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THE IMPACT OF CLIMATE CHANGE ON FOOD INSECURITY IN THE SOUTHERN AFRICAN DEVELOPMENT COMMUNITY

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ABSTRACT

Despite the fact that the Southern African region is one of the most vulnerable to climate change, research on the impact of climate change on food insecurity in the SADC region as a whole is scarce. We make two major contributions to the literature. First, we examine how climate change affects a group of SADC countries. Second, in contrast to previous studies, we supplement an analysis of climate change on crop yield with an analysis of climate change on other food insecurity indicators such as food affordability, malnutrition, and a food insecurity measure. Relying on the system generalized method of moments (GMM) estimator, results show that precipitation has a statistically significant impact on all four indicators of food insecurity in both its linear and non-linear forms; precipitation has the greatest impact on food affordability, followed by its negative impact on malnutrition; and temperature -whether in its linear or nonlinear form- has no statistically significant influence on all four indicators of food insecurity. However, temperature change gains statistical significance in explaining movements in food security after controlling for the interaction of temperature and precipitation. The policy implications of these findings highlight the need to increase precipitation availability in the SADC region by designing sustainable irrigation programs while also implementing climate change mitigation initiatives alongside those designed to ensure food affordability and access to a healthy and decent meal, particularly for the poor.

***Key words**: Climate Change, Food Insecurity, SADC*

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Introduction

While the impacts of climate change on food security in Sub-Saharan Africa continue to gain traction (see for example, Affoh et al., 2022; Berck et al., 2018; Ofori et al., 2021), and whereas it is well established that the SADC region is one of the most vulnerable regions to climate risks (Adaawen et al., 2019; Waema & Njue, 2020; Ziervogel et al., 2022), studies focusing on the impact of climate change in the SADC region as a whole remain rare but are still needed. However, a growing body of literature, though, has concentrated on a country-level examination (Militao et al., 2022; Muringai et al., 2020; Verschuur et al., 2021). Though it is undeniable that country-level climate change analysis is necessary, we argue that the impacts of climate change on food insecurity can extend beyond the country level and result in regional instability, necessitating a SADC regional analysis of the impacts of climate change on food insecurity. Given this gap in the literature, we contribute not only by analyzing the impact of climate change on food security in the SADC region as a whole, but also – unlike previous studies- we analyse the impact of climate change on non-crop productivity measures of food insecurity such as malnutrition, food affordability, and food insecurity.

Climate change is affecting livelihood conditions and raising the danger of food insecurity in the SADC area. According to the 2022 Global Report on Food Crisis, the bulk of people in SADC region, over 70% of the SADC population, rely on agriculture for a living. Climate change has had a negative impact on agricultural production, livelihoods, and regional food security, particularly changes in temperature and rainfall patterns (World Food Programme, 2022). The SADC (2022) report also underlined the detrimental effects of climate change on food insecurity, concluding that climate-related extreme weather events and disasters including droughts, floods, and tropical cyclones have worsened food and livelihood insecurity across the SADC area. The SADC (2022) report also highlighted the negative effects of climate change in SADC, such as those in Madagascar, which is currently experiencing its worst drought in over 40 years, and sections of Angola, Tanzania, Zimbabwe, and Zambia, which have been badly affected by protracted dry spells and droughts.

Furthermore, the effects of climate change are not only impacting agricultural livelihoods, but also impeding development, affecting important sectors, and worsening poverty and livelihood insecurity in the region. An ACCORD REPORT (2022) concluded that climate change is also damaging key infrastructure such as houses, schools, hospitals, marketplaces, and hydropower generating, among other things. Worsening livelihood conditions as a result of climate change can escalate grievances, particularly among marginalized and disadvantaged groups, and heighten tensions over access to and control over resources and livelihood options (Davis & Vincent, 2017; Mobjörk et al., 2020; Richardson et al., 2018). This can result in low opportunity costs for participating in violence and being recruited by non-state armed groups.

Against this backdrop, Figure 1 depicts the progression of malnutrition in the nine[1] SADC countries included in this study.

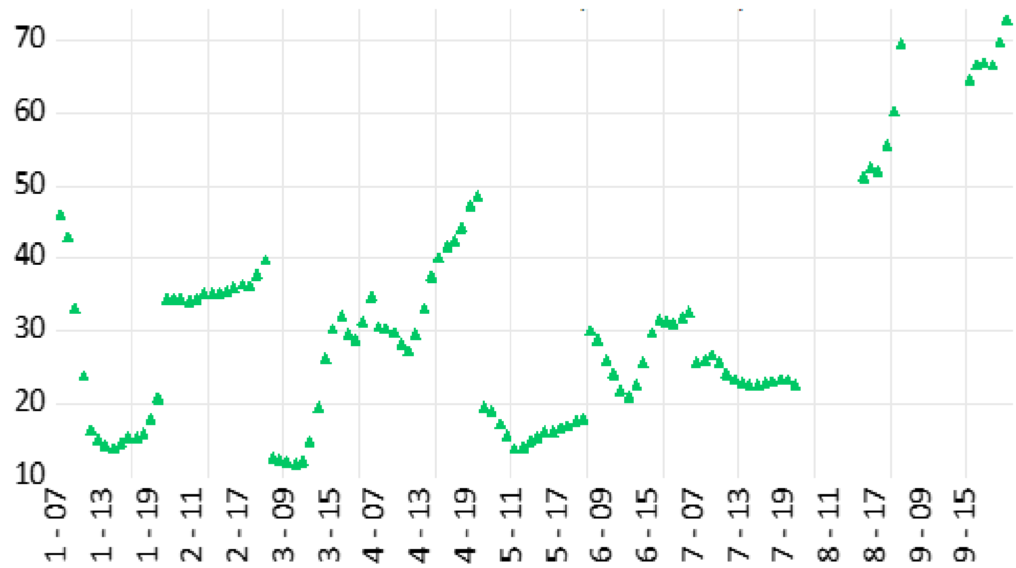

Figure 1: Evolution of Malnutrition Among SADC Economies (2007-2020)

Figure 1 depicts a clearly discernible upward trajectory in malnutrition performance, implying worsening undernourishment among SADC economies. While Figure 1 does not provide evidence to attribute the worsening of malnutrition among SADC countries to the negative effects of climate variability, several studies, including those by Akombi et al. (2017), Serdeczny et al. (2017) and Baker and Anttila-Hughes (2020), have produced robust results regarding the detrimental effects of climate change on food security in developing economies. If the worsening of malnutrition among SADC economies, as shown in Figure 1, can be attributed entirely or partially to climate change, it may be safe to conclude that climate change threatens to reverse any gains made thus far and slow progress toward the Sustainable Development Goal number 2, which aims to "end hunger, achieve food security and improved nutrition, and promote sustainable agriculture" (Gitz, et al., 2016).

Despite the fact that the SADC area contains some of the most fragile and climate susceptible countries, much of the African continent's policy and academic attention on climate security is concentrated on other regions such as the Horn of Africa and the Sahel region (see, for example, Gebreegziabher et al., 2018; Pemunta et al., 2021; Teklewold et al., 2019; Zakari et al., 2022). There is, however, a growing body of literature concentrating on the effects of climate change on food insecurity in the SADC region but, so far, attention has focused on single country level (see for example, Militao et al., 2022; Muringai et al., 2020; Verschuur et al., 2021).

Regardless of the necessity to investigate the moderating effects of climate change on food insecurity across the SADC region, the death of literature reveals a significant gap in the literature that this study tries to fill. In addition to its empirical contributions, this study pushes the boundaries of the field in terms of methodology. Whereas earlier research relied mostly on crop production as a measure of food insecurity, a methodology that, in our opinion, results in a narrow measure of food insecurity (Kabubo-Mariara & Kabara, 2018; Massetti & Mendelsohn, 2011) and culminates to a partial climate change-food insecurity analysis. This study, instead, relied on a variety of FAO (2008) proposed broad measures of food insecurity as will be fully discussed in our methodology section, and in so doing, this study hopes to provide a more comprehensive analysis of the impact of climate change on food insecurity in SADC.

Literature Review

Before engaging the literature on climate change and food security among SADC economies, this study is underpinned on the hypothesis that climate change negatively impacts on food security among SADC countries.

The discussion now embarks on a literature review regarding the impact of climate change on food security. The negative consequences of climate change are well espoused in the literature. Climate change has a direct and indirect impact on food security outcomes for the four components of food security, namely, food availability, food accessibility, food utilization, and food system stability (Easterling et al., 2007; FAO, 2008; Kurukulasuriya & Rosenthal, 2013). The link between climate change and food insecurity is complicated. Variables associated with climate change have an impact on biophysical elements and the way they are managed through agricultural practices and land use for food production. Climate change also has an impact on both physical and human capital, which, in turn, have an impact on the economic and sociopolitical variables that influence food access and utilization.

Most models contend that the majority of the impacts of climate variability on food insecurity are driven primarily by temperature trends rather than precipitation (McCarthy et al., 2001; Devereux & Edwards, 2004; Gregory & Ingram, 2005). Crop yield variability in rainfed crops is largely driven by changes in both precipitation and temperature, whereas yield variability in irrigated land is driven solely by temperature changes. Warmer temperatures may cause many crops to grow faster, but they may also reduce crop yields in some cases. The effect of increased temperature on any particular crop will depend on the crop's optimal temperature for growth and reproduction; in areas where warming exceeds a crop's optimum temperature, yields can decline.

According to Lobell and Field (2007), regions in the mid- to high latitudes may not experience the yield declines expected in tropical regions, which are anticipated to be the most severely impacted by climate change, experiencing suffering due to significant agricultural production losses. Many of these countries are also experiencing severe economic and environmental stress. Climate change is predicted to worsen the agricultural sectors in these countries.

A growing body of literature has conducted studies close to the examination of the impact of climate change on food security in the SADC region. A notable study is that by Kajombo et al. (2014) who conducted a study to provide empirically-based evidence to advocate for the support of subsistence farming in the SADC region. The study, which relied on secondary data from various sources, emphasized the importance of smallholder agricultural production, social protection, and development initiatives in overcoming vulnerability to food insecurity. It also emphasizes the significance of understanding household heterogeneity, their interactions with resources, and the role of policies in improving household welfare. The study by Kajombo et al. (2014) is particularly relevant to our research because it demonstrates widespread food insecurity in the SADC region. Nonetheless, our research, inspired by the findings of Kajombo et al. (2014), pushes the bounders of knowledge by analysing the various ways in which climate change worsens food insecurity in the SADC region.

Another compelling study is a recent study by Gbashi et al. (2021), who conducted a review of the current situation of food safety and security and attempted to reconcile major viewpoints on genetically modified organisms in Africa, with special emphasis on the food safety and security crisis. The study concluded that factors such as vulnerability and conflict, deprivation, climate change and demographic change have been established as significant positive associations to the intensifying food security challenges on the African continent. The study by Gbashi et al. (2021) is particularly relevant to our study in that it, again, following a growing body of literature, underscored the escalating food insecurity in Africa and again singles out climate change as one of the contributing factors to food insecurity. Taking a leaf from this study, ours, particularly analyses the impact of climate change on food insecurity in the SADC region, an area of focus that has not been given due scholarly attention.

Again, in a study almost identical to that of Gbashi et al. (2021), Muzhinji and Ntuli (2021) examined the issues surrounding the adoption of Genetically Modified Organisms (GMOs) and the lack thereof as a means of combating food insecurity in Southern Africa. The study emphasized GMOs' potential crop productivity benefits in Southern Africa. This study is particularly relevant to ours because it emphasizes the need to address the rising food insecurity in Southern Africa. This justifies studies like ours, which seek to provide specific evidence on the effects of climate change on food insecurity in the SADC region, and thus contributes to the growing body of literature seeking empirically based policy interventions to mitigate food insecurity, particularly in the SADC region.

An examination of previous studies reveals two critical conclusions. First, there is a growing body of literature demonstrating food insecurity in the Southern African region. Second, previous studies single out climate variability as one contributing factors to food insecurity in the Southern African region. Nonetheless, as significant as these studies are, and despite growing evidence that the SADC region is one of the most vulnerable to climate change, there is a death of literature analyzing the role of climate change on food insecurity in the SADC region. As a result, our research fills a gap in the literature.

Data and Research Methods

Data Description and Sources

We examine the influence of climate change on food insecurity in an unbalanced sample of nine SADC economies from 2007 to 2020. The data availability, particularly for the primary variables utilized in the study, determined the sample size and time range employed in the analysis.

Our analysis uses four measures of food insecurity, namely, malnutrition, food insecurity, crop yield, and food affordability sourced from The Food Prices for Nutrition of the World Bank Food Prices Data as the dependent variables in separate regression analysis. Malnutrition is defined as the proportion of the population whose regular consumption pattern is insufficient to deliver the dietary energy levels essential to live a normal life in good health. Our definition of food affordability is the proportion of the population who cannot afford to purchase a balanced diet, or the proportion of the population whose food budget is less than the cost of a healthy diet. Food insecurity, on the other hand, is the percentage of the population who live in seriously food insecure families. These are people who, at some point in their lives, were compelled to restrict the amount of food they ate, skip meals, go hungry, or go an entire day without eating due to lack of money or other resources. One of our food insecurity measures is a series called food insecurity which is defined as the proportion of the population who live in relatively or seriously food-insecure households. Finally, our crop yield metric is the crop production index, which displays agricultural production for each year relative to the base period of 2014-2016.

For our main explanatory variable of interest, we use two measures of climate change, namely precipitation and temperature all sourced from the World Bank Food Prices Data Precipitation is the long-term average of any kind of water that falls from clouds as liquid or solid measured in millimeters (mm) per year while temperature is defined as the temperature change in degrees Celsius. Precipitation enters the regressions in logarithmic form.

We use a battery of control variables which are classified as either time invariant, time variant, or other control variables used in a standard climate change-food insecurity analysis. We utilize fertilizer usage (kilograms per hectare of arable land) for the time variant variables, which is the amount of plant nutrients consumed per unit of arable land. For our time-invariant control variables, we use cropland which is defined as the percentage of the cropland which is cultivated with crops that occupy the land for long periods and need not be replanted after each harvest; land hectares defined as the proportion of arable land allocated per person; and lastly agricultural land which refers to the proportion of the land area that is arable, under permanent crops, and under permanent pastures

Acknowledging the growing recognition of the important role of institutions in determining the impacts of climate change on food security, see for example, studies by Awad (2023), Murshed et al. (2018), and Subramaniam et al. (2020), we use a measure of institutional quality defined as policy and institutions for environmental sustainability rating ranking from a low value ranking of 1 to a high value ranking of 6 to assess the extent to which environmental policies foster the protection and sustainable use of natural resources and pollution management in the SADC region. To control for economy-wide macroeconomic stability, we used inflation which shows the rate of price change in the economy as a whole. Finally, we use the total population aged 15 to 64 based on the de facto definition of population, which includes all residents regardless of legal status or citizenship.

Estimation Strategy

Our estimation strategy focuses on applying the Ricardian model to an unbalanced panel data set of nine SADC countries. The standard framework of analysis of food insecurity - climate change regression analysis groups the explanatory variables into a vector of time varying variables, X a vector of time invariant control variables Z ; and a vector of climate variables C (Massetti & Mendelsohn, 2011). The Ricardian regression specification takes the general form as shown in Equation 1:

$$V_{it} = X_{it}\beta + Z_{it}Y + C_{it}\varphi + \varepsilon_{it} \quad (1)$$

Where varies across time while are the estimated coefficients. is the resulting error term. The time varying variable in our study is fertilizer consumption. Both of our regressions are controlled for standard determinants of climate change-food insecurity analysis which include population density, inflation, and institutional quality. The time invariant variables include soil type and geographic variables as defined earlier. Following conventional reasoning (Masipa, 2017; Mendelsohn & Dinar, 2009; Schlenker et al., 2005) that climate variables impact positively on measures of food insecurity up to a certain level beyond which they start to have detrimental effects, our climate variables and other determinants of food insecurity in this analysis include squared terms.

We proceed our analysis of the impact of climate change on food insecurity in SADC in the spirit of Hsiao & Pesaran (2008), who decomposed the regression estimation process into two stages, as followed by Massetti and Mendelsohn (2011) and Kabubo-Mariara and Kabara (2018).

In the first stage, we regress food insecurity measures on time varying food insecurity determinants, climate change variables, as well as other standard determinants of food insecurity using the covariance method with county fixed effects. Our empirical estimation regression specification takes the following form:

$$V_{it} = X_{it}\beta + X_{i,t}^{2}\varphi + Z_{i,t}\vartheta + Z_{i,t}^{2}\rho + \eta_{i} + \lambda_{t} + \varepsilon_{i,j} \quad (2)$$

Where; η_i is a vector of unobserved country fixed effects, λ_i are unobserved time-specific effects, $X_{i,t}^2$, $Z_{i,t}^2$, and ε_{ij} are the climate variables, squared standard determinants of food insecurity, and the resulting error term, respectively. The first step of the Hsiao (2008) model performs a better task of adjusting for omitted variable that are linked with space by introducing county fixed effects. Similarly, the time-mean residuals are regressed on the time invariant variables in the second stage.

For our empirical evidence, we rely on the system Generalized Method of Moments (sGMM) estimator developed by Arellano and Bover (1995) and Blundell and Bond (1998) which has the advantage of purging the regressions of country fixed effects as well as the apparent endogeneity arising from omitted variable bias (Deschênes & Greenstone, 2007).

Unlike previous studies for example, Kabubo-Mariara and Kabara, (2018); Massetti and Mendelsohn (2011), our measure of food insecurity adheres to FAO (2008), broader definition of food insecurity, which includes food security-related aspects such as food affordability, malnutrition, and food insecurity. These analyses are done in separate regression specifications in addition to crop production as a measure of food insecurity. We believe that by taking this approach, we provide a more in-depth and complete investigation of the effects of climate change on food insecurity. The reasoning is, for example, climate change may have disastrous effects on certain crops, making a balanced meal costly for the bulk of the people, and as well, climate variability may result to a severe crop production decline for some crops leading to acute malnutrition (Dietz, 2020). This renders the over-reliance on crop output as a metric of food insecurity problematic, as it provides only a partial picture of food insecurity.

Finding and Discussions

Pre-estimation Diagnostic Checks

The study started by analysing the descriptive statistics whose results are reported in Table 1. Regarding climate change indicators, descriptive statistics results show an annual average mean precipitation of 1084.18 mm per year with a high standard deviation of 305. This demonstrates a huge discrepancy in the rainfall patterns among SADC countries. The plausible implications of this could be that if precipitation does matter for food insecurity, there could be huge disparities on food insecurity among SADC countries. Focusing on temperature change, descriptive statistics results show a mean annual temperature change of 1.07 degrees Celsius and a low standard deviation of 0.64 degrees Celsius. This reflects both a low degree of temperature change at the country level, on average, as well as a low variation in atmospheric temperature among SADC countries, implying that SADC countries have low temperature variability and have nearly identical atmospheric temperatures.

The study also included a rating of country institutional quality for policy on environmental sustainability as a determinant of food insecurity. The average is 3.43, with a maximum of 4 and a minimum of 3, and a standard deviation of 0.35. An average of 3.43 on a scale of 1 to 6, with 1 being the lowest and 6 being the highest institutional rating, may be evidence that SADC countries have a moderate institutional rating on environmental policy for environmental sustainability. The clear implications of this could be that, if institutional quality on policy for environmental sustainability really matters for food security in SADC, SADC countries may need to intensify on their policy on environmental sustainability.

Food affordability, defined as the percentage of the population who cannot afford a healthy diet, is one of the key indicators of food insecurity examined in this study. The average food affordability is 71%, while the maximum food affordability is 97%, with a standard deviation of 38.93. These findings indicate that, on average, the majority of the population in SADC countries cannot afford a decent meal, yet results unmask a large disparity in food affordability among SADC countries as indicated by a standard deviation of 38.93. These findings may point to rising food insecurity in SADC countries, as well as significant differences in food affordability between SADC economies. While the policy implications of these findings are clear that policymakers should seriously consider intensifying initiatives to improve food affordability across all SADC economies in general, the huge disparity in food affordability among SADC economies provides sufficient evidence for an urgent need for country-specific measures to address food affordability.

Following conventional analysis on the impact of climate change on food insecurity, we use crop yield as a measure of crop productivity, which is a crop production index that includes all crops and uses 2014-2016 as the base period harvest. The crop productivity index averages 111.33 with a maximum of 144.82, a minimum of 93.61 and a standard deviation of 13.83. The results show that, in comparison to the 2014-2016 harvest seasons, an average SADC country's crop harvest is increasing, with those with bumper harvests outperforming the 2014-2016 harvest season. With a standard deviation of 13.83, results show not a marked disparity among SADC countries on crop productivity.

Reconciling the findings of this study on descriptive statistics on crop yield and food affordability among SADC economies, an intriguing result emerges. The findings show that while crop yields differ very little across SADC countries, there is a significant disparity in food affordability across SADC economies. If one were to rely on crop yield as a sole indicator of food insecurity – just like what previous studies have done as discussed earlier-, the likely policy implications of one's study would point to uniform measures to increase crop yield across SADC economies so as to address food insecurity, yet this could be an inappropriate policy choice if one considers food affordability as an indicator of food insecurity, as our study has done. The conclusion one makes is that studies that heavily rely on crop yield as a measure of food insecurity are likely to result in sub-optimal policy recommendations as they rely on a narrow definition and scope of food insecurity. This conclusion further underscores the uniqueness and superiority of our study over previous similar studies that have emphasized crop yield as a measure of food insecurity thereby misguiding themselves and resulting in them proffering suboptimal policy choices.

Regression Results on the Impact of Climate Change on Food Insecurity in SADC

We divide our analysis of the impact of climate change on food insecurity in SADC into two separate regressions, as Mundlak (1978) did. In the first set of regressions, we regress climate change variables on food insecurity measures, controlled for other time variant measures of food insecurity, as well as other standard food insecurity determinants. Our time variant explanatory variable is fertilizer consumption, which is defined as the amount of fertilizer used per unit of arable land in kilograms.

In similar fashion, our second set of regressions, we regress our climate change measures on food insecurity, controlled for time invariant determinants of food insecurity, together with other standard determinants of food insecurity. In this respect, we rely on three measures of land size and characteristics as our time invariant determinants of food insecurity. These are; hectares of land per person including land defined by FAO as land under temporary crops, the cropland defined as the percentage of land permanently used as cropland, and lastly, arable land defined as the share of land area that is arable, under permanent crops, and under permanent pastures.

We report the empirical results of our regression results on the impact of climate change on food insecurity for our time variant determinants of food insecurity in Table 2.

Results show that temperature variation is insignificant in accounting for changes in food insecurity for the four measures of food insecurity. An almost similar trend is discernable in our analysis of the non-linear effects of the impact of temperature change on food insecurity, only serve for the non-linear impact of temperature change on malnutrition.

The implications of these results are that – whether at low or high levels - temperature change does not contain enough statistical information to account for food insecurity, only in the case of the nonlinear impact on malnutrition where high temperature changes are associated with high levels of malnutrition. Overall, these results could be taken to mean that

Table 1: Descriptive Statistics

	Precip	Temp	Pop	Infl	Inst	Food afford	Food insec	Fertcon	Crop land	Crop yield	Agri land	Malnutr
Mean	1084.18	1.07	18155165	27.39	3.43	71.33	32.39	24.70	0.91	111.33	43.65	36.86
Median	1051.5	1.04	12551759	6.96	3.50	89.7	34.35	17.97	0.59	106.9	42.88	34.5
Max	1543	3.22	45441388	225.4	4.0	97.10	51.0	72.05	2.24	144.82	70.29	73.0
Min	657	0.26	7647871	0.39	3.0	0.60	9.50	1.11	0.04	93.61	14.67	14.5
Std.Dev	305	0.64	12844001	61.01	0.35	38.93	9.57	20.46	0.83	13.83	15.99	16.69
Skew	0.10	1.5	1.1	2.74	0.19	-1.27	-0.25	0.84	0.67	1.11	-0.29	0.65
Kurt	2.10	6.5	2.78	8.8	2.07	2.60	3.21	2.95	1.80	3.46	2.57	2.44
JB	0.77	19.65	4.75	58.40	0.91	6.07	0.63	2.61	2.96	4.75	0.46	4.41
Prob	0.67	0.00	0.09	0.00	0.63	0.04	0.72	0.27	0.22	0.09	0.79	0.01
Obser	22	22	22	22	22	22	22	22	22	22	22	22

Notes to Table 1: Data were obtained from the various sources as discussed earlier temperature changes, at all levels, may not have a significant impact on food insecurity among SADC economies. If these findings are taken seriously, the clear policy implications could be that SADC economies may not need to include policy initiatives to address food insecurity during times of extreme temperature variation because temperature variation has no effect on food security.

For our analysis of the impact of precipitation on food insecurity, results show that, in both the linear and non-linear effect, precipitation is statistically significant in explaining variations in food insecurity in all the four regression specifications. Consistent with both theory confirming that rainfall provides the much-needed moisture that encourages the regrowth of grasses and facilitates the growth of vegetables, cereal crops and fruit trees, as well as findings from similar studies, such as those Ringler et al. (2010), by Kabubo-Mariara and Kabara (2018), and Affoh et al. (2022), results show that precipitation enhances crop production (yield), reduces the chances of malnutrition, enhances food affordability, and reduces the chances of food insecurity. The clear policy implications of these findings could be that precipitation matters for food security, emphasizing the need for SADC economies to ensure adequate precipitation either through increased irrigation initiatives or enhanced moisture retention measures.

Results also show that out of the four non-linear regression specifications, the squared precipitation variable is statistically significant in three out of the four cases. In the main, we can conclude evidence of the non-linear effects of precipitation on food insecurity. Again, this conforms to theory (see for example, Ringler et al., 2010; Zewdie, 2014), among several others who conclude that higher levels of precipitation detrimentally affect crop productivity in several ways including, waterlogging that destroy crops at the formative periods, while heavy rains during the harvest season lead to rotting of mature crops, through leaching, through direct damage to plants by damaging the shoots, leaves and, in severe cases, the stems and branches of fruit trees.

Our analysis of the impact of precipitation on food insecurity again show that for both the linear and non-linear regression specifications, precipitation has the greatest impact on food insecurity through its detrimental impacts on food affordability followed by its detrimental impacts on malnutrition. Our findings in this regard highlight the importance of climate change mitigation policies that systematically target the most vulnerable members of society, who are increasingly pushed into poverty and malnutrition as a result of climate change variability. In this regard, our findings confirmed previous findings by Kajombo et al. (2014). The study by Kajombo et al. (2014) and Mamoko, et al. (2022) sought to establish evidence for assisting poor households during times of climate change vulnerability and emphasized the importance of smallholder agricultural production, social protection, and development policies in combating vulnerability to food insecurity.

Thus, by analysing the impact of climate change on food insecurity based on empirical evidence from a basket of food insecurity measures that go beyond merely relying on crop yield, our study provides a more holistic picture. In our study, we provided additional empirical evidence highlighting the negative effects of climate change on malnutrition and food affordability. The policy implications of our research are enormous, as it highlights the need for policy initiatives aimed at reducing malnutrition and improving food affordability in the face of climate change. As a result, this study stands out among its peers by providing a more comprehensive, holistic, and instructive policy guideline on the effects of climate change on food insecurity in SADC economies.

Table 2: Regression Results of Time-Variant Food Insecurity Determinants

Variables	Yield	Malnutrition	Affordability	Foodinsec
Temperature change	-0.31	-1.54	2.53	-1.88
	(0.24)	(2.41)	(4.19)	(2.50)
Temperature change squared	0.07	-1.32*	0.45	0.911
	(0.08)	(0.73)	(1.11)	(0.762)
Precipitation	30.85***	-1605.9***	-3676.0***	-922.4***
	(8.56)	(162.95)	(160.96)	(158.38)
Precipitation squared	2.39***	-119.32***	-2.56.36***	-69.96***
	(0.62)	(10.91)	(11.42)	(11.30)
Population density	-10.96	279.60**	299.41***	748.49***
	(6.72)	(115.85)	(101.47)	(119.92)
Population density squared	-0.328	-9.04**	8.55**	22.46***
	(0.20)	(3.41)	(3.00)	(3.53)
Fertilizer consumption	0.547***	6.44***	2.267	6.44***
	(0.146)	(1.41)	(2.97)	(1.46)
Fertilizer consumption squared	-0.01)	-0.11	-1.81**	0.79*
	(0.03)	(0.43)	(0.67)	(0.44)
Inflation		0.008	0.035**	-0.01
		(0.01)	(0.01)	(0.01)
Growth rate of the economy		-39.43***	9.32***	-27.22***
		(2.46)	(2.79)	(2.54)
Institutional quality for environmental sustainability	0.29***	10.73***	0.23***	6.26**
	(0.108)	(2.88)	(686.43)	(2.99)
Constant	12.47	3000	-10517.75	3406.8)
Observations	97	38	31	38
R-squared	0.65	97.9	0.99	0.93
Instrument rank	11	13	13	13

Notes to Table 2: ***, **,* Signify significance at 1%, 5%, and 10%, respectively; Numbers in parenthesis are standard errors.

Recognizing the growing recognition of the role of institutional quality on policy for environmental sustainability on food security (see, for example, Herbel et al., 2012; Jiren et al., 2021; Rossignoli & Balestri, 2018) we incorporated a measure of institutional quality among the determinants of food insecurity. Results show that the four measures of food security used in this study, as shown in Table 2, are positively related to institutional quality. These findings highlight the critical need for SADC economies to strengthen their environmental policies in order to significantly reduce food insecurity in the region.

Turning to our analysis of the time variant measure of food security, results show that fertilizer consumption is positive and statistically significant in explaining movements in food security in three out of the four regression specifications. However, at higher levels of fertilizer consumption, results uncover a negative and statistically significant relationship in two out of the four regression specifications. In the main, though results are indecisive for the non-linear relationship between fertilizer consumption and food insecurity, but results generally show a positive crop production payoffs of fertilizer usage among SADC economies. The policy implications of this study provide clear empirical evidence highlighting the critical need for SADC economies to rely on fertilizer usage in their crop production processes while also exercising caution not to apply too much fertilizer per hectare of land as this has the potential to negatively affect crop production.

Next we analysed the impact of climate change variables on food security for our time invariant regression specifications as indicated earlier. We report our results in Table 3.For our analysis of the impact of climate change variables on food security, results - in the main-uphold those of our previous analysis. The temperature change variable, like in the previous analysis, does not show a statistically significant relationship with food insecurity in both its linear and non-linear relationships. These empirical results are consistent with those of previous studies (see for example, Kabubo-Mariara & Kabara, 2018; Kurukulasuriya & Mendelsohn, 2008) which uncovered an insignificant impact of temperature change on the majority of the regression specifications. Combining our empirical evidence on the impact of temperature change on food insecurity in both our time variant and time invariant regression specifications raises an important question: could this be interpreted to mean that temperature change has no effect on food insecurity at all levels? To provide more empirical answers and policy recommendations, we contact additional robustness regressions, which will be presented in the following subsection. Our empirical results, in this regard, are presented in the section on robustness checks to be presented in the subsequent section.

Our results on the impact of precipitation on both linear and non-linear relationships consistently affirm those of our regression results for the time variant regression specifications. In four of the linear relationship cases, our results show that precipitation at lower levels is associated with higher crop yields, lower cases of undernourishment, lower percentage of the population who cannot afford a decent meal, and lastly precipitation leads to significant proportions of the population that escape from being in a state of being severe food insecurity. Thus, our empirical evidence highlights the positive role of precipitation in food security, highlighting the need for policymakers to increase precipitation availability among SADC economies if they are to ensure food security in the face of critically low rainfall.

Again, confirming our earlier empirical results, our results on the impact of precipitation show that precipitation, in both the linear and non-linear relationships, exerts its greatest impact on food affordability followed by its impacts on malnutrition. These findings have significant policy implications for the SADC economies. A plausible policy implication of these findings could be that SADC economies, in their climate change mitigation intervention measures, may target more on enhancing food affordability for the majority of the population particularly the already disadvantaged in society followed by measures to guarantee balanced diets in the face of climate change variability.

Regarding our analysis of the impact of institutional quality on food insecurity, our results, again uphold those we uncovered for the time variant regression specifications. Results show that institutional quality is statistically significant in explaining movements in food insecurity, in its four different measures, in three cases. This provides further empirical evidence highlighting for policy choices that enhance environmental sustainability measures among SADC economies as this results to significant food security payoffs.

Turning to our empirical results on the impact of our time invariant determinants of food insecurity, results show that land quality and size, in its three different measures - in the main- show a statistically significant relationship with the four variants of food insecurity. Results show that increasing the proportion of land hectares per person, increasing cropland under permanent crop cultivation, and the more there is arable land, the higher the crop productivity, the lower the malnutrition, the more a higher percentage of the population can afford a decent meal and the more people escape from food insecurity. The policy implications of these findings point to the need for improved land management and efficient land distribution policies among SADC economies, as land is empirically proven to boost crop yields.

Table 3: Regression results of Time-Invariant Determinants of Food Insecurity

Variables	Yield	Malnutrition	Affordability	Foodinsec
Temperature change	-10.11	0.917	0.91	-0.89
	(0.19)	(2.97)	(1.15)	(2.090
Temperature change squared	0.08	1.30	-0.14	0.44
	(0.067)	(1.05)	(0.35)	(0.67)
Precipitation	18.69***	-1580.8***	-3189.9***	-457.2***
	(10.88)	(211.87)	(48.65)	(105.78)
Precipitation squared	-1.53*	112.04***	223.0***	36.27***
	(0.79)	(15.24)	(3.55)	(7.78)
Population density	9.256***	109.39***	-164.73***	-53.07***
	(1.59)	(31.24)	(7.507)	(17.85)
Population density squared	-0.318)***	-3.112***	5.01***	1.55**
	(0.05)	(1.02)	(0.24)	(0.56)
Institutional quality for environmental management	0.208***	8.23***	0.807	12.72***
	(178.5)	(2.95)	(0.53)	(2.26)
Inflation	0.002***	-0.007	0.0058	-0.027**
	(0.001)	(0.03)	(0.05)	(0.011)
Growth rate of the economy	-0.036	4.02*	-0.91	-33.7***
	(0.156)	(2.03)	(0.96)	(1.89)
%age of land permanently used as cropland	1.004***	-6.80***	-3.62***	-2.38*
	(0.171)	(1.95)	(0.48)	(0.99)
Hectares of arable land per person	1.19***	-4.058	-3.34**	-2.95
	(0.32)	(5.63)	(1.32)	(2.97)
Arable land	0.06)***	-0.07	-0.16***	-0.53***
	(0.01	(0.12)	(0.02)	(0.05)
Constant	-1.94	4586.57	-9964.87	-732.13
Observations	110	94	34	40
R-squared	0.53	0.75	0.99	0.94
Instrument rank	14	14	14	14

Notes to Table 3: ***, **,* Signify significance at 1%, 5%, and 10%, respectively; Numbers in parenthesis are standard errors

Robustness Checks on the Impact of Temperature on Food Insecurity

Our discussion of the impact of temperature change on food insecurity above clearly shows that temperature change is statistically insignificant in explaining changes in food insecurity in both the linear and non-linear regression specifications for the two cases analysed. This is in sharp contrast to findings by earlier studies such as those by McCarthy et al., (2001), Devereux & Edwards (2004), and Gregory & Ingram (2005) who concluded that the majority of the impacts of climate variability on food insecurity are driven primarily by temperature trends rather than precipitation. In view of this apparent empirical anomaly, we did further regressions to gauge as to whether or not the non-significant role of temperature on food insecurity is dependent on the amount of precipitation. To this end, we did further regression specifications where an interaction term between temperature change and precipitation was incorporated in both of our regression specifications. We report results of our robustness checks in Tables 4 and Table 5, both in Appendix I and Appendix II, respectively.

Our results show that the interaction term is highly statistically significant in three out of four regression specifications for our time variant regressions while the interaction term is highly statistically significant in all the four cases in the case of our time invariant regressions. In both cases, the precipitation variable in both its linear and non-linear form retains its high statistical significance on food insecurity. These results provide further evidence that precipitation in the SADC region, is consistently statistically significant in accounting for food insecurity and its impacts on food security is not affected by temperature change. This, again, provides further empirical evidence highlighting the need for SADC economies to intensify precipitation availability through intensified irrigation schemes and water conservation measures.

Regarding our need to further explore whether temperature change has no impact on food insecurity at all levels of precipitation or not – an issue driving this robustness regressions - notably, temperature change variable gains statistical significance in similar fashion. In fact, with the inclusion of the interaction term, results show that temperature change gains statistical significance for changes in food security in the majority of cases both at lower and higher levels of temperature change.

These results may be taken to mean that the impacts of temperature change on food insecurity are more prevalent on condition of the level of precipitation. Rather, on its own, temperature change may not have significant statistical information to account for changes in food insecurity but that relationship is clearly marked depending on the rainfall patterns. These results may provoke policy options to the effect that it is precipitation that matters most for the impact of temperature on food insecurity. This calls for policy options that results to more water available for irrigation as precipitation, whether by way of natural rainfall or irrigation, both in its own right and its combination with temperature has a consistent impact on food insecurity.

Conclusion

Substantial empirical evidence has shown that, despite being the poorest emitter of carbon emissions, Sub-Saharan Africa bears the brunt of climate change impacts. Globally, changing climatic conditions jeopardize agricultural production and food security in developing economies disproportionately, threatening to derail any prospects of achieving the 2030 Sustainable Development Goal of ending hunger and poverty. Despite being one of the most vulnerable regions to climate change variability, the SADC region has received insufficient scholarly attention regarding the impact of climate change on food insecurity. This necessitates SADC-specific research-driven policy initiatives to mitigate the impacts of climate change on food insecurity, without which the region's increasing climate risk-induced food insecurity will push more people into poverty, worsening global inequality. In light of this crucial need and the apparent scholarly gap, this study analyses the impact of climate change on food insecurity in SADC.

While adding to the limited literature on the impact of climate change on food insecurity in the SADC region, the study takes a novel approach to the analysis. Acknowledging that climate change affects food insecurity in a variety of ways, including undernourishment, food affordability, and food insecurity, the study expands knowledge by using crop productivity as a proxy for food insecurity but also augments this empirical evidence with analyzing the impact of climate change on measures of malnutrition, food affordability, and food insecurity. This approach is appealing to this study because, when developing climate change policy mitigation initiatives, it is critical to understand the various differential negative impacts of climate change on food insecurity in order to help direct policy priorities, targets, resources, and policy design. We rely on the system Generalized Methods of Moments (sGMM) estimator for our empirical analysis since it has the advantage of purging the regressions of the problems of unobserved country-specific effects as well as the problem of endogeneity.

This study uncovers several pieces of empirical evidence. Most notably, the study concludes that precipitation is statistically significant in accounting for food insecurity in the majority of food insecurity measures, in both linear and non-linear interactions. The results also show that, in both its linear and non-linear interactions with food insecurity, precipitation has the greatest impact on food insecurity by impeding food affordability, followed by its worsening effects on malnutrition. In terms of the impact of temperature on food insecurity, our findings show that temperature changes have no statistically significant impact on all four measures of food security in this study, in both linear and non-linear forms. If this empirical evidence is to be believed, the clear implications of this could be that, on its own, whether at low or high levels, temperature change does not meaningfully impact food insecurity. This kind of empirical anomaly prompted the study to further analyze whether this empirical reality still exists when accounting for the impact of temperature change on food insecurity given the levels of precipitation. To this end, the study conducted robustness regressions incorporating an interaction dummy between temperature change and precipitation for all the eight regression specifications. Results show that temperature change in both its linear and non-linear form gains statistical significance in accounting for changes in food security in seven out of the eight regressions. The implications of this empirical evidence are simple, the impacts of temperature change on food insecurity depends on the amount of precipitation. The study also established a positive and statistically significant relationship between institutional quality on environmental policy sustainability and food security. The implication of this is that enhancing environmentally friendly policy frameworks do matter for food security in the SADC region.

This study's empirical evidence has important policy implications for climate change mitigation initiatives to protect food security for the SADC region. That precipitation matters for food security at all levels suggests that policy measures to ensure consistent and reliable precipitation are really needed in the SADC region to mitigate food insecurity. This can be accomplished by improving irrigation programs that provide a consistent and dependable source of precipitation. This policy suggestion is further supported by evidence that the impact of temperature on food insecurity begins to be felt once precipitation levels are taken into account. Overall, to achieve a consistent supply of precipitation, SADC governments should seriously consider intensifying efforts to ensure more irrigation projects by redirecting more funding towards sustainable irrigation farming, which has proved to have evidence-based remarkable crop productivity benefits at all levels of temperature change.

The study's empirical evidence on the effects of precipitation on food affordability, followed by its negative impacts on malnutrition, is yet another call for policy reconsideration.

The policy implications of this are that, in order to mitigate the effects of climate change on food insecurity, SADC policymakers may seriously consider a package of climate adaptation initiatives coupled with climate change mitigation initiatives supplemented by additional policy initiatives premised on ensuring food affordability and reducing the incidence of malnourishment in the region. This can be accomplished by allocating more funds to social security programs that protect the poor from rising food prices caused by climate change. This is yet another urgent call for adopting pro-poor budgeting as the poor may continue to bear a disproportionate impact of climate change thereby worsening income inequality in the region. In the same spirit, in designing climate change mitigation policy interventions, policy makers in SADC are strongly advised to continue policy initiative efforts to guarantee attainment of a healthy and balanced meal for the poor during climate change induced food insecurity. Finally, that institutional quality policy for environmental sustainability provides robust positive crop productivity and food security pay offs underscores the need for SADC economies to enhance their policy framework for environmental sustainability.

Declaration

Conflict of Interest

I declare that there are no material competing financial, professional, or personal interests that may have influenced the writing and publication of this manuscript.

Availability of Data and Materials

No new data were created but the data used in this manuscript were sourced from the World Bank publicly available World Development Indicators and the data used in this manuscript are available upon request.

Authors' Contribution

Elisha Mavodyo, the sole author of this article, conceptualized the study, created the methodology, wrote the original draft of the manuscript, reviewed the manuscript in line with reviewers' comments and suggestions, and finally edited the manuscript.

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Appendix

Table 4: Robustness Checks on Temperature and Precipitation Interaction Dummy with Time Variant Regression Results

Variables	Yield	Malnutrition	Affordability	Foodinsec
Temperature	-898.22***	45.26***	8.499	-3.42**
	(287.2)	(2522)	(33.82)	(937.9)
Temperature squared	-7.54*	0.903**	-0.51	1.01***
	(4.04)	(2.45)	(0.46)	(608.04)
Precipitation	2235***	837.45**	2900.9***	898.32***
	(681.31)	(293.96)	(89.47)	(197.47)
Precipitation squared	-174.55***	-57.90**	-201.97***	-68.32***
	(49.85)	(21.51)	(6.58)	(14.39
Temperature*Precipitation	133.27***	-6.43***	-0.87	0.001*
	(42.18)	(0.10)	(4.96)	(0.49)
Population density	1730.45*	-2453.4***	276.7***	-731.1***
	(781.67)	(337.3)	(80.79)	(122.44)
Population density squared	-52.05*	73.46***	-8.41***	21.94***
	(23.19)	(10.00)	(2.39)	(3.61)
Institutional quality for environmental management ranking	-7.88	-15.09***	-0.69	6.16*
	(5.08)	(2.19)	(0.55)	(3.19)
Fertilizer consumption	-32.61*	24.63***	-5.64***	-6.408)***
	(15.30)	(6.60)	(1.66)	(1.55)
Fertilizer consumption squared	5.77*	-7.98***	0.71*	0.86*
	(3.65)	(1.57)	(0.39)	(0.48)
Inflation	0.01	0.01	0.004	-0.013
	(0.04)	(0.02)	(0.005)	(0.01)
Growth rate of the economy	-7.09)	15.96***	1.71	-27.65***
	(10.64)	(4.590	(1.19)	(2.63)
Constant	-21263	17417.9	-12592	3349.25
Observations	31	31	31	38
R-squared	0.66	0.98	0.99	0.93
Instrument rank	14	14	14	14

Notes to Table 4: ***, **,* Signify significance at 1%, 5%, and 10%, respectively; Numbers in parenthesis are standard errors

Table 5: Robustness checks on Temperature and Precipitation Interaction Dummy With Time Invariant Regressions Results

Variables	Yield	Malnutrition	Affordability	Foodinsec
Temperature	-2.43*	-3.577**	987.37***	-151.85***
	(0.02)	(0.17)	(153.40)	(49.46)
Temperature squared	0.03	0.10	11.67***	1.93**
	(1.06)	(0.06)	(3.21)	(0.90)
Precipitation	-1.97	-19.99*	20.76***	1038.23***
	(4.69)	(11.36)	(2.76)	(191.5)
Precipitation squared	0.11	1.609*	4.765***	-79.12***
	(0.34)	(0.84)	(2.309)	(14.11)
Temperature*Precipitation	0.34**	0.48*	-149.22***	20.81***
	(0.15)	(0.32)	(23.04)	(6.82)
Population density	-0.69	5.63***	-166.56**	-81.22***
	(0.644)	(1.56)	(60.31)	(21.31)
Population density squared	0.02	-0.18***	4.88**	2.42***
	(0.02)	(0.04)	(1.93)	(0.66)
Institutional quality for environmental management	0.01	0.407***	7.001	5.34***
	(0.020)	(0.13)	(4.577)	(3.37)
Inflation	0.0001	8.98	-0.028	-0.01
	(0.0007)	(0.001)	(0.04)	(0.01)
Growth rate of the economy	-0.003	0.33**	-0.19	-36.24***
	(0.058)	(0.14)	(9.65)	(2.30)
%age of land permanently used as crop-land	0.007***	0.0022	-0.35	-1.276***
	(0.001)	(0.004)	(0.22)	(1.32)
Hectares of arable land per person	0.26*	0.87***	-7.04	14.73***
	(0.13)	(0.33)	(12.23)	(5.01)
Arable land	-0.0064)**	0.008*	0.22	-0.408
	(0.002)	(0.004)	(0.309)	(0.06)
Constant	17.85	22.63	525.9	-2408.52
Observations	110	110	34	40
R-squared	0.27	0.54	0.54	0.99
Instrument rank	15	15	15	14

Notes to Table 5: ***, **,* Signify significance at 1%, 5%, and 10%, respectively; Numbers in parenthesis are standard errors