Transformative Engagement Network (TEN)

Building resilience against hunger and climate change in smallholder farming communities through transformative engagement

Masters in Transformative Community Development

Title of Research Paper: ***Crop Yield Responses to temperature and Rainfall Variability in Bolero, Malawi.***

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I, Elias Gaveta, certify that the research paper is my own work and I have not obtained a Degree in this University or elsewhere on the basis of this Research.

ABSTRACT

Intensity and distribution of rainfall and temperature affect crop yield output as such households dependent on rain fed agriculture are more vulnerable to climate change and variability. It is impossible to influence climate patterns but understanding nature of temperature and rainfall variability equips farmers to plan ahead and adapt accordingly. A study was conducted in Bolero, Malawi, to analyze rainfall and temperature trends, examine the relationship with four main food crops (maize, cassava, millet and groundnuts) and characterize farming practices. Sixty years rainfall data, 32 years temperature data, 18 years crop production data and 120 household responses were gathered. Parametric and non-parametric tests done were; descriptive, correlation, regression, t-test, Mann-Kendall and chi-square. Results revealed a significant increase in temperature trend and a reduction of rainfall by 84.65mm between 1954 and 2013, pointing towards a decreasing rainfall trend. Total annual rainfall has minimal influence on crop yield as compared to monthly rainfall variations. Ground nuts and maize are more sensitive to climate variability as compared to cassava and millet. The increasing temperature trend displayed potential of reducing land productivity. However, there are opportunities for transforming food production and these include; most farmers own land for cultivation which favors adoption of conservation agriculture and agroforestry, farmers are aware that cassava and millet are more resilient, interventions may only focus on attitude change towards cassava and millet as staple food, provision of seasonal weather forecasts and strengthening local seed systems. Crop diversification should be promoted to spread climate risk at farm level and promote nutrition and income source diversity.

1. INTRODUCTION

1.1 Background and Justification

Crop yield is defined as the crop produced per unit area of land (USDA, 2012). Quantity and quality of crop yield is central in ensuring food and nutrition security (Porter & Semenov, 2005). Physiological processes of crop growth such as germination, flowering, nutrients uptake and maturity are either enhanced or delayed depending on rainfall and temperature regimes within a given location (Adejuwon, 2006; Zinyengere et al., 2014). Rainfall and temperature are among the most important climate parameters that impact on food production especially in rain dependent agricultural systems (Mangisoni et al., 2011; Peprah, 2014).

Climate change is understood as the significant deviation of the mean values of climate variables such as rainfall and temperature (IPCC, 2007). Climate change is usually determined and monitored over a period of 30 years, known as climatological normal. Climate variability refers to the manner how climate fluctuates above or below the climatological normal average value (Dinse, 2011). Extreme climate events such as floods and droughts affect ecosystems and livelihoods in general (Swain et al., 2011; Porter et al., 2014).

The fourth assessment report of the IPCC explains that warmer climate, with its increased climate variability, will lead to escalation of the risk of both floods and droughts due to temperature increase and rainfall inconsistency (Boko et al., 2007). Variations in temperature and rainfall accelerate the shrinkage of the food production base and aggravate food insecurity in the climate and hunger hotspots of Sub-Saharan Africa (Kori et al., 2012; Lal, 2013). Porter et al, (2014) explains that food insecurity is further aggravated because farmers have not fully adjusted farming practices to respond to the changing climate.

Almost every facet of life in Malawi will require climate proofing with agriculture being the critical one (UNEP, 2006; FAO, 2011). Around 85% of Malawians live in the rural areas and derive their source of livelihoods from rain fed agricultural activities (FAO, 2011). Smallholder farmers produce above 70 percent of the food consumed in Malawi (FAO, 2011; Manda & Makowa, 2012). Rainfall and temperature variability puts smallholder farmers in Malawi at great threat, this is further aggravated due to farmers' geographic exposure, rapid population growth, and low income levels (Altieri & Koohafkan, 2008; FAO, 2011; Kori et al., 2012).

Heavier rains, less predictable rains, hot spells, and prolonged dry periods contribute to making farmers' decisions about farming more challenging thereby enhancing vulnerability and increasing the risk of food insecurity (Easterling et al., 2000; ARCC, 2013). It is close to impossible to influence the pattern or amount of rainfall and temperature, but the knowledge of the variability of such climate parameters is a tool in deciding suitable transformative actions to promote sustainable food production (Rossell, 2014; Nyasimi et al., 2014).

Recommendations on optimal planting window, appropriate agricultural technologies, type of crops and crop mixes, flood frequency analysis and flood hazard mapping depend on the understanding of the nature and characteristics of temperature and rainfall variability within a specific location (Chabala et al., 2013; Rossell, 2014; Kumbuyo et al., 2014). So it is important to understand rainfall and temperature trends to ignite ecological and cognitive processes on measures that smallholder farmers may take to adapt and mitigate future negative impacts of climate change and variability (IFAD, 2008; Gama et al., 2014).

A study was carried out in Bolero to examine extent of rainfall and temperature trend changes, and the associated crop yield responses. The study also attempted to understand the farmers' adaptive responses with attention on changes in land size and farming practices.

1.2 Statement of the Problem

Rainfall and temperature variability has resulted into the occurrence of both floods and dry spells in Bolero between 1982 and 2014 (Kumbuyo et al., 2014; Pagona, 2014). Notably, Bolero was affected by landslides in 2003 and heavy flooding in 2009 attributed to high rainfall intensity (Msilimba, 2010; World Meteorological Organization, 2010). Floods, in times of high rainfall, may cause crop failure due to water logging, leaching of nutrients, and soil erosion (Chabala et al., 2013).

Bolero experiences the shortest rainy season of 88 days on average (Ngongondo et al., 2014). This is less than the average length of maize growing period of 125 days (Kimaro & Sibande, 2007). The Malawi climate change vulnerability assessment reports that the rainy season in Malawi is commonly characterized with late onset, erratic rains and increasing heat spell duration (ARCC, 2013). Significant moisture deficits and high temperatures during critical periods of crop growth have led to production shortfalls, with consequent impact on food and nutrition security (Chabala, 2013).

Farming practices that are well suited have the potential to reduce the impact of climate change and variability on crop production. The impact of both water excess (floods) and deficit (droughts) on crop production could be aggravated or reduced depending on the type of farming techniques a farmer practices (FAO, 2014). To adapt crop production to the impacts of climate change and exploit the opportunities associated with rainfall and temperature variability requires a farmer to understand the relationship between climate variables, farming practices and crop production (Chabala et al., 2013; Rossell, 2014).

In Bolero, Up to 87% of the households experience food shortage especially in the months of January, February, March and April (Mataya et al., 2014). It is not clear to what extent rainfall and temperature trends have changed in Bolero over the years and if the food shortages could be attributed to the impact of temperature and rainfall variability on food crops production. It is also not known to what extent farmers have utilized the different farming practices to respond to temperature and rainfall variability to improve production of maize, cassava, millet and ground nuts, the four main food crops in Bolero. Hence the study was conducted.

1.3 General Objective

The main objective of the study was to examine the relationship between climate variables (rainfall and temperature) and production of maize, cassava, millet and groundnuts and how farming practices could assist to enhance the resilience of crop production in Bolero.

1.4 Specific objectives

- To analyze the nature and trends of temperature and rainfall variability
- To analyze the relationship between climate variables (temperature and rainfall) and crop yield output
- To characterize farming practices in relation to temperature and rainfall variability

2. LITERATURE REVIEW

2.1 Rainfall and Temperature Trends in Sub-Saharan Africa

Countries in the Sub-Saharan region are facing common issues in relation to climate change and food security due to geographic, demographic and socio-economic similarities (Zuberi & Thomas, 2012). It is generally expected that warming in Sub-Saharan Africa will be greater than the global average while rainfall decline will vary from place to place (Ringler et al., 2010). The global circulation models predict precipitation decrease from June to August in Southern Africa and increases from December to February in Eastern Africa (Ringler et al., 2010). Such projections prompted a series of location specific studies on temperature and rainfall trends. Below is a discussion of some findings from different studies in Sub-Saharan Africa.

Results of a stable temperature trend were reported with two distinct peaks between 1970 and 2012 in Ibadan, Nigeria (Egbinola and Amobichukwu, 2013). Egbinola and Amobichukwu also report that there is a positive relationship between rainfall and temperature increase in Ibadan. According to Chabala et al. (2013), minimum temperatures in Choma, Zambia, are increasing significantly with time explaining 56% of the increase (R^2=0.560) accompanied with generally variable and less clear rainfall trend. In the same study, it is reported that in Mpika and Serenje, no significant temperature increase was detected but decreasing rainfall trends were observed.

Kumbuyo et al. (2014) analyzed the rainfall trends for Malawi using a 31 year time series. The study found strong inter-annual variations with topography and location playing major roles in annual rainfall distribution. A cyclic rainfall pattern of 5 to 8 years was identified. Kimaro and Sibande (2007) reported no significant rainfall trend changes in Mzimba, Kasungu, Salima, Mangochi, Ngabu and Chileka. But decreasing trends were reported in Karonga and Chitedze. In a more recent study, Gama et al. (2014) projects a 1.1 percent decreasing rainfall trend in Mzimba associated with an increasing temperature trend of 1ºC to 3 ºC between 2040 and 2070.

Rainfall and temperature variability affect different populations differently owing to the diverse characteristics present in those communities (Gama et al., 2014). Saka et al. (2013) explain that the variation of the landscapes in Malawi results into wide spatial differences in rainfall and temperature, it is therefore expected that different agro-ecological zones will be affected by climate variability differently. As a consequence, alterations in rainfall and temperature values may imply agricultural gains for others while others will lose out (Antle, 2011).

2.2 Food Production and Climate Variability

According to FAO (2008), food security exists when all people, at all times, have physical and economic access to food. In this definition one of the key components is physical availability of food and this is determined by the level of food production (FAO, 2008). Matshe (2009) indicates that in Sub-Saharan Africa food security depends on the output of cereal crops. In Malawi, availability of rain fed maize is associated with food security for majority of smallholder farmers with a relatively small percentage relying on cassava, millet, sorghum, sweet potato and groundnuts (Mangisoni et al., 2011, MZADD, 2014). Mataya et al. (2014) reports that in Bolero, maize is the main food crop followed by cassava, millet and ground nuts.

Food production is affected by temperature and rainfall variability in the following ways; Increased rainfall intensity may lead to decline of soil quality and quantity through increased runoff, soil erosion and leaching of nutrients, whilst dry and heat spells may lead to water stress, wilting of crops and diminishing physiological processes (Sownmi & Akintola, 2009). It is expected that yield decreases will be very large for crops such as maize and millet as they are sensitive to temperature and rainfall variability (Altieri & Koohafkan, 2008; ARCC, 2013).

Rainfall variability and increase in annual temperatures will likely reduce the productivity of groundnuts and may also promote occurrence of aflotoxin (ARCC, 2013). Zinyengere et al. (2014) projects negative responses of maize and groundnuts yield to rainfall and temperature changes with 33% projected decline of groundnut yields.

Despite the fears associated with rainfall and temperature changes, area specific advantages and opportunities may exist (Chikodzi et al., 2013). For instance, Nwaobola and Nottidge (2013) found that in Abia state in Nigeria, 1% increase in temperature will lead to 99% increase in cassava output. This may be due to the fact that temperature increase enhances photosynthetic rate and faster branching (Jarvis et al., 2011). Saka et al. (2013) report that 1.5ºC to 2ºC increase in temperature will mean increase in maize yield by between 5 and 25 percent in the central and northern parts of Malawi, whilst in the southern region maize yield is expected to decline by the same percentage between now and 2050. A study by Kimaro and Sibande (2007) detected decreasing annual rainfall trends associated with increasing temperature in Karonga, but no significant changes in maize yield were detected. The study also noted that monthly rainfall variations have a stronger influence on crop production as compared to annual rainfall amounts.

Both biophysical and socio-economic spheres are affected by rainfall and temperature variability with each influencing the other (Mbilinyi et al., 2013). Chances are that large scale assessments on the impact of climate change may miss out on local impacts and agronomic conditions that that farmers at community level operate in (Zinyengere et al., 2014). This considers that crop production varies depending on local characteristics such as topography, management interventions and farming practices (Zinyengere et al., 2014; Kumbuyo et al., 2014).

2.3 Climate Variability and Farming Practices

Crop yield is a function of land availability (USDA, 2012) but quantity and quality of yield is also dependent on farm practices (FAO, 2013). Farming systems are largely dependent on annual amounts and distribution of rainfall and temperature (FAO, 2006). Boko et al. (2007) explains that rainfall and temperature changes may force marginal land out of production. Farmers may decide to leave arable land idle or use it for other purposes other than agriculture production when they are not certain about rainfall and temperature changes (Kori et al., 2012).

Kori et al. (2012) report a negative correlation between rainfall and arable land use in Nzhelele valley, South Africa. Farmers significantly reduced total arable land for cultivation in response to rainfall variability. Balakrishnan et al. (2011) observed that a decline of rainfall amounts by 207mm and an increase of temperature by 1.34ºC led to abandonment of 15772 hectares of agricultural land in Tamil Nadu, India. On the other hand, yield increases have also been attributed to farming practices such as conservation agriculture and crop diversification in times when rainfall and temperature variability would have negative effects (Kimaro & Sibande, 2007)

Temperature and rainfall variability makes it challenging for farmers to select with reliability the most adapted agricultural practice (Birhanu et al., 2013). Increase in temperature may change the soil microbial activities thereby affecting soil fertility (FAO, 2006). The decline in soil productivity is largely attributed to exploitative farming practices such as heavy plowing, cutting down of trees to expand land size for agriculture as well as mono-cropping (Birhanu et al., 2013). It is believed that temperature and rainfall variability will worsen this trend leading to serious consequences on food production (IFAD, 2008). Other land use responses to climate change include land fragmentation, change of cropping calendar and farming in flood prone areas (Hamza & Iyela, 2012).

3. MATERIALS AND METHODS

3.1 Study Site

The study was carried out in Bolero, in Rumphi district, Malawi. Bolero is in the rain shadow area located on latitude -11.02 and longitude 33.78 with an elevation of 1100m (Kumbuyo et al., 2014; Ngongondo et al., 2011). The total area of Bolero is 364 square kilometers and it has a population of around 58, 550 with 11, 958 farming households (MZADD, 2014). Below in figures 1 and 2 show the location of the study site.

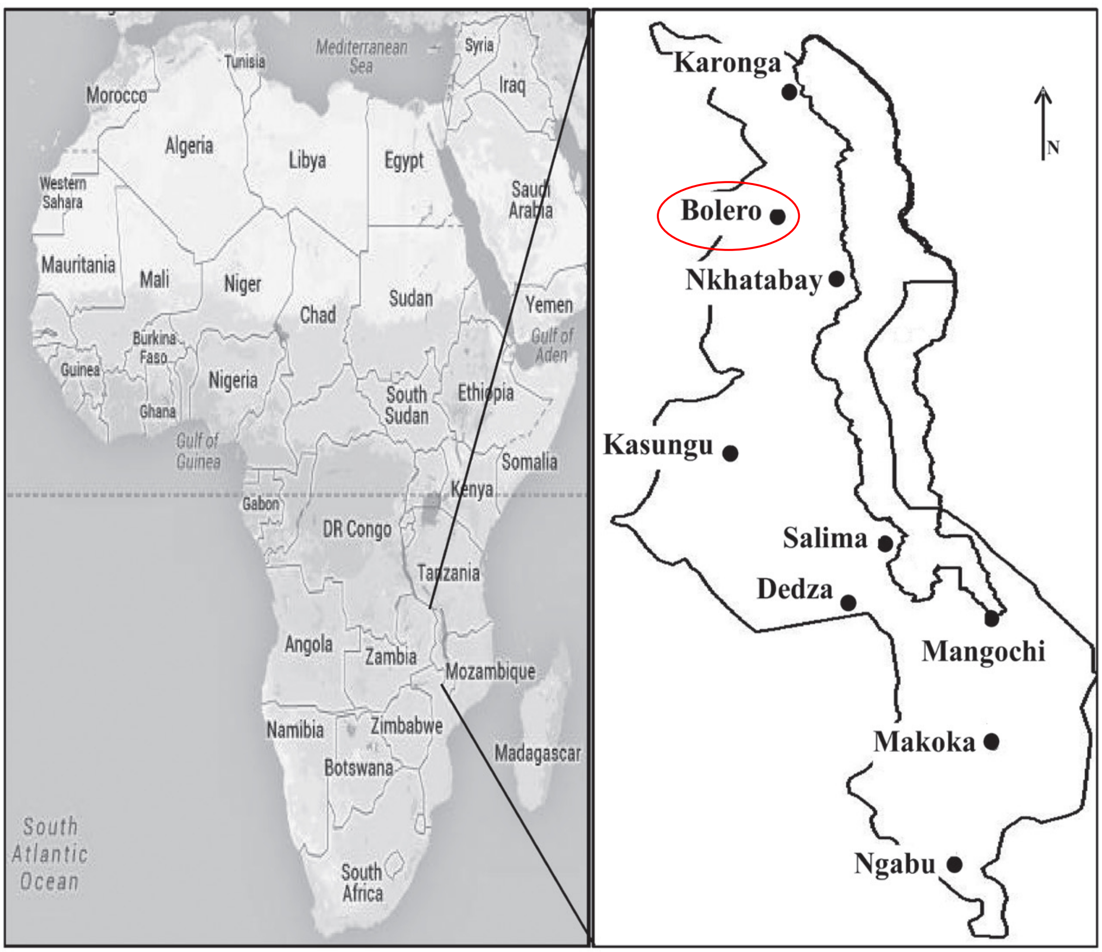

Fig 1: Map of Africa and Malawi locating Bolero (circled in red)

Source: Kumbuyo et al. (2014)

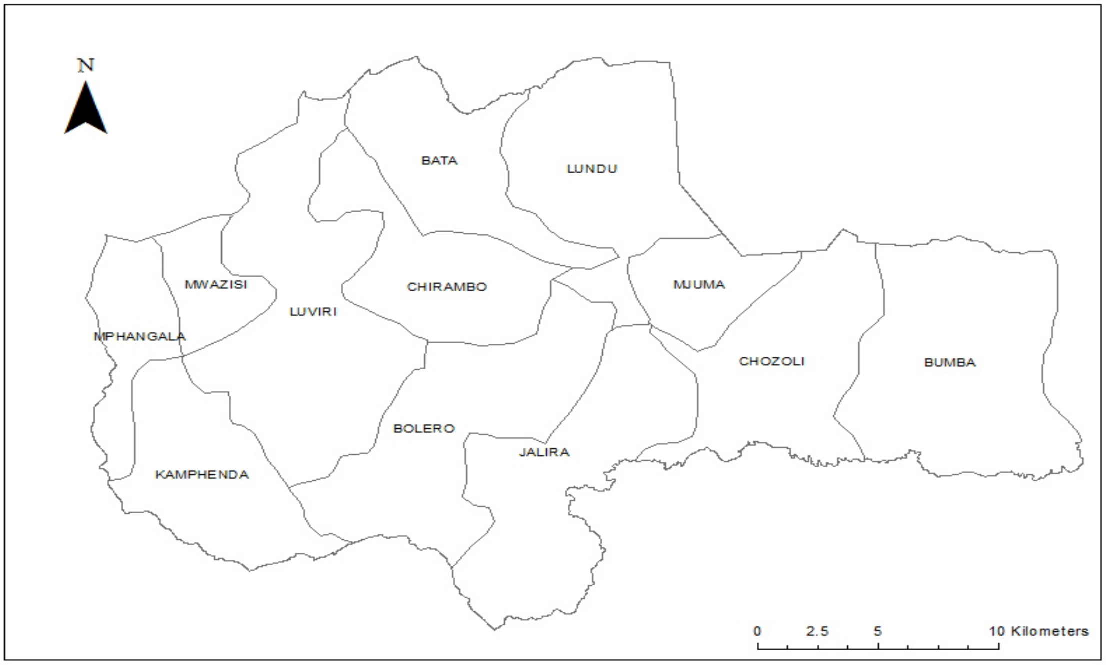

Fig 2: Map of Bolero Extension Planning Area

Source: Mataya et al. (2014)

3.2 Data Collection

The study utilized both primary and secondary quantitative data. Primary data on farming practices was collected through use of household survey. Secondary data collected was on climate variables (rainfall and temperature) and crop yield (hectares and crop production).

3.2.1 Rainfall and temperature data

Rainfall and temperature data was supplied by the Department of Climate Change and Meteorological Services, Bolero Meteorological Station. Bolero station is closely monitored by the Department of Agriculture Research Services. The station uses automatic rain gauges and wet and dry bulb thermometer to record daily rainfall and temperature values. The daily rainfall figures were summed up to give monthly and annual total rainfall values. Minimum and maximum temperatures were recorded on daily basis and average values calculated for monthly and annual means. The rainfall data available for this study was collected from 1954 to 2013 (60 years) while temperature data was collected between 1982 and 2013 (32 years) with no missing data. See appendix 1 for raw data.

3.2.2 Crop production data

The Ministry of Agriculture through the planning department of Rumphi Agriculture District Office provided data on crop production. The data was gathered though agriculture production estimates survey (APES) exercise which was carried out by extension staff four times per agriculture season. The agriculture production estimate survey exercise provided data on main food crops i.e. number of farming households, hectarage cultivated per farming season and yield output. Agriculture production estimates survey used random sampling to select sections and blocks within each section. Thirty farming households per section were also randomly selected. Garden measurements were done using GPS instrument for the selected farming households.

The first and second rounds of the agriculture production estimate survey were carried out during the vegetative phase and provide subjective estimates of yield. Third and fourth rounds were usually during maturity and harvesting, between April and June, during which actual weighed figures were recorded and used to estimate total yield at Extension Planning Area (EPA) level. The study utilized fourth round estimates gathered between 1996/97 and 2013/14 farming seasons representing a total of 18 years. Years before 1996 had a lot of missing data hence were not considered for the study. See appendix 2.

3.2.3 Farming practices data

This section utilized two data sets, the 1996/97 to 2013/14 secondary data on total cultivated area (hectarage) obtained from Rumphi district agriculture and gathered through agriculture production estimate survey (see appendix 2). Secondly, primary data gathered through household survey. Primary data was gathered through use of close ended household questionnaires. Only lead farmers were targeted because of their role in agriculture extension delivery. Lead farmers are community members with responsibility as agriculture focal persons in the community. They facilitate knowledge sharing and farmer to farmer learning. Lead farmers supports and represent views of follower farmers hence were targeted for the study (Masangano and Mthinda, 2012; Mulwafu and Krishnunkutty, 2012). Bolero has 12 sections and 321 lead farmers who work with Mzuzu Agriculture Development Division (MZADD), Total Land Care, Find Your Feet, FAO and Farm Income Diversification Programme (FIDP). The questionnaires were administered to 120 lead farmers from four sections (Bolero, Bata, Chozoli and Luviri), representing 37% of lead farmers and 30% of the sections.

3.3 Data Analysis

Data entry for all variables was done in Microsoft Excel whilst analysis was done using SPSS 16.0 except for Mann-Kendall test was done using XLSTAT 2015.2.02.18098. All the data were checked for multicollinearity, tolerance and variance inflation factor (VIF). Scatter and Normal Probability plots were used to check for outliers, normality, linearity, homoscedasticity and independence of residuals. In order to deal away with the doubt that parametric assumptions were violated, alternative non-parametric tests were carried out to compare and add confidence to the results (Pallant, 2007; Jain & Kumar, 2012). All the tests were carried out at 5% significance level.

3.3.1 Analysis of temperature and rainfall trends

Analysis of trends is done to understand the underlying structure and function of a time series, pattern changes and deviations over time. It is assumed that a time series data set has at least one systematic pattern that can inform future planning (Yanovitzky & VanLear, 2007; Jain & Kumar, 2012). Analysis of rainfall and temperature trends consists of determining magnitude and statistical significance of the time series using parametric tests such as Pearson's correlation, t-test and regression analysis. However, studies on time series have also utilized non-parametric methods such as Mann-Kendall and Spearman's rank correlation tests (Kimaro & Sibande, 2007; Jain & Kumar, 2012; Adamgbe & Ujo., 2013; Obot et al., 2010).

Parametric methods are regarded as more efficient in giving the best linear and unbiased estimates because of the associated assumptions of normal distribution, independence of observations and homogeneity of variance (Pallant, 2007; Obot et al., 2010). The regression analysis assumes a linear trend and is carried out on the time series or on the anomalies such as deviation from the mean (Jain & Kumar, 2012). A non-parametric test is usually preferred because it is a function of the ranks of observations and displays less sensitivity to outliers unlike parametric tests (Pallant, 2007; Kimaro & Sibande, 2007; Obot et al., 2010; Pagona, 2014). For example, Mann-Kendall method uses relative magnitudes of sample data rather than data values themselves to detect if there is any significant trend (Gilbert, 1987). Mann-Kendall method provide results on the rate of change through Sen's slope estimator (Obot et al., 2010).

This study utilized both parametric and non-parametric methods as follows; 1) Descriptive analysis provided a description of characteristics such as mean, minimum, maximum and standard deviation, 2) Pearson and Spearman correlation analyses explored the strength and direction of the relationship between time, climate variables and crop yield, 3) Mann-Kendall test evaluated rainfall and temperature trends and also gave results of Sen's slope estimator, 4) Paired sample student's t-test was done to establish any significant changes in rainfall amounts between the first 30 years (1954 to 1983) and the last 30 years (1984 to 2013). Climatologist recommend at least 30 years climate data to produce reliable statistics on climate change hence provided the basis for splitting the data (Australian Bureau of Meteorology, 2007; Dinse, 2011).

3.3.2 Analyzing relationships

Bivariate correlation and standard multiple regression analyses were done to establish relationships and to explore predictive ability of total annual rainfall, monthly rainfall, minimum and maximum temperatures (independent variables) on crop production and cultivatable land area (dependent variables).

3.3.3 Farming practices

Results from correlation and regression analyses between climate variables and crop hectarage were used a basis of understanding how land use is affected by climate variability. The results were then compared and contrasted with farmers' responses on farm practices. The household survey data was coded into numerical values and subjected to descriptive analysis to obtain frequencies and percentages. The relevant proportions were subjected to chi-square goodness-of-fit tests to validate proportional differences.

4. RESULTS

4.1 Rainfall, Temperature and Yield Trends

This section provide results on the nature and trends of temperature and rainfall variability responding to objective one. Below in table 1 are the results from descriptive analysis.

Table 1: Descriptive statistics of climate and yield variables

Variable	N	Minimum	Maximum	Mean	Std. Deviation
Annual rainfall (mm)	60	297.7	1206.5	666.165	152.8871
Maximum temperature (^oC)	32	27.3	29.2	28.314	0.5489
Minimum temperature (^oC)	32	14.3	16.3	15.563	0.5419
Maize yield (Mt)	18	5124	15850	9857.78	2719.156
Maize hectarage (Ha)	18	3571	8699	5284.06	1803.954
Millet yield (Mt)	18	8	42	21.72	7.737
Millet hectarage (Ha)	18	21	58	35.22	11.670
Ground nuts (Mt)	18	210	710	431.50	162.315
Groundnuts hectarage (Ha)	18	306	668	517.61	110.487
Cassava yield (Mt)	18	402	3024	1542.78	626.448
Cassava hectarage (Ha)	18	26	189	98.28	34.889

The standard deviation values confirms the variability of all the variable in the study. For instance, year 1991 received the minimum rainfall amount of 298 mm, while 1964 was the wettest year with 1207 mm rainfall. No crop data was available to correspond to these extremes. The lowest maize output of 5124 metric tons was in 2004/05 season corresponding to 660.7 mm rainfall on 4838 mm hectares. The lowest maize output fell in the same year of highest cassava output of 3024 metric tons. Table 2 below show correlation and regression results of rainfall and temperature against time.

Table 2: Annual rainfall and temperature against time

Variables	**Pearson's (r)**	**Sig. (2-tailed)**	**Spearman's (rho)**	**Sig. (2-tailed)**	**R^2**	**Sig**
Rainfall/Time	-0.196	0.133	-0.121	0.356	0.039	0.066
Maximum temperatures/time	0.572[a]	0.001	0.530[a]	0.002	0.327[a]	0.001
Minimum temperatures/time	0.471[a]	0.001	0.715[a]	0.001	0.549[a]	0.001

[a] significant at 0.05

A negative relationship exist between time and rainfall (r=-0.196, rho=-0.121) signifying a decreasing rainfall trend but the results are not significant at 95% confidence limit (P=0.133 and P=0.356). Similarly, Sen's slope estimator assumed a decreasing rainfall trend but Mann-Kendall test detected no significant trend in the rainfall time series (Kendall's tau = -0.071, S = -126.000, Var (S) = 24583.333 P= 0.425). However, results from paired-samples t-test show a significant difference of rainfall events between the first 30 years data, 1954 to 1984 (mean = 708.49, standard deviation = 168.75) and the last 30 years data, 1984 to 2013 (mean = 623.84, standard deviation = 123.98). This implies a decrease of mean rainfall amount by 84.65mm significant at 95% confidence level, t (29) = 2.104, sig. = 0.044 (two-tailed).

A significant increasing temperature trend was detected by correlation tests for maximum temperatures (r=0.572, rho=0.530) and minimum temperatures (r=0.471, rho=0.715). Similar results were obtained from Mann-Kendall test (Kendall's tau =0.391, S=194.000, Var (S) = 0.000, P= 0.001) and (Kendall's tau = 0.571, S =277.000, Var (S) =0.0001, P< 0.0001) for maximum and minimum temperatures respectively. Time explains about 33% (R^2=0.327) and 55% (R^2=0.549) increase in maximum and minimum temperatures.

4.2 Rainfall, Temperature and Crop Yield Relationship

This section responds to objective two, it provides correlation and regression results in table 3 below for total annual rainfall, mean minimum and maximum temperatures, and table 4 monthly rainfall amounts (independent variables) against yield of maize, cassava, millet and ground nuts (dependent variables).

Table 3: Annual rainfall, mean temperatures and crop yields

	Maize	**Millet**	**Cassava**	**Groundnuts**
Pearson correlation results				
Rainfall	0.098	0.342	0.355	0.537[a]
Temperature (max)	0.036	0.122	-0.162	-0.277
Temperature (min)	0.125	-0.261	0.158	0.242
Regression results				
R^2	0.144	0.359	0.362	0.556
Significance	0.960	0.573	0.565	0.148

[a] significant at 0.05

Weak and insignificant correlation was observed between maize yield and total annual rainfall (P=0.349), maximum temperature (P=0.443) and minimum temperature (P=0.311). Similarly, the regression (R^2=0.144) was found to be statistically insignificant (P=0.960). No significant correlation was detected between total annual rainfall and the yield of millet (P=0.342) and cassava (P=0.074) and so was the regression results as shown in table 3 above. However, a positive correlation between annual rainfall and groundnuts yield was significant at 0.05 (P=0.011). This indicates that yield of ground nuts would decrease significantly with decreasing annual rainfall.

Table 4: Monthly rainfall and crop yield

Variables		**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**R**	R^2
Rainfall	Maize	0.338^b	-0.310^b	0.286	-0.029	0.158	-0.130	0.722^b	0.522
	Cassava	0.388^b	0.144	0.306	-0.121	0.300	-0.235	0.643	0.414
	Millet	-0.021	0.200	-0.023	0.222	0.338	0.056	0.429	0.184
	G/nuts	0.527^a	0.269	0.434^a	0.012	0.305	0.400^b	0.925^a	0.855

^{a} significant at 0.05, ^{b} significant at 0.10

All the four crops displayed a strong relationship with monthly rainfall amounts. Groundnuts displayed positive relationship with rainfall amounts from November to April, indicating a high degree of moisture requirement. Monthly rainfall variability explains up to 86% of groundnut yield, 52% of maize yield, 41% of cassava yield and 18% of millet yield. Maize in Bolero is positively correlated with rainfall in November and negatively correlated with rainfall in December, both circumstances are significant at 0.10 confidence level.

4.3 Characterizing Farming Practices

This section responds to objective three of the study. It provides results of relationship between cultivatable land area and climate variables (rainfall and temperature). Secondly, the section presents lead farmer responses as obtained through the household survey.

4.3.1 Climate variability and land usage

Results of correlation and regression tests between rainfall and temperature (independent variables) and cultivatable land area (dependent variable) are summarized in table 5 below.

Table 5: Rainfall and temperature against land size

	Maize hectarage	**Millet hectarage**	**Cassava hectarage**	**Groundnuts hectarage**	**Total hectarage**
Pearson correlation (r) results					
Rainfall	0.075	-0.258	0.038	-0.247	0.058
Temperature (max)	-0.204	-0.212	-0.083	-0.253	-0.219
Temperature (min)	-0.46[a]	-0.687[a]	-0.078	-0.653[a]	-0.499[a]
Regression results					
R^2	0.263	0.012	0.476	0.44	0.305
Significance	0.137	0.982	0.025[a]	0.039	0.153

[a] significant at 0.05

Increase or decrease of annual rainfall amount does not correlate with total land area cultivatable per season (r=0.058, P=0.409). However, increase in minimum temperatures has a negative effect on total hectarage cultivated (r=-0.499, P=0.018), hectarage for millet (r=-0.687, P=0.001), ground nuts (r=-0.653, P=0.002) and maize (r=-0.46, P=0.027). Temperature or rainfall alone has a weak and insignificant correlation with land area for cassava but the combined effect of rainfall and temperature explains up to 48% of the changes in land size for cassava (R^2=0.476, P=0.025).

4.3.2 Household survey analysis

Out of 120 respondents 47.5% were males and 52.5% females. Chi-square test revealed no significant difference in the proportion of participation in the study (x^2 = 1.203; df= 1; p=0.273). Majority of the respondents (95%) have been farming in Bolero for more than 7 years with the same proportion having acquired land through inheritance. Inter-annual rainfall variability was rated by all respondents as a big issue affecting farming activities. This agrees with the finding of 152.89 mm standard deviation on annual rainfall indicating high variability.

Farmers believe that cassava is the most shock tolerant crop with 64% indicating that cassava still does better in times of floods and 93% associated cassava with drought tolerance. The respective proportions were found to be statistically significant as revealed through chi-square goodness-of-fit test (x^2 = 33.882; df = 3; p=0.00) and (x^2 =1880.604; df = 4; p=0.000). Farmers responses are in agreement with regression results which showed that rainfall and temperature have an insignificant influence on cassava yield (R^2=0.362, P=0.565).

Groundnuts is the most prone crop to floods and dry spells according to the 120 respondents. This agrees with the quantitative findings in table 3 above, annual rainfall and temperature explain 56% (R^2=0.556) and in table 4, monthly rainfall variation explain up to 86% (R^2=0.855) of groundnut yield changes, showing ground nuts sensitivity to climate variability.

Majority of the farmers (66%) increase their land area for maize cultivation following a year of extremes, while 20% maintain their land size and 14% decrease land size to pave way for other crops. A chi-square test indicates that the differences are statistically significant (x^2 = 35.003; df = 2; P = 0.001) implying that hectarage for maize expected to increase following a year of floods or droughts. Up to 51% of farmers still practice maize mono-cropping, 47% inter plant with legumes even after an experience of floods. The proportions are statistically significant through chi-square test (x^2= 144.401; df =3; p=0.000).

5. DISCUSSION OF RESULTS

The results have confirmed the variability of crop yields and land area as a result of the impact of temperature and rainfall changes. The temperature is increasing and rainfall is decreasing though at different rates and direction. The climatic behavior of rising temperature and somewhat declining rainfall is in agreement with findings by Kimaro and Sibande (2007) for Karonga and Chitedze, Gama et al. (2014) for Mzimba, Kumbuyo et al. (2014) and Pagona for Salima (2014). Results of this study imply that Bolero will most likely become drier and warmer in future.

On the contrary, results by Saka et al. (2013) foresee an increase in precipitation trend in northern Malawi. Results of the current study are also in sharp contrast with results by Kori et al. (2012) for Nzhelele valley in South Africa where an increasing rainfall trend was detected. Such disparities emphasize on the need of community specific studies on climate change and variability. The differences may be attributed to factors such as location, topography and scope of the study as also explained by Kumbuyo et al. (2014). Results by Saka et al. (2013) for northern Malawi could be influenced by the fact that the study was conducted at a broader scope as compared to the recent study confined for Bolero.

Total annual rainfall displayed minimal influence on crop production as compared to monthly rainfall variations. No significant effect of annual rainfall was detected on maize yield but up to 52% of maize production is explainable by monthly rainfall variations. The study observed that maize yield is positively correlated to total November rainfall amounts ($r = 0.338$), whilst it is negatively correlated to December rainfall amounts ($r = -0.310$). Crop yield response to monthly rainfall amounts better reflect the multiplicity of impacts on germination, crop growth, development, flowering, seed production and maturity (Adejuwon, 2005; Alam et al., 2011). This could explain the maize yield difference of 15850 metric tons in 2000/01 season with total annual rainfall of 619mm and the lowest yield of 5124 metric tons in 2004/05 farming season with 661mm. December rainfall total in 2000/01 was 124 mm whilst in 2004/05 was 240 mm, it may be that December 2004/5 had too much rains that led to excessive nutrient leaching and affected biological processes at a critical period.

Increase in temperature trend was found to have a negative influence on total land area for cultivation. This indicates that the anticipated increase in temperature may mean reduction of total land area for cultivation. This could be as a result of continued maize mono-cropping and excessive moisture stress which catalyze land fragmentation and seasonal changes in cropping patterns leading to abandonment of unproductive land portions.

Transformative interventions to address the above issues include promoting maximum soil cover through use of dead or live mulch (i.e. crop residues or intercropping with legumes such as cowpeas), box ridging to conserve water, crop diversification and agroforestry. These interventions would spread the climate risk at farm level and promote nutrition and income source diversity (Birhanu, 2013). The opportunity that exists is that most farmers own the land they cultivate on and are likely to adopt these practices. Mlamba (2010) and Parwada et al. (2010) argues that adoption of land conservation practices is greatly influenced by land tenure rights as opposed to situations where land is hired or rented.

Up to 48% of changes in total land size for cassava production can be attributed to the combined effect of rainfall and temperature changes. The household survey revealed that 93% of respondents' associate cassava with drought tolerance and 64% indicated that cassava still does well in times of floods. It may imply that in times of floods or dry spells more land is allocated for cassava production, while in times of normal rains the land area for cassava is reduced. This is well illustrated by the instance in 2004/5 where maize yield was at the lowest whilst cassava yields at the highest. Farmers may have anticipated extreme weather conditions and changed proportions of land allocation.

Farmers regard cassava and millet as a fall back crops when weather conditions are not favorable for maize. The opportunity here is that farmers already know that cassava and millet are more resilient to climate variability. Transformative interventions should strengthen cassava and millet seed systems to ease access of improved varieties, promote awareness on post-harvest management and train households in staple meal preparation for cassava and millet (Kandji et al., 2006).

The study has recognized that most of the farmers' responses are closely aligned with the quantitative findings. For instance, farmers confirmed on rainfall variability as a big issue affecting crop production. Farmers are aware of the resilience of cassava and millet and the vulnerability of ground nuts. This is an opportunity for transformation because interventions would build on the existing community knowledge. It would be important to learn farmers' experiences and coping mechanism in order to design interventions that build on farmers' experience. This would ensure adoption and sustainability of such interventions.

6. CONCLUSION AND RECOMMENDATIONS

The study found that both annual rainfall and mean temperatures trends are significantly changing. However, these changes are in different magnitudes and directions with rainfall decreasing and temperature increasing with time. These trends have been influencing yield output and will have great impact on crop productivity in future. The effect of rainfall and temperature variability will affect crops differently with groundnuts being the most affected and millet being the least affected. It was also observed that climate variability will also affect arable land use. Agricultural investments by government and non-governmental organizations should be very strategic knowing that Bolero is getting drier and warmer.

It is recommended that area specific climate and crop research platform be instituted to offer timely seasonal forecasts on weather and crop production. This could be an arm of the already existing development committees. Seasonal forecasts would allow farmers reschedule planting dates and allocate resources accordingly (Kandji et al., 2006). It should be kept in mind that the irregularity of rainfall and temperature also factors in with the likelihood of extreme floods and droughts. Research should determine the return period of disastrous weather events. Further research on attitude of farmers towards cassava and millet should be carried out to identify areas for intervention in order to promote these resilient crops.

Farmers should be encouraged to adopt improved crop varieties that are adapted to increasing temperature and decreasing rainfall. This would require collaboration with research institutions and seed suppliers in order to strengthen the seed system. Practitioners in agriculture should ensure availability of diversified legume seed to allow farmers have a wide range of choices for intercropping. Alternative groundnut varieties and investments in irrigation be promoted for farmers in Bolero.

A clear linkage between agriculture, nutrition and health should be highlighted in agricultural interventions to act as a motivation for crop diversification. It is important that development agencies understand that farmers are not an identical group but rather a diverse set of households with varying capacities. Some farmers have the potential to adapt to climate change and transform the sector whereas some households have the potential to improve livelihoods and transform agriculture from outside the sector.

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APPENDICES

Appendix 1: Rainfall and temperature data

Season	**Rainfall (mm)**	**Min Temp (°C)**	**Max temp (°C)**	**Season**	**Rainfall (mm)**	**Min Temp (°C)**	**Max temp (°C)**
1954/55	671.3			**1984/85**	803.3	14.5	27.5
1955/56	861.1			**1985/86**	751.7	14.6	27.3
1956/57	614.7			**1986/87**	629.0	15.0	27.7
1957/58	593.2			**1987/88**	487.5	15.6	28.9
1958/59	591.9			**1988/89**	560.8	14.7	28.1
1959/60	775.0			**1989/90**	690.7	15.1	27.3
1960/61	445.8			**1990/91**	531.0	15.5	28.0
1961/62	943.4			**1991/92**	297.7	15.4	27.5
1962/63	890.8			**1992/93**	667.1	15.3	28.5
1963/64	529.9			**1993/94**	446.8	16.4	28.1
1964/65	1206.5			**1994/95**	589.2	15.4	28.2
1965/66	573.0			**1995/96**	686.1	15.7	28.5
1966/67	777.6			**1996/97**	655.8	15.1	28.4
1967/68	777.5			**1997/98**	539.4	15.9	28.8
1968/69	602.8			**1998/99**	494.2	15.4	29.1
1969/70	626.0			**1999/00**	409.7	15.4	27.9
1970/71	798.3			**2000/01**	618.9	15.8	28.0
1971/72	415.8			**2001/02**	752.5	15.3	28.4
1972/73	656.5			**2002/03**	672.0	15.5	28.0
1973/74	680.8			**2003/04**	695.4	15.6	28.9
1974/75	850.0			**2004/05**	660.7	15.8	28.5
1975/76	820.5			**2005/06**	476.7	15.9	28.4
1976/77	623.9			**2006/07**	745.4	16.2	28.3
1977/78	613.6			**2007/08**	700.9	16.1	28.4
1978/79	691.1			**2008/09**	752.2	16.1	28.3
1979/80	820.2			**2009/10**	780.0	16.1	28.4
1980/81	845.5			**2010/11**	501.3	16.1	29.0
1981/82	443.3			**2011/12**	720.5	16.1	28.9
1982/83	644.9	14.3	27.7	**2012/13**	728.3	16.1	29.2
1983/84	869.8	15.9	28.9	**2013/14**	670.4	16.1	29.1

Appendix 2: Crop yield and hectarage data

Season	Maize hectare	Maize (Mt)	Millet hectares	Millet (Mt)	g/nuts hectare	G/nuts (Mt)	Cassava hectares	Cassava (Mt)
1996/97	4884	8618	45	42	452	210	87	708
1997/98	5666	10671	58	29	607	292	122	993
1998/99	4343	10191	58	29	540	260	146	1188
1999/00	5900	9499	35	14	622	258	65	804
2000/01	8699	15850	46	32	585	663	94	1872
2001/02	8615	11940	42	23	606	628	114	2391
2002/03	7577	8457	46	24	630	337	26	402
2003/04	4043	5163	40	21	618	461	137	2331
2004/05	4838	5124	31	14	668	522	189	3024
2005/06	4055	7171	21	8	577	333	71	1492
2006/07	4206	13287	32	24	547	710	92	1575
2007/08	3571	8003	28	21	520	652	96	1734
2008/09	3618	12792	27	19	412	539	91	1627
2009/10	3733	9410	24	17	416	419	87	1549
2010/11	3878	11072	24	18	362	358	86	1529
2011/12	4619	11640	27	20	508	552	90	1575
2012/13	8452	9428	24	18	341	280	88	1460
2013/14	4416	9124	26	18	306	293	88	1516