Climate Change and Food Security in Tanzania: Analysis of Current Knowledge and Research Gaps

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Abstract

A review of literature was conducted in order to identify knowledge gaps in climate change and food security research in Tanzania. The review focused on published literature covering the past 20 years addressing climate change effects on various components of the food security. The review of literature reveals, among other things, that the current agricultural practices cannot ensure food security due to the fact that they heavily rely on the increasingly erratic and unreliable rainfall. Food systems in Tanzania are highly vulnerable to climate change and variability due to poor adaptive capacity of the socio-economic systems and limited community resilience to cope with climate variability and change. Response to climate change impacts is affected by multiple factors at different scales, ranging from the individual to the household and landscape, which in turn affects food security. Quality climate change science research in Tanzania is limited by few, scattered, unevenly distributed, and ill-equipped meteorological stations. This calls for research that is geared towards combining mitigation and adaptation strategies against the impacts of climate change, focusing on adaptation strategies that build climate resilience, reduce greenhouse gas emissions, and increase food security. Multidisciplinary research is required to provide a science-based analysis of potential coping and adaptation strategies and their economic and social effects.

Keywords: climate change, food security, agriculture, adaptation, Tanzania

Introduction

Climate change is a complex phenomenon that has short, medium and long-term effects on ecosystems and natural resources, physical infrastructure, and many other aspects of life. Climate change is mainly caused by greenhouse gas emissions through the burning of fossil fuels, deforestation and forest degradation. Developing countries, including Tanzania, are particularly vulnerable to extreme climate events due to their high dependence on rainfed agriculture and natural resources for their livelihoods, limited knowledge on climate change, inadequate resources for adaptation, and limited capacity to mitigate the impacts of climate change (UNFCCC, 2007). In general, the state of preparedness against adverse impacts of climate change in Tanzania and other poor countries in general is limited.

The Food and Agriculture Organization (1996) defines food security as a situation achieved when all people, at all times have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life. In other words, food security has four dimensions - the availability of food, access to food, utilization of food, and food system stability. All four dimensions must be fulfilled simultaneously for food security to be realized. Climate change affects food security directly through changes in agro-ecological conditions and indirectly by affecting growth and distribution of incomes and thus demand for agricultural produce (Schmidhuber and Tubiello, 2007).

Trends of current and projected climate change in Tanzania

According to the IPCC (2008) report, global warming is already impacting the hydrological cycle and systems as evidenced by changing precipitation patterns, intensity, and extremes. Local studies in Tanzania (Zorita and Tilya, 2002; Agrawala *et al.,* 2003; Mary and Majule, 2009; Kijazi and Reason, 2012; Kashaigili *et al.,* 2013) have reported changes in climate patterns in such as rising of maximum and minimum temperatures, increased variability of rainfall, and increased frequency and severity of extreme events. Studies indicate that the onset and cessation of rainy seasons are highly variable particularly in central and northeastern highlands. According to Zorita and Tilya (2002), the March-April-May (MAM) rainy season has characteristics different to those in October–November–December (OND), the former being much less persistent within the season and associated with high intra-seasonal variability over the northeastern highlands of Tanzania (NEH). Empirical analysis of rainfall and temperature suggested a trend of decreasing rainfall between 1922 and 2007, whereas mean, maximum, and minimum temperature increased by 1.9 and 0.2°C respectively (Mary and Majule, 2009). Using station rainfall data, Kijazi and Reason (2012) found that the anomalously wet MAM seasons over the NEH of Tanzania tended to result from an earlier onset of the rains and a late cessation and, thus, a longer-than-average rainfall season, whereas dry years were characterized by a shorter-than-average duration of the rains. However, it was argued that given the constraints of the available data and the regional atmospheric circulation, it is possible that additional predictors may be required to develop forecast models of the MAM and OND seasonal rainfall.

Studies have also examined climate change projections using General Circulation Models (GCMs) for Tanzania (e.g. Mwandosya *et al.,* 1998; Hulme *et al.,* 2001; Agrawala *et al.,* 2003; Paavola, 2008; Tumbo *et al.,* 2008). Several future projections indicate a decrease of rainfall over the SWH and central Tanzania, while NEH and the Lake Victoria basin will experience an increase in rainfall (Mwandosya *et al.,* 1998). Temperatures in Tanzania are projected to rise by 2 – 4°C by 2100, warming more during the dry season in the interior regions of the country (Hulme *et al.,* 2001; Paavola, 2008; Tumbo *et al.,* 2008). A review of climate scenarios in Tanzania from seventeen GCMs and empirical meteorological observations indicate that temperatures over the country will increase by up to 2.2°C by 2100 with higher increases of up to 2.6°C in June to August (Agrawala *et al.,* 2003). The interior areas are expected to experience a reduction in precipitation of up to 20%, prolonging the dry season and increasing the risk of drought. In eastern Tanzania and the regions around Lake Victoria, rainfalls are expected to increase by up to 50% during this period, increasing the frequency and severity of floods (Hulme *et al.,* 2001; Paavola, 2008). There is a need however to improve the current climate change research in terms of analysis of observed meteorological data by using the best available GCMs and downscaling techniques for Tanzania.

Climate change and food security

An overview of food security in Tanzania

According to the 2012 Comprehensive Food Security and Vulnerability Analysis (CFSVA), overall the Tanzania's food security situation appears to be improving over the years. However, CFSVA reported that rural households are more exposed to food insecurity than urban households; food shortages more commonly reported by households situated in drought-prone bimodal rainfall zone (north and west); and that the more farming households depend on their own produce, the greater their vulnerability to food insecurity (UNWFP, 2013). A 2013 report titled Agricultural dynamics and food security trends in Tanzania indicates that although the country's food production performance at the moment is fairly good, the country has experienced many ups and downs (Leliveld *et al.,* 2013).

Agriculture is a major source of food in Tanzania but the full potential of this sector to create food security in Tanzania has not been realized due to various constraints. These include over-dependence on rain-fed agriculture, poor post-harvesting systems, weak research-extension-farmer linkages, rapid population growth, poor agricultural policies, inadequate application of agricultural technologies, poor agricultural practices, unreliable markets, crop pests and diseases, global energy demand, and climate change and variability (Ernhart and Twena, 2006; Enfors and Gordon, 2007, 2008; Enfors *et al.* 2008; Müller *et al.,* 2011).

Impact of climate extremes on food security

Several studies (e.g., Downing *et al,* 1997; Kijazi and Reason, 2009a, 2009b; Shemsanga *et al.,* 2010; Kandji *et. al.,* 2006; Tumbo *et al.,* 2010) have been conducted on climatic extremes and how they have affected agricultural production and food security in Tanzania. Most of these studies agree that both extreme droughts and floods can occur within one season, and that the frequency and severity of these extreme events is expected to increase. Shemsanga *et al.* (2010) examined adaptations of poor Tanzanians living in rural areas to the effects of climatic extremes. The study reviewed various literatures and compiled proposed adaptive responses in agriculture and other sectors at both local and national levels. A similar literature review on climatic extreme events and their effects was conducted by Hemp (2005), who examined forest fires and their impact in the Kilimanjaro Region in northern Tanzania, and Hulme *et al.* (2001), who reviewed Africa's changing climate from 1900 to 2100 and its implications for food security. However, these reviews did not include results from field experiments.

Studies conducted by Kijazi and Reason (2009a, 2009b) reviewed some of the most severe flooding episodes that Tanzania experienced in recent years and their implications to food security. The results of large-scale climate events such as the 1993, 1997/98, and 2000/2001 El Niño illustrate the way communities suffer from less predictable extreme weather patterns. In some cases, large floods destroy infrastructure, affecting food distribution and access. Despite these massive losses, the abundant rainfall was beneficial, especially in semi-arid areas in which the production of crops was above average. The La Niña event of 1996/97 was responsible for a severe drought that occurred in most parts of Tanzania, leading to insufficient water for hydroelectric power generation and urban water supplies. In January 2010, unusually heavy rainfall associated with an El Niño event saw widespread flooding in the Morogoro (Kilosa) and Dodoma regions (IFRC Update, 2010). A systematic documentation and publication of these impacts is required to build up a knowledge base of how much damage is occurring and where.

Research has also indicated that there is inadequate information on weather and climate forecasts, which increases the vulnerability of poor farmers to extreme climatic events (e.g., Mjelde, 1997; O'Brien *et al.,* 2000; Hansen, 2002; Tumbo *et al.,* 2010). A study by Tumbo *et al.* (2010) used downscaling techniques to change coarse resolution data from the GCMs into useful data that could be used for plot scale studies. This study underscored that one of the main problems faced by Tanzanian farmers is access to climate information that is location-specific, timely, and easier to interpret for farm-level decision making. Kijazi and Reason (2009b) also earmarked availability of climate information as a factor that contributes to increased vulnerability to climatic extreme events in Tanzania. However, both studies covered the northeastern part of the country only. This calls for more research in other agro-ecological zones of the country to make the conclusions more relevant to country level. There is also a need for filling the communication gap between weather and climate forecasters and the high level of variability of weather forecast models that reduces forecasting accuracy, particularly of long-term (10 day) forecasts (O'Brien *et al.,* 2000; Hansen, 2002). In addition, the generality and spatial resolution of the information provided and the macro-scale level of regional weather models commonly issued by the Tanzania Meteorological Agency (TMA) make them less useful for landscape and micro-level (farm-level) decision processes (Tumbo *et al.,* 2010).

Impacts of current climate change on food security

Several studies (e.g., Mwandosya *et al.,* 1998; Ehrhart and Twena, 2006; Strzpeck and McCluskey, 2006; de Wit and Stankiewicz, 2006; Munishi, *et al.,* 2010; Jack, 2010; Arndt *et al.,* 2012; Rowhani *et al.,* 2011) have been conducted in Tanzania that focus on the effects of climate change on crop production. Many studies have reported a general decline in crop productivity as a result of the changing climate (e.g., Jones and Thornton, 2003; URT, 2008; Rowhani *et al.,* 2012). In severe drought years, the performance of local drought-tolerant cultivars is often poor, and losses as high as 50 percent due to drought related stress have been reported (AATF and COSTECH, 2010).

A countrywide household survey that was carried out to establish strategies for addressing negative effects of climate change in food insecure areas of Tanzania indicated a declining trend in productivity of maize and sorghum mainly due drought, floods, strong winds and excessive rainfall (URT, 2008). Kangalawe (2012) used a multidisciplinary approach to evaluate the impact of climate change and other stress factors on food security and human health in the southern highlands of Tanzania. He concluded that although the influence of climate variability on crop phenology and crop yields is very important, it is still poorly understood. Therefore, there is a need to improve climate records in order to increase understanding of these relationships.

Mwandosya *et al.* (1998) assessed different climate change scenarios and their potential impacts and vulnerability of different crops in Tanzania. This is one of the most comprehensive and widely referenced early studies that covered all agro-ecological zones of Tanzania. Several methodologies were used, including analysis of data from GCMs, modeling, fieldwork, and analysis of data from local meteorological stations. The study mainly focused on cash crops and less on major food crops such as rice, which are responsible for ensuring country's food security. Studies by Lema and Majule (2009) and Ehrhart and Twena (2006) used qualitative approaches and literature reviews to understand climate change impacts on agriculture in specific areas in Tanzania. There are also other studies (e.g., Shemsanga *et al.,* 2010; Lyimo and Kangalawe 2010; Kangalawe, 2012) in Tanzania that are qualitative and based on literature survey, focus group discussions, interviews with agricultural officers and farmers, and field observations to evaluate the impact of climate change. These studies have significant shortcomings due to a lack of scientific evidence of how climate change is affecting food security in Tanzania.

Whereas many studies have reported a decline in crop productivity due to changing climate, some studies indicate increased production of some crops. Kangalawe *et al.* (2009) reported an increase in mango and oil palm harvests with rising temperatures compared to twenty years ago. Experience from the highlands in the western plateau of Tanzania also indicates that the productivity of mangoes and oil palm has increased considerably during the last twenty years, which is locally attributed to the areas having become warmer than in earlier years (URT, 2008). It is, however, important to note that even without considering climate variability, the gap between potential yield and realized production of most crops is very big. Therefore, there is a need for targeted research on how to narrow the yield gap through judicious use of inputs and selecting drought and disease tolerant varieties for adaptation to climate variability and change.

Impacts of projected future climate change and crop productivity

Available literature indicates that projected climatic changes in Tanzania will have significant impacts on Tanzania's rain-fed agriculture and will increase poverty and food insecurity among others. Generally, most studies project decreasing production for food crops. A review of climate scenarios at the national level based on an examination of results from 17 GCMs concluded that maize yields will decline as a result of higher temperatures and decreased rainfall. Simulation results show that the average maize yield decrease over the entire country to be 33%, but decreases were as high as 84% in the central regions of Dodoma and Tabora. The maize yields in the NEH were estimated to decrease by 22% and by 17% in the Lake Victoria region. The southern highlands of Mbeya and Songea were estimated to have decreases of 10 – 15% (Agrawala *et al.,* 2003).

According to Rowhani *et al.* (2011), seasonal temperature increases have the most important impact on crop yields. The impacts of both seasonal means and variability on yields were measured at the sub-national level. Results indicated that both intra- and inter-seasonal changes in temperature and precipitation influence cereal yields in the country, of which seasonal temperature had the most significant impact. Projected seasonal temperature increase of 2°C by 2050 will reduce average maize, sorghum, and rice yields by 13, 8.8, and 7.6%, respectively. Similarly, rainfall variability also plays a significant role in reducing crop yields. A major limitation in this study was poor availability of some regional climate information that could enhance the understanding of these relationships. Arndt *et al.* (2012) examined the consequences of climate change for agriculture and food security in Tanzania using detailed sub-national crop models. Four GCM projections were chosen to reflect a range of possible temperature and precipitation changes by mid-century. The results informed a highly disaggregated, dynamic economy-wide model of Tanzania. It was found that food security in Tanzania would deteriorate as a consequence of climate change, although there is a high diversity of outcomes across climate scenarios, sectors, and regions. This calls for more research to improve climate records and obtain updated downscaled climate change projections to finer scale that is suitable for specific agro-ecological zones.

Several other studies in Tanzania have also used GCMs either directly (Strzpeck and McCluskey, 2006; de Wit and Stankiewicz, 2006; Ahmed *et al.,* 2011; Arndt *et al.,* 2012) or downscaled (Jack, 2010). Studies that adopt GCM approaches have important limitations (Moore *et al.,* 2012) especially because GCMs classically run at resolutions of 120 km square or coarser they cannot simulate dynamics associated with landscape variability. In addition, the impacts on climate due to changes in land cover and land use change (LCLUC) are generally not considered, and neither are the impacts on climate caused by the combination of LCLUC and changing greenhouse gases (GHG) concentrations, despite the fact that they could affect crop yields.

There are, however, some disagreements regarding the effects of climate change on crop yields across Tanzania. Some studies indicate that the agriculture sector may experience positive impacts. Bezabih *et al.* (2010) analyzed the economic impacts of climate change-induced adjustments using a countrywide computable general equilibrium (CGE) model and found that despite the projected reduction in agricultural productivity, the negative impacts could potentially be quite limited. The Tanzania Initial National Communication (2003) also indicated that coffee yields are expected to increase by 18% and 16% for areas located within bimodal and unimodal rainfalls respectively.

Overall, there are several limitations to current estimates of climate change impacts in Tanzania. Firstly, most studies are based on coarse resolution data from old version GCMs, which have been downscaled for the eastern Africa region. Secondly, many studies do not take into account the topographic diversity and large water bodies in the region and their influence on local climate. Thirdly, most studies ignore many physical, biological, and socio-economic processes that influence climate change processes. This is particularly important as Tanzania has been experiencing drastic land use and land cover changes, which have implications on local climate (Moore *et al.,* 2012). A key to reducing these uncertainties is improved understanding of the relative contributions of individual factors. This further emphasizes the need for location specific climate and agronomic research to obtain more relevant data. Studies of climate change impact on food security in Tanzania require higher resolution climate change information due to regional heterogeneity. Tanzania has several physical features that contribute to its high local variability in climate - topography ranging from sea level to 1600 m in the west and Mt. Kilimanjaro at 5895 m altitude in the north. Much of the country lies above 1000 m altitude with many areas above 1500 m in the central and north. It also has a complex seasonality associated with the Indian Ocean (Black *et al.,* 2003; Black, 2005; Anyah and Semazzi 2007) and complex equatorial circulation influences (Ogallo, 1989).

Current Adaptation Measures in Crop Production

Considerable research in Tanzania focuses on climate change adaptations or coping measures in agriculture. Most of these studies have focused on various communities' adaptive strategies that aim at improving the production of food crops under current climate variability. The majority of the studies (Mongi *et al.,* 2009; Mturi, 2009; Nsemwa *et al.,* 2009; Lyimo and Kangalawe, 2010; Kangalawe *et al.,* 2011; Mwingira *et al.,* 2011; Nindi and Mhando, 2012) employed survey methods to assess communities' vulnerability and strategies used to adapt to the challenges of climate change and variability. Some studies (Shemdoe *et al.,* 2009; Swai and Majule, 2009; Gwambene and Majule, 2010) focused on various tillage methods undertaken by farmers in response to climate variability. Only a few studies (Below, 2010; Below *et al.,* 2012) addressed the factors influencing adaptation to climate change and farmers' experimentation with adaptation processes in the changing climate.

Mongi *et al.* (2009), Lyimo *et al.* (2010) and Nsemwa *et al.* (2009) conducted vulnerability assessments of rain-fed agriculture to climate change and variability in Tabora, Shinyanga, and the southern highlands, respectively using interviews, focus group discussions, review of documents, and field observations. The studies found that farmers used various adaptation measures including expanding the area under cultivation, switching to more drought-resistant crops/varieties, changing planting times, growing alternative crops, increasing cultivation in wetlands, and diversification into non-farm activities such as brick and charcoal-making, casual labor, and carpentry. Unfortunately, these studies had very small sample sizes and limited spatial and temporal representation.

Nindi and Mhando (2012) used a checklist of questions to collect information on adaptation strategies to climate change and variability from farmer groups in two villages in the Mbinga District. Mturi (2009) carried out a socio-economic study in the Jipendea Division of the Mwanga District in Kilimanjaro using direct field observations, a participatory research approach, and questionnaire. Mwingira *et al.* (2011) carried out a study in eight villages of the Katavi ecosystem to analyze the impacts of climate change on biodiversity and community livelihoods using a sample size of 233 households. Data was collected using key informant interviews, semi-structured questionnaire, focus group discussions, and participant observations. Generally, these studies have either identified or recommended several adaptation measures to the impact of climate change on food security, including the use of improved crop varieties, crop and livestock breeding for drought tolerance and pest resistance, pest risk analysis, and improvement of pest management techniques. Other measures include creating awareness of climate change and adaptation strategies, strengthening early warning systems, better use of climate and weather data, improving irrigation potential, and development of sound land management practices. However, there are very few action research projects, and some studies had a limited sample size and very small spatial representation.

In another study, Below (2010) assessed factors influencing the decisions made by rural households in two Tanzanian wards (Ngerengere and Gairo) to adapt to climate change. Quantitative data were collected from 300 households and this was complemented by information from focus group discussions. The results showed that households' vulnerability to climate variability and change was a function of demographic aspects, household assets, livelihood strategies, and other factors. Recently, Below *et al.* (2012) conducted a study in the Mlali and Gairo wards in the Morogoro region to advance methods related to developing indices of adaptation processes, define household-level socio-economic variables explaining adaptation, and investigate the socio-economic determinants of adaptation by means of an explanatory factor analysis and a regression model. They concluded that the newly developed activity-based adaptation index (AAI) is a simple but promising way to capture the complexity of adaptation processes that address a number of shortcomings of previous index studies.

The vulnerability assessment studies discussed above are generally based on small household surveys and only covered small geographical areas. There is, therefore, a need for studies that cover larger areas, encompass different agro-ecological zones, and use statistically valid sample sizes. There is also a need for studies that employ action research methods to better understand farmer situations with regard to local adaptation options.

Adaptation initiatives through irrigation

There is limited research on irrigation in Tanzania, and the available research has focused mainly on rainwater harvesting (Senkondo *et al.,* 2004; Mbilinyi *et al.,* 2005; Mzirai and Tumbo, 2010). Senkondo *et al.* (2004) conducted a study using a household survey in two villages of the Western Pare Lowlands and one village in the Maswa District to understand the profitability of Rainwater Harvesting (RWH) for agricultural production in semi-arid areas of Tanzania. Data was collected on crop yield and farm sizes. Gross margin and investment (cost-benefit) analysis were used to assess the profitability of the RWH systems. The study found that rainwater harvesting improves gross margin (GM) as well as returns on labor. The limitation of this study is that only one village was selected for each crop, and the sample size was small making it difficult to extrapolate the findings from this study to other semi-arid agro-ecological zones.

In another study, Mbilinyi *et al.* (2005) studied indigenous rainwater harvesting technologies in three villages purposely selected to represent major landscape positions/topographic sequences in the Makanya catchment in the Kilimanjaro region. Data was collected through participatory research methods including focus group discussions, key informant interviews, field visits, and participatory workshops. Findings indicated that farmers had substantial local knowledge that could be extrapolated over a wider geographic extent using geographic information system (GIS). Mzirai and Tumbo (2010) studied the complexity of biophysical and social economic factors affecting the potential of runoff harvested from a macro catchment in two villages within the Chome-Makanya catchment in the Pangani basin in northern Tanzania. Four field plots were used to evaluate the performance of macro-catchment RWH systems. Data were collected for two long rain seasons and one short rain season from 2004 to 2005. Results indicated that due to inadequate short rains, supplementary irrigation water was needed to meet the water requirements for maize crops, and that fields in close proximity to runoff sources received more water and had higher crop yields compared to fields that received rainfall only. They recommended that modelling of macro-catchments RWH should also include social economic factors for efficient and equitable distributions of resources to utilize runoff from macro-catchments. The major limitation of these two studies is that they were located in one water catchment area.

There are a few scattered large-scale irrigation schemes in Tanzania most of which are private companies growing cash crops such as rice, tea, coffee, and sugarcane. However, the Kilimo Kwanza initiative estimated that over 29.4 million hectares of arable land could be made productive under national irrigation schemes. Approximately 7.8% of this land has very high production potential, 16.3% is of medium potential, and the remainder would require a significant investment to become productive. For long-term success, any irrigation plan should include smallholder farmers since about 85% of the arable land is rain-fed and cultivated by smallholder farmers (URT, 2011). These small farms could be bundled into larger blocks to take advantage of economies of scale for irrigation purposes.

Knowledge gaps on climate change and food security in Tanzania

The reviewed literature on climate change and food security in Tanzania indicates that there are important knowledge gaps due to lack of relevant research. In particular, there is very little research on how climate change impacts food security in the country and the potential mitigation and adaptation strategies. Most reviewed studies have methodological weaknesses, including narrow geographic coverage, inadequate sample sizes and sampling framework, poor analytical tools, data gaps, and limited temporal coverage. Similarly, there is little biophysical research that focuses directly on agriculture and how agro-ecosystem processes such as crop responses are affected by climate variability and change. Climatological research related to agriculture in Tanzania is also currently lacking. There are knowledge gaps regarding the effect of climate change on the growth and development of crops in Tanzania.

Climate and agronomic analyses, however, are hampered by how meteorological data is generated, processed, stored, and disseminated to various stakeholders. Currently, the meteorological stations in the country are too few, scattered, unevenly distributed, and ill equipped. Current impact assessment models are limited by input data, which reduces their use to addressing only fairly general questions without providing specific results required for planning at the local and national level. Therefore, early warning systems are also generally weak and unreliable. Moreover, very little analysis has been done on the needs and the current availability and accessibility of timely and reliable meteorological information for actors in the agriculture sector. Furthermore, institutional capacity building needs to be strengthened in terms of high capacity computing facilities for climate change downscaling, and enhanced human capacity in climate modeling. Ultimately, quality climate change research will assist in improving the agricultural productivity, thereby ensuring the nation's food security.

Considering vulnerability and adaptation to climate change, current research has not adequately addressed the socio-economic dimensions of climate change and food security. The economics of adaptation and mitigation, as well as linkages between climate change, human health, water, food systems, and food security have been the least studied. Climate change vulnerability assessments have had limited scope and covered small areas. Therefore, there is a dearth of information on community strategies and ability to cope with climate variability, extremes, and trends. There are knowledge gaps in terms of understanding local indigenous knowledge and coping strategies, which are essential to ensuring food security in a changing climate.

There is limited information if any, on differential vulnerability of various social groups to climate change consequences in relation to food security. In particular, research is needed on gender dimensions of climate change and food security (Olson *et al.,* 2010). There is a need to understand gender dimensions of climate change and to use this information to inform adaptation strategies by different social groups and decision makers. Most significantly, increased and focused research is needed on how to enhance the capacity of national and local communities to build resilience to extreme events such as floods and drought. Future research of these aspects should employ interdisciplinary and multidisciplinary teams that employ rigorous research techniques that are statistically viable and robust.

Availability and accessibility of weather and climate information

There are limitations to how weather and climate information is generated, processed, stored, and disseminated to various stakeholders in the agriculture sector. Currently, the available climate information has a coarse resolution and is not very useful for landscape-level decision making. Additionally, little research has been done on the availability and accessibility of timely and reliable meteorological information needed by different actors in the agriculture sector. There are also knowledge gaps in terms of understanding local indigenous knowledge and copying strategies, which are essential for ensuring food security under changing climate. Furthermore, there are capacity deficiencies in terms of human resources and facilities for conducting research and monitor climatic variables. Consequently, early warning systems are generally weak and unreliable. Most significantly, increased and focused research is needed about how to enhance the capacity of national and local community and how to build resilience to respond to and cope with extreme events such as floods and drought.

Conclusions

The current agricultural practices in Tanzania cannot ensure food security under changing climate, partly due to the fact that the conventional practices rely on the increasingly erratic and unreliable rainfall. Furthermore, shifting cultivation exacerbates deforestation, resulting in low yields and environmental degradation. The current approach recommended for coping with climate change has been either to adapt or to mitigate without considering possible synergies. Research geared towards combining mitigation and adaptation strategies against the impacts of climate change, focusing on adopting strategies that build climate resilience, reduce greenhouse gas emissions, and increase food security.

Food systems in Tanzania are highly vulnerable to climate change and variability due to the poor adaptive capacity of the socio-economic systems and limited community resilience to cope with climate variability and change. Response to climate change impacts is affected by multiple factors at different scales, ranging from the individual to the household and landscape, which affect food security. Multidisciplinary research is required to provide a science-based analysis of potential coping and adaptation strategies and their economic and social effects. There is a research gap in farmers' knowledge regarding coping and adaptation strategies that can handle the impacts of climate change and variability and reduce food insecurity. An important knowledge gap is how socio-economic factors affect coping and adaptation. In addition, better integration of biophysical and socio-economic approaches across relevant spatial and temporal scales are likely to result in policy and technical options that are more robust and flexible and enhance the adaptive capacities of various stakeholders.

Quality climate change science research in Tanzania is limited by few, scattered, unevenly distributed, and ill-equipped meteorological stations. The available meteorological station data is based on too short a time scale and is of inconsistent quality to statistically detect climate change. There is a need for research to determine the optimum number of weather stations, which would increase the accuracy of information for calibrating climate models. Quality climate change research will assist in improving agricultural productivity, thereby ensuring food security. This calls for more research to improve climate records and obtain improved climate change projections with a finer scale that is suitable for specific agro-ecological zones.

Acknowledgement

The authors wish to acknowledge the Innovative Agricultural Research Initiative iAGRI for providing funding to undertake this review work. The iAGRI is a project implemented in Tanzania within the framework of the US Government's Global Hunger and Food Security Initiative (GHFSI).

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