Taylor & Francis
Taylor & Francis Group

Ecosystem Health and Sustainability

ISSN: 2096-4129 (Print) 2332-8878 (Online) Journal homepage: http://www.tandfonline.com/loi/tehs20

Climate variability and crop yields synergies in Tanzania's semiarid agroecological zone

Msafiri Y. Mkonda & Xinhua He

To cite this article: Msafiri Y. Mkonda & Xinhua He (2018): Climate variability and crop yields synergies in Tanzania's semiarid agroecological zone, Ecosystem Health and Sustainability, DOI: 10.1080/20964129.2018.1459868

To link to this article: https://doi.org/10.1080/20964129.2018.1459868

Published online: 04 Apr 2018.

ECOSYSTEM HEALTH AND SUSTAINABILITY, 2018
https://doi.org/10.1080/20964129.2018.1459868

Taylor & Francis
Taylor & Francis Group

ARTICLE

OPEN ACCESS Check for updates

Climate variability and crop yields synergies in Tanzania's semiarid agroecological zone

Msafiri Y. Mkonda [a,b] and Xinhua He [a,c]

[a]Centre of Excellence for Soil Biology, College of Resources and Environment, Southwest University, Chongqing, China; [b]Department of Geography and Environmental Studies, Solomon Mahlangu College of Science and Education, Sokoine University of Agriculture, Morogoro, Tanzania; [c]School of Biological Sciences, University of Western Australia, Crawley, Australia

ABSTRACT

Introduction: The consequences of climate change have been considerably high to smallholders in most of Sub-Saharan Africa. These impacts have been more enormous to crop production and other attached livelihoods. However, the comprehensive assessment of these impacts has suffered numerous challenges because crop productivity is also susceptible to other factors involved in the production process. This study aimed to understand how crop yields are affected by climate change in the semiarid zone of Tanzania. The findings would establish a thorough literature within smallholder adaptation in the area. Furthermore, they will intensify strategies to cope with reduced yields attributed by climate-change impacts.
Outcomes: There has been a dramatic decrease in rainfall (R^2 = 0.21) and increase in temperature (R^2 = 0.30). In addition, we found that rainfall and temperature variability had positive (R^2 ~ 0.5) and negative (R^2 ~ 0.3) correlations with crop yields, respectively.
Discussion: The decline in yields at both local and national levels elevated the magnitude of food shortage and poverty. The increasing climate impacts necessitate undertakings of various studies to plan, design, recommend, and implement various useful adaptation measures, especially in the vulnerable communities.
Conclusion: To limit climate effects, we need to increase investments in adaptation and mitigation measures.

ARTICLE HISTORY
Received 31 October 2017
Revised 26 March 2018
Accepted 28 March 2018

KEYWORDS
Climate variability; crop yields; environmental sustainability; vulnerability; Tanzania

Introduction

In this era of climate change, it is worthwhile to assess the effects of climate variability on agriculture and environment in order to design proper adaptation and mitigation measures that improve resilience (IPCC 2014; Serdeczny et al. 2017). The Intergovernmental Panel on Climate Change (IPCC) has confirmed that there is substantial evidence that the mean and extremes of climate variables have been changing in recent decades, and that rising atmospheric greenhouse gas concentrations could cause the trends of climate variables to intensify in the coming decades (Intergovernmental Panel on Climate Change 2014). Ahmed et al. (2011) found that rainfall has significantly decreased in Tanzania, especially in the recent years, and is further expected to decrease by the mid of this century. In addition, Challinor et al. (2007) warned of the increased vulnerability of the rain-fed agriculture due to the changing climate. Under such situation, Lobell et al. (2008) realized the importance of studying and proposing ways of reducing the vulnerability among the rural communities in most developing countries, because their livelihoods depend on rain-fed agriculture. Likewise, this vulnerability has implications for agricultural production and the ecosystems services as farmers may degrade the environmental resources when trying to cope with the associated challenge (Nyong, Francis, and Osman-Elasha 2007; Speranza et al. 2009; Rao et al. 2011; Muller and Shackleton 2014).

To date, there is substantial literature examining the effects of climate change on agriculture and ecosystems in various developing countries. National Adaptation Plan of Action (NAPA) and Tanzania's National Strategy for Growth and Reduction of Poverty identified droughts and floods as among the primary threats to agricultural productivity and vulnerability to poverty in the country (URT 2007, 2005). In addition, Paavola (2008), Rowhani et al. (2011), and Msongaleli et al. (2015) confirmed on the decreasing rainfall and insisted that this scenario has significant implications for crop yields. Furthermore, Lobell et al. (2008) and FAO (2009) emphasized that rain-fed agriculture will be more susceptible to any further intensification of climate change.

Similarly, Challinor et al. (2007) confirmed that climate change and variability have significantly affected food crops, especially cereals like maize, rice, sorghum, and millet. In addition, Paavola (2008), Mongi, Majule, and Lyimo (2010), Mkonda

CONTACT Msafiri Y. Mkonda msamkonda81@yahoo.co.uk; Xinhua He xinhua.he@uwa.edu.au Centre of Excellence for Soil Biology, College of Resources and Environment, Southwest University, Chongqing, 400715, China.

(2011), and Yanda (2015) affirmed that there is a positive correlation between climate change and crop yields under the rain-fed scenario. Rowhani et al. (2011) specified that 20% increase in intra-seasonal precipitation variability reduces agricultural yields by 4.2%, 7.2%, and 7.6%, respectively, for maize, sorghum, and rice, which are the major food crops in Tanzania. Consequently, they projected that by 2050 climate change and variability will affect crop yields in Tanzania by 3.6%, 8.9%, and 28.6% for maize, sorghum, and rice, respectively. Kangalawe (2016) further asserted that the impacts of climate change have significantly dried water sources such as wetland, thus narrowing the threshold of community livelihoods. Other scholars have warned of the increased degradation and vulnerability of the ecosystems due to increased incidences of droughts and temperature (Paavola 2008; Muller and Shackleton 2014).

Although the science of assessing the impacts of climate changes on agriculture (crop yields) and ecosystems in various agroecological zones is progressing rapidly, a variety of knowledge gaps still exist. Most of these studies have paid little attention to the analyses of semiarid agroecological zones where most peoples' livelihood is considerably susceptible due to insufficient yields and abject poverty; thus, the present study aims to advance from where other studies ended. Since the vulnerability posed by climate change is progressing high, compelling adaptation measures for either adjusting or healing the stress are inevitably required to curb the situation. By doing so, the livelihoods of over 80% smallholders will be rescued (Mkonda and He 2017b). The study will further enable planners and policy makers to propose robust policies and sound tools with new techniques of curbing the impacts of the increasingly changing climate at both local and global scales, which mostly affect smallholder farmers in developing countries, especially sub-Saharan Africa.

Essentially, this paper aims at establishing the correlation between climate variability and that of crop yields in the semiarid agroecological zone of Tanzania (focusing on Kongwa District). Furthermore, it aims to intensify the adaptation measures that would increase crop production in the area. These objectives are addressed through the following research questions: a) what are the trends of rainfall and temperature in the area? b) what is the production trend of the major food crops in the area? c) is there any substantial correlation between climate variables and crop yields? d) what are the non-climate factors that seem to affect crop yields? and e) what is the contribution of the present study to smallholder adaptation in the area? In this aspect, climate variables were rainfall and temperature, while maize, sorghum, and millet were the selected crops. We selected these crops because they are staple food crops contributing to about 90% of the food security in the area (URT 2014, 2013, 2007). The current Agricultural Policy advocates the adoption of adaptation strategies; however, it has not exhausted solving the problems, and therefore, this study suggests the best practices that can optimize yields, food security, and socioeconomic welfare, especially in the face of climate change.

Materials and methods

Profile of the study site

Kongwa District is among the semiarid districts of Central Tanzania (Figure 1). The vegetation type of most semiarid areas of the country (including the study area) mainly comprises bush or/and thicket. The total annual precipitation is 400–600 mm, with the maximum rain between December and April, and the mean annual temperature is 26°C. The soils in the area are classified as Chromic Luvisols (FAO 1988), with a sandy loam texture.

The silt contents of the soils at the different farms were not significantly different ($P > 0.05$) and ranged between 170 and 255 g kg–1 soil with a bulk density between 1.25 and 1.65 mg/m^3. The soils have neutral to alkaline pH (*potential of hydrogen*) values and medium levels of organic carbon, nitrogen, phosphorus, potassium, and other micro soil elements (e.g., manganese). It has moderately high cation exchange capacity (CEC) and high base saturation (Solomon, Lehmann, & Zech 2000; Glaser, Lehmann, Führböter, Solomon & Zech 2001; Bationo, Kihara, Vanlauwe, Waswa & Kimetu 2006).

The potential evaporation (PE) in the area ranges from 700 to 900 mm per year, while rainfall ranges from 400 to 600 mm per year. This is why the ratio between rainfall (precipitation) and PE is around 0.05–0.65 (Intergovernmental Panel on Climate Change 2014). The P/PE is sometimes referred to as the aridity index, where the total annual precipitation is divided by PE (Zomer et al. 2008). The low P/PE value in this semiarid area has significantly affected the agricultural systems and the environment (Elliott et al. 2014).

Data collection

Our data were collected in the study area from June to September 2016. Climate data (i.e., from 1980 to 2015) were collected from the authentic meteorological stations in the study area and from Tanzania meteorological Agency (TMA). For authenticity, the data from the two sources were compared, and where contrast arose, we calculated the mean of the varying aspects. In the study area, we obtained the recorded data of over 30 years, and where records were not found, we used the data from TMA to fill the gaps. Practically,

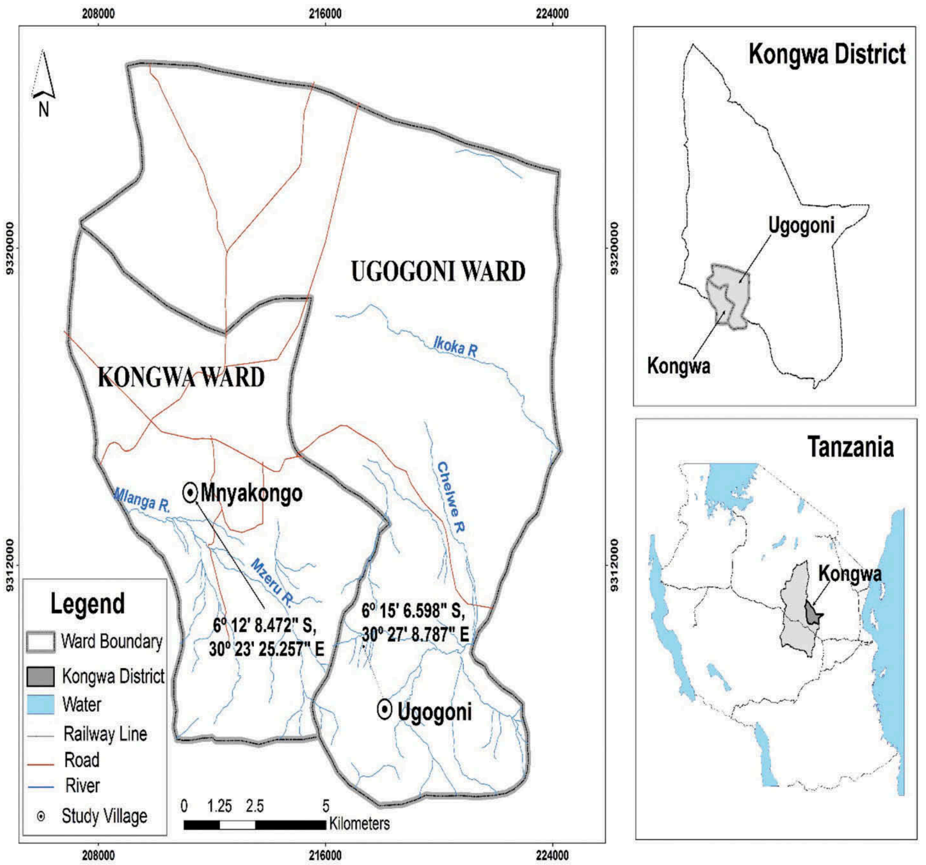

Figure 1. Location and sampling positions of the selected villages in Kongwa District. The study sites are also denoted with latitude and longitude degrees.

Source: IRA GIS Lab, UDSM: 2016

the data from several met stations were collected, and finally the mean of these data was calculated to get one set of data. Precipitation was measured in terms of both the total annual rainfall and the monthly rainfall during the growing season (i.e., January, February, and March). Nevertheless, when comparing with crop yields, we used the total annual rainfall (1980–2015) versus the yields. As reference, we would append the temporal rain data for readers.

Most qualitative data were obtained through Participatory Rural Appraisal method (PRA) and group discussion. Some of these data included the approximate date of onset, cessation of rains, and the approximate crop yields obtained per year. All these were enquired from every household head. On the other hand, crop data were first measured based on the data collected by the District Agricultural and Livestock Officers (DALDO) and the Ministry of Agriculture. Similarly, we collected crop data from individual households to estimate the yields quantity. From that, we treated all data equally by estimating their mean that would serve when comparing with climate data. Additionally, we interviewed some agricultural experts in the area to understand the overall implications of the same (i.e., climate impacts on crop yields).

Geographical proximity between the met stations and the sampled villages was observed. We sampled the villages that were located within 10 km from the met stations. A total of 400 questionnaires were collected from household heads of smallholders (farmer/livestock households) as seen in *Appendix A*. The questionnaires involved both closed and open questions (see Table 1). We sampled about 10% of the total households in each community (Table 1), which has also been mentioned by Saunders (2011). The household lists were obtained from village government leaders in the study area.

We also used PRA to collect socioeconomic data in the area. PRAs include informative interviews, group discussion, and physical observation. The PRA method has been used in various studies to explore perceptions of rural communities on environmental issues that affect their lives (Cramb, Purcell, and Ho 2004; Brown 2006; Humphrey and Kimberly 2007). In the present study, PRA was used to acquire data on climate, yields, and environmental changes.

One group discussion comprising 15 people was organized in each village (Table 1). We also conducted a total of 20 interviews with agricultural experts, farmers, livestock keepers, and village government leaders (see Table 1). In this category, we

Table 1. Summary of questionnaire administration and PRA tools in the selected villages.

	Mnyakongo	Ugogoni
Questionnaires (*N* = 400)	Total HH (2050)	Total HH (2080)
Number of households interviewed	200	200
Crop farmers (%)	70	80
Livestock farmers (%)	10	10
Both crop and livestock farmers (%)	20	10
Focus group discussion (*N* = 30)		
Number of people participating in group discussion	15	15
Crop farmers	15	10
Livestock farmers	0	2
Both crop and livestock farmers	3	3
Interview (*N* = 20)		
Number of people participating in informative interviews	10	10
Crop farmers	8	9
Livestock farmers	0	0
Both crop and livestock farmers	2	1

PRAs: Participatory Rural Appraisal.
HH: Household heads.
N: Number of observations.
Source: Field Data Survey, 2016.

used a checklist of questions recapping the main theme of the study (*see Appendix A*). Finally, scientific works such as books, journal papers, government reports, and academic dissertations, just to mention a few, were sources of secondary data, especially during the establishment and development of the study.

Data analyses

The yields data collected from the Ministry of Agriculture and from the study area (i.e., from respondents) were parameterized, compared, and averaged to acquire a reliable and representative data package. We analyzed the yields data and the trend of rainfall and temperature, focusing on their mean annual variability using the Mann–Kendall Test (at 95% level of confidence) and Microsoft excel (window 13) (Stern, Dennett, and Dale 1982). The qualitative data from the household surveys were analyzed using theme content methods.

Pearson's Moment correlation coefficient and regression analyses were used to compare the trends of rainfall and temperature variability versus crop yields and extrapolate the future correlations (McCullagh 1974). *P*-values less than 0.05 were supposed to be statistically significant ($P < 0.05$). In addition, a conceptual framework (Figure 6) was constructed to portray the correlation among the salient aspects of the study (see the results section).

Results

The majority of respondents agreed that climate variability is a true phenomenon and has been affecting their livelihoods significantly. Table 2 presents the demographic characteristics of the household heads. Most of them were male farmers (62.8%) (female 37.3%) with different years of farming experiences. Length of farming experience ranged between 10 and 40 years. The demographic characteristics were further used in correlation analysis to test the relationship between farmers' understanding of climate and their experiences.

Table 2. Summary of demographic and farming characteristics of respondents in the two villages.

Variables	Percentage
Age	
i. 18–33	7.2
ii. 34–53	25.5
iii. 54–73	60.5
iv. >73	6.8
Sex of the Household Head	
i. Male	62.8
ii. Female	37.2
Marital Status	
i. Married	90.3
ii. Single	7.7
iii. Divorced/Separated	2.0
Level of Education	
i. Primary	72.3
ii. Secondary	20.2
iii. Post-secondary certificates	4.1
iv. University	3.4
Experience in farming	
i. 10–19	40.2
ii. 20–39	55.3
iii. ≥40	4.5
Agricultural practices	
i. Crop production	60.5
ii. Livestock keeping	10.2
iii. Mixed farming (i.e., crop and livestock)	29.3
N	400

Source: Field Data Survey, 2016.

Furthermore, farmers' experience mostly involved their age and the years spent involved in agriculture. The results in this aspect determined the number of years the farmer has intensively or fully engaged in agriculture. Thus, the best results in *farmers' experience* were obtained following the actual quantification of the farmers' age and the total years they have engaged in agriculture. The results from PRAs presented in Table 3 indicate that 93.8% old people (>74 years) were sure that climate variables have been varying/changing, compared to 90.4% of 54–73-year-olds, 89.4% of 34–53-year-olds, and 80.5% of 18–33-year-olds.

There were positive correlations between the number of years spent in agriculture and the experience

Table 3. Response (based on age) to the question *"Have you noticed climate change."*

Age range	Yes	No	Not sure	Total
18–33	80.5	7.2	12.3	100
34–53	89.4	5.4	5.2	100
54–73	90.4	3.2	6.4	100
≥74	93.8	0	6.2	100

Source: Field Data Survey, 2016.

($P < 0.05$). Thus, it was discerned that the older the farmers, the more the experience accumulated.

Climate variability

The total annual rainfall and mean annual temperature patterns from 1980 to 2015 experienced dramatic changes. The former decreased at $R^2 = 0.21$, while the latter increased at 0.30 (Figure 2). These climate trajectories increased the vulnerability of agricultural systems. The temporal variability of rainfall pattern affected the onset and cessation, intensity, frequency, and amount of rains. The changes of onset dates have had significant impacts on the farming calendar for most farmers in the study area, while intensity, amount, and frequency affected the whole process of agricultural production (Mkonda and He 2017a).

The results from Figure 2 provide a general exploration of the trend of rainfall in the study area based on the annual amount. It displays a wider context on long-term variability that explores the general situation on the ground (Challinor et al. 2014; Mkonda 2011). About 70% of the respondents also reported that rainfall and temperature have been decreasing and increasing, respectively. Table 4 reveals that the farmers were assertive that rainfall has been decreasing (70%), fluctuating (25%), and increasing (5%), while temperature has been increasing (65%), fluctuating (25%), and decreasing (10%). Overall, these results indicate that there has been a scenario of decreasing rainfall and increasing temperature in the area.

Crop production

There were significant variations in crop yields among maize, sorghum, and millet in the study area ($P < 0.05$). Maize had high yields (in tons per hectare) compared to sorghum and millet (Figure 3). However, in all crops, there was significant yields fluctuation. On average, about all crops experienced optimal yields from 1980 to 1980, while meager yields were observed from 1997 to 2000 and from 2011 to 2015 (Figure 3).

Impacts of climate variability on agricultural production, i.e., crop yields

Rainfall

The results from analyses show that there was a strong relationship between rainfall and crop yields in the area ($P < 0.05$). The significant correlation between rainfall and yields is shown in Figure 4.

For example, rainfall had a positive correlation with maize (*Zea mays* L.), sorghum, and millet at

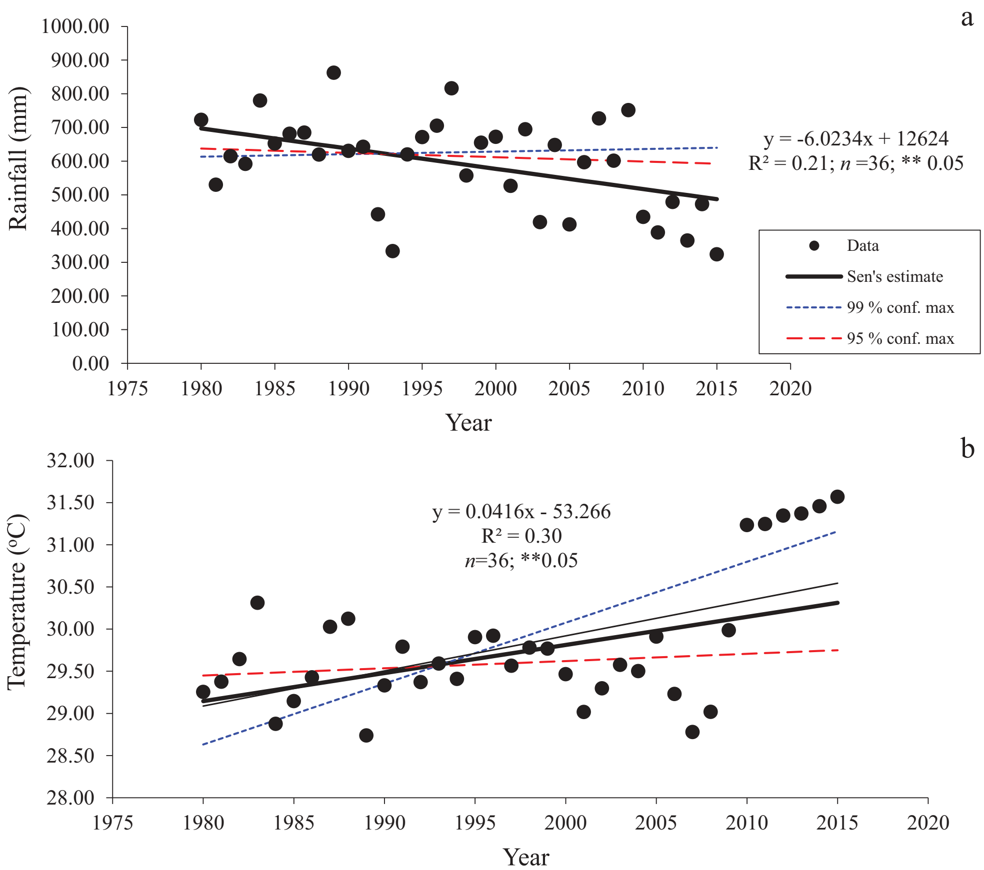

Figure 2. Trend of total annual rainfall (a) and mean annual temperature (b) in the study area.
Source: Field Survey Data, 2016

Table 4. Farmers' response (in percent) on climate change (i.e., closed questions).

	Rainfall			Temperature		
Village	Increasing	Decreasing	Fluctuating	Increasing	Decreasing	Fluctuating
Mnyakongo	5	65	30	70	5	25
Ugogoni	5	70	25	65	8	27

Source: Field Data Survey, 2016.

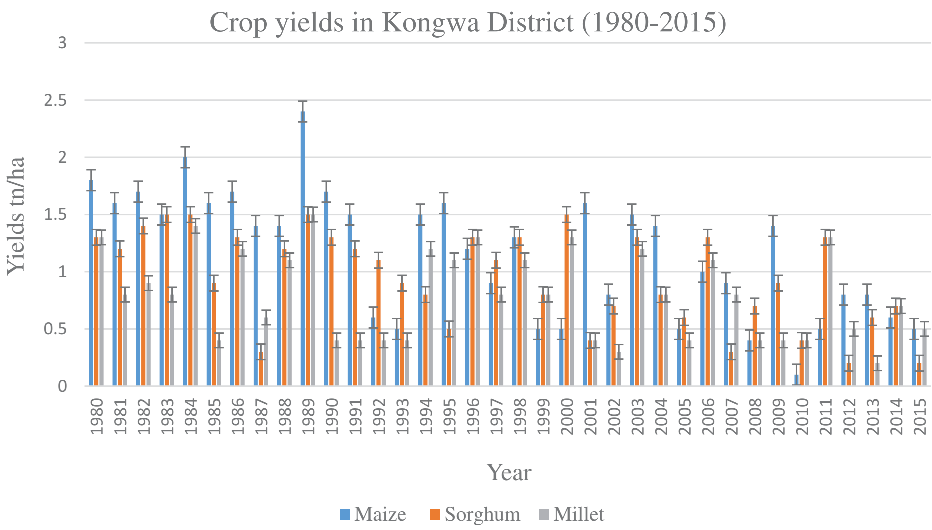

Figure 3. Crop yields in Kongwa District. The data from the sources were calculated in tons per hectare. The selected crops in the figure are the major food crops in the study area.

Source: Kongwa District Agricultural and Livestock Development Office, and the Ministry of Agriculture, Livestock and Fishery, 2016

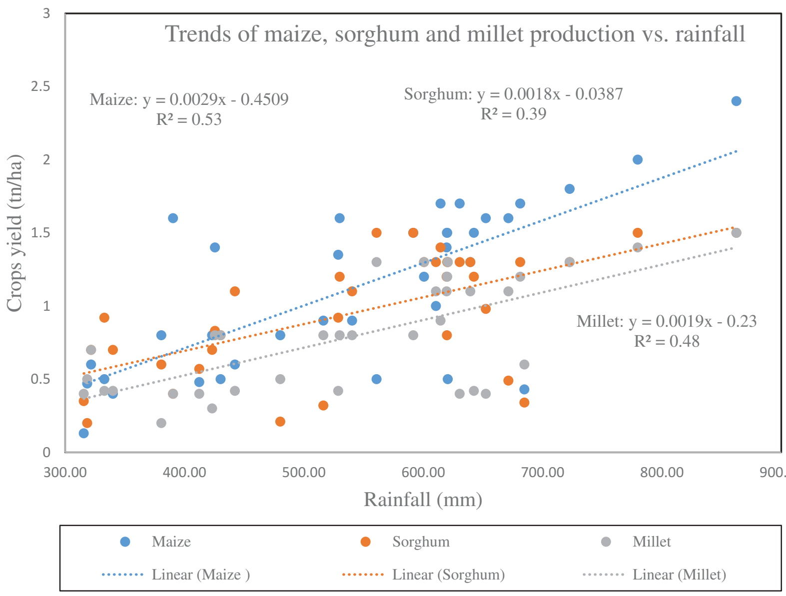

Figure 4. Correlation between rainfall and crop yields in the study area.

Source: Field Survey Data, 2016

R^2 = 0.53, 0.39, and 0.48, respectively (see Figure 4). Consequently, the result in Table 5 indicates that the decrease in rainfall has been affecting the yields of maize, millet, and sorghum at 90%, 65%, and 45%, respectively. Furthermore, the results from informative interviews, discussions, and physical observations had similar findings. In the present study, the posed effects ranged from slight, moderate, severe, to very severe. Maize and sorghum were the most and least vulnerable to rainfall variability, respectively.

Since maize is a major cereal staple food crop for more than 70% of Tanzanian communities, its failure had repercussions on the whole country (United Republic of Tanzania 2014; 2013). Studies by Challinor et al. (2014), Ahmed et al. (2011), Schelenker and Lobell (2010), Lobell et al. (2008),

Table 5. Impacts of climate change (in percent) on specific crop yields.

Crop	Mnyakongo (*N* = 200)	Ugogoni (*N* = 200)
Maize	90 (Very severe)	85 (Very severe)
Millet	60 (Severe)	65 (Severe)
Sorghum	50 (Moderate)	40 (Slight)

Source: Field Data Survey, 2016.

and Challinor et al. (2007), just to mention a few, had similar observations, as they found that the yields for major staple cereal food crops like maize, sorghum, and millet have been affected by climate impacts and will continue to be affected.

Temperature

Despite temperature being a useful abiotic factor in crop production, its excess has negative impacts on crop productivity. In this study, there was a negative relationship between temperature alterations and crop yields in the area ($P < 0.05$). Both Pearson's moment correlation coefficient and regression analysis showed that type of correlation between these variables. For years that encountered high temperature, there were meager yields and vice versa (Figure 5).

For instance, temperature had a negative correlation with maize (*Zea mays* L.), sorghum, and millet at R^2 = 0.36, 0.30, and 0.33, respectively (see Figure 5). However, maize and sorghum were the most and least vulnerable to temperature alterations, respectively. Maize production was impacted by extreme temperature, which resulted in meager yields and eventually caused frequent food shortage for about 70% of the people. These results were also supported by the respondents in the study area (Table 5). The findings from informative interviews, discussions, and physical observations also supported the same. Besides, these results were in agreement with the studies by Rowhani et al. (2011), Challinor et al. (2014), Mkonda (2011), and Mkonda and He (2017b), which were conducted in diverse agroecological zones of Tanzania.

Various projections (e.g., from CMIP5 GCMs) have indicated that over the Tanzanian context, there will be a decrease in rainfall by the end of the 21st century despite the occurrences of some extremes. This will have substantial impacts on crop production through excessive droughts in most areas and floods in fewer lowland areas. Therefore, the direction of yields change in the study area depends on the state of current climatic condition, physiology of the crop, and soil management of the area (Lobell et al. 2008; Challinor et al. 2014).

Discussion

Although the study has used Tanzania as a case study, its findings are applicable in many countries of sub-Saharan Africa where semiarid and tropical climates are predominant (Hertel, Burke, and Lobell 2010; Elliott et al. 2014; Serdeczny et al. 2017). This study has largely established the relationship among climate variability, i.e., rainfall and temperature, crop yields, and the environment (see Figures 2–5). The differences of rainfall and temperature variability have also been confirmed by this study. It has been revealed that the total annual rainfall and mean annual temperature were decreasing and increasing, respectively

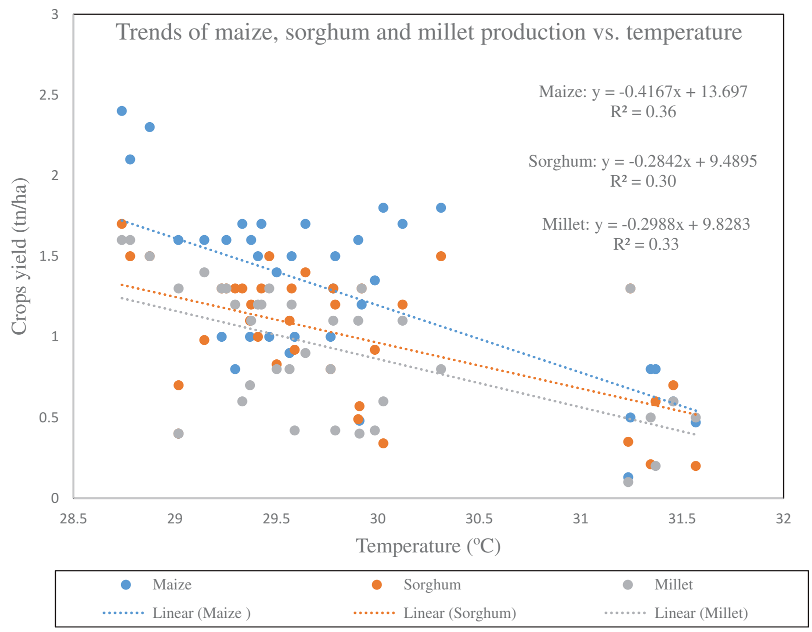

Figure 5. Correlation between crops yields and temperature in the study area.
Source: Field Survey Data, 2016

(Figure 2). This variation had impacts on agricultural production (Table 5) and the environment (Figures 2–5).

These results have complied with those established in different models at both local and global levels. For example, the rainfall projection from CMIP5 GCMs over the Tanzanian context suggests a decrease in rainfall by the end of the 21st century despite the occurrences of extremes (droughts and floods). These models further reveal that the whole east African region will experience more drought incidences than flood. In addition, the findings of the present study are in agreement with those by Mongi, Majule, and Lyimo (2010), Rowhani et al. (2011), Challinor et al. (2014), and Muller and Shackleton (2014), just to mention a few. In all means, these incidences have adverse impacts on agriculture and the ecosystems of the locality, thus upsetting the sustainability of the peoples' livelihoods (Mkonda, He, and Festin 2018).

On the other hand, the agriculture sector, in which over 70% of the people in Tanzania are engaged, has been giving diminishing returns, especially in the past three decades. This decline has been incremented by a number of factors, but mostly being excessive droughts and increase in temperature (Hertel, Burke, and Lobell 2010). For example, the yields of maize, sorghum, and crops from 1980 to 2015 in tons per hectare fluctuated significantly (Figure 3). The impacts of climate change, including prolonged number of dry days, also have had adverse effects on this agricultural turbulence. The optimal shift of rains onset and Cessation, the reduced number of wet days, and the shrinking of the growing season have all affected the farming calendar in the area. Previously, rain onset occurred in December, while cessation was in April; thus, it was clear to the farmers about when they could start their farming operation.

Similarly, various models have shown that an increase of 2°C in temperature during the growing seasons (1992–2005) reduced maize and sorghum yields by 18.6 ± 5.2% and 12.6 ± 5.3%, respectively, while an increase of 20 mm in average monthly precipitation during that time increased yields by 6.7 ± 1.7% and 5.7 ± 1.7%, respectively (Rowhani et al. 2011). Similarly, Figure 2(b) shows that the increase in temperature influenced the decrease of crop yields. The scenario of increased temperature mostly impacted maize than millet and sorghum (Figure 4). It is also evident that maize, which is a major staple food in the country, has a high sensitivity to temperature above 30°C (Luo 2011). Lobell et al. (2008) concluded that each day of the growing season with such amount of temperature reduces yields by 1% compared to optimal, drought-free, and rain-fed conditions. In this aspect, maize was the most vulnerable to rainfall variability, while sorghum was the least vulnerable.

Since maize is the most preferred food for over 70% Tanzanians, its yield decline has significant repercussions on the livelihoods of the majority of people (United Republic of Tanzania 2014). In years with worst yields, farmers became more vulnerable, destitute, and sorrowful (Mkonda, He, and Festin 2018). Despite the fact that the area has already been experiencing temperatures above the optimal range, it is projected to increase in future (Mwandosya, Nyenzi, and Luhanga 1998). Therefore, compelling adaptation measures need to be adopted to curb this trend and elevate the living standards.

Temperature alterations further increased evapotranspiration, thus affecting crop production and increasing farmers' vulnerability. This observation is in agreement with the study by Rowhani et al. (2011), who argued that the adaptive capacity of vulnerable smallholder farmers is significantly weakened by increased stress due to climate-change impacts. On the other hand, Sen (1986) found that vulnerability increases among the poor people due to lack of resource endowments and entitlement failure. By comparing the wealthy and destitute, the author found that the former had compelling resilience than the latter. Thus, most smallholder farmers in Tanzania's semiarid agroecological zone are destitute and thus are easily affected by any challenging conditions posed by any environmental stress.

Despite plotting the total annual rainfall and temperature, the intra-rainfall variability had significant impacts on crop production during the growing seasons. In that area, January is a planting month, but it has been experiencing high rainfall variability in terms of intensity, frequency, and amount. This variation has implications on the production process of the crops. In years when the month received optimal rains, the yields were significantly high and vice versa (Mkonda and He 2017a). For example, in 1985, 1990, 2002, 2008, and 2014, there was somewhat high total annual rainfall and crop yields (Figures 2(a) and 3). In contrast, in 1988, 1995, 2005, and 2014, there were low total monthly rainfall and less yields. Thus, in years with low rainfall, vulnerability among smallholder farmers increased significantly.

In most scenarios, February was the driest month in the growing season compared to January and March (Mkonda and He 2017a). This was evidenced by the result from meteorological analyses and responses from farmers in the study area. The month experienced low total rainfall and wet spells (see Figure 2(a)). Besides, about 80% of the farmers agreed that February had low rains and the fewest wet spells. However, better yields were also reported when February had optimal rainfall and increased number of wet days. For example, in 1982, 1990, 2005, and 2012, there were high rainfall and crop yields, while in 1985, 1988, 2001, and 2010, as seen in Figure 3. Low yields elevated food shortage, resulting in further vulnerability to the destitute farmers. March saw optimal rains in terms of both total and wet spells. During March, most crops are always at the ripe stage; thus, the month of March greatly determines crop yields.

In addition, the farmers agreed that, in successful years, during March the early-maturing maize varieties, i.e., Stuka, Staha, and Tan 250, and sorghum varieties, i.e., *Macia,* are almost at the completed stage of ripeness. These breeds are early maturing, give high yields, and are tolerant to drought and nitrogen deficiency. However, the general trend showed that for the past 36 years, March has experienced climatic turbulence and thus was not giving the best in terms of both frequency and intensity of rains.

By doing so, it has significantly affected crop yields ($P < 0.05$). Fortunately, in some few years when rainfall was at its best, there were optimal yields. For example, in 1981, 1988, 1993, and 2012, March had high total rainfall and numerous wet days, and concurrently increased maize, sorghum, and millet yields (Figures 2(a) and 3). This was in contrast to 1985, 1990, 2000, 2010, and 2014, for example, when both rains and yields were low (Figures 2(a) and 3).

Recently, in 2015, the level of household self-sufficient ratio in the area was found to be around 70%, making the magnitude of food insecurity in the area to be around 30% (URT 2005; 2007; Mkonda and He 2017b). In some areas, this deficit accrued to 50% depending on the level of livelihoods vulnerability. This percent (50%) implies that if livelihood options are not well established, the situation could lead to serious problems, i.e., hunger, famine, diseases, and death, just to mention a few. Since frequent food shortages have been reoccurring since the last three decades, this justifies that no compelling measures have been taken to fully address the disturbing crisis. This study calls for compelling mechanisms to optimize crop yields aimed at curbing the above-mentioned challenges.

Likewise, various studies have also been carried out on the impacts of climate change on livestock production (United Republic of Tanzania 2007). Thornton et al. (2011) confirmed that despite livestock being a source of income, or insurance, in many countries (especially Tanzania), its production has been significantly affected by climate change. This happens because most pastoral systems of the arid and semiarid lands of Tanzania and other sub-Saharan countries are highly dependent on the limited natural resources, especially pasture, fodder, forest products, and water. These resources are limited because they are also directly affected by climate variability (Morton 2012). In the study area and in other parts of central and northern Tanzania, i.e., especially Singida, Dodoma, Arusha, and Manyara regions, there have been increased incidences of animal deaths due to excessive droughts. This has increased the level of vulnerability and poverty among the people.

Apart from affecting crop yields, the impacts of climate change, especially droughts, amplify the degradation of soil fertility and other soil microorganisms. The projected warming in east African countries can have significant impacts on the same. In terms of environment, the increase in temperature can affect the plant pathogens. In most cases, high temperature and excessive drought can affect microorganisms, e.g., mycorrhiza. Figure 6 depicts the relationship among climate, yields, and ecosystems, where important aspects like soil management, crop production, photosynthesis, soil respiration, and carbon emission/sequestration have been covered.

Figure 6 illustrates the existing interrelationship among climate, agricultural production, and ecosystems.

Among other things, the major entities of the ecosystems include but not are limited to soils, water, vegetation, microorganisms, and animals (Luo 2011). In a wider perspective, the development of good ecosystems needs to have a balanced mutual relationship among the members of a particular ecosystem. Many of the areas that are classified as semiarid in Tanzania have been adversely affected by prolonged droughts thus far, and most of the important aspects of various ecosystems are not properly functioning (Serdeczny et al. 2017).

It also appeared that most water sources have dried out due to excessive drought. Various vegetation species such as *miombo woodlands* have almost disappeared, leaving the *cactus* because they are drought resistant. As a result, most of the carbon that was stored in the plant biomass before degradation was offset in the atmosphere (Zomer et al. 2008), as depicted in Figure 5. To curb this, soil organic management can be recommended to optimize the functions of microbial activity and soil mineralization. This can optimize the formation of organic matter, soil fertility, and soil carbon accumulation.

The findings of this study are in agreement with those from other studies like Paavola (2008) and Mwandosya, Nyenzi, and Luhanga (1998), who

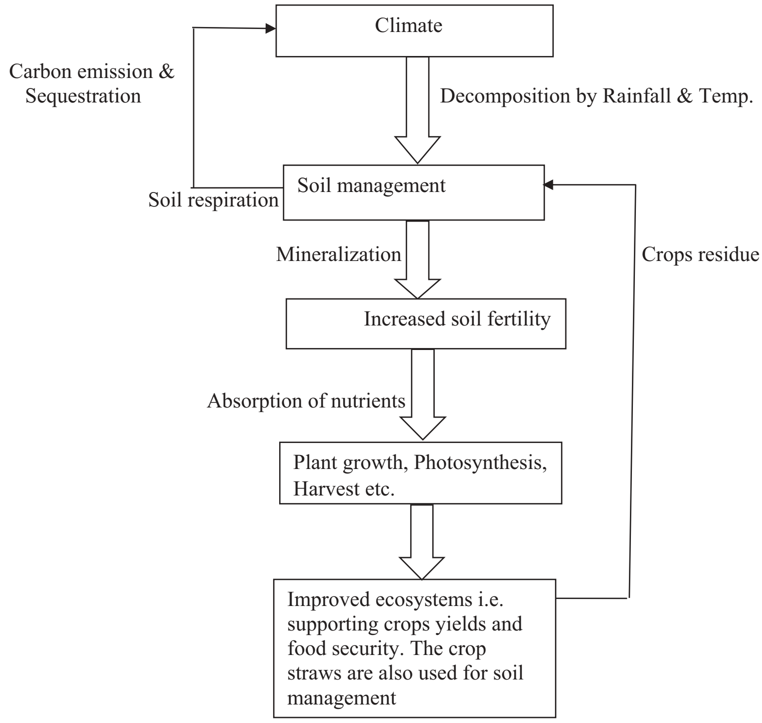

Figure 6. Relationship among climate, crops yields, and ecosystems.
Source: Created by the authors, 2017

stated that the overall climate variability has impacts on agro-ecosystems. Mwandosya, Nyenzi, and Luhanga (1998) further predicted that the expected increase in temperature by 2°C and 4°C by 2050 and 2100, respectively, will aggravate the situation. They warned that further exacerbation of the ecosystems will incapacitate them from providing environmental services, especially soil fertility and water for both agricultural production and livelihoods.

Soil organic management, i.e., conservation agriculture, irrigation, and good agricultural practices, is significant for crop production as it forms a complex web of agricultural systems. However, under rain-fed agriculture, improved soil management alone may not bring the expected crop yields, but a combination of diverse farming approaches can achieve this. This is because climate-change also affects water sources, forestry, and a wide range of biotic ecosystems in diverse locations.

In most cases, it has been discerned that the affected ecosystems, i.e., dried water sources, cannot further help in the livelihoods of the people (Kangalawe 2016). To underpin climate resilience, there is a need to improve the existing adaptation and mitigation measures (Table 6). These include good agronomic practices, organic fertilizations, conservation agriculture, small-scale irrigation, and adoption of drought-tolerant breeds. This will optimize yields, carbon sequestration, and environmental conservation, all of which are important for sustaining peoples' livelihoods.

Table 6. Existing adaptation and mitigation measures in the study area.

Adaptation activities	Mnyakongo (N = 200)	Ugogoni (N = 200)	Total (N = 400)	CYC
Early planting	72%	54%	63.0%	60%
Adopting resistant crop cultivars	55%	50%	52.5%	50%
Mulching	35%	43%	39.0%	45%
Agroforestry	23%	25%	24.0%	20%
Crop rotation	35%	30%	32.5%	30%
Small-scale irrigation	10%	8%	9.0%	5%
Fallowing	42%	48%	45.0%	40%
Afforestation	20%	15%	17.5%	15%
Transformative adaptation	21%	23%	22.0%	20%
Conservation of water sources	25%	20%	22.5%	25%

CYC: Contribution to crop yields.
Source: Modified from Mkonda and He (2017a).

Influence of non-climatic factors

Despite the significant influence of rainfall and temperature on maize, sorghum, and millet production, the influence of non-climatic factors such as soil management, agronomic practices, labor, and capital could not be underrated. Among these, soil fertility was degraded by continuous cultivation without fertilization. This situation affected other biological functions of the soils. Thus, poor soil fertility brought about poor yields and environmental services. However, these factors accounted for less than 50% of the total impacts on the area. Therefore, climate change had significant impacts compared to non-climate factors.

Community adaptation strategies

The results in Table 6 indicate that early planting and small-scale irrigation were the most (63%) and least (9%) used adaptation measures in the area, respectively. In general, the farmers in the sampled villages (i.e., Mnyakongo and Ugogoni) have been applying both incremental and transformative adaptation strategies (Mkonda and He 2017a). Incremental adaptation involves the improvement of the existing strategies such as the use of more drought-resistant crops, while transformative adaptation involves the complete change of strategies (Mkonda and He 2017b). Here, farmers completely shift from agriculture to other economic activities, such as business, employment, and so on.

On other hand, the timing of farm operation received high attention in both villages. More than 60% of the farmers confirmed that they have been starting farm operation in November instead of December. This is done regardless of the availability of rains. Moreover, about 50% of these farmers adopt resistant cultivars as a way of addressing the situation (i.e., climate impacts). For instance, they had adopted maize cultivars like TMV-1, Staha, Tan 250, Kilima, and STUKA M1, which are drought resistant and can mature within two to three months. Furthermore, about 45% and 40% of the farmers adopted fallowing and mulching, respectively, as their adaptation strategy. On the other hand, early planting, adopting resistant crop cultivars, and mulching had significant contributions to crop yields (Table 6).

We realized that there were very few irrigation schemes/rivers in the area (Figure 1). For example, Mseta River had an irrigation scheme that at least serves the livelihood of a few people who live around it. The farmers efficiently use water for irrigation under the auspices of Irrigators Organization (formerly water user association). These adaptation measures can be up-scaled or intensified to form an adaptation plan that can be recognized/introduced in the policy. Although most of the adaptations are meant to improve agricultural production, they are also conserving the environment, especially soil fertility (Hertel, Burke, and Lobell 2010). For example, organic fertilization can optimize yields and create favorable condition for microbial development and functioning.

Therefore, this study has confirmed that the variability of the intensity, onset, and cessation of rains has posed significant negative impacts to both agriculture and livelihoods at large. To reduce the vulnerability of climate-change impacts, all stakeholders have to play their role at its best. Moreover, for smallholder farmers to achieve their expected yields, they should adhere to proper adaptation strategies that are relevant to their locality.

Conclusion

Although climate is changing, it's realistic especially on the magnitude of change and impacts to agriculture and ecosystems is not yet well established across the whole country. This study found that there were temporal climate changes and variabilities in the study area (semiarid agroecological zone). This was evidenced by the results from both meteorological and farmers' perceptions analyses. Furthermore, these results confirmed that local communities, especially old people, had significant awareness on the same. At the local level, rainfall variability had been the major concern for both farmers and other climate practitioners. In this respect, rainfall varied in terms of amount, occurrences, and intensity. On the other hand, there was a significant relationship between climate variability and crop yields ($P < 0.05$). This was confirmed in the study area as the increase in rainfall influenced optimal yields and vice versa. However, this was contrary to temperature, which increased with the decrease in crop yields and vice versa.

Despite maize being the preferred crop, it was the most vulnerable to climate alterations compared to sorghum and millet (Figures 3 and 4). Thus, the decline of maize yields had significant repercussions on the status of food security in the area and at the national level. In addition, the diminishing yields increased land conflict, poverty, and degradation. These happened as people were seeking out other alternative livelihoods. Thus, the changing climate affected the entire livelihood of the destitute communities, who entirely depend on rain-fed agriculture.

To address this problem, a robust policy and sound tools associated with raising climate resilience need to be in place. Furthermore, a set of compelling adaptation plans and measures needs to be adopted by farmers corresponding to the biophysical characteristics. This will optimize crop yields to curb frequent food shortage and abject poverty. Since the science of climate impacts is dynamic, we call for more studies to detail the information on climate-change and adaptation in various agroecological zones of the country and other areas at the global level. *We need to think globally but act locally.*

Acknowledgments

We are indebted to the Chinese Government Scholarship (CSC) for providing a scholarship to Mr. Msafiri Y. Mkonda. We also wish to thank the research assistants who were involved in data collection. The study was funded by the College of Resources and Environment, Southwest University and Chongqing Municipal Innovative Talents Program. We thank Dr. Lorena Talonia Ruiz, University New England, Australia, for editing our paper. Lastly, we convey our gratitude to anonymous reviewers for their comments and insights on our paper. Their constructive suggestions and inputs remain permanent assertions for reporting similar scientific works in the future.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Southwest University, College of Resources and Environment.

ORCID

Msafiri Y. Mkonda http://orcid.org/0000-0002-1626-3724

References

Ahmed, S., N. Deffenbaugh, T. Hertel, D. Lobell, N. Ramankutty, A. Rios, and P. Rowhani. 2011. "Climate Volatility and Poverty Vulnerability in Tanzania." *Global Environmental Change* 21: 46–55. doi:10.1016/j.gloenvcha.2010.10.003.

Bationo, A., Kihara, J., Vanlauwe, B., Waswa, B., and Kimetu, J. 2006. Soil organic carbon dynamics, functions and management in west African agro-ecosystems. *Agricultural Systems, 94*(1): 13–25. doi: 10.1016/j.agsy.2005.08.011.

Brown, M. E. 2006. "Assessing Natural Resource Management Challenges in Senegal Using Data from Participatory Rural Appraisals and Remote Sensing." *World Development* 34: 751–767. doi:10.1016/j.worlddev.2005.10.002.

Intergovernmental Panel on Climate Change. 2014. "Climate Change 2014 Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects." In *Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. C. B. Field, V. R. Barros, R. C. Estrada, G. B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, and L. L. White. Cambridge, United Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Challinor, A. J., J. Watson, D. B. Lobell, S. M. Howden, D. R. Smith, and N. Chhetri. 2014. "A Meta-Analysis of Crop Yield under Climate Change and Adaptation." *Nature Climate Change* 4: 287–291. doi:10.1038/nclimate2153.

Challinor, A. J., T. R. Wheeler, C. Garforth, P. Craufurd, and A. Kassam. 2007. "Assessing Vulnerability of Food Crop Systems in Africa to Climate Change." *Climatic Change* 83: 381–399. Development. doi:10.1080/17565529.2016.1139487.

Cramb, R. A., T. Purcell, and T. C. S. Ho. 2004. "Participatory Assessment of Rural Livelihoods in the Central Highlands of Vietnam." *Agricultural Systems* 81: 255–272. doi:10.1016/j.agsy.2003.11.005.

Elliott, J., D. Deryng, C. Müller, K. Frieler, M. Konzmann, D. Gerten, M. Glotter, et al. 2014. "Constraints and Potentials of Future Irrigation Water Availability on Agricultural Production under Climate Change." *Proceeding of the National Academy of Science USA* 111 (9): 3239–3244. doi:10.1073/pnas.1222474110.

Food and Agriculture Organization. 1988. "FAO/Unesco Soil Map of the World, Revised Legend, with Corrections and Updates.*" (World Soil Resources Report 60) FAO.* Rome (reprinted with updates as Technical Paper 20, ISRIC, Wageningen, 1997).

Food and Agriculture Organization. 2009. "FOASTAT Database." *Food and Agriculture Organization*, Rome Accessed 27 August 2017. faostat.fao.org/

Glaser, B., Lehmann, J., Führböter M., Solomon, D., and Zech, W. 2001. Carbon and nitrogen mineralization in cultivated and natural savanna soils of northern tanzania. *Biology and Fertility of Soils, 33*: 301–309. doi: 10.1007/s003740000324.

Hertel, T. W., M. B. Burke, and D. B. Lobell. 2010. "The Poverty Implications of Climate-Induced Crop Yield Changes by 2030." *Global Environmental Change* 20 (4): 577–585. doi:10.1016/j.gloenvcha.2010.07.001.

Humphrey, W. K., and E. M. Kimberly. 2007. "Participatory Resource Mapping for Adaptive Collaborative Management at Mt." *Landscape and Urban Planning* 82: 145–158. doi:10.1016/j.landurbplan.2007.02.005.

Kangalawe, R. Y. M. 2016. "Climate Change Impacts on Water Resource Management and Community Livelihoods in the Southern Highlands Of." *Tanzania, Climate and Development* 1–11. doi:10.1080/17565529.2016.1139487.

Lobell, D. B., M. B. Burke, C. Tebaldi, M. D. Mastrandrea, W. P. Falcon, and R. L. Naylor. 2008. "Prioritizing Climate Change Adaptation Needs for Food Security in 2030." *Science* 319 (5863): 607–610. doi:10.1126/science.1152339.

Luo, Q. 2011. "Temperature Thresholds and Crop Production: A Review." *Climatic Change* 109: 583–598. doi:10.1007/s10584-011-0028-6.

McCullagh, P. 1974. "Data Analysis and Interpretation." *Science in Geography* 4: 75–92, chap. 6.

Mkonda, M. Y. 2011. "Impacts of Climate Change and Variability on Crop Production and Its Implications to Food Security a Case of Mvomero District." Master's Dissertation., Tanzania African review (Dar es Salaam, Tanzania).

Mkonda, M. Y., and X. H. He. 2017a. "Are Rainfall and Temperature Really Changing? Farmer's Perceptions, Meteorological Data, and Policy Implications in the Tanzanian Semi-Arid Zone." *Sustainability* 9: 1412. doi:10.3390/su9081412.

Mkonda, M. Y., and X. H. He. 2017b. "Yields of the Major Food Crops: Implications to Food Security and Policy in Tanzania's Semi-Arid Agro-Ecological Zone." *Sustainability* 9: 1490. doi:10.3390/su9081490.

Mkonda, M. Y., X. H. He, and E. S. Festin. 2018. "Comparing Smallholder Farmers' Perception of Climate Change with Meteorological Data: Experiences from Seven Agro-Ecological Zones of Tanzania." *Weather Climate and Society Journal* Accepted. doi:10.1175/WCAS-D-17-0036.1.

Mongi, H., A. E. Majule, and J. G. Lyimo. 2010. "Vulnerability Assessment of Rain-Fed Agriculture to

Climate Change and Variability in Semi-Arid Areas of Tanzania." *African Journal of Environmental Science and Technology* 4 (6): 370–383.

Morton, J. 2012. "Livestock and Climate Change: Impacts and Adaptation." *Agriculture for development. Tropical Agriculture Association Report No 17*. 17–20.

Msongaleli, B., F. Rwehumbiza, S. Tumbo, and N. Kihupi. 2015. "Impacts of Climate Variability and Change on Rainfed Sorghum and Maize: Implications for Food Security Policy in Tanzania." *Journal of Agricultural Science* 7(5): 124–142. Canadian Center of Science and Education. doi:10.5539/jas.v7n5p124.

Muller, C., and S. E. Shackleton. 2014. "Perceptions of Climate Change and Barriers to Adaptation Amongst Commonage and Commercial Livestock Farmers in the Semi-Arid Eastern Cape Karoo." *African Journal of Range & Forage Science* 31: 1–12. doi:10.2989/10220119.2013.

Mwandosya, M. J., B. S. Nyenzi, and M. L. Luhanga. 1998. *The Assessment of Vulnerability and Adaptation to Climate Change Impacts in Tanzania*. Dar es Salaam: Centre for Energy, Environment, Science and Technology (CEEST).

Nyong, A., A. Francis, and B. Osman-Elasha. 2007. "The Value of Indigenous Knowledge in Climate Change Mitigation and Adaptation Strategies in the African Sahel." *Mitigation and Adaptation Strategies for Global Change* 12: 787–797. doi:10.1007/s11027-007-9099-0.

Paavola, J. 2008. "Livelihoods, Vulnerability and Adaptation to Climate Change in Morogoro, Tanzania." *Environmental Science & Policy* 11: 642–654. Leeds, UK. doi:10.1016/j.envsci.2008.06.002.

Rao, K., W. Ndegwa, K. Kizito, and A. Oyoo. 2011. "Climate Variability and Change: Farmer Perceptions and Understanding of Intra-Seasonal Variability in Rainfall and Associated Risk in Semi-Arid Kenya." *Experimental Agriculture* 47: 267–291. doi:10.1017/S0014479710000918.

Rowhani, P., D. B. Lobell, M. Linderman, and N. Ramankutty. 2011. "Climate Variability and Crop Production in Tanzania." *Agricultural and Forest Meteorology, Science Direct* 151 (2011): 449–460. doi:10.1016/j.agrformet.2010.12.002.

Saunders, M. N. 2011. *Research Methods for Business Students, 5/E*. Pearson Education India.

Schelenker, W., and Lobell, D. B. 2010. Environ. *Environmental Research Letters. 5*: 014010.

Sen, A. 1986. "Food, Economics and Entitlements." WIDER Working Papers (1986-2000) 1986/001, Helsinki, UNU-WIDER.

Serdeczny, O., S. Adams, F. Baarsch, D. Coumou, A. Robinson, W. Hare, M. Schaeffer, M. Perrette, and J. Reinhardt. 2017. "Climate Change Impacts in Sub-Saharan Africa: From Physical Changes to Their Social Repercussions." *Reg Environ Change* 17: 1585–1600. doi:10.1007/s10113-015-0910-2.

Solomon, D., Lehmann, J., and Zech, W. 2000. Land use effects on soil organic matter properties of chromic luvisols in the semiarid tropics: Carbon, nitrogen, lignin and carbohydrates. *Agriculture, Ecosystems & Environment, 78*: 203–213.

Speranza, I., B. Kiteme, P. Ambenje, U. Wiesmann, and S. Makali. 2009. "Indigenous Knowledge Related to Climate Variability and Change: Insights from Droughts in Semi-Arid Areas of Former Makueni District, Kenya." *Climatic Change* 100: 295–315. doi:10.1007/s10584-009-9713-0.

Stern, R. D., M. D. Dennett, and I. C. Dale. 1982. "Analyzing Rainfall Measurements to Give Agronomically Useful Results." *II Modelling Approach Experiments Agricultural* 18: 237–253.

Thornton, P. K., P. G. Jones, P. J. Ericksen, and A. J. Challinor. 2011. "Agriculture and Food Systems in Sub-Saharan Africa in a 4 C? World." *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 369: 117–136. doi:10.1098/rsta.2010.0246.

United Republic of Tanzania. 2005. "National Strategy for Growth and Reduction of Poverty." *Vice President's Office, United Republic of Tanzania*. Accessed 20 June 2017. www.tanzania.go.tz/pdf/nsgrptext.pdf

United Republic of Tanzania. 2007. "National Adaptation Program of Action." *Vice President's Office, Division of Environment*. Accessed 20 October 2016 unfccc.int/resource/docs/napa/tza01.pdf

United Republic of Tanzania. 2013. *National Agriculture Policy*. Dar es Salaam, Tanzania: Government Publishing Press.

United Republic of Tanzania. 2014. "Review of Food and Agricultural Policies in the United Republic of Tanzania." *MAFAP Country Report Series, FAO*. Rome, Italy.

Yanda, P. Z. 2015. "Climate Change Implications for Management and Use of Agricultural Biodiversity Resources in Africa." *Environment and Ecology Research* 3 (2): 35–43. doi:10.13189/eer.2015.030201.

Zomer, R. J., A. Trabucco, D. Bossio, and L. V. Verchot. 2008. "Climate Change Mitigation: A Spatial Analysis of Global Land Suitability for Clean Development Mechanism Afforestation and Reforestation." *Agriculture, Ecosystems & Environment* 126 (1–2): 67–80. doi:10.1016/j.agee.2008.01.014.

Appendix A. Research Instruments for the Household Survey

Appendix I. Farmers Questionnaire

(1) Demographic and Socio-economic Characteristics of Respondents
General Information

Zone	Region	District	Village	Age	Sex	Marital status	Education level

(2) How do you perceive climate change and variability through? (Tick as appropriate)

Code	Perceptions	Tick
A	Change in total amount of rainfall during main rain season	
B	Increasing rainfall in amount during main rain season	
C	Decreasing rainfall in amount during main rain seasons	
D	Shift in the timing of the onset of rain in the main season	
E	Rain starting later than normal	
F	Rain starting earlier than normal	
G	Short rains than normal	
H	Long rains than normal	
I	Planting date change applying to most crops	
J	Temperature of the area decreasing	
K	Temperature of the area increasing	
L	Rainfall increasing	
M	Rainfall decreasing	
N	Rainfall fluctuating	
O	Increase in recurrences of floods	
P	Decrease in recurrence of floods	
Q	Increase in intensity of floods	
R	Increase in recurrence of droughts	
S	Increase in intensity of droughts	

(3) What has been the trend of rainfall for the past 30 years to date according to your memory? (Please tick as appropriate)
- (A) Increasing
- (B) Decreasing
- (C) Fluctuating
- (D) No change
- (E) Don't know

(4) What has been the trend of temperature for the past 20 years to date according to your memory? (Please tick the appropriate answer)
- (A) Increasing
- (B) Decreasing
- (C) Fluctuating
- (D) No change
- (E) Don't know

(5) In your view, how do you perceive the following:
- (A) Rainfall and its variability
- (B) Temperature and its variability

(6) Information on existing adaptation strategies and the reasons for doing so.

6.1. Please tick in the appropriate box matching and give the reasons for those farming practices as indicated

Adaptation Strategies	Tick where appropriate	Reasons
Adopted higher yielding crop varieties		
Introduce new crop varieties		
Adopted shorter cycle crop varieties		
Stop cultivating some crop varieties		
Agroforestry		
Timing of farm operations		
Practicing crop rotation		
Crop rotations		

6.2. Please distinguish by listing between the old and new adaptation strategies as indicated hereunder

Code	Old adaptation strategies	New adaptation strategies (within 30 years)
i		
ii		
iii		
iv		
v		
vi		

6.3. What do you think you can do in the future to be able to adapt to the changes if they persist?

Code	Future adaptation options	Tick
A	Abandon agriculture at the expense of other economic activities	
B	Abandon the current farms and move to wetter areas like river banks	
C	Emigrate from your village to other areas with better conditions	
D	Continue changing agricultural practices in line with the changes in the local climate	
E	Ask for food aid	
F	Ask for government support like introduction of new and modern adaptation options	
G	Seek to obtain more information, knowledge and education on adaptation to climate change	
H	Promote irrigation using underground water	
I	Promote conservation practices further	

Appendix II.

Research Instrument for group discussions with farmers and informative interviews

(1) What are your comments on the local climate
- a. Give your view on the local climate situation for the past 30 years
- b. Are there any changes, in so far what are the extremes in terms of high/low ones
- c. What do you think are the major reasons for those changes (if any)?
- d. What is you anticipation on the future state of the climate? Increase or decrease?

(2) **Key changes in the farming practices and their sustainability**
- a. Are there any changes in crops cultivars, soil management techniques, water harvesting, storage, etc.
- b. How about the timing of the farm practices, e.g., early planting
- c. Is there any sustainable livelihood option, e.g., income sources

(3) **Motivating factors for changes in the farming practices and adoption of alternative livelihoods options**
- a. Climatic conditions
- b. Economic factors
- c. Policy changes
- d. Social
- e. Any other

(4) **Socioeconomic implications of the changes in the local climate**

Identification of the effects of the changes, e.g.,
Food production and social security
Financial situation
Water availability
Conflicts over resources base
Health status of the vulnerable people
Household conflicts if associated with the impacts of climate change, etc.

(5) **Policy and strategic interventions for enhanced capacity to adapt to climate change impacts and strengthening long-term resilience**