

**VULNERABILITY OF SMALLHOLDER MAIZE PRODUCTION TO
CLIMATE CHANGE AND ADAPTATION CHOICES IN LAIKIPIA AND
KITUI COUNTIES IN KENYA**

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University or any other award.

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DEDICATION

This thesis is dedicated to Paul, Larry, Laura and Lance.

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ABBREVIATIONS AND ACRONYMS

AEZs	Agroecological Zones
ASALs	Arid and Semi-Arid Lands
CSA	Climate Smart Agriculture
DSU	Dutch sustainability Unit
FAO	Food and Agriculture Organization
FGD	Focused Group Discussions
GDP	Gross Domestic Product
GHGs	Greenhouse Gases
IFAD	International Fund for Agricultural Development
IPCC	Intergovernmental Panel on Climate Change
KDC	Kenya Disaster Concern
KIIs	Key Informant Interviews
KIRA	Kenya Inter-Agency Rapid Assessment
LVBC	Lake Victoria Basin Commission
MCE	Multiple Criteria Evaluation
MDGs	Millennium Development Goals
MLE	Maximum Likelihood Estimation
MLND	Maize Lethal Necrotic Disease
MNL	Multinomial Logit
MOALFC	Ministry of Agriculture, Livestock, Fisheries and Cooperatives
MRS	Marginal Rate of Substitution

NCCRS	National Climate Change Response Strategy
NCCAP	National Climate Change Action Plan
OLS	Ordinary Least Squares
pH	potential of Hydrogen
RESET	Regression Specification Error Test
ROK	Republic of Kenya
UNICEF	United Nations International Children’s Emergency Fund
VIF	Variance Inflation Factor
WFP	World Food Programme
WHO	World Health Organization

OPERATIONAL DEFINITION OF TERMS

Adaptation:	Adjustment of maize production in response to actual/expected climatic changes by minimizing its adverse effects or harnessing its benefits.
Adaptive capacity:	The ability of smallholder maize production to adjust favorably to environmental stress and changes in human and environmental conditions autonomously or through smallholder interventions.
Climate change:	Change in the state of climate observable by changes in the mean or variability of its properties such as temperature and rainfall over an extended period of time like decades.
Climate normal:	Average monthly temperature/rainfall data for the period 1961 to 2017.
Communal land:	Land jointly owned or managed by a group or community.
Drought:	Period with rainfall deficit which is insufficient for maize production in a given region.
Efficacy of adaptation:	Smallholders perceived judgement of the capability of adaptation choices in being successful in producing the desired result in respect to effectiveness, high yield, affordability, farmer implementability and additional benefits.
Exposure:	Environmental stress (threats, risks or hazards) on smallholder maize production.

Hermetic maize bags:	Airtight bags that prevent moisture from affecting stored maize.
High level of efficacy:	Perception that adaptation choice performs above smallholder expectations.
Low level of efficacy:	Perception that adaptation choice performs below smallholder expectations.
Moderate level of efficacy:	Perception that adaptation choice performs within smallholder expectations.
Sensitivity:	Response of smallholder maize production to exposure influenced by human and environmental conditions.
Smallholders:	Households practising maize production on five or less acres of land.
Vulnerability:	The extent to which smallholder maize production is exposed to, sensitive to and is adaptive to climate change.

ABSTRACT

Maize is a staple food for majority of Kenyans. However, unpredictable timing, frequency, duration, character and distribution of rainfall especially during the growing season and increasing temperatures are contributing to declining yields hence increased incidence of food insecurity. Inappropriate selection or application of adaptation choices could further contribute to low maize yields. However, vulnerability of smallholder maize production and levels of efficacy of adaptation is unclear. For Kitui and Laikipia counties in Kenya, the study investigated the extent and determinants of vulnerability of smallholder maize production to climate change. The levels of efficacy of adaptation of smallholder maize production to climate change were evaluated and determinants of the levels of efficacy were estimated. Data on demographics and socio-economic characteristics and adaptation choices was collected from smallholder maize producers using a questionnaire. Temperature data in degree Celsius was obtained from the Global Historical Climatology Network monthly dataset gridded version 4 while monthly rainfall data in millimeters was obtained from Centennial Trends Greater Horn of Africa precipitation dataset version 1.0. Exposure, sensitivity and adaptive capacity indices were derived based on factor analysis and combined to obtain vulnerability index. Determinants of vulnerability of smallholder maize production to climate change was estimated based on Ordinary Least Squares. The level of efficacy of adaptation was evaluated based on the Multiple Criteria Evaluation while ordered probit model was used to estimate the determinants of level of efficacy of adaptation. Results showed that most of the smallholders were in the lowest tercile. However, most of the smallholders in Kitui County were in the highest tercile hence more vulnerable than smallholders in Laikipia County. Longer maize shortage, prevalence of climate related diseases, stored water lasting shorter period and being single increased vulnerability while receiving accurate climate information and eating alternatives to maize decreased vulnerability. In addition, majority of smallholders in the study reported low levels of efficacy of adaptation. Smallholders likely to report high levels of efficacy undertook soil analysis, had more farming experience, accessed extension services, produced maize in communally owned land and applied multiple adaptation choices. The study recommends support from state and non-state actors to facilitate provision of input subsidies, accurate and timely climate information; support towards water harvesting and construction of maize silos at Ward level to minimize vulnerability. In addition, build the capacity of smallholders to undertake frequent soil analysis; apply multiple adaptation choices and procure appropriate resources to enhance efficacy of adaptation.

CHAPTER ONE

INTRODUCTION

1.1 Background

World over, there is heightened concern on the need to increase food production to feed the growing population owing to the magnitude of challenges relating to hunger and famine. To address these challenges world leaders formed the Food and Agriculture Organization (FAO) in 1945 to facilitate improvement of food production, distribution and allied systems (Food and Agriculture Organization, 1945). In addition, the World Food Programme (WFP) was formed in 1961 to assist in combating hunger during crises such as war and natural disasters and providing food aid after crisis to reinstate communities to normalcy (United Nations (UN), 1961).

Although a lot of effort has been exerted at the global level to combat hunger and famine, over 690 million people experienced hunger in 2019 translating to 8.9 percent of world population (FAO, International Fund for Agricultural Development (IFAD), United Nations International Children's Emergency Fund (UNICEF), WFP, World Health Organization (WHO), 2020). During the year 2020, the estimated number of people who experienced hunger grew to a range of 720 million and 811 million while the number of food insecure population increased from 2 billion to 2.37 billion (FAO, IFAD, UNICEF, WFP, WHO, 2021). The large increase of the food insecure population in the year 2020 was attributed to COVID-19 pandemic.

To sustain the resolve to combat hunger, the global fraternity through the Sustainable Development Goal (SDG) number two reiterates the need to achieve food security by promoting sustainable agriculture (UN, 2015). This would be achieved through supporting agricultural practices that lead to increased agricultural output, protection of ecosystems that support agriculture, strengthening the capacity to adapt agriculture to climate change, improvement of the quality of soils, increased access to inputs and knowledge to enhance agriculture production among other ways (UN, 2015). Furthermore, goal number thirteen reiterates the importance of addressing challenges relating to climate change by enhancing resilience and adaptive capacity of systems, education and awareness and setting up early warning systems to reduce adverse impacts on systems which includes agriculture systems (UN, 2015). At the regional level, the African Union committed to eliminate hunger and food insecurity by 2025 by implementing strategies to improve agricultural productivity as outlined in the Africa's Agenda 2063 and Malabo declaration (Hedden *et al.* 2016; Department of Rural Economy and Agriculture (DREA), 2014; Ambali, 2013).

Food security is defined as a situation where all people have access to adequate, nutritious, safe and preferred food at all times to enjoy healthy lives (FAO, 2008). It has four dimensions namely, availability, access, utilization and stability that must be attained for a household to be considered food secure (FAO, 2008). Food availability depends on quantities of food produced domestically or imported while access to food of the right quantity and quality depends on the ability of a person to afford the food they do not produce (Connolly-Boutin and Smit, 2016). Food utilization focuses on nutritional value

and safety of food, and it encompasses complementary inputs to food security such as access to clean water, proper sanitation facilities and health care (FAO, 2016). Stability of food systems imply that people are always guaranteed access to food (Connolly-Boutin and Smit, 2016).

Agriculture and food security are an important subject globally. FAO estimates that 500 million smallholders are responsible for about 80 percent of the world's food (Graeub *et al.*, 2016). However, most smallholders have farm sizes of approximately 2 hectares (Lodwer, Skoet & Raney, 2016; Rapsomanikis, 2015; Kang'ethe, Mutua, Roesel and Grace, 2020). Furthermore, maize is a staple crop for most people in SSA and the area under maize increased by 60 percent between 2007 and 2017 (Santpoort, 2020). In 2015, it was estimated that 208 million people depend on maize as a source of food security and it occupies 33 million hectares out of the estimated 200 million hectares of cultivated land (United Nations Economic Commission for Africa, 2015). It was further estimated that a large proportion of land cultivated in Sub-Saharan Africa (75 percent to 80 percent) are degraded thereby contributing to 30-60 kilogramme of nutrient losses per hectare per year (Africa Group of Negotiators Experts Support (2020)).

Under the Vision 2030, Kenya targets to transform agriculture to enhance food and nutrition security through increasing agricultural output and value addition (Republic of Kenya, 2018a). This is in line with the constitutional provisions on the right to food security to every person (Republic of Kenya, 2010a). Accelerating achievement of food security was emphasized in the Big Four Agenda of the Government of Kenya in 2017

with a target to reduce food insecure Kenyans by 50 percent; reduce malnutrition among children below 5 years by 27 percent and increase the contribution of agriculture to Gross Domestic Product (GDP) by 48 percent (ROK, 2020).

Agriculture continues to play an important role as the main source of food and nutrition in Kenya. It remains one of the most important sectors contributing 75 percent of total employment in Kenya (United States Agency International Development (USAID), 2022). Agriculture contributed the most to GDP in Kenya in the year 2021 as compared to the other sectors of the economy (Republic of Kenya, 2022a). For instance, crop production contributed to 16.3 percent of GDP as compared to transport and storage services which was the second highest contributor at 11.4 percent in the year 2021 (Republic of Kenya, 2022a). However, there was a drop in the real agriculture growth rate from 5.2 percent in 2020 to negative 0.1 percent in 2021 (Republic of Kenya, 2022a). In addition, agriculture was adversely affected by impacts of COVID-19 in the year 2020. Some of the effects included increase in cost of production and agricultural losses due to restrictions in movements both nationally and internationally (Republic of Kenya, 2020).

1.1.1. Vulnerability of Smallholder Agriculture to Climate Change

According to the Intergovernmental Panel on Climate Change (IPCC), climate change arises from changes in the mean or variability of climate properties including increasing temperatures, rainfall variability, recurrent droughts and recurrent famine over an extended period of time such as decades (United Nations Framework Convention on Climate Change (IPCC, 2012; Olsson *et al.*, 2019). Agriculture is one of the sectors

vulnerable to climate change to the extent of its exposure to climate change, its sensitivity and adaptive capacity (Tao, Xu, Liu, Pan and Gou, 2011).

Smallholders have low adaptive capacity and are more likely to experience adverse unfavorable impacts of climate than other farmers (Republic of South Africa, 2012). In addition, declining agricultural productivity due to climate change worsens poverty among smallholders (Intergovernmental Panel on Climate Change, 2014). They also engage in human activities that intensifies exposure of natural and human systems to climate stimuli including land use and management practices such as deforestation, intensified use of inorganic fertilizers that increase nitrous oxide and animal production that increases emission of methane to the atmosphere (Arneth *et al.*, 2019). Some sectors are sensitive to climatic stimuli directly or indirectly in a way that intensifies adverse impacts to the agriculture sector. For instance, the transport sector contributes to GHG emission but is also adversely impacted by extreme weather events that destroy transport infrastructure which further impacts supply of raw materials and cause disruption of food supply chains (Kenya Private Sector Alliance, 2014).

Smallholders are also affected by climate sensitive diseases such as water borne, vector borne and cardiovascular diseases which impact productivity of labour in farming activities and also divert resources to access treatment (IPCC, 2022). The level of sensitivity of smallholders could worsen with location with those residing in semi-arid and arid areas more likely to have greater sensitivity due to exposure to high temperatures in most months of the year than residents of high potential areas (Kalele,

Ogara, Oludhe and Onono, 2021). A large proportion of smallholders are food insecure and their adaptive capacity is limited by poverty and access to markets hence could experience high levels of vulnerability (Harvey *et al.*, 2018; Rapsomanikis, 2015).

1.1.2. Vulnerability of Maize Production to Climate Change in Kenya

Maize production is climate sensitive. Most maize varieties require rainfall of above 1000 millimeters distributed well over the growing season (One Acre Fund, 2015). The medium maturity maize requires 500 millimeters to 800 millimeters of water depending on temperature levels that affect evapotranspiration during the growing season (Food and Agriculture Organization, 2016). The optimum temperature for maize production is between 18 Degrees Celsius to 32 Degree Celsius above which could be destructive (Esilaba, Nyongesa, Okoti, Otipa and Wasilwa, 2021).

Maize production in Kenya is mainly undertaken during the two rainy seasons; long rain and short rain seasons. The long rain season is from March to May while the short rain season is from October to December (ROK, 2022b). Over time, rainfall in Kenya has declined during the long rain season while increasing over the short rain season (Dutch sustainability Unit, 2015). The average rainfall for the months of March, April and May over the years 1961 to 1990 was 97.61 millimeters while for the period 1991 to 2020 was 90.22 millimeters (World Bank, 2021). On the other hand, over the months of October, November and December for the period 1961 to 1990 average rainfall was 71.78 while for the period 1991 to 2020 average rainfall was 78.5 millimeters (World Bank, 2021). The decline in rainfall over the long rain season enhances sensitivity demonstrated by low maize yield since most smallholder maize producers mainly depend on the long rain

season. Nonetheless, an increase in rainfall over the short rain season could lead to increased production over that season. The trends for rainfall for the long rain and short rain seasons for the years 1961 to 2020 are shown in Figure 1.1. The figure elaborates the shift in rainfall in the two seasons.

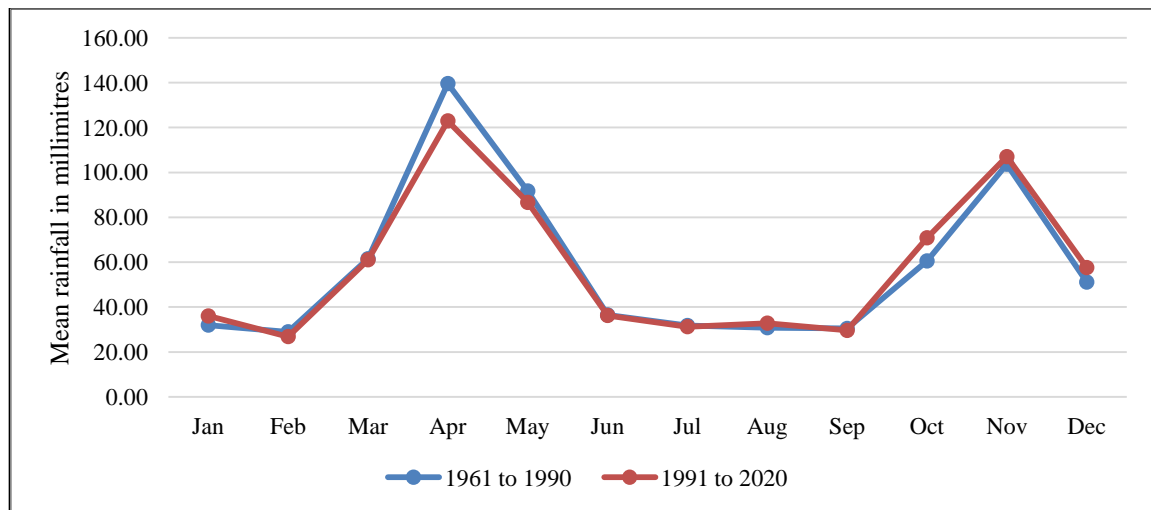


Figure 1.1: Average Rainfall Normal Trends for Kenya Over the Period 1961 to 2020

Source of data: <https://climateknowledgeportal.worldbank.org>

Figure 1.1 shows the change in the average rainfall trends with the short rain season depicting higher average rainfall in the months of October, November and December for the period 1991 to 2020 as compared to the period 1961 to 1990. On the other hand, the long rain season depicts a decline in average rainfall for the months of April and May for the period 1990 to 2020 relative to the period 1961 to 1990.

Very high rainfall can lead to floods, landslides or mudslides. Floods cause water logging, soil erosion and leaching of soil nutrients which affects the stability, water holding capacity, potential of Hydrogen (pH), organic matter content, total nitrogen and phosphorus in the soil which affect the quality of soil ideal for maize production (Brevik,

2013). Ideal soil conditions for maize production include well drained, well aerated with high organic matter and pH levels ranging between 5.5 and 6.8 (Esilaba *et al.*, 2021). Levels of pH outside the given range are associated with very high or very low levels of certain soil elements thereby affecting soil fertility (Republic of Kenya, 2014). Consequently, smallholders would have to increase use of fertilizers to enhance soil fertility. Very low rainfall on the other hand, enhances sensitivity of maize production exhibited by crop failure. Low or lack of rainfall for extended periods enhances exposure through drought occurrences with adverse consequences on food security. Temperature is also critical in the growth and development of maize. Higher temperatures reduce soil moisture content thereby leading to crop failure and alteration of microbial soil respiration rates due to the sensitivity of microorganisms and the processes they regulate (Rurinda *et al.*, 2014; Classen, *et al.*, 2015).

Climate change can also enhance exposure of maize production to crop pests and diseases because it accelerates the rate of multiplication of disease-causing pathogens, pests and insects (Pareek *et al.*, 2017). For instance, Maize Lethal Necrotic Disease (MLND) which thrives best under humid conditions, causes chlorotic mottling that prevents processes such as photosynthesis and chlorophyll formation from taking place effectively thus leading to low yields or crop loss of between 80 percent and 100 percent (Republic of Kenya, 2012b; Makone, Menge and Basweti, 2014). The highest incidence of MLND affects the physiological mature maize growth stage while the effect of the disease on the dough maize growth stage is severe (Joyce, Miano, Muiru, Mutito and Macharia, 2021).

Further, incidents of invasive weeds have increased due to increase in atmospheric levels of carbon dioxide. The increased levels of carbon dioxide concentration stimulate growth and development of the invasive weeds and consequently geographical expansion (Ramesh, Matloob, Aslam, Florentine and Chauhan, 2017). The adverse competition between weeds and crops consequently lead to loss in crop yields as in the case of striga which contributed up to 90 percent of crop losses in Busia, Bungoma, Siaya, Migori and Kakamega counties in Kenya (African Agricultural Technology Foundation, 2017).

Global Climate Models predict that temperatures will rise by 1.7 Degree Celsius by the 2050s and by 3.5 Degree Celsius by the end of the 21st Century in Kenya (World Bank Group, 2021). On the other hand, precipitation is forecasted to continue being uncertain and highly variable. In particular short rains occurring between October and December are projected to increase and the frequency, duration and intensity of extreme rainfall events are expected to increase (World Bank Group, 2021). Furthermore, frequent nationwide droughts have been predicted and are likely to affect farmers in the East and North of Kenya (Republic of Netherlands, 2018). This would be detrimental to maize production in Kenya especially where already 80 percent of land area constitutes the Arid and Semi-Arid Lands (ASALs) with low rainfall in the range of 200-700 millimeters thus susceptible to exposure (Republic of Netherlands, 2018). The adaptive capacity of smallholders could be low due to low levels of human and physical capital and high poverty levels which could dent their ability to deal with the consequences of climate change (Kabubo- Mariara and Kabara, 2015).

1.1.3. Adapting Smallholder Maize Production to Climate Change

Maize is the staple food for approximately 96 percent of Kenyans and is produced by about 75 percent of smallholders (Kang'ethe *et al.*, 2020; Njagi, Mathenge, Mukundi and Carter, 2017). Furthermore, it accounts for about 40 percent of crop area in Kenya (International Maize and Wheat Improvement Center, 2015). The contribution of smallholder maize production to food nutrition and security and households' income makes adaptation vital for sustained production and improved household livelihoods. The major goal of adaptation is to increase the capacity of maize production systems to minimize or overcome the impacts of climatic shocks (Nhemachena and Hassan, 2007). Adapting smallholder maize production to climate change requires robust crop husbandry practices in water management, weed management, soil fertility management, planting appropriate crop variety, accurate timing during planting as well as proper land tillage among other interventions (Kalungu, Filho, and Harris, 2013).

Water management involves optimal use of rainfall water, reducing water loss through surface runoff and evaporation, efficient use of water during irrigation, growing crops that utilize water efficiently, and use of farming technologies that encourage moisture retention (Muhamad *et al.*, 2021). Water management could be intensified through rainwater harvesting (Thakur, 2018). In addition, water for farming could also be obtained from boreholes, wells and water pans (Lake Victoria Basin Commission, 2011).

Soil fertility management requires that soil analysis is undertaken to determine the missing nutrients from the soil. In addition, it also requires that the right nutrients are

added to soil depending on the crop to be grown because different crops require different quantities of soil nutrients (Ketterings, Czymmek, Beegle and Lawrence, 2016). Soil fertility can be managed in several ways such as using organic or inorganic fertilizer, intercropping with legumes such as beans and pigeon peas to fix nitrogen biologically and crop rotation (Fung, Tai, Yong, Liu and Lam, 2019). Other than legumes, crops such as cassava improve soil properties by creation of biomass, enhancement of nitrogen and soil organic carbon which is beneficial to maize (Udom, Benwari and Osaro, 2015). They also have a low depletion of nitrogen and phosphorus and thus could be intercropped or rotated with maize (Howeler, 2017).

Weeds could be managed through growing weed tolerant varieties as in the case of striga; sowing seeds that are not contaminated with weeds; rotating cereals with trap crops that induce abortion in striga germination; application of organic and inorganic fertilizer to improve fertility and to suppress germination of striga; use of herbicides; intercropping cereals with legumes and pulling out the weeds (Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture, 2009).

Proper crop husbandry also requires appropriate timing of operations, selection of crop varieties that match available water and adjusting planting times to coincide with periods of adequate water (Mati, 2012). Some adaptation measures have multiple effects. Agroforestry enhances soil fertility, prevents soil erosion, provides shade for crops and provides off-farm incomes which can be ploughed back to maize production (Nyaga,

Muthuri, Barrios, Oborn and Sinclair, 2019). This implies that application of multiple adaptation simultaneously could be beneficial in maize production.

Farmers, particularly smallholders are encouraged to practice Climate Smart Agriculture (CSA) to reinforce adaptation efforts (FAO, 2013). This involves increasing agricultural productivity and incomes and combining adaptation to climate change with initiatives targeting reduction of levels of emission of GHGs from agriculture (mitigation) (Abegunde and Obi, 2022). To ensure the realization of sustainable agriculture and boost food security policy, technical and investment conditions must be deployed (United Nations Economic Commission for Africa, 2015). However, most smallholders are financially limited to adapt and invest in reduction of GHGs from agriculture simultaneously (United Nations Economic Commission for Africa, 2015).

Adaptation could be undertaken at farm level or macro level scales. Farm level adaptation involves decision making by smallholders to respond to the season-to-season climate variability (Hassan and Nhemachena, 2008). Such decisions could be driven by household characteristics, geographical location, level of resource endowment or technical support available (Mulungu and Ng'ombe, 2019). On the other hand, adaptation at macro level involves adaptation decisions at national, regional or international level (Hassan and Nhemachena, 2008). These decisions are driven by policies and the policy environment and take cognizance of current and future threats based on the long-term climatic projections and simulations (ROK, 2010b). Moreover, decisions at the macro level are multisectoral. For instance, the National Climate Change Response Strategy,

2010 outlines adaptation meant for agriculture and food security taking cognizance of the interlinkages with other sectors (ROK, 2010b). An interrelationship between micro and macro level adaptation exists. Micro level adaptations could be successful if supported by macro level adaptation while results of macro level adaptation can be realized when implemented mostly at the micro level.

Adaptation could be limited by level of resource endowment and information both at micro and macro levels. Thus, although smallholders may be aware of the climatic changes, resource and information limitations may affect the level or results of adaptation, a situation that may contribute to maladaptation. (Schipper, 2020; Antwi-Agyei, Dougill, Stringer and Codjoe, 2018). Assessment of adaptation could facilitate identification and practicing of appropriate adaptation choices that minimize vulnerability of smallholder maize production. Coherent policies and legislations on the management of climate change and adaptation informed by research and data analytics are important for strengthening smallholder maize production.

1.1.4. Policy Landscape on Climate Change and Adaptation in Kenya

Kenya has created an enabling environment to deal with climate change issues including adaptation through policy, strategies and other instruments nationally, regionally and globally. Kenya ratified the United Nations Paris Climate Change agreement in December 2016. The ratification entailed commitment under the Nationally Determined Contribution to reduce Greenhouse Gas emissions by 30 percent by 2030 relative to the business-as-usual scenario of 143 metric tonnes of carbon dioxide equivalent (ROK,

2018a). The actions prescribed would be implemented through various sectors such as agriculture and environment (ROK, 2018a). Kenya also ratified the following Multilateral Environment Agreements as a commitment to address climate change and its impacts: United Nations Convention on Biological Diversity on 27 July 1994; United Nations Convention on Combating Desertification on 24 June 1997; United Nations Framework Convention on Climate Change on 30 August 1994; and Stockholm Convention on Persistent Organic Pollutants on 24 September 2004 (Manek, 2001; ROK, 2002; ROK, 2007).

At regional level, Kenya signed up to the Maputo declaration of 2003 where African Heads of States committed to prioritize agriculture as the main driver of economic growth, reduce poverty, improve food and nutrition security by allocating 10 percent of the annual budgets to the agriculture sector (ROK, 2019). Similarly, Kenya committed to end hunger by 2025 by doubling productivity, reducing child malnutrition and reducing post-harvest losses under the Malabo declaration in 2014. These initiatives largely informed the review of existing policies and legislation and development of new ones (Sakho-Jimbira and Hathie, 2020).

At national level, Kenya's long-term blueprint Vision 2030 recognizes impacts of climate change as more likely to slow down the economic growth because Kenya is highly dependent on climate sensitive sectors such as agriculture yet existing coping mechanisms remain weak (ROK, 2012). The first three Medium-Term Plans (MTPs) of the Kenya Vision 2030 proposed a raft of strategies and actions towards climate resilient

development (ROK, 2013; ROK, 2018). Subsequent to the Kenya Vision 2030, the National Climate Change Response Strategy, 2010 was developed which articulated coherent and comprehensive multi sectoral measures and actions that would be implemented to address the challenges of climate change (ROK, 2010b). The strategy was a key facilitator towards integrating climate information into government policies and development plans (ROK, 2010b).

To facilitate effective implementation of National Climate Change Response Strategy (NCCRS), the first National Climate Change Action Plan (NCCAP) (2013-2018) was developed to ensure specific actions were identified and mainstreamed into government operations including planning and budgeting (ROK, 2013). The plan prescribed climate change mitigation and adaptation actions (ROK, 2013). The second NCCAP for 2018 to 2022 identified enhanced actions by building on the progress achieved during implementation of the NCCAP (2013-2018). Furthermore, the Climate Change Act of 2016 established policy, coordination and oversight structures on management of climate change affairs (ROK, 2016a). In addition, Kenya developed a draft National Policy on Climate Finance (2016) to enhance resource mobilization towards implementation of climate change related actions and strategies (ROK, 2016b). The sources of funding include but are not limited to Global Environment Facility, Green Climate Fund and Adaptation Fund (ROK, 2016b).

The Government of Kenya also launched the Green Economy Strategy and Implementation Plan for the period 2016 to 2030 in July 2017. The Plan guides pursuit of

low carbon growth path through implementation of the following five thematic areas: resource efficiency, sustainable management of natural resources, promotion of economic resilience, development of sustainable infrastructure and support for social inclusion and sustainable livelihoods by national agencies, counties, private sector and civil societies (ROK, 2016c). The County Governments are expected to develop policies and legislations aligned to the National Government policies and legislations. At the sectoral level, ministries, departments and state corporations are also expected to develop policies and legislations that support climate change mitigation and adaptation in agriculture and environment closely linked with sectors such as: forestry, energy, water, transport, infrastructure and health among others (ROK, 2018a).

Besides the policies addressing climate change and adaptation for all sectors including agriculture and environment, there are complementary policies, legislations, strategies and initiatives specific to the agriculture sector which address maize production among other issues. Some of the policies, legislations and strategies include: The Crops Act No.16 of 2013 which aims at promoting accelerated growth and development of the crop sub-sector by among other things promoting soil and water conservation and plant disease control (ROK, 2019). Agricultural Sector Transformation and Growth Strategy (2019-2029) aims at transforming the agriculture sector by promoting achievement of food security, improving farming income, lower cost of food, increasing employment and building resilience to effects of climate change (ROK, 2019). Furthermore, National Food and Nutrition Security Policy (2011) aims at addressing food insecurity and

malnutrition including addressing the challenges occasioned by climate change (ROK, 2019).

From the foregoing, there is robust policy and legislation in Kenya and commitment towards addressing the challenges posed by climate change. The implementation of the prescribed actions remains critical especially at the household level.

1.2 Statement of the Problem

In Kenya, maize is the main staple food for approximately 96 percent of Kenyans hence its adequate production is synonymous to food security. Maize production is exposed to climate change through unpredictable frequency, timing, duration, and distribution of rainfall especially during the growing season and increasing temperatures and increasing incidents of pests and diseases among other issues. Smallholders supply approximately 75 percent of maize produced in Kenya and therefore likely to bear the largest impacts especially those in semi-arid areas which are more sensitive to climate change than other areas. Climate change poses an additional resource burden to smallholders who already face resource constraints. Although elaborate policies towards tackling climate change are in place, it remains a great threat to maize production. Adoption of robust adaptation measures are necessary to enhance adaptive capacity and maize productivity because selection of wrong and inappropriate application of adaptation choices could exacerbate low maize yields and financial losses. Examining vulnerability of smallholder maize production to climate change; adaptation choices used and evaluating the level of

efficacy of adaptation are needed to inform any further improvements required to boost smallholder maize production.

The empirical studies conducted on vulnerability of agriculture to climate change established vulnerability index at regional, national and household levels (Gbetibouo *et al.*, 2010; Heltberg and Bonch-Osmolovkiy, 2010; Antwi-Agyei *et al.*, 2012; Opiyo *et al.*, 2014; Sisay, 2016; Epule *et al.*, 2017 and Masambaya, Oludhe, Lukorito, Onwoga, 2018). The studies found that regions and households are affected differently depending on their characteristics and socio-economic circumstances. Most of the studies utilized data on farmers in general hence do not demonstrate the disproportional vulnerability on smallholders. In addition, some of the studies (Tesso *et al.*, 2012 and Opiyo *et al.*, 2014) did not segregate exposure, sensitivity and adaptive capacity indices. Aggregation may weaken the importance of exposure, sensitivity and adaptive capacity to overall vulnerability. In addition, studies by Heltberg and Bonch-Osmolovkiy (2010) and Epule *et al.* (2017) applied equal weights for the indicators used in the generation of exposure, sensitivity and adaptive capacity yet the number of indicators were different across the sub-indices. The study by Masambaya *et al.* (2018) on vulnerability of maize production focusing on areas with a high potential for maize production in the Rift Valley of Kenya used sub-national data on maize farmers in general and also failed to assess the relationship between vulnerability and specific indicators affecting maize production and the magnitude of influence. Additional empirical study estimating vulnerability of smallholder maize production in Kenya disaggregating analysis on overall exposure, sensitivity and adaptive capacity was deemed necessary.

Studies on adapting agriculture to climate change (Hassan and Nhemachena (2008); Kabubo-Mariara (2008); Kebede and Adane (2011); Bryan *et al.* (2013); Mabe, Sienso and Donkoh (2014); Fadina and Barjolle (2018); Ndamani and Watanabe (2016); Ahmed (2016) and Shikuku *et al.* (2017)) have explored numerous adaptation choices such as change in crop variety, crop diversification, multiple cropping, mixed farming, changing planting dates among others. The choices were mainly influenced by household characteristics, access to credit, access to extension services, land area and capital endowment among other factors. The main focus for most studies was adaptation choices and the determinants of adaptation. However, there were no studies estimating efficacy of adaptation particularly in reference to smallholder maize production taking cognizance of simultaneous application of adaptation. This provided a basis for further evaluation of the efficacy of adaptation on smallholder maize production in Kenya. This study therefore sought to analyze vulnerability of smallholder maize production to climate change, evaluate the efficacy of adaptation choices to address the research gaps identified and add to existing knowledge.

1.3 Research Questions

- (i) To what extent is smallholder maize production vulnerable to climate change in Kitui and Laikipia counties in Kenya?
- (ii) What are the determinants of vulnerability of smallholder maize production to climate change in Kitui and Laikipia counties in Kenya?
- (iii) What are the levels of efficacy of adaptation of smallholder maize production to climate change in Kitui and Laikipia counties in Kenya?

- (iv) What are the determinants of the levels of efficacy of adaptation of smallholder maize production to climate change in Kitui and Laikipia counties in Kenya?

1.4 Research Objectives

The main objective of the study was to analyze vulnerability of smallholder maize production to climate change and adaptation choices in Kitui and Laikipia counties in Kenya. The specific objectives were:

- (i) To analyze the extent of vulnerability of smallholder maize production to climate change in Kitui and Laikipia counties in Kenya.
- (ii) To estimate the determinants of vulnerability of smallholder maize production to climate change in Kitui and Laikipia counties in Kenya.
- (iii) To evaluate the levels of efficacy of adaptation of smallholder maize production to climate change in Kitui and Laikipia counties in Kenya.
- (iv) To estimate the determinants of the levels of efficacy of adaptation of smallholder maize production to climate change in Kitui and Laikipia counties in Kenya.

1.5 Significance of the Study

Climate change is a global phenomenon which does not spare regions, countries and households and affects them disproportionately. Findings from this study are useful to policy makers at the national and county governments. The understanding on vulnerability of smallholder maize production and levels of efficacy of adaptation could inform policies and actions to promote viable adaptation interventions to improve maize production and food security in Kenya. Maize producers may also be enlightened on possible areas of modification of their agricultural practices including modes of

adaptation and prioritization on areas where support from the national and county governments is needed.

1.6 Scope of the Study

The study assessed the vulnerability of smallholder maize production to climate change and adaptation in Laikipia and Kitui County. Maize is staple food for most Kenyans hence focus on maize production. The selection of Laikipia County and Kitui County was to facilitate comparison of two predominantly semi-arid regions, one in the highlands and one in lowlands.

1.7 Organization of the Study

The study is organized as follows: Chapter one covers the background of the study, the statement of the problem, research questions, research objectives, significance and scope of the study. Chapter two presents theoretical and empirical literature review and overview of the literature. Chapter three presents the methodology used in the study which includes description of the research design; theoretical framework and empirical model for analyzing vulnerability of smallholder maize production and levels of efficacy of adaptation, definition of variables, study areas, target population and sampling procedure, data types, sources and collection, data collection procedure and piloting and data processing and analysis. Chapter four presents empirical findings while chapter five presents the summary of the findings, conclusions, policy implications and recommendation for further research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In this chapter, theoretical and empirical literature is reviewed. The chapter is divided into three sections. The first section (2.2) reviews theory of land rent, vulnerability theory, utility maximization theory and the random utility maximization theory. The second section (2.3) reviews empirical literature on vulnerability and adaptation of agriculture to climate change while the third section (2.4) provides the overview of literature.

2.2 Theoretical Literature Review

Vulnerability of smallholder maize production to climate change can be explained using the theory of land rent as it explains the association between quality of land and levels of agricultural productivity. On the other hand, utility maximization and random utility maximization theories can be used to explain consumer behavior. The utility maximization theory can explain the rationale behind allocation of income by a smallholder between adaptation and other goods and services. The random utility maximization theory is ideal in modelling adaptation since the process of selection of modes of adaptation is discrete.

2.2.1 The Theory of Land Rent

The theory of land rent explains the relationship between quality of land and its productivity (Lackman, 1977). The theory postulates that land rent is obtained when superior land is subjected to its most productive use relative to use of marginal land

through application of homogenous quantities of labour and capital (Taussig, 1917). Land rent therefore is earned due to limitations in quantity and differences in quality of land. Ricardo (1821) was the first to develop a coherent theory on land rent. Ricardo (1821) defined land rent as “that portion of the produce of the earth which is paid to the landlord for original and indestructible use of the soil” (Keirstead and Coore, 1946).

The main assumption of this theory is that differences in land fertility gave rise to land rent thus land was categorized into grades. The theory further assumes that land has original and indestructible powers regardless of its use. In addition, land productivity is subject to the law of diminishing marginal returns. The theory also assumes that labour and capital are the only factors of production and are homogenous (Herscovici, 2015).

The production function was conceptualized by Ricardo 1821 as:

$$Y = f\{T(L, K)\} \dots\dots\dots 2.1$$

Where Y is corn produced, T is the cultivated land of different levels of productivity, (L, K) is labour and capital as a composite factor (Herscovici, 2015). According to the theory, as demand for corn rises the first grade of land becomes insufficient in providing adequate food, this necessitates cultivation of the next grade of land. The produce from both grades of land are sold at the same price. However, since the first grade of land has more output, there is more surplus attributed to the first portion of land. This is what accrued to the land owners as land rent (Lackman, 1976). The theory further asserts that as more labour and capital are applied to the first portion of land its productivity rises up to a certain point then falls necessitating cultivation of the next portion of land (Jhingan, 2009).

The main limitation of the theory is the argument advanced by Ricardo (1821) and other classical economists on labour and capital as the only factors of production, which is impractical. Marshall (1883) recognized organization as an additional factor of production besides land, labour and capital (Xu, Chaudhry and Li, 2009). Organization is the factor responsible for employing factors of production and in the right proportions in the production process. Marshall (1883) further qualified land to include precipitation, air, light and heat (Xu *et al.*, 2009). Six factors of production namely: labour force which is the required labour resources; materials forces as the raw and processed resources; financial forces as the fixed and circulating capital; transport forces for mobility during production; natural forces which are the natural resources and conditions required for production and time forces which represents the amount of time needed in production were established (Xu, 1965). Becker (1978) went further and considered labour as human capital broken down to knowledge, skills and physical ability to increase productivity. Human capital was classified into four categories: education capital; technology and knowledge capital; health capital; and migration and movement capital (Xu *et al.*, 2009).

The assumption that land possesses original and indestructible power regardless of use is unrealistic. Fertility of land may not necessarily be original and indestructible. Marshall, 1890 noted that continued cultivation of land exhausts fertility necessitating restoration of fertility through human effort (Taussig, 1917). In addition, use of superior seeds and technology also enhance land productivity (Jhingan, 2009). Furthermore, the state of climate which provides the natural conditions to facilitate land productivity may impact on agriculture production adversely due to variability (Mendelsohn, Nordhaus and Shaw,

1994). Mendelsohn *et al.*, 1994 proposed inclusion of climate variables to enhance the theory of land rent (Mendelsohn *et al.*, 1994). The assumption that labour and capital are homogenous and composite factors of production is also unrealistic. These two factors of production can be applied in different proportions and substituted accordingly in production to enhance efficiency (Jhingan, 2009).

The theory of land rent therefore, provides a good foundation for the present study as it explains vulnerability from the perspective of reduced farm output. It is envisaged that as the fertility of land declines and as climate change intensifies, the level of vulnerability of smallholders producing maize will increase. Allocation of more resources to farming will either increase or minimize vulnerability depending on farmer resource endowment.

2.2.2 Vulnerability Theory

The theory of vulnerability arose from the recognition that disasters are as a result of natural calamities and interference with the environment by human beings to meet their needs (Winchester, 1992). The theory is attributed to the works of White (1961; 1964; 1974); Kates (1962); Burton and Kates (1964); Burton *et al.*, (1968); O'keefe and Wisner (1976) and others (Alwang, Siegel and Jorgensen, 2001). The theory aims at bringing out the link between natural disasters and human activities, the impact of disasters to humans and human response to disasters (Turner *et al.*, 2003).

The theory assumes that a system that has limited capacity to adapt to environmental challenges is vulnerable and that the impact of vulnerability differs with systems (Wisner, Blaikie, Cannon and Davis, 2004). This implies that the sensitivity levels

between two (2) systems or enterprises are not the same. It also assumes that different communities in different parts of the world, region or countries have differing vulnerability levels and that availability and equitable distribution of resources decreases vulnerability and vice versa (Adger and Kelly, 1999). The theory further assumes that demographic characteristics influence vulnerability because they affect economic, social and political circumstances of people (Wisner *et al.*, 2004). For instance, the elderly, children, persons living with disability and migrants among others are more prone to impacts of hazards more than the rest of the population. The theory of vulnerability can be depicted as shown in Figure 2.1:

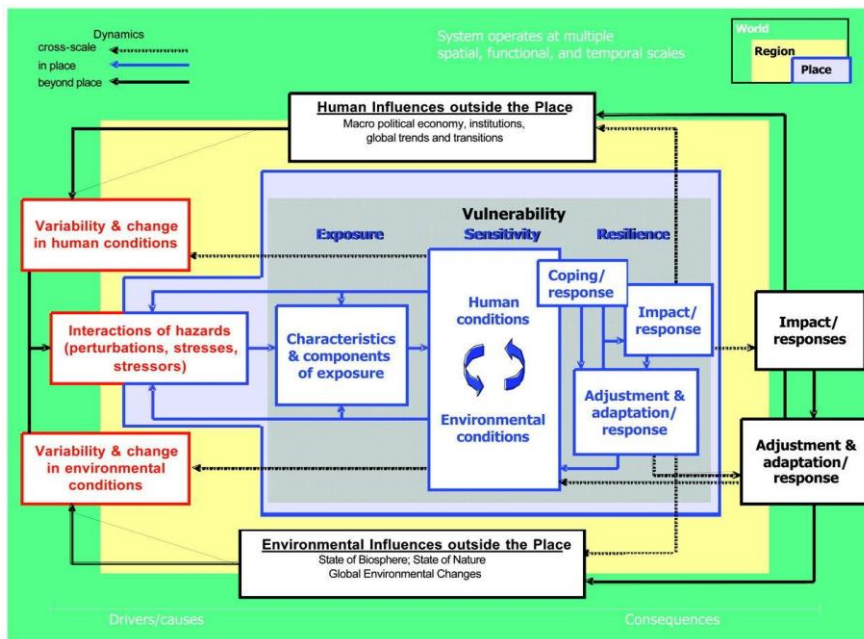


Figure 2.1: Vulnerability and its Components (adopted from Turner *et al.*, 2003)

From figure 2.1, a system such as ecosystem, sector, economy or enterprise within a region or place is subjected to environmental stress (risks, threats or hazards) which emanate from either within or outside it. The intensity of the effect of environmental

stress is determined by the characteristics of the region or place. The response by a system, that is sensitivity to exposure, depends on the prevailing human and environmental conditions. The conditions of the system further determine its ability to cope deliberately or autonomously with the impact of the environmental stress. Environmental characteristics that intensify stress or losses known as liabilities are the root cause of vulnerability (Zakour and Gillespie, 2013). The root causes may be economic, social, demographic or political processes which influence resource allocation and distribution to different groups (Twigg, 2001). They include limited access to natural environmental resources, low incomes, diseases, lack of social institutions, limited knowledge and information, poor infrastructure, poverty and minority status among others (Blaikie *et al.*, 1994).

On the other hand, capabilities within the environment enhance resilience by facilitating mitigation, response and recovery from environmental stress. Capabilities can be social, physical, environmental, political and economic resources (Twigg, 2001). Some examples of the resources include social institutions, education, access to water, proper infrastructure, access to credit, access to assets and access to technology among others (Zakour and Gillespie, 2013). The interaction between liabilities, capabilities and exposure to environmental stress is complex (Turner *et al.*, 2003). This is because the association may not be direct because either capabilities may reduce vulnerability in an additive way or may minimize vulnerability by cushioning a system.

The theory holds that less developed communities and regions are greatly affected due to their low capacity to respond, prevent or recover from disaster incidents (O'Keefe, Westgate and Wisner, 1976). The theory also recognizes that although different groups or individuals in the society may share similar exposure to a natural hazard, the consequences to these individuals and groups differ due to differences in their levels of sensitivity (Chambers, 1989). Generally, different decision contexts and scales require well defined indicators to examine differences in vulnerability levels for populations living in different locations. Some of the indicators which could be used in analyzing vulnerability include age, income, health status, poverty levels, literacy levels, dependence on certain forms of livelihood, access to information among others (Matyas and Pelling, 2012).

One of the bottlenecks encountered in assessment of vulnerability is data availability, especially future socio-economic data (Fekete, 2011). Socio-economic data on population may represent past and present status; the future levels may not be available to facilitate projection of levels of vulnerability such as data on education and income (Jurgilevich, Räsänen, Groundstroem and Juhola, 2017). Furthermore, the use of composite indices depends on the integrity of the data used to develop the indicators for constructing the index. An area may have a high level of vulnerability either due to high potential impact (exposure and sensitivity) or due to low adaptive capacity of households. An aggregate score may weaken the importance of the specific contributing factors. This may lead to development and implementation of inconsistent plans and policies in relation to the problem that needs to be addressed (Jurgilerich *et al.*, 2017). One of the proposed

solutions to improve data quality, availability and usability is involvement of stakeholders at the local level (Fekete, 2011).

Vulnerability theory in the context of climate change conceptualizes vulnerability as being determined by three dimensions: exposure, sensitivity and adaptive capacity. In this study, exposure is the predisposition of the smallholder maize production system to threats, risks or hazards emanating from within or outside Kitui and Laikipia County as a result of climate change. Sensitivity is the response of smallholder maize production to exposure as a result of changes in human and environmental conditions that could be either beneficial or harmful. On the other hand, adaptive capacity is the capabilities of the maize production system to respond, mitigate or recover from exposure or its impacts. This study assumed that systems, regions and communities are disproportionately vulnerable. Kitui and Laikipia counties were selected to establish these differences. To resolve aggregation challenges, the indices for the dimensions of vulnerability: exposure, sensitivity, adaptive capacity were derived prior to construction of the vulnerability index. In addition, variables were normalized to facilitate comparability and aggregation. Furthermore, most of the data was collected directly from smallholder maize producers to circumvent data quality and availability challenges.

2.2.3 The Utility Maximization Theory

The theory of utility maximization is critical in explaining how farmers allocate their limited income to adaptation and other goods and services they require. The theory was developed by Menger (1947), Gossen (1854), Jevon (1871), Walras (1874), Marshall

(1895), Pigou (1912), Hicks (1939) among others to explain how consumers satisfy their unlimited wants with the scarce resources at their disposal (Stigler, 1950). The central assumptions of the theory are that consumers are rational and aim to get value for money, face resource constraints due to limited income, have preferences for goods and services and have to choose from among many alternatives (Hicks and Allen, 1934). The problem of the consumer is therefore to maximize utility subject to a budget constraint as stated in equations (2.2) and (2.3):

$$\text{Max } U(X_1, X_2, \dots, X_n) \dots\dots\dots 2.2$$

$$\text{Subject to } M = P_1X_1 + P_2X_2 + \dots\dots\dots + P_nX_n \dots\dots\dots 2.3$$

Where X_i represents quantity of good i ($i = 1, 2, \dots, n$) that might be chosen by the individual, P_i is the price of good i ($i = 1, 2, \dots, n$) and M is the income of the consumer (Snyder and Nicholson, 2008). Maximum utility is attained when the ratio of marginal utility for any two goods is equal to the price ratio of the two goods. This can be expressed as in equation (2.4):

$$\frac{MU_i}{MU_j} = MRS_{ij} = \frac{P_i}{P_j} \dots\dots\dots 2.4$$

Where MU_i is the marginal utility of good i while MU_j is the marginal utility of good j . MRS_{ij} is the marginal rate of substitution between good i and good j ($i \neq j$). The first order condition of the maximization problem yields demand functions which are homogenous in prices and income expressed as in equation (2.5):

$$X_i^* = X_i(P_i, P_j, M) \dots\dots\dots 2.5$$

Where X_i^* is quantity of good i demanded by an individual to maximize satisfaction.

Although utility is an abstract representation of unobservable behavior of a consumer, it is applicable in modeling observable behavior. A farmer allocates resources between adaptation and consumption of other goods within a given resource set to maximize utility. Therefore, demand for an adaptation choice would be a function of the cost of implementing that adaptation choice, the cost of implementing alternative adaptation choice and the farmer's income.

The utility maximization theory is robust since it permits analysis of non-market commodities such as environmental aspects that may not be used directly by the individual (Leary, 1999). The main drawback of the standard utility theory is that it limits choice to only economic variables. This present study applied the theory in the context of smallholders having an array of adaptation options to choose from, the basis of selection is informed by the perception that maximum benefits will be derived and that the smallholders face resource constraints hence optimum use of resources must be exercised.

2.2.4 The Random Utility Maximization Theory

The theory was developed by Thurstone (1927) and aimed at modeling rational decision processes that motivate the choices made by consumers faced by choices that are discrete rather than continuous in nature. According to the theory, the choice process comprises four elements namely: decision maker (individual, household or organization), the alternatives, the attributes of the alternatives and the decision rule (Wittink, 2011). The choice process is such that the decision maker with given characteristics settles on

feasible alternative(s) from a choice set then evaluates the attributes of each alternative that satisfies their needs and uses a decision rule to choose the alternative with the highest utility (Cascetta, 2009).

The basic assumptions of this theory include: the alternatives are mutually exclusive within a choice set and the choice set differs between individuals; a decision maker assigns perceived utility to each alternative and the utility assigned to each alternative depends on the attributes of the alternatives and the characteristics of the decision maker (Ben-Akiva and Lerman, 1985). The utility of a decision maker i facing a set of available alternatives $C = (1,2,3,\dots,M)$ and choosing alternative j from the choice set can be decomposed into two components: deterministic component (V) which is observable and the stochastic component (ε) which represents the portion of utility that is not observable. This can be expressed as in (2.6):

$$U_{ij} = V_{ij} + \varepsilon_{ij} = X'_{ij}\beta + \varepsilon_{ij} \dots\dots\dots 2.6$$

Where U_{ij} is the utility derived by individual i ($i = 1,2,\dots, n$) who has chosen alternative j ($\forall j \in C$), X_{ij} is the vector of explanatory variables describing the individual i and alternative j , β is a vector of unknown parameters while ε_{ij} is the random disturbance term (Ben-Akiva and Walker, 2002). The error term captures the portion of utility that is unknown occasioned by information asymmetry, errors in measurement of variables, omission of attributes of alternative or characteristics of the decision maker that influence

their decisions, and errors in the specification of the utility function (Koppleman and Bhat, 2006).

The objective of the decision maker is to maximize utility subject to the attributes of the alternatives. The decision maker i chooses j if and only if $U_{ij} \geq U_{ik} \forall k \in C$ and $k \neq j$ (Ben-Akiva and Walker, 2002). The probability of the decision maker choosing j over k will be as in (2.7):

$$\pi_{ij} = P(V_{ij} + \varepsilon_{ij} > V_{ik} + \varepsilon_{ik}) = P(\varepsilon_{ik} - \varepsilon_{ij} < V_{ij} - V_{ik}) \dots\dots\dots 2.7$$

Where π_{ij} is the cumulative distribution function of a random variable $\varepsilon_{ik} - \varepsilon_{ij} = \varepsilon_{ijk}^*$. Different discrete choice models can be formulated based on assumptions about probability distribution (Vojáček and Pecáková, 2010). Where a standard normal distribution is assumed in finding probabilities then a probit model is specified and where a logistic distribution is assumed then a logit model is specified (Salvatore and Reagle, 2011).

The choice of the person can be represented by a dummy variable y_{ij} for each alternative and it assumes the value of 1 when a decision maker chooses a given alternative and 0 if they do not choose that alternative (Salvatore and Reagle, 2011). Estimation of the random utility model involves maximizing the likelihood of a decision maker taking a specific action of choosing or not choosing a given alternative. The estimation of choice of the decision maker is achieved through a likelihood function specified as:

$$P(j | X_i; \beta, \varepsilon_{ij}) = \prod_{j \in C} P(j | X_i; \beta, \varepsilon_{ij})^{y_{ij}} \dots \dots \dots 2.8$$

The main weakness of the theory is that with a large number of alternatives and explanatory variables, there would be several variants which if ignored may generate results that may lead to inconsistent policy implications (Baltas and Doyle, 2001). According to Parsons and Needelman (1992) aggregation of alternatives brings about aggregation bias that becomes large as the number of differing alternatives increases (Baltas and Doyle, 2001). Fader and Hardie (1996) proposed a solution pointing that aggregation be based on similarities of alternatives within a set to reduce variation within a choice set (Baltas and Doyle, 2001).

Random utility models are also prone to computational challenges arising from a large number of alternatives. One way to resolve this challenge is to cluster items with similar attributes and estimate a Nested Multinomial Logit (NMNL) model as suggested by Kannan and Wright (1991). However, since a large proportion of smallholders in this study applied multiple adaptation choices simultaneously, the NMNL was inappropriate for estimation. To overcome computational challenges and aggregation bias, the dependent variable for estimating levels of efficacy of adaptation was derived based on Multiple Criteria Evaluation (MCE) which provides for simultaneous analysis of multiple indicators for choice alternatives.

The random utility framework was found ideal in modelling levels of efficacy of adaptation since it supports assessment of effects of choice from a mix of varying alternatives with varying attributes (Baltas and Doyle, 2001). Smallholders selected

single or multiple adaptation choices and evaluated the choices based on prescribed criteria. The results of the evaluation culminate in the establishment of levels of efficacy analyzed based on an ordered probit model. The random utility maximization model also accommodates the differences among smallholders' choices of adaptation and levels of efficacy.

2.3 Empirical Literature on Vulnerability and Adaptation of Agriculture to Climate Change

This section provides empirical literature on vulnerability to climate change, determinants of vulnerability, adaptation choices and determinants of adapting crop production to climate change.

2.3.1 Studies on Vulnerability to Climate Change

Gbetibouo, Ringler and Hassan (2010) examined the vulnerability of farming in South Africa to climate change. The study followed the IPCC formulation of vulnerability and developed a vulnerability index for 9 provinces of South Africa from 19 indicators. The study found that the regions with many small-scale farmers who produced for subsistence using low technology and depending on rainfall were highly sensitive to climate change. The provinces that had a high combined effect of exposure and sensitivity had the largest potential impacts. The study further found that areas with better infrastructure networks, high literacy and income levels and low levels of unemployment had the highest adaptive capacity.

Gbetibouo, Ringler and Hassan (2010) concluded that in the most vulnerable provinces, modest climate changes would disrupt livelihoods of subsistence farmers while in least vulnerable areas where exposure was high, their high adaptive capacity would reduce the adverse impacts. The study recommended application of interventions fit for local conditions and integration of adaptation to development strategies. Gbetibouo, Ringler and Hassan (2010) derived the exposure, sensitivity and adaptive capacity indices and compared nine provinces prior to establishing the vulnerability index, hence demonstrating the multidimensionality of vulnerability. The main limitation of this study was that it was conducted at the sub-national level with a mix of both large scale and small-scale farmers which may present huge heterogeneity especially regarding household scale of farming activities, resource endowments and ecological consideration among other differences. The present study borrowed the segregation of exposure, sensitivity and adaptive capacity indices and analysis of vulnerability based on regions. However, unlike Gbetibouo, Ringler and Hassan (2010), the present study focused on semi-arid regions and smallholder maize producers and not the general population.

Heltberg and Bonch-Osmolovkiy (2010) analyzed Tajikistan's vulnerability to climate change and variability in both rural and urban areas. Ten (10) agroecological zones and one (1) urban area were identified for the analysis. To construct a composite vulnerability index, the study applied an unweighted average of normalized variables of the three sub-indices and computed a simple average to derive the composite index. All independent variables were normalized through linear transformation of the interval between 0 and 1.

The independent variable denoted as X was transformed as: $X' = (X - X_{min}) / (X_{max} - X_{min})$.

The composite vulnerability was therefore derived as:

$$vulnerability = \frac{1}{3} (Exposure + Sensitivity + (1 - adaptive\ capacity)) \dots\dots\dots 2.9$$

The results of the study indicated that exposure, sensitivity and adaptive capacity varied much more separately than the composite vulnerability. The highland region had the highest exposure but also the highest adaptive capacity and medium sensitivity. Lowland areas tended to be more vulnerable which was attributed to high population density, food insecurity, disaster sensitivity and heavy reliance on agriculture. Heltberg and Bonch-Osmolovkiy (2010) also found that lowland areas had a low adaptive capacity mainly due to low income and education levels.

Heltberg and Bonch-Osmolovkiy (2010) concluded that populous areas rather than remote areas were the most vulnerable and recommended channeling more climate change funding to rural areas to build resilience. Normalization of variables allowed comparability. However, the main weakness of the study was equal weighting of exposure, sensitivity and adaptive capacity components yet the variables under each component had differing numbers of variables. This may bias the importance of the components in the overall vulnerability index (Baptista, 2014). The current study borrowed the use of a composite vulnerability index and normalization of variables. As a departure from Heltberg and Bonch-Osmolovkiy (2010), factor analysis was applied to take cognizance of the varying weights for exposure, sensitivity and adaptive capacity. In

addition, the present study omitted urban areas as the focus was smallholder maize production.

Antwi-Agyei *et al.* (2012) conducted vulnerability analysis of crop production to drought at national and regional level for Ghana. The aim of the study was to evaluate the vulnerability of ten (10) regions in Ghana. The study conceptualized vulnerability as a function of the sum of exposure and sensitivity less adaptive capacity. To analyze a region's exposure to drought, mean rainfall data for 30 years covering 1971 to 2000 for the maize growing period of April to August was derived. Sensitivity was measured by crop yield sensitivity index while adaptive capacity was measured by literacy and poverty rates. The results indicated that vulnerability was mainly associated with high exposure and sensitivity to drought. Low and erratic rainfall led to low production since most crops such as maize required substantial amounts of rainfall during the growing season. Poor farming practises such as continuous cropping of land without proper fertilization also led to low production. This practise was attributed to poverty which was found to constrain the ability of households to adapt to impacts of climate change. The study concluded that low adaptive capacity due to high poverty levels and limited capital assets enhanced vulnerability.

Antwi-Agyei *et al.* (2012) recommended adoption of region-specific climate adaptation policies and strategies to address livelihood diversification. This study developed an empirical methodology that can be used to evaluate vulnerability for specific regions or systems. The main limitation of the study was use of data that had a mix of both large

scale and small-scale crop production, yet vulnerability affects the two disproportionately. In addition, although the adaptive capacity had two variables while exposure and sensitivity had one variable each, they were all accorded equal weights which may interfere with the overall importance of the components in the overall vulnerability (Fekete, 2011). The present study borrowed the conceptualization of vulnerability as exposure plus sensitivity minus adaptive capacity and focus on the maize growing period. Unlike Antwi-Agyei *et al.* (2012), the present study employed factor analysis to address the challenge of equal weighting.

Tesso *et al.* (2012) investigated the vulnerability and resilience of households in North Shewa in Ethiopia. A total of 452 households were randomly sampled based on the agroecological Zones (AEZs). The study used the Principal Component Analysis (PCA) to obtain vulnerability indices for each AEZ based on the socio-economic and biophysical indicators. All the indicators were assumed to contribute equally to vulnerability. The conceptual framework used in the study was that vulnerability was a function of adaptive capacity (AC) minus the sum of exposure and sensitivity. Tesso *et al.* (2012) further used an ordered probit model to analyze determinants of resilience to climate shocks. Resilience was classified into three based on how fast households resumed normal agricultural activities in the subsequent season. The speed of recovery to normal agricultural operations was determined by the number of agricultural seasons households took to recover normal agricultural operations in the absence of government intervention. The results indicated that highlands were the most vulnerable agroecology due to possession of small and fragmented land, and low productivity due to low soil

fertility, lower level of asset base and low level of experience to adapt. On the other hand, mid-land was found less vulnerable due to low prevalence of pests and diseases, potential to diversify crops, relatively gentle sloping of farmlands, moderate rainfall and low number of hazards.

Tesso *et al.* (2012) concluded that location of households greatly influenced the level of vulnerability. Apart from location, frequency of natural shocks, erosion in farmlands and low capability to adapt aggravated vulnerability of households. The study recommended improving access to markets and household education to build the resilience of households and community. The key strength in the study was the use of PCA which allowed for analysis of many variables with minimal risk of overfitting the model or correlation among the variables. However, the study generalized farmers yet there were differences in how vulnerability affects small scale farmers and large-scale farmers. The current study adopted factor analysis in establishing vulnerability which has great similarities with PCA. As a departure from Tesso *et al.* (2012), the present study focused on smallholder maize production in semi-arid areas.

A similar conceptualization of vulnerability analysis was applied by Opiyo *et al.* (2014) in a study on level of vulnerability of 302 purposively selected pastoralist households in the range land of Turkana in Kenya. The explanatory variables were grouped into economic, social and environmental variables associated with vulnerability. In assessing determinants of vulnerability of households the study used ordinal logit model unlike Tesso *et al.* (2012) who used ordered probit model. Vulnerability was classified in three

levels: Y=1 representing highly vulnerable, Y=2 representing moderately vulnerable while Y=3 representing less vulnerable. The findings showed that households headed by females and with no primary education and had no access to early warning information were highly vulnerable and vice versa. Most of the households who had less than 5 years' experience in the area, had no social linkages, no access to extension services, and had more than two coping strategies were moderately vulnerable.

The study concluded that household vulnerability was mostly influenced by sex and age of the head of the household, size of the household, the number of dependents, marital status, social linkages, access to extension services and early warning systems, herd size and diversity, access to markets, herd size, diversity and structure, employment status, coping strategies and access to credit. The study recommended enactment and implementation of policies mainly focusing on empowerment of women, education, extension services, income source diversification, employment creation and access to markets and early information sharing among others. Although the study demonstrated the association between vulnerability and socio-economic and environmental factors, it did not establish indices for the key components of vulnerability that is exposure, sensitivity and adaptive capacity. The aggregate score may weaken the importance of the specific components of vulnerability thereby undermining policy interventions (Fekete, 2011). The current study addressed the challenge of aggregation of vulnerability index by establishing exposure, sensitivity and adaptive capacity indices before computing the vulnerability index. The present study employed factor analysis which operates under similar principles as the Principal Component Analysis used by Opiyo *et al.* (2014). The

present study focused on smallholder maize production as a departure from Opiyo *et. al.* (2014) who focused on pastoralist.

Sisay (2016) analyzed vulnerability of farm households to climate change in Dabat and West Belesa Districts of North Gondar in Ethiopia using selected environmental and socio-economic indicators. Data was obtained from 790 farming households from five Districts who were selected using simple random sampling. The study analyzed Livelihood Vulnerability Index (LVI) using the LVI-IIPCC framework for each District. Derivation of LVI-IPCC index involved classification of vulnerability Contributing Factors (CF) into exposure, sensitivity and adaptive capacity. The results indicated that West Belesa was more vulnerable to climate change impacts than Dabat District.

Sisay (2016) concluded that social, economic and natural factors had a high influence on vulnerability of farming households in the rural areas and varied with location. Households exposed to the same levels of adverse climate change impacts had different levels of vulnerability depending on their adaptive capacity. The study recommended the following interventions: improved access to markets, road, weather information, early warning systems and education. The study used robust variables to measure exposure. However, data used obtained from farmers in general yet small scale and large-scale farming households were affected by vulnerability disproportionately. The present study focused on smallholder maize production unlike Sisay (2016) but borrowed the IPCC conceptualization of vulnerability.

Epule *et al.* (2017) developed a vulnerability index for Uganda that integrated agroecological, climatic and socioeconomic variables in evaluating national and spatial pattern of vulnerability of maize yields to drought using a similar approach adopted by Antwi-Agyei *et al.* (2012). Ten (10) districts were considered in the study. Vulnerability was considered as a function of sensitivity of maize to drought, exposure of maize to drought and adaptive capacity of maize to absorb shock relating to decline in precipitation and ability of farmers to adapt to changes. Sub-index was developed for each of the components of vulnerability which were then combined to obtain a vulnerability index like Antwi-Agyei *et al.* (2012). The study established that 91 percent of the variations in the vulnerability were explained by the level of sensitivity of maize while 92 percent were explained by exposure. The higher the exposure levels the higher the vulnerability level. The study also established that 88 percent of the changes in vulnerability were explained by changes in adaptive capacity.

Epule *et al.* (2017) concluded that sensitivity and exposure to drought increased with rise in latitude while adaptive capacity was lower at lower latitudes and that both biophysical and socioeconomic factors were key in determining the vulnerability of maize yields to drought. The study recommended agroforestry, irrigation, use of agroecology based organic nutrients inputs, research and training and innovation and information diffusion as measures to enhance resilience of maize production. The study focused on maize production and used rainfall data for the growing season to measure exposure. However, the main drawback of the study was that it used data that had a mix of both large scale and small-scale crop production yet vulnerability affects the two disproportionately. In

addition, although the adaptive capacity had two variables while exposure and sensitivity had one variable each, they were all according equal weights which may interfere with the overall importance of the components in the overall vulnerability (Fekete, 2011). The present study applied factor analysis to address the challenge of weighting variables. In addition, the present study focused on smallholder maize production in two semi-arid areas.

Masambaya *et al.* (2018) investigated the vulnerability of maize production to climate change in major maize producing counties (Trans Nzoia, Nakuru, Narok and Uasin Gishu) of the Rift Valley region of Kenya. The study was based on secondary data on biophysical and socio-economic indicators. The study employed Principal Component Analysis (PCA). Vulnerability was conceptualized as a function of exposure, sensitivity and adaptive capacity. The vulnerability index was established by summing up exposure and sensitivity index less adaptive capacity index then divided by three. Vulnerability index was classified into five categories on a scale of 0 to 5: very low vulnerability, low vulnerability, moderate vulnerability, high vulnerability and very high vulnerability. Results of the study indicated that Trans Nzoia which was least exposed, most sensitive and with the highest adaptive capacity was the least vulnerable county while Narok with the highest exposure, least sensitivity and least adaptive capacity was the most vulnerable.

Masambaya *et al.* (2018) concluded that maize production in Narok County was more susceptible to adverse impacts of climate change as compared to Trans Nzoia County.

The study recommended adoption of irrigation and reduction of dependency on rainfed farming to minimize adverse impacts of climate change on maize production. The main strength of the study was the use of PCA which facilitated weighting of indicators thus minimizing bias in the importance of the components unlike Heltberg and Bonch-Osmolovkiy (2010). However, the main limitation of the study like earlier analyzed studies was that it combined both small scale and large-scale maize farmers. The present study adopted factor analysis which is similar to PCA and focused on smallholder maize production.

2.3.2 Studies on Adapting Crop Production to Climate Change

Hassan and Nhemachena (2008) investigated the determinants of farm level adaptation strategies to climate change, farmers' perception about climate change and actual adaptation strategies used by farmers in Africa. The study used cross-sectional data by surveying over 8000 farmers in 11 African countries. In the study, adaptation strategies were grouped into three (3) categories: multiple crops and mixed farming; switching from crops to livestock; and switching from dry land to irrigation. The dependent variable was a random variable for choice of adaptation from a set of options where mono cropping was selected as the base category to represent no adaptation and other adaptation measures were analyzed as alternatives. Data was analyzed using the Multinomial Logit (MNL). The findings of the study indicated that different adaptation alternatives were driven by seasonal climate changes. The findings of the study suggested that irrigation, multiple cropping and mixed farming were the most popular adaptation strategies practised by farmers. The main factors that influenced the choice of adaptation

were: better access to credit, access to extension services, farmer's experience, family size, capital resources and land area.

Hassan and Nhemachena (2008) concluded that choice of adaptation strategies was driven more by temperature changes than precipitation changes. Irrigation, multiple cropping and mixed farming were the most preferred choices of adaptation while mono cropping was the least preferred. The study recommended government interventions and policies in supporting improved access to climate information, access to credit, access to extension services and market development. The key strength of the study was inclusion of climate variables which made it possible to show the probability of selecting adaptation alternatives as temperature and rainfall changed. The main limitation of the study was that it grouped adaptation measures. Grouping adaptation alternatives may make it difficult to determine which ones were more efficacious. Furthermore, MNL applied in the study suffers from the assumption of the independence of irrelevant alternatives. The present study borrowed selection of irrigation and mixed farming adaptation choices. As a departure from Hassan and Nhemachena (2008), adaptation choices were combined based on Multiple Criteria Evaluation after which the ordered probit model was analyzed.

Kabubo-Mariara (2008) examined the impact of climate change on crop selection in Kenya using probit regression model. Data was collected from 724 households across 38 Districts. Each District was divided into AEZ. Large, small and medium farm sizes were sampled from each AEZ. The dependent variable was crop choice. Crops were divided

into three categories as major food crops, minor food crops and cash crops. Maize was analyzed as a major food crop. Results suggested that maize crop was the most popular crop adopted by 93 percent of households and was responsive to both temperature and precipitation. The findings also indicated no differences in choice of maize crop between agroecological zones. In addition, crop choice had a hill-shaped relationship with climate variables. The main conclusion of this study was that selection of crops to farm depended on climate change and that farmers in Kenya practised crop selection as an adaptation measure. The study recommended enhanced supply of knowledge to farmers through agriculture extension services and enhanced access to credit by farmers. The key strength of the study was that the disaggregation of farms into three categories could facilitate comparison of adaptation choices applied across different farm sizes. The main limitation of the study was that the influence of independent variables on additional adaptation choices was not estimated. The present study borrowed analysis of maize since it was the most popular food crop in Kenya. Unlike Kabubo-Mariara (2008), the present study focused on smallholder maize production and assessed the efficacy of adaptation choices.

Kebede and Adane (2011) carried out a study to assess and analyze farmers' perceptions and adaptations to climate change in the Lake Tana Basin and agro pastoralist areas of Oromiya and Amhara regional states in Ethiopia. Three (3) Districts were sampled: Medda Wolabu, Lay Armachiho, and Dembia out of which four (4) Kebeles were selected purposively cognizant of the agroecology. A sample of 594 households was randomly selected from the Kebeles. The study employed a logistic regression model where the dependent variable was adaptation strategies identified as: change in crop

variety, change in planting date, crop diversification, use of irrigation, building water harvesting schemes, tree planting, engaging in off-farm activities and temporal migration. The study found that changing planting dates was one of the most popular adaptation alternatives. Access to climate information, location of the area, sex, age of the head of the household, experience and climate change understanding were statistically significant implying they influenced the choice of adaptation.

The study concluded that agricultural production had declined and therefore households had been adjusting their farming practices to reverse this trend. The study recommended enhancement of education and information access; building capacity for adaptation; enhancement of research and networking; and strengthening of institutions responsible for coordination of climate change adaptation programmes. The classification of determinants of adaptation choices into household characteristics and institutional factors and agroecology made it possible to determine broad factors that influenced adaptation choices for policy prioritization. The main limitation of this study was that although it analyzed specific adaptation choices practised by households, the methodology used in estimation did not allow for analysis simultaneous application of multiple adaptation choices Mabe *et al.* (2014). The present study borrowed use of irrigation and change in planting dates adaptation choices. However, the main focus of the present study was smallholder maize production as opposed to agro pastoralists. In addition, current study estimated multiple adaptation choices applied simultaneously by employing Multiple Criteria Evaluation.

Bryan *et al.* (2013) analyzed adaptation measures and factors influencing farmers' decision to adapt in Garissa, Mbeere, Njoro, Mukurwe-ini, Othaya, Gem, and Siaya Districts in Kenya. Cross sectional data based on: AEZs, production systems, agriculture management practises, policy and institutional environment, nature and extent of exposure and vulnerability to climate change were analyzed. A total of 710 households were sampled. The study used the logit model to analyze factors that influenced adaptation choices. The findings indicated that households were using multiple adaptation choices at the same time. The adaptation choices identified were: planting trees (9 percent), change of planting dates (20 percent), change of crop type (33 percent), soil water conservation (5 percent), while 19 percent of farmers did not adapt. The study established that adaptation was greatly influenced by food aid and weather forecast while membership to associations negatively influenced adaptation. The study concluded that although the majority of farmers had perceived changes in rainfall and temperature, they faced numerous challenges that inhibited their ability to adapt. The study recommended investing in rural agricultural support and adoption of technologies to enhance long-term resilience to climate change among rural households. A key strength of the study was analysis of diverse districts across Kenya and adaptation choices. The present study adopts agroforestry and changing planting dates. One of the limitations of the study was that results could not be analyzed using MNL since most farmers applied multiple adaptation strategies simultaneously and the response categories were too great to be grouped appropriately. The current study addressed the challenge of estimating multiple adaptation choices by applying MCE.

Similarly, Mabe *et al.* (2014) used a binary logit model. The study investigated determinants of choice of climate change adaptation strategies in Northern Ghana from a sample of 155 farmers selected using purposive sampling from three northern regions in Ghana. Data was analyzed using the binary logit model where the dependent variable was a random term representing the adaptation options while independent variables comprised socioeconomic factors, farm characteristics among others. The study found that adaptations practised were: changing planting dates, changing crop varieties, destocking, fallowing, fertilization, mulching, increasing farm size, planting trees and adaptation of a combination of at least five options. The results revealed that farming experience, farm income, access to phones, mixed farming, perception on reduction in rainfall amount and access to weather information were considerable determinants of the decision of farmers to use at least five adaptation strategies. Farmers with more farming experience, large farm size, access to phone, access to weather information, practised mixed farming and those who perceived a decrease in rainfall amount had a higher probability of using at least five climate change adaptation strategies. The study circumvented the challenge of analysis of multiple adaptation choices by analyzing the number of adaptations used. However, the study combined crop and livestock sub-sectors yet the two sub-sectors had distinct adaptation choices that were not comparable. The present study included changing planting dates and mulching as adaptation choices.

Shongwe (2014) analyzed the factors influencing the choice of adaptation strategies by households in Mpolonjeni, Swaziland. A sample of 350 households were drawn using stratified random sampling. The multinomial logistic model was used to analyze the

determinants of adaptation strategies. The dependent variable was the adaptation strategies grouped into: no adaptation; drought tolerant varieties, shifting planting dates and conservation agriculture; conservation agriculture and shifting planting dates; irrigation and any other adaptation strategies; and all strategies. Results indicated that 90.4 percent of land cultivated was for maize production and the rest was used for cultivation of other crops. In addition, the majority of the farmers were using traditional seeds rather than the recommended drought tolerant seeds. The most popular adaptation choices were use of drought tolerant varieties, early and late planting, minimum tillage, crop rotation, intercropping, irrigation and mulching. Results further indicated that the choice of not adapting was influenced by ownership of land and age of the head of the household.

The study concluded that although farmers were aware that climate was changing not all of them were adapting. The choice of adaptation was mainly influenced by age of the head of the household, occupation, membership to a social group, land category, access to credit, access to extension services, training, high incidences of crop pests and diseases, high input prices, high food prices and perception of households on climate change. The study recommended strengthening of extension and financial services to farmers and the meteorological department to improve early warning. The main weakness of the study was that it combined some adaptation strategies which were not specified making it difficult to identify determinants. It was also not clear whether the adaptation choices were suitable for all crops or the dominant crop. Nonetheless, the study captured numerous adaptation options. As such, the current study included the

following adaptation choices: early and late planting, minimum tillage, irrigation and mulching adaptation choices applied by Shonge (2014).

Thi and Chavanapoonphol (2014) evaluated levels of adaptation for highland robusta coffee production in Daklak province in Vietnam. A sample of 176 farmers was selected using simple random sampling. The study adopted the Multiple Criteria Evaluation (MCE) to evaluate adaptation strategies. The following aspects were assessed: effectiveness, economic efficiency, flexibility, farmer implementability and independent benefits. The adaptation options considered in the study were: crop diversification, irrigation techniques, soil conservation; crop diversification and irrigation technique; crop diversification and soil conservation; soil conservation and irrigation; and a combination of the three techniques. The five criteria were normalized and weights were also assigned to each criterion used to find weighted scale for each adaptation in proportion to each of the criterion. The weighted scale for each adaptation was used to obtain a single measure for each adaptation choice. The adaptation options were then ranked as high, medium and low categories. The study analyzed an ordered logit model to determine the factors impacting on the choice of adaptation. The dependent variable was the three adaptation categories: high, medium and low. Results indicated that economic efficiency and effectiveness were assigned the highest weight by farmers. Majority of the farmers adopted one adaptation choice while the minority adopted all the options. Farmers were in favour of adaptation choices such as irrigation though sprinkling, crop diversification or soil conservation.

Thi and Chavanapoonphol (2014) found that adaptation was influenced by education of the head of the household, access to extension services, credit and information on climate. The study concluded that farmers were reactive rather than proactive in adapting to climate change. The study recommended the need for strategies to help rural households respond effectively to climate change. One of the strengths of the study was analysis of multiple adaptation choices without creating aggregation bias by employing MCE. The present study adopted MCE from this study. However, the main focus of the present study was smallholder maize production and obtained and not all farmers in general unlike Thi and Chavanapoonphol (2014) who analyzed coffee farmers. In addition, criteria weights were obtained from experts as opposed to farmers in the present study.

Uy, Linnirankul and Chaovanapoonphol (2015) assessed factors that impacted on adaptation to drought in maize production in the highland district in Central Vietnam. The study involved random selection of 180 farmers. Factor analysis and Multinomial Logit regression was used to undertake analysis. The factor analysis was used to identify factor scores which were used as the explanatory variables. The maize adaptation choices were analyzed using a multinomial logit model where the dependent variable was the adaptation measure chosen by the farmer. The following adaptation choices were identified: no adaptation, adaptation by improving adaptation techniques, adaptation by reducing the amount of cultivated land and combination of improving adaptation techniques. The key finding of the study was that the probability of selecting no adaptation decreased by a unit change in households' capital, maize production scale and

gender and non-farm income holding other factor scores constant. In addition, the probability of adapting by reducing cultivated area was reduced by one-unit change in maize production scale. The probability of combining the adaptation measures improving cultivation techniques and reducing cultivated area was increased by one-unit change in households' capitals, experience, maize production scale and gender and non-farm income.

Uy, Limnirankul and Chaovanapoonphol (2015) concluded that households who had better personal and socio-economic characteristics were likely to adapt maize production to climate change. The study recommended evaluation of the effectiveness of the current adaptation models. The study further recommended that farmers below poverty line, ethnic minority and female households to undergo practical training in their own farms. The key strength of the study was use of factor analysis which facilitated extraction of factors that were uncorrelated and used as independent variables. The study included reduction of cultivated land as an adaptation choice also adopted in the present study. The main weakness of the study was that it identified changing to another crop as an adaptation choice yet doing this would not increase maize production which was the focus of the study. The present study categorized the dependent variable and modelled an ordered probit model unlike Uy, Limnirankul and Chaovanapoonphol (2015) who analyzed MNL which is affected by independence of irrelevant alternatives.

Ndamani and Watanabi (2016) analyzed the determinants of farmers' adaptation to climate change in Ghana. Data was collected from 100 households and analyzed using

logistic regression. The dependent variable was whether households adapted or not where households who adapted at least one choice were given a value of 1 and zero given to those who did not. The adaptation choices identified were: use of improved crop varieties, crop diversification, farm diversification, change in planting date, income generating activities, irrigation and agroforestry. The most popular adaptation choice was diversification of crops. Results of the study showed that adaptation was boosted by education, increased access to information, large household size, increased access to credit facilities and household income while farming experience and large farm size diminished the probability of adapting. The study recommended that factors determining choice of adaptation be mainstreamed in policies, projects and programmes. The study further recommended increased access to climate information and water to facilitate irrigation. The key strength of the study was identification of diverse adaptation choices. The main weakness of the study was that it was not specific on which sub-sector was being adapted to climate change. The study did not assess simultaneous application of multiple adaptation choices. As a departure from Ndamani and Watanabi (2016), the present study analyzed multiple adaptation choices applied simultaneously. The present study included the following adaptation choices used in this study: irrigation, changing planting dates and agroforestry.

Ahmed (2016) analyzed the most used adaptation strategies that farm households applied and determinants of these choices for maize production in Central Rift Valley of Ethiopia. A total of 135 households were sampled and data analyzed using the Multivariate Probit Model (MVP). The dependent variable was the choice of adaptation

strategies that included: use of improved crop varieties, adjusting planting date, crop diversification and soil conservation practices. The key finding was that adjusting planting date was one of the most popular adaptation choices and was positively influenced by education, access to credit, farming experience and frequent extension visits while it was influenced negatively by distance from the market center. The study concluded that age, level of education, family size, experience in maize production, nonfarm income, social responsibility, frequency of extension services, credit, distance from farm to the market greatly influenced the choice of adaptation strategies. The study recommended the need for appropriate policy interventions to reduce impact of climate change thus promoting farm productivity and poverty reduction. Although the study showed the determinants of all the adaptation choices applied, it did not analyze simultaneous application of multiple adaptation strategies. Nevertheless, the study adopted a robust model which allowed for simultaneous identification of determinants of adaptation and as such forestalled problems of correlation between error terms. The present study included size of cultivated land and adjusting planting date as adaptation choices and distance to the market and access to extension as independent variables as included by Ahmed (2016).

Shikuku *et al.*, (2017) examined smallholder farmers' attitudes and determinants of adaptation to climate risks in East Africa. A sample of 500 farmers was drawn randomly from Borana, Ethiopia; Nyando, Kenya; Hoima, Uganda and Lushoto in Tanzania perceived to be predisposed to weather shocks, poverty and depend on rainfed agriculture. The adaptation choices considered in the study were: changes in crops and

varieties of crops, changing planting dates, planting trees, irrigation and conservation. The dependent variable was livelihood-based adaptation index constructed through livelihood regression where weights were assigned to adaptation strategies based on their marginal contribution to a household's livelihood. Ordinary Least squares was used to regress the livelihood index against several explanatory variables. The study also analyzed each adaptation strategy against explanatory variables to determine what influenced choice of adaptation. Probit regression model was specified to estimate the individual adaptation strategies that ranked highest from the Rasch analysis. The study identified variables that increased or decreased adaptation index.

The study concluded that adaptation was determined by: sex of the head of the household, household size, membership to crop production group, number of months of food shortage, household's perception about delayed rainfall, observation of higher incidences of pests and diseases. Farming experience, livestock ownership and extension services had an adverse influence on the decision to adapt. The study recommended increased investment in human, social and physical capital to enhance use of soil, water and land management practices. The main strength of the study was the use of Rasch analysis which facilitated identification of differentiated preferences or attitudes across groups. However, the Probit regression model applied did not allow analysis of simultaneous application of multiple adaptation choices. The present study included the following adaptation alternatives used in this study: changing planting dates, planting trees and irrigation. The present study applied MCE as opposed to Rasch analysis.

Fadina and Barjolle (2018) examined farmers' adaptation strategies to climate change and their implications in the Zou Department of South Benin. A total of 120 respondents were sampled. Two models were used for analysis; a binomial logit model was used to analyze the status of adaptation where the dependent variable was a choice between adapting and not adapting. In addition, a multinomial logit model was used to analyze determinants of choice of adaptation where the dependent variable was the adaptation choice selected by a farmer. The options were: no adaptation; crop-livestock diversification (mixed cropping, crop rotation, mulching, organic fertilizer); use of improved varieties, chemical fertilizers and pesticides; agroforestry and perennial plantation; diversification of income generating activities and multiple coping strategies. Results of the study indicated that although 90.8 percent of farmers had observed changes in climate, only 85 percent of them acted. Most of the farmers preferred crop-livestock diversification, use of improved varieties and agroforestry and perennial plantation while 14.2 percent did not adapt at all. The study further established that education level influenced the choice of all adaptation strategies significantly. Farming experience also influenced choice of adaptation strategies except diversification of income generating activities.

The study concluded that agroforestry was one of the most preferred adaptation strategies while factors influencing the choice of adaptation were: educational level, gender, farming experience and farm size. The study recommended adoption of climate sensitive agricultural policies. The study analyzed farmers' perception on climate change and included diverse adaptation choices. The present study borrows use of organic fertilizer,

chemical fertilizer, mixed cropping and mulching. However, the main drawback of the study was that it grouped adaptation strategies which have different outcomes under crop-livestock diversification. In addition, one of the adaptation choices “diversification of income generating activities” may not directly increase farm output. In the present study, adaptation choices were not grouped but combined based on MCE.

2.4 Overview of Literature

The theory of rent has shown that low output due to cultivation of marginal lands could be worsened by climate change thereby increasing the vulnerability of smallholder maize production. The theory also showed that inclusion of climate variables in vulnerability analysis is critical. Vulnerability may differ with systems and the characteristics of systems could either be the root cause or could intensify vulnerability as shown by the vulnerability theory. However, the theory also shows that social, physical, economic, political and environmental resources could facilitate mitigation, response and recovery. The theory also demonstrates an inverse relationship between vulnerability and adaptive capacity and a positive relationship between exposure and sensitivity with vulnerability. The theory provides a basis for measurement of vulnerability in different systems, regions and communities. The utility maximization and random utility maximization theories have shown that decision makers maximize their utility by making a choice from an array of options subject to resource constraints or attributes of alternative choices. The theories provided a basis for analyzing levels and determinants of efficacy of adaptation.

Empirical studies on vulnerability have shown that farmers are disproportionately vulnerable to climate change and that higher level of exposure and sensitivity relative to adaptive capacity increases vulnerability and vice versa. Findings of previous studies show that physical, financial, human and natural capital influence vulnerability and should be factored in models analyzing vulnerability and that age, sex, household size, number of dependents, marital status, social linkages and access to extension were among the determinants of vulnerability. However, data used in the previous studies generalized maize producers. Furthermore, some of the studies applied equal weighting which may interfere with the importance of the components in the overall vulnerability since they had differing numbers of indicators. Most of the analysis were based on specific indicators and components prior to aggregation to a composite index.

Empirical literature on adaptation shows that although most farmers were aware that climate was changing, not all farmers were adapting. Those who adapted to enhance crop production had an array of adaptation alternatives to select and that some of them applied multiple adaptation alternatives simultaneously. Generally, the studies focused on adaptation and determinants of adaptation. Some adaptation choices identified from the literature and were relevant for the present study include: use of fertilizer, changing planting dates, mixed cropping, agroforestry, soil conservation, irrigation, conservation agriculture and mulching.

Nearly all the studies did not analyze multiple adaptation choices applied simultaneously without grouping. In addition, there were no studies evaluating the efficacy of adaptation

particularly in reference to smallholder maize production taking cognizance of simultaneous application. This implies that policies are established only based on adaptation practiced by smallholders. Evaluation of efficacy is important to provide insights on adaptation choices promoting smallholder maize production to enhance existing policies or prescribe new policies. It is envisioned that evaluation of the efficacy of adaptation could facilitate insights on why maize production was insufficient despite adaptation by most farmers. The focus of the present study on adaptation was therefore to establish the levels of efficacy and estimate the determinants of the levels of efficacy of adaptation of smallholder maize production to climate change.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter presents the theoretical framework and the models estimated to address the research questions of the current study. The chapter also includes description of the research design, theoretical model, empirical model specification, variables used in the study and how they were measured, sampling procedure and sample size, data collection types and sources, data collection instruments and piloting, data collection procedure, processing and analysis.

3.2 Research Design

A non-experimental research design based on a cross-sectional study specifically was adopted. It focusses on finding association between variables without manipulations (Reio, 2016). Inferences are drawn based on heterogeneity among a variety of people or phenomena (Olsen and Marie, 2004). Data on smallholder experience and adaptation cover many seasons and years therefore, non-experimental research design was preferred since data required for the study was on smallholders past experiences and the results of the study would facilitate generalization of results with populations with similar characteristics. This research design was deemed appropriate as it allowed estimation of prevalence of vulnerability and adaptation, and estimation of the relationship among variables at a point in time and undertaking analysis on multiple geographical locations concurrently (Reio, 2016).

3.3 Theoretical Framework

The current study was informed by the concept of vulnerability and the random utility maximization theory.

3.3.1 Theoretical Framework for Analyzing Extent of Vulnerability of Smallholder Maize Production to Climate Change

The vulnerability of smallholder maize production to climate change was premised on the concept of vulnerability (IPCC, 2001). According to IPCC (2001), vulnerability has an external dimension represented by exposure and an internal dimension represented by sensitivity and adaptive capacity (Füssel and Klein, 2006). The external dimension is influenced by biophysical factors while the internal dimension is influenced by socioeconomic factors. As such, vulnerability is determined through an integrated assessment approach that combines both biophysical and socioeconomic factors (Žurovec *et al.*, 2017). The integrated assessment of vulnerability offers comprehensive evaluation of interactions of diverse factors and demonstrates interlinkages across regions and sectors of the economy (IPCC, 2001).

It is premised that human activities are responsible for altering climate which subsequently lead to exposure of natural and human systems to climatic stimuli that affects these systems adversely (IPCC, 2001). The adverse effects depend on the sensitivity of these systems to exposure. As a result, natural response by such systems may trigger autonomous adaptations. Besides the natural response by such systems, deliberate adaptations to counteract perceived or expected future adverse impacts form

part of the responses (IPCC, 2001). The deliberate responses could be implemented by individuals or relevant institutions depending on their adaptive capacity.

There is unequivocal evidence that maize production is one of the systems adversely affected by climate change (IPCC, 2007). Vulnerability of smallholders may be apparent considering that they form a large proportion of maize producers (International Maize and Wheat Improvement Center, 2015). A framework to assess the vulnerability of smallholder maize production is therefore expected to reflect the three dimensions of vulnerability.

Turner *et al.*, 2003, developed a conceptual framework in line with the IPCC concept focusing on coupled human-environment systems where vulnerability is a function of exposure, sensitivity and resilience. According to this framework, the components of exposure are individual(s), firms, regions and ecosystems and is characterized by frequency, magnitude and duration of environmental threats, risks or hazards; sensitivity is influenced by human and environmental conditions while resilience is determined by the response of the system or impact of the hazard on the system (Turner *et al.*, 2003; Miller and Bowen, 2013). This framework recognizes the multifaceted nature of vulnerability and therefore considers the whole system. However, focus on resilience of the system presupposes that the system has adaptive capacity.

The present study therefore conceptualized vulnerability of smallholder maize production to climate change as a function of exposure, sensitivity and adaptive capacity expressed as in equation (3.1):

$$Vulnerability = f(Exposure, Sensitivity, Adaptive\ capacity) \dots \dots \dots 3.1$$

The approach was found appropriate as it allows for analysis at a local scale thus capturing the biophysical and socioeconomic context of smallholders at county level. The framework accommodates dynamics and diversity of communities (Ludena and Yoon, 2015). The County Vulnerability Assessment Framework (CVAF) used in the present study is shown in Figure 3.1:

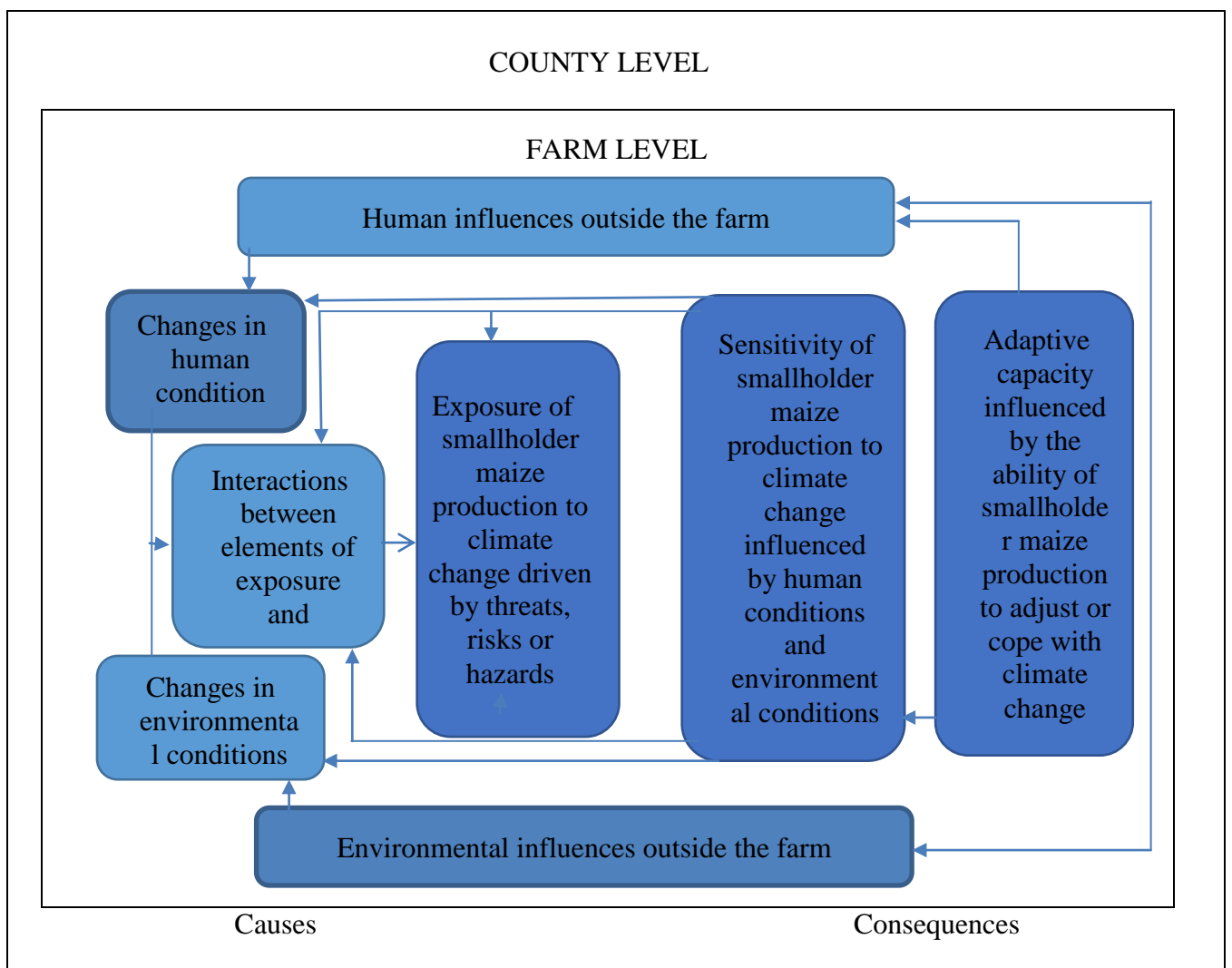


Figure 3.1: Framework for Analyzing Vulnerability of Smallholder Maize Production to Climate Change (adopted from Turner *et al.*, 2003)

Smallholder maize production is predisposed to threats, risks or hazards which are the main drivers of exposure (Füssel and Klein, 2006). These drivers to the maize production system originate from within or outside it (Turner *et al.*, 2003). The exposure is manifested in terms of magnitude, frequency, character, location and duration of the threats, risks or hazards (IPCC, 2001; Füssel and Klein, 2006). The direct threats, risks or hazards to maize production systems include variability in temperature and rainfall and climate related events such as drought and famine while changes in pest and diseases, changes in soil moisture and other changes in land conditions are indirect consequences of threats, risks or hazards (IPCC, 2001; Füssel and Klein, 2006).

Therefore, exposure has heterogeneous effects on smallholder maize production across farms and regions. The exposure may provoke changes in the human and environmental conditions of smallholder maize production (Turner *et al.*, 2003). These changes may affect the maize production system beneficially or adversely. This is known as sensitivity which is influenced by human and environmental conditions such as social, environmental, demographic, physical or economic conditions (Füssel, 2007). The interaction between exposure and sensitivity generates potential impact.

The extent of adjustment of smallholder maize production to the potential impact depends on its capacity to counteract the potential impact (Zarafshani *et al.*, 2016). The adaptive capacity may be enhanced through deliberate actions by smallholders or relevant institutions. These actions could: vary by individuals or communities; vary by timelines (short-term or long-term); be reactive or anticipatory; be planned or unplanned or result

from policy direction (Turner *et al.*, 2003). Therefore, the capacity of maize production to adapt depends on human, social, physical and financial capital endowments (Twigg, 2001).

Limitations in the access to socio-economic resources, low levels of technology, weak institutions, poor infrastructure, low access to information are some of the indicators of low adaptive capacity and hence high levels of vulnerability (Blaikie *et al.*, 1994). Some of the indicators used to measure endowments in some of the studies include: farmer's age, education and degree of family labour (as human endowment); membership to associations, social networks (as social endowment); equipment, machinery and infrastructural facilities (as physical endowment); land, water quality (as natural endowment); and income, cost of production, land ownership (as financial capital) (Zarafshani *et al.*, 2016; Zakour and Gillespie, 2013; Matyas and Pelling, 2012).

3.3.2 Framework for Estimating Levels of Efficacy of Smallholder Maize Production to Climate Change

The random utility maximization theory which allows decision makers to make choices that are discrete was used in analyzing levels of efficacy of adaptation and determinants of levels of efficacy of adaptation. The analysis was based on the choices of adaptation selected by each smallholder.

According to the Random Utility Maximization theory, a decision maker with given characteristics settles on feasible alternative(s) from a choice set, evaluates the choices and uses a decision rule to choose the alternative with the highest utility (Cascetta, 2009).

A smallholder selects an adaptation alternative if the net utility from selecting the alternative is positive (Salisu, 2016). In the present study, smallholders are assumed to select adaptation alternatives and then evaluate the choices based on the criteria effectiveness, high yield, affordability, farmer implementability and additional benefits.

Effectiveness measures the ability of the adaptation choice to reduce losses in smallholder maize production. Smith (1996) used effectiveness to demonstrate the ability of adaptation in reducing vulnerability to climate change (Thi and Chaovanapoonphol, 2014). High yield was used to measure the ability of adaptation choice to increase yield despite climate change. Titus (1990) measured the ability of adaptation choice to perform well under different climate change settings with the criteria flexibility (Thi and Chaovanapoonphol, 2014). Affordability was used to measure the extent to which smallholders could meet the cost of adapting. According to Dolan *et al.* (2001), economic efficiency could be used to assess whether additional cost of farming occasioned by adaptation exceed economic benefits of adaptation. Farmer implementability was used to measure the extent to which smallholders can implement selected adaptation considering their level of knowledge and skills. Thi and Chaovanapoonphol (2014) measured implementability as the degree to which an adaptation choice was understandable, observable and compatible with farm operations. Additional benefits criterion was used to measure the extent to which an adaptation choice had multiple benefits. Smith and Lenhart (1996) suggested that benefits of adaptation irrespective of adverse impacts of climate change could be evaluated based on the criteria independent benefits (Dolan *et*

al., 2001). The Multiple Criteria Evaluation was used to evaluate the adaptation choices based on the outlined criteria.

The results of the evaluation of the adaptation choices culminated to perception on the levels of efficacy of adaptation. The random utility function was formulated such that the net utility derived from outcome j by smallholder i (U_{ij}) is unobservable. Thus, the random utility function is specified as in equation (3.2):

$$U_{ij} = X'_{ij}\beta + \varepsilon_{ij} \dots\dots\dots 3.2$$

Where U_{ij} is the utility derived by smallholder i ($i= 1, 2, \dots n$) who is faced by a set of levels of efficacy of adaptation j ($\forall j \in C$); X_{ij} is the vector of explanatory variables describing smallholder i with outcome j ; β is a vector of unknown parameters while ε_{ij} is the random disturbance term representing heterogeneity of smallholders (Greene, 2008).

Different discrete choice models can be formulated based on different assumptions about probability distribution (Vojáček and Pecáková, 2010). Discrete choice models with error terms that have a normal distribution are estimated with probit models while those with error terms that have a logistic distribution are estimated with logit models (Salvatore and Reagle, 2011). In the present study, the dependent variable was an ordered probit model whose coefficients were estimated based on Maximum Likelihood Estimate (MLE). This model was formulated by Mckelvey and Zavoina (1971,1975) to facilitate analysis of ordered choices (Greene, 2008). The ordered probit model is such

that the utility of a smallholder i faced by several possible outcomes of levels of efficacy of adaptation can be described within the range $-\infty < U_{ij}^* < +\infty$ (Greene, 2008). The model is expressed as in equation (3.3):

$$Y_i^* = X_i' \beta + \varepsilon_i \dots\dots\dots 3.3$$

$$\forall i = 1, 2, 3, \dots n$$

Where Y_i^* is unobserved and represents the levels of efficacy of adaptation for smallholder i , X is a vector of independent variables, β is the vector of coefficients to be estimated while ε is the error term mainly arising from heterogeneity of smallholders and has a standard normal distribution with a zero mean and a variance of one and is independent from X (Salisu, 2016; Alauddin and Tisdell, 2006). The model establishes Y_i^* in a discrete form such that: $y_i = j$ if $\mu_{j-1} < y_i^* \leq \mu_j$ where smallholder $i = 1, 2, 3, \dots n$ and the probability that smallholder i is at the level of efficacy of adaptation j is expressed as in equation (3.4):

$$p_{ij} = p(y_i = j) = p[(\mu_{j-1}) < y_i^* \leq \mu_j]$$

$$= F(\mu_j - x_i' \beta) - F(\mu_{j-1} - x_i' \beta) \dots\dots\dots 3.4$$

Where $F(\cdot)$ is the standard normal cumulative distribution function (Salisu, 2016). The categories of the latent variable y_i^* were derived through Multiple Criteria Evaluation (MCE) of the adaptation alternatives chosen by smallholder i to obtain the index of the levels of efficacy of adaptation which forms the basis for categorization. Therefore, each ordered band corresponds to one of the discrete response options (low levels of efficacy of adaptation, moderate levels of efficacy of adaptation and high levels of efficacy of

adaptation). Therefore, the choice rule in respect to the three levels of efficacy of adaptation is observed as in equations (3.5, 3.6 and 3.7):

$$y_i = 0 \text{ if } y_i^* \leq \mu_0; \quad \dots\dots\dots 3.5$$

$$y_i = 1 \text{ if } \mu_0 < y_i^* \leq \mu_1; \quad \dots\dots\dots 3.6$$

$$y_i = 2 \text{ if } y_i^* > \mu_1; \quad \dots\dots\dots 3.7$$

The threshold parameter μ is unknown and facilitates the estimation of various observed values of y_i and is estimated by β . μ could be interpreted as an intercept for equation 3.3 (Alauddin and Tisdell, 2006). The probabilities associated with the three levels of efficacy of adaptation are shown in equation (3.8, 3.9 and 3.10) (Alauddin and Tisdell, 2006):

$$\text{Prob } (y_i=0|x) = F(\mu_0 - x_i'\beta) \quad \dots\dots\dots 3.8$$

$$\text{Prob } (y_i=1|x) = F(\mu_1 - x_i'\beta) - F(\mu_0 - x_i'\beta) \quad \dots\dots\dots 3.9$$

$$\text{Prob } (y_i=2|x) = 1 - F(\mu_1 - x_i'\beta) \quad \dots\dots\dots 3.10$$

For all probabilities to be positive,

$$\mu_0 < \mu_1 < \mu_2 < \dots\dots < \mu_{j-1} \quad \dots\dots\dots 3.11$$

The marginal effects of the changes in the explanatory variables that correspond to the above probabilities are derived as in equation (3.12):

$$\frac{\partial p_{ij}}{\partial x_{ik}} = [f'(\mu_{j-1} - x_i'\beta) - f'(\mu_j - x_i'\beta)]\beta \quad \dots\dots\dots 3.12$$

For each of the three levels of efficacy of adaptation, the marginal effect is derived as expressed in equations (3.13, 3.14 and 3.15):

$$\begin{aligned} \frac{\partial Prob (y=0|x)}{\partial x_i} &= \frac{\partial f(\mu_0 - x'_i \beta)}{\partial x_i} \beta \\ &= -f' (x'_i \beta) \beta \dots\dots\dots 3.13 \end{aligned}$$

$$\begin{aligned} \frac{\partial Prob (y=1|x)}{\partial x_i} &= \frac{\partial f(\mu_0 - x'_i \beta) - f(\mu_1 - x'_i \beta)}{\partial x_i} \beta \\ &= [f'(\mu_0 - x'_i \beta) - f'(\mu_1 - x'_i \beta)] \beta \dots\dots\dots 3.14 \end{aligned}$$

$$\begin{aligned} \frac{\partial Prob (y=2|x)}{\partial x_i} &= \frac{\partial f(\mu_1 - x'_i \beta)}{\partial x_i} \beta \\ &= [f'(\mu_1 - x'_i \beta)] \beta \dots\dots\dots 3.15 \end{aligned}$$

3.4 Empirical Model Specification

3.4.1 Extent of Vulnerability of Smallholder Maize Production to Climate Change

From equation 3.1, the vulnerability index was computed by combining exposure, sensitivity and adaptive capacity indices. The vulnerability index is a continuous variable. This formulation was preferred as it permits combination of variables to derive the indices in respect to each component and allows comparison of vulnerability across selected counties of the present study. A similar empirical model was used by Epule *et al.*, 2017); Gbetibouo *et al.*, 2010); Antwi-Agyei *et al.*, 2012; Epule *et al.*, 2021 and Mckonen and Berlie, 2021. Equation 3.16 was used to derive the vulnerability index for each smallholder while equations 3.17, 3.18 and 3.19 were employed to derive exposure, sensitivity and adaptive capacity indices respectively:

$$V_i = \sum_{i=1}^n \{(E_i + S_i) - AC_i\} \dots\dots\dots 3.16$$

The equations for exposure (E_i), sensitivity (S_i) and adaptive capacity (AC_i) indices for each smallholder are shown as in equations (3.17), (3.18) and (3.19):

$$E_i = \beta_1 \text{rain_anomaly} + \beta_2 \text{temp_anomaly} + \beta_3 \text{cropest_diseases} + \beta_4 \text{drought} + \beta_5 \text{famine} + \beta_6 \text{know_soiltype} + \beta_7 \text{irrigation} + \beta_8 \text{clim_changes} \dots \dots \dots 3.17$$

$$S_i = \gamma_1 \text{maizYield} + \gamma_2 \text{crop_failure} + \gamma_3 \text{age} + \gamma_4 \text{maize_shortage} + \gamma_5 \text{water_freq} + \gamma_6 \text{buy_maize} \dots \dots \dots 3.18$$

$$AC_i = \omega_1 \text{Exten_access} + \omega_2 \text{Education} + \omega_3 \text{Input_subsidies} + \omega_4 \text{expCertSeedsNorm} + \omega_5 \text{expfertilizer} + \omega_6 \text{exp_farmequipNorm} + \omega_7 \text{number_sociogrp_Norm} \dots \dots \dots 3.19$$

Where V_i is the vulnerability index for smallholder i , E_i is the exposure index for smallholder i , S_i is the sensitivity index for smallholder i , AC_i is the adaptive capacity index for smallholder i . Where E_i , S_i , AC_i represent exposure, sensitivity and adaptive capacity indices respectively while β , γ and ω are the standardized regression coefficients (Nelson, 2007).

The exposure index was generated from the following variables: rainfall anomaly, temperature anomaly, drought occurrences, famine occurrences, occurrences of crop pests and diseases, irrigation, smallholder’s perception of climate changes and knowledge of soil type. The sensitivity index was generated from the following variables: frequency of fetching water, maize yield, crop failure, age of the head of the household, length of time maize produced lasted the household and smallholders buying maize during maize

shortage. Adaptive capacity index was generated from the following variables: expenditure on fertilizers, expenditure on certified seeds, education of the head of the household, access to extension services, input subsidies and number of social groups the head of the household belonged to.

The vulnerability index was classified into lowest, middle and highest tercile. The tercile with most smallholders was used in determining the extent of vulnerability. Extent of vulnerability between the two counties was based on comparison of the distribution of smallholders across the terciles and comparison of the vulnerability index of the median smallholder.

3.4.2 Determinants of Vulnerability of Smallholder Maize Production to Climate Change

The vulnerability index derived in section 3.4.1 was used in estimating determinants of vulnerability using Ordinary Least Squares (OLS). An index was preferred as it provides a convenient measure that facilitates comparison across regions and different periods of time. In addition, indices support decision making by facilitating analysis and interpretation of complex issues (Papathoma-Kohle, Cristofari, Wenk, and Fuchs, 2019). The determinants of vulnerability were therefore estimated based on the following equation:

$$V_i = X_i' \alpha + \mu_i \dots\dots\dots 3.20$$

Where V_i represents the vulnerability index of smallholder i ; α represents the coefficients to be estimated while μ_i is the stochastic term. X is a vector comprising the following

explanatory variables: agroecological zone (x_1), household size (x_2), accuracy of climate information (x_3), maize shortage period (x_4), eat alternatives (x_5), suffered from climate human diseases (x_6), stored water period (x_7), land type (x_8), farm type (x_9), marital status of the head of the household (x_{10}), and county (x_{11}).

3.4.3 Levels of Efficacy of Adaptation of Smallholder Maize Production to Climate Change

The following adaptation alternatives were selected by smallholders: manure, fertilizer, agroforestry, changing planting dates, increasing land size, decreasing land size, irrigation, mulching, mixed cropping and conservation agriculture. The smallholders further evaluated the adaptation choices based on a five-point scale to assess effectiveness, high yield, affordability, farmer implementability and additional benefit criteria. The Multiple Criteria Evaluation was applied to obtain index of efficacy of adaptation (Z_i) as in equation 3.21:

$$Z_i = MWsum_i + FWsum_i + AGWsum_i + PWsum_i + INWsum_i + DWsum_i + IRWsum_i + MUWsum_i + MXWsum_i + CAWsum_i \dots\dots\dots 3.21$$

Where $MWsum_i$ is the weighted sum for manure, $FWsum_i$ is the weighted sum for fertilizer, $AGWsum_i$ is the weighted sum for agroforestry, $PWsum_i$ is the weighted sum for changing planting dates, $INWsum_i$ is the weighted sum for increasing land size, $DWsum_i$ is the weighted sum for decreasing land size, $IRWsum_i$ is the weighted sum for irrigation, $MUWsum_i$ is the weighted sum for mulching, $MXWsum_i$ is the weighted

sum for mixed cropping and $CAWsum_i$ is the weighted sum for conservation agriculture. The variable Z_i was used in deriving the levels of efficacy as indicated in section 3.11.3.

3.4.4 Determinants of the Levels of Efficacy of Smallholder Maize Production to Climate Change

Equation 3.22 was used to estimate the determinants of the levels of efficacy of adaptation based on Maximum Likelihood Estimate:

$$y_i = \sum_{i=1}^n X_i \beta + \varepsilon_i \dots\dots\dots 3.22$$

Where y_i is the level of efficacy of adaptation; X_i is a vector comprising the following explanatory variables: soil analysis, accuracy of climate information, extension access, number of social groups, farm type, land type, stored water period, farming experience, distance to the market and number of adaptation alternatives applied; β represents the parameters estimated while ε_i is the stochastic error term.

3.5 Definition of Variables

The objectives of the study were addressed through analysis of the empirical models outlined in section 3.4. The section defines the variables used in the analysis of each of the research objectives.

3.5.1 Variables Used in Analyzing Extent of Vulnerability of Smallholder Maize Production

The exposure, sensitivity and adaptive capacity indices were combined in line with equation 3.16 to obtain the vulnerability index. The variables used in the analysis of the extent of vulnerability are presented in Table 3.1, 3.2, 3.3 and 3.4.

Table 3.1: Definition of Variables Used in Estimating Vulnerability Index

Variable	Definition	Measurement
Exposure	Environmental stress on smallholder maize production.	Index
Sensitivity	Response of smallholder maize production to exposure.	Index
Adaptive capacity	Ability of smallholders to implement actions to minimize impact of exposure and sensitivity on maize production.	Index

Table 3.2: Definition of Variables Used in Estimating Exposure Index

Variable	Definition	Measurement
Rainfall anomaly (Rain_anomaly)	Deviation of the average rainfall for the long rain growing season for 2017 from the average rainfall for the long rain growing season for the period 1960 to 2017.	$R = \frac{r_{2017} - r_{Normal}}{\sigma}$ (r_{2017} - mean rainfall in millimeters; r_{Normal} - mean rainfall in millimeters; and σ - standard deviation.)
Temperature anomaly (Temp_anomaly)	Deviation of the average temperature for the long rain growing season for 2017 from the average temperature for the long rain growing season for 1960 to 2017.	$T = \frac{t_{2017} - t_{Normal}}{\sigma}$ (t_{2017} - mean temperature in millimeters; t_{Normal} - mean temperature in millimeters; and σ - standard deviation.)
Crop pests and diseases (cropests_diseases)	Frequency of experiencing crop pests and diseases by a smallholder.	Never=0; Rarely=1; Occasionally=2; Frequently=3; Very frequently=4
Irrigation (irrigation)	Early termination of rainfall.	Yes=1; No=0
Drought	Frequency of experiencing rainfall deficiency over an extended period of time.	Never=0; Rarely=1; Occasionally=2; Frequently=3; Very frequently=4
Famine	Frequency of experiencing scarcity of maize due to crop failure.	Never=0; Rarely=1; Occasionally=2; Frequently=3; Very frequently=4
Knowledge of soil type (Know_soiltype)	Smallholder's knowledge of the soil type on their farms.	Yes=1; No =0
Perceived Climate changes (Perceivedclim_changes)	Perception of smallholders that there were erratic climatic changes.	Yes=1; No=0

Table 3.3: Definition of Variables Used in Estimating Sensitivity Index

Variable	Definition	Measurement
MaizYield	90-kilogram bags per acre per season	Number of 90-kilogram bags produced per acre
Crop failure (crop_failure)	Frequency of experiencing crop failure by a smallholder.	Never=0; Rarely=1; Occasionally=2 Frequently=3; Very frequently=4
Age	The age of the head of the household	Years
Water frequency (Water_freq)	Frequency of fetching water by a smallholder.	Daily=0; Monthly=1; during rainy season=2 after rainy season=3
Buy maize	Whether smallholders buy maize during shortage.	Yes=1; No=0
Maize period (maize_period)	Length of time that maize produced lasted the family.	Over 12 months=0; Less than one month=1; 1-3 months=2; 4-6 months=3; 7-9 months=4 10-12 months=5

Table 3.4: Definition of Variables Used in Estimating Adaptive Capacity Index

Variable	Definition	Measurement
Expenditure on certified seeds (expCertSeeds)	Expenditure on certified seeds per season	Amount spent on maize seeds in the last season in Kenya shillings
Education (edu)	The level of education of the head of the household	No formal=0; Primary=1 Secondary=2; College=3 University=4
Expenditure on fertilizer (expfertilizer)	Expenditure on fertilizer in maize production per season.	Amount spent on fertilizers in the last season in Kenya shillings
Extension access (Exten_access)	Whether a smallholder received extension services.	Yes=1; No=0
Input subsidies (inputSubsidies)	Smallholders access to input subsidies.	Yes=1; No=0
Number of social group (N_sgrp)	Number of social groups a smallholder belongs to.	Numbers

3.5.2 Variables used in analyzing determinants of vulnerability

The dependent variable to estimate the determinants of vulnerability was vulnerability index derived based on equation 3.16. The independent variables used in the analysis of the determinants of vulnerability are presented in Table 3.5.

Table 3.5: Definition of Variables Used in Analyzing Determinants of Vulnerability

Variable	Definition	Measurement
Agroecological Zone (AgroZone)	The agroecological zone where the smallholder resides.	Lower Midland 4 (LM4) =0; Lower Midland 4-5 (LM4-5) =1; Upper Midland 3-4 (UM3-4) =2; Lower Midland 5 (LM5) =3; Lower Highland 1-5 (LH1-5) =4; Upper Midland 5-6 (UM5-6) =5; Lower Midland 3 (LM3) =6
Household size (Hhsize)	Number of members of a household	Number
Marital status (marital_status)	Marital status of the head of the household	Widow/widower=0 Single=1 Married=2 Divorced=3
Land type (land_type)	Farming land ownership regime	Privately owned with title deed=0 Communal=1; Ancestral=2; Leasehold=3; Rented/borrowed=4; Privately owned without title deed=5
Farm type (farm_type)	The type of farming system practiced by the smallholder	Crop farming=0; Mixed farming=1
Accuracy of climate information (accuracy_clinfo)	Perception of smallholders that the climate information provided was accurate.	Yes=1; No=0
Eating alternatives to maize (eatAlter)	Whether smallholders consume substitutes due to poor maize harvest	Yes=1; No=0
Suffered from Climate human diseases (Suffered_ClimDisease)	Whether smallholders have suffered from climate related diseases	Yes=1; No=0
Maize shortage period (Maizeshort_period)	Length of time with maize shortage	No shortage=0; Less than 3 months=1; 4-6 months=2; 6 months=3
Stored_waterPeriod (water_period)	Length of time water stored lasts the smallholders	One day=0; One week=1; One month=2 Over one month =3
County	County of residence of a smallholder	Laikipia County=0 Kitui County=1

3.5.3 Variables Used in Analyzing Levels of Efficacy of Adaptation

The variables used in analyzing levels of efficacy of adaptation are presented in Table 3.6, 3.7, 3.8, 3.9 and 3.10.

Table 3.6: Definition of Variables Used in Analyzing Effectiveness Score of Adaptation Choices

Variable	Definition	Measurement
Manure effectiveness score (manureEFF)	The extent to which manure could reduce losses in smallholder maize production	Not effective=1,slightly effective=2,moderately effective=3, effective=4, very effective=5
Fertilizer effectiveness score (fertilizerEFF)	The extent to which fertilizer could reduce losses in smallholder maize production	Not effective=1,slightly effective=2,moderately effective=3, effective=4, very effective=5
Agroforestry effectiveness score (agroforestryEFF)	The extent to which agroforestry could reduce losses in smallholder maize production	Not effective=1,slightly effective=2,moderately effective=3,effective=4,very effective=5
Changing planting dates effectiveness score (plantingDatesEFF)	The extent to which changing planting dates could reduce losses in smallholder maize production	Not effective=1,slightly effective=2,moderately effective=3,effective=4,very effective=5
Increasing land size effectiveness score (increasingLandsizeEFF)	The extent to which increasing land size could reduce losses in smallholder maize production	Not effective=1,slightly effective=2,moderately effective=3,effective=4, very effective=5
Decreasing land size effectiveness score (decreasingLandsizeEFF)	The extent to which decreasing land size could reduce losses in smallholder maize production	Not effective=1,slightly effective=2,moderately effective=3, effective=4,very effective=5
Irrigation effectiveness score (irrigationEFF)	The extent to which irrigation could reduce losses in smallholder maize production	Not effective=1,slightly effective=2,moderately effective=3,effective=4, very effective=5
Mulching effectiveness score (mulchingFF)	The extent to which mulching could reduce losses in smallholder maize production	Not effective=1,slightly effective=2,moderately effective=3,effective=4, very effective=5
Mixed cropping effectiveness score (mixedCroppingFF)	The extent to which mixed cropping could reduce losses in smallholder maize production	Not effective=1,slightly effective=2,moderately effective=3,effective=4, very effective=5
Conservation agriculture effectiveness score (conservationAgricEFF)	The extent to which conservation agriculture could reduce losses in smallholder maize production	Not effective=1,slightly effective=2,moderately effective=3,effective=4,very effective=5

Table 3.7: Definition of Variables Used in Analyzing High Yield Score of Adaptation Choices

Variable	Definition	Measurement
Manure high yield score (manureHY)	Extent to which manure could increase maize yields despite climate change	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Fertilizer high yield score (fertilizerHY)	Extent to which fertilizer could increase maize yields despite climate change	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Agroforestry high yield score (agroforestryHY)	Extent to which agroforestry could increase maize yields despite climate change	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Changing planting dates high yield score (plantingDatesHY)	Extent to which changing planting dates could increase maize yields despite climate change	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Increasing land size high yield score (increasingLandsizeHY)	Extent to which increasing land size could increase maize yields despite climate change	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Decreasing land size high yield score (decreasingLandsizeHY)	Extent to which decreasing land size could increase maize yields despite climate change	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Irrigation high yield score (irrigationHY)	Extent to which irrigation could increase maize yields despite climate change	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Mulching high yield score (mulchingHY)	Extent to which mulching could increase maize yields despite climate change	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Mixed cropping high yield score (mixedCroppingHY)	Extent to which mixed cropping could increase maize yields despite climate change	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Conservation agriculture (conservationAgricHY)	Extent to which conservation agriculture could increase maize yields despite climate change	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5

Table 3.8: Definition of Variables Used in Analyzing Affordability Score of Adaptation Choices

Variable	Definition	Measurement
Manure affordability score (manureAFF)	Cost efficiency of manure	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Fertilizer affordability score (fertilizerAFF)	Cost efficiency of fertilizer	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Agroforestry affordability score (agroforestryAFF)	Cost efficiency of agroforestry	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Changing planting dates affordability score (plantingDatesAFF)	Cost efficiency of changing planting dates	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Increasing land size affordability score (increasingLandsizeAFF)	Cost efficiency of increasing land size	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Decreasing land size affordability score (decreasingLandsizeAFF)	Cost efficiency of decreasing land size	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Irrigation affordability score (irrigationAFF)	Cost efficiency of irrigation	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Mulching affordability score (mulchingAFF)	Cost efficiency of mulching	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Mixed cropping score (mixedCroppingAFF)	Cost efficiency of mixed cropping	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Conservation agriculture score (conservationAgricAFF)	Cost efficiency of conservation agriculture	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5

Table 3.9: Definition of Variables Used in Analyzing Farmer Implementability Score of Adaptation Choices

Variable	Definition	Measurement
Manure Farmer_implementation score (manureEXT)	Ease of adoption of manure	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Fertilizer Farmer_implementation score (fertilizerEXT)	Ease of adoption of fertilizer	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Agroforestry Farmer_implementation score (agroforestryEXT)	Ease of adoption of Agroforestry	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Changing planting dates Farmer_implementation score (plantingDatesEXT)	Ease of adoption of changing planting dates	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Increasing land size Farmer_implementation score (increasingLandsizeEXT)	Ease of adoption of increasing land size	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Decreasing land size Farmer_implementation score (decreasingLandsizeEXT)	Ease of adoption of decreasing land size	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Irrigation implementable score (irrigationEXT)	Ease of adoption of irrigation	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Mulching Farmer_implementation score (mulchingEXT)	Ease of adoption of mulching	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Mixed cropping Farmer_implementation score (mixedCroppingEXT)	Ease of adoption of mixed cropping	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Conservation agriculture Farmer_implementation score (conservationAgricEXT)	Ease of adoption of conservation agriculture	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5

Table 3.10: Definition of Variables Used in Analyzing Additional Benefit Score of Adaptation Choices

Variable	Definition	Measurement
Manure additional benefit score (manureCB)	Multiple benefits derived from adapting through application of manure	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Fertilizer additional benefit score (fertilizerCB)	Multiple benefits derived from adapting through application of fertilizer	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Agroforestry additional benefit score (agroforestryCB)	Multiple benefits derived from adapting through practising agroforestry	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Changing planting dates additional benefit score (plantingDatesCB)	Multiple benefits derived from adapting through changing planting dates	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Increasing land size additional benefit score (increasingLandsizeCB)	Multiple benefits derived from adapting through increasing land size	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Decreasing land size additional benefit score (decreasingLandsizeCB)	Multiple benefits derived from adapting through decreasing land size	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Irrigation additional benefit score (irrigationCB)	Multiple benefits derived from adapting through irrigation additional benefit	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Mulching additional benefit score (mulchingCB)	Multiple benefits derived from adapting through mulching	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Mixed cropping additional benefit score (mixedCroppingCB)	Multiple benefits derived from adapting through mixed cropping	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5
Conservation agriculture additional benefit score (conservationAgricCB)	Multiple benefits derived from adapting through conservation agriculture	Strongly disagree=1, disagree=2, not at all=3, agree=4, strongly agree=5

3.5.4 Variables Used in Analyzing Determinants of Levels of Efficacy of Adaptation

The dependent variable to estimate the determinants of levels of efficacy of adaptation was levels of efficacy of adaptation categorized as low level, moderate level and high level. The independent variables used in the analysis are presented in Table 3.11.

Table 3.11: Definition of Variables Used in Analyzing Determinants of Levels of Efficacy of Adaptation

Variable	Definition	Measurement
Land type (land_type)	Farming land ownership regime	Privately owned with title deed=0; Communal=1; Ancestral=2; Leasehold=3; Rented/borrowed=4; Privately owned without title deed=5
Soil analysis	Whether smallholders undertook soil analysis	Yes=1; No=0
Accuracy of Climate information (accuracy_clinfo)	Perception of smallholders that the climate information provided was accurate.	Yes=1; No=0
Farming experience (farmexp)	The range of duration a smallholder has been farming	Less than 1 year=0; 1-5 years =1; 6-10 years = 2; 11-15 years=3; 16-20 years=4; 21-25 years=5; 26-30 years=6; Over 30 years =7.
Stored waterPeriod (water_period)	Length of time water stored lasts the smallholders	One day=0; One week=1; One month=2 Over one month =3
Farm type (farm_type)	The type of farming system practiced by the smallholder	Crop farming=0; Mixed farming=1
Extension access (Exten_access)	Whether a smallholder received extension services.	Yes=1; No=0
Number of adaptation choices (NAdapt)	Number of adaptation alternatives applied by a smallholder	Numbers of different measures used in the farm to adapt maize farming to climate change
Number of social group (N_sgrp)	Number of social institutions a smallholder was involved in.	Number of groups that a smallholder belongs to
Distance from the market	The distance from the smallholder's farm to the market	Less than 1km=0; 1-5 km =1; 6-10 km = 2; Over 10 km =3

3.6 Study Area

The study was conducted in Kitui and Laikipia Counties. These two counties were selected due to reported frequent incidences of droughts. The counties have also been reported to suffer from food insecurity. Although the two counties are both classified as semi-arid, Kitui County is located in the lowlands while Laikipia County is located in the highlands as per the maps provided in Appendix I. Opiyo *et al.* (2014) notes the importance of vulnerability analysis at household level particularly in semi-arid regions to inform policy on appropriate adaptation measures to minimize vulnerability.

3.6.1 Kitui County

Kitui County comprises 8 sub-counties namely: Kitui Central, Kitui Rural, Kitui South, Kitui West, Kitui East, Mwingi Central, Mwingi North and Mwingi West, 40 Wards and 247 villages (Republic of Kenya, 2018b). The population was estimated to be 1,136, 187 (Republic of Kenya, 2019). The absolute poverty level was estimated as 47.5 percent compared to the national average of 36.1 percent while the food poverty rate was estimated as 39.4 percent as compared to the national average of 32 percent (Republic of Kenya, 2018b). Agriculture supports food production, employment and source of livelihoods. The annual rainfall varies between 500 millimeters and 1050 millimeters with 40 percent reliability while minimum temperature ranges from 22 to 28 Degree Celsius and maximum temperature ranges from 28 to 32 Degree Celsius (Oremo, 2013). The county has nine (9) agroecological zones upper midland 3, upper midland 3-4 suitable for coffee, upper midland 4 suitable for sunflower, maize and pigeon peas; lower midland 3 and 4 suitable for cotton, lower midland 5 suitable for livestock, sorghum, fodder and millet; lower midland 6 and Inner lowland 6 suitable for ranching and inner lowland 5 suitable for livestock and millet production (Republic of Kenya, 2018b). Although a large area (77,551 Ha) was dedicated for maize production, the annual production was lower (10,858 metric tonnes) as compared to sorghum (11,989 metric tonnes) with a lower land area (68,307) (Republic of Kenya, 2018b).

3.6.2 Laikipia County

The County is divided into five administrative sub-counties namely: Laikipia Central, Laikipia East, Laikipia North, Laikipia West and Nyahururu Sub-Counties and 15 Wards

(Republic of Kenya, 2018c). Laikipia County had a total population of 518,560 (Republic of Kenya, 2019). The absolute poverty level was estimated as 46 percent compared to the national average of 36.1 percent while the food poverty rate was estimated as 24.2 percent as compared to the national average of 32 percent (Council of Governors and Kenya Institute of Policy, Research and Analysis, 2020). Agriculture supports over 60 percent of the population. The annual rainfall varies between 400 millimeters and 750 millimeters while the mean annual temperature ranges between 16 degrees Celsius and 26 Degree Celsius (Republic of Kenya, 2018c). The county has the following nine (9) agroecological zones: upper highland 2 suitable for wheat and pyrethrum, upper highland 3 suitable for wheat and barley; lower highland 2 suitable for wheat, maize and pyrethrum; lower highland 3 suitable for wheat, maize and barley; lower highland 4 suitable for cattle, sheep and barley; lower highland 5 and 6 suitable for ranching; upper midland 5 suitable for livestock and sorghum and upper midland 6 suitable for ranching (Jaedzold *et al.*, 2010). The main crop cultivated is maize which comprises 51 percent of total crop area while other crops cultivated include: beans, wheat, irish potato, cabbage and tomato (Republic of Kenya, 2018c).

3.7 Target Population and Sampling Procedures

The sample to facilitate conduct of the study was drawn from smallholder maize producers from the following four sub-counties of Kitui County: Kitui Central, Kitui South, Kitui Rural and Mwingi Central and two sub-counties in Laikipia County (Laikipia North and Laikipia East). The sub-counties were selected randomly. The targeted maize producers were those who had land sizes of five acres and below.

Smallholders residing in town centers were excluded from the sample to avoid urbanization effects (Kabubo-Mariara and Karanja, 2007).

The sample size for the study was obtained following Cochran (1977) as in equation (3.23):

$$n = \frac{Z^2 P(1-P)}{e^2} \dots\dots\dots 3.23$$

Where e is the desired level of precision estimated at ± 5 percent and e represents the margin of error allowable between the sample and the population (Israel, 1992). Z is the selected critical value of the desired confidence level (Israel, 1992). In the study, 95 percent confidence level translating to $Z=1.96$ from the standard normal cumulative distribution table was preferred. P is the proportion of the population expected to comprise smallholder maize producers estimated at 0.5. This estimate represents maximum variability applied where there is a large population whose variability is not known (Israel, 1992). Therefore, the sample size was estimated as follows:

$$n = \frac{1.96^2 \times 0.5 \times 0.5}{0.05^2} = 384.16 \dots\dots\dots 3.24$$

Half of the sub-counties of Kitui County and Laikipia county were considered in the distribution of the sample size of 384 translating to a ratio of 2 (Laikipia County): 4 (Kitui County) totaling to 128 respondents for Laikipia County and 256 for Kitui County. The distribution was informed by the total of six sub-counties; four in Kitui County while two were in Laikipia County. Over and above the sample size of 384 respondents, 27 more respondents representing 7 percent of the sample size were included to compensate for targeted respondents who could not be reached, nonresponse or questionnaires that

would not be admissible due to errors (Israel, 1992). Therefore, a total of four hundred and eleven (411) smallholder maize producers were sampled. However, nine (9) of the respondents sampled owned more than 5 acres of land were dropped out. Therefore, a total of 402 questionnaires were used for analysis.

Respondents from each sub-county were clustered according to Wards then selected using simple random sampling. All the wards in a sub-county were included except Sosian and Mukogodo West Ward from Laikipia County which were mainly on the range lands and Nanyuki Ward in Laikipia County and Kitui Township Ward in Kitui County located in the urban areas. The distribution of the respondents is shown in Appendix II. The sampling frame for the smallholder maize producers was obtained from the County Directors of Agriculture of the respective counties from where smallholders with land sizes of 5 acres and below were identified.

The identification of respondents was facilitated by the extension officers in the respective Wards. Multistage cluster sampling was preferred because it allowed breaking down of groups into smaller units which have a low group variance than simple random sampling was applied in selection of respondents from the smaller units. In the first stage Kitui South, Kitui Rural, Kitui Central and Mwingi Central sub counties were selected from Kitui County while Laikipia North and Laikipia East were selected from Laikipia County. The following wards within the sub counties were included in the study: Mutomo, Athi, Ikanga, Ikutha and Kanziko from Kitui South Sub-County; Kisasi, Yatta Kwa Vonza, Kanyangi and Mbitini from Kitui Rural; Kyagwitha East, Kyagwitha West,

Miambani and Mulango from Kitui Central; Mwingi Central, Waita, Kivou, Mui, Nguni and Nuu from Mwingi Central; Mukogodo East and Segera from Laikipia North; Thingithu, Tigithi, Umande and Ngobit from Laikipia East. In the second stage, smallholders from the list of smallholder maize producers with 5 acres and below provided by the County Directors of Agriculture were randomly selected from each of the wards as shown in Table 3.12 as follows:

Table 3.12: Smallholders Selected Per County and Per Ward

Counties	Selected sub-Counties	Wards	Number of smallholders selected
Kitui	Kitui South	Mutomo	12
		Athi	5
		Ikanga	25
		Ikutha	11
		Kanziko	6
	Kitui Rural	Kisasi	12
		Yatta Kwa Vonza	20
		Kanyangi	15
		Mbitini	15
	Kitui Central	Kyangwitha East	18
		Kyangwitha West	14
		Miambani	47
		Mulango	15
	Mwingi Central	Mwingi Central	10
		Waita	7
Kivou		10	
Mui		25	
Nguni		11	
Nuu		5	
Laikipia	Laikipia North	Mukogodo East	20
		Segera	14
	Laikipia East	Thingithu	15
		Tigithi	25
		Umande	15
		Ngobit	39
Total			411

3.9 Data Types, Sources and Collection

The study used primary data. Specifically, a survey was conducted to collect data on household-based variables. Data on climate variables were downloaded from online databases. Temperature data in degree Celsius was obtained from Global Historical Climatology Network (GHCN) gridded version 4 (Menne, Williams, Gleason, Rennie and Lawrimore, 2018). On the other hand, monthly rainfall data in millimeters was obtained from Centennial Trends (CenTrends) version 1.0 precipitation dataset (Funk *et al.*, 2016). These datasets were preferred due to completeness and availability. Additional information on smallholders and agroecological zones was obtained from the county offices of the Ministry of Agriculture, Livestock and Fisheries.

3.10 Data Collection Instrument, Data Collection Procedure and Piloting

The main data collection instrument was a questionnaire due to convenience of administration and the volume of data it could collect. It was used to collect socio-economic data on the respondents' and other variables of the study. To minimize response bias, the following was undertaken: selection of respondents was random; the survey was conducted anonymously; both open ended and closed ended questions were included in the questionnaire and double-barreled questions were avoided. The questionnaire is provided in Appendix III.

Prior to data collection, requisite authorization was sought from National Commission for Science, Technology and Innovation (NACOSTI), Ministry of Education and Office of Commissioner of County based in Kitui, Laikipia and Machakos counties. The

authorization was instrumental in facilitating a smooth data collection process. The research authorization is provided in Appendix IV.

A pilot study of forty-five (45) smallholders was undertaken in Kangundo Sub-County of Machakos County in the first and second week of the month of August 2018. Kangundo sub-county was selected because of its proximity to one of the study areas thus envisaged to possess similar characteristics. During the pilot study, it was established that some Wards were vast, hence during the data collection each ward was assigned one research assistant. In addition, a budget was allocated to facilitate calling of respondents in advance to ensure they were available on the data collection day. Respondents who had relocated were replaced. It was further established that some respondents required interpretation in the local language hence this informed selection of the research assistants who were able to speak the local language. Furthermore, the research assistants were extension officers familiar with the study area and were deployed in neighboring Wards away from their duty station. Due to the length of the questionnaire and vastness of some areas the enumerators were able to administer on average 1 to 2 questionnaires per day in Kitui County and 2-3 questionnaires per day in Laikipia County. The pilot study further informed the decision that questionnaires be completed on administration rather than leaving it with the respondents for collection later.

Generally, the respondents were able to comprehend the questionnaire albeit with interpretation in the local language for some respondents. The data collected was analyzed in Stata and was found adequate to address the study objectives. However, it

was noted that three questions in the data collection tool on quantity of fertilizer, certified seeds and chemicals for disease and pest control did not provide a section to capture types making it difficult to enter and analyze data on expenditure on fertilizer, certified seeds and chemicals. This informed review of the tool to incorporate the missing information.

After the pilot study and review of the data collection instrument, research assistants and supervisors from Kitui and Laikipia County were identified and trained on use of the data collection instrument. This was done to ensure that the research assistants and supervisors were conversant with the objective of the study and the nature of data required. The training of research assistants and administration of questionnaires was undertaken from the last week of August to mid-October 2018. The research assistants reached out to the selected smallholders at their farms where the questionnaires were completed. Primary data collected was in respect to the long rain growing season since maize production was mainly undertaken during the long rain growing season.

Other than primary data, additional data on AEZs, prices of farm inputs, farm gate and market price for maize and costs relating to adaptation choices was obtained from the respective directors of agriculture and extension officers from the respective counties.

3.11 Data Processing and Analysis

Data collected was processed, cleaned and analyzed. Data cleaning culminated in dropping five out of the 402 observations from the dataset due to inconsistencies. The likelihood of multicollinearity resulting from dummy variables (dummy variable trap)

was eliminated by excluding one of the dummy variable categories by setting it equal to zero (Williams, 2015). To address endogeneity in the study, respondents were selected randomly to eliminate selection bias. In addition, omitted variable bias was assessed and the null hypothesis satisfied. The scale anchors were also varied to minimize measurement errors.

In addition, some variables were recoded due to few numbers of respondents in some categories. The table below shows the recoded variables:

Table 3.13: Recoded Variables

Variable	Categories
Crop failure (crop_failure1)	Occasionally=0; Rarely=1; Frequently=2
Crop pests and diseases (cropests_diseases1)	Frequently=0; Occasionally=1; Very frequently=2
Water frequency (Water_Freq1)	Daily=0; Weekly and beyond=1
Stored_waterPeriod (water_period1)	One week =0; One day=1; One month and beyond=2
Education (edu1)	Secondary=0; No formal education=1; Primary=2 Tertiary=3
Land type (land_type1)	Privately owned=0; Communally owned=1
Farming experience	11-20 years=0; 1-10 years=1; over 20 years=2

In addition, sections 3.11.1, 3.11.2 and 3.11.3 provide data analysis in respect to each of the objectives:

3.11.1 Data Processing and Analysis to Establish the Extent of Vulnerability of Smallholder Maize Production to Climate Change

Factor analysis was used in the analysis of the extent of vulnerability of smallholder maize production to climate change. It was preferred due to its capability in generating

indices for further analysis (Rietveld and Van Hout, 1993). Factor analysis splits variance into two parts: common variance and error variance. Thus, as opposed to the Principal Component Analysis (PCA), factor analysis enables creation of index based on the part of the variance accounted for by common factors (communality) excluding the parts not accounted for by the common factors (error variance) (Field, 2009). In addition, factor analysis was more ideal since the data set had mixed variables thus could not be analyzed effectively by PCA (Kemalbay and Korkmazoğlu, 2014).

The variables used in the present study to derive the vulnerability index (V_i) (exposure, sensitivity and adaptive capacity) were extracted from a combination of variables provided in section 3.4.2 in respect to each component. Since variables were measured in different units they were normalized using the formula below to facilitate comparability:

$$Z_i = \frac{z_i - \bar{z}}{z_{max} - z_{min}} \dots\dots\dots 3.25$$

Where \bar{z} is the mean of z_i across smallholders and z_{max} is maximum value of z while z_{min} is the minimum value of z .

Estimation of Factor Loadings

The common factors were expressed as a linear combination of the set of variables representing the major components of vulnerability as follows:

$$F_j = \beta_1 z_1 + \beta_2 z_2 + \beta_3 z_3 + \dots + \beta_m z_m + \mu_j \dots\dots\dots 3.26$$

Where F_j represents the first common factor based on the variables representing exposure, sensitivity or adaptive capacity, z represents the respective independent

variables associated with the factor, β represents the factor loading while μ represents the proportion of variance not shared between the factor and the respective variable. The square of the coefficient (β) produced the proportion of variance accounted for by the common factor known as the EigenValues (Field, 2009). The solution for 3.26 was rotated to ensure that higher loadings were on the first common factor. Higher loadings on the first common factor ensured that it provides the greatest amount of information from all the variables (Taherdoost *et al.*, 2014). Orthogonal rotation was preferred since the factors used in deriving the indices were uncorrelated with other factors (Goldberg and Velicer, 2006). Orthogonal rotations are replicable in future samples as they reduce sampling error variance while oblique rotations are less parsimonious and tend to increase sampling error variance (Kimani, 2019).

Estimation of Exposure, Sensitivity and Adaptive Capacity Indices

The exposure, sensitivity and adaptive capacity indices were computed on the basis of factor loadings (Nelson, 2007). The factor loadings were first used to compute the regression coefficient which was then multiplied with the actual values of the variables to obtain the indices for each smallholder (Nelson, 2007). A positive factor loading for variables measuring exposure, sensitivity and adaptive capacity imply that the respective variables increase exposure, sensitivity or adaptive capacity. On the other hand, a negative factor loading for variables measuring exposure, sensitivity or adaptive capacity imply that the respective variable decreases exposure, sensitivity or adaptive capacity.

Diagnostic Test for Factor Analysis

Bartlett's test of sphericity was conducted. The test measures the Kaiser-Meyer-Olkin (KMO) sampling adequacy that is whether the distribution of values in the sample are adequate for factor analysis to be conducted (Taherdoost *et al.*, 2014). A KMO >0.5 and near 1 indicates a good fit (Taherdoost *et al.*, 2014). This test compares the correlation matrix with a matrix of zero correlations (identity matrix). The test measures whether the correlation matrix used in factor analysis is an identity matrix that is, all correlation coefficients are equal to zero (Taherdoost *et al.*, 2014). A rejection of the null hypothesis test constitutes a conclusion that the correlation matrix was not obtained from a population with zero correlations thus the relationship among variables is adequate (Taherdoost *et al.*, 2014). In addition, data was further inspected for adequacy by assessing the determinant of the correlation matrix to establish if the p-value was greater than 0.00001 (Field, 2009).

3.11.2 Data Processing Relating to Estimation of Determinants of Vulnerability of Smallholder Maize Production to Climate Change

A linear regression model of determinants of vulnerability was estimated using Ordinary Least Squares (OLS). The model was subjected to the following diagnostic tests:

(a) Specification Test

Linktest

The Linktest was conducted after running the ordinary least squares regression to test if the model was correctly specified. In undertaking the linktest, the dependent variable was

regressed against the predicted dependent variable and the squared predicted dependent variable (Long and Freese, 2001). The null hypothesis is that there is no specification error if the specified model yields a significant \hat{u} and an insignificant \hat{u}^2 (Long and Freese, 2001).

Omitted Variables Test

The Regression Specification Error Test (RESET) was conducted to test whether the model for estimating determinants of vulnerability had omitted variables. The null hypothesis provides that the model does not have omitted variable bias (Torres-Reyna, 2007). If the null hypothesis is rejected, then it implies that there was omitted variable bias (Torres-Reyna, 2007). However, if the null hypothesis was not rejected then the model was correctly specified.

(b) Tests for Multicollinearity

Studentized Residual

The studentized residuals were assessed to identify outliers. A value of 3 and higher or a value of -3 or lower signifies the presence of outlier (Williams, 2015).

Cook's Distance

To assess the influence of each observation on the whole regression model, Cook's distance was measured. Observations with Cook's distance values greater than 0.5 indicate great influence while values greater than 1 indicate outlier problem (Torres-Reyna, 2007).

Leverage

To assess the leverage of each of the observations on the regression coefficients, leverage was measured. Leverage is bound between $\frac{1}{n}$ and 1 implying that observations with leverage value closer to 1 have a high leverage on the predictor variable (Williams, 2016).

(c) Goodness of Fit Test

F test

An F-test to test whether coefficients were jointly different from zero was conducted upon running the regression. The null hypothesis provides that coefficients of the model are jointly equal to zero (Stock and Watson, 2007). If the null hypothesis was rejected, then it implied that the coefficients were not jointly equal to zero. Therefore, the independent variables had a significant effect on the dependent variable.

(d) Normality Test

Shapiro-Wilk normality test was conducted to check whether the sample was from a normally distributed population. This entailed obtaining the residual after running the regression. Thereafter, the distribution of the residual was tested for normality. The null hypothesis was that the distribution of the residual was normal (Torres-Reyna, 2007). If the null hypothesis was rejected, then it implied the residuals were not normally distributed.

(e) **Heteroscedasticity**

The white test to check whether the residuals of the model were homoscedastic was conducted. The null hypothesis is that the residuals are homoscedastic (Williams, 2020). Rejection of the null hypothesis signifies heteroscedasticity. Thus, the model would not yield the correct estimates of the standard errors and p-values for the coefficients (Williams, 2020).

3.11.3 Data Processing Relating to Analysis of Levels of Efficacy of Adaptation

Smallholders selected their preferred adaptation choices from the following options: manure, fertilizer, agroforestry, changing planting dates, increasing land size, decreasing land size, irrigation, mulching, mixed cropping and conservation agriculture. Thereafter, they evaluated the adaptation choices by assigning scores to the adaptation applied in respect to a five-point scale on account of effectiveness, high yield, affordability, farmer implementability and additional benefit criteria. To facilitate weighting of the five criteria, each criterion was assigned weights based on consultations with extension officers (Dolan *et al.*, 2001).

In addition, the extension officers were asked to rank each of the criteria on a scale of 1 to 5 based on how best they felt the criteria contributed to reduction of the adverse impacts of climate change. The scores by the respective extension officers were averaged for each criterion and weighted out of 10. The weights for the respective criteria are provided in Table 3.14:

Table 3.14: Criteria weight

Criterion	Average score	Ranking	Weight (W_c)
Effectiveness	4.57	1	3.2
High yield	3.29	2	2.3
Affordability	2.71	3	1.8
Farmer implementability	2.14	4	1.5
Additional benefit	1.67	5	1.2
Total			10

The scores assigned by smallholders in respect to each criterion to selected adaptation and criteria weight in Table 3.14 were used to compute the weighted score for each adaptation based on each criterion as follows:

$$Wscore_{ij} = S_j \times W_c \dots\dots\dots 3.27$$

Where $Wscore_{ij}$ is the weighted score for each smallholder corresponding to adaptation choice. S_j is the score assigned by smallholder i for adaptation j , W_c is the assigned weight for criterion c (Thi and Chaovanapoonphol, 2014). The weighted score was summed to generate the weighted sum as follows:

$$Wsum_{ij} = \sum_{i=1}^5 S_j \times W_c \dots\dots\dots 3.28$$

Where $Wsum_j$ is the weighted sum corresponding adaptation choice j for smallholder i . Since most of the smallholders applied multiple adaptation alternatives at the same time, the weighted sum in respect to all the adaptation choices applied by a smallholder were added up to create an index for efficacy as per equation 3.28.

The following equal interval scale was used in ranking the weighted sum of adaptation into three levels as shown in equation (3,29) (Thi and Chaovanapoonphol, 2014; Steven, 1946:

$$Interval = \frac{Highest\ Value - Lowest\ Value}{3} \dots\dots\dots 3.29$$

3.11.4 Data Processing Relating to Analyzing Determinants of Level of Efficacy of Adaptation

(i) The ordered probit model was subjected to the following diagnostic tests:

3.11.4.1. Specification Tests

(a) Linktest

Linktest was conducted to check whether the ordered probit model was correctly specified. Some of the aspects checked included whether the model required more variables (Torres-Reyna,2007). The linktest is based on running a regression of the observed dependent variable against the predicted dependent variable and the square of the predicted dependent variable. The null hypothesis is that there is no specification error if the specified model yields a significant \hat{u} and an insignificant \hat{u}^2 (Long and Freese, 2001).

(b) Parallel Regression Assumption Test

The ordered probit regression assumes that outcome groups have the same relationship. That is, the coefficient describing the relationship between all the categories are the same and therefore provides only one set of coefficients (Long and Freese, 2001). A

likelihood ratio test of equality of coefficients across response categories with the null hypothesis that there is no difference in the coefficient between the models for each of the categories to test the parallel regression assumption was undertaken (Long and Freese, 2001). The test compares the log likelihood from the oprobit model to the one obtained by pooling the J-1 binary model estimated by probit (Long and Freese, 2001). A statistically significant result implies that the coefficients are different.

3.11.4.2 Model Fit

The goodness of fit was assessed based on Wald test. It tests the hypothesis that all the coefficients except the intercept are simultaneously equal to zero (Long and Freese, 2001). If the null hypothesis is rejected at 5 percent level of significance, then it implies that the coefficients are not simultaneously equal to zero.

3.11.4.3 Multicollinearity

Further to the assessment of correlation among the variables, multicollinearity was tested based on Variance Inflation Factor (VIF). VIF greater than 10 indicates serious multicollinearity, VIF greater than 5 indicates critical multicollinearity while VIF of 2.5 indicates moderate multicollinearity (Williams, 2015). Multicollinearity was also tested based on Pearson Correlation Coefficient to identify whether there were collinear variables (Hinkle *et al.*, 2003). Variables were considered to have moderate collinearity if the Pearson Correlation coefficient ranged between 0.50 and 0.70 (Hinkle *et al.*, 2003).

(ii) Transformation of the Variable “Number of Adaptations”

The variable “number of adaptations” was transformed into natural logarithm to facilitate estimation of the ordered probit model. Thereafter, the proportional change of the natural logarithm of number of adaptations for the low, moderate and high efficacy of adaptation arising from the marginal effects were converted to percentage to facilitate interpretation. A log transformed variable is multiplied by the base $e=2.71828$ (Bernoit, 2011). Let the proportional change of the natural logarithm of number of adaptations equal to y . The proportional change of the natural logarithm of number of adaptations can be converted to percentage as follows:

$$[(2.71828 \times y) - y] \times 100 \dots\dots\dots 3.30$$

The proportional change of the natural logarithm of number of adaptations (y) is multiplied with the value 2.71828 then subtracted from itself and the result multiplied by 100 (Bernoit, 2011).

CHAPTER FOUR

EMPIRICAL FINDINGS AND DISCUSSIONS

4.1 Introduction

This chapter presents results from data analysis and their discussions. Section 4.2 presents the results on the extent of vulnerability of smallholder maize production to climate change in Kitui and Laikipia counties. Section 4.3 presents results on the determinants of vulnerability of smallholder maize production to climate change in Kitui and Laikipia counties. Section 4.4 presents results on the levels of efficacy of adaptation of smallholder maize production to climate change. Section 4.5 presents results on determinants of levels of efficacy of adaptation of smallholder maize production to climate change.

4.1.1. Response Rate

Table 4.1 presents the summary of the response rate for the present study:

Table 4.1 Response Rate

County	Sample size (frequency)	Response (frequency)	Response rate (percentage)
Laikipia	128	124	97
Kitui	283	278	98
Combined sample	411	402	98

Source: Survey data

From Table 4.1 the overall response rate was 98 percent while that for Laikipia and Kitui counties were 97 percent and 98 percent respectively. The response rate was considered adequate for further analysis. The details of respondents by county, sub-county and Ward are presented in Appendix II. Upon data cleaning, data from 397 smallholders was fit for estimation out of which 274 were from Kitui County while 123 were from Laikipia County.

4.2 Extent of Vulnerability of Smallholder Maize Production to Climate Change in Kitui And Laikipia Counties

The analysis of the extent of vulnerability of smallholder maize production to climate change was based on data from a total of 397 smallholders. The analysis involved derivation of vulnerability index by combining exposure, sensitivity and adaptive capacity indices based on equation 3.16 in section 3.4.1. Factor analysis was employed in the derivation of exposure, sensitivity and adaptive capacity indices. The results are presented in section 4.2.3.

4.2.1 Descriptive Statistics

Descriptive statistics were computed to summarize the data collected on the variables used in the analysis of the extent of vulnerability of smallholder maize production to climate change in Kitui and Laikipia counties.

4.2.1.1 Continuous Variables

The continuous variables used in the study were: rainfall anomaly (rain_Anomaly) and temperature anomaly (temp_Anomaly) representing exposure component of vulnerability; maize yield (maizYield) and age of the head of the household representing sensitivity component of vulnerability; and expenditure on certified seeds (expCertSeeds), expenditure on fertilizer (expfertilizer) and number of social groups (N_Sgrp) representing adaptive capacity component of vulnerability. Table 4.2 shows the descriptive statistics for the continuous variables aforementioned:

Table 4.2: Descriptive Statistics for Continuous Variables

Variables	Kitui County			Laikipia County			Combined		
	Median	Min	Max	Median	Min	Max	Median	Min	Max
Maize yield (bags per acre)	1.6 (2.89)	0	20.0	4 (4.89)	0	32.0	2.00 (3.82)	0	32.0
Expenditure on certified seeds (Kshs. '000' per season)	1.20 (1.50)	0	13.00	1.56 (1.27)	0	7000	1.30 (1.44)	0	13.0
Expenditure on fertilizer (Kshs. '000' per season)	0 (4.61)	0	30.0	2.70 (4.95)	0	29.00	0 (4.79)	0	30.0
Rainfall Anomaly	-0.28 (0.07)	-0.44	-0.27	-0.39 (0.27)	-1.13	-0.39	-0.35 (0.18)	-1.13	-0.27
Temperature Anomaly	0.32 (0.03)	0.27	0.35	0.33 (0.01)	0.33	0.36	0.32 (0.03)	0.27	0.36
Number of social group (numbers)	0 (1.03)	0	5.00	0 (1.05)	0	4.00	0 (1.04)	0	5.00
Age of the Head of the Household (years)	48 (13.2)	23	95	55 (10.2)	28	94	50 (12.66)	23	95

(SD-Standard Deviation; Min-Minimum; Max-Maximum); (standard deviation is presented in the parenthesis)

Source: Survey data

Table 4.2 shows that half of the smallholders sampled had maize yield below 2 bags per acre. However, in Laikipia County half of the smallholders had maize yield below 4 bags per acre which was higher than in Kitui County (1.6 bags per acre). Statistics further show that half of the smallholders in the combined sample spent below Kenya Shillings 1,300 per season. In Laikipia County half of the smallholders spent below Kenya Shillings 1,560 which was higher than smallholders in Kitui County (Kenya Shillings 1,200). On the other hand, half of the smallholders in the combined sample and in Kitui County did not buy fertilizers while in Laikipia County half of the smallholders spent below Kenya Shillings 2,700.

The climate variables showed that rainfall had varied negatively while temperature anomaly varied positively implying rainfall had decreased while temperature had increased. The rainfall anomaly was higher for half of the smallholders from Laikipia County (-0.27) than Kitui County (-0.28). On the other hand, the temperature anomaly for half of the smallholders in Laikipia County was higher (0.33) than Kitui County (0.32).

Statistics further indicated that half of the smallholders in Kitui County and Laikipia County did not belong to social groups. Furthermore, half of the heads of the households in the combined sample were below 50 years old. However, in Laikipia County half of the heads of the households were older (55 years) than smallholders in Kitui County (48 years old).

4.2.1.2 Categorical Variables

The following categorical variables were used in the study: crop pests and diseases (croppests_diseases1), famine, drought, knowledge of soil type (know_soiltype), irrigation and perceived climate changes (Perceivedclim_changes) representing exposure component of vulnerability; crop failure (crop_failure1), maize period (maize_period), frequency of fetching water (water_freq1) and buy maize representing sensitivity component of vulnerability; and extension access (extension_access), education (edu1) and input subsidies (inputSubsidies) representing adaptive capacity component of vulnerability. Table 4.3 shows the descriptive statistics for the discrete variables aforementioned:

Table 4.3: Descriptive Statistics for Discrete Variables

Variable	Categories	Kitui		Laikipia		Combined	
		Frequency	%	Frequency	%	Frequency	%
Knowledge of soil type	No	121	44	54	44	175	44
	Yes	153	56	69	56	222	56
Extension access	No	78	28	6	5	84	21
	Yes	196	72	117	95	313	79
Perceived climate changes	No	11	4	0	0	11	3
	Yes	263	96	123	100	386	97
Crop failure	Occasionally	121	44	61	50	182	46
	Rarely	19	7	9	7	28	7
	Frequently	134	49	53	43	187	47
Crop pests diseases	frequently	135	49	49	40	184	46
	occasionally	73	27	70	57	143	36
	V. frequently	66	24	4	3	70	18
Famine	Never	114	42	66	54	180	45
	Rarely	16	6	17	14	33	8
	Occasionally	77	28	32	26	109	28
	Frequently	54	20	7	5	61	15
	V. frequently	13	4	1	1	14	4
Drought	Never	110	40	22	18	132	33
	Rarely	10	4	15	12	25	6
	Occasionally	67	24	41	33	108	27
	Frequently	63	23	40	33	103	26
	V. frequently	24	9	5	4	29	8
Frequency of fetching water	Daily	214	78	84	68	298	75
	Weekly & beyond	60	22	39	32	99	25
Irrigation	No	253	93	95	77	348	88
	Yes	21	7	28	23	49	12
Input Subsidies	Received subsidies	65	24	42	34	107	27
	No subsidies	209	76	81	66	290	73
Maize period	< one month	18	5	4	1	22	6
	1-3 months	79	20	23	6	102	26
	4-6 months	77	19	39	10	116	29
	7-9 months	16	4	14	3	30	7
	10-12 months	35	9	19	5	54	14
	> 12 months	49	12	24	6	73	18
Buy maize	Buy	224	82	85	69	309	78
	Do not buy	50	18	38	31	88	22
Education	Secondary	60	22	50	41	110	28
	No formal	39	14	22	42	41	10
	Primary	143	52	66	54	209	53
	Tertiary	32	12	5	4	37	9
Number of observations		274		123		397	

Source: survey data

From Table 4.3, a considerable proportion of smallholders (56 percent) knew the soil type on their farms. In addition, most of the smallholders had access to extension services (79 percent) out of which 72 percent were from Kitui County while 95 percent were from Laikipia County. Furthermore, all the smallholders from Laikipia County and 96 percent of the smallholders from Kitui County perceived changes in climate.

Most of the smallholders encountered crop failure occasionally (46 percent) and frequently (47 percent). The statistics show that the occurrence of crop failure affected Kitui County more than Laikipia County since most smallholders from Kitui County experienced crop failure frequently (49 percent) as compared to Laikipia County (43 percent). Many (46 percent) smallholders sampled were affected by pests and diseases frequently while few (18 percent) were affected very frequently. However, for Laikipia County, the majority (57 percent) of the smallholders were affected by pests and diseases occasionally. Similarly, the majority of the smallholders who had experienced famine (58 percent) were from Kitui County while 46 percent were from Laikipia County. Overall, occurrence of crop failure, crop pests and diseases and famine affected Kitui County much more than Laikipia County.

The statistics further indicate that smallholders from Laikipia County (82 percent) were affected by drought much more than those from Kitui County (60 percent). In addition, the frequency of fetching water for the majority (75 percent) of smallholders was daily, most of whom were from Kitui County (78 percent). From the findings, very few respondents (12 percent) practised irrigation.

Majority of the smallholders who did not access input subsidies (76 percent) were from Kitui County while 66 percent were from Laikipia County. In addition, maize produced lasted most smallholders 4-6 months (29 percent) most of whom were from Kitui County. However, in Kitui County maize produced lasted the majority of smallholders (20 percent) 1-3 months while in Laikipia County it lasted 6 percent of the smallholders. Similarly, the majority of the smallholders (78 percent) had high dependency on maize (buy maize) out of which 69 percent were from Laikipia County and 82 percent were from Kitui County. In this sample, the highest proportion (53 percent) of smallholders had primary education; the majority (54 percent) were from Laikipia County while 52 percent were from Kitui County. Overall, very few (9 percent) had tertiary education while 10 percent had no formal education.

4.2.2 Diagnostic Tests

In order to compute vulnerability of smallholder maize production, the study employed factor analysis. The common factors were expressed as a linear combination of a set of variables representing exposure, sensitivity and adaptive capacity in line with equation 3.26. The correlation matrix for each of the equations was assessed. In addition, Bartlett's test of sphericity was conducted on each of the models to determine whether the distribution of values in the sample was adequate.

(a) Bartlett's Test of Sphericity

Bartlett's test to establish whether the distribution of values in the sample was adequate for factor analysis was conducted. The results are presented on Table 4.4.

Table 4.4: Results of the Bartlett's Test of Sphericity

	Exposure	Sensitivity	Adaptive capacity
KMO	0.53	0.61	0.63
Chi-square	189.956	84.86	97.569
p-value	0.000	0.000	0.000
Determinant of correlation matrix	0.616	0.806	0.780

Source: survey data

From Table 4.4, the KMO was found to be 0.53 for exposure, 0.61 for sensitivity and 0.63 for adaptive capacity thus satisfying the KMO criteria for factor analysis to be conducted (Taherdoost *et al.*, 2014). In addition, the null hypothesis that the correlation matrix was an identity matrix was rejected at 1 percent level of significance in all cases implying that the observed correlation matrix was not obtained from a population with zero correlation (Taherdoost *et al.*, 2014). In addition, the determinant of the correlation matrix was found to be greater than 0.00001 thus satisfying the requirement for factor analysis to be conducted (Field, 2009).

(b) Correlation Among Variables

The correlation among variables was assessed based on a polychoric correlation matrix for variables on exposure, sensitivity and adaptive capacity. The polychoric correlation matrix was appropriate since variables used in the factor analysis consisted of binary, continuous and ordinal (Watkins, 2018). There was no multicollinearity among the variables. In addition, orthogonal rotation of factors was applied to ensure that factors were uncorrelated with each other to ensure reliable estimates (Yakubu *et al.*, 2009). The correlation matrices for exposure, sensitivity and adaptive capacity are presented on Tables A1, A2 and A3 respectively on Appendix VI.

4.2.3 Empirical Results

The extent of vulnerability of smallholder maize production to climate change was established through factor analysis. Equation 3.26 in section 3.11.1 was solved to obtain the factor loadings, Eigenvalues and proportion of variance explained for the models on exposure, sensitivity and adaptive capacity (Field, 2009). Thereafter, equation 3.17, 3.18 and 3.19 in section 3.4.1 were solved to obtain the standardized regression coefficients (Nelson, 2007). Table 4.5 presents the results of factor analysis.

Table 4.5: Results of Factor Analysis

Variables	Factor loading	Standardized regression coefficient
Exposure		
Rainfall anomaly	0.0284	0.03970
Temperature anomaly	-0.0774	-0.00536
Crop pests and diseases	0.1628	0.02319
Famine	0.6825	0.39075*
Drought	0.6216	0.29721*
Knowledge of soil type	0.0193	0.00525
Irrigation	0.0425	0.02249
Perceived climate changes	0.6134	0.34403*
Sensitivity		
Maize yield	-0.3210	-0.14658*
Crop failure	0.4410	0.21954*
Age	-0.2280	-0.10755
Maize period	0.1243	0.06402
Water frequency	-0.5187	-0.28046*
Buy maize	0.6145	0.37539*
Adaptive capacity		
Extension access	0.5843	0.32550*
Education	-0.0237	-0.01228
Input subsidies	0.5456	0.30240*
Expenditure on certified seeds	0.2267	0.06652
Expenditure on fertilizer	0.3955	0.17145*
Number of social groups	0.4903	0.24475*
Eigenvalue exposure =1.31276 Eigenvalue sensitivity= 1.01163 Eigenvalue adaptive capacity=1.08789 Total observations=397		

(Factor loading greater than 0.30 is statistically significant (*))

Source: Survey data

From Table 4.5, it can be observed that the first factor with an eigenvalue of 1.31276 was used to generate the exposure index (Taherdoost *et al.*, 2014). On the other hand, the first factor with an eigenvalue of 1.01162 was used in generating the sensitivity index while the first factor with an eigenvalue of 1.08789 was used to generate the adaptive capacity index. To facilitate analysis, variables with factor loading greater than 0.3 for a sample size of at least 350 are considered statistically significant (Hair *et al.*, 2006). The results of factor analysis for the variables with significant factor loading in respect to the components of vulnerability are discussed below:

4.2.3.1. Exposure

For the factor explaining exposure, the coefficients of three variables (drought (0.29721), famine (0.39075) and perceived climate changes (0.34403)) were statistically significant and had a positive relationship with the factor explaining exposure. As shown, the exposure index is predicted to increase for smallholders reporting famine occurrence as compared to those who did not report famine occurrence. This is expected because famine is associated with high temperatures over a long period of time especially during the growing season leading to poor harvest. Climate change leads to increased exposure by enhancing famine in three ways: high temperatures and low precipitation especially over the growing season leading to low yield; high temperatures causes high humidity especially in arid and semi-arid areas that increase fungal infection in stored food and increase in pest attacks; and low food harvest leads to food price hikes making food inaccessible especially for the poor (ROK, 2018d; Midega, Murage, Pittchar and Khan, 2016; FAO *et al.*, 2018). The results are supported by predictions by the Organization for

Economic Cooperation and Development that lower income countries will experience food deficits by more than half of the quantities required by 2025 due to increased exposure to climate change (Balasubramanian, 2018). This result suggests that when climate is favourable for maize production, actions such as proper preservation of maize during glut for consumption during famine could minimize famine. Data has shown that a large proportion of smallholders in the sample were affected by famine.

It was further established that the exposure index is predicted to increase for smallholders reporting drought occurrence as compared to those who did not report drought occurrence. The results were as expected since Kitui and Laikipia counties, just like the rest of the counties in Kenya, rely mainly on rainfed agriculture. Drought occurrences have increased in the recent past in Kenya. (Physicians for Social Responsibility (PSR) (2013) reported that land area for producing crops such as corn affected by drought increased from 5-10 percent in the 1960s to 15-25 percent in the 2000s. In addition, drought exacerbates exposure leading to resource use conflicts which have been reported in Laikipia County and this affects maize production (ROK, 2018d). A similar result was obtained by Adepetu and Berthe (2007) who found that more drought episodes increased exposure to climate change and contributed to loss of assets thus enhancing vulnerability. It is projected that drought will elevate exposure to climate change by becoming more common and worse in areas where they are prevalent and could lead to an increase in the number of people predisposed by 9 percent to 17 percent by 2030 (Hallegatte *et al.*, 2015). The results suggest that building coping mechanisms such as early warning information and enhancing access to water could minimize the adverse impact of

drought. United Nations Convention to Combat Desertification (2022) suggests strengthening the capacity of communities to anticipate, respond or recover from drought efficiently and timely. However, Mukherjee and Mishra (2018) notes that man-made infrastructure such as dams and reservoirs established to enhance water supply could cause hydrological based drought.

Furthermore, exposure index is predicted to increase for smallholders who perceived changes in climate as compared to those who did not perceive changes in climate. The result was as expected and implies that smallholder maize production was highly exposed to climate stimuli. Exposure of maize production to climate change could be elevated by late or early onset of rainfall (Bedeke *et al.*, 2018). It is worth noting that the start and the end of the growing season differs with regions making targeted awareness of the right timing for smallholder maize production imperative (Reidsma and Ewert, 2008). Pickson and He (2021) found that unpredicted rainfall patterns enhanced exposure to climate change. The uncertainty of the onset of rains and duration of the growing season in Laikipia and Kitui County and moisture stress was perceived to enhance exposure to climate change (MoALF, 2017; MoALFC, 2021). These findings suggest that supply of climate information at the beginning of each cropping season and in between the season could facilitate reduction of the adverse impact of exposure on smallholder maize production.

4.2.3.2. Sensitivity

The coefficients for crop failure (0.21954), maize yield (-0.14658), water frequency (-0.28046) and buying maize (0.37539) explaining sensitivity were statistically significant. The findings show that sensitivity index is predicted to increase for smallholders who buy maize as compared to those who do not buy maize. The results are as expected and implies that buying maize increased sensitivity to climate changes. Smallholders, especially the poor, are much more sensitive to price changes than those who are not poor (Hallegatte *et al.*, 2015). Zelingher, Makowski and Brunelle (2021) found that a small decline in maize yield in Northern America increased sensitivity due to the likelihood of increase in global maize prices.

Sensitivity index is predicted to increase for smallholders reporting crop failure as compared to those who did not report crop failure. The finding implies that maize production is highly sensitive to climate changes. Crop failure was serious considering that a large proportion of smallholders had encountered it. Crop failure in Kitui County and Laikipia County were linked to reduced rainfall (MoALF, 2017; MoALFC, 2021). Sensitivity of maize production to climate change leading to crop failure is caused by low soil moisture attributed to delayed rainfall thus affirming the need to adjust cropping dates (Bedeke *et al.*, 2018). Sensitivity could be reduced by growing drought tolerant maize varieties based on the findings by Simtowe *et al.* (2019) that crop failure was reduced by 30% in Uganda by growing drought tolerant crops. The results suggest the need to implement coping mechanisms that reduce sensitivity of smallholder maize production to climate change.

Conversely, sensitivity index is predicted to reduce when yield increases by one unit. This implies that smallholders with high maize yields had less sensitivity. The result is as expected considering that smallholders from the two counties had great dependency on maize. Maitah *et al.*, (2021) established a negative correlation between maize yield and water deficit in the Czech Republic implying increased sensitivity. Furthermore, Mulungu and Ng'ombe (2019) established negative sensitivity of maize yields to temperatures of 35 Degrees Celsius and above alongside decrease in rainfall. Srivastava, Panda and Chakraborty (2021) projected differing sensitivity of maize yields over different periods for Eastern India under rainfed conditions (lower yields were projected for the period (2051 to 2080) than (2021-2050)). The finding suggests irrigation with rain harvested water could guarantee better yields consequently reduced sensitivity implying need to invest in water harvesting infrastructure.

On the other hand, sensitivity is predicted to reduce for smallholders reporting weekly and beyond frequency of fetching water as compared to daily. This implies that smallholders with low water storage capacity fetch water frequently and are likely to have water shortages especially during seasons with low rainfall hence high sensitivity. Water scarcity was reported in Kitui County as a result of drying rivers thereby increasing sensitivity (MoALFC, 2021). This is supported by studies that found that water shortage contributed to high sensitivity (Sisay, 2016; Madhuni *et al.*, 2014). The most sensitive regions were those that relied heavily on rainfed agriculture (Gbetibouo *et al.*, 2010). This reinforces the need for alternative sources of water to support maize production.

4.2.3.3. Adaptive Capacity

The coefficients of access to extension (0.3255), input subsidies (0.3024), expenditure on fertilizer (0.17145) and number of social groups (0.24475) explaining adaptive capacity were statistically significant. The adaptive capacity index is predicted to increase for smallholders who had access to extension services as compared to those who had no access to extension services. This implies that the capacity to adapt to climate change for smallholders who accessed extension services was high. The finding was as expected because smallholders are guided on better agronomic practices which facilitate adaptive capacity for increased maize production. MoALF (2017) points out that farmers located far from extension officers in Laikipia County were likely to miss out on timely and up to date information requisite for farming thus reduce their adaptive capacity. The importance of extension services was also noted in other studies (Opiyo *et al.*, 2014; Chepkoech *et al.*, 2020). It is worth noting that the majority of the smallholders in the present study had access to extension services. Increase in frequency of extension services was fundamental.

Adaptive capacity index is predicted to increase for smallholders who received input subsidies as compared to those who did not receive input subsidies. This is expected because input subsidies facilitate reduction in the cost of maize production and therefore enhance adaptive capacity to produce more maize. Low adoption of inputs in crop production was reported in Kitui County indicating low adaptive capacity (MoALFC, 2021). Input subsidies could be provided in the form of chemicals, fertilizers and seeds (Searchinger *et al.*, 2020). Earlier studies (Epule *et al.* (2017); Antwi-Agyei *et al.* (2012))

found that poor households could not afford adequate quantities of input to support maize farming thus restraining their ability to cope with impacts of climate change. Therefore, provision of input subsidies could be critical in enhancing adaptive capacity. Searchinger *et al.* (2020) observed that the contribution of input subsidies to increased maize yield was modest. This was attributed to support flowing more to large scale than small scale farmers. The results suggest the need to ensure farm inputs were more affordable and available to smallholders to boost their adaptive capacity.

The findings also indicate that adaptive capacity index is predicted to increase for smallholders who increased the number of social groups they belonged to significantly. The result suggests that social groups could be one of the ways to enhance maize production resources hence enhanced adaptive capacity. This was corroborated by Pickson and He (2021) who found that farmers who belonged to social groups had a higher adaptive capacity to climate change. Social groups are fundamental in learning, pooling and sharing of resources and information. In addition, earlier studies (Antwi-Agyei *et al.* (2012); Opiyo *et al.* (2014); Chepkoech *et al.* (2020)) alluded that non-governmental and government institutions and policies promoted adaptive capacity thus corroborating the positive relationship between adaptive capacity and number of social groups.

Adaptive capacity index is predicted to increase for smallholders who increased expenditure on fertilizer by one shilling. This denotes that fertilizer was an essential input to maize production. This result underscores that increase in use of fertilizer whether

organic or inorganic could boost smallholders' adaptive capacity. Sigaye, Nigussei, Lulie, Nekuria and Kebede (2020) observes that combination of organic and inorganic fertilizer improves soil properties leading to higher maize yields, enhanced economic returns and hence higher adaptive capacity.

4.2.4 Average Exposure, Sensitivity, Adaptive Capacity and Vulnerability Indices

The average exposure, sensitivity and adaptive capacity indices derived in line with equations 3.17, 3.18 and 3.19 in section 3.4.1 were computed for Laikipia and Kitui County. Thereafter, vulnerability index was established by combining exposure, sensitivity and adaptive capacity indices as per equation 3.16 in section 3.4.1. The derivation of exposure, sensitivity and adaptive capacity indices was based on unequal weighting of variables whereas aggregation of these components to the overall vulnerability index was based on equal weighting (Baptista, 2014). The respective indices for each smallholder are presented in Appendix VII. Table 4.6 shows the average exposure, sensitivity, adaptive capacity and vulnerability indices in the two counties:

Table 4.6: Exposure, Sensitivity, Adaptive Capacity and Vulnerability Indices

Description	Kitui	Laikipia	Combined
Mean exposure index	1.299827	1.236506	1.28021
Mean sensitivity index	0.576215	0.469995	0.54331
Adaptive capacity index	0.377363	0.499167	0.4151
Vulnerability Index	1.498678	1.207334	1.40841

Source: Survey data

The findings as shown on Table 4.6 indicate that exposure contributed the most to vulnerability as compared to sensitivity as shown by the results for Laikipia, Kitui and

combined results for the two counties. In addition, the average adaptive capacity index was the lowest for the combined sample and Kitui County while sensitivity index was the lowest for Laikipia County of the three components of vulnerability. The lower sensitivity for Laikipia County contributed to reduced vulnerability as compared to vulnerability for Kitui County and combined sample. The findings imply that enhancement of adaptive capacity would be critical in reducing sensitivity and impacts of exposure of smallholder maize production to climate change. The smallholders were further categorized into three terciles as shown in Table 4.7:

Table 4.7: Distribution of Smallholders by Vulnerability Index

Description		Kitui	Laikipia	Combined
Lowest tercile	Frequency	85	48	133
	Percentage	31	39	33.50
	Minimum vulnerability index	(0.77587)	(0.56949)	(0.7758737)
	Maximum vulnerability index	0.987944	1.003853	1.003853
Middle tercile	Frequency	82	50	132
	Percentage	30	41	33.25
	Minimum vulnerability index	1.016638	1.008913	1.008913
	Maximum vulnerability index	1.742728	1.741506	1.742728
Highest tercile	Frequency	107	25	132
	Percentage	39	20	33.25
	Minimum vulnerability index	1.773481	1.749989	1.749989
	Maximum vulnerability index	3.928847	2.898821	3.928847
50 th percentile	Median smallholder	1.513331	1.192464	1.38807

Source: Survey data

From Table 4.7, the vulnerability index ranged from -0.77587 to 3.928847 and was categorized into lowest, middle and highest tercile. From Table 4.7, smallholders with vulnerability index less or equal to 1.003853 were in the lowest tercile; smallholders with

vulnerability index greater or equal to 1.749989 were in the highest tercile while smallholders with vulnerability index between 1.008913 to 1.742728 were in the middle tercile. The median smallholder with a vulnerability index of 1.38807 was in the middle tercile. This implies that the vulnerability in the combined sample was generally on the average.

Results in Table 4.7 shows that most of the smallholders in Kitui County (39 percent) were in the highest tercile as compared to Laikipia County where the lowest proportion of smallholders (20 percent) was in the highest tercile. The highest proportion of smallholders from Laikipia County were in the middle tercile. In addition, the mean vulnerability index for Kitui County (1.498678) was higher than the combined sample (1.40841) and was also higher than the mean vulnerability index for Laikipia County (1.207734). The mean vulnerability index for Laikipia county was lower than for the combined sample. Furthermore, the vulnerability index for the median smallholder in Kitui County was 1.513331 implying that half of the smallholders had a vulnerability index above 1.513331. On the other hand, half of the smallholders in Laikipia County had a vulnerability index above 1.192464 which was much lower compared to Kitui County. The results imply that many smallholders in Kitui County were more vulnerable than smallholders in Laikipia County.

From the findings on Table 4.6, it can be deduced that Kitui County located in the lowland had higher exposure, higher sensitivity and a lower adaptive capacity as compared to Laikipia County which is in the highlands. The results in Table 4.6 and

Table 4.7 show that smallholders in Kitui County were more vulnerable than smallholders in Laikipia County. The results imply that high adaptive capacity reduces overall vulnerability. This finding was in congruence with the findings of Tessema and Simane (2019) that lowland areas had higher exposure and sensitivity but a low adaptive capacity. The higher sensitivity by smallholders from Kitui County relative to Laikipia County could have been occasioned by the fact that the majority had a higher frequency of crop failure and were buying maize to address maize shortage making them susceptible to high prices (Hallegatte *et al.*, 2015). The findings by Epule *et al.* (2017) that areas with households unable to invest in farm inputs had low adaptive capacity corroborates the findings for Kitui County where investment on inputs was much lower than Laikipia County.

The finding is also supported by Gbetibouo, Ringler and Hassan (2010) who found that areas with higher adaptive capacity were better-resourced and therefore less vulnerable while areas with high exposure were mainly located in highly degraded land areas. It is further corroborated by MoALFC (2021) who observed that farmers in lowland areas were more vulnerable to climate change due to high exposure to drought, heat stress and moisture stress. Reidsma and Ewert (2008) also found that areas with low water availability as was established for Kitui County would not be able to cope with high exposure. In addition, the Human Development Index for Kitui County was lower (0.481) for Kitui County than for Laikipia County (0.574) (Republic of Kenya, 2018b and 2018c). Moreover, Kitui County had a higher level of poverty relative to the national level (Republic of Kenya, 2018b). The results suggest that enhancing adaptive capacity

of smallholder maize producers in Kitui County could facilitate reduction in levels of vulnerability.

4.3 Determinants of Vulnerability of Smallholder Maize Production to Climate Change in Kitui and Laikipia County

The Ordinary Least Squares (OLS) regression was employed to establish the determinants of vulnerability of smallholder maize production to climate change using the vulnerability index derived from section 3.4.1. The concerns about weighting during establishment of the vulnerability index were alleviated by applying factor analysis which facilitated objective weighting of variables under exposure, sensitivity and adaptive capacity (Baptista, 2014). In addition, the establishment of exposure, sensitivity and adaptive capacity indices prior to aggregation ensured that the sub-components were equally weighted in the overall vulnerability index (Baptista, 2014). Section 4.3 presents the descriptive statistics of the independent variables, diagnostic test results and the regression results.

4.3.1 Descriptive Statistics

The variables used to analyze the determinants of vulnerability of smallholder maize production to climate change included continuous and discrete variables.

4.3.1.1 Continuous Variables

The continuous variables used in the analysis of the determinants of vulnerability of smallholder maize production to climate change in Kitui and Laikipia counties was

household size (Hhsize). Table 4.8 presents the descriptive statistics for the continuous variables:

Table 4.8: Descriptive Statistics for Continuous Variables

Continuous variable	Kitui County N=274				Laikipia County N=123				Combined N=397			
	Mean	SD	Mn	Mx	Mean	SD	Mn	Mx	Mean	SD	Mn	Mx
Household size (Number)	6	2.5	1	17	5	1.6	1	9	6	2.3	1	17

(SD-Standard Deviation; Mn-Minimum; Mx-Maximum)

Source: survey data

From Table 4.8 statistics show that the largest household had 17 members while the smallest household had 1. The average household size in Kitui County was 6 which was higher than household size in Laikipia County (5).

4.3.1.2 Categorical Variables

The categorical variables used in the analysis of the determinants of vulnerability of smallholder maize production to climate change in Kitui and Laikipia counties were: agroecological zone (AgroecologZone), county, maize shortage period (maizeshort_period), suffered from climate related human diseases (Suffer_climDiseases), length of time stored water lasted (Stored_WaterPeriod), accuracy of climate information (accuracy_clinfo), land type (Landtype1), farm type (Farm_type), marital status, eating alternatives to maize (eatAlt). Table 4.9 presents the descriptive statistics for these variables:

Table 4.9: Descriptive Statistics for Categorical Variables

Categorical Variable		Kitui County N=274		Laikipia County N=123		Combined N=397	
		Frequency	%	Frequency	%	Frequency	%
Agroecological zone	LM4	62	16	0	0	-	-
	LM4-5	59	15	0	0	-	-
	UM3-4	76	19	0	0	-	-
	LM5	62	15	0	0	-	-
	LH1-5	0	0	94	24	-	-
	UM5-6	0	0	29	7	-	-
	LM3	15	4	0	0	-	-
Maize shortage period	No shortage	45	11	36	9	81	20
	Less than three months	27	7	12	3	39	10
	4-6 months	72	18	28	7	100	25
	over 6 months	130	33	47	12	177	45
Suffered from climate related human diseases	No	120	30	60	15	180	45
	Yes	154	39	63	16	217	55
Stored water Period	one week & beyond	66	24	83	67	149	38
	one day	208	75	40	33	248	62
Accuracy of climate information	No	135	34	64	16	199	50
	Yes	139	35	59	15	198	50
Marital status	Widow/widower	28	10	14	11	42	11
	Single	14	5	14	11	28	7
	Married	223	81	93	76	316	80
	Divorced	9	3	2	2	11	3
Land type	Communally owned	168	61	29	24	197	50
	Privately owned	106	39	94	76	200	50
Farm type	Crop farming	33	17	5	6	38	14
	Mixed farming	157	83	78	94	235	86
Eating alternatives to maize	No	194	49	84	21	278	70
	Yes	80	20	39	10	119	30

Source: survey data

From Table 4.9, the following agroecological zones were in Kitui County: UM3-4, LM3, LM 4, LM4-5 and LM5 while LH1-5 and UM5-6 were in Laikipia County. As shown in Table 4.9, many respondents (24 percent) resided in the agroecological zone LH1-5 while a minority (4 percent) of the respondents resided in LM3. Each of the agroecological zones were analyzed independently. Statistics further show that 31 percent of smallholders were from Laikipia County whereas 69 percent were from Kitui County. It

was also established that most of the smallholders experienced maize shortage for over six months (45 percent) majority of whom were from Kitui County (33 percent) while 19 percent were from Laikipia County and only 20 percent did not experience maize shortage. The study further established that most of the respondents (55 percent) suffered from climate related diseases, the majority of whom were from Kitui County. The study also found that stored water by most smallholders (62 percent) lasted one day out of which 75 percent were from Kitui County whereas 33 percent were from Laikipia County. Furthermore, half of the respondents perceived climate information disseminated to be accurate while half did not.

The highest proportion of respondents (80 percent) were married, majority of whom were from Kitui County (81 percent). It is also worth noting that the proportion of smallholders who owned land communally was nearly the same as those who owned land privately. However, majority of smallholders who owned land communally were from Kitui County (61 percent) while in Laikipia County, the majority of smallholders (76 percent) owned private land. Furthermore, the majority of smallholders practiced mixed farming (86 percent) as opposed to crop farming only (14 percent). Most of those who practiced crop farming only were from Kitui County (17 percent) while the majority of those who practiced mixed farming were from Laikipia County (94 percent). It is worth noting that the majority of respondents (70 percent) did not eat alternatives to maize affirming the status of maize as a staple food. Nonetheless, of the 30 percent who ate alternatives to maize, many (20 percent) were from Kitui County.

4.3.2 Diagnostic Tests Results

The vulnerability index was regressed against selected independent variables based on ordinary least squares. The results of the regression were subjected to the following diagnostic tests prior to the interpretation of the regression results: specification tests, normality tests, goodness of fit test, multicollinearity tests and heteroscedasticity test. For categorical variables, the dummy variable trap was eliminated by setting one dummy variable category to zero. The model was subjected to the diagnostic tests whose detailed results are presented on Appendix VIII (Table A4, A5 and A6) and IX. The summary test results are presented on Table 4.10.

Table 4.10: Diagnostic Tests

Test	What was tested	Results	Verdict
Link test	The null hypothesis was that there was no specification error if the specified model yields a significant \hat{u} and an insignificant \hat{u}^2	The p value of the variable \hat{u} was statistically significant at 1 percent while \hat{u}^2 was statistically insignificant (0.158). The estimated model was correctly specified	Model fit for further analysis
Regression Specification Error Test (RESET)	Null hypothesis provides that the model does not have omitted variable bias	The p value of the F statistics was 0.1458. Null hypothesis was not rejected at 5 percent significance level.	Model fit for further analysis
Shapiro-Wilk normality test	The null hypothesis is that the distribution of the residual is normal.	The p value was 0.17231. Null hypothesis was not rejected at the 5 percent level of significance.	Model fit for further analysis
F-test	The null hypothesis is that coefficients of the model are jointly equal to zero.	The p value (0.0000) was significant at 1 percent level. Null hypothesis was rejected at 1 percent significance level.	Model fit for further analysis
Studentized residuals	A value of 3 and higher or a value of -3 or lower signifies the presence of an outlier.	No values exceeded 3 or were below -3. There were no outliers.	Model fit for further analysis
Cook's distance	Observations with Cook's distance values greater than 0.5 indicates great influence while values greater than 1 indicate outlier problems.	There were no influential observations.	Model fit for further analysis
Leverage	Leverage is bound between $\frac{1}{n}$ and 1 implying that observations with leverage value closer to 1 have a high leverage on the predictor variable	There were no observations with extreme leverage.	Model fit for further analysis
Variance Inflation Factor (VIF)	VIF greater than 10 indicates serious multicollinearity, VIF greater than 5 indicates critical multicollinearity while VIF of 2.5 indicates moderate multicollinearity.	Maize shortage period (category over 6 months) had the highest VIF of 2.5. This was considered as moderate multicollinearity thus the variable was included in the regression model. Mean VIF for the model was 1.61 implying multicollinearity was not a problem.	Model fit for further analysis
Pearson Correlation Coefficient	Variables were considered collinear if the Pearson Correlation coefficient was above 0.50.	The variable County and Agroecological zone had a correlation coefficient of 0.6736. Therefore, the variable "county" was omitted from the regression model.	Model fit for further analysis
White test	The null hypothesis is that the residuals are homoscedastic	The p value was 0.3067 which is greater than 0.05. The null hypothesis that the residuals of the model were homoscedastic was not rejected at 5 percent significance level.	Model fit for further analysis

Source: Survey data

4.3.3 Regression Results for Determinants of Vulnerability of Smallholder Maize Production to Climate Change

The determinants of vulnerability of smallholder maize production to climate change was estimated based on equation 3.20 in section 3.4.2 using ordinary least squares. The detailed regression output from the ordinary least squares is reported on Appendix IX. The estimation results show that the determinants of vulnerability were: agroecological zone, maize shortage period, eating alternatives to maize, accuracy of climate information, suffering from climate human diseases, stored water period and marital status. However, there was no statistically significant relationship between the vulnerability index and the following variables: household size, land type and farm type. In addition, the variable county was dropped from the analysis due to multicollinearity. The summary of the results for the independent variables with statistically significant coefficients are presented in Table 4.11.

Table 4.11: Determinants of Vulnerability of Smallholder Maize Production to Climate Change

Dependent variable: Vulnerability Index	Coef.	Std. Err.	P- value
Agroecological zone			
LM 4-5	-0.2116524	0.1310718	0.107
UM 3-4	-0.6318166	0.1279922	0.000***
LM 5	0.0712064	0.1340353	0.596
LH 1-5	-0.3232808	0.1307597	0.014**
UM 5-6	-0.2379031	0.1754271	0.176
LM 3	-0.9974157	0.2195564	0.000***
Accuracy of climate information (yes)	-0.1276646	0.0744171	0.087*
Maize shortage period			
less than three months	0.6554954	0.1443818	0.000***
4-6 months	0.7815155	0.1156078	0.000***
over 6 months	1.004095	0.1127304	0.000***
Eating alternatives to maize (yes)	-0.2385402	0.083498	0.005***
Suffered from climate human diseases (yes)	0.1897273	0.0733667	0.01***
Stored water period (one day)	0.2833599	0.0900659	0.002***
Marital status			
1.single	0.3231503	0.176725	0.068*
2.married	0.149763	0.119231	0.21
3.divorced	0.1766815	0.2496717	0.48

(***, **, *- 1 percent, 5 percent and 10 percent significance levels)

Source: survey data

4.3.3.1. Agroecological zone

Agroecological zones in Kenya were classified based on their likelihood to achieve the required temperature and water needs for leading crops such as maize (Jaetzold *et al.*, 2005). Maize zones were classified as: Lower Highland 1-3 (LH1-3), Upper Midland 1-4 (UM1-4), Lower Midland 1-4 (LM1-4) while hybrid maize zones were classified as:

Lower Highland (LH1-3), Upper Midland 1-3 (UM1-3) and Lower Midland (LM1-3) (Jaetzold *et al.*, 2005). LM5 is classified as mainly suitable for millet and livestock farming, UM5 is suitable for sorghum and livestock farming while LH5 and UM6 are suitable for ranching (Jaetzold *et al.*, 2005). The zones applicable to the current study were ranked in the following order starting with the zone with the highest potential for maize production to the lowest: LH, UM then LM (Jaetzold *et al.*, 2005). The following seven agroecological zones were considered in the study: LM4-5, UM3-4, LM5, LH1-5, UM5-6, LM3 and LM4. LH1-5 and UM5-6 agroecological zones were based in Laikipia County while LM4-5, UM3-4, LM5, LM3 and LM4 were based in Kitui County. The reference category was LM4.

Table 4.11 shows that smallholders who resided in UM3-4 are predicted to have an average vulnerability index of 0.2117 less than smallholders who resided in LM4 agroecological zone at 1 percent significance level. The results were as expected since UM3-4 ranks higher than LM4 in relation to its potential for maize production (Jaetzold *et al.*, 2005). The average vulnerability index for smallholders who resided in LH1-5 is predicted to be less by 0.3233 than the average vulnerability index for smallholders who resided in LM4 at 5 percent significance level. Although LH1-5 includes LH5 classified as suitable for ranching, it includes LH1-3 classified as maize zones (Jaetzold *et al.*, 2005). In addition, smallholders who resided in LM3 are predicted to have an average vulnerability index of 0.9974 less than smallholders who resided in LM4 agroecological zone at 1 percent significance level. This result was expected since LM3 ranks better than LM4 in relation to its potential for maize production (Jaetzold *et al.*, 2005). There was no

statistically significant difference in vulnerability in LM4-5, LM5 and UM5-6 relative to LM4.

These findings demonstrate that location is a fundamental contributor to vulnerability. Earlier studies uphold this finding (Tesso *et al.*, 2012; Roopam *et al.*, 2017; Tessema and Simane, 2019). The results show that some agroecological zones in the lowland areas contribute to less vulnerability of smallholders as compared to others. The findings point that agroecological zones representing geographical areas with defined climatic conditions that influence their ability to support crops suited for the respective zones could be a better proxy for location in the analysis of vulnerability rather than the general reference to lowland and highlands as a description of location. Agroecological zones capture differential impacts of climate change as noted by Gummadi *et al.* (2020). The findings that zone LH1-5 contributes to less vulnerability of smallholders than LM4 is supported by the findings of Tessema and Simane (2019) who found that lowland areas were more vulnerable than highland areas.

4.3.3.2. Accuracy of climate information

Accuracy of climate information was classified into smallholders who perceived the information they received was accurate and those who perceived that the information they received was inaccurate. The reference category was smallholders who did not perceive that the climate information provided was accurate. As expected, the results in Table 4.11 indicate that the average vulnerability index for smallholders who perceived that climate information relayed was accurate is predicted to be lower by 0.1277 in

comparison to smallholders who perceived it as inaccurate at 1 percent level of significance. The result implies that accurate climate information could facilitate reduction in vulnerability while inaccurate information could enhance vulnerability. Singh *et al.*, (2017) observed that climate information tailored for specific sectors or locations promoted climate smart farming systems while integration of short-term and long-term climate information facilitated building resilience.

4.3.3.3. *Maize shortage period*

The vulnerability of smallholder maize production to climate change impeded maize production capacity. Considering this, smallholders experienced maize shortage for varied periods depending on their levels of production. These periods were classified into the following four categories: less than three months, 4-6 months, over 6 months and no shortage. The variable maize shortage period was used to measure maize security. The reference category was smallholders who had no maize shortage.

Table 4.11 indicates that the coefficients of all the categories of maize shortage period in comparison to no shortage period were shown to have statistically significant influence on the vulnerability of the smallholders at 1 percent level. The results show that the smallholders who had a maize shortage period of less than three months had an average vulnerability index of 0.6555 more than those who did not experience shortage. Similarly, those with a maize shortage period of 4-6 months and over six months had an average vulnerability index of 0.7815 and 1.0041 respectively more than those who had no maize shortage. The results show that smallholders who experienced longer maize

shortage periods were more vulnerable than those who had shorter maize shortage periods.

Maize yields are projected to decline by 10-20 percent by the year 2050 which may increase incidences of maize shortage hence increased vulnerability (Omoyo *et al.*, 2015). Furthermore, Omoyo *et al.* (2015) observes that in addition to climate change, self-sufficiency in maize production was being adversely affected by low adoption of technology and high incidents of pests and diseases hence increased vulnerability. Ayinde *et al.* (2018) found that vulnerability was likely to be enhanced by low maize production due to small land sizes, fragmented farms and low maize yields due to low soil fertility hence increased incidences of maize shortage.

4.3.3.4. *Eating alternatives to maize*

The variable eating alternatives to maize was identified to assess how smallholders dealt with poor maize harvest. The variable was classified into those who ate alternatives such as millet, sorghum, cassava and yams and those who did not. The reference category was smallholders who did not eat alternatives to maize. From the results in Table 4.11, smallholders who ate alternatives to maize had an average vulnerability index of 0.1289 less than those who did not at 1 percent level of significance. This result indicates that smallholders who ate alternatives to maize had less vulnerability than those who did not. However, from the descriptive statistics the highest proportion of smallholders (70 percent) did not eat alternatives to maize.

The results suggest that smallholders depend on maize as the main source of food hence proper preservation of maize could sustain smallholders throughout the year. Stevens and Madani (2016) using the AquaCrop model to simulate maize production in Malawi, projected lower maize yields by 2080 which in addition to increased population could lead to reduction in maize available for consumption thus enhanced vulnerability. Worldwide reduction in maize production was projected and that East Africa could lose up to 40 percent of maize production leading to increase in maize prices that would exacerbate vulnerability (Mulungu and Ng'ombe, 2019). Some of the agroecological zones in this study are mostly suitable for production of maize suggesting that specializing maize production in the most suitable locations could maximize its production.

4.3.3.5. Suffered from climate human diseases

The variable suffered from climate human diseases assessed the extent to which climate human diseases contributed to vulnerability of smallholder maize production. The variable was categorized into smallholders who had suffered from climate human related diseases such as malaria, cholera and flu and those who had not. The reference category was those who had not suffered from climate human related diseases. The findings on Table 4.11 were as expected that smallholders who had suffered from climate human related diseases had an average vulnerability index of 0.1897 more than those who had not at 1 percent level of significance.

A link between some infectious diseases and vulnerability to climate change was established where some diseases were linked to very high rainfall and high humidity while others were linked to high temperatures. Prevalence and spread of water borne diseases such as cholera and flu; and vector borne diseases such as malaria are linked to flooding hence increased vulnerability (Okaka and Odhiambo, 2018). On the other hand, cardiovascular related diseases such as heart failure and stroke attributed to high temperatures also enhance vulnerability (Kakaei, Zakerimoghadam, Rahmanian, Abbasi and Dolatabadi, 2021). The socio-economic circumstances of smallholders could be worsened by the health burden arising from impacts of climate change and is more severe for those with high poverty and few economic opportunities (Maizlish, English, Chan and English, 2017). In addition, the risk of climate change worsening existing health conditions was high (Maizlish *et al.*, 2017).

It is projected that climate change could enhance vulnerability, thus increasing the prevalence of: cholera, dysentery and typhoid in lowland areas; respiratory diseases in ASALs; malnutrition; and malaria in both traditional malaria zones and new areas (World Health Organization, 2016). It is projected that towards the year 2070 approximately 83 million people in Kenya will be at the risk of contracting malaria under both high and low greenhouse gas emissions scenarios hence elevated vulnerability (World Health Organization, 2016). Conlon *et al.*, (2016) suggest that climate related disease burden could be estimated and results used to inform appropriate coping strategies. The results further suggest the need to identify climate related health issues specific to respective locations.

4.3.3.6. *Stored water period*

Water is a critical resource for smallholders' day to day needs and irrigation to supplement rainfall. The variable was classified into stored water period for one day and one week and beyond. The reference category was smallholders with stored water period of one week and beyond. The findings in Table 4.11 were as expected. Smallholders with stored water period of one day had an average vulnerability index of 0.2834 more than those with stored water period of one week and beyond at 1 percent level of significance. This implies that the longer stored water lasts the less vulnerable smallholders will be. However, the length of time stored water would last depend on the capacity of the smallholder to store water. Smallholders with a higher capacity to store water would not only use the water for domestic needs but also use it on their farms to supplement rainfall.

Al-Ansari, Abbas, Laue and Knutsson (2020) observed that climatic changes such as increasing temperature, declining precipitation and drought enhanced water scarcity thus increasing vulnerability in most of the regions of Iraq adversely affecting the agriculture sector. The results suggest that water harvesting and storage practices which boosts access and the length of time water lasts could reduce vulnerability of smallholder maize production to climate change (Deressa *et al.*, 2008). Infrastructural support towards water harvesting such as facilitating water tanks, sinking boreholes and water pumps which require substantial resources could go a long way in strengthening water harvesting by smallholders. Alavian *et al.* (2009) observes that inadequate capacity, infrastructure and institutions to manage hydrological challenges could threaten water security and

aggravate vulnerability. It was predicted that water supply could significantly decline due to the reduction in surface run-off occasioned by climate change (Schilling *et al.*, 2020; Benaddalla *et al.*, 2018; Kang, 2013).

4.3.3.7. *Marital status*

The variable marital status facilitated assessment of the vulnerability based on whether a smallholder was a widow/widower, single, married or divorced. The reference category was widow/widower. From the results in Table 4.11, it was established that smallholders who were single had an average vulnerability index of 0.3232 more than widows/widowers at 10 percent level of significance. There was no statistically significant difference in vulnerability for the married and divorced relative to widows/widowers. The result imply that widows/widowers had lower vulnerability hence better off than single smallholders. It is critical to assess the underlying factors driving this result. The results are contrary to Mohamed (2020) who found that singles were the least vulnerable to impacts of climate change in comparison to divorcees, widows/widowers and the married.

4.4 Evaluation of the Levels of Efficacy of Adaptation of Smallholder Maize Production to Climate Change

The evaluation of the levels of efficacy of adaptation was based on 273 smallholders who selected adaptation choices out of the total 397 smallholders in the preceding analysis. A total of 190 smallholders were from Kitui County while 83 were from Laikipia County. The Multiple Criteria Evaluation (MCE) was applied. In this approach, adaptation options are evaluated relative to a range of criteria (Dolan *et al.*, 2001). Each adaptation

choice was evaluated separately against the set criteria. Smallholders first selected the adaptation choices they used followed by scoring each of the adaptation choices applied in terms of: effectiveness criterion, high yield criterion, affordability criterion, farmer implementability criterion and additional benefits criterion.

The following adaptation choices were applied by smallholders: manure, fertilizer, agroforestry, changing planting dates, increasing land size, decreasing land size, irrigation, mulching, mixed cropping and conservation agriculture. Although some smallholders applied a single adaptation choice, others applied multiple adaptation choices.

4.4.1. Descriptive Statistics

The following adaptation choices facilitated evaluation of the levels of efficacy of adaptation in smallholder maize production to climate change in Laikipia and Kitui counties: manure, fertilizer, agroforestry, changing planting dates, increasing land size, decreasing land size, irrigation, mulching, mixed cropping and conservation agriculture.

Table 4.12 presents the descriptive statistics for these variables:

Table 4.12: Descriptive Statistics

Adaptation choices	Categories	Laikipia County		Kitui County		Combined	
		Frequency	%	Frequency	%	Frequency	%
Manure	No	23	28	44	23	67	25
	Yes	60	72	146	77	206	75
Fertilizer	No	61	73	134	71	195	71
	Yes	22	27	56	29	78	29
Agroforestry	No	142	75	67	81	209	77
	Yes	48	25	16	19	64	23
Changing Planting Dates	No	43	52	96	51	139	51
	Yes	40	48	94	49	134	49
Increasing Land size	No	70	84	165	87	235	86
	Yes	13	16	25	13	38	14
Decreasing Land size	No	74	89	177	93	251	92
	Yes	9	11	13	7	22	8
Irrigation	No	76	92	171	90	247	90
	Yes	7	8	19	10	26	10
Mulching	No	75	90	166	87	241	88
	Yes	8	10	24	13	32	12
Mixed Cropping	No	47	57	116	61	163	60
	Yes	36	43	74	39	110	40
Conservation Agriculture	No	65	78	129	68	194	71
	Yes	18	22	61	32	79	29
Observations 273							

Source: Survey data

From Table 4.12, Kitui County ranked higher than Laikipia County in the application of the following 6 out of the 10 adaptation choices: manure, fertilizer, changing planting dates, irrigation, mulching and conservation agriculture. On the other hand, Laikipia County led in the application of the following 4 out of 10 adaptation choices: agroforestry, increasing land size, decreasing land size and mixed cropping. Overall, the most popular adaptation alternative used by the majority of smallholders was manure (75 percent). The second most preferred adaptation choice was changing planting dates applied by 49 percent of smallholders followed by mixed cropping (40 percent). The three least utilized adaptation choices were decreasing land size applied by 8 percent of

the smallholders; irrigation applied by 10 percent of the smallholders and mulching selected by 12 percent of the smallholders.

4.4.2. Evaluation Results for the Adaptation Choices

The levels of efficacy of adaptation were derived based on the weighted scores for the adaptation choices. Smallholders first selected an adaptation choice then assigned scores to each adaptation choice in respect to effectiveness, high yield, affordability, farmer implementability and additional benefit criteria. The scores assigned were based on a five-point scale ranging from 1 (very poor score) to 5 (very high score) for each of the criteria. The scores by smallholders were multiplied by the criteria weight provided in chapter 3 section 3.11.3 to obtain the weighted scores for each adaptation choice. The summary results are presented in Table 4.13.

Table 4.13: Weighted Scores for the Adaptation Choices

Adaptation choices	Effective ness	High yield	Affordability	Farmer implement ability	Additional benefit	Weighted sum	Ranking
Manure	10.90	9.55	7.51	4.73	4.74	37.42	4
Fertilizer	11.94	9.65	6.23	3.81	4.77	36.40	7
Agroforestry	10.20	8.76	6.83	4.13	4.55	34.47	9
Changing planting dates	11.59	9.42	7.58	4.14	4.76	37.49	3
Increasing land size	9.51	9.44	6.35	5.51	4.13	34.94	8
Decreasing land size	7.42	6.17	7.20	4.98	4.04	29.80	10
Irrigation	12.38	10.21	7.13	4.67	4.80	39.20	1
Mulching	10.63	8.84	7.26	5.03	4.80	36.56	6
Mixed cropping	11.20	9.05	7.48	4.49	4.72	36.94	5
Conservation Agriculture	12.04	9.80	7.66	3.78	4.85	38.12	2

Source: survey data

Results in Table 4.13 show that although conservation agriculture had high scores on effectiveness, high yield, affordability and additional benefits, it had the lowest score on farmer implementability. Similarly, irrigation which attained high scores on effectiveness, high yield, and additional benefits criteria, had a relatively low score under the affordability criterion. Changing planting dates had high scores on affordability and effectiveness but a low score on farmer implementability. Conversely, decreasing land size which had lowest scores under the criteria effectiveness, high yield and additional benefits but a relatively high score under farmer implementability. Similarly, increasing land size had relatively low scores under the criteria effectiveness, affordability and additional benefit yet it had the highest farmer implementability. Fertilizer had low scores on the affordability and farmer implementability criteria, but relatively high scores on effectiveness and high yield criteria. The results suggest that adaptation choices that promote soil moisture and soil fertility should be prioritized over adjustment of land size since they are efficacious and could facilitate enhancement of food security.

The results on conservation agriculture in Table 4.13 suggest that capacity building and investment on farming equipment to promote conservation agriculture is necessary. A total of 29 percent of smallholders in the current study practiced conservation agriculture which is a small proportion. Conservation agriculture is robust in many ways. For instance, conservation agriculture improves water holding capacity, reduces evaporation hence facilitates minimization of the adverse impacts of climate change (Su *et al.* (2021)). Verma (2021) notes that conservation agriculture contributes to reduction of warming of the atmosphere by sequestering carbon dioxide thereby reducing the

vulnerability to impacts of global warming. Liu and Basso (2020) simulated long term maize yields using a crop model and confirmed that conservation agriculture reduced yield loss considerably as compared to conventional tillage. The enhancement of yield by conservation agriculture is attributed to presence of crop residues which facilitate enhanced soil organic matter, water retention capacity and reduction in soil water evaporation and surface runoff (Su *et al.*, 2021; Mutuku *et al.*, 2021). Conservation agriculture also reduces the cost of farming significantly since ploughing is not required and it preserves crop cover permanently (Verma, 2021). In addition, conservation agriculture saves time, reduces production and environmental costs, and improves soil quality (Jat *et al.*, 2021).

The results showing low adoption of conservation agriculture suggest that smallholders could be experiencing technical challenges. Tadesse (2016) noted that few farmers adopt conservation agriculture due to technical constraints. Conservation agriculture requires specialized equipment particularly for seeding and planting hence farmers may require training to use them appropriately (Verma, 2021). There could be uncertainties relating to management of pests especially for farmers accustomed to conventional tillage (Fanadzo, Dalicuba, Reis, Liu and Gu, 2018). Smallholders may also need knowledge on sustainable weed management strategies (Lee and Thierfelder, 2017). The results imply that although conservation agriculture was found affordable, effective and contributing to high yield, its adoption is hampered by implementation challenges. The findings suggest the need for capacity building including demonstration plots.

The results in Table 4.13 further showed that irrigation was robust in most of the categories suggesting the need to promote its application. Despite attaining high scores in most of the criteria, only 10 percent of the smallholders in the present study adopted it. Irrigation moderates canopy temperature thus reducing heat stress on crops and thereby effective in reducing loss in maize production (Moradi *et al.*, 2013). Furthermore, it also contributed to increased maize yields as compared to baseline values (Moradi *et al.* 2013; Olajire *et al.* 2020)). Irrigation also promotes increase in farm income besides lessening adverse impacts of climate change (Osewe, Liu and Njagi, 2020; Da Cunha, Coelho and Feres, 2015). The low adoption and low score on account of affordability suggest the need for policies that promote adoption of irrigation such as subsidies on irrigation and water harvesting equipment.

Fertilizer was robust on account of high scores under effectiveness and high yield criteria as shown in Table 4.13. However, the low score on affordability and farmer implementability criteria suggest need for subsidies and extension services or access to application manuals. Knowledge on the right time, type and quantity of fertilizer and condition of the soil is necessary. Fagariba *et al.* (2018) found that fertilizer was less affordable to the majority of farmers even though they acknowledged that it boosted yields. It was therefore ranked low among other adaptation choices such as changing planting dates, agroforestry, manure, irrigation and growing drought resistant crops. Other studies (Wushuai *et al.*, 2021; Elise *et al.*, 2020) found that fertilizer costs could be prohibitive leading to low application especially with increase in land size. In China, increase in subsidies made fertilizer affordable leading to increased agricultural

productivity (Ren *et al.*, 2019). Besides the cost of fertilizer, farmer implementability may hamper successful adoption of fertilizer. Mideksa, Moti and Fikadu (2021) found that the majority of the farmers applied fertilizer below the recommended quantities. However, education was found to improve the intensity of fertilizer usage attributed to the ability of farmers to understand and interpret information (Mideksa *et al.*, 2021).

The findings on changing planting dates in Table 4.13 suggest that accurate identification of appropriate planting time could promote this adaptation choice. This adaptation choice does not require any financial outlay. Changing planting dates by smallholders mostly depends on indigenous knowledge (Nyakaisiki, Mugume, Ngailo and Nakabugo, 2019). Waongo, Laux and Kunstmann (2015) observed that changing planting dates was a low-cost climate change adaptation strategy. Although affordable, smallholders may be challenged in determining when to commence planting. Mugiyo, Mhizha, Chimonyo and Mabhaudhi (2021) found that there was no consistency on the dates reported by farmers as the early planting date. The study recommended establishment of a crop calendar to facilitate selection of planting time in respect to specific crop varieties.

Table 4.13 further shows that mulching had the highest weighted score under the farmer implementability criterion. The results are plausible because most commonly used mulches are largely available locally from the farms. Some of the materials used include: crop residues such as ground nut cover, wheat and paddy straws, dry leaves, grass, bark, sawdust and compost (Telkar *et al.*, 2017). Mulch is applied on the surface of land artificially or naturally therefore is not knowledge intensive (Ranjan *et al.*, 2017).

Mulching on the other hand helps to moderate soil temperature, conserves soil moisture and suppresses diseases and pests (Ranjan *et al.*, 2017). The results suggest the need for sensitization of smallholders on mulching to promote the practise since only 12 percent of smallholders in the study practised mulching.

Decreasing land size was not as robust as other adaptation choices in most of the criteria other than farmer implementability as shown in Table 4.13. For instance, it had the lowest score on effectiveness, high yield and additional benefits criteria. The results suggest that adjustment of farm size may not be effective in reducing losses in maize production or increasing yield. The result is supported by Abdulaleem *et al.* (2019) who established a positive relationship between farm size and maize yield. However, increased yield due to reduction of farm size could occur if fertility levels of the cultivated land were high (Gollin, 2018). Conversely, if land with low fertility was further reduced then yields would decline.

Table 4.13 shows that increasing land size attained high score under the criterion farmer implementability suggesting that it is the easiest adaptation choice to implement as it does not require technical knowledge to apply. Adjustment of land size could be affected by other factors such as inability of farmers to apply adequate input to boost production in the case of increasing land size (Zhang *et al.*, 2021). However, in the present study, increasing land size had a relatively high score under high yield criterion. The results suggest that combining adjustment of land size and other adaptation choices could promote achievement of desired results.

The finding on agroforestry in Table 4.13 was not as expected. Agroforestry was expected to have relatively high scores under high yield and additional benefits. Agroforestry is associated with a long-time lag before benefits are derived. The results imply that smallholders may prefer adaptation choices with benefits realized within the short run. Agroforestry is instrumental in improving microclimate, carbon sequestration, soil fertility and soil moisture, but may contribute to low maize yields since smaller crops may compete for light, water and nutrients with the trees (Nyaga, Muthuri, Barrios, Oborn, Sinclair (2019). In addition, agroforestry may inhibit use of machinery during farming due to hindrance by the roots of the trees thus the low implementability (Ibrahim *et al.*, 2019). The findings on agroforestry suggest that provision of technical guidance on agroforestry to smallholders could enhance its adoption and its ability to promote increased yields. For instance, identification of the right tree species to combine with maize production and the right tree species for the respective agroecological zones since results could be site specific (Raskin and Osborn, 2019). Planting of fruit trees could contribute to additional benefits to smallholders. The findings further suggest the need for proper farm planning and diversification of trees to enhance positive results on the five criteria.

Although manure and mixed cropping are practiced by the majority of smallholders and deemed affordable, they did not emerge top but ranked 4th and 5th in aggregate score as shown in Table 4.13. The result may imply that better results from these two choices are realized when practiced alongside other adaptation choices. Fagariba *et al.* (2018) found that manure was ranked 3rd and observed as a good adaptation choice to boost soil

fertility and was more affordable than fertilizer. Asfaw *et al.* (2014) found that manure could be substituted with fertilizer but was complementary to mixed cropping. Manure enhances soil organic matter hence increased soil infiltration and water holding properties (Ndambi, Pelster, Owino, Buisonje and Vellinga, 2019). In addition, mixed cropping and manure were attributed to reduced cost of managing soil fertility (Oyetunde-Usman *et al.*, 2020).

The benefits of adaptation are undisputed. However, variations in adoption dictates the end results for smallholders. It was noted that adaptation choices ranking high in most of the criteria have low adoption. This suggests the need to support smallholders to enhance their adoption. It is also critical to build smallholders capacity in applying multiple adaptation choices.

4.4.3 Distribution of Smallholders Based on the Levels of Efficacy of Adaptation

The weighted scores for each of the adaptation choices in respect to the five criteria for each of the smallholders was aggregated as per equation 3.28 in section 3.11.3 to establish the weighted sum. The weighted sum was then used as the proxy for efficacy of adaptation in smallholder maize production. The details of the weighted sum are presented on Appendix X.

The weighted sum was further used to establish levels of efficacy of adaptation based on the perception of the smallholders. The weighted sum in respect to the smallholders was ranked from the lowest to the highest. Thereafter, the interval scale was established based on equation 3.29 then levels of efficacy of adaptation were derived. The lowest weighted

sum was 12.4 while the highest was 260.4. The difference between the highest and lowest weighted sum was divided by three to establish the interval scale as 82.6. The interval scale was established in line with Thi and Chaovanapoonphol (2014) and Stevens (1946). Based on the interval scale, the levels of efficacy were defined as follows: low levels of efficacy (12.4 to 95); moderate levels of efficacy (95.1 to 177.7) and high levels of efficacy (177.8 to 260.4). Table 4.14 shows the levels of efficacy of adaptation for Kitui and Laikipia County.

Table 4.14: Distribution of Smallholders as Per the Levels of Efficacy of Adaptation

Levels of efficacy	Laikipia County		Kitui County		Combined	
	Frequency	%	Frequency	%	Frequency	%
Low	45	54	84	44	129	47
Moderate	32	39	93	49	125	46
High	6	7	13	7	19	7

Source: survey data

Table 4.14 shows that most of the smallholders experienced low levels of efficacy (47 percent) while very few (7 percent) experienced high levels of efficacy. Majority of the smallholders who experienced low levels of efficacy were from Laikipia County (54 percent) while most of those who experienced moderate levels of efficacy were from Kitui County (49 percent). However, an equal proportion of smallholders (7 percent) experienced high levels of efficacy in both counties.

The findings indicate that although Laikipia County is located in the highlands and perceived to have agroecological zones with better potential for maize production than Kitui County, levels of efficacy of adaptation was low for most of the smallholders than in Kitui County. This suggests that there is a possibility that smallholders in areas

perceived to have better potential for maize production might not be practicing intensive adaptation despite the knowledge that climate was changing (Adeagbo *et al.*, 2021). The results are also supported by Mutunga *et al.* (2017) who found that smallholders in drier areas adopted more than those who resided in wetter areas. This further brings to question optimality of adaptation especially where multiple adaptation choices are practiced. For instance, a combination of organic and inorganic fertilizer was found to enhance soil fertility and consequently maize productivity hence high levels of efficacy (Roba, 2018). However, the proportion to be applied when they are used in combination to achieve optimal results may not be obvious to smallholders. These results suggest that capacity building on multiple application of adaptation choices could facilitate enhancement of levels of efficacy of adaptation to smallholder maize production (Bedeke *et al.*, 2019).

4.5. Determinants of the Levels of Efficacy of Adaptation of Smallholder Maize Production to Climate Change

The determinants of the levels of efficacy of adaptation of smallholder maize production to climate change was estimated based on Maximum Likelihood Estimate (MLE) of the ordered probit model. The dependent variable was the levels of efficacy of adaptation (AdaptLV) classified into three levels: low, moderate and high against selected independent variables. The dependent variable was derived from the analysis presented in section 4.4.3. The independent variables are described in section 4.5.1, section 4.5.2 presents the diagnostic tests while the regression results are presented in section 4.5.3. Estimation of the model was based on 273 smallholders who adapted maize production to climate change.

4.5.1 Descriptive Statistics

Categorical and continuous variables were used in the model to establish the determinants of the levels of efficacy of adaptation of smallholder maize production to climate change in Laikipia and Kitui counties. The following variables were employed in the model: soil analysis, accuracy of climate information (accuracy_clinfo), access to extension (extension_access), number of social groups, land type (land_type1), stored water period (Stored_waterperiod1), farming experience (farmexp1), farm type, distance to the market (dist_market), and number of adaptation choices applied (numbadapt). The categorical and continuous variables are discussed below.

4.5.1.1. Categorical Variables

The descriptive statistics for categorical variables are shown in Table 4.15.

Table 4.15: Descriptive Statistics for Categorical Variables

Discrete Variables		Kitui County		Laikipia County		Combined	
		Frequency	%	Frequency	%	Frequency	%
Soil analysis	No	188	99	70	84	258	94
	Yes	2	1	13	16	15	6
Accuracy of climate information	No	84	44	42	51	126	46
	Yes	106	56	41	49	147	54
Extension access	No	56	30	5	6	61	22
	Yes	134	70	78	94	212	78
Farm type	Crop farming	33	17	5	6	38	14
	Mixed farming	157	83	78	94	235	86
Land type	Communally owned	118	62	19	23	137	50
	Privately owned	72	38	64	77	136	50
Stored water period	one week	39	20	20	24	59	22
	one day	144	76	25	30	169	62
	one month & beyond	7	4	38	46	45	16
Farming experience	11-20 years	28	15	9	11	37	14
	1-10 years	53	28	23	28	76	28
	over 20 years	109	57	51	61	160	58
Distance to the market	over 10 kilometers	72	38	7	8	79	29
	1-5 kilometers	63	33	44	53	107	39
	5-10 kilometers	55	29	32	39	87	32

Source: survey data

Table 4.15 indicates that most of the respondents (94 percent) who adapted maize production to climate change did not conduct soil analysis most of whom were from Kitui County while in Laikipia County 84 percent did not conduct soil analysis. Majority of smallholders (54 percent) perceived climate information provided as accurate most of whom (56 percent) were from Kitui County. Majority of smallholders in Laikipia County (51 percent) perceived the information provided on climate as inaccurate. Overall, most of the smallholders had access to extension services (78 percent) with the greatest

percentage being smallholders from Laikipia County (94 percent) while 70 percent were from Kitui County.

Findings in Table 4.15 revealed that the majority of smallholders practiced mixed farming (86 percent) as opposed to crop farming only (14 percent). Most of those who practiced crop farming were from Kitui County (17 percent) while the majority of those who practiced mixed farming were from Laikipia County (94 percent). Majority of smallholders in Laikipia County owned land privately while majority of smallholders in Kitui County owned land communally. Overall, the proportion of land owned privately and communally were the same. The study also established that the majority of smallholders whose stored water period was one day were from Kitui County (76 percent) while 30 percent were from Laikipia County. On the other hand, stored water period for the least proportion of smallholders (16 percent) was one month and beyond, of which 4 percent were from Kitui County while 46 percent were from Laikipia County. Overall, stored water period was far much shorter for smallholders in Kitui County than Laikipia County.

Most of the smallholders surveyed (58 percent) had over 20 years farming experience while the minority (14 percent) had 11 to 20 years of farming experience. There was a notable near balance of farming experience of smallholders across the two counties. Furthermore, the majority of the smallholders (39 percent) resided 1-5 kilometers from the market. Majority (53 percent) were from Laikipia County while 33 percent were from Kitui County. A small proportion of smallholders from Laikipia County resided over 10

kilometers from the market while 38 percent of smallholders from Kitui County resided over 10 kilometers from the market.

4.5.1.2. Continuous Variables

The continuous variables used in the analysis of the determinants of levels of efficacy of adaptation in smallholder maize production to climate change were: number of social groups (number_socigrp) and number of adaptation choices applied by smallholders (numbadapt). Table 4.16 presents the descriptive statistics for the continuous variables.

Table 4.16: Descriptive Statistics for Continuous Variables

Variables	Kitui County				Laikipia County				Combined			
	Mean	SD	Mn	Mx	Mean	SD	Mn	Mx	Mean	SD	Mn	Mx
Number of social groups	1	1.06	0	5	1	1.07	0	4	1	1.07	0	5
Numbadapt	2.95	1.57	1	8	2.76	1.38	1	7	2.89	1.61	1	8

(SD-Standard Deviation; Mn-Minimum; Mx-Maximum)

Source: survey data

Table 4.16 shows that on average the highest number of social groups was recorded in Kitui County (5) compared to Laikipia County (4). However, some smallholders did not belong to any social group in both counties. Furthermore, the mean number of adaptation choices applied by smallholders in Kitui County was higher (2.95) compared to Laikipia County (2.76).

4.5.2 Diagnostic Tests Result

The following diagnostic tests were conducted after running the regression model prior to the interpretation of the regression results: specification tests, goodness of fit test and

tests for multicollinearity. The detailed results are presented on Appendix XI (Tables A7 and A8) and XII. The summary test results are presented in Table 4.17.

Table 4.17: Diagnostic Tests and Results

Test	What was tested	Results	Verdict
Link test	The null hypothesis was that there was no specification error if the specified model yields a significant $\hat{\rho}$ and an insignificant $\hat{\rho}^2$	The estimation of the model with the variable “number of adaptation choices” yielded a statistically significant $\hat{\rho}$ of 0.000 and $\hat{\rho}^2$ of 0.013 implying misspecification. This necessitated transformation of the variable to natural logarithm (Bernoit, 2011). Estimation of the model with the transformed variable yielded a statistically significant $\hat{\rho}$ (0.07) and $\hat{\rho}^2$ of 0.643 which was statistically insignificant (Bernoit, 2011). This implies that the estimated model with the transformed “number of adaptation choices” was correctly specified (Long and Freese, 2001).	Model fit for further analysis
Parallel regression test (omodel test)	The null hypothesis was that there was no difference in the coefficient between the models for each of the categories.	The results indicate an insignificant p-value (0.4317). Therefore, the null hypothesis that there was no difference in the coefficient between the models for each of the categories was not rejected at 5 percent level of significance. The parallel regression assumption was therefore satisfied.	Model fit for further analysis
Wald test	The null hypothesis is that the coefficients of the model are simultaneously equal to zero	The p-value (0.0000) was significant at 1 percent level. The null hypothesis that coefficients of the model are simultaneously equal to zero was rejected at 1 percent significance level.	Model fit for further analysis
Variance Inflation Factor (VIF)	VIF greater than 10 indicates serious multicollinearity, VIF greater than 5 indicates critical multicollinearity while VIF of 2.5 indicates moderate multicollinearity.	The average VIF was 1.5 which was within acceptable levels.	Model fit for further analysis
Pearson Correlation Coefficient	Variables were considered collinear if the Pearson Correlation coefficient was above 0.50.	There were no collinear variables	Model fit for further analysis

Source: Survey data

4.5.3 Regression Results for Determinants of the Levels of Efficacy of Adaptation of Smallholder Maize Production to Climate Change

The determinants of the levels of efficacy of adaptation on smallholder maize production to climate change was estimated based on equation 3.22 in section 3.4.4. The results are presented in terms of the marginal effects. This is because it presents results as differences in probabilities considered more informative than log odds or odds ratio (Perrillon, 2019). The detailed regression output for the ordered probit model and the marginal effects are reported in Table A9 and Table A10 respectively on Appendix XII. The estimation results show that the determinants of level of efficacy of adaptation were: soil analysis, extension access, land type, farming experience and number of adaptation choices applied. However, the coefficients for accuracy of climate information, number of social groups, stored water period, farm type and distance to the market were not statistically significant. The summary of the results is presented on Table 4.18.

Table 4.18: Estimates for the Determinants of the Level of Efficacy of Adaptation

Description	Levels of adaptation	Soil analysis (Yes)	Extension access (Yes)	Land type (Privately owned)	Farming experience (1-10 years)	Number of adaptation choices applied
dy/dx	Low	-0.0520602	-0.0393948	0.0464018	0.0606605	-0.5216637
	Moderate	-0.0013767	0.0128934	-0.0104548	-0.0169055	0.1289001
	High	0.0534369	0.0265014	-0.035947	-0.043755	0.3927636
Delta-method Standard Error	Low	0.0262	0.0216	0.0189	0.0238	0.0452
	Moderate	0.0095	0.0098	0.0077	0.0114	0.0652
	High	0.0305	0.0131	0.0139	0.0198	0.0460
P-value	Low	0.05	0.07	0.014	0.01	0.00
	Moderate	0.88	0.19	0.18	0.14	0.05
	High	0.08	0.04	0.01	0.03	0.00
Dependent variable: AdaptLV (levels of efficacy)						

Source: Survey data

4.5.3.1. Soil analysis

The variable soil analysis was used to assess whether smallholders conducted soil analysis to understand the deficiencies on the soils they farmed on. Soil analysis was classified into those who conducted soil analysis and those who did not. The reference category was those who did not conduct soil analysis. From Table 4.18, smallholders who conducted soil analysis were less likely to report low levels of efficacy by 5.2 percent at 5 percent level of significance than smallholders who did not conduct soil analysis. On the other hand, smallholders who conducted soil analysis were more likely to report high levels of efficacy by 5.3 percent at 10 percent significance level than those who did not conduct soil analysis. The coefficient for moderate level of efficacy was insignificant. These results imply that soil analysis enhances levels of efficacy.

Generally, soils have unique characteristics that may either promote or impede realization of a high level of efficacy of adaptation. Less intensive adaptation in soils considered fertile could contribute to low levels of efficacy of adaptation since continuous maize cultivation on a piece of land reduces total carbon, nitrogen, phosphorus and exchangeable potassium (Fujisao *et al.*, 2020). Furthermore, over-applying farming input by some smallholders where inputs are subsidized could adversely affect the level of efficacy of adaptation (Wushuai *et al.*, 2021). In addition, the level of efficacy of adaptation could be adversely affected by activities such as burning vegetation which may lead to reduction or elimination of microorganisms that convert organic materials to organic matter (Deshwal, Kumar, Mishra and Singh, 2019). From the results of the present study and earlier studies, the level of efficacy of adaptation greatly depends on

the decisions smallholders make regarding the soil they farm on. Soil analysis to establish required soil nutrients for supplementation in respect to maize production is a critical driver of high levels of efficacy of adaptation (Sunny *et al.*, 2018).

4.5.3.2. *Extension access*

The variable extension access was used to assess the extent to which extension services promoted level of efficacy of adaptation. The variable was classified into those who accessed extension services and those who did not. The reference category was smallholders who did not access extension services. Table 4.18 shows that smallholders who accessed extension services were 3.9 percent less likely to report low levels of efficacy of adaptation at 10 percent level of significance. On the other hand, smallholders who accessed extension services were more likely to report high levels of efficacy by 2.7 percent at 5 percent significance level. The coefficient for moderate level of efficacy was insignificant.

These results suggest that levels of efficacy are enhanced by access to extension services. This could be because during extension visits, smallholders are exposed to information on good agronomic practices including appropriate crop breeds to promote levels of efficacy of adaptation. The results are in line with earlier studies by Belay *et al.* (2017); Nguyen, Sahin and Howes (2021) and Jha and Gupta (2021). In India, extension services increased levels of efficacy of adaptation by enhancing the capacity of farmers to respond timely to risks occasioned by climate change thus reducing cost of adaptation (Jha and Gupta, 2021). In addition, Belay *et al.* (2017) found that in Ethiopia extension services

influenced the capacity of farmers to choose efficacious adaptation choices while Nguyen *et al.* (2021) found that lack of access to extension services undermined the capacity of farmers to apply multiple adaptation choices thus affecting efficacy of adaptation.

4.5.3.3. *Land type*

Land type was classified into communally owned and privately owned. The reference category was communally owned land. The variable was used in assessing whether land tenure affected levels of efficacy of adaptation. From Table 4.18, smallholders farming on privately owned land were more likely to report low levels of efficacy of adaptation by 4.6 percent at 5 percent significance level than those who farmed on communally owned land. On the other hand, smallholders who farmed on privately owned land were less likely to report high levels of efficacy of adaptation by 3.6 percent at 1 percent significance level. The coefficient for moderate level of efficacy of adaptation was insignificant. These results suggest that a community owned land tenure system enhances levels of efficacy of adaptation. This could be due to the potential to pool resources required to reduce cost of adaptation thereby enhancing scale of adaptation.

The results are contrary to Nguyen *et al.* (2021) who found that ownership of land made it easier for farmers to make farming decisions and were therefore likely to experience high levels of efficacy as they could practise multiple adaptation choices. Antwi-Agyei, Dougill and Stringer (2015) found that land tenure affects management of land including decisions on adaptation and that migrant farmers and land tenants practiced short term

adaptations while indigenous farmers and landowners employed long term climate change adaptation practises.

4.5.3.4. Farming experience

Farming experience was categorized into: 1-10 years, 11-20 years and over 20 years. The reference category was 11-20 years. Results from Table 4.18 were as expected that smallholders with 1-10 years of farming experience were more likely to report low levels of efficacy of adaptation by 6.1 percent at 5 percent significance level than those who had 11-20 years of farming experience. On the other hand, smallholders with 1-10 years of experience were less likely to report high levels of efficacy of adaptation by 4.4 percent at 5 percent significance level as compared to those who had 11-20 years of farming experience. There was no statistically significant relationship between over 20 years of farming experience relative to 11-20 years farming experience.

These results imply that more years of farming experience increases levels of efficacy of adaptation. This could be because smallholders with more years of experience have been exposed to diverse climate patterns and could have tested diverse adaptation choices to know the most efficacious for different scenarios of weather. The results further imply the need for knowledge management in maize production to build the capacity of smallholders with fewer years of farming experience. Adzawla and Al Hassan (2021) established that the performance of adaptation was high for farmers who practised one, eight and eleven choices. It was further established that farmers who accumulated knowledge over a period of time were proficient in changing planting dates and planting

appropriate maize varieties thus enhancing the efficacy of adaptation (Diallo, Donkor and Owusu, 2020). The results are also supported by Thi and Chaovanapoonphol (2014) who found that coffee growing experience had a positive relationship with levels of adaptation.

4.5.3.5. Number of adaptation choices applied

The coefficients in respect to the natural logarithm of number of adaptation choices were first converted to percentage to facilitate interpretation as shown in the Table 4.19 (Benoit, 2011):

Table 4.19: Coefficients of Natural Log of Number of Adaptation Choices in Percentage

Levels of efficacy of adaptation	Coefficient of natural log of number of adaptation choices (X)	Product of the coefficient of natural log of number of adaptation choices with the base (2.71828) (Z)	Coefficient in percentage (Z-X)
Low	-0.52166	-1.41803	-0.89636
Moderate	0.12890	0.35039	0.22149
High	0.39276	1.067641	0.67488

Source: Author's computation

Table 4.19 shows that one percentage point increase in the number of adaptations applied was associated with adaptation being 89.6 percent less likely to generate low levels of efficacy at 1 percent level of significance. Findings also indicate that one percentage point increase in the number of adaptations applied was associated with adaptation being more likely to generate moderate levels of efficacy by 22.2 percent at 5 percent level of significance. Furthermore, one percentage point increase in the number of adaptations applied was associated with adaptation being more likely to generate high levels of efficacy by 67.5 percent at 1 percent level of significance.

The findings on the number of adaptation choices applied suggests that the higher the number of adaptation choices applied by smallholders the more likely that adaptation will lead to high level of efficacy. This could be true for smallholders who combined adaptation choices that enhanced soil fertility and soil organic matter. Smallholders who owned livestock, had access to extension services and had access to credit were likely to achieve high levels of efficacy of adaptation since they were motivated to adopt several adaptation alternatives (Jairo and Korir (2019)). Fadina and Barjolle (2018) found that more coping strategies were adopted in large farms thus enhanced levels of efficacy of adaptation.

Furthermore, smallholders in areas that were more exposed to climate change were also likely to realize high efficacy of adaptation since they tend to select multiple adaptation alternatives (Adeagbo *et al.* (2021); Mutunga *et al.* (2017)). The results of the present study and earlier studies demonstrate that adoption of multiple adaptation choices depend on the circumstances of the smallholders such as location and their endowments in terms of knowledge and input. The findings suggest that support to smallholders to enhance their ability to apply multiple adaptation choices could increase their chances of attaining high levels of efficacy of adaptation.

CHAPTER FIVE

SUMMARY, CONCLUSION AND POLICY IMPLICATIONS

5.1 Introduction

This chapter presents a summary of the study, conclusion and suggested policy implications, contribution to knowledge and areas for further research.

5.2 Summary of the Study

Maize is staple food for the majority of Kenyans yet its production is climate sensitive. The changing climate and unpredictability are posing a huge threat to food security at global, regional and local scale. Some of the threats posed by climate change to maize production include: increasing temperatures exceeding the levels appropriate for maize production; unreliable rainfall including frequency, duration, and distribution; increased incidents of pests and diseases such as MLND, aphids and fall armyworms. Due to resource constraints the unfavorable impacts of changes in climate are likely to affect smallholders much more than other farmers more so because they are responsible for a large proportion of maize production in Kenya. The exposure and sensitivity and the adaptive capacity of maize production to climate change differs with ecosystems, regions, countries and households. Therefore, examining the vulnerability of smallholder maize production to climate change in Kenya is essential. Majority of smallholders are adapting to climate change based on imitation, knowledge and resources at their disposal. However, the outcome may not always be as expected. Inappropriate application or wrong selection of adaptation choices could further contribute to low maize yields

coupled with financial losses hence the need to evaluate the levels of efficacy of adaptation.

Most of the previous empirical studies on vulnerability assessed agriculture in general and those that considered maize production assessed maize farmers in general. In Kenya, one of the empirical studies on vulnerability was based on assessment of major maize growing areas in high potential areas and considered farmers in general as well. The study did not assess the relationship between vulnerability and specific indicators affecting maize production and the magnitude of influence. This study takes a departure from previous empirical studies in Kenya as it undertakes a comparison of two semi-arid areas; one on the highlands and the other on the lowlands. This study focused on smallholder maize producers and not maize farmers in general. In addition, the study examined the levels of efficacy of adaptation and the determinants, noting that previous studies in Kenya had mostly assessed determinants of adaptation and none of the studies evaluated efficacy of adaptation in reference to smallholder maize production taking cognizance of simultaneous adaptation. Most of the studies reviewed are unequivocal that vulnerability affects regions and households differently. In addition, studies recognised that smallholders practise single or multiple adaptation. However, limited knowledge by smallholders on the capability of adaptation choices in producing the desired results could limit robust adaptation leading to low maize yields.

For the two selected counties; Kitui and Laikipia, the study objectives were to: analyze the extent of vulnerability of smallholder maize production to climate change; estimate

the determinants of vulnerability of smallholder maize production to climate change; evaluate levels of efficacy of adaptation of smallholder maize production to climate change; and estimate determinants of levels of efficacy of adaptation of smallholder maize production to climate change. Primary data on demographic, socio-economic characteristics was collected directly from smallholder maize producers. Data from a total of 397 smallholder maize producers was analyzed. Smallholders were sampled through multistage cluster sampling. The respondents were drawn from Kitui South, Rural, Central and Mwingi Central sub counties of Kitui County and Laikipia North and East sub counties of Laikipia County. Temperature data in degree Celsius was obtained from the Global Historical Climatology Network monthly dataset gridded version 4 while monthly rainfall data in millimeters was obtained from Centennial Trends Greater Horn of Africa precipitation dataset version 1.0. Information on agroecological zones, prices of farm inputs, farm gate and market price for maize and costs relating to adaptation choices was obtained from the respective Directors of Agriculture and extension officers from the respective counties.

Factor analysis was employed to analyze the vulnerability of smallholder maize production to climate change in Kitui and Laikipia counties. Factor analysis was undertaken to establish exposure, sensitivity and adaptive capacity. Results showed that exposure was positively influenced by drought, famine and perceived changes in climate while sensitivity was positively influenced by buying maize and crop failure and negatively by frequency of fetching water and maize yield. On the other hand, adaptive capacity was positively influenced by access to extension, expenditure on fertilizer and

number of social groups. Overall, exposure contributed the most to vulnerability in each of the counties and in both counties combined. Moreover, sensitivity and adaptive capacity was higher for smallholders in Laikipia County than Kitui County. Vulnerability index was computed from the exposure, sensitivity and adaptive capacity indices which were the three components of vulnerability. Results revealed that overall most of the smallholders were in the lowest tercile. However, the mean vulnerability index was higher for smallholders in Kitui County than Laikipia County and the combined sample. In addition, the study also found that half of the smallholders in Kitui County had a higher vulnerability index compared to half of the smallholders in Laikipia County and in the combined sample.

Determinants of vulnerability of smallholder maize production to climate change were estimated based on Ordinary Least Squares (OLS). The vulnerability index was regressed against household size, agroecological zone, marital status, accuracy of climate information, eating alternatives to maize, land type and farm type. Findings showed that smallholders who resided in the Upper Midland 3-4, Lower Midland 3 and Lower Highland 1-5 were significantly less vulnerable than smallholders who resided in Lower Midland 4. It was further established that smallholders who were single were more vulnerable than Widows/Widowers. In addition, smallholders who ate alternatives to maize were less vulnerable than those who did not eat alternatives to maize. Equally, smallholders who perceived information provided on climate as accurate were less vulnerable than those who perceived climate information provided as inaccurate. On the other hand, smallholders who experienced longer maize shortage, smallholders with

higher prevalence of climate related human diseases and smallholders whose stored water lasted shorter periods were more vulnerable.

Levels of efficacy of adaptation of smallholder maize production to climate change were evaluated based on Multiple Criteria Evaluation (MCE). The results showed that on aggregate most of the smallholders experienced low levels of efficacy while very few experienced high levels of efficacy. This implies that although the majority of smallholders in the overall sample adapted maize production to climate change, they did not achieve desired results. Majority of the smallholders who experienced low levels of efficacy were from Laikipia County while the majority of those who experienced moderate levels of efficacy were from Kitui County. Overall, findings indicated that irrigation and conservation agriculture were the most efficacious adaptation choices in aggregate.

The determinants of the levels of efficacy of adaptation of smallholder maize production to climate change were estimated based on Maximum Likelihood Estimate. Results showed that smallholders who conducted soil analysis, had access to extension services, had more years of farming experience, farmed in communally owned land and increased number of adaptation choices applied were likely to report high levels of efficacy.

5.3 Conclusions

The study concludes that combined vulnerability of smallholder maize production in semi-arid areas was low. The study also concludes that smallholders in semi-arid areas located on the lowlands are more vulnerable than smallholders in semi-arid areas located

on the highlands. This conclusion is demonstrated by the high proportion of smallholders in Kitui County in the highest tercile compared to Laikipia County and the fact that half of the smallholders in Kitui County had a much higher vulnerability index than half of the smallholders in Laikipia County and in the combined sample. Overall, a low sensitivity and high adaptive capacity lowers vulnerability. The study further concludes that longer maize shortage, prevalence of climate related diseases, stored water lasting shorter period and being single increased vulnerability. On the other hand, receiving accurate climate information and eating alternatives to maize decreased vulnerability.

The study results have also shown that although the majority of smallholders sampled adapted maize production to climate change, most of them reported low levels of efficacy of adaptation. The study concludes that levels of efficacy of adaptation for smallholder maize production in semi-arid areas is low. The study also concludes that high levels of efficacy is not guaranteed by the potential of farm land. This is because most of the smallholders in areas perceived to have better potential in maize production such as Laikipia County reported low levels of efficacy in comparison to smallholders in areas with lower maize production potential such as Kitui County. The study further concludes that smallholders likely to report enhanced levels of efficacy undertook soil analysis, had more farming experience, accessed extension services, produced maize in communally owned land and increased the number of adaptation choices in maize production.

5.4 Policy Implications

This study provides evidence that smallholder maize production is vulnerable to climate change. This vulnerability is likely to exacerbate food insecurity in Kenya and therefore calls for deliberate actions to minimize vulnerability of maize production to climate change.

5.4.1. Policy Implications of Findings on The Extent of Vulnerability of Smallholder Maize Production to Climate Change

Smallholders require support from the Government at national and county levels and by other non-state actors to enhance their adaptive capacity to minimize sensitivity and impacts of exposure of smallholder maize production to climate change. Some of the initiatives to enhance adaptive capacity could be through provision of input subsidies and enhanced water supply. This is because the major contributors of exposure and sensitivity were drought, famine, crop failure and buying maize; increasing maize yield and lower frequency of fetching water reduced sensitivity while investment in fertilizers increased adaptive capacity. In addition, social groups should be promoted to enhance learning and a platform through which support could be channeled to smallholders by the Government or donor agencies to increase adaptive capacity.

5.4.2. Policy Implications of Findings on Determinants of Vulnerability of Smallholder Maize Production to Climate Change

Enhancement of mechanisms for collection, analysis and dissemination of accurate climate information to smallholders producing maize by the Kenya Meteorological Department (KMD) and the department in charge of crop production through the support

of development partners and multilateral agencies is key. This is because smallholders who perceived climate information as accurate were less vulnerable. This could be undertaken by creating Maize Production Centers that integrate climate and farming information at the County level. The time schedules when smallholders expect this information should be clearly defined and the information packaged and delivered using the most effective modes of communication including through online means. In addition, smallholders producing maize could be registered at Village or Ward level not only for purposes of information dissemination but also to facilitate planning, budgeting and implementation of other county and national government programmes relating to maize production. The center could also provide a repository of current information on maize production at the Ward level as well as online for ease of access. In addition, a hotline could be provided to enable smallholders to report climate related incidents for timely resolution as part of risk mitigation.

The national government through departments in-charge of water, irrigation and environment could provide incentives to enable smallholders to invest in water harvesting during rain seasons. This is because smallholders whose stored water lasted one day were more vulnerable than those whose stored water lasted one week and beyond. The departments could provide incentives to enable farmers sink boreholes and water pans to enhance water at their disposal and also explore establishment of policies and infrastructure to collect, recycle and redistribute water used at county level especially from the urban setting for use in farming. This will reduce water wastage and enhance water availability for farming. The private sector could support the Government

initiatives by developing affordable technologies for use by smallholders. Moreover, the departments in charge of environment, water, security and justice at the national and county Governments should enhance enforcement of laws protecting water catchments through collaboration with smallholder groups.

Maize shortage could be mitigated by proper maize storage during glut through collaborations between the department in-charge of crop production in the national and county Governments. The two levels of Government could be supported by development partners and the private sector in constructing well equipped maize silos at Ward level and provision of hermetic maize storage bags. The establishment of silos at the Ward level will facilitate knowledge on the state of maize security at the lower level of administration and inform both the National and County Governments of areas with plenty and areas of shortages to avert crisis. This would also provide a window for collaboration between and among county governments where counties with shortages could procure maize from counties with plenty. In addition, the County Governments through the department in charge of crop production and Kenya Bureau of Standards should ensure through surveillance and enforcement that the drought resistance maize varieties supplied within the counties are suitable for the locations within respective counties. Furthermore, the National and County Governments through the departments in-charge of environment and agriculture could work in partnership with smallholders in reclamation of marginal lands that are likely to boost maize production.

The national and county Government should ensure provision of timely climate and weather predictions particularly in agroecological zones with low potential for maize production such as LM4. In addition, since vulnerability is not homogenous to the different locations, the interventions prescribed in national development plans should be customized to county, sub-county, Ward levels and agroecological zones to address the unique needs. Climate related human diseases contributed to the vulnerability of smallholders. The National and County Governments through Kenya Bureau of Standards and the departments in-charge of water should improve provision of clean water or promote manufacturing of affordable water treatment equipment by the private sector to minimize water borne diseases. Furthermore, the department in charge of environment should provide smallholders with incentives to enhance tree planting to improve microclimate to minimize diseases attributed to high temperature.

5.4.3. Policy Implications of Findings on Levels of Efficacy of Adaptation of Smallholder Maize Production to Climate Change

The County Governments through the department of agriculture and environment could establish guidelines for robust combination of adaptation choices. Smallholders may therefore require support from the department in charge of crop production through capacity building programmes such as; field practical training on effective ways to implement conservation agriculture and irrigation to enhance adoption. This is because the two adaptation practices were adopted by few farmers and had relatively low farmer implementability yet were found to be most effective in minimizing effects of climate change and contributed to high yield. The capacity building should also be backed up by

policies and incentives such as affordable pricing for the requisite tools and equipment to encourage adaptation choices providing high levels of efficacy. The County Government in areas perceived to have better potential for maize production should sensitize smallholders on the need to augment adaptation. The study has shown that the majority of smallholders adapt maize production to climate change but most of them report low levels of efficacy of adaptation especially in areas that were less vulnerable.

5.4.4. Policy Implications of Findings on Determinants of Levels of Efficacy of Adaptation of Smallholder Maize Production to Climate Change

The County Government through the department in charge of crop production should put in place measures to ensure soil samples are collected for testing across all farms and smallholders provided with the correct information on managing maize production. To further enhance soil properties, smallholders should intercrop maize with crops that enhance: soil fertility such as legumes; biomass such as cassava; and moisture such as trees. Soil analysis was found to enhance the likelihood of reporting high levels of efficacy of adaptation. However, few smallholders were undertaking soil analysis.

The present study recommends promotion of secure land tenure systems at community level and enhanced collaboration in maize production among smallholders farming on communally owned land to enjoy economies of scale thus enhancing levels of efficacy of adaptation. This is because smallholders farming in communal owned land were more likely to report high levels of efficacy. In addition, the department in-charge of crop production should enhance extension services at the Ward and village level to provide

current information to smallholders to boost levels of efficacy of adaptation. Furthermore, robust and regular training programmes for extension officers should be established by the department in-charge of crop production to ensure that they are up to date with current affairs and maize production technologies including exchange programmes both within the country and abroad. Moreover, the department in-charge of crop production at the County level should establish demonstration plots at Ward level which could be managed in partnership with farmer groups to build capacity for practicing multiple adaptation. The departments in charge of crop production, water and irrigation should provide incentives for smallholder innovations in maize production including adaptation. This can be undertaken by putting up a County level fund to support and award innovators. The department in charge of crop production should establish knowledge management systems to harness indigenous knowledge from farmers with more maize production experience to facilitate capacity building of smallholders with few years of experience.

5.5 Contribution to Knowledge

The present study augments the understanding of vulnerability and determinants of vulnerability of smallholder maize production to climate change and confirms theoretical underpinnings that although different groups or individuals may share similar exposure to climate change the consequences may differ due to differences in sensitivity and adaptive capacity. The present study established that majority of studies assessing vulnerability were based on general agriculture. The present study focused on small-scale maize production to establish its vulnerability to climate change which may differ from

vulnerability of large-scale maize production. In addition, the present study selected two semi-arid counties one located in the highlands while the other located in the lowlands and established differences in vulnerability despite both being located in semi-arid areas. It was further established that most empirical studies focused on adaptation and determinants of adaptation. Efficacy of adaptation of smallholder maize production in the context of simultaneous adaptation was not evaluated. Evaluation of adaptation practises could shed more light on why there was insufficient maize production despite adaptation by the majority of the smallholders. The present study also explored an alternative approach that could be used in analyzing multiple adaptation to address the challenges faced by most empirical studies undertaking assessment of adaptation. In addition, the study provided a methodology that can be used in ranking adaptation practises to facilitate policy decisions.

5.6 Limitations of the Study and Areas for Further Research

The scope of the present study was to assess the vulnerability of smallholder maize production to climate change and adaptation in Kitui and Laikipia counties in Kenya. The study focused on smallholder maize production and the results of the analysis may not be generalized for large scale maize production. In addition, the areas of study were mainly semi-arid and although results may be generalized for similar semi-arid ecosystems, the same may not be generalized for high potential areas.

Further research should be conducted on the vulnerability of large-scale maize production and compared with vulnerability of smallholder maize production within semi-arid areas.

Further research could also be undertaken to compare vulnerability of maize production in high potential areas with low potential areas. Experimental research could also provide more insights on levels of efficacy of various adaptation choices. In addition, a study on maladaptation in smallholder maize production could explain low levels of efficacy despite adaptation by smallholder maize producers.

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Appendix II: Respondents Per Ward of Residence

Counties	Sub- Counties	Wards	Number of questionnaires received	Number of questionnaires analyzed
Kitui	Kitui South	Mutomo	12	12
		Athi	5	3
		Ikanga	25	25
		Ikutha	11	11
		Kanziko	6	6
	Kitui Rural	Kisasi	12	12
		Yatta Kwa Vonza	20	20
		Kanyangi	15	15
		Mbitini	15	15
	Kitui Central	Kyangwitha East	18	18
		Kyangwitha West	14	14
		Miambani	47	47
		Mulango	15	15
	Mwingi Central	Mwingi Central	10	10
		Waita	7	7
		Kivou	10	10
		Mui	25	25
Nguni		11	11	
Nuu		5	2	
Laikipia	Laikipia North	Mukogodo East	20	20
		Segera	14	10
	Laikipia East	Thingithu	15	15
		Tigithi	25	25
		Umande	15	15
		Ngobit	39	39
Total			411	402

Appendix III: Questionnaire on Vulnerability of Smallholder Maize Production to Climate Change and Adaptation Choices in Kenya

INFORMED CONSENT

Dear sir/madam,

My name is Millicent Kabara, a graduate student at the School of Economics at Kenyatta University conducting research on vulnerability of smallholder maize production to climate change and adaptation choices in selected counties in Kenya. To achieve the objectives of the study, it is important that I collect data from smallholder maize producers from selected counties. This information will be collected for academic purposes and there are no personal benefits or risks involved if you participate. Your participation in this study by giving required information will be very much appreciated. Your name will not be recorded in the questionnaire and any details considered private will be handled as confidential. It will take you approximately 20 minutes to complete the questionnaire.

A. PERSONAL INFORMATION		
County		
Ward.....		
Agro-ecological zone.		
No.	Questions	Answers
1.	Sex of the head of the household (please tick as appropriate)	[1.1] Male [1.2] Female
2.	Indicate the approximate age of the head of the household	
3.	Marital status of the head of the household (Please tick as appropriate)	[3.1] Single [3.2] Married [3.3] Divorced/ Separated [3.4] Widow/ Widower
4.	How many people belong to the farm household? (please indicate the number)
5.	What is the highest attained level of education of the head of the household (Please tick as appropriate)	[5.1] No formal education [5.2] Primary

		[5.3] Secondary [5.4] College [5.5] University
6.	What is the main occupation of the head of the household? (Please tick as appropriate)	[6.1] Farming [6.2] Formal employment [6.3] Informal employment [6.4] Retired [6.5] Unemployed [6.6] Student
7.	What are the main sources of income? (You can tick more than one option as appropriate)	[7.1] Selling farm produce [7.2] Renting out land [7.3] Renting out farm equipment [7.4] Cultivating other people's farms [7.5] Formal employment [7.6] Doing business (Informal employment) [7.7] Specify any other
8.	Please estimate the amount of income earned from the sources you have ticked in question 7 above?	
	Main source of income	Estimated earnings
	[8.1] Selling farm produce	Earnings per season
	[8.2] Renting out land	Earnings per season
	[8.3] Renting out farm equipment	Earnings per season
	[8.4] Cultivating other people's farms to earn income	Earnings per season
	[8.5] Formal employment	Earnings per month
	[8.6] Doing business (Informal employment)	Earnings per week
	[8.7] Specify any other	
9.	How long have you lived in this County? (Please tick as appropriate)	[9.1] less than one year [9.2] 1-5 years [9.3] 5- 10 years [9.4] 10-15 years [9.5] 16-20 years [9.6] 21-25 years [9.7] 25-30 years [9.8] Over 30 years
LAND OWNERSHIP, USE AND ACCESS TO FARMING INPUTS		
10.	Specify the type of land ownership used for maize cultivation? (Please tick as appropriate)	[10.1] Privately owned land with title deed [10.2] Communal land [10.3] Ancestral land [10.4] Leasehold [10.5] Rented/Borrowed [10.6] Specify any other

11.	What is the size of your land? (Please specify)	
12.	What proportion of this land is dedicated to maize production?
13.	How long have you been a farmer? (Please tick as appropriate)	[13.1] less than one year [13.2] 1-5 years [13.3] 5- 10 years [13.4] 10-15 years [13.5] 16-20 years [13.6] 21-25 years [13.7] 25-30 years [13.8] Over 30 years
14.	Which type of farming do you practise? (Please tick as appropriate)	[14.1] Crop farming only [14.2] Both crop and livestock farming (mixed farming)
15.	Please list at least five (5) main types of crops that you produce?
16.	Do you know the type of soil on your farm?	[16.1] Yes [16.2] No
17.	If yes to question 16, please tick the type of soil?	[17.1] Poorly drained soils [17.2] Soils rich in organic matter [17.3] Highly weathered and poor soils [17.4] Naturally fertile soils [17.5] Acidic soils [17.6] Soils with low organic matter and low water storage [17.7] Rocky soils [17.8] Saline soils [17.9] Dark colored and strongly cracking clay soils
18.	Please tick the farming equipment/ tools you use in maize production? (You may tick more than one)	[18.1] Pick-up/truck [18.2] Tractor and plough [18.3] Ox/donkey cart [18.4] Tractor planter/ ox planter [18.5] Wheelbarrow [18.6] Hoe/Jembe/Spade [18.7] Sprayer [18.8] Harvester [18.9] None [18.9] Specify any others
19.	How do you access the farming equipment? (Please tick as appropriate)	[19.1] Own [19.2] Hired [19.3] Both own and hired [19.4] Farmer organizations/ cooperative societies

		[19.5] Specify any other										
20.	If the equipment is hired, how much do you spend hiring the equipment for one cropping season? (Please indicate estimated expenditure)											
21.	What type of labor do you engage in the farming activities?	[21.1] Hired workers [21.2] Family members [21.3] Both hired workers and family members [21.4] Farmer organization members [21.5] Specify any other										
22.	If all the activities for maize production were to be taken by hired labour, indicate how much you would spend in your farm in one cropping season? (Please indicate estimated expenditure)	<table border="1"> <thead> <tr> <th></th> <th>Estimated amount (Kshs.)</th> </tr> </thead> <tbody> <tr> <td>[22.1] Ploughing</td> <td></td> </tr> <tr> <td>[22.2] Weeding</td> <td></td> </tr> <tr> <td>[22.3] Planting</td> <td></td> </tr> <tr> <td>[22.4] Harvesting</td> <td></td> </tr> </tbody> </table>		Estimated amount (Kshs.)	[22.1] Ploughing		[22.2] Weeding		[22.3] Planting		[22.4] Harvesting	
	Estimated amount (Kshs.)											
[22.1] Ploughing												
[22.2] Weeding												
[22.3] Planting												
[22.4] Harvesting												
23.	Do you irrigate your farm?	[23.1] Yes [23.2] No										
24.	If yes to question 23, how do you access water for irrigation?	[24.1] Harvested water from rainfall [24.2] Public water supply from the taps [24.3] Buy water from vendors [24.4] River/wetland [24.5] Water pan [24.6] Well or borehole [24.7] Specify any other sources used										
25.	Do you use fertilizer in maize production?	[25.1] Yes [25.2] No										
26.	If yes in question 25, which type of fertilizers do you use on maize production? (you can tick more than one)	[26.1] Diammonium phosphate (DAP) [26.2] Nitrogen, phosphorus and potassium (NPK) [26.3] Calcium Ammonium Nitrate (CAN) [26.4] Single Super Phosphate (SSP) [26.5] Urea [26.6] Specify any other										
27.	If you use fertilizer, specify the quantity you use for each of the type of fertilizers ticked in question number 26?	<table border="1"> <thead> <tr> <th>Type of fertilizer</th> <th>Quantity</th> </tr> </thead> <tbody> <tr> <td></td> <td></td> </tr> <tr> <td></td> <td></td> </tr> <tr> <td></td> <td></td> </tr> </tbody> </table>	Type of fertilizer	Quantity								
Type of fertilizer	Quantity											
28.	Do you have access to certified maize seeds?	[28.1] Yes [28.2] No										

29.	If yes to question 28, name the type and quantity of certified maize seeds you use?	<table border="1"> <thead> <tr> <th>Type of certified maize seeds</th> <th>Quantity</th> </tr> </thead> <tbody> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> </tbody> </table>	Type of certified maize seeds	Quantity								
		Type of certified maize seeds	Quantity									
30.	Give reasons why you prefer the type of certified seeds you have indicated?	<table border="1"> <tbody> <tr><td> </td></tr> <tr><td> </td></tr> <tr><td> </td></tr> <tr><td> </td></tr> </tbody> </table>										
31.	Over the last 5 years has your expenditure on maize production increased or decreased?	[31.1] Increased [31.2] Decreased [31.3] Has not changed [31.4] I do not know										
32.	If the cost increased, what are the main reasons for the increased cost?	[32.1] I spend more on farm inputs [32.2] I plant more than once [32.3] I need to weed many times [32.4] Specify any other										
33.	How many bags of maize did you produce during the last year's long rain season? (Indicate the number of bags)											
34.	Estimate the distance to the nearest market where you buy farm inputs?	[34.1] less than 1kilometer [34.2] 1-5 kilometers [34.3] 5- 10 kilometers [34.8] Over 10 kilometers										
35.	How accessible are the means of transport to the market where you buy farm inputs?	[35.1] Not accessible [35.2] Less accessible [35.3] Not sure [35.4] Accessible [35.5] Very accessible										
36.	Do you have access to extension services for maize production? (Please tick as appropriate)	[36.1] Yes [36.2] No										
37.	If yes to question 36, who offers the extension services? (Please tick as appropriate)	[37.1] Government [37.2] Private sector [37.3] NGO [37.4] Specify any others..... [37.5] Don't know										
38.	How often do you get extension advice on maize during a cropping season? (Please tick as appropriate)	[38.1] Never [38.2] Rarely [38.3] Occasionally [38.4] Frequently [38.5] Very frequently										
39.	Do you require credit facilities for	[39.1] Yes										

	farming? (Please tick as appropriate)	[39.2] No
40.	If yes to question 39, do you have access to credit? (Please tick as appropriate)	[40.1] Yes [40.2] No
41.	If yes to question 40, what is the source of credit? (Please tick as appropriate)	[41.1] Banks [41.2] Cooperative society/SACCO [41.3] Microfinance [41.4] Friends [41.5] Donor support [41.6] Specify any others.....
42.	If the answer to question 40 is Yes, how much credit did you obtain for farming during last year's long rain cropping season? (Please indicate in Kenya shillings)	
IMPACTS OF CLIMATE CHANGE		
43.	How often do you access climate information during one cropping season? (Please tick as appropriate)	[43.1] Never [43.2] Rarely [43.3] Occasionally [43.4] Frequently [43.5] Very frequently
44.	In your experience, is the climate information you receive been accurate to inform your farming decisions?	[44.1] Yes [44.2] No
45.	Have you noticed any significant changes in the weather patterns over the last 5 years? (Please tick as appropriate)	[45.1] Yes [45.2] No
46.	If the answer to question 45 is Yes. What significant changes in weather patterns have you observed over the last 5 years? (You can tick more than one)	[46.1] Unpredictable rains [46.2] Floods [46.3] Inadequate rainfall [46.4] Late onset of rainfall [46.5] Early onset of rainfall [46.6] Prolonged droughts [46.7] Don't know [46.8] Specify any other
47.	In the past five (5) years, what are the main problems faced in the community due to climatic related changes? (You may tick more than one option)	[47.1] Crop failure [47.2] Human disease outbreak [47.3] Famine [47.4] Crop diseases and pests outbreak [47.5] Drought [47.6] No challenges [47.7] Specify any other
48.	If you experience problems as specified in question 47, how frequent do you experience the stated problems? (tick against the choice ticked in number 47 only)	

		Never	Rarely	Occasionally	Frequently	Very frequently
	48.1	Crop failure				
	48.2	Human disease outbreak				
	48.3	Famine				
	48.4	Crop diseases and pests outbreak				
	48.5	Drought				
49.	What are the common maize crop pests and diseases? (You may tick more than one option)		[49.1] Maize Lethal Necrotic Disease (MLND) [49.2] Aphids [49.3] Cutworms [49.4] Stalk borers [49.5] Fall armyworm [49.6] Increased incidences of the usual pests and diseases [49.7] Specify any other.....			
50.	If you have experienced pests and diseases, what actions did you take to deal with the problem?		[50.1] Did not take any action [50.2] Use of chemicals [50.3] Crop rotation [50.4] Specify any other.....			
51.	If you took action, how did you identify the appropriate one?		[51.1] Experience [51.2] Extension officer [51.3] Imitating your neighbors [51.4] Trial and error [51.5] Any other			
52.	If you used chemicals, specify the name and the quantity used during one cropping season for the pests/diseases specified in question 49? (Please indicate the estimated quantity)					
		Pests/diseases	Name of the chemicals used	Quantity used in one cropping season		
	52.1	Maize Lethal Necrotic Disease (MLND)				
	52.2	Aphids				
	52.3	Cutworms				
	52.4	Stalk borers				
	52.5	Fall armyworm				
		Specify any other pests/diseases				
	52.6					
	52.7					
VULNERABILITY TO CLIMATE CHANGE						
53.	How long does the maize you harvest last the family?		[53.1] Less than 1 month [53.2] 1-3 months [53.3] 4-6 months [53.4] 7-9 months [53.5] 10-12 months [53.6] Over 12 months			

54.	Did your household experience maize shortages in the last 2 years?	[54.1] Yes [54.2] No
55.	If yes to question 54 how many months did you experience maize shortage in the last year?	[55.1] Less than 3 months [55.2] 4-6 months [55.3] Over 6 months
56.	If yes to question 54, what were the causes of maize shortages? (You may tick more than one answer)	[56.1] Poor crop harvest [56.2] Inadequate income to purchase maize from the market [56.3] People have substituted maize growing with other crops [56.4] Maize relief from the government was not provided [56.5] Please specify any other
57.	If your answer in question 56 is poor crop harvest, what were the reasons for the poor crop harvest?	[57.1] Drought [57.2] Floods [57.3] Lack of farm inputs [57.4] Lack of enough land to cultivate [57.5] Destruction by pests and diseases [57.6] Please specify any other
58.	If yes to question 54, how do you cope with the maize shortage? (You may tick more than one answer)	[58.1] Buy [58.2] Eat alternative foods available [58.3] Borrow from relatives, friends or neighbours [58.4] Get maize relief from government and other organizations? [58.5] Specify any other.....
59.	If you buy maize to deal with the shortage, how much maize do you buy in one month? (Please specify the quantity)	
60.	How often do you fetch the water you need for domestic use?	[60.1] Daily [60.2] Weekly [60.3] Monthly [60.4] After more than one month [60.5] During rainy season [60.6] Specify any other
61.	What is the source of water you fetch for domestic use? (Please tick as appropriate)	[61.1] River [61.2] Water harvested from rain [61.3] Tap water supplied by government [61.4] Buy water from water vendors [61.5] Well/borehole [61.6] Please specify any other.....
62.	Please indicate how you store water? (Please tick as appropriate)	[62.1] I do not store water [62.2] Water pans [62.3] Water tanks [62.4] 20 litre gallons [62.5] Please specify any other

63.	How long does the stored water last?	[63.1] One day [63.2] One week [63.3] One month [63.4] Over one month
64.	In your opinion, are there disease experiences that are related to changes in climatic patterns that have affected the health of your household in the last 2 years?	[64.1] Yes [64.2] No
65.	If yes in question 64, name the types of diseases that have affected the health of the household?	[65.1] Typhoid [65.2] Cholera [65.3] Malaria [65.4] Please specify any other.....
LIVELIHOOD STRATEGIES AND ADAPTATION TO CLIMATE CHANGE		
66.	Have you made any adjustment to maize farming due to existing changes in climatic patterns?	[66.1] Yes [66.2] No
67.	If yes to question 66, what adjustments have you made in maize farming to address the challenges of changing climate patterns in the last 2 years? (Can tick more than one option)	[67.1] Increased use of manure [67.2] Increased use of fertilizer [67.3] Planting more agroforestry trees [67.4] Changing planting dates/timing [67.5] Increasing the size of land under maize cultivation [67.6] Reducing the size of land under maize cultivation [67.7] Irrigation [67.8] Mulching [67.9] Mixed cropping [67.10] Planting without ploughing the land (CA) [67.11] Specify any other
68.	Please indicate how maize output from your farm has changed since you started adjusting farming practises to address challenges of climate variability. (Please tick as appropriate)	[68.1] Increasing [68.2] Decreasing [68.3] No change
69.	How has adjustment of farming practices affected your expenditure on farming? (Please tick as appropriate)	[69.1] Increased [69.2] Decreased [69.3] No change

70.	How has adjustment of farming practices affected your expenditure on other important goods and services for the household? (Please tick as appropriate)	[70.1] Increased [70.2] Decreased [70.3] No change				
71.	Please tick the goods and services for the household which have been affected negatively by adjustment in farming practices?	[71.1] Health [71.2] Education [71.3] Purchase of clothing [71.4] Payment of rent [71.5] Please specify any other				
72.	How effective are the adaptation choices you selected in question 67 above in reducing losses in maize production? (Please tick as appropriate)					
		Not effective (1)	Slightly effective (2)	Moderately effective (3)	Effective (4)	Very Effective (5)
72.1	Increased use of manure					
72.2	Increased use of fertilizer					
72.3	Planting more agroforestry trees					
72.4	Changing planting dates/timing					
72.5	Increasing the size of land under maize cultivation					
72.6	Reducing the size of land under maize cultivation					
72.7	Irrigation					
72.8	Mulching					
72.9	Mixed cropping					
72.10	Planting without ploughing (CA)					
73.	From your experience, please tick the option that best describes additional benefits associated with each of the adaptation choices you selected in question 67?					
		Increased soil fertility	Improved soil structure	Enhanced soil moisture	Increased income	I don't know
73.1	Increased use of manure					
73.2	Increased use of fertilizer					
73.3	Planting more agroforestry trees					
73.4	Changing planting dates/timing					
73.5	Increasing the size of land under maize cultivation					
73.6	Reducing the size of land under maize cultivation					
73.7	Irrigation					
73.8	Mulching					
73.9	Mixed cropping					
73.10	Planting without ploughing (CA)					

	Please specify any other benefits					
74.	From your experience to what extent do you agree that the adaptation choices you selected in question 67 increase maize yields? (Please tick as appropriate)					
		Strongly disagree (1)	Disagree (2)	Not at all (3)	Agree (4)	Strongly agree (5)
74.1	Increased use of manure					
74.2	Increased use of fertilizer					
74.3	Planting more agroforestry trees					
74.4	Changing planting dates/timing					
74.5	Increasing the size of land under maize cultivation					
74.6	Reducing the size of land under maize cultivation					
74.7	Irrigation					
74.8	Mulching					
74.9	Mixed cropping					
74.10	Planting without ploughing (CA)					
75.	From your experience, to what extent do you agree that the implementation of the adaptation choices you selected in question 67 is affordable? (Please tick as appropriate)					
		Strongly disagree (1)	Disagree (2)	Not at all (3)	Agree (4)	Strongly agree (5)
75.1	Increased use of manure					
75.2	Increased use of fertilizer					
75.3	Planting more agroforestry trees					
75.4	Changing planting dates/timing					
75.5	Increasing the size of land under maize cultivation					
75.6	Reducing the size of land under maize cultivation					
75.7	Irrigation					
75.8	Mulching					
75.9	Mixed cropping					
75.10	Planting without ploughing (CA)					
76.	From your experience, to what extent do you agree that the selected adaptation measures would only be implemented if extension services are available? (Please tick as appropriate)					
		Strongly disagree (1)	Disagree (2)	Not at all (3)	Agree (4)	Strongly agree (5)
76.1	Increased use of manure					
76.2	Increased use of fertilizer					
76.3	Planting more agroforestry trees					
76.4	Changing planting dates/timing					
76.5	Increasing the size of land under maize cultivation					
76.6	Reducing the size of land under maize cultivation					

	76.7	Irrigation					
	76.8	Mulching					
	76.9	Mixed cropping					
	76.10	Planting without ploughing (CA)					
77.	From your experience, please tick the option that best describes the extent to which the adaptation choices you selected in question 67 above have additional benefits over and above the costs of adapting to climate variability?						
			Strongly disagree (1)	Disagree (2)	Not at all (3)	Agree (4)	Strongly agree (5)
	77.1	Increased use of manure					
	77.2	Increased use of fertilizer					
	77.3	Planting more agroforestry trees					
	77.4	Changing planting dates/timing					
	77.5	Increasing the size of land under maize cultivation					
	77.6	Reducing the size of land under maize cultivation					
	77.7	Irrigation					
	77.8	Mulching					
	77.9	Mixed cropping					
	77.10	Planting without ploughing (CA)					
78.	Indicate the constraints you face in adapting maize production to climate variability? (You may tick more than one choice)		[78.1] Inadequate capital [78.2] Inadequate information on climate [78.3] High input prices [78.4] Lack of farm equipment [78.5] Inadequate extension services [78.6] Inadequate farming experience [78.7] Poverty [78.8] Low access to appropriate farming technology [78.9] Please specify any other				
79.	Please provide two suggestions on how to overcome the constraints to adaptation? 						
80.	Are there organizations that your community is working with to address the effects of climate variability on farmers' livelihood? (Please tick as appropriate)		[80.1] Yes [80.2] No				
81.	If Yes in question 80 above, please tick the type of organization?		[81.1] Government [81.2] Private sector [81.3] NGO [81.4] Community groups [81.5] Donors/development partners				

		[81.6] Please specify any other..... [81.7] Don't know
82.	Are you a member of any social group or cooperative that offer any form of support to maize farmers?	[82.1] Yes [82.2] No
83.	If yes to question 82, how many social groups do you belong to? Please specify the number	
84.	What benefits have you derived from your membership in the social institutions?	[84.1] Marketing produce [84.2] Accessing inputs [84.3] Accessing information on output and input prices [84.4] Accessing credit [84.5] Communal land preparation [84.6] Please specify any other.....
85.	Are you aware of any policies pursued by the government to assist farmers adjust farming practices to overcome climate change?	[85.1] Yes [85.2] No
86.	Are you aware of any such programmes coordinated or implemented by the Government or other agencies in your area?	[86.1] Yes [86.2] No
87.	If yes to question 86, how have you benefited from these programmes?(You may tick more than one option)	[87.1] Farm inputs free of charge [87.2] Subsidies on farm input [87.3] Food aid when maize crop fails [87.4] Food for work [87.5] Money [87.6] Marketing produce/ selling maize on your behalf [87.7] Analyzing types of soil [87.8] I have not benefitted [87.9] Please specify any other.....
88.	Please list three (3) recommendations you would you make to the County/ National government on the support maize farmers should be given to address climate changes? 	

THANK YOU FOR PARTICIPATING IN THIS SURVEY


Appendix IV: Research Authorization


THIS IS TO CERTIFY THAT:
MS. MILLICENT AKINYI KABARA
of KENYATTA UNIVERSITY, 3194-506
NAIROBI, has been permitted to conduct
research in Kitui , Laikipia , Machakos
Counties

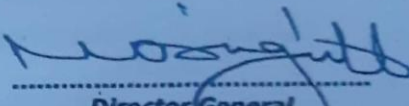
Permit No : NACOSTI/P/18/82735/22271
Date Of Issue : 27th June,2018
Fee Recieved :Ksh 2000

on the topic: VULNERABILITY OF
SMALLHOLDER MAIZE PRODUCTION TO
CLIMATE VARIABILITY AND ADAPTATION
CHOICES IN SELECTED COUNTIES KENYA

for the period ending:
23rd April,2019




.....
Applicant's
Signature


.....
Director General
National Commission for Science,
Technology & Innovation

Appendix V: Ranking the Criteria for Evaluation of Adaptation Choices

1. INTRODUCTION

Adaptation in the context of maize production is adjustment of maize production systems in response to actual or expected climate changes. The aim of adaptation is to reduce the negative impacts of climate change. It is therefore important to evaluate adaptation practiced by smallholder maize producers to determine the adaptation choices that should be promoted for implementation. A tool to assist in ranking the criteria for evaluation of adaptation choices selected by farmers consisting of five (5) criterion was established.

2. RANKING CRITERIA FOR EVALUATING ADAPTATION CHOICES

Please rank each of the criterion on table 1 on a scale of 5 to 1. 5 representing the criteria that contributes **the most** in safeguarding smallholder maize producers from the negative impacts of climate variability and 1 the criteria **ranked the least** in safeguarding smallholder maize producers from the negative impacts of climate variability.

Table 1: Ranking of criteria for evaluating adaptation choices.

Criteria	Definition	Please rate
Effectiveness	Adaptation choices contributing the most to minimizing the negative impacts of climate variability.	
High yield	Adaptation choices contributing the most to high yields.	
Affordability	Adaptation choices that are the most affordable.	
Farmer Implementability	Adaptation choices that can be implemented by farmers with ease.	
Additional benefits	Adaptation choices with multiple benefits.	

Appendix VI: Correlation Analysis

Table A1: Correlation Analysis for Variables on Exposure

	rainNorm	tempNorm	cropests_diseases1	famine	drought	know_soiltype	irrigation	clim_changes
rainNorm	1							
tempNorm	0.17787625	1						
cropests_diseases1	0.02602037	-0.20314746	1					
famine	0.19056218	-0.23076127	0.05321664	1				
drought	0.06549683	-0.00688179	0.09470443	0.47848375	1			
know_soiltype	0.28708336	0.11529536	0.01936173	-0.0503647	0.0099946	1		
irrigation	0.44667388	0.17049603	0.11262529	-0.09682421	0.15884165	0.14616338	1	
clim_changes	0.27687826	0.08000295	0.24969937	0.4126684	0.37486894	0.11351726	0.07535476	1

Table A2: Correlation Analysis for Variables on Sensitivity

	yieldNorm	crop_failure1	ageNorm	maize_period	water_freq1	buy
yieldNorm	1					
crop_failure1	-0.21674728	1				
ageNorm	0.04817266	-0.01778396	1			
maize_period	0.1210693	0.02074459	-0.06161998	1		
water_freq1	0.14481167	-0.23010763	0.13954974	-0.11004371	1	
buy	-0.23659763	0.32484962	-0.17697494	0.09592319	-0.38475435	1

Table A3: Correlation Analysis for Variables on Adaptive Capacity

	exten_access	edu1	inputSubsidies	expCertSeNorm	expfertNorm	NsociogrpNorm
exten_access	1					
edu1	0.0737189	1				
inputSubsidies	0.36660116	0.10302617	1			
expCertSeNorm	0.21935192	0.0848624	0.04679817	1		
expfertNorm	0.26175206	0.17660677	0.27705017	0.21041462	1	
NsociogrpNorm	0.35806442	0.06714468	0.29887893	0.15836272	0.16768085	1

Appendix VII: Exposure, Sensitivity, Adaptive Capacity and Vulnerability Indices

	EIndex	SIndex	ACIndexiv	VInX
1.	1.084906	0.1544997	0.034022	1.643551
2.	2.757326	0.9036323	0.0326975	1.665275
3.	1.021824	0.6557493	0.6502014	1.527822
4.	1.1054	0.5133705	0.3573332	2.153238
5.	1.134233	0.8825538	0.0143966	0.9768012
6.	2.155091	0.9735609	0.0143966	1.244942
7.	1.24487	0.9567325	0.6324061	0.9647672
8.	0.4322831	0.8216872	0.3538473	1.40039
9.	1.01452	0.4819016	0.3394507	1.544452
10.	0.3041003	0.3076343	0.3394507	1.130823
11.	0.6404578	0.5181903	0.3699868	2.751073
12.	0.5461329	0.6873745	0.3394507	2.636612
13.	0.4026124	0.966548	0.3394507	1.049373
14.	0.0484552	0.0109904	0.0143966	1.239574
15.	2.281636	0.742071	0.0143966	0.8788726
16.	1.848502	0.9207945	0.3429366	2.800079
17.	1.512546	0.8841467	0.0231113	3.354533
18.	1.388316	0.9095414	0.3394507	2.21399
19.	1.262916	1.077699	0.3438081	1.152613
20.	2.298877	0.793338	0.3734727	1.22261
21.	1.523294	0.4736895	0.3660479	1.823158
22.	2.549652	1.079226	0.3428495	1.686086
23.	0.3418048	0.3751512	0.6324061	0.5262421
24.	2.276412	0.9927663	0.3538473	0.8436331
25.	1.105498	0.7741326	0.635892	1.557777
26.	1.883857	0.3104639	0.0331505	0.659397
27.	0.3418048	0.2372925	0.3411937	3.263945

	EIndex	SIndex	ACIndexiv	VInX
28.	1.833836	0.193023	0.3499084	1.826696
29.	2.246242	0.7651873	0.3765229	0.8546074
30.	2.374924	0.90506	0.6324061	0.2302063
31.	0.5685974	0.8202264	0.3538473	3.32895
32.	0.3414026	0.8217202	0.0143966	3.255928
33.	1.01452	0.1327422	0.031826	2.239299
34.	1.262916	1.015008	0.0458041	2.294739
35.	0.3041003	0.7102991	0.3512156	0.4009703
36.	0.5685974	0.897591	0.0287931	3.845456
37.	1.380646	0.9036654	0.3462482	0.5818381
38.	1.864007	1.112056	0.0143966	2.095509
39.	1.241312	-0.3591327	0.0519045	0.8787154
40.	2.484087	0.8935574	0.6520315	-0.2672816
41.	1.752397	0.9380228	0.6324061	2.636772
42.	2.886009	0.9915196	0.3538473	0.87966
43.	1.218848	0.9549379	0.381316	2.747336
44.	1.016564	0.339403	0.6402494	2.20791
45.	1.505185	0.5547847	0.6446067	1.38807
46.	1.252502	1.002619	0.0484186	1.419967
47.	0.3414026	0.3582806	0.0143966	2.263527
48.	1.689279	0.1344342	0.3464225	3.133447
49.	1.636644	0.9167964	0.0143966	2.178712
50.	1.044288	0.6536841	0.6324061	2.869076
51.	0.3145145	0.8840476	0.3394507	0.8265576
52.	0.3414026	0.5518665	0.3394507	0.3602325
53.	0.0331226	0.371701	0.3594946	1.1889
54.	1.082862	0.4780307	0.0143966	1.906438
55.	2.757326	0.8897733	0.0143966	1.553407
56.	2.374924	0.7680913	0.0287931	0.8167734

	EIndex	SIndex	ACIndexiv	VInX
57.	1.11263	0.6416077	0.6324061	1.54138
58.	0.3189381	0.5266284	0.3394507	2.350969
59.	1.841542	0.8468107	0.3960965	2.184932
60.	1.259634	0.4690679	0.0143966	2.7549
61.	0.3414026	0.8560777	0.6324061	3.055529
62.	1.1428	0.2629846	0.3446796	2.219234
63.	1.57767	0.9600506	0.3568802	0.2548544
64.	0.4026124	0.9439344	0.364305	2.145921
65.	2.360086	0.9102387	0.3394507	1.742728
66.	1.538132	0.46379	0.3540915	1.947304
67.	0.4403169	0.2522306	0.3459868	1.477727
68.	0.9792621	0.5426484	0.3394507	1.126738
69.	0.3145145	1.090347	0.3394507	0.8236722
70.	1.232745	0.9452778	0.3073519	2.784863
71.	1.252502	0.4585122	0.3656122	2.322741
72.	1.689279	0.4999263	0.0143966	0.8151865
73.	2.648164	1.039771	0.3394507	1.069259
74.	0.3418048	0.5888151	0.3429366	1.683923
75.	2.886009	0.9808646	0.3756341	1.684335
76.	2.003172	0.9122819	0.3394507	0.1115457
77.	1.871266	0.4301299	0.3394507	1.06541
78.	0.6150444	0.1371415	0.0143966	1.696617
79.	1.560597	0.8573732	0.3481655	1.500208
80.	1.014118	0.3929651	0.362562	0.8351135
81.	1.120336	0.4493101	0.0248543	0.3799693
82.	1.014118	0.3945918	0.6324061	2.647578
83.	1.191292	0.8164424	0.3073519	1.894251
84.	1.006986	0.8769171	0.6751428	2.336286
85.	1.758023	0.3570934	0.3394507	2.078519

	EIndex	SIndex	ACIndexiv	VInX
86.	0.8955877	0.2205552	0.0222398	1.324307
87.	0.3414026	0.4881804	0.3428495	1.673938
88.	0.4327829	-0.048033	0.3608191	2.176901
89.	0.3715731	0.8261025	0.3438081	2.052885
90.	0.4130267	0.9354193	0.3464225	3.314536
91.	1.175787	0.9341191	0.3438081	1.968197
92.	2.757326	0.9006116	0.3608191	1.410385
93.	1.841542	0.4704626	0.3394507	3.527423
94.	0.3342707	0.5283416	0.3568802	3.04163
95.	1.632221	0.0943664	0.3464225	2.569032
96.	1.553465	0.4792113	0.3531764	1.526454
97.	1.735157	0.4585122	0.3445489	1.382038
98.	0.3145145	0.9607148	0.6324061	2.996471
99.	1.689279	0.4448697	0.3507799	2.997722
100.	0.4403169	0.5508808	0.0196254	0.6973306
101.	1.361428	0.870265	0.3438081	2.679899
102.	1.153989	0.3944049	0.0287931	2.086323
103.	1.016564	0.5806089	0.6664281	-0.3554474
104.	1.757621	0.163213	0.6358048	0.5627574
105.	1.689279	0.8614423	0.3446796	2.628626
106.	0.3491085	0.9835721	0.0196254	1.127637
107.	2.757326	0.8478122	0.3555467	1.876146
108.	0.3189381	0.3924182	0.0287931	2.255518
109.	1.211544	0.6368289	0.3481655	1.659569
110.	-0.0429251	0.4939214	0.3560087	-0.2965631
111.	0.5461329	0.7132055	0.0372727	1.202133
112.	0.3715731	0.7944353	0.3717298	1.630193
113.	2.436301	0.9622086	0.357246	0.9256476
114.	2.787497	0.8953007	0.3394507	2.211271

	EIndex	SIndex	ACIndexiv	VInX
115.	2.954351	0.9198989	0.3429366	1.062848
116.	2.549652	0.9518307	0.3492548	1.99136
117.	1.560999	0.5240915	0.0370721	2.048018
118.	1.153989	1.117136	0.0161395	2.238981
119.	2.549652	0.7766724	0.0196254	3.032233
120.	1.24487	0.9317344	0.0196254	3.627474
121.	0.344685	0.8824547	0.0231113	2.144001
122.	2.984521	0.958722	0.0355906	1.351946
123.	2.488269	0.0927591	0.3525228	1.016638
124.	1.973002	0.5375687	0.0178825	0.1311238
125.	2.420969	0.9275331	0.3682439	3.509285
126.	0.5796018	0.9882015	0.3394507	0.6749486
127.	2.147729	0.9041285	0.3394507	0.542729
128.	1.123819	0.4722635	0.3394507	1.85487
129.	0.344685	0.9382087	0.6520315	0.6806492
130.	1.123819	0.6473846	0.6637092	0.6916827
131.	1.237169	0.9299432	0.347294	1.0227
132.	1.070143	1.05473	0.3394507	1.230195
133.	1.765327	0.5156608	0.0143966	1.101746
134.	-0.0425229	0.1915292	0.6380271	0.7104189
135.	0.3418048	0.8893255	0.6468027	1.651055
136.	0.4476207	0.7225855	0.0187539	3.639184
137.	0.4327829	-0.1218022	0.0431897	0.6681666
138.	1.689279	0.3928998	0.0331505	0.5459468
139.	1.262916	0.0924761	0.3555467	0.9196827
140.	1.085308	0.2387863	0.6324061	0.7235613
141.	1.01452	0.4538655	0.3711197	1.247651
142.	0.5685974	0.9016759	0.3695338	1.037549
143.	1.134233	0.8947025	0.3160667	1.205844

	EIndex	SIndex	ACIndexiv	VInX
144.	2.200364	0.9206954	0.0248543	2.100019
145.	1.350475	0.8426335	0.356026	0.9680687
146.	1.864007	0.4765369	0.0143966	1.714305
147.	2.163062	0.3471638	0.3682439	1.192648
148.	1.636644	0.9272687	0.3446796	2.981644
149.	2.084611	0.8886943	0.3394507	1.794698
150.	1.500761	-0.1132248	0.0143966	3.928847
151.	2.954351	0.5255192	0.0213684	1.148838
152.	1.962519	0.8856406	0.0143966	1.982587
153.	0.9180522	0.4519421	0.0207148	2.260273
154.	0.4431972	0.4848891	0.0346756	1.192464
155.	0.9896763	0.8503909	0.6583605	1.181707
156.	1.632221	0.4387953	0.3580516	1.712965
157.	1.227522	0.0818212	0.6476815	0.6616614
158.	1.837119	0.086567	0.3689437	1.554742
159.	1.134233	0.7299224	0.6546984	1.209457
160.	0.6862663	0.7082071	0.6498166	0.7446568
161.	1.022624	0.3985001	0.3731377	1.047986
162.	1.688906	0.5209387	0.3577982	1.852047
163.	2.207623	0.2283297	0.3538904	2.082062
164.	1.962146	1.034494	0.3499687	2.646671
165.	1.022624	0.1764225	0.3826835	0.8163628
166.	1.864007	0.9036654	0.6416242	2.126048
167.	1.380646	0.6155378	0.3653377	1.630846
168.	1.022624	0.8319387	0.6653499	1.189213
169.	1.530828	0.2894517	0.0281348	1.792145
170.	1.787419	0.5423386	0.3692598	1.960497
171.	1.47179	0.6981679	0.3591518	1.810806
172.	1.287759	0.6173103	0.3294152	1.575655

	EIndex	SIndex	ACIndexiv	VInX
173.	0.8911641	0.4892714	0.3765827	1.003853
174.	0.344685	0.8900229	0.663002	0.5717059
175.	1.257589	0.4673394	0.3270417	0.1297778
176.	0.3418048	0.1150148	0.0340864	1.690842
177.	1.1428	0.6381431	0.3821031	1.39884
178.	0.4773439	0.4925564	0.3664714	0.603429
179.	1.142427	0.5866082	0.368937	1.360098
180.	1.394376	0.3990732	0.3665715	1.426877
181.	1.523294	0.7580495	0.3699313	1.911413
182.	2.306135	0.3117215	0.3852122	2.232645
183.	1.022624	0.9124209	0.6762123	1.258832
184.	0.5086586	0.6684631	0.3907357	1.273488
185.	1.150059	0.5141648	0.3758222	1.150028
186.	1.205957	0.3198934	0.0497163	1.127405
187.	1.688906	0.3248997	0.3998359	1.61397
188.	0.4697122	0.0316908	0.3707986	0.1306045
189.	0.3788318	0.9883873	0.3914697	0.9757494
190.	1.023823	0.5080926	0.4004037	0.1676461
191.	0.9595059	0.3945918	0.3740942	0.9800035
192.	0.9896763	0.9008281	0.3699112	0.857417
193.	0.5682244	-0.0001747	0.3831312	1.507373
194.	0.5340776	0.6932505	0.3716105	1.160305
195.	2.234186	0.9414971	0.6791736	2.49651
196.	0.3788318	0.0406536	0.3815227	1.209567
197.	1.164404	0.8840476	0.3718493	1.676602
198.	1.297063	0.2940272	0.3713264	1.73975
199.	1.164404	0.9466724	0.3825684	0.036917
200.	1.023823	0.2991068	0.3825684	0.9403615
201.	1.530828	0.3874112	0.0472401	1.871

	EIndex	SIndex	ACIndexiv	VInX
202.	1.194471	0.298806	0.0563906	1.436886
203.	1.940054	0.4385971	0.3958413	1.98281
204.	-0.0425229	0.9261625	0.0656505	0.8179892
205.	0.5086586	1.117932	0.6902421	0.936349
206.	2.160654	0.5024369	0.3911784	2.271913
207.	1.289431	0.0018148	0.6877185	0.8233562
208.	1.022624	0.4884509	0.3998786	0.8798336
209.	1.023823	0.2558891	0.3866585	0.9045873
210.	0.344685	0.8735249	0.3993305	0.8188794
211.	1.437643	0.65486	0.4084935	1.886899
212.	1.134233	0.5951031	0.4079707	0.9371636
213.	1.080557	0.2645775	0.4079707	2.694655
214.	2.143306	0.9593202	0.6867909	1.405712
215.	1.353796	0.9415962	0.702974	1.026362
216.	1.783339	-0.338616	0.4156756	1.029047
217.	1.530828	0.9448812	0.0761621	2.399548
218.	1.479197	0.61567	0.7419145	1.352952
219.	0.8581135	0.6458908	0.0914715	1.412533
220.	1.632221	0.5488095	0.4395246	1.741506
221.	1.350877	0.3862009	0.749134	0.9879442
222.	0.4026124	0.9583915	0.4021623	2.904899
223.	2.200364	0.8082761	0.4019009	1.546956
224.	2.200364	0.8634476	0.4174303	-0.122478
225.	1.380646	0.6020936	0.4004194	2.684832
226.	1.479197	0.9127478	0.4061012	2.727527
227.	0.8581135	0.3229051	0.3951034	1.353347
228.	1.632221	0.1942371	0.3986764	1.594483
229.	1.353796	0.6636279	0.3968027	1.141348
230.	1.536155	0.2122944	0.3740024	2.017942

	EIndex	SIndex	ACIndexiv	VInX
231.	0.4403169	0.8915166	0.6863593	0.8638028
232.	2.344754	0.9623078	0.3917046	2.672107
233.	0.3342707	-0.0350316	0.0666505	2.94199
234.	1.553465	0.4396943	0.3995479	1.834791
235.	1.968578	0.8396459	0.6880587	2.120165
236.	1.134233	1.100106	0.41133	1.794896
237.	1.232745	0.3174168	0.0753652	1.214216
238.	1.553465	0.6527616	0.0888903	1.242943
239.	1.328011	0.919998	0.7063769	1.120081
240.	1.672039	0.7940528	0.3917046	1.856304
241.	0.9940999	0.5028148	0.4148159	2.051275
242.	1.889822	0.5479262	0.393404	1.636182
243.	1.391495	-0.0523492	0.0840799	1.276924
244.	1.232745	0.6033891	0.4004194	1.657255
245.	1.262916	0.938906	0.0861451	1.749989
246.	1.181374	0.7133892	0.6898888	0.6003279
247.	1.553465	0.4950484	0.6999543	1.292983
248.	2.147729	0.9858989	0.7212964	1.464346
249.	2.488269	0.6260936	0.4012908	1.581448
250.	0.9792621	0.3109547	0.3917046	0.4997543
251.	1.295863	0.2422874	0.4165589	1.478204
252.	2.163062	0.9221892	0.3596058	2.078143
253.	1.632221	0.3973654	0.0700492	1.947375
254.	1.553465	0.5042095	0.081047	2.271449
255.	0.6404578	0.2510011	0.4117658	-0.1125267
256.	1.723101	0.2257552	0.3917046	1.10521
257.	0.4403169	-0.1453646	0.4139445	0.9252017
258.	0.4026124	0.8869691	0.3975871	1.804235
259.	1.479197	0.7064457	0.6977321	0.4832865

	EIndex	SIndex	ACIndexiv	VInX
260.	1.475014	0.977811	0.4239837	2.028842
261.	1.389152	0.6037856	0.3969335	1.65158
262.	1.426523	0.9259732	0.1041583	3.010204
263.	2.034143	0.8648265	0.6902654	2.208704
264.	0.9820446	0.2469262	0.7150773	0.5138936
265.	1.353796	-0.347678	0.4402158	0.5659026
266.	2.151911	0.8939061	0.3961541	2.649663
267.	1.022624	-0.090308	0.6970193	0.2352964
268.	1.90546	-0.0487947	0.4080686	1.448597
269.	1.632221	0.6263723	0.4319769	1.826616
270.	1.197351	-0.1311295	0.4114057	0.6548159
271.	0.9595059	0.2136561	0.7166938	1.145287
272.	1.723101	0.1388797	0.4320873	0.7410746
273.	0.3292288	-0.3559434	0.1116475	-0.1383621
274.	2.200364	0.6681538	0.4177356	2.450783
275.	1.632221	-0.0950018	0.7063637	0.8308554
276.	1.530828	0.9554369	0.4337034	1.632711
277.	1.391495	0.6749192	0.4202872	1.419958
278.	1.292983	0.547262	0.4382959	1.626661
279.	1.391495	0.6558484	0.7103013	1.775964
280.	1.568303	0.4966537	0.4142958	1.633048
281.	1.077774	1.090945	0.1014423	2.067277
282.	1.804068	-0.058787	0.7076869	1.037594
283.	2.241818	0.2524796	0.7129572	1.78134
284.	1.662391	0.2613103	0.4385536	1.485148
285.	1.255284	0.5724823	0.4317476	1.396019
286.	1.441855	0.6532607	0.1033327	1.991783
287.	1.052794	0.2375569	0.7312163	0.5591348
288.	0.344685	0.9124299	0.7314551	0.5256597

	EIndex	SIndex	ACIndexiv	VInX
289.	0.3418048	-0.0969704	0.7240396	-0.5225254
290.	0.3418048	-0.1402906	0.1130018	0.1318326
291.	1.194471	0.0482879	0.7590713	0.4836876
292.	1.353796	0.6905006	0.4167782	1.627519
293.	1.404593	-0.0301735	0.4433895	0.9310297
294.	-0.0726933	0.2111646	0.7518308	-0.6133595
295.	0.3116343	0.2310533	0.7433167	-0.200629
296.	0.746504	-0.0391363	0.1448409	0.5625268
297.	2.234186	0.0967779	0.4476581	1.883306
298.	0.3418048	-0.1306305	0.4669779	-0.2558036
299.	1.38152	0.2309716	0.4893728	1.123119
300.	0.3116343	0.6301267	0.7694063	0.1723547
301.	1.386744	0.1648725	0.7734897	0.7781267
302.	0.3116343	0.5802819	0.7862869	0.1056293
303.	0.4355654	0.6554582	0.5280691	0.5629545
304.	0.3116343	0.6114046	0.8416928	0.0813461
305.	1.388316	0.8961963	0.4526732	2.568651
306.	1.358981	0.1006874	0.4541547	0.47979
307.	0.4026124	0.5328891	0.4478801	1.652544
308.	0.5086586	0.391178	0.1189043	2.165608
309.	1.113032	0.5409507	0.4509303	1.71467
310.	1.287759	0.504606	0.7713715	-0.1612722
311.	1.811372	0.8950512	0.4526732	-0.2518178
312.	0.8581135	0.5621669	0.7460643	-0.2913808
313.	1.553465	0.5991988	0.4901811	2.839345
314.	2.423204	0.9063225	0.4528911	-0.1343952
315.	1.553465	0.612135	0.4749131	0.8216835
316.	2.132892	0.9102594	0.450756	1.008913
317.	1.01452	0.2820768	0.4439585	0.816823

	EIndex	SIndex	ACIndexiv	VInX
318.	0.4327829	0.1460788	0.4472265	1.168025
319.	2.329916	0.6914085	0.4474444	2.258979
320.	0.4327829	0.2183362	0.4537626	0.5841002
321.	0.8450162	0.4843546	0.461841	1.330524
322.	2.534814	1.098315	0.7421427	2.492994
323.	1.295863	-0.3619187	0.4526732	1.699991
324.	0.4327829	0.1773164	0.4474444	0.8819264
325.	0.5312951	0.6818413	0.1189043	3.202724
326.	2.389757	0.8067822	0.4635839	1.735647
327.	1.134233	0.966191	0.4457015	2.750838
328.	0.3418048	-0.1409493	0.4583551	0.7547812
329.	0.5086586	-0.0539752	0.7486787	0.1511579
330.	2.534814	0.700323	0.461388	2.581763
331.	0.6150444	0.6213148	0.7369139	2.896214
332.	0.4101465	-0.0916507	0.4890918	0.1620274
333.	0.3041003	0.9566813	0.7437114	1.169536
334.	1.262916	0.9363149	0.7565393	-0.1776776
335.	2.397389	0.9242402	0.1223902	0.8131113
336.	0.9896763	0.9235715	0.4439585	1.772678
337.	1.323626	0.8930104	0.461841	1.192142
338.	1.113032	0.50222	0.4500588	0.9702216
339.	0.5086586	0.5292041	0.4644554	2.822391
340.	2.329916	0.9569308	0.4679413	0.7684178
341.	1.134233	1.023042	0.7566921	1.400583
342.	1.262916	0.9422901	0.4527771	1.752429
343.	0.3116343	0.33937	0.4716403	0.179364
344.	0.344685	-0.1545257	0.7596492	-0.56949
345.	1.510621	0.8605523	0.4800748	1.891098
346.	1.055138	0.4529848	0.4669854	1.041137

	EIndex	SIndex	ACIndexiv	VInX
347.	1.634668	0.7633786	0.7676626	1.630384
348.	1.323626	0.7677609	0.7690737	0.4396585
349.	1.563879	-0.355147	0.5059572	1.58543
350.	1.563879	-0.1009629	0.7673743	0.695542
351.	0.7795547	-0.1157916	0.7954739	-0.1317109
352.	1.530828	0.132634	0.7854612	0.8780013
353.	2.610689	0.3289794	0.4807237	2.458945
354.	0.4101465	-0.0177855	0.7789079	-0.3865469
355.	1.328377	0.3448336	0.4890948	1.184116
356.	1.052794	-0.4042738	0.7994081	-0.1508877
357.	1.664735	0.6048254	0.8128167	1.585308
358.	1.90258	0.495544	0.7892524	0.0547327
359.	0.8732613	-0.0292762	0.4960791	1.773481
360.	1.055138	0.683882	0.5042325	1.545446
361.	1.055138	0.9945402	0.4976964	1.241323
362.	2.436301	0.688454	0.5060676	2.618688
363.	1.530828	0.4878767	0.5257851	1.49292
364.	0.7164367	0.1034504	0.5281677	0.2917194
365.	1.530828	0.1770207	0.8629304	0.8449187
366.	1.530828	0.5074944	0.8813775	1.156945
367.	0.5388291	-0.3237805	0.5044914	0.9312505
368.	1.723101	0.4239564	0.5328488	2.59425
369.	0.3116343	0.3475594	0.483739	2.851269
370.	2.163062	0.9640363	0.520413	0.9715939
371.	0.8609937	0.6310133	0.1711582	3.132817
372.	2.397389	0.9065868	0.7926536	2.49416
373.	0.4101465	0.3652785	0.80529	-0.1460962
374.	1.082862	0.3528803	0.803547	-0.028122
375.	2.397389	0.8894246	0.4996111	-0.0395752

	EIndex	SIndex	ACIndexiv	VInX
376.	0.3418048	0.5447734	0.5066701	1.961951
377.	2.752903	0.6675077	0.8258041	1.321254
378.	1.616583	0.4351104	0.5215895	2.898821
379.	2.36762	0.9673874	0.8079216	-0.5139323
380.	0.6862663	-0.2262304	0.5114632	1.54023
381.	-0.050057	0.3440462	0.4996983	0.3868799
382.	1.525035	0.9435857	0.2291457	-0.0140972
383.	1.227522	0.4328201	0.5044299	1.155912
384.	1.632221	0.4848891	0.8061051	1.311005
385.	1.260469	0.8960642	0.5244141	1.632119
386.	1.662391	-0.3544497	0.8198667	0.488075
387.	0.4403169	-0.3723753	0.8438154	-0.7758737
388.	0.5236633	-0.0692516	0.8308182	-0.3764064
389.	1.662391	-0.3628837	0.8510084	0.4484992
390.	1.530828	-0.3705841	0.8992214	0.261023
391.	1.194471	-0.3406089	0.9147822	-0.0609201
392.	1.07811	0.1884094	0.9267009	0.3398185
393.	0.3116343	0.354308	0.8562366	-0.1902943
394.	1.050386	-0.0585176	0.5644041	0.4274646
395.	1.662391	0.2487947	0.5950226	1.316163
396.	2.298877	0.8456211	0.8936755	2.250822
397.	1.153989	0.7970404	0.6558035	1.295226

Appendix VIII: Diagnostic Tests

Table A4: Rstudent, Leverage and Cooks Distance Test Results

	RSTUDENT	LEVERAGE	COOKS DISTANCE
1.	-0.4699153	0.0339525	0.0003888
2.	0.1607285	0.0620862	0.0000857
3.	-0.1137427	0.0383064	0.0000258
4.	0.1907699	0.0276002	0.0000518
5.	-0.5167186	0.0351557	0.0004874
6.	-0.132147	0.0454061	0.0000416
7.	-1.442393	0.0388789	0.0041959
8.	-0.6139683	0.0641265	0.0012936
9.	-0.4714237	0.0411857	0.0004783
10.	-0.987181	0.0281863	0.0014133
11.	1.145302	0.0340202	0.0023079
12.	0.7134364	0.0307847	0.0008094
13.	-1.350928	0.0297531	0.0027921
14.	-0.6795883	0.0392228	0.0009441
15.	-1.629166	0.0640362	0.0090399
16.	0.9956998	0.0401609	0.0020742
17.	2.060398	0.0346202	0.0075471
18.	0.5190725	0.0553319	0.0007906
19.	-0.7506396	0.0400248	0.001176
20.	-0.255904	0.053684	0.0001862
21.	-0.1120827	0.0385083	0.0000252
22.	-0.4751302	0.0335787	0.000393
23.	-1.946098	0.0351213	0.0068422

	RSTUDENT	LEVERAGE	COOKS DISTANCE
24.	-1.833388	0.0978684	0.0181192
25.	0.0893628	0.0665302	0.0000285
26.	-0.1192482	0.0784802	0.0000607
27.	1.760585	0.0320651	0.0051057
28.	0.2600904	0.0698685	0.0002547
29.	-0.3844777	0.0443705	0.000344
30.	-2.048132	0.0462689	0.0100899
31.	1.664339	0.047712	0.0069068
32.	1.279509	0.0681041	0.0059721
33.	0.242372	0.072515	0.0002302
34.	0.6505182	0.0506644	0.0011309
35.	-0.119624	0.0932659	0.0000738
36.	2.557959	0.0623174	0.0214275
37.	-1.1043	0.0335683	0.0021167
38.	-0.2654931	0.0718267	0.0002734
39.	0.5289013	0.0325457	0.0004714
40.	-2.011572	0.0440099	0.0092394
41.	0.4940852	0.0279392	0.0003515
42.	0.1080094	0.0371424	0.0000226
43.	2.108633	0.0306831	0.0069735
44.	0.1686547	0.0390709	0.000058
45.	-0.5109148	0.042256	0.000577
46.	0.298559	0.0874997	0.0004284
47.	1.122192	0.0541573	0.0036028
48.	1.599039	0.0491698	0.0065841

	RSTUDENT	LEVERAGE	COOKS DISTANCE
49.	-0.1041632	0.1161793	0.0000715
50.	1.223528	0.0367007	0.002848
51.	-1.423979	0.034175	0.0035777
52.	-1.4045	0.0784068	0.0083697
53.	0.281249	0.0388229	0.0001601
54.	-0.0348916	0.0469122	3.00E-06
55.	0.0151588	0.0633913	7.80E-07
56.	-0.8743591	0.0700162	0.0028797
57.	-0.4380939	0.1272805	0.0014026
58.	0.5535529	0.0517454	0.0008376
59.	1.579703	0.0492777	0.0064417
60.	1.470162	0.0488463	0.0055328
61.	1.229962	0.0455681	0.0036064
62.	0.278521	0.0397092	0.0001608
63.	-0.7062233	0.0493542	0.0012964
64.	1.525081	0.0425089	0.0051449
65.	0.046767	0.0363954	4.14E-06
66.	1.01747	0.0475182	0.0025821
67.	-0.4438138	0.032555	0.0003321
68.	-0.9673015	0.0573298	0.0028457
69.	-1.709153	0.046459	0.0070804
70.	1.205619	0.0378434	0.002855
71.	1.229317	0.0608301	0.0048875
72.	-1.622981	0.0495864	0.0068418
73.	-1.518984	0.1407117	0.0188263

	RSTUDENT	LEVERAGE	COOKS DISTANCE
74.	-0.482221	0.0396538	0.0004811
75.	0.1414707	0.0404679	0.0000423
76.	-2.505674	0.0609182	0.0200828
77.	-0.7019596	0.0585408	0.001534
78.	-0.4054955	0.0518624	0.0004507
79.	0.359379	0.0322931	0.000216
80.	-1.391637	0.0311598	0.0031066
81.	-1.472757	0.0536092	0.0061243
82.	0.6959955	0.0443252	0.0011249
83.	0.1657198	0.040884	0.0000587
84.	1.527962	0.0643282	0.0079972
85.	-0.0123211	0.0428631	3.41E-07
86.	-0.4827377	0.0557814	0.0006898
87.	-0.7645889	0.0642124	0.0020079
88.	0.4315271	0.0631726	0.0006292
89.	1.14335	0.0352211	0.0023842
90.	1.81697	0.0322646	0.0054701
91.	0.2866529	0.0396179	0.0001699
92.	-0.7305664	0.0327037	0.0009034
93.	1.956375	0.0433172	0.0086005
94.	1.354144	0.0871128	0.0087298
95.	1.040156	0.0634765	0.0036658
96.	-0.4885689	0.0900465	0.0011834
97.	0.7482002	0.035892	0.0010432
98.	1.320638	0.0443979	0.0040436

	RSTUDENT	LEVERAGE	COOKS DISTANCE
99.	1.533014	0.0557808	0.0069171
100.	-0.0631285	0.0784802	0.000017
101.	0.8442099	0.0345363	0.0012757
102.	1.259929	0.0711129	0.006067
103.	-1.267776	0.0438953	0.0036836
104.	-1.811038	0.0301215	0.0050625
105.	0.867062	0.0400353	0.0015687
106.	0.6523259	0.1209147	0.002931
107.	1.628856	0.0582913	0.0081757
108.	0.0574293	0.0718803	0.0000128
109.	-0.0475558	0.0396753	4.68E-06
110.	-1.377885	0.0447659	0.0044381
111.	-0.9796474	0.0952752	0.0050538
112.	-0.820054	0.0294576	0.0010214
113.	-0.9275811	0.0809664	0.0037915
114.	0.9374116	0.0383486	0.0017527
115.	-1.0893	0.0488955	0.0030485
116.	0.2372225	0.0537601	0.0001603
117.	1.071491	0.040238	0.0024057
118.	0.1304786	0.0289084	0.0000254
119.	2.011451	0.0545911	0.0115877
120.	2.204311	0.0321442	0.007987
121.	1.331134	0.0811774	0.0078114
122.	1.540187	0.0701286	0.0089127
123.	-1.130899	0.033477	0.0022133

	RSTUDENT	LEVERAGE	COOKS DISTANCE
124.	-0.6349211	0.0897351	0.0019902
125.	1.801755	0.0369453	0.00619
126.	-1.732567	0.0435908	0.0068046
127.	-0.1292284	0.0659213	0.0000591
128.	0.6252757	0.1318928	0.0029748
129.	-0.9356191	0.0444591	0.0020372
130.	-0.1511979	0.0619711	0.0000757
131.	-1.865579	0.0338543	0.0060579
132.	-1.197114	0.0659845	0.0050563
133.	-0.6920428	0.0556787	0.0014139
134.	-1.569555	0.0306952	0.0038855
135.	-0.6708105	0.0367811	0.0008604
136.	2.544162	0.0450177	0.0150379
137.	-0.2665913	0.0872773	0.0003406
138.	-0.2960717	0.0782812	0.0003731
139.	-0.9574676	0.0368544	0.0017543
140.	-1.820464	0.0370408	0.006335
141.	0.6270159	0.0513265	0.0010653
142.	-0.8022085	0.0517728	0.0017585
143.	-1.028234	0.0409156	0.0022549
144.	0.2841632	0.0404959	0.0001708
145.	-0.3642711	0.0453771	0.0003161
146.	-0.2582448	0.0557026	0.0001972
147.	-0.3287737	0.0753785	0.0004416
148.	0.6517296	0.0746915	0.0017169

	RSTUDENT	LEVERAGE	COOKS DISTANCE
149.	-0.0120477	0.0307654	2.31E-07
150.	2.701716	0.034175	0.0166404
151.	-0.3068208	0.0430703	0.0002124
152.	-0.625081	0.0318503	0.0006437
153.	0.7185488	0.0379403	0.0010194
154.	-0.6175935	0.1238031	0.0026991
155.	-0.3046798	0.0780495	0.0003939
156.	0.9087376	0.0690599	0.0030644
157.	0.195079	0.0745228	0.0001536
158.	1.284403	0.0589121	0.0051546
159.	-0.9091036	0.0815448	0.0036706
160.	-0.8741995	0.0739863	0.0030549
161.	0.7701619	0.0275518	0.0008412
162.	0.6193768	0.0475035	0.0009582
163.	1.304129	0.0851757	0.0079028
164.	1.266751	0.0582241	0.0049524
165.	0.3463251	0.025616	0.000158
166.	-0.1658963	0.0335535	0.0000479
167.	-0.313734	0.1302232	0.0007386
168.	-0.460479	0.0633198	0.0007182
169.	0.92418	0.048564	0.0021806
170.	1.106875	0.0741417	0.0049026
171.	1.055111	0.0643256	0.0038256
172.	0.8262436	0.100837	0.0038312
173.	-0.7032142	0.0311534	0.0007961

	RSTUDENT	LEVERAGE	COOKS DISTANCE
174.	-1.578524	0.0503781	0.0065834
175.	-0.6036197	0.09758	0.0019732
176.	1.683012	0.0508021	0.0075433
177.	-0.6161265	0.0482809	0.0009645
178.	-1.544162	0.0514629	0.0064447
179.	0.4867724	0.0519152	0.0006501
180.	-0.312283	0.0354009	0.0001794
181.	-0.1244371	0.0574928	0.0000474
182.	0.8592827	0.0857868	0.0034667
183.	-0.2863884	0.0351198	0.0001496
184.	-0.3963469	0.057811	0.000483
185.	-0.7702026	0.0606486	0.0019171
186.	-0.266937	0.0324977	0.00012
187.	0.6293514	0.0751468	0.0016117
188.	-1.571503	0.0528567	0.0068643
189.	-1.005608	0.0495905	0.0026382
190.	-1.583482	0.053516	0.0070605
191.	-0.9700971	0.0387757	0.0018985
192.	-0.0104569	0.0543232	3.15E-07
193.	-0.4149711	0.0306952	0.0002733
194.	0.0404123	0.0878229	7.88E-06
195.	0.7052153	0.0342002	0.0008817
196.	-0.414558	0.0539068	0.0004907
197.	-0.1881656	0.0292102	0.0000534
198.	1.285538	0.1250692	0.0117914

	RSTUDENT	LEVERAGE	COOKS DISTANCE
199.	-2.082322	0.081218	0.0189968
200.	-0.4586689	0.051036	0.0005669
201.	0.9313293	0.0341014	0.0015317
202.	0.125326	0.0360444	0.0000294
203.	0.403075	0.0453442	0.0003867
204.	-0.7144985	0.0528697	0.0014267
205.	-0.5022273	0.0320758	0.0004188
206.	0.8934025	0.0470278	0.0019705
207.	0.4376358	0.0284911	0.0002814
208.	-0.9229256	0.052644	0.0023676
209.	-0.4095534	0.0747256	0.0006788
210.	-0.6734474	0.0316609	0.0007425
211.	0.4457272	0.0339389	0.0003497
212.	-0.4190516	0.0474015	0.0004379
213.	1.883759	0.0326244	0.0059435
214.	-0.0725663	0.0663368	0.0000188
215.	-0.7269772	0.0312245	0.0008528
216.	1.386861	0.0455616	0.0045796
217.	1.672175	0.0423253	0.0061497
218.	-0.1326387	0.1362601	0.0001391
219.	0.4353988	0.0472441	0.000471
220.	0.9584931	0.0551941	0.0026841
221.	0.4119209	0.0294847	0.0002583
222.	1.588437	0.034175	0.004446
223.	1.462738	0.0344248	0.0038026

	RSTUDENT	LEVERAGE	COOKS DISTANCE
224.	-0.792268	0.0354329	0.001154
225.	0.3979888	0.0335009	0.0002751
226.	0.7631037	0.0294576	0.0008847
227.	-0.301196	0.0361301	0.0001704
228.	-0.8957525	0.0251739	0.0010366
229.	0.4986294	0.0373905	0.0004838
230.	0.134651	0.0542766	0.0000522
231.	-0.7692083	0.0326244	0.0009988
232.	0.8096877	0.0324778	0.0011014
233.	1.218467	0.0323071	0.0024751
234.	0.5189585	0.0297728	0.000414
235.	0.8060608	0.033114	0.0011136
236.	-0.7915258	0.026918	0.0008674
237.	-0.8443736	0.033477	0.0012357
238.	0.2374315	0.0554837	0.000166
239.	0.1760776	0.0406134	0.0000658
240.	-0.2673467	0.1303146	0.0005368
241.	0.8300586	0.0462208	0.0016708
242.	0.6810247	0.0741632	0.0018602
243.	-0.5520608	0.0557814	0.0009019
244.	-0.8334759	0.0298047	0.0010679
245.	0.9949028	0.0349225	0.001791
246.	-1.500295	0.0514702	0.0060868
247.	-0.014892	0.0391176	4.53E-07
248.	0.1451715	0.0970834	0.0001136

	RSTUDENT	LEVERAGE	COOKS DISTANCE
249.	-0.6243547	0.0456734	0.0009343
250.	-0.9835296	0.0581129	0.0029844
251.	-0.3121503	0.0321952	0.0001625
252.	-0.4011028	0.0290017	0.0002408
253.	0.2249657	0.0416795	0.0001103
254.	0.2273128	0.0367811	0.0000989
255.	-1.618645	0.0391776	0.0053187
256.	-1.267239	0.0453061	0.0038044
257.	0.5872813	0.0324197	0.0005788
258.	0.9477533	0.0554679	0.0026382
259.	-0.9093627	0.0354055	0.0015183
260.	0.2785959	0.0515914	0.0002116
261.	-0.9900439	0.02753	0.0013875
262.	2.626832	0.0632419	0.0229333
263.	0.7745407	0.0491535	0.0015523
264.	-1.103182	0.0731173	0.0047974
265.	-0.382577	0.0603001	0.0004707
266.	0.7150125	0.0408105	0.001089
267.	-0.7027724	0.0339844	0.0008699
268.	1.763634	0.048617	0.0079031
269.	1.309718	0.0352987	0.0031323
270.	0.2210223	0.0289809	0.0000731
271.	0.8202198	0.025616	0.0008851
272.	-0.4202681	0.0510241	0.0004759
273.	-0.2768919	0.0938103	0.0003978

	RSTUDENT	LEVERAGE	COOKS DISTANCE
274.	0.6820103	0.039192	0.00095
275.	0.6595438	0.0303507	0.0006818
276.	0.675472	0.0443778	0.0010609
277.	0.4500348	0.0519984	0.0005566
278.	-0.8343865	0.0304906	0.0010956
279.	0.89648	0.0349707	0.0014569
280.	0.4891423	0.0306831	0.0003794
281.	0.0661867	0.0510745	0.0000118
282.	0.6983421	0.0498397	0.0012808
283.	1.345549	0.0352903	0.0033044
284.	1.303333	0.0266674	0.0023227
285.	1.191224	0.0256671	0.001867
286.	-0.3062805	0.0275996	0.0001334
287.	-0.8402807	0.0454881	0.0016837
288.	-1.58497	0.0561076	0.0074366
289.	0.1850421	0.1192334	0.0002324
290.	0.5864916	0.080065	0.0014995
291.	-0.4785852	0.0516968	0.0006256
292.	0.5072194	0.0356653	0.0004767
293.	0.6045308	0.0325457	0.0006157
294.	-1.445791	0.0445791	0.0048625
295.	-1.325358	0.0683654	0.0064322
296.	0.0721846	0.0325457	8.79E-06
297.	1.685937	0.0604625	0.0091014
298.	0.2268032	0.0943355	0.0002686

	RSTUDENT	LEVERAGE	COOKS DISTANCE
299.	0.3906938	0.0352903	0.0002798
300.	-0.2773856	0.0494441	0.0002006
301.	-0.282053	0.0650127	0.0002773
302.	-0.6120524	0.052698	0.0010437
303.	-0.7228841	0.0349225	0.0009467
304.	-0.6811853	0.0483282	0.0011799
305.	0.8092504	0.0389495	0.0013283
306.	-0.0399645	0.0277151	2.28E-06
307.	-0.2410263	0.0770324	0.000243
308.	-0.0820761	0.0256149	8.88E-06
309.	-0.907357	0.026918	0.0011393
310.	-1.680825	0.0388229	0.0056781
311.	-0.004149	0.0936072	8.91E-08
312.	-0.9789354	0.0351317	0.0017448
313.	0.9690556	0.0378142	0.0018456
314.	-2.194784	0.0347762	0.0085908
315.	-0.2123309	0.0493115	0.0001172
316.	-0.166919	0.0523113	0.0000771
317.	-0.9234897	0.0548294	0.0024746
318.	0.0265055	0.1247095	5.02E-06
319.	0.987083	0.0338429	0.0017066
320.	-0.5757896	0.0565005	0.0009944
321.	-0.206728	0.0299467	0.0000661
322.	2.038342	0.0766673	0.0171063
323.	-0.752516	0.0256149	0.0007452

	RSTUDENT	LEVERAGE	COOKS DISTANCE
324.	-0.4157239	0.0443778	0.0004022
325.	1.78185	0.0296815	0.0048282
326.	-0.3423861	0.034007	0.0002068
327.	0.9236981	0.0324778	0.0014326
328.	-1.6094	0.0470984	0.0063742
329.	-0.5658304	0.076185	0.0013225
330.	0.4302499	0.0883217	0.0008986
331.	1.447732	0.129661	0.0155671
332.	-0.4788288	0.0445501	0.0005356
333.	-0.0510108	0.0778153	0.000011
334.	-1.904203	0.0419149	0.0078767
335.	-1.773603	0.028438	0.0045777
336.	0.8420463	0.0451354	0.0016771
337.	0.0931091	0.077949	0.0000367
338.	-0.839295	0.0407171	0.0014961
339.	0.804104	0.0526868	0.0017997
340.	1.042781	0.0471664	0.0026907
341.	-0.130358	0.0311534	0.0000274
342.	0.0386238	0.0315191	2.43E-06
343.	-1.128244	0.0577845	0.0039005
344.	-1.838577	0.0247317	0.0042592
345.	0.6230838	0.0321487	0.0006458
346.	-0.1931364	0.044011	0.0000861
347.	0.3856948	0.0323	0.0002488
348.	-0.3619779	0.0258373	0.0001742

	RSTUDENT	LEVERAGE	COOKS DISTANCE
349.	0.2612378	0.0648002	0.000237
350.	0.0062615	0.0258373	5.21E-08
351.	-1.235097	0.0339844	0.0026796
352.	-0.095446	0.0398472	0.000019
353.	1.686635	0.0306831	0.0044805
354.	-1.351672	0.0386209	0.0036617
355.	0.0168361	0.0330337	4.85E-07
356.	-0.9412557	0.0289809	0.0013225
357.	-0.1752925	0.034896	0.0000557
358.	-0.2954504	0.0527254	0.0002435
359.	1.043483	0.0506554	0.0029043
360.	0.5302396	0.033589	0.0004895
361.	-0.2136584	0.0369021	0.0000877
362.	1.005212	0.0429241	0.0022658
363.	0.0219655	0.031552	7.88E-07
364.	-0.1571417	0.0601386	0.0000792
365.	0.6337388	0.0357863	0.0007465
366.	-0.4545347	0.0315582	0.0003373
367.	-0.6082881	0.0327588	0.0006276
368.	0.3136366	0.0663957	0.0003506
369.	2.172339	0.032625	0.0078798
370.	0.1715349	0.0352903	0.000054
371.	1.808465	0.0418299	0.0070962
372.	0.7358804	0.0297531	0.0008313
373.	-1.812219	0.0456452	0.0078064

	RSTUDENT	LEVERAGE	COOKS DISTANCE
374.	-1.487922	0.0472721	0.0054748
375.	-1.323454	0.0543232	0.0050207
376.	0.0187539	0.0296616	5.39E-07
377.	-0.3485175	0.033114	0.0002085
378.	1.713914	0.0278716	0.0041895
379.	-1.52738	0.0450721	0.0054862
380.	-0.157704	0.0861715	0.0001176
381.	-1.019112	0.0549777	0.0030207
382.	0.3613639	0.0807972	0.0005752
383.	-0.163418	0.0740283	0.000107
384.	-0.562706	0.0286344	0.0004675
385.	0.4109749	0.0309659	0.0002705
386.	-0.1220546	0.0555903	0.000044
387.	-1.008676	0.0879062	0.0049027
388.	-1.955401	0.0418446	0.0082871
389.	-0.3577947	0.0247332	0.0001627
390.	0.0232995	0.0513024	1.47E-06
391.	-0.4291661	0.0542897	0.0005298
392.	-1.633357	0.0294568	0.0040307
393.	-1.439331	0.0642035	0.0070866
394.	-0.1958793	0.0268208	0.000053
395.	0.8516975	0.0344935	0.0012967
396.	0.384596	0.0297531	0.0002273
397.	-0.2492356	0.0658353	0.0002194

Table A5: Variance Inflation Factor

Variable	VIF	1/VIF
agroecologZone		
1.LM4-5	1.75	0.573048
2.UM3-4	2.04	0.491239
3.LM5	1.9	0.526142
4.LH1-5	2.48	0.403144
5.UM5-6	1.67	0.597777
6.LM3	1.41	0.710774
Hhsize	1.17	0.855253
1.accuracy_cInfo	1.11	0.899734
Maizeshortperiod		
1.less than three months	1.48	0.674537
2.4-6 months	2.02	0.494593
3.over six months	2.52	0.396735
1.eatAlter	1.17	0.851206
1.clim_humDiseases	1.07	0.933787
1.water_period1	1.53	0.654968
1.land_type1	1.25	0.803072
1.farm_type	1.2	0.833994
marital_status1		
1.single	1.64	0.608412
2.married	1.85	0.539545
3.divorced	1.35	0.741753
Mean VIF	1.61	

Table A6: Correlation Analysis for Variables on Determinants of Vulnerability

	VInX	agroecolog~e	Hhsize	accuracy_c~o	maizeshort~d	eatAlter	clim_humdi~s	water_peri~1	land_type1	farm_type	marital_st~1
VInX	1										
agroecologZone	-0.2608	1									
Hhsize	0.1395	-0.1307	1								
accuracy_clinfo	-0.0361	0.0635	0.0508	1							
maizeshortperiod	0.5098	-0.1218	0.1932	0.0604	1						
eatAlter	0.0258	-0.0037	0.0311	0.0181	0.27	1					
clim_humdiseases	0.1193	-0.0359	0.0171	-0.0023	0.0005	-0.0005	1				
water_period1	0.3252	-0.4922	0.1307	-0.028	0.2501	0.0075	0.0151	1			
land_type1	-0.0773	0.2036	0.0002	-0.0579	-0.0904	0.0006	0.0878	-0.2491	1		
farm_type	-0.0195	-0.0738	0.0268	-0.0009	-0.1254	-0.0103	-0.0118	0.0317	0.0955	1	
marital_status1	0.101	-0.0874	0.1114	0.0997	0.1181	0.0266	0.0839	0.0777	-0.0829	-0.1053	1

Appendix IX: Regression Results for Determinants of Vulnerability of Smallholder Maize Production to Climate Change

Dependent variable: VInX	Coef.	Std. Err.	t	P>t	[95% Conf.Interval]	
agroecologZone						
LM 4-5	-0.2116524	0.1310718	-1.61	0.107	-0.4693758	0.0460709
UM 3-4	-0.6318166	0.1279922	-4.94	0.000	-0.8834846	-0.3801485
LM 5	0.0712064	0.1340353	0.53	0.596	-0.1923442	0.3347569
LH 1-5	-0.3232808	0.1307597	-2.47	0.014	-0.5803906	-0.0661711
UM 5-6	-0.2379031	0.1754271	-1.36	0.176	-0.5828412	0.1070351
LM 3	-0.9974157	0.2195564	-4.54	0.000	-1.429124	-0.5657072
Hhsize	0.0060757	0.0165115	0.37	0.713	-0.0263903	0.0385418
accuracy_clinfo						
yes	-0.1276646	0.0744171	-1.72	0.087	-0.2739893	0.01866
maizeshort_period						
less than three months	0.6554954	0.1443818	4.54	0.000	0.371601	0.9393899
4-6 months	0.7815155	0.1156078	6.76	0.000	0.5541986	1.008832
over 6 months	1.004095	0.1127304	8.91	0.000	0.7824357	1.225754
eatAlter						
yes	-0.2385402	0.083498	-2.86	0.005	-0.4027203	-0.0743601
clim_humdiseases						
yes	0.1897273	0.0733667	2.59	0.01	0.0454681	0.3339865
water_period1						
one day	0.2833599	0.0900659	3.15	0.002	0.1062655	0.4604543
1.land_type1	-0.0240932	0.0787705	-0.31	0.76	-0.1789778	0.1307914
farm_type						
both crop and livestock/ mixed farming	0.188629	0.1185425	1.59	0.112	-0.0444584	0.4217164
marital_status1						
1.single	0.3231503	0.176725	1.83	0.068	-0.02434	0.6706406
2.maried	0.149763	0.119231	1.26	0.21	-0.084678	0.384204
3.divorced	0.1766815	0.2496717	0.71	0.48	-0.3142421	0.6676052
_cons	0.4922177	0.2255052	2.18	0.03	0.0488122	0.9356233

		Coef.	Std. Err.	t	P>t	[95% Conf.Interval]	
Linktest	_hat	0.7196106	0.206608	3.48	0.001	0.3134186	1.125803
	_hatsq	0.1125229	0.0795473	1.41	0.158	-0.0438673	0.2689132
	_cons	0.1324068	0.1291661	1.03	0.306	-0.1215342	0.3863478
		Obs	W	V	z	Prob>z	
Shapiro-Wilk test results		397	0.99456	1.488	0.945	0.17231	
Source		SS	DF	MS	Number of obs	397	
					F (19, 377)	14.75	
Model		138.63506 9	19	7.29658258	Prob > F	0.000	
Residual		186.43571	377	0.494524429	R-squared	0.4265	
					Adj R-squared	0.3976	
Total		325.07077 9	396	0.820885805	Root MSE	0.70322	
White test	Wald chi ² (160): 168.52						
	Prob>chi ² : 0.3067						
Ovtest	F (3,374): 1.80						
	Prob>F: 0.1458						

Source: Survey data

Appendix X: Weighted Sum of Adaptation Choices

	Adp_impact
1.	12.4
2.	15.1
3.	24.2
4.	26.6
5.	27.4
6.	27.4
7.	27.5
8.	27.9
9.	28.2
10.	28.5
11.	30.6
12.	30.6
13.	30.6
14.	32.1
15.	32.3
16.	32.7
17.	33.3
18.	33.3
19.	33.6
20.	33.8
21.	33.8
22.	33.8
23.	33.8
24.	33.8

	Adp_impact
25.	33.9
26.	35.1
27.	35.1
28.	35.6
29.	35.6
30.	35.6
31.	36.1
32.	36.1
33.	36.5
34.	36.9
35.	37
36.	37
37.	37
38.	37
39.	37
40.	37
41.	37.1
42.	37.2
43.	37.5
44.	38.5
45.	38.6
46.	38.8
47.	39.2
48.	39.3

	Adp_impact
49.	40
50.	40
51.	40
52.	41.1
53.	41.2
54.	41.4
55.	41.5
56.	41.5
57.	42.4
58.	42.5
59.	42.7
60.	43.5
61.	43.8
62.	44
63.	44
64.	45.6
65.	45.6
66.	48.6
67.	50.8
68.	55.4
69.	61
70.	62.8
71.	63.6
72.	64

	Adp_impact
73.	65.3
74.	66.5
75.	67.7
76.	69
77.	69
78.	69.1
79.	69.2
80.	69.39999
81.	69.4
82.	69.6
83.	70.2
84.	70.6
85.	70.6
86.	70.8
87.	71.2
88.	71.5
89.	72.3
90.	73.2
91.	73.6
92.	73.8
93.	73.8
94.	74
95.	74
96.	74
97.	74
98.	74.1

	Adp_impact
99.	74.89999
100.	75.9
101.	77.2
102.	77.5
103.	77.6
104.	78.1
105.	78.1
106.	78.1
107.	78.8
108.	79
109.	81
110.	81.7
111.	82.2
112.	82.2
113.	83.6
114.	84.3
115.	84.6
116.	84.8
117.	85.2
118.	85.3
119.	86.5
120.	87.6
121.	87.8
122.	88.5
123.	89.7
124.	90.1

	Adp_impact
125.	91
126.	91.5
127.	92.8
128.	94
129.	94.5
130.	95.39999
131.	96.7
132.	97.6
133.	98.8
134.	100
135.	100.4
136.	100.6
137.	101.4
138.	101.4
139.	101.4
140.	102.5
141.	103.4
142.	103.7
143.	104.6
144.	105.3
145.	105.4
146.	105.9
147.	106.2
148.	109.1
149.	109.2
150.	109.5

	Adp_impact
151.	110.6
152.	111
153.	111
154.	111
155.	111.2
156.	111.5
157.	111.9
158.	112
159.	112.2
160.	112.8
161.	114.2
162.	114.6
163.	115.1
164.	115.8
165.	116.7
166.	117
167.	117.5
168.	118
169.	118.3
170.	118.3
171.	119.5
172.	120
173.	120
174.	121.2
175.	122.1
176.	122.3

	Adp_impact
177.	124.8
178.	125.3
179.	126.9
180.	127.7
181.	128.5
182.	128.7
183.	128.7
184.	129.5
185.	132.8
186.	134.1
187.	134.9
188.	135.8
189.	139.7
190.	140.8
191.	141.6
192.	143.6
193.	143.9
194.	144.4
195.	144.6
196.	144.8
197.	146.2
198.	146.3
199.	146.8
200.	146.9
201.	147.4
202.	148.6

	Adp_impact
203.	148.6
204.	148.6
205.	148.7
206.	148.7
207.	149.2
208.	149.2
209.	150.3
210.	150.6
211.	150.6
212.	151
213.	151.7
214.	152.1
215.	152.2
216.	152.2
217.	152.5
218.	152.5
219.	153
220.	153.2
221.	153.4
222.	153.7
223.	154
224.	154.6
225.	155.1
226.	155.2
227.	157
228.	157.3

	Adp_impact
229.	157.4
230.	158.1
231.	158.5
232.	158.6
233.	159.1
234.	159.3
235.	159.6
236.	159.9
237.	160
238.	160.4
239.	160.8
240.	161.1
241.	163.5
242.	163.6
243.	164.5

	Adp_impact
244.	164.5
245.	165.5
246.	168
247.	172.2
248.	172.5
249.	173.4
250.	174.4
251.	174.7
252.	175.7
253.	176.1
254.	177.1
255.	178.5
256.	179.4
257.	181.5
258.	182.1

	Adp_impact
259.	186.2
260.	190
261.	190.8
262.	193.2
263.	196.5
264.	202
265.	203.9
266.	206.9
267.	206.9
268.	207.2
269.	212.9
270.	219.9
271.	224.6
272.	247.6
273.	260.4

Source: Survey data

Appendix XI: Tests for Multicollinearity

Table A7: VIF Results

Variable	VIF	SQRT VIF	Tolerance	R-Squared
AdaptLV	3.4	1.84	0.2943	0.7057
soilAnalysis	1.11	1.05	0.9013	0.0987
accuracy_clinfo	1.03	1.02	0.967	0.033
exten_access	1.13	1.06	0.8839	0.1161
number_socigrp	1.13	1.06	0.8823	0.1177
land_type1	1.13	1.06	0.8869	0.1131
farm_type	1.08	1.04	0.9293	0.0707
water_period1	1.08	1.04	0.9272	0.0728
farmexpl	1.04	1.02	0.9658	0.0342
dist_market	1.02	1.01	0.9836	0.0164
Lnumbadapt	3.46	1.86	0.2891	0.7109
Mean VIF	1.51			

Source: Survey data

Table A8: Correlation Analysis for Variables on Determinants of the Levels of efficacy of Adaptation

	AdaptLV	soilAnalysis	accuracy_clinfo	exten_access	number_socigrp	land_type1	farm_type	water_period1	farmexp1	dist_market	Lnumbadapt
AdaptLV	1										
soilAnalysis	0.0011	1									
accuracy_clinfo	0.0028	-0.0347	1								
exten_access	0.0774	0.1293	0.0502	1							
number_socigrp	0.0683	0.1462	-0.0939	0.2314	1						
land_type1	0.0095	0.1777	-0.0916	0.1475	-0.0522	1					
farm_type	-0.0569	0.0041	0.0098	0.14	0.1308	0.1043	1				
water_period1	0.0131	0.1769	0.0303	0.1268	-0.0196	0.0712	0.1385	1			
farmexp1	-0.0201	0.0277	0.0487	0.0059	-0.0712	0.1091	0.0899	0.0935	1		
dist_market	0.0627	0.0528	-0.0312	-0.0363	0.0196	-0.0281	-0.0392	-0.0198	-0.0105	1	
Lnumbadapt	0.8356	-0.0204	-0.0342	0.0903	0.0663	0.0912	-0.053	-0.0186	-0.0379	0.0838	1

Source: survey data

Appendix XII: Regression Results for Determinants of Level of Efficacy of Adaptation of Smallholder Maize Production to Climate Change

Table A9: Oprobit Model Results on the Determinants of the Level of Efficacy of Adaptation of Smallholder Maize Production to Climate Change

Dependent variable: AdaptLV						
	Coef.	Robust Std. Err.	z	P>z	[95% Conf. Interval]	
soilAnalysis						
Yes	0.9141877	0.4390235	2.08	0.037	0.0537174	1.774658
accuracy_clinfo						
yes	0.0766483	0.2667493	0.29	0.774	-0.4461707	0.5994673
exten_access						
yes	0.6028527	0.3120737	1.93	0.053	-0.0088005	1.214506
number_socigrp	-0.0625602	0.1166117	-0.54	0.592	-0.291115	0.1659947
farm_type						
both crop & livestock/ mixed farming	-0.2723418	0.3296824	-0.83	0.409	-0.9185075	0.3738238
l.land_type1	-0.7434543	0.3028162	-2.46	0.014	-1.336963	-0.1499454
water_period1						
one day	0.180741	0.3567583	0.51	0.612	-0.5184924	0.8799744
one month & beyond	0.1624817	0.4537175	0.36	0.72	-0.7267883	1.051752
farmexpl						

Dependent variable: AdaptLV							
	Coef.	Robust Std. Err.	z	P>z	[95% Conf. Interval]		
1-10 years	-1.040928	0.4661388	-2.23	0.026	-1.954543	-0.1273126	
over 20 years	-0.290933	0.3780483	-0.77	0.442	-1.031894	0.450028	
dist_market							
1-5 kilometers	0.1832595	0.3426257	0.53	0.593	-0.4882745	0.8547935	
5-10 kilometers	0.4055407	0.324422	1.25	0.211	-0.2303148	1.041396	
Lnnumbadapt	8.33865	1.117536	7.46	0	6.148319	10.52898	
/cut1	7.874489	0.947656			6.017117	9.73186	
/cut2	13.81107	1.52817			10.81591	16.80623	
linktest	_hat	0.7996108	0.4414823	1.81	0.07	-0.0656786	1.6649
	_hatsq	0.0109111	0.0235434	0.46	0.643	-0.0352332	0.0570553
Omodel test	Waldchi2(11): 10.10		Prob > chi2: 0.4317				
Wald test	Wald chi2(13): 97.41		Prob > chi2:0.0000				
Log pseudolikelihood	-53936633		Pseudo R2: 0.7798				
Observations:	273						

Source: Survey data

Table A10: Marginal Effects of Oprobit Model Results on the Determinants of the Level of Efficacy of Adaptation of Smallholder Maize Production to Climate Change

Dependent Variable: AdaptLV							
	Delta dy/dx	method Std. Err.	z	P>z	[95% Conf. Interval]		
soilAnalysis (yes)							
_predict							
Low	-0.0520602	0.0262138	-1.99	0.047	-0.1034382	-0.0006821	
Moderate	-0.0013767	0.0094708	-0.15	0.884	-0.0199391	0.0171857	
High	0.0534369	0.0305148	1.75	0.08	-0.0063711	0.1132449	
accuracy_clinfo (yes)							
_predict							
Low	-0.004795	0.0168901	-0.28	0.776	-0.037899	0.028309	
Moderate	0.0011876	0.0043301	0.27	0.784	-0.0072992	0.0096745	
High	0.0036074	0.0126014	0.29	0.775	-0.021091	0.0283057	
exten_access (yes)							
_predict							
Low	-0.0393948	0.0216184	-1.82	0.068	-0.081766	0.0029765	
Moderate	0.0128934	0.0098373	1.31	0.19	-0.0063874	0.0321742	
High	0.0265014	0.0130734	2.03	0.043	0.000878	0.0521248	
number_socigrp							
_predict							
Low	0.0039138	0.0075122	0.52	0.602	-0.0108098	0.0186373	

Dependent Variable: AdaptLV							
	Delta dy/dx	method Std. Err.	z	P>z	[95% Conf. Interval]		
Moderate	-0.0009671	0.0019837	-0.49	0.626	-0.004855	0.0029209	
High	-0.0029467	0.0055911	-0.53	0.598	-0.013905	0.0080116	
farm_type (mixed farming)							
_predict							
Low	0.0164723	0.0199564	0.83	0.409	-0.0226416	0.0555861	
Moderate	-0.0028821	0.0033989	-0.85	0.396	-0.0095438	0.0037797	
High	-0.0135902	0.0173351	-0.78	0.433	-0.0475664	0.020386	
land_type1 (privately owned)							
_predict							
Low	0.0464018	0.0189354	2.45	0.014	0.0092891	0.0835144	
Moderate	-0.0104548	0.00771	-1.36	0.175	-0.0255662	0.0046566	
High	-0.035947	0.0138634	-2.59	0.01	-0.0631186	-0.0087753	
water_period1(one day)							
_predict							
Low	-0.0114478	0.0235898	-0.49	0.627	-0.0576829	0.0347873	
Moderate	0.0031678	0.0075549	0.42	0.675	-0.0116394	0.0179751	
High	0.00828	0.0161803	0.51	0.609	-0.0234329	0.0399928	
water_period1 (one month & beyond)							
_predict							

Dependent Variable: AdaptLV							
	Delta dy/dx	method Std. Err.	z	P>z	[95% Conf. Interval]		
Low	-0.0103221	0.0288313	-0.36	0.72	-0.0668305	0.0461863	
Moderate	0.0029156	0.0082298	0.35	0.723	-0.0132145	0.0190457	
High	0.0074065	0.0209042	0.35	0.723	-0.0335651	0.0483781	
Farmexp1 (1-10 years)							
_predict							
Low	0.0606605	0.0238146	2.55	0.011	0.0139848	0.1073363	
Moderate	-0.0169055	0.0114317	-1.48	0.139	-0.0393113	0.0055002	
High	-0.043755	0.0198168	-2.21	0.027	-0.0825951	-0.0049149	
Farmexp1 (over 20 years)							
_predict							
Low	0.0145061	0.0170811	0.85	0.396	-0.0189723	0.0479846	
Moderate	0.0002206	0.0036612	0.06	0.952	-0.0069553	0.0073963	
High	-0.0147267	0.0192274	-0.77	0.444	-0.0524117	0.0229583	
dist_market (1-5 kilometers)							
_predict							
Low	-0.0119315	0.0227664	-0.52	0.6	-0.0565529	0.0326898	
Moderate	0.0038022	0.0076807	0.5	0.621	-0.0112517	0.0188562	
High	0.0081293	0.0152641	0.53	0.594	-0.0217878	0.0380464	
dist_market (5-10 kilometres)							

Dependent Variable: AdaptLV							
	Delta dy/dx	method Std. Err.	z	P>z	[95% Conf. Interval]		
_predict							
Low	-0.0255387	0.0216447	-1.18	0.238	-0.0679615	0.016884	
Moderate	0.00643	0.00727	0.88	0.376	-0.0078189	0.0206789	
High	0.0191087	0.0154368	1.24	0.216	-0.011147	0.0493644	
Lnumbadapt							
_predict							
Low	-0.5216637	0.0452026	-11.54	0	-0.6102593	-0.4330682	
Moderate	0.1289001	0.065196	1.98	0.048	0.0011183	0.2566818	
High	0.3927636	0.0460491	8.53	0	0.3025091	0.4830183	

Source: Survey data