger and water scarcity can be correlated as common phenomena (Loewenberg 2014). This is due to overreliance on rain-fed agriculture which is highly vulnerable to the frequent severe droughts in Kenya. An estimated 75% of the population in the country derive their livelihoods from crop and livestock production (Loewenberg 2014), half of whom survive on less than a dollar a day. People who live on less than a dollar a day to meet their food and water needs are said to be poor (Nthambi et al. 2021; Loewenberg 2014).

**Impact of Drought on the Gross Domestic Product (GDP)**

The agriculture sector contributes approximately 25.9% to the GDP in employment and in providing food to local communities in Kenya (Ochieng et al. 2016). This means that the impact of drought on the agriculture sector is likely to affect the national GDP. Data from the World Bank (2017) show that agriculture, value-added
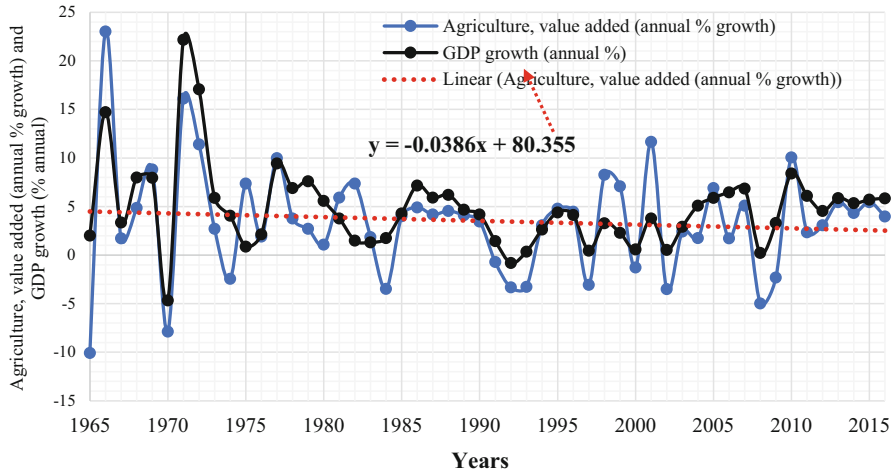
**Fig. 9** Agriculture, value added annual % growth versus GDP annual % growth between 1965 and 2016 in Kenya (Data source: World Bank 2017)
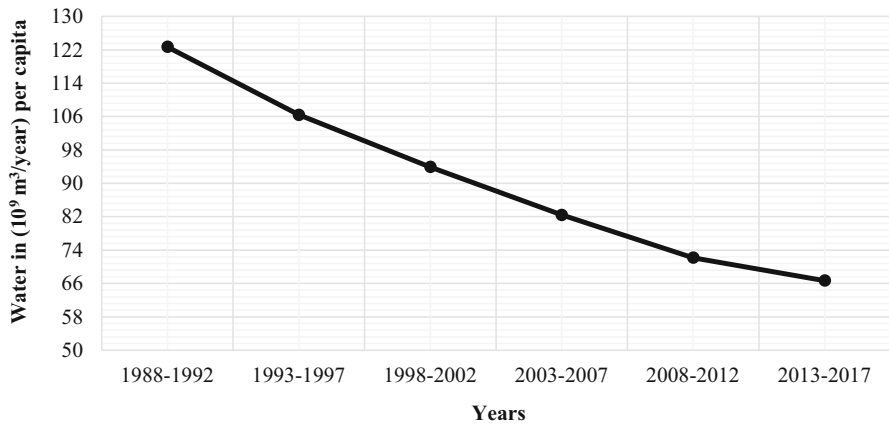


**Fig. 10** Total renewable water resources in m³ per capita in Kenya (Data source: FAOSTAT 2017)

annual % growth values are negative during the years of drought in Kenya. For example, the annual % growth for the valued added in agriculture 1991 (−1%), 1992 (−3%), 1993 (−3%), 2008 (−5%), and 2009 (−2%) (Fig. 9). The agriculture, value-added annual % growth describes the net value output of the agriculture sector obtained by summing up all the outputs minus intermediate inputs. When agriculture, value-added annual % growth curve is compared with that of the GDP % annual growth in Kenya for the period between 1965 and 2016, the curves behave similarly. That is, as agriculture, annual % growth increases, the GDP annual growth % also increases and vice versa (Fig. 9). These trends suggest that the agriculture sector correlates linearly to the GDP. This means that the impact of drought on the

agriculture sector will lead to negative value-added annual % growth, which in turn leads to the reduction of the GDP annual growth %.

## Impact of Drought on Water Security

Kenya is water-scarce and has only about 3–4% of its land cover composed of wetlands. The country experiences loss of wetlands estimated at 7% per annum due to the expansion of land for crop and livestock production (Böhme et al. 2016). Therefore, severe droughts have led to decline in surface and groundwater recharge. The total renewable water resources per capita per year between 1988 and 2017 have followed a declining trend (Fig. 10). Total renewable water resources are internal and external water resources (both surface water and groundwater) generated through the hydrological cycle (FAO 2016). The internal water resources are generated through endogenous precipitation while external water resources are the resources that enter the country through the transboundary flow from external surface and groundwater resources (FAO 2016). With the total renewable water resource being finite and the population continuing to grow, the water consumption per capita will dwindle. The drought events will have very harsh impact on the population. Hence, alternative water sources and conservation techniques are required to supplement the deficits caused by the drought.

## Statistical Analysis of Drought Impact on Selected Economic Indicators

Table 2 shows the descriptive statistics of the dataset obtained from FAOSTAT 2019, consisting of some economic indicators used in the binary logit regression model. These indicators represent independent variables that were hypothesized to be influenced by drought in the agriculture sector. The producer prices represent the average cost of producing a ton of maize – the staple food crop per annum. The annual growth of GDP (%) is the macroeconomic indicator representing the status of the economy in which agriculture, forestry, and fisheries are major contributors. Credit to agriculture represents the average amounts of loans that producers in the agriculture sector, forestry and fisheries, household producers, cooperatives, and agro-businesses have borrowed from private/commercial banking sectors per year (FAOSTAT 2019) to support agricultural production.

**Table 2** Descriptive statistics of economic indicators influenced by drought from 1991 to 2016

| Economic indicators | Mean | Standard deviation |
| --- | --- | --- |
| Pesticide use in tons | 0.44 | 0.26 |
| Producer prices (US dollars) | 224.38 | 84.39 |
| Number of under-nourished persons | 10.15 | 0.86 |
| Annual growth in gross domestic product (%) | 7.59 | 12.023 |
| Credit to agriculture (US dollars) | 387.69 | 273.61 |

**Table 3** Summary of the results of the binary logit regression model

| Choice (drought/no drought) | Coefficient | Std. Err | z | P > \|z\| | 95% Conf. Interval | |
|---|---|---|---|---|---|---|
| Pesticide use | 9.787 | 2.956 | 3.31 | 0.001*** | 3.993 | 15.580 |
| Producer price | −0.024 | 0.0131 | −1.85 | 0.064 | −0.050 | 0.001 |
| Undernourished | −1.467 | 0.9917 | −1.48 | 0.139 | −3.411 | 0.476 |
| GDP | −0.176 | 0.0619 | −2.85 | 0.004*** | −0.298 | −0.055 |
| Credit resources | −0.013 | 0.0047 | −2.73 | 0.006** | −0.022 | −0.004 |
| Constant | −1979.512 | 11.857 | −166.94 | 0.000 | −2002.8 | −1956.3 |
| Number of observations | 26 | | | | | |
| Wald chi²(5) | 158.7 | | | | | |
| Prob > chi² | 0.000 | | | | | |
| Log likelihood | −12.659 | | | | | |

Regression results (Table 3) show that pesticide use has a positive relationship with drought events while the coefficient estimates of producer prices, number of undernourished persons, GDP, and credit to agriculture have a negative relationship with drought events.

Pesticide use has a positive coefficient of variation and significant relationship with drought events. Increasing drought episodes means increased use of pesticides to control disease causing pests and vectors.

During drought events, soil moisture reduces the level of pesticide uptake. Moisture-deficient crops attract insects as such crops are unable to produce metabolites that prevent them from being susceptible to pest attacks (Yihdego et al. 2018). The annual growth percent of GDP is negative and statistically significant to drought events. Drought decreases food availability leading to decline in agriculture value added %. During drought events, farmers' ability to borrow money to support agricultural inputs declines as collateral for loans in form of farm assets becomes less available and valuable.



**Fig. 11** Water ponds for harvesting during rainwater (**a**) dry season and (**b**) filled pond in the rainy season (Photos taken by Mary)



**Fig. 12** An example of a household owned water pond for irrigating a kales/vegetable garden showing (**b**) drip and (**c**) furrow irrigation (Photos taken by Mary)

## Identified Climate Change Adaptation Measures in Makueni County

### Autonomous Climate Change Adaptation Measures

Makueni county has pilot private ponds already in place that are owned by a few households (Fig. 11a, b). Water accumulates in the ponds during the rainy season, and the farmers use it to irrigate the farm and/or fish farming. A standard water pond holds a minimum of 200,000 L of water and can be used by an individual farmer to farm an acre of maize and vegetables for approximately three seasons (Fig. 12). However, the disadvantage of this adaptation measure is that most farmers are unable to purchase the polythene sheet used as an inner lining of the water pond because it is costly (KES 70,000 exchange rate @ 103.2270 KES = 1 USD as at June 2015). The plastic layer is used to prevent the harvested rainwater from permeating into the groundwater. However, these water ponds can be a health hazard and that can lead to the drowning of livestock and children if not well guarded, as well as act as a breeding ground for malaria-causing mosquitoes.

### Anticipatory Climate Change Adaptation Measures

Anticipatory climate change adaptation coping strategies to climate change are those public adaptation measures provided to the rural communities through the support of organized groups such as the farmer networks/groups, NGOs, and government institutions. These measures are in most cases capital intensive and might require highly skilled technical input to put them in place. A universal set of community-based water projects suggested include boreholes, earth dams, shallow wells, water tanks, subsurface, and sand storage dams. The communities chose a sand storage dam as the best option because of the following reasons; (1) it is the world's cheapest way of providing rainwater to communities in arid and semi-arid areas, (2), a sand storage dam creates an indigenous, reliable, clean water supply up to about 1000 people, (3), water sinks through the sand to the bedrock preventing it from evaporation and pollution as compared to water in shallow wells, and (4) it saves farmers a lot of stress regarding land disputes since it is constructed along seasonal rivers

**Fig. 13** A sand storage dam construction in Makueni County during the dry season (Photo taken by Mary)
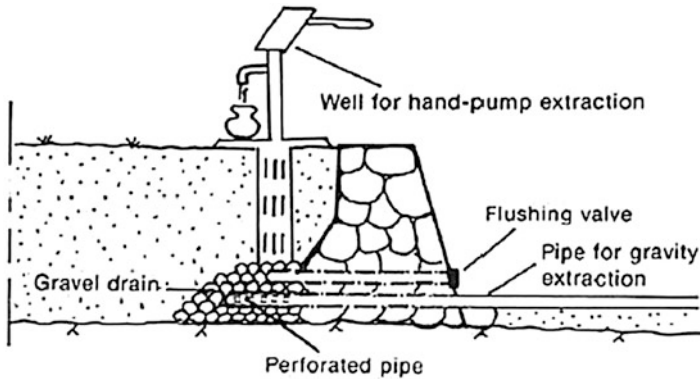
**Fig. 14** Cross-section of water extraction from a sand-storage dam (modified from Hanson and Nilsson 1986)

which are owned by the government and (5) sand storage dam reduces the risk of flooding and increases chances of water availability during the dry seasons. A sand dam is constructed across a shallow riverbed such as an ephemeral stream and water is extracted using pumps. An example of sand dam is shown in the following photograph (Fig. 13).

A subsurface sand dam is an underground facility that can be used as an alternative to the surface dams. It has some advantages over the conventional surface dam because it prevents excessive loss of water through evaporation and does not support the breeding of vectors such as malaria-causing mosquitoes on it. However, the subsurface dam is constructed below the ground level to tap from the flowing groundwater in the natural aquifers. It also has enhanced surface permeability to cause faster infiltration of rainwater to the groundwater during the rainy season. The sand-storage dam stores water in the sand which accumulates naturally behind a dam wall (Onder and Yilmaz 2005). The wall constructed across the seasonal river should be tight and stable to withstand the pressure of running water downstream. The riverbanks of the sand storage dam ought to be protected from erosion on sloppy areas and the dam bottom (Nilsson 1988). According to Hanson and Nilsson (1986), the extraction of the water from the sand storage dam can either be through pumping or gravity. The use of gravity means a drain is placed at the reservoir bottom in the upstream direction of the sand storage dam or a pipe downstream as shown in Fig. 14. The construction of a sand storage dam has four stages: the first stage deals with the capacity of the dam. It is described by the height of the dam wall to be constructed and the quantity of water it is expected to hold.

The second stage involves a careful selection of a proper water pumping mechanism and how to incorporate it into the sand storage dam design. The third step involves the protection of the dam banks through the planting of trees on the sloppy areas both downstream and upstream of the river where the sand storage dam is constructed. The fourth stage involves a careful selection of the donor (management structure) to support the construction of the wall and one that would organize the

farmers who will be involved in the construction process. The loss of benefit accruing from the choice of management structure in the area has been fully documented in Nthambi et al. (2021). Farmers should be involved in the four phases and the actual construction process of the selected climate adaptation measure. Other forms of participation can be accounted through contribution of labor time or cash for the purchase of raw materials.

## Conclusions

The frequent severe drought events in SSA region have heavily affected the growth of the agriculture sector, forcing crop and livestock farmers to work under very dry conditions in countries such as Kenya. In this chapter, the impacts of drought on the economy of Kenya were discussed, and a possible climate change adaptation measures demonstrated using a case study area in one of the counties. The findings can be summarized in three main ways. First, the analyzed climate indicators revealed frequent drought episodes, which have led to direct and indirect economic impacts on the agriculture sector and the economy. The analysis shows drought events have a positive relationship with pesticide use and negative relationship with credit resources, producer prices, number of undernourished people, and annual percentage growth of gross domestic product (GDP). Again, drought events negatively affect the number of undernourished people as the quantities of crop yields, for example, maize as the staple food crop in Kenya reduces. During the years of drought events, the agriculture value added % growth declines reducing the annual GDP. Producers and households' access to credit resources reduce during drought episodes. The amount of water from renewable water resources also declines due to decreasing rainfall amounts causing water scarcity.

Second, farmers and households can adapt to the negative impacts of drought using either autonomous or anticipatory climate adaptation measures. The major concern is the dryness that comes with drought events, and given the arid and semi-arid nature in most parts of Kenya, rainwater harvesting in sand dams would be the most suitable adaptation measure to reduce the impact of drought. Generally, farmers in the area prefer a sand dam over water ponds or boreholes. However, the lack of financial support hamper farmers' desire to execute this type of anticipatory climate change adaptation measure.

Third, from a methodological perspective, the use of available secondary data to avail important literature required for climate change research in SSA region was promoted. It demonstrates a simple way of relating climate variables with economic indicators using existing qualitative and quantitative approaches. In terms of determining suitable climate change adaptation measures, we consulted stakeholders to suggest the adaptation measures and propose a practical approach to implement them.

Two main recommendations were suggested in this chapter. First, the Kenya National Adaptation Plan (NCCAP) 2015–2030 highlights financing as one of the limitations in the mainstream of climate change adaptation in the water sector. The

country is keen on providing adequate water management strategies that can ameliorate the water scarcity problem caused by drought events. We established the involvement of stakeholders to participate in constructing sand dams to harvest rainwater across seasonal rivers. Thus, the NCCAP, 2015–2030 should integrate community participation strategy to provide local materials such as water, sand, and stones or cash when possible, as a way for farmers to partially finance the provision of adaptation measures for sustainable water harvesting techniques. A bottom-top approach to adaptation measure is necessary to understanding farmers' willingness to take part in adaptation projects such as the construction of a sand dam in the SSA region.

The National Drought Management Authority (NDMA) in Kenya, charged with the responsibility to identify risks, end drought emergencies, and ensure adaptation for sustainable livelihoods, should encourage farmers to form community-based organizations. NDMA should also encourage farmers to form farmer networks/groups and register them under the Self-help Association Bill (2015) to provide legal protection to farmers who wish to participate in sand storage dam construction. Membership of community-based organization would encourage collective action efforts that enhance trust among farmers thus strengthening stakeholders' participation in community adaptation projects. Government institutions and non-governmental organizations should work with farmer networks to ensure adaptation measures are implemented in a way that is acceptable to the communities that benefit from them.

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