Livelihood Vulnerability Levels of Smallholder Farmers to Climate Change in Selected Parts of Makueni County, Kenya

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Abstract— *Climate change poses a significant threat to smallholder farmers' livelihoods, particularly in arid and semi-arid regions such as Kenya's Makueni County, where rain-fed agriculture dominates. Increasing rainfall variability, recurrent droughts, and extreme temperatures have undermined food security, incomes, and resilience. This study assessed livelihood vulnerability to climate change in three agro-ecological zones, Mbooni (semi-humid), Makueni (semi-arid), and Kibwezi East (arid), focusing on exposure, sensitivity, and adaptive capacity. Guided by the Sustainable Livelihoods Approach and using the Livelihood Vulnerability Index (LVI) framework, a descriptive mixed-methods design was employed. Data from 289 smallholder households were collected through questionnaires, focus group discussions, and key informant interviews, with quantitative analysis conducted in SPSS and qualitative data thematically analyzed. Results showed that 76.8% of farmers experienced extreme weather, with water scarcity emerging as the most critical vulnerability. Key indicators influencing vulnerability included high dependency ratios, female-headed households, limited crop diversity, low grain storage capacity, reliance on own-farm production, long distances to healthcare facilities, and weak access to credit and extension services. Adaptive capacity was constrained by inadequate irrigation infrastructure, limited non-farm income opportunities, and underutilization of indigenous knowledge. The study recommends strengthening water infrastructure, promoting drought-tolerant crops and diversified farming systems, improving access to agricultural finance, and integrating climate-smart practices into extension services. Policy interventions should embed climate adaptation into county development plans and enhance social safety nets to protect the most vulnerable. Such measures are vital for safeguarding livelihoods and sustaining agricultural productivity amid intensifying climate risks.*

Keywords— Smallholder farmers, vulnerability levels, climate change, Makueni County, Kenya.

I. INTRODUCTION

Climate Change has been known to be one of the most pressing complexes and perplexing global environmental challenge (FAO, 2010), threatening food security, poverty alleviation, and livelihoods for smallholder farmers. Climate change has led to adverse effect to every region across the globe, with many irreversible changes, such as the rise of CO_2 concentrations in the atmosphere, increase of the global surface temperatures and also the rise of the global mean sea levels (Intergovernmental Panel on Climate Change –(IPPC), 2021), and therefore, disrupting the global movement towards sustainable development (Harvey *et al.,* 2018). Evidence of experienced climatic changes across the entire globe of extreme events such as heavy precipitation leading to floods, heatwaves, droughts and tropical cyclones has strengthened and are more likely to reach unbearable threshold for agriculture, health and may also lead to adverse effect to natural water cycle (IPPC, 2021). In the recent years, the world has grappled around the effects related to changes of climate in all the main economic areas, including agriculture, which is the mainstay for more than 475 million smallholder farmers across the globe (Harvey *et al.,* 2018). As explained by Donattia *et al.,* 2019), agriculture contributes about 60% of the world's workforce, providing about eighty percent of the food for domestic consumption in the third world countries.

The Africa's Agenda 2063, which was concluded in 2013, recognized change in climate as a major challenge for the continent's progress and growth. Africa's economy highly depends on agriculture accounts for the majority of livelihoods, therefore, an exposure and vulnerability hot spot for climate change impacts and variability. Decreased crop production coupled with increased temperature and drought pressure, increased pest damage and disease damage, flood effects on food system infrastructure, leading to serious consequences for food security and health are major agricultural threats at the regional

cascading to local levels. Promotion of socioeconomic growth mostly in the agronomic sector is one of the promising approaches towards reducing climate related risks, poverty and extreme event impacts throughout the continent (UN, 2020).

Kenya has been impacted negatively by climate change due to its nascent economic growth trends. Majority of Kenyan agriculture totally relies on rainfall, with only less than 5% under irrigation, and the sector has suffered from increasing variability in rainfall. Floods and drought which constitute some of the climatic extreme events have negative impacts on the socio-economic development, with devastating consequences on the country's economy (SEI, 2009; Government of Kenya – (G.O.K), 2010; G.O.K, 2019). Agricultural activities are the main sources of economic growth, livelihood, food security, foreign construction and job creation, and foreign exchange earnings for the majority of the population of Kenya (KEPSA, 2014; Ochieng *et.al.,* 2016). Demand for food, fuel wood and forest products has increased tremendously over the years, leading to unprecedented environmental degradation. An estimation of over 57% of Kenyan population lives below poverty line (FAO, 2010) while, most of smallholder farmers (70%), basically rely on climate-sensitive economic activities including agriculture (Simotwo *et al.,* 2018; Ylva *et.al.,* 2020), therefore, increasing farmers' vulnerability and affecting the Sustainable Development Goal (SDG) 13, Target 13.1, that is aimed at strengthening adaptability and resilience so as to enable farmers respond to risks associated to climate change and natural calamities (GOK, 2018).

The study aimed to examine how variability as well as change in climate influences smallholder agriculturalists in the study area and how these changes have influenced their livelihood vulnerability. It also sought to assess the current mitigation strategies to changes in climate in order to make recommendations on the appropriate adaptation measures and coping mechanisms. According to Mogelgaard *et al.* (2018) resilience of development outcomes can be improved by mainstreaming climate adaptation actions into progressive growth plans and strategies, leading to the effective utilization of available natural resources, while avoiding investments that could lead to serious harm.

Hahn and colleagues (2009) developed the Livelihood Vulnerability Index (LVI), based on Sustainable Livelihoods Approach (SLA) which typically emphasize on the five capitals, namely, environmental, financial, social, human and physical built by Conway and Chambers (Minh *et al*., 2019). The SLA approach has been used successfully within United Nations agencies and other international development organizations for planning and assessing households' ability to withstand shocks like natural disasters, which include climate change, epidemics and even civil conflicts (Hahn *et al.,* 2009; Minh *et al.,* 2019). SLA to some extent discourses aspects of sensitivity and adaptive capacity to climate change issues, but it is limited to address exposure (Hahn *et al.,* 2009).

The LIV, therefore, describes these previous methods of incorporating the various influences of climate change as well as variables that take the level of exposure to natural disasters, their sensitivity to the impacts associated with changing climate and dynamics of household capacity to cope (Hahn *et al.,* 2009). With such elaborate method, it has become possible for researchers to evaluate livelihoods risks from climate change with increased precision and improved accuracy for better planning and better mitigation and adaptation strategies recommendations (Etwire *et al.,* 2013; Hahn *et al.*, 2009; Minh *et al.,* 2019).

The LIV is easier to compute, its strengths lie in the fact that it predominantly uses primary data, it captures in wide context the susceptibility to droughts, floods, climate change, conflicts and a wide range of other natural disasters (Hahn *et al.,* 2009). It effectively transcends postulated hypothesis inherent in earlier methods in its ability to account existing susceptibility that is critical and more valuable for present and timely planning. Many studies have shown the secondary data hitherto relied upon extensively in the earlier approaches suffered from lack of regular update, hence compromising the quality of findings and proposed strategies and recommendations (Hahn *et al.*, 2009; Etwire *et al.,* 2013).

II. METHODS

2.1 General Study Area:

Makueni County is among the 47 counties in Kenya, located in the South Eastern region. The neighbourhood include Kitui County to the East, Kajiado County to West, Machakos County to the North and Taita Taveta County to the south. It has an area of 8,008.7 KM^2 and is between Latitude 1º 35 ′ and 3 ° 00 ′ South as well as Longitude 37º10 'and 38º 30 ′ East. The county experience frequent droughts as it is in the Arid and Semi-Aid area. It has six sub-counties including Makueni, Kibwezi East, Kaiti, Mbooni, Kilome and Kibwezi West sub-counties. The county is then sub-divided in to further 30 wards, containing 60 sub-wards (G.O.K, 2013).

The study was done in selected parts of Makueni County which were classified according to agro-ecological zones (Maluki, *et al.,* 2016). The agro-ecological zones were classified as Semi Humid zone (upper part) covering Mbooni Sub County area,

Semi-Arid areas (middle part) which covered Makueni Sub County and Arid area (lower part) which covered Kibwezi East Sub County.

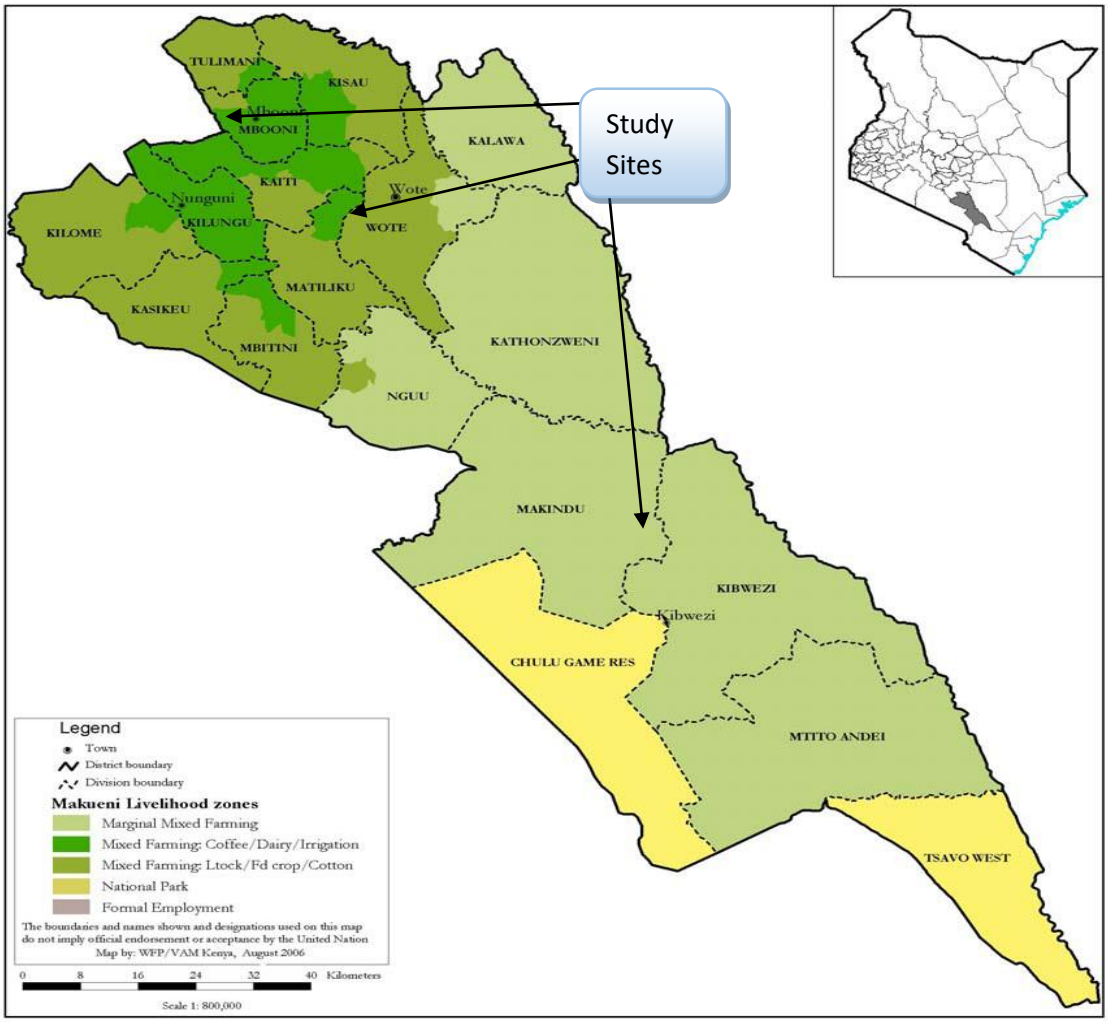

FIGURE 1: A Map of Makueni Livelihood Zones
Source: Makueni LRA Report, 2013.

2.2 Research Design:

Descriptive research design was embraced to examine and calculate the susceptibility of smallholder farmers due to changes in climate and variability, including factors that affect their vulnerability. The design was also used to explore their climate change strategies (Asfaw *et al.*, 2021). Mixed methods of both quantitative and qualitative methods were used to collect primary data. Information was collected from family heads regarding socio-economic, biophysical and demographic factors of the study area.

2.3 Sample frame and sampling techniques:

The sample frame for the study was drawn from farmer beneficiaries from the Kenya Cereals Enhancement Program – Climate Resilient Agricultural Livelihood (KCEP-CRAL). KCEP-CRAL is a national government funded and implemented program in selected counties in Kenya, with Makueni county being a beneficiary. KCEP-CRAL program, which kicked off in 2018 in Makueni, aimed at reducing rural poverty and food insecurity among smallholder farmers in arid and semi-arid lands by developing their economic potential, while improving their natural resource management capacity and resilience to climate change in an increasingly fragile ecosystem. At least 16,000 subsistence farmers benefited from the program through the provision of farm inputs through e-voucher system, financial inclusion, post-production management practices and market linkages for targeted value chains, along with other agricultural resources to enhance their resilience. The current study dwelt on three sub-counties selected on the basis of their agro-ecological zone localities and which were beneficiaries of the KCEP-CRAL program.

TABLE 1

SAMPLING FRAME OF FARMER BENEFICIARIES FROM KCEP-CRAL PROGRAM

Area (Sub- County)	KCEP-CRAL Beneficiaries	Percentage
Mbooni Sub- County	140	44.9
Muvau Sub- County	79	25.3
Masongaleni Sub- County	93	29.8
Totals	312	100.0

Source: Ministry of Agriculture Makueni County

The survey research used a randomized multi-stage sampling process to select households (Asfaw *et al.,* 2021).

2.4 Sample Size Determination:

The following formula was embraced for the study (Asfaw *et al.,* 2021).

$$n = \frac{Z^2 * N * p * q}{e^2(N-1) + Z^2 * p * q} \quad (1)$$

Where; N represents the total targeted population for smallholder farmers, n is the sample size, and Z is the set standard deviation picked at 95% confidence level, which is 1.96. *P* is the alpha levels of 0.5, showing the estimated proportion present while *q* (1-p)(0.5) represents the estimated proportion of the attribute not present in the population, while *e* is the required accuracy level, usually set as 0.05 (5% of acceptable sample error). From the calculations, the entire sample size was 244 households spread at 140 for Mbooni, 79 for Makueni and 93 for Kibwezi East.

2.5 Research Instruments:

A household questionnaire was used for the study. The questionnaire divided into five sections. The first section captured household demographic information. The second section was capturing household general information, while section three was capturing socioeconomic activities and livelihood options. Section four was on adaptations to climate change and variability. The last section was on institutional support. The questions were distributed across the five sections capturing demographics and socio-economic responses, their livelihoods, outcomes and experiences of climate change in agriculture, land use practices related mitigations to climate actions provided by County Government and other climate actors in the study area.

2.6 Data Analysis:

The data collected was analyzed by both quantitative and qualitative approaches. The study used Statistical Package for Social Sciences (SPSS) software for analyzing data obtained from the questionnaire and the generated results were presented through tables and statistics.

A balanced weighted average method was embraced in this study to compute the LVI, which incorporates both the gap and the methods (Hahn *et al.,* 2009; Etwire *et al*., 2013). The authors emphasize that the gap method assesses vulnerability based on the deviation of vulnerable people living conditions and on standard living conditions when there are no changes in climate. The approach is grounded on accurately valuing each predictor variable based on its contribution to climate change and vulnerability to such people or groups.

The major components include several different indicators or sub-components, each sub-element contributing correspondingly to the general index. An easy-to-compute LVI formula uses an easy way to apply equivalent weights to all major elements. Similarly, each of these subdivisions is therefore measured on a different scale that needs to be standardized as an index using Eqn (1), which is commonly used in the human development indicator to compute life expectancy, and is also used in LVI risk assessment (Can *et al.,* 2013).

$$Index\ Sq = \frac{Sq - Smin}{Smax - Smin} \quad (2)$$

When S_q represents the index value of the sub-component indicator for q, and s_{min} and s_{max} are the lower and upper values, indicating the higher and lower vulnerability respectively of all readings. After each sub-components values are standardized, the value of each major value was calculated using Eqn. (2)

$$Mq = \frac{\sum_{i-1}^{n} index\ Sq}{n} \quad (3)$$

where M_q is one of the Twelve components of the tested area q, Water (W), Food (F), Health (H), Social Networks (SN), Livelihood Strategies (LS), Social Demographic Profile (SDP), Indeginous Knowledge (IK), Land (L), Environmental Resources (NR), Housing and Production (HP) or Finance and Income (FI), Natural Disasters and Climate Diversity (NDCV), for region q; $index_{sqi}$ represents the smallest parts, identified by i, that form each major component, and n is the number of sub-elements in each major element. When the values of each of the twelve major components are calculated, they were measured using Eqn (3) for the LVI of each location.

$$LVI = \frac{\sum_i^{11} Wmi\ Mqi}{\sum_i^{11} Wmi} \tag{4}$$

Also expressed as;

$$LVI = \frac{W_{SDP}SDP_q + W_{LS}LS_q + W_H H_q + W_{SN}SN_q + W_F F_q + W_W W_q + W_{IKS}IKS_q + W_L L_q + W_{NR}NR_q + W_{HP}HP_q + W_{FI}FI_q + W_{NDC}NDCV_q}{W_{SDP} + W_{LS} + W_H + W_{SN} + W_F W_W + W_{IKS} + W_L + W_{NR} + W_{HP} + W_{F1} + W_{NDC}} \tag{5}$$

LVI calculation-IPCC Framework Approach

In Eqn 4, where LVI_q is the studied location Livelihood Vulnerability, which is equal to the average of the twelve major elements. Weights of each major W_{Mi} element is determined by the other smaller elements that make up each major element. In addition, they were included to ensure that all sub-components contribute equally to LVI as a whole (Hahn *et al*, 2009; Sujakhu *et al*, 2019). Where LVI values range from 0 (Least vulnerable) to 0.5 (Most vulnerable) in calculations from statistics of Eqns (3) - (5), Hahn *et al*., (2009), another method (LIV-IPCC index) is used for new variables for LVI based on the IPCC definition of vulnerability and its tools for adaptive capacity, sensitivity and exposure (Etwire *et al.,* 2013; Sujakhu *et al.*, 2019). The adaptive capacity was framed on Socio-Demographic Profile, Livelihood Strategy and Social Networks. Exposure was incorporated into the framework of Natural Disaster and Climate Variability and Sensitivity on Food, Water and Health (Sujakhu *et al.,* 2019; Hahn *et al.,* 2009). The vulnerability index was calculated using Eqn 5 as shown.

Vulnerability = (Adaptive capacity) – (Sensitivity + Exposure) (6)

In this study, *exposure* was measured using the number of adverse events (Drought and floods) over the past 5 years that occurred in the study area. Sensitivity was measured using food availability, water conditions and home health status. Adaptive capacity was measured using the demographic profile in the study area obtained from the study.

Climate variability was measured from secondary data sources using standard deviation of minimum and maximum value of monthly air temperatures as well as monthly precipitation in the last 5years. Instead of merging the major components into the LVI in Equation (4) in the LVI-IPCC approach, Eqn 6 integrates the critical contributing factors to climate change, which include the elements of sensitivity, exposure and adaptability, large components into three stages of exposure, and sensitivity. These are important factors that contribute to climate change as well as variability vulnerability (Etwire *et al.,* 2013; Gravitiani, *et al.,* 2017; Sujakhu *et al.,* 2019) as shown in Eqn 6 below.

$$CF_q = \frac{\sum_{i-1}^{n} W_{Mi}\, M_q}{\sum_{i-1}^{n} W_{Mi}} \tag{7}$$

where CF_q represents factors contributing to exposure, sensitivity and adaptability of location d. M_{qi} is the main component of location q, denoted by i, W_{mi} is the weight of each major component and n is the number of major components for each contributing factor. The level of exposure, sensitivity and adaptability was calculated by combining three influential factors using Eqn 7 as shown.

$$LVI - IPCC_q = (e_q - a_q) * S_q \tag{8}$$

Where LVI_{IPCCq} is the local LVI for location q expressed using the IPCC vulnerability framework, e_q represent the calculated exposure score for location q (equal to the climate variability and natural disaster major component); a_q is the calculated capacity score for location q (weighted average of the social networks, livelihood strategies and socio-demographic major components) and sq is the calculated sensitivity score for location q (estimated health, water and food consumption major components) (Minh *et al.,* 2019; Hahn *et al.,* 2009). The LVI-IPCC scale ranges from -1 (Least vulnerable) to 1 (Most vulnerable). SPSS software was used to analyse and evaluate the livelihood vulnerability index.

2.7 Ethical Considerations:

The study was guided by research ethics. The six elements of research ethics were considered including informed consent, beneficence, confidentiality, anonymity, no harm and the right to withdraw from the exercise. Farmers, who were the main respondent, were first informed of the intentions and objectives of the study, requesting for their informed consent. Once the informed consent was given, then the other ethical considerations were also worked on. Confidentiality was also considered

and adhered to, where information collected from farmers was not shared with third parties. The information collected was also kept confidential, as no farmer details were used to expose them to any unauthorized third party.

III. FINDINGS

3.1 Response rate and demographic characteristics of the respondents:

A sample of 289 respondents was reached and the target for each specified study area within the three agro-ecological zones is shown in Table 2 below.

TABLE 2

DISTRIBUTION AND RESPONSE RATE OF THE RESPONDENTS

Constituency (Ward)	Targeted sample size	Reached respondents	Percentage reached
Mbooni (Mbooni)	103	105	102
Makueni (Muvau)	66	79	120
Kibwezi East (Masongaleni)	75	105	140
Totals	**244**	**289**	**120**

The study response rate was 120% as six focus group discussions were reached instead of the initially intended five, which meets the threshold for sample size requirement according to Mugenda and Mugenda (2003).

3.2 Summary of demographic characteristics:

Most of the respondents were drawn from Kibwezi East and Mbooni (Table 3), both sub-counties having a representation of about 36.3%. Makueni had the least representation at 27.4%, in terms of relations to the household head. Majority of the respondents were spouses at 48.1%, while respondents who were the household heads were 38.1%. Further, there were 10.0% and 3.8% of the respondents who identified themselves as children and parents of the household heads. In terms of gender representation, more of the respondents at 64.0% were female, while the other 36% were male. In terms of level of education, majority of the respondents at 56.4% had achieved primary level education, followed by 29.8% who reported to have attained secondary education level. Respondents who had achieved college and university education were 5.5% and 1.4% respectively.

The distributions of respondents in terms of their age, the majority were aged between 26 to 40 years, representing 34.9% of the population. This category was followed by those aged between 41 to 60 years at 33.6%. The study revealed that 20.1% and 11.4% of the respondents were aged above 61 years and below age 25 years respectively. In terms of occupation, majority of the respondents (66.1%) indicated that they were farmers. Those engaged in small scale business and casual laborers were 10.4% and 10.0% respectively. A further 4.2% of the respondents reported to have been engaged with other different occupational roles, while 3.5% of the respondents indicated that they were not engaged in any form of economic activities.

Majority of the respondents in the study area were married in monogamous union at 78.2%. The study established that 12.5% of the respondents were widowed while 5.2% reported to have had orphans in their households. There was a small percentage of respondents (1.7%) who were in polygamous marriage.

TABLE 3

SUMMARY OF DEMOGRAPHIC CHARACTERISTICS

Variable	Category	Frequency	Percentage
Relations to household head	Household head	110	38.1
	Spouse	139	48.1
	Child	29	10
	Parent/guardian	11	3.8
Gender	Female	185	64
	Male	104	36
Education	College	16	5.5
	None	20	6.9
	Primary	163	56.4
	Secondary	86	29.8
	University	4	1.4

Age of respondent	18-25 years	33	11.4
	26-40 years	101	34.9
	41-60 Years	97	33.6
	Above 61 years	58	20.1
Occupation	Students	8	2.8
	Business	30	10.4
	Casual Labourer	29	10
	Farmer	191	66.1
	Teacher	9	3.1
	Not employed	10	3.5
	Other roles	12	4.2
Marital Status	Married (Monogamous)	226	78.2
	Married (Polygamous)	5	1.7
	Separated/Divorced	8	2.8
	Single	14	4.8
	Widowed	36	12.5
Type of Household	Dejure female headed (widow, never married, divorced)	13	4.5
	Female headed	32	11.1
	Male headed	242	83.7
	Polygamous	2	0.7
Presence of an orphan	No	274	94.8
	Yes	15	5.2
Sub-county	Kibwezi East	105	36.3
	Makueni	79	27.4
	Mbooni	105	36.3

3.3 Farmer's perception on climate change in the study area:

3.3.1 Experience of extreme weather conditions:

The study established that 76.8% of the farmers experienced extreme weather conditions, with only 23.2% not experiencing extreme weather conditions. In relation to the agro-ecological zones, more farmers in Kibwezi East and Makueni at 88.6% and 70.9% respectively experienced extreme weather conditions, compared to 69.5% in Mbooni (Table 4). There was significant correlation between the climate change and the agro-ecological zones studied (X^2=13.3, df=2, P<0.01). The Pearson correlation portrayed that the agro-ecological zones studied experienced some form of climate change.

TABLE 4

EXPERIENCE OF EXTREME WEATHER CONDITIONS

	Sub County			Total	Pearson Chi-Square Value	df	Asymptotic Significance (2-sided)
	Kibwezi East	Makueni	Mbooni				
No	12	23	32	67	13.297a	2	0.001
	11.40%	29.10%	30.50%	23.20%			
Yes	93	56	73	222			
	88.60%	70.90%	69.50%	76.80%			
Total	105	79	105	289			

3.4 Livelihood Vulnerability Level:

The livelihood vulnerability index (LVI) for this study used the seven components developed and suggested by Hahn *et al.* (2009). The elements include; climate and natural disasters; access to water; access to food; health; livelihood strategies; social profile; and social networks. The study included other five additional components namely, land, indigenous knowledge, natural

resources, housing and production methods and finance and income to assess climate-related risks owing to climate change. The components had several other inherent indicators or sub components, which were selected after review of literature.

Climate variability was measured from secondary data sources using standard deviation of minimum and maximum value of monthly air temperatures as well as monthly precipitation in the last five years. For the vulnerability, the indices were calculated using the adaptive capacity, subtracted from sensitivity and exposure indices. The general indices before standardization are as shown in Table 5.

TABLE 5

GENERAL INDICES FOR THE HUMAN VULNERABILITY INDEX

Sub County	General Index	Kibwezi East	Makueni	Mbooni
Livelihood index	0.173	0.192	0.154	0.168
Water Index	0.575	0.700	0.487	0.533
Food Index	1.168	1.053	1.238	1.231
Health Index	1.196	1.259	1.209	1.123
Social networks index	1.125	1.106	1.142	1.132
Social Demographic Networks Index	2.387	2.571	2.376	2.210
Land Index	2.087	1.937	1.966	2.330
Environmental Resources Index	0.035	0.016	0.035	0.072
Housing production index	1.143	1.227	1.089	1.074
Finance and Income Index	1.434	1.377	1.447	1.481
Natural disasters and climate diversification Index	0.713	0.729	0.741	0.670
Knowledge and Indigenous Knowledge index	1.816	1.761	1.835	1.856

3.4.1 Livelihood Strategies (LS) Index:

Livelihood Strategy index was measured using seven sub-indicators. These included; HHs dependent solely on agriculture as major source; Average agricultural livelihood diversification; HHs not growing horticultural crops like vegetables and fruit trees; HHs not using irrigation; HHs with no non-farm activities; HHs with a member working outside the community/wage labour; and HHs exploiting natural resource during times of extreme events, e.g. charcoal burning.

Livelihood Strategy index = (HHs dependent solely on agriculture as major source + Av. Agricultural livelihood diversification + HHs not growing horticultural crops like vegetables and fruit trees + HHs not using irrigation + HHs with no non-farm activities + HHs with a member working outside the community/wage labour + HHs exploiting natural resource during times of extreme events, e.g. charcoal burning) /7 (the n -number of the weighted components). The resultant weighted index for the livelihood component, and for the three ecological zones is as shown in Table 6.

TABLE 6

LIVELIHOOD STRATEGIES INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean Index	0.173	0.192	0.154	0.168
Weighted Index (Sq)	0.173	-0.142	0.154	-0.165

3.4.2 Water (W) Index:

Water index was calculated as an average of seven components as shown in Table 7;

Water index = (Av. Distance to water source (Km) + HHs using natural water sources + HHs without constant water supply + HHs harvesting and storing rain water + HHs with piped water from public water systems + Av. Daily water use litres per household + HHs reporting water conflicts) /7.

TABLE 7
WATER INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean	0.575	0.700	0.000	0.533
Weighted Index (Sq)	-0.758	0.000	0.000	-0.800

The weighted water index for the three ecological zones was -0.758, where it was 0.000 for Kibwezi East and Makueni and -0.800 for Mbooni. This means that the two ecological zones, Kibwezi East and Makueni were extremely vulnerable when it came to water sources.

3.4.3 Food (F) Index:

Food index was calculated using six sub-components as shown. This was shown by the method below;

Food index = (HHs dependent on farm produce for food + HHs dependent on animal product from own source + Av. Crop diversification and crop types grown + HHs who do not save/store their grain crop + HHs without saved seeds for next season + Av. No of months HHs struggle with food shortage)/6 (n-frequency of the variables). The resultant indices for the three regions combined and for each specific ecological zones are as shown in Table 8

TABLE 8
FOOD INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean	1.168	1.053	1.238	1.231
Weighted Index (Sq)	0.739	0.624	0.438	0.802

3.4.4 Health (H) Index:

Health index was calculated as follows;

Health index = (Av. Distance to health care facility (km) + HHs with a family member with chronic illness + HHs with a family member with illness who missed work or school in the last 1 month + HHs with a family member with illness due to extreme events)/4. The following were the indices (Table 9).

TABLE 9
HEALTH INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean index	1.196	1.259	1.209	1.123
Weighted Index (Sq)	0.196	0.259	0.209	-0.211

3.4.5 Social Networks (SN) Index:

The social networks index was calculated using the four sub-components as shown;

Social networks (SN) index = (HHs received cash aid in last 12 months + HHs received relief/help due to extreme events + HHs reporting no membership to any organization + HHs not receiving any government aid in the last 12 months)/4. The following were the indices (Table 10).

TABLE 10
SOCIAL NETWORKS INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean Index	1.125	1.106	1.142	1.132
Weighted Index (Sq)	0.125	-0.894	0.142	-0.201

3.4.6 Social Demographic Profile (SDP) Index:

The social demographic profile (SDP) index was calculated as follows;

Social demographic profile (SDP) index = (Dependency ratio + HHs headed by female (Male head away>6 Months) + HHs headed by child + Av. Household family size + HHs with orphans (Children< 18 years) /4. The following were the indices (Table 11).

TABLE 11
SOCIAL DEMOGRAPHIC INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean Index	2.387	2.571	2.376	2.210
Weighted Index (Sq)	2.087	2.270	2.076	1.781

3.4.7 Indigenous Knowledge (IK) Index:

Indigenous Knowledge (IK) Index = (HHs head attended no school + HHs head attained /completed primary level + HHs head did not receive training to cope with extreme events + HHs not satisfied with Governments sharing of climate change information + HHs reporting use of indigenous knowledge) /5. The following were the established indices (Table 12).

TABLE 12
INDIGENOUS KNOWLEDGE (IK) INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean Index	1.816	1.761	1.835	1.856
Weighted Index (Sq)	1.217	1.162	1.237	1.257

3.4.8 Land (L) Index:

Land (L) index = (HHs participation in local government decisions + Av. Land hold size + HHs with small land scale (0.5-1 Ha)) /3. The following were the indices (Table 13).

TABLE 13
LAND INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean Index	2.087	1.937	1.966	2.330
Weighted Index (Sq)	1.657	1.508	1.537	1.901

3.4.9 Environmental Resources (NR) Index:

Environmental Natural Resources index = (HHs exploiting natural resource for livelihood + HHs using crop residues as source of energy + HHs using traditional jikos for cooking + HHs using LPG cylinders) /4. The following were the indices s calculated (Table 14).

TABLE 14
ENVIRONMENTAL RESOURCES INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean Index	0.036	0.000	0.035	0.072
Weighted Index (Sq)	0.036	0.000	0.035	0.072

3.4.10 Housing and Production (HP) Index:

Housing and Production Index = (HHs with no means of production + HHs with temporary house + HHs house affected or property during extreme events (Floods)) /3. The following were the indices (Table 15).

TABLE 15
HOUSING PRODUCTION INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean Index	1.1426	1.227	1.0893	1.0741
Weighted Index (Sq)	1.0326	1.062	0.9793	0.9091

3.4.11 Finance and Income (FI) Index:

The finance and income (FI) index was as follows;

Finance and income (FI) index = (HHs with net annual income lower than Ksh 200,000 + HHs borrowing money in the last 1 month + HHs lending money in the last 1 month + HHs with no income during extreme events + HHs with no access to financial institutions) /5. The following was the indices (Table 16).

TABLE 16
FINANCE AND INCOME (FI) INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean Index	1.434	1.377	1.447	1.481
Weighted Index (Sq)	0.682	0.377	0.117	0.729

3.4.12 Natural Disasters and Climate Diversity (NDCV):

The following was the natural disasters and climate diversity index;

natural disasters and climate diversity index = (Av. No. of extreme events drought and floods in the last 5 years + HHs reporting crop damage due to extreme events in last 5 years + HHs not receiving Early warning preceding extreme events + HHs reporting crop failure due to extreme events in last 5 years + HHs with death or injury as a result of extreme events)/5. The following were the indices (Table 17).

TABLE 17
NATURAL DISASTERS AND CLIMATE DIVERSITY INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Mean Index	0.713	0.729	0.741	0.670
Weighted Index (Sq)	-0.287	-0.271	-0.259	-0.330

Livelihood index was calculated as a general from all the other indices as presented on Table 7.1, where the general index along with those for each of the agro-ecological zones was presented. The summary of the LVI - IPCC index was presented on Table 18.

TABLE 18
LVI INDEX

Components	General Index	Kibwezi East	Makueni	Mbooni
Livelihood Index	0.575	0.496	0.555	0.479

The livelihood vulnerability index for the Makueni County smallholder farmers was 0.574, while for the three ecological zones were Kibwezi East at 0.496, Makueni was 0.555 while for Mbooni was 0.479.

3.4.13 Vulnerability Index:

From the literature review, vulnerability was calculated as follows;

Vulnerability = (Adaptive capacity) – (Sensitivity + Exposure)

The adaptive capacity was framed on Socio-Demographic Profile, Livelihood Strategy and Social Networks. Exposure was incorporated into the framework of Natural Disaster and Climate Variability and Sensitivity on Food, Water and Health. The general adaptive index for the three agro-ecological zones was 1.229, while for Kibwezi East was 1.289, Makueni was 1.224 and for Mbooni at 1.170. The index was shown on Table 7.15.

The adaptive capacity was calculated as follows; (Adaptive capacity = (Socio-Demographic Profile, + Livelihood Strategy + Social Networks)/3)

TABLE 19
ADAPTIVE CAPACITY INDEX

Adaptive capacity	General Index	Kibwezi East	Makueni	Mbooni
Socio-Demographic Profile	2.387	2.571	2.376	2.210
Livelihood Strategy	0.173	0.192	0.154	0.168
Social Networks	1.125	1.106	1.142	1.132
Index	1.229	1.289	1.224	1.170

Exposure for this study was measured by finding the average of natural disaster and climate variability as shown on Table 7.16. Further, the general exposure index is calculated, along with the index for the three agro-ecological zones is presented on Table 20.

Exposure = (Natural Disaster + Climate Variability)/2

TABLE 20
EXPOSURE INDEX

Exposure	General Index	Kibwezi East	Makueni	Mbooni
Natural Disaster	0.713	0.729	0.741	0.670
Climate Variability	1.242	1.270	1.415	1.130
Index	0.651	0.666	0.719	0.600

Further, the researcher calculated the general sensitivity index for the study area, and one each for the three agro-ecological areas. The sensitivity index was calculated by combining three components, food, water and health as shown on Table 21 below.

Sensitivity = (Food +Water + Health)/3

TABLE 21
SENSITIVITY INDEX

Sensitivity	General Index	Kibwezi East	Makueni	Mbooni
Food	1.168	1.053	1.238	1.231
Water	0.575	0.700	0.000	0.533
Health	1.196	1.259	1.209	1.123
Index	0.980	1.004	0.816	0.962

This objective sought to find and establish the vulnerability index for the three agro-ecological zones. The vulnerability was calculated using adaptive capacity, minus the sensitivity and exposure (Vulnerability = (Adaptive capacity) – (Sensitivity + Exposure)). Vulnerability levels for the entire study area, along each for the agro-ecological zones as shown on Table 22.

TABLE 22
VULNERABILITY LEVELS

Components	General vulnerability Index	Kibwezi East	Makueni	Mbooni
Vulnerability levels	-0.464	-0.443	-0.332	-0.462

The study established that the vulnerability index for the three agro-ecological zones combined was -0.464. In respect to the three areas, Mbooni had the highest vulnerability index at 0.462, followed by Kibwezi East at 0.443 and Makueni at 0.332

IV. DISCUSSIONS

Based on the findings from the current study, the three ecological zones had indices less than 0.4 (general 0.17, Kibwezi East at 0.14, Makueni at 0.15 and Mbooni 0.16) showing that the households had high livelihood strategies. This meant that there were many households depending solely agriculture as a major source of livelihood, and there was low agricultural livelihood diversification, and many households not growing horticultural crops like vegetable and fruit trees. The indices means that many of the households had limited livelihood strategies. The findings relate to findings by Moret (2014) on livelihood strategies index who showed ranges for livelihood strategies (as depicted by the changes in household income and expenditure patterns) ranged from low (>0.6), moderate (0.4 to 0.6) and high (<0.4).

Based on the findings from the current study, the three ecological zones had indices less than 0.4 (general 0.17, Kibwezi East at 0.14, Makueni at 0.15 and Mbooni 0.16), showing that the households had high livelihood strategies. This meant that many households were depending solely on agriculture as a major source of livelihood, and there was low agricultural livelihood diversification, and many households did not grow horticultural crops like vegetables and fruit trees. The indices mean that many of the households had limited livelihood strategies. The findings relate to findings by Moret (2014) on the livelihood strategies index, who showed ranges for livelihood strategies (as depicted by the changes in household income and expenditure patterns) ranged from low (>0.6), moderate (0.4 to 0.6) and high (<0.4).

Climate variability was measured from secondary data sources using the standard deviation of minimum and maximum values of monthly air temperatures as well as monthly precipitation in the last five years. For the vulnerability, the indices were calculated using the adaptive capacity, subtracted from sensitivity and exposure indices. A study by Salman et al. (2022) examined the livelihood vulnerability of smallholder farmers to climate change using a comparative analysis based on irrigation access in South Sulawesi, Indonesia. The study aimed to evaluate the vulnerability of the livelihood system among rice-growing farmers in the Bettu River irrigation area. The study classified the area into two zones based on the distance from the main irrigation canal, namely the upstream and downstream areas. The livelihood vulnerability index (LVI) approach was applied through the selection of socio-demographic and geographic indicators which impacted farmer households.

Empirical results from the study indicated that farmers in the downstream area were more vulnerable to climate change than those in the upstream area. Major components that used the LVI were livelihood strategy, health, water, food, and natural disasters and climate variability. In short, the study concluded and recommended that the sub-components of agricultural livelihood diversification, consistent supply of water for farming activities, and drought mitigation strategies were valuable in the downstream area. Farmers who practice irrigation in the upstream area are vulnerable to socio-demographic profile and social network components.

Compared to findings in this study, the study by Salman et al. (2022) recommends that concerned authorities should now prioritize farmers in the downstream area as a way to develop resilience strategies, specifically by improving or increasing irrigation infrastructure and the number of available reservoirs and drilling holes to control erosion. Also, farmers can increase their adaptive capacity through diversification of agricultural livelihood systems. Governments in collaboration with donor agencies should provide farmers with training on the development of home food industries for poor farmers and households that are vulnerable and were affected by climate change disasters.

In terms of vulnerability to the water and food index, Makueni and Kibwezi East were found to be completely vulnerable to water. Water index was measured in terms of distance and time spent to access natural water sources. Health index was calculated using distance covered to access the nearest public or private health facility and the number of family members who have had a health-related complication for the last month (Tables 7 and 8).

In this study, the mean social networks index was 0.1254, which showed that the households in the three agro-ecological zones were highly vulnerable. Those most vulnerable were in Kibwezi East (-0.8939) followed by those in Mbooni at -0.2011. In comparison, households in Makueni were better off than the other two areas, but still fell under the highly vulnerable households. The study by Moret (2014) on the social networks index showed that scores above 0.6 (>0.6 are low, while 0.4 to 0.5 are moderately exposed, and scores below 0.4 are highly exposed and vulnerable. Further, the study by Moret (2014) gives a range of vulnerability score which reflects the findings in this study.

The current study's findings on the Livelihood Vulnerability Index (LVI) closely align with the results from Madhuri et al. (2014), who applied a similar index-based approach in Bihar to capture multi-dimensional vulnerability. Both studies identify water, food security, and health components as major drivers of vulnerability, highlighting the dependence of rural households on climate-sensitive resources. However, while Madhuri et al. found socio-demographic factors (such as high dependency ratios and low education levels) as dominant contributors, the present study reports land access and indigenous knowledge as critical, with indices above 1.8 for IK and 2.0 for land. This difference can be attributed to the contextual variations, where indigenous knowledge systems remain strong in the Kenyan setting, whereas in Bihar, institutional support and infrastructure gaps are more influential in determining vulnerability levels.

The findings also share similarities with Saha et al. (2024), who assessed the vulnerability of coastal communities to climate change using an index-based approach. Like the current study, Saha et al. emphasize the importance of water access and food security as sensitive components driving vulnerability. In both cases, water indices indicated significant exposure, with Kibwezi East and Makueni showing extreme vulnerability due to long distances to water sources, echoing Saha et al.'s findings in coastal zones with saline intrusion challenges. However, the present study diverges by highlighting social demographic profiles and indigenous knowledge as unique elements contributing to adaptive capacity, whereas Saha et al. focused more on income diversification and institutional support. This suggests that inland agro-ecological systems like Makueni's require a different adaptation lens compared to coastal ecosystems.

Further, Quandt (2018) proposes the Household Livelihood Resilience Approach (HLRA), which measures resilience rather than just vulnerability, stressing household assets, adaptive capacity, and coping strategies. When compared to the current findings, the adaptive capacity index (1.229) for Makueni County indicates moderate resilience; however, the strong negative vulnerability score (-0.464) suggests that sensitivity (0.980) and exposure (0.651) outweigh adaptive mechanisms. Quandt argues that resilience improves with social networks and livelihood diversification, yet in this study, the social networks index remained low (0.125) and the livelihood strategy index (0.17) was below the resilience threshold, reflecting limited non-farm activities and weak institutional linkages. This contrast illustrates that while the HLRA framework advocates for asset-based resilience building, regions with poor water and income diversification remain structurally vulnerable despite some coping strategies.

Additionally, Rubiyanto and Hirota (2021) emphasize livelihood diversification as a crucial adaptation measure for reducing vulnerability in Southeast Asia. Their review underscores that households adopting multiple income sources exhibit lower exposure to climate shocks. In contrast, the current study reveals that most households in Kibwezi East, Makueni, and Mbooni rely primarily on agriculture, with limited non-farm opportunities, leading to a high vulnerability score in livelihood strategies (below 0.4). Similarly, Sadekin et al. (2021) highlight that dependence on a single resource (like fisheries) amplifies vulnerability in small-scale systems. Both findings align with the Kenyan context, where over-reliance on rain-fed agriculture exacerbates risk, reinforcing the need for policy-driven livelihood diversification programs. These cross-comparisons indicate that while index-based assessments consistently identify water, food, and income as critical factors, regional variations in socio-cultural practices and economic structures shape the intensity and drivers of vulnerability.

V. CONCLUSIONS AND RECOMMENDATIONS

The study focused on livelihood levels for smallholder farmers in the three agro-ecological zones in Makueni, Kibwezi East and Mbooni. The livelihood levels were measured by livelihood rates/rates and compared to the established standards. The human variability index was measured by 12 components, where the results were as follows; livelihood index was 0.173, water index 0.575, and food index was 1.168. Further, health index was 1.196 and social networks index was 1.125. Further, the social demographic networks index was 2.387, while land index was 2.087a, and environmental resources index (0.035). The other indices were; housing production index (1.143), finance and Income index (1.434), natural disasters and climate diversification index (0.713), knowledge and Indigenous Knowledge index (1.816). The general adaptive index for the three agro-ecological zones was 1.229, where Kibwezi East was 1.289, Makueni was 1.224 and for Mbooni at 1.170. The study established that the overall vulnerability index for the three agro-ecological zones combined was 0.464. In respect to the three

areas, Mbooni had the highest vulnerability index at 0.462, followed by Kibwezi East at 0.443 and Makueni at 0.332. The findings showed that the respondents in the three agro-ecological zones had few livelihood options and strategies, often depending on agriculture which was not sustainable due to effects of climate change.

The following were the recommendations:

i. There is need for the local actors to improve on the components that contribute to high vulnerability levels in the study area.

ii. There is need to do more studies on vulnerability indices for Makueni County, and compare different sub-counties, as well as comparing it with the national vulnerability levels

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