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Climate Change Vulnerability Assessment for Riparian Based Livelihoods in Semi Arid Parts of Zimbabwe (A Geotechnological Approach)

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Abstract

This paper presents a study based approach to assess climate change vulnerability for riparian based livelihoods in the semi-arid region of Zimbabwe, who had limited abilities to cope with the adverse effects of climate change. The study area is the semi-arid regions of Zimbabwe which are ranked as being extremely vulnerable to the adverse effects of climate variability because of poverty and limited access to clean water as well as education. There has been a difficulty in the identification of vulnerable communities and the full exploitation of these assessments by policy implementers though adaptive capacity and vulnerability assessment help in guiding policy formulation through the identification of with low copying capacities. The study used a geo-stastistical approach was used to assess and evaluate adaptive capacities of resource poor communities in the semi-arid regions of Zimbabwe. A multi step geospatial approach was used to map adaptive capacities of different communities. Statistical component used demographic indicators comprising of age, literacy levels, income levels, Temperature and rainfall and access to clean water run automated summation and ranking of indicator scores in Maxent to produce maps with spatial locations of communities with varying levels of different levels of adaptive capacities as well as crop suitability maps.

Keywords: Vulnerability • Assessments • Riparian • Livelihoods • Climate change • Cope.

Introduction

Global warming is leading to climate change, and is now scientifically widely accepted as a key global challenge [1]. Narratives of climate change are now central not only to the development discourse, but are also increasingly framing the understanding of other key global such as food security, deforestation, desertification, health, high energy demand and poverty, which are rooted in climate, among others challenges [2-4]. Global Climate change is an issue with potential impacts on the developing world far more severe than those predicted for the developed [5]. Climate change impact is severe in Africa, where it has brought about serious disturbances in ecosystems, reduction in water resources and decline in agricultural and food production [6]. Thus, climate change is a major threat to both human and natural ecosystems in the African region [7-9]. Climate change is already imposing additional stresses to most ecosystems which are already faced with a reduced capacity to deliver essential services to society [10,11]. The Intergovernmental Panel on Climate Change [12] technical paper on climate change and water, highlights on the vulnerability of fresh water resources to climate change impacts which are increasing in frequency and intensity and the associated consequences for human societies and ecosystems [13] noted that climate change will affect hydrologic and thermal regimes of rivers resulting in direct impact on freshwater ecosystems and human water use. In trying to address these issues, the (UNFCCC, 2011) commits nations to "develop appropriate and integrated plans for coastal zone management and water resources management for the protection and rehabilitation of areas affected by drought, desertification and floods". Similarly, the United Nations Framework recognize that climate change is one of the greatest threats to biodiversity and Africa is considered to be one of the most vulnerable regions to climate change impacts, mainly due to its dependence on natural resources and rain-fed agriculture [14-17]. Moreover, the impacts of climate change are expected to be more severe the next century and become one of the major drivers for the loss of African biodiversity [18,19].

A riparian zone/ ecosystem is defined as the interfaces between terrestrial and aquatic ecosystems [21]. They can also be defined as those ecosystems occurring in semi-terrestrial areas adjacent to water bodies and influenced by fresh waters [20]. The riparian ecosystems extend to the continuum from headwaters to the mouths of streams and rivers, the vertical dimension that extends upward into the vegetation canopy and extends to the limits of flooding on either side of a stream [21]. Riparian ecosystems provide goods and ecosystem and human services including those 'with use' as well as 'with non-use' values [22]. Apart from this, growing population problems are the root cause of river degradation coupled with threats from impoundments, inter-basin transfers, catchment degradation, water abstraction, pollution and introduced species (ibid).

In Africa, riparian ecosystems are of crucial importance since they contribute to biodiversity and human wellbeing [23]. Thus, riparian based ecosystems are a major biodiversity hub contributing to human livelihoods. However, they are not spared from climate change related impacts. Southern Africa is prone to multi-year droughts spanning over decadal time scales (Strauch, 2009). The impacts of climate change on riparian ecosystems depend on several factors including the rate and magnitude of change relative to historical climate [24,25] noted that riparian ecosystems in the 21st century are likely to play a critical role in determining the vulnerability of natural and human systems to climate change, and influencing the capacity of these systems to adapt. Rivers provide a special suite of fresh water goods and services depending on changes on the environmental flow regime [20,26,27]. However, rivers face multiple stressors ranging from anthropogenic activities such as infrastructure development, dams, or extractive uses and natural disasters [28-30]. The aims of this climate change and vulnerability assessment for riparian based livelihoods is therefore: to a) Determine the level of vulnerability for riparian based livelihoods b) Asses the adaptive capacity for riparian based livelihoods to climate change, c) Model climate change condition for adaptive capacityin order to prioritise needs for action and justify certain actions. Climate change interacts with these anthropogenic stressors resulting in the magnification of risks that are already present through changes in rainfall, temperature, runoff patterns, and disruption of biological communities and severing of ecological linkages [23,31].

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Methods

Study area

The arid and semi-arid areas of Zimbabwe include those found in natural regions 4 and 5 (Mbire, Chiredzi and Mwenezi) of the Zimbabwe natural regions classification. These are the areas most vulnerable to climate change related extreme events as they receive less rainfall and also experience higher temperatures. Any slight change in these climate elements increases the areas' vulnerability significantly.

Mwenezi district lies in Zimbabwe's agro-ecological regions four (7%) and five (93%), whilst Chiredzi is wholly in region 5. On the other hand, Mbire district lies in regions 3 (5%) and region 4 (95%). Thus, the majority of the area of the three districts lies in agro-ecological regions four and five. Region four receives around 450-650 mm of rainfall per annum. However, the rainfall subject to frequent seasonal droughts and severe dry spells during the rain season (Moyo, 2000; Vincent and Thomas, 1961). In Mwenezi, region four is confined to wards 1, 2, 5 and parts of wards 13. In these wards, small holder farmers grow drought-tolerant varieties of maize, sorghum, pearl millet (mhunga) and finger millet (rapoko). All the other wards are in Region 5, which receives less than 450 mm of rain per annum. The same applies to all the wards of Chiredzi district which lie in region five and thus depend on very erratic rainfall, hence most people indicated that they depend on borehole water. Generally, agro-ecological region five is suitable for extensive cattle production and game-ranching. However, small holder farmers in region five also grow drought-tolerant varieties of maize, sorghum, pearl millet (mhunga) and finger millet (rapoko).

This assessment employed a mixed methods approach to allow for the gathering of multiple data sets, to collect primary and secondary data at district and ward levels, thus a combination of qualitative and quantitative data collection methods for the collection of biophysical, agro-economic and socio-economic data. These included desk study of relevant documents, archives and secondary material, questionnaires, digital mapping and modelling techniques. Gis and Satellite imagery were used to place the project beneficiary communities in a landscape context. The baseline data collected were then used to benchmark the current status in terms of demographic information and quantifiable indicators on respective communities, both direct and indirect segregated on gender, current land use practices, understanding of climate change, adaptation needs, rangeland condition, among others.

Demographic profile of study districts

For the demographic profile of the people in the study areas a total of 608 questionnaires were administered in Mwenezi, Mbire and Chiredzi districts (Figure 1). Questionnaires were administered in wards 2, 3, 6, 7, 9 and 11 (Mbire district); wards 2, 3, 7, 8 in Mwenezi District; and wards 6, 7, 8, 11, 13 and 15 for Chiredzi district.

Bioclimatic modelling

In this study, Maximum Entropy software (MaxENT version 3.4) was used to analyse current and future shifts in lands suitable for the cultivation of maize, sorghum, millet and pastures. MaxENT is chosen based on the following reported advantages: it performs well with presence only data and a small number of records and also can utilize continuous and categorical data (Elith et al. 2006). Secondly it is superlative analytical and precision in predicting distribution of different species (Garcia et al 2013) and lastly it is resistant to spatial errors (Graham et al. 2008, Phillips et al. 2006). Using MAXENT for the bioclimatic modelling of crop and pasture suitability, it was assumed that people grow crops (maize, sorghum and millet) in the same fields on a rotational basis. Based on that, 19 bioclimatic factors, slope and elevation were

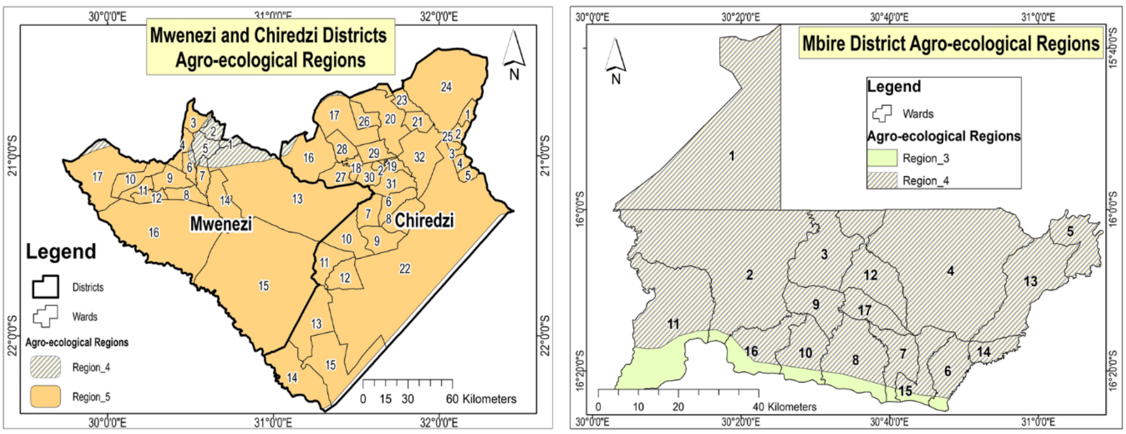


Figure 1. Map showing the arid and semi-arid parts of Zimbabwe Chiredzi, Mbire and Mwenezi.

Table 1. Bioclimatic Variables used for suitability modelling.

BIO1 = Annual Mean Temperature
BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3 = Isothermality (BIO2/BIO7) (×100)
BIO4 = Temperature Seasonality (standard deviation ×100)
BIO5 = Max Temperature of Warmest Month
BIO6 = Min Temperature of Coldest Month
BIO7 = Temperature Annual Range (BIO5-BIO6)
BIO8 = Mean Temperature of Wettest Quarter
BIO9 = Mean Temperature of Driest Quarter
BIO10 = Mean Temperature of Warmest Quarter
BIO11 = Mean Temperature of Coldest Quarter
BIO12 = Annual Precipitation
BIO13 = Precipitation of Wettest Month
BIO14 = Precipitation of Driest Month
BIO15 = Precipitation Seasonality (Coefficient of Variation)
BIO16 = Precipitation of Wettest Quarter

used to determine the current and future crop suitability. The 19 bioclimatic factors are derived from the monthly temperature and rainfall values in order to generate more biologically meaningful variables. The bioclimatic variables represent annual trends (e.g., mean annual temperature, annual precipitation) seasonality (e.g., annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the wet and dry quarters). A quarter is a period of three months (1/4 of the year) (Table 1).

In addition to the above 19 bioclimatic variables (derived from rainfall and temperature), additional variables (Table 2) were also used to determine suitability for crops and pasture (grasslands).

Slope was derived from the STRM 30m digital elevation model downloaded from the bio climatic website (https://worldclim.org/data/worldclim21.html). The potassium, phosphorus and nitrogen were downloaded from the International Soil Reference and Information Centre (ISRIC) website https://files.isric.org/soilgrids/latest/. Cattle density data were downloaded from Gridded Livestock of the World (GLW3) is a spatial dataset website (https://www.livestockdata.org/contributor/gridded-livestock-world-glw3), and land cover data layer was obtained from Zimbabwe forestry commission. Soils data layer was obtained from the European Soil Data Centre (ESDAC) website. (https://esdac.jrc.ec.europa.eu/content/soil-map-soil-atlas-africa). Current status in terms of demographic information and quantifiable indicators on respective communities, both direct and indirect segregated on gender, current land use practices, level of degradation, understanding of climate change, adaptation needs, rangeland condition, biodiversity status (flora, fauna and aquatic).

Climate data analysis

A total of six downscaled Global Climate Models (GCMs) from the Coupled Model Inter comparison Project Phase 6 (CMIP6) data sets were used in assessing the likely impacts of climate change in Mwenezi District. CMIP6 is a project coordinated by the Working Group on Coupled Modelling (WGCM) as part of the World Climate Research Programme (WCRP). The downscaled GCM data were downloaded from the following website: https://www.worldclim.org/data/cmip6/cmip6_clim10m.html.

Temperature and precipitation data for the immediate future (2021-2040) were processed for six downscaled global climate models: BCC-CSM2-MR, CNRM-CM6-1, GFDL-ESM4, IPSL-CM6A-LR, MIROC-ES2L, MRI-ESM2-0, and for two Shared Socio-economic Pathways (SSPs): ssp126 and ssp585 corresponding to two Representative Concentration Pathways (RCPs) RCP2.6 and RCP8.5 as in the Firth Assessment Report (AR5). (These updated scenarios are called SSP1-2.6 and SSP5-8.5, each of which result in similar 2100 radiative forcing levels as their predecessor in AR5) (Table 3).

The RCP2.6 emission and concentration pathway is representative of the literature on mitigation scenarios aiming to limit the increase of global mean temperature to 2°C. This scenario forms the low end of the scenario literature in terms of emissions and radiative forcing. On the other hand, the RCP8.5 emission and concentration pathway combine assumptions about high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long term to high energy demand and GHG emissions in absence of climate change policies. Compared to the total set of Representative Concentration Pathways (RCPs), RCP8.5 thus corresponds to the pathway with the highest greenhouse gas emissions. Results for the vulnerability analysis are mostly based on the RCP8.5 representing the possible worst-case scenario.

Results and Discussion

Demographic profile of study districts

Of the 608 questionnaires, only 466 (77%) questionnaires were analysed with Chiredzi having the highest number of questionnaires (61%), followed by Mbire (22%) and then Mwenezi (17%). In Chiredzi and Mwenezi districts, more females were interviewed than males whilst in Mbire district, more males were interviewed (Figure 2).

The remaining 23% of the questionnaires did not correctly capture the respective coordinates where the interviews were carried out and some were incomplete and hence were not included in the analysis. The coordinates of where the interviews were carried out were important in order to place the respondents in the correct geographical context, i.e.,

Table 2. Bioclimatic Variables used for suitability modelling.

DEM = Digital Elevation Model
Slope = Slope
K = Potassium
P = Phosphorus
N = Nitrogen
Cattle = Cattle Density
LC = Landcover
Soils = Soils

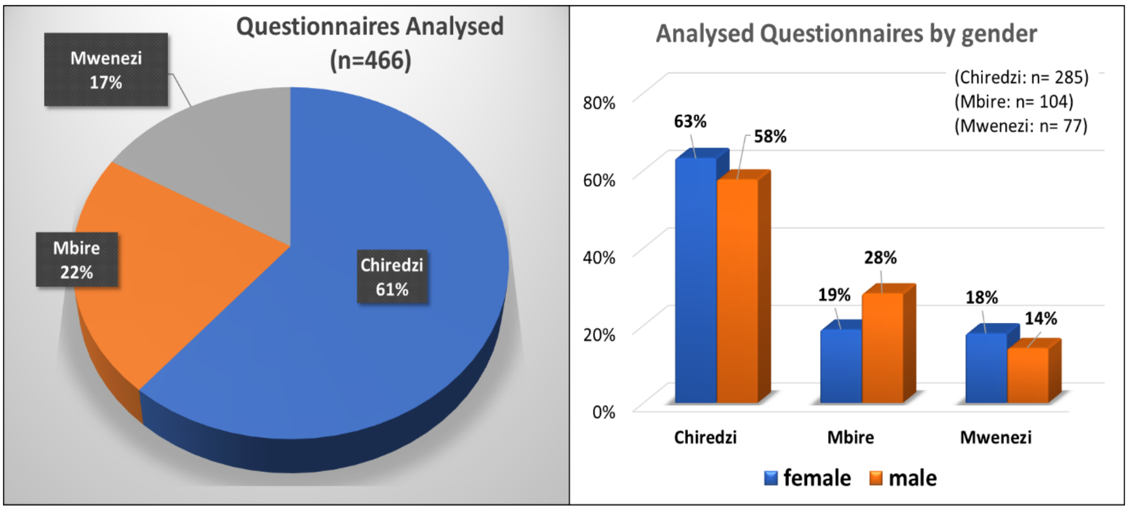


Figure 2. Demographic profile of Mbire, Mwenezi and Chiredzi district.

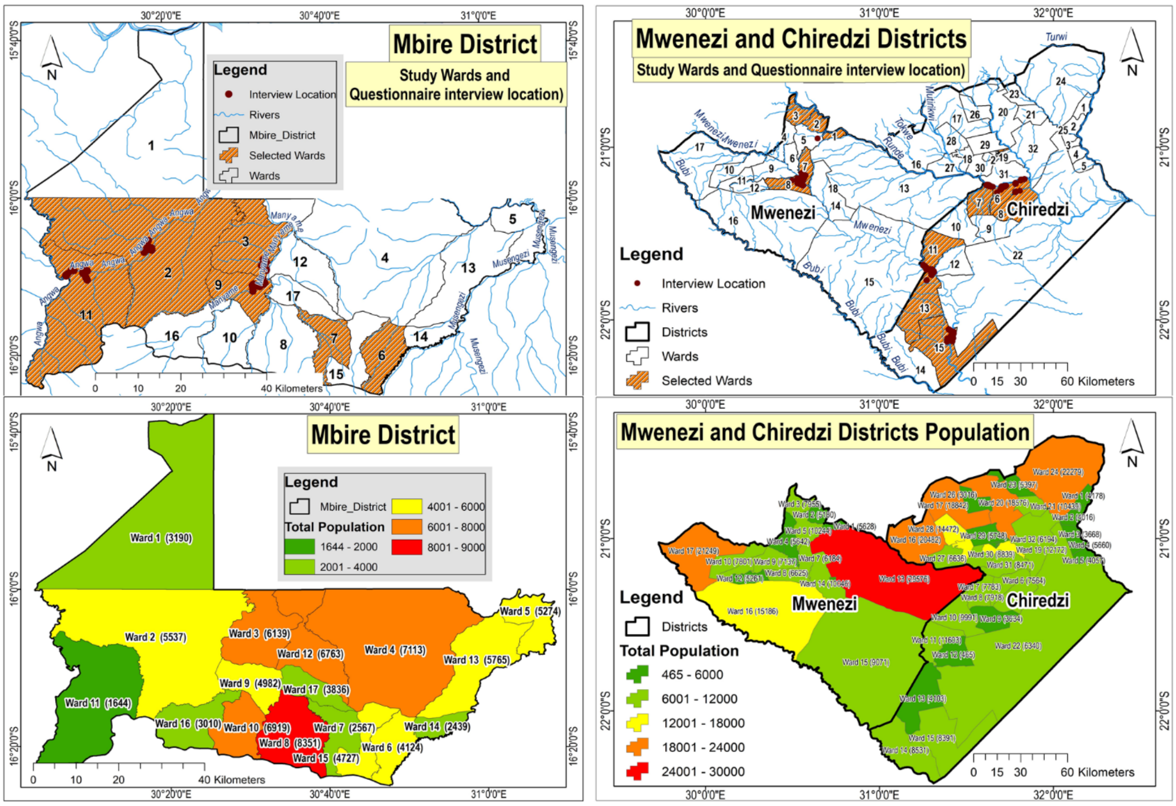


Figure 3. Demographic profile of the three study sites.

Table 3. Bioclimatic models and Institutions.

Model Name	Institution
BCC-CSM2-MR	Beijing Climate Center, Beijing 100081, China
CNRM-CM6-1	Centre National de Recherches Meteorologiques, Toulouse 31057, France
GFDL-ESM4	Geophysical Fluid Dynamics Laboratory. Princeton University, USA
IPSL-CM6A-LR	Institut Pierre Simon Laplace, Paris 75252, France
MIROC-ES2L	Japan Agency for Marine-Earth Science and Technology, Kanagawa 236-0001, Japan
MRI-ESM2-0	Meteorological Research Institute Tsukuba Ibaraki 305-0052 Japan

Table 4. Education levels attained in the three districts.

Ward * Education * District Crosstabulation								
				Education				
			literate	No education	primary	secondary	tertiary	Total
Chiredzi	Ward 6	6%	1%	1%	11%	9%		28%
	Ward 7	4%	2%		7%	8%	0.35%	22%
	Ward 11	2%	1%		12%	8%		24%
	Ward 13				3%	1%		4%
	Ward 15	1%	1%		8%	11%	0.35%	22%
	Total	14%	6%	2%	41%	37%	1%	100%
Mbire	Ward 2	10%	1%		7%	3%		20%
	Ward 3	1%		1%	6%	8%		15%
	Ward 6	2%			1%	3%		6%
	Ward 7		2%		1%	3%		6%
	Ward 9	8%			13%	12%		33%
	Ward 11	1%	2%		12%	6%		20%
	Total	21%	5%	1%	39%	34%		100%
Mwenezi	Ward 2						1%	1%
	Ward 3	3%			5%	5%		13%
	Ward 7					1%		1%
	Ward 8	8%		1%	22%	49%	4%	84%
	Total	10%		1%	27%	56%	5%	100%

where the interviewees came from in terms of ward and village location. Figure 3 below shows the wards within which the interviewees came from the three study districts.

The results aboveon the demographic profile of the three study sites is a clear representation of how the demographic structure of most climatic vulnerable parts in different countries in Southern Africa, thus having relatively more females than men. It is so because most me would be away seeking for greener pastures. These results tally well with a research done on mapping adaptive capacities of resource-poor communities to climate change in Nkonkobe Local Municipality, Eastern Cape Province, South Africa(Chari et al 2017) where the area of study focus had more or less the same numbers with those found in the vulnerable areas of our three study areas.

Education levels attained

The majority of the people interviewed had attained primary and secondary education for the three districts. In Chiredzi 41% and 37% had attained primary and secondary education respectively whilst for Mbire it was 39% and 34%, and for Mwenezi it was 27% and 56% respectively. With more females having attained both primary and secondary education with 25% and 29% respectively. The ward and district disaggregation of the education levels attained by respondents is shown in Table 4.

Overall, there were more females (40%) who had attained primary education than males (35%), and more males with secondary education (42%) as compared to females (38%). Table 5 below shows the disaggregation of education levels by gender for each district.

Table 5. Education level according to gender in the three districts.

District * Education * Gender Crosstabulation								
		Education						
		not stated	literate	no education	primary	secondary	tertiary	Total
male	Mwenezi	1%			3%	9%	1%	14%
	Mbire	6%	1%		7%	14%		28%
	Chiredzi	9%	2%	2%	25%	19%	1%	58%
	Total	16%	2.40%	2%	35%	42%	2%	100%
female	Mwenezi	2%			5%	9%	1.00%	18%
	Mbire	4%	1%		10%	4%		19%
	Chiredzi	8%	5%	1%	25%	24%		63%
	Total	14%	6%	1%	40%	38%	1%	100%

Table 6. Livelihood sources in the three study sites.

Main Livelihood Source	Mwenezi	Mbire	Chiredzi	Total
Crop Production	13%	17%	38%	**68%**
Casual labour	1%	3%	6%	**10%**
Formal employment	0.40%		3%	**4%**
Remittances	0.20%	0.20%	3%	**3%**
Informal trading	1%		2%	**3%**
Horticulture	0.20%	1%	2%	**3%**
Support from NGOs	0.20%		2%	**2%**
Livestock production		0.20%	1%	**2%**
Other (gold panning, brick moulding, weaving, pension)	0.20%	1%	3%	**5%**
Total (n =466)	17%	22%	61%	**100%**

Table 7. Water sources in the study sites.

		Main Water sources * Word* District Crosstabulation						
Mbire		Ward 2	Ward 3	Ward 6	Ward 7	Ward 9	Ward 11	Total
	Well	3%	2%	6%		8%	1%	19%
	River	13%	1%		4%	6%	19%	42%
	Borehole	4%	13%		2%	19%		38%
	Toal(n=104)	20%	15%	6%	6%	33%	20%	100%
		Main Water sources * Word* District Crosstabulation						
Chiredzi		Ward 6	Ward 7	Ward 8	Ward 11	Ward 13	Ward 15	Total
	Well	15%	1%		14%		7%	37%
	River	5%	9%	0.40%	6%	3%	1%	23%
	Borehole	8%	12%		4%	1%	14%	38%
	Toal(n=285)	28%	22%	0.40%	24%	4%	22%	100%
		Main Water sources * Word* District Crosstabulation						
Mwenezi		Ward 2		Ward 3	Ward 7		Ward 8	Total
	Well			7.80%			2.60%	10.40%
	River			1.30%			41.60%	44.20%
	Borehole	1.30%		3.90%	1.30%		40.30%	45.50%
	Toal(n=285)	1.30%		13.00%	1.30%		84.80%	100%

The results show that more ladies attend primary level as compared to those that proceed for secondary education. This may mean that ladies in developing countries are somehow forced to drop from school because of poverty which has been driven by climate variability. This will force them to join the marriage fraternity and poverty as well as vulnerability to climate change increases [32,33].

Livelihood vulnerability assessment

Main livelihood sources: For the three districts, crop production vis a vis agriculture was the main source of livelihood as stated by around 68% of the respondents. In Mwenezi, crop production was the main livelihood source for 13% of the people, Mbire - 17% and Chiredzi - 38% (Table 6). This implied that people in all the three districts survived from agriculture and agricultural related activities, hence analysis of climate shocks due to climate change would be imperative. In addition, a significant number of the people in the three districts dependent on water from natural water ways especially rivers. For example, the main water source for people in Mbire district was identified as from the rivers (42%) followed by boreholes (38%). However, for Chiredzi and Mwenezi districts, the main water source was identified as from boreholes with 38% (Chiredzi) and 46% of respondents in Mwenezi using borehole water. For these two districts, the use of river water came second with Chiredzi and Mwenezi having 23% and 44% respectively (Table 7).

The results above tally well with those from a study done in Zimbabwe on the response of hydrological regimes to climate change where the results indicated that there was a decrease and disturbance in hydrological regimes due to climate change vulnerability as well as the disasters associated with them. Hence this has lead to high vulnerabilities in the indicated areas especially to those that rely much on riverine ecosystem goods and services [34].

Vulnerability assessment

Given the above it was therefore noted that people in the three districts (Chiredzi, Mwenezi, and Mbire) are dependent on agriculture, riverine water as well as underground water for their livelihood. In agriculture, crop production was most dominant. The most important crops grown in these districts being maize, millet and sorghum. Thus, rainfall variability plays an important role in the daily lives of people in these three districts. For example, rainfall variation directly influences available water in rivers and indirectly influences groundwater availability, pasture condition, and ecosystems in general. In addition, the growing of crops and water availability is also heavily influenced by temperature variation. Temperature changes may lead to changing patterns of rainfall and hence the spatial and temporal distribution of runoff, soil moisture and groundwater reserves, as well as potentially increase the frequency of occurrence of droughts and floods [35]. Thus, temperature and rainfall variation significantly influence the people's livelihoods, directly and indirectly. Overall, the increased rates of global warming leading to climate change, is now scientifically widely accepted as a key global challenge with narratives of climate change are now central not only to the development discourse, but are also increasingly framing the understanding of other key challenges, such as: food security, deforestation, desertification, health, population growth vs resource balance, high energy demand and poverty, among others.

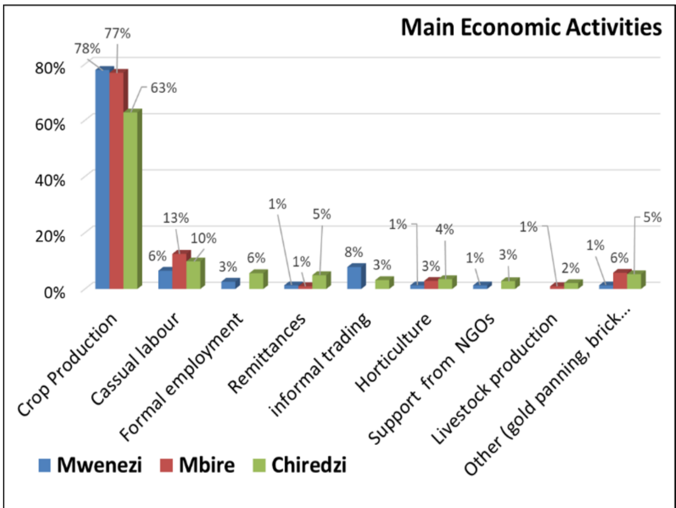
Vulnerability assessments (VAs) on the other hand help to define the nature and extent of the climate change threat that may harm a given system, providing a basis for devising measures that will minimize or avoid this harm – i.e., adaptation. Therefore, vulnerability assessments are central to shaping climate change adaptation decisions as they help to define the nature and extent of the threat that may harm a given human or ecological system, providing a basis for devising measures that will minimise or avoid this harm. In this context, clarifying the 'what' in vulnerability assessments is key. Vulnerability of what (e.g., people, regions, ecosystems, economic sectors) and vulnerability to what (e.g., storms, sea level rise, temperature extremes etc) – is a good first step to framing an assessment. The three study districts are vulnerable regions owing in part, to lack of financial, institutional and technological capacity, low adaptive capacity, endemic poverty, low technology uptake, and dependence on rain fed agriculture. This was evident from the demographic profile of respondents (e.g., high population, lack of significant tertiary qualifications, dependence on rainfed agriculture) as is the case for most wards in most districts.

Level of vulnerability

Typically, spatial vulnerability assessment involves data integration in which geo-referenced socio-economic and biophysical data are combined with climate data to understand patterns of vulnerability and, in turn, inform where adaptation may be required vulnerability assessment. From the questionnaire interviews it was established that 90% of the people interviewed in the three districts depend on agricultural and agricultural related activities. Of these activities, the growing of crops and rearing of livestock constitute over 68% of the agricultural activities (Figure 4).

Only a few respondents are into other activities such as contract workers, informal trading and gold panning. The main source of livelihood is agriculture yet it is the one that is affected mostly by climate change. In a way this has seen the general economic setup being affected because the main source of livelihood is affected by climate change. The respondents end up having no option other than relying on donors for survival especially in bad seasons. Some have since resorted to cross boarder trading as a way of trying to make ends meet. Instead of depending on agriculture only, other respondents have extra activities to add such as brick moulding, beer, work among others. All these activities indicate that the general economic outlook is poor.

From the respondents, the first irrigation scheme started in the 1960s and more were developed with time due to variability in seasonal rains. The area witnessed a boom in the irrigation development from the year 2000 onwards.



	Mwenezi	Mbire	Chiredzi	Total
Crop Production	60	80	179	319
Cassual labour	5	13	28	46
Formal employment	2		16	18
Remittances	1	1	14	16
informal trading	6		9	15
Horticulture	1	3	10	14
Support from NGOs	1		8	9
Livestock production		1	6	7
Other (gold panning, brick moulding, weaving, pension)	1	6	15	22
Total	77	104	285	466

Figure 4. Main economic activities of three study sites.

This has helped the economic setup of the area to boost a little bit despite the changes that have occurred due to climate change. From the irrigation produce, the highest percentage is for household consumption and the rest is for sale. The sales they get are hardly reach 500 US per month. This well explains the poor economic setup in the area. They are no longer getting the high sales from their goods as they used to because their market is restrained. For the past 5 years the area has seen a remarkable decrease in the resources in the area. Most of the ecosystem services from which they used to benefit from have decreased. The Provisional services from the riverine ecosystem have decreased, people no longer get the aquatic resources they used to get, rather they have resorted to streambank cultivation, sand abstraction and artisanal mining along the river banks. This tally very well with the studies which were done on the assessment of services offered by the riverine system in Lake Kariba (Figure 5) [36].

The area has seen a remarkable decrease in resources over the past 5 years due to climate change. This have affected the economy of the area in that the services that they used to get from the natural environment are no longer available, for instance fish from the river have decreased. Because of the changes in seasons, people have now resorted to nature for a living, for instance cutting firewood for sell, sand mining and brick moulding. These results concur with those from a research which was doneon rainfall variability, drought and implications of its impacts on Zambia (Sichingabula,1998). Whereall the copying strategies have resulted in heavy damage to the ecosystems hence facilitated in the general depletion of resources. From the respondents it is very clear that the dry spells are increasing and this has posed high risk on the natural resources on which people depend on.

Bioclimatic modeling

Vulnerability of livelihoods to current temperature and rainfall variation: The range of rainfall for the current climate for Mwenezi District is 407 – 681mm, whilst the temperature range is from 20 to 24°C. For Chiredzi District, the mean annual rainfall ranges is from 398 to 914 mm, whilst for Mbire district, the mean annual rainfall ranges from 684 – 877mm. Overall. Mbire district receives more rainfall than the other two districts, whilst rainfall variability is higher for Chiredzi (range =516mm) as compared to the other two districts. Mbire District on the other hand had higher temperature variability (range =5.8 °C) as compared to Chiredzi (range =4°C) and Mwenezi (range =3.8°C). Table 1 below summarises the ranges of rainfall and temperature variation for the three districts under the current climate. Figure 6 shows the rainfall and temperature spatial variation, whilst Table 8 show the rainfall and temperature variation for the respective wards for the three districts. Overall, these three districts are hot and dry and are located within the low-lying areas of Zimbabwe's lowveld.

Vulnerability of livelihoods to current temperature and rainfall variation: The range of rainfall for the current climate for Mwenezi District is 407 – 681mm, whilst the temperature range is from 20 to 24°C. For Chiredzi District, the mean annual rainfall ranges is from 398 to 914 mm, whilst for Mbire district, the mean annual rainfall ranges from 684 – 877mm. Overall. Mbire district

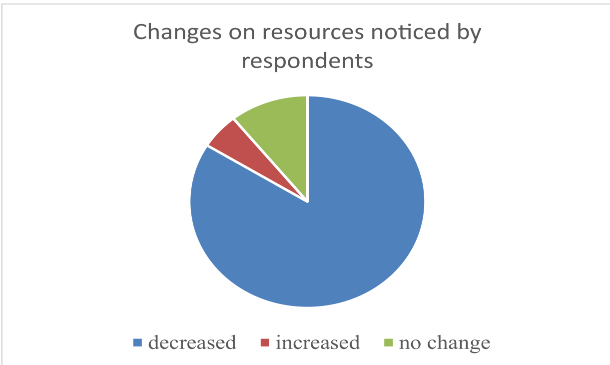


Figure 5. Changes on resources over the past 5 years.

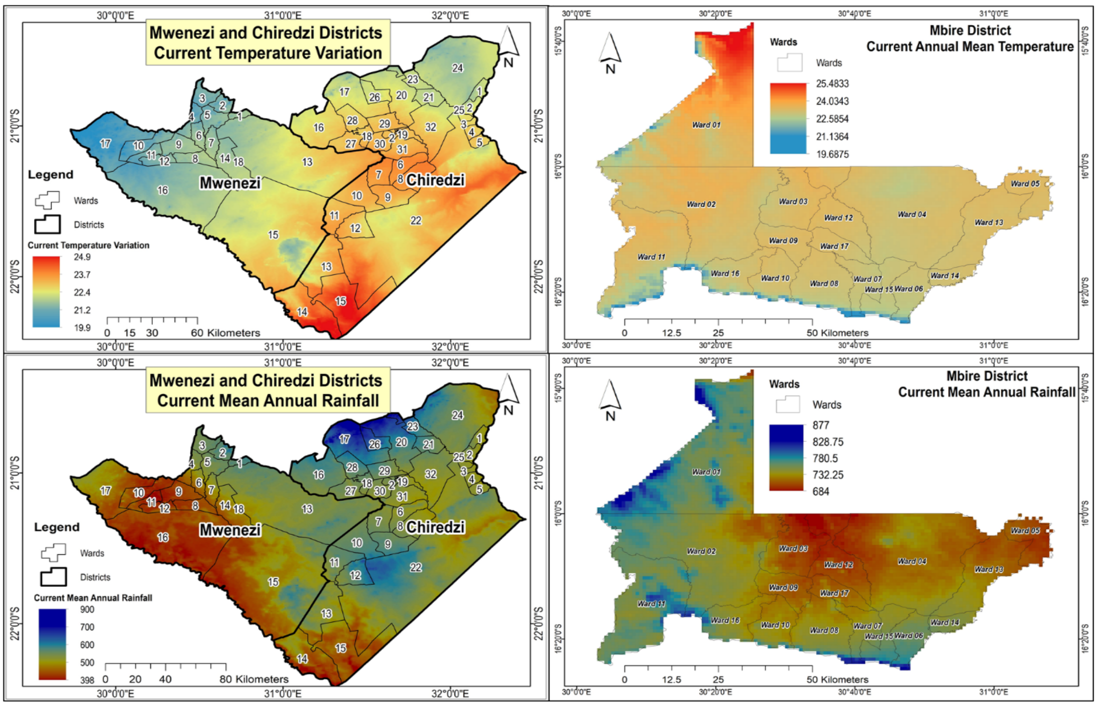


Figure 6. Rainfall and Temperature Variations for Chiredzi, Mbire and Mwenezi Districts for the current climate.

Table 8. Rainfall and Temperature Variations for Chiredzi, Mbire and Mwenezi Districts for the current climate.

Rainfall Variation					
District	**Min**	**Max**	**Range**	**Mean**	**Std**
Chiredzi	398	914	516	575.5	61.7
Mwenezi	407	681	274	511.4	59.3
Mbire	684	877	193	740.3	25
Temperature Variation					
Chiredzi	20.9	24.9	4	23	0.7
Mwenezi	19.9	23.7	3.8	22	0.7
Mbire	19.7	25.5	5.8	23.3	0.5

Table 9.Suitability ranges summaries.

% Range	Classification
80 – 100%	Highly suitable
60 – 79%	Suitable
40 – 59%	Marginally suitable
Blow 40%	Unsuitable

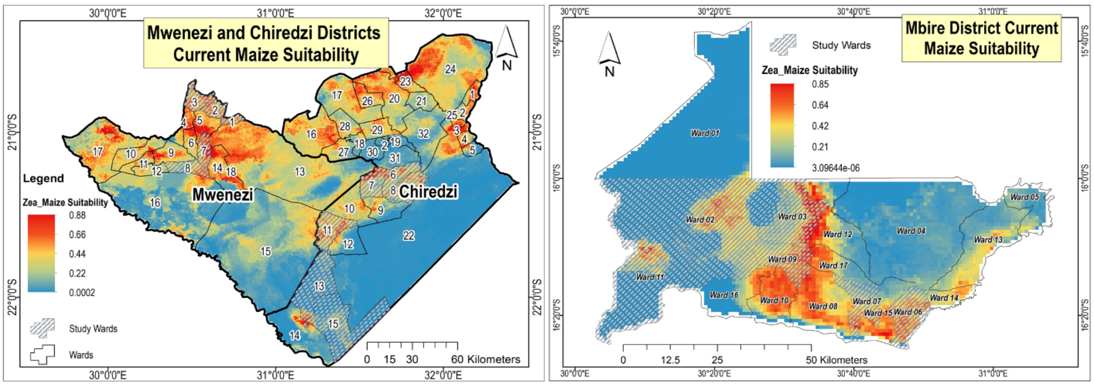


Figure 7. Spatial variability for maize suitability.

receives more rainfall than the other two districts, whilst rainfall variability is higher for Chiredzi (range =516mm) as compared to the other two districts. Mbire District on the other hand had higher temperature variability (range =5.8 °C) as compared to Chiredzi (range =4°C) and Mwenezi (range =3.8°C). Table 1 below summarises the ranges of rainfall and temperature variation for the three districts under the current climate. Figure 6 shows the rainfall and temperature spatial variation, whilst Table 8 show the rainfall and temperature variation for the respective wards for the three districts. Overall, these three districts are hot and dry and are located within the low-lying areas of Zimbabwe's lowveld.

These results indicate that there are relatively high temperatures as well as low seasonal rains in the three study areas which is indicative of high level of vulnerability specifically for people who rely on riverine ecosystem as one of the main source of survival.

Crop suitabilty analysis: Suitability ranges of above 60% indicate that a crop can safely be grown in an area, otherwise any suitability below 60% implies that the area is not suitable for a particular crop, plant or animal. Maximum suitability of greater than 80% implies that there are some areas in those wards which are highly suitable for crop production. Wards with a maximum suitability less than 60% implies that these wards are unsuitable for the production of a crop. Table 9 below summaries interpretation of suitability ranges. From the maxent modelling of suitability, maize suitability was highest in Mwenezi District (up to 88%) followed by Mbire (85%) and least in Chiredzi (80%). However, in all districts there were more areas unsuitable for maize production with only limited areas with high suitability. As a result, the mean suitability for the three districts was very low across the board at 20%, 27%, and 18% for Chiredzi, Mwenezi and Mbire district respectively. The spatial variability for maize suitability is shown in Figure 7 below.

For Mwenezi District, results of maize suitability analysis showed that in wards 6 – 10, and small portions of ward 16; suitability ranges from 70% to 84%, thus making these wards suitable for maize production. Thus, in these wards' maize can be grown successfully under the current climate regime. For Chiredzi districts, wards located in the northern areas (wards 16, 17, 22, 2324, 25, 26 and 27) exhibited higher suitability to maize production ranging from 66% to 88%. This was the same scenario with wards in the eastern side of the district (wards 1, 2, 3, 4, 5) which had maize suitability ranging from 75% to 84% (Figure 8 For Mbire district, wards with suitability ranging from 70% to 80% were wards 3, 6, 9,10, 12, 17, 8, and 15).

Millet and Sorghum showed the same suitability ranges in the three districts. Below is a presentation of millet suitability only, and since they showed the same suitability ranges, it is used to interpret sorghum suitability as well. The maximum millet /sorghum suitability for Mbire district was 82%, for Chiredzi it was 83%, and for Mwenezi - 87%. Wards with maximum suitability greater than 70% are highlighted below. Maximum suitability of greater than 80% implies that there are some areas in those wards which are highly suitable for millet /sorghum production. Wards with a maximum suitability less than 60% implies that these wards are unsuitable for the production of millet /sorghum. Figure 8 below shows the spatial variability for millet suitability.

Overall, millet showed higher suitability in parts of Mwenezi (up to 88%) then Chiredzi (up to 83%) then Mbire (up to 82%) under the current climate.

Vulnerability to future climate scenarios in future temperature and rainfall variation: The immediate future is likely to be drier as compared to the current rainfall regime and less rainfall should be expected. The average of models for both RPC 2.6 and RPC8.5 for the immediate future period (2021-2040) showed reduced rainfall for all the models (Figure 9). On the other hand, for temperature, for both RPC scenarios (RCP2.6 and RCP8.5), showed slightly

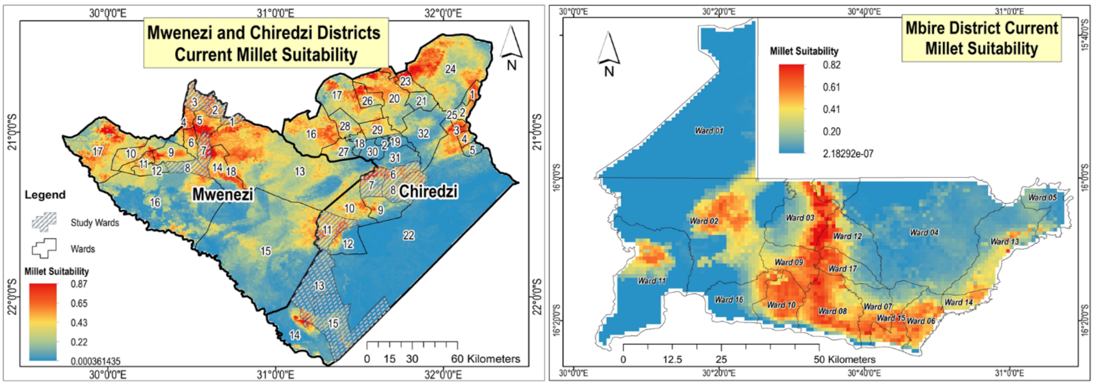


Figure 8. Spatial variability for millet suitability.

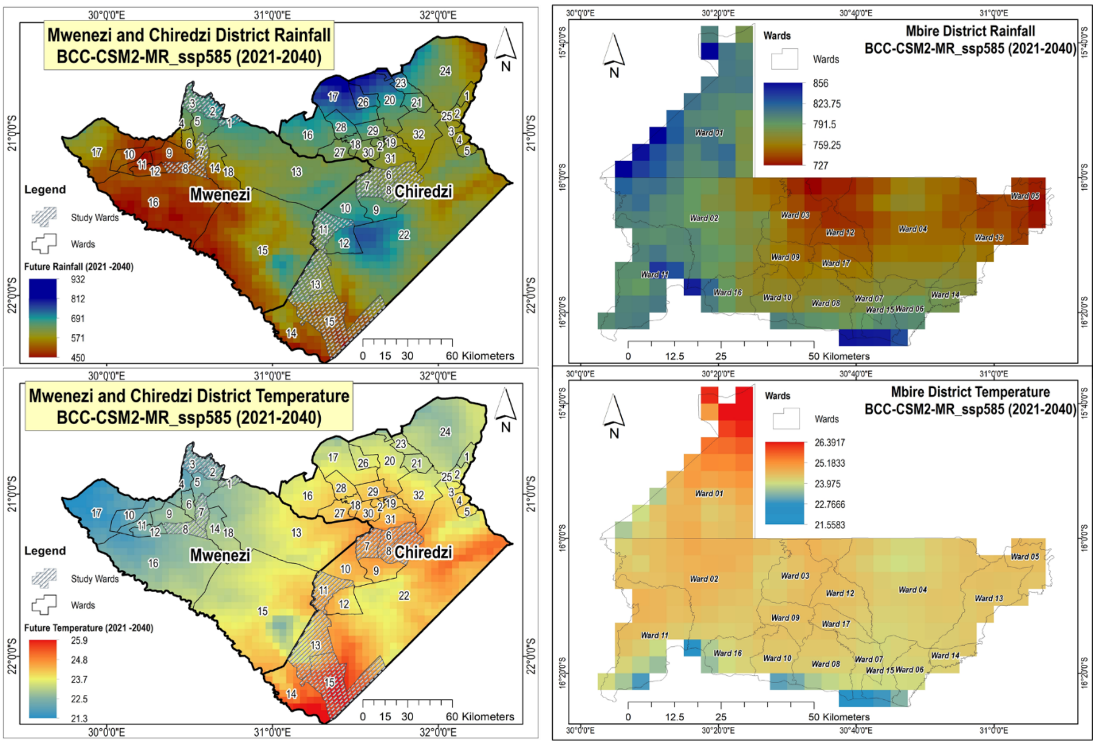


Figure 9. Spatial Vulnerability Assessment for maize, millet and sorghum for future climate.

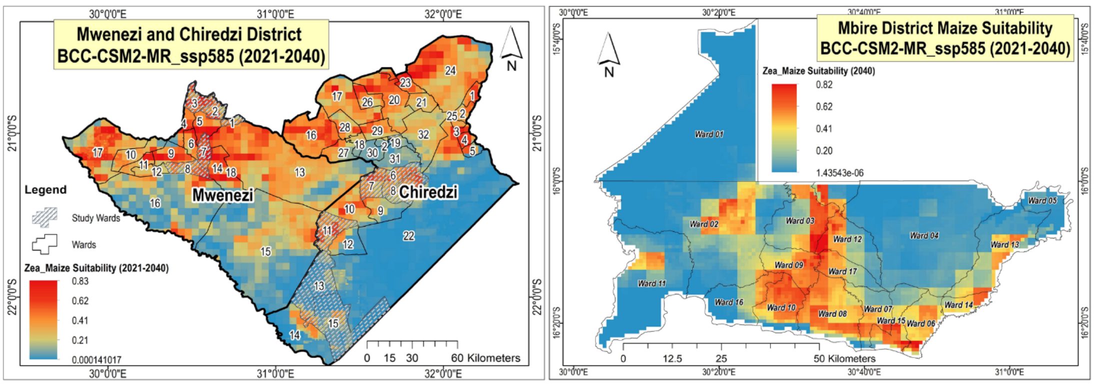


Figure 10. Spatial variability for future maize suitability.

higher temperature in future. Thus, overall, the immediate future is likely to see higher temperatures as well as less rainfall for the three districts. These results concur well with the research on adaptation to climate change and variability, farmer responses to intra-seasonal precipitation trends in South Africa, where the overall trends in rainfall depicted that the future is likely to experince less rainfall which is a threat to the general livelihoods of all humanity.

Given the projected less rainfall and higher temperatures (above), it was then necessary to model the potential future suitability for maize, millet and sorghum in Mwenezi District. Overall, for the three crops, suitability ranges decreased.

Future (2040) maize suitability analysis: For maize, the maximum suitability decreased from 88% for the current climate to as low as 60% in future using the BCC-CSM2 climate model under the RPC8.5 scenario (Figure 10). A total of seven wards in Chiredzi had maximum suitability greater than 70%, whilst for Mwenezi a total of 12 wards in Mwenezi had suitability of more

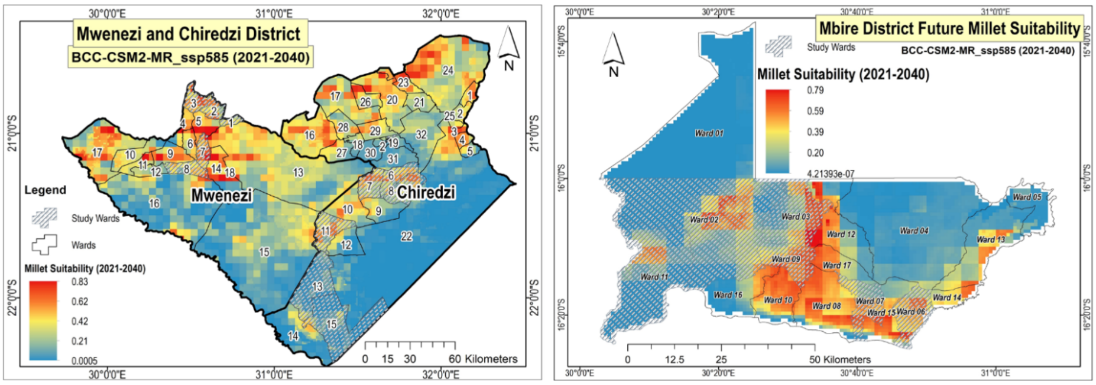


Figure 11. Spatial variability for Millet and Sorghum suitability analysis.

than 70%. For Mbire, a total of eight wards had suitability of more than 70%. Suitability greater than 70% shows that these wards are suitable to highly suitable for the production of maize.

This well explains the continued recurrence of droughts which posethreat to livelihoods. These results concur with a study which was done on intensity and spatial extent of droughts in southern Africa (Rouault et al., 2005). Where the results indicated that there was a remarkable decrease in the future rainfall predictions which is a likely driver to increase of vulnerable communities. The same predictions made for millet and sorghum (Figure 11) under this study posethreats on the sustainable livelihoods of the three study areas.

Future (2040) millet and sorghum suitability analysis: Overall, for the future climate (2021-2040) maximum millet suitability for Mwenezi district is 83%; Mbire district 79% and Chiredzi district 75%. Generally, for Mwenezi and Chiredzi districts the wards in the northern areas are more suitable for millet production than the wards in the southern regions. For Mbire district, the wards in the southern areas are more suitable for millet production that the wards in the northern regions. Figure 11 There are more wards in Mwenezi becoming more suitable for millet production than in the other districts.

Conclusion

Findings from the research indicate that climate change related extreme events such as drought, cyclones and floods and its associated impacts have influenced on riparian based ecosystems and livelihoods in the three study areas. A variety of ecosystems services have been affected, both positively and negatively, including provisioning services of food production and water supply, regulating services supporting flood prevention and health; supporting services related to primary productivity and cultural services relating to ecotourism. Ultimately, a range of approaches is needed to address climate change impacts to ensure that resilience building efforts and sustainable development can continue.

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