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Ecosystem tipping points due to variable water availability and cascading effects on food security in Sub-Saharan Africa

Celestine Muli, Nicolas Gerber, Tekalign Gutu Sakketa, and Alisher Mirzabaev

Abstract

The frequency, duration, and magnitude of extreme weather events such as droughts, floods, and variation in rainfall onset and cessation periods will continue to increase. Such stress may result in significant shifts in the functioning of ecosystems. As climate change affects the capacity of ecosystems to mitigate the effects of extreme events such as drought and floods, leading to disruptions in water supply and food production, or to the destruction of infrastructure, human well-being is ultimately impacted. Chief among those impacts are those on the four dimensions of food security: food availability, accessibility, utilization, and stability. An interesting channel of impacts is through the observed and forecasted increase in the variability of water availability. This is said to cause uncertainty in agricultural production resulting in reduced productivity, food insecurity, weak economic growth and the widespread food poverty in Africa today. Due to overreliance on rain-fed agriculture in Sub-Saharan Africa, people usually engage in both temporary and permanent migration after consecutive years of bad harvests and reduced incomes from agriculture with migration acting as an adaptation strategy to climatic shocks. Food value chains can be significantly affected, something that the paper identifies as an area that requires further research mainly on the resilience of food value chains to water variability.

Keywords: Ecosystem, climate change, water variability, migration, food security, food value chains, Sub Saharan Africa

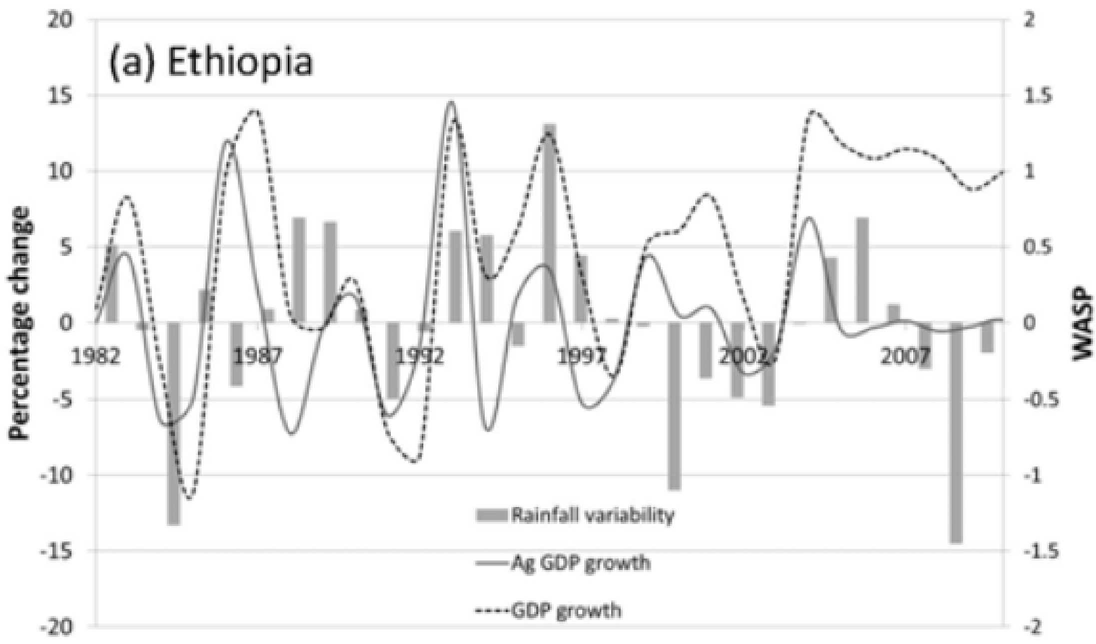
JEL classification: Q10, Q54, J43, J62

1 Introduction

This paper is based on literature, which focuses on the impacts of increased variability in water availability on household's food security levels, and on the adaptation strategies that some households adopt to protect themselves from adverse effects of water variability. We hypothesize that farmers adapt to higher production risks associated with increasing water variability by choosing any combination of strategies for reducing the hazard or improving their resilience. These include shifts to food value chains that are more resilient to the new conditions and household/individual behavioral shifts through labor and time allocation decisions. The shifts could be in terms of alternative livelihood options, including individuals' occupational choices through labor allocation to farm, off-farm and non-farm activities, and in and out-migration. The former strategy is directly related to production and food availability, whereas the latter targets economic resilience to ensure food security through access to and use of more and diverse food. The paper aims at looking at the characteristics and shifts of the socio-ecological system in relation with variable water availability, its effects on food crop producing households, how that can be related to regional and household food security, and the drivers connected to the potential tipping point(s) of food security. Using search words as "climate change", "rainfall variability", "vulnerability", "food security", "labour migration", "value chains" and "Sub Saharan Africa" more than a thousand literature sources were collected from international journals from platforms such as science direct, Google Scholar, Scopus, African Journal Online and websites of institutions such as the IFPRI, FAO, and World Bank. The sources comprised of peer-reviewed, non-peer reviewed, and unpublished sources, which were selected according to the relevance of the topic. The ninety five most relevant literature sources on the subject were reviewed in detail.

The paper looks at Sub-Saharan Africa (SSA) where the economy and the livelihoods of the majority of people remain highly dependent on agriculture. Agriculture contributes up to 30% of GDP and 55% of the total value of African export (World Bank 2007). The majority of the population in Africa still live in rural areas, with 85% on average of rural livelihoods being dependent on agriculture and agriculture-based activities (Shah et al., 2008). Most of the farming in SSA remains rain-fed, covering about 97% of total cropland, and is therefore exposed to climatic risks such as seasonal rainfall variability and continuous degradation of the soils and environment (Shah et al., 2008; Aregheore 2009). In many SSA countries, climate change is being experienced through the rise in temperatures and unpredictable rainfall patterns across all ecological zones with a **s**hift in the rainfall regime towards a longer dry season and vanishing wet season (Asante and Amuakwa-Mensah, 2014a). Recurrent droughts have hindered GDP growth in many African countries and slowed their pace of development (Shiferaw et al., 2014). Yearly variation in the onset of rainfall makes the planning of sowing dates as well as a selection of crop type and variety quite difficult (Mugalavai et al., 2008). Climatic shocks highly increase the vulnerability of rural people as their livelihoods depend to a large extent on environmental conditions (Brücker and Gemenne, 2013) resulting in increased food prices and food insecurity (Sultan and Gaetani, 2016). Reduction in food production, in turn, leads to increased poverty constraining economic growth (Asante and Amuakwa-Mensah, 2014a). Existing poverty and weak institutional, financial and technical capacity to adapt to climate change make African countries more vulnerable in addition to their overreliance on agriculture and natural resources for their livelihood (Abeygunawardena et al., 2002). A close relationship between annual rainfall variability and Gross Domestic Product has been observed in many countries that depend heavily on agriculture for their economic development. For example, the trend as depicted in figure 1 below shows a close relationship between variability in annual rainfall and changes in both the agricultural gross domestic product and the total gross domestic product for Ethiopia (Thornton et al., 2013).

Figure 1: Relationship between variability in annual rainfall and changes in the gross domestic product in Ethiopia.



Source (Thornton et al., 2013)

1.1 Conceptual framework: the impacts of water variability on the functioning of ecosystems and its implications on food security and occupational choices

The paper reviews literature based on:

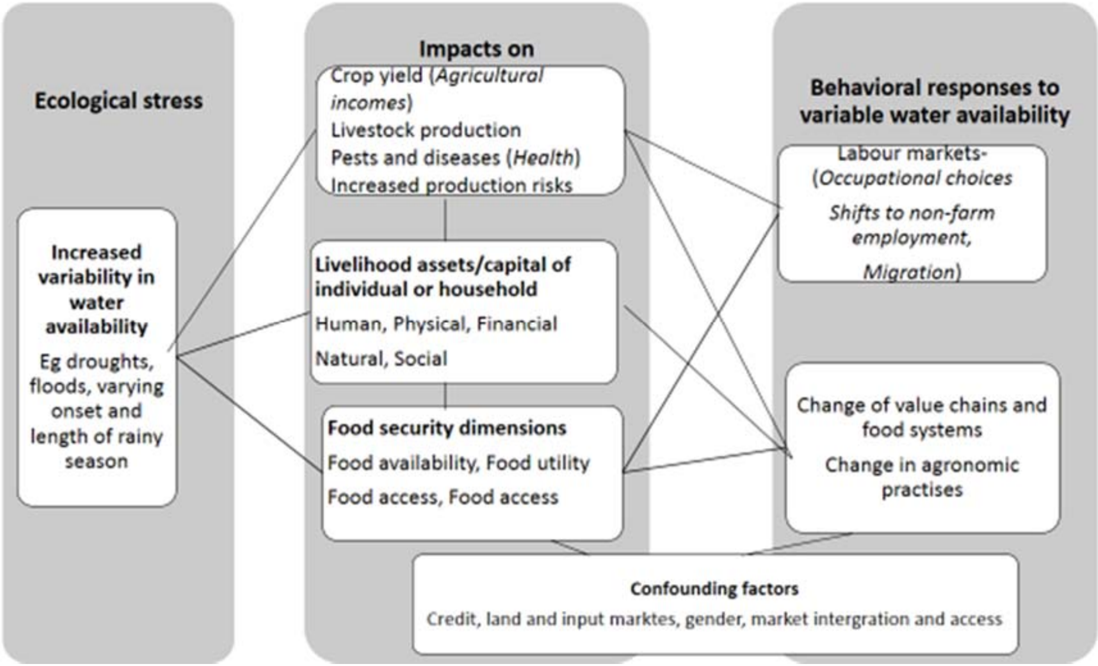
i. The type of ecological stress considered; mainly the variability in water availability,

ii. The impacts of the ecological stress on crop and livestock yields, the health of people, production risks, and how it impacts the four dimensions of food security (food availability, access, utility, and stability). Also household capital endowment and the implications on the overall food security level of population at the household and national levels

iii. Behavioral responses to disturbances due to variable water availability, which include change in individual/household labour allocation for example movement to non-labor activities, change to different food value chains that are more resilient and adoption of agronomic practices to increase resilience of the farming households to these shocks.

The literature also takes into account other confounding factors such as credit, land and input markets, gender and market integration that impact on household decisions towards increasing their resilience to new conditions.

Figure 2: Ecological stress due to water variability implication on food security and the behavioural responses of affected populations



Source (Authors' composition)

2 Literature review

In Sub Saharan Africa (SSA) about 90% of the population depends on agriculture for their livelihood and rainfall availability is a significant determinant of small-scale farmer's agricultural production (AGRA, 2014). Inadequate and uneven distribution of rainfall remain huge threats not only to agricultural systems but also to the livelihood of small-scale farmers in SSA (OECD, 2016). High-intensity rainfall results in the inability of soils to absorb water due to poor infiltration causing runoff, which accelerate land degradation and depletion of groundwater levels. At the same time, irregular and insufficient rainfall patterns (extended dry spells) cause crop failures due to inadequate moisture in the soil for plant growth. According to Tadesse (2010), in 2010 up to 250 million people were estimated to be living under water stress due to climate change. This in addition to increased demand is likely to affect livelihoods and heighten problems related to water deficiency. Agricultural food production and food access in a majority of African countries are likely to be compromised by variability in weather patterns. For example, there is a high likelihood of a decrease in the length of growing seasons and decline in yield potential, especially along the margins of semi-arid and arid areas. In return, this will negatively impact on food security and aggravate the levels of malnutrition in these countries (AGRA, 2014).

In the last decade, the frequency, intensity, and severity of extreme climatic events and weather patterns have continued to increase, impacting human and natural systems. Some of these extreme events include heat stress, drought, and flooding. Variability in the timing and intensity of weather events has had significant impacts on farming systems of smallholder communities who are entirely dependent on natural resources for their livelihood (IPCC, 2014). . In SSA, large percentage of the population remains rural and tends to be highly vulnerable to climatic shocks, as their livelihoods depend largely on environmental conditions. This coupled with rapid population growth, and limited institutional capacity to cope and adapt to the changing weather patterns leads to regular food crises due to a reduction in staple food production (Perez et al., 2015).

Water resource is one of the sectors that are highly vulnerable to the changing climatic conditions and its shortage results in ecological stress. Vulnerability to extreme events such as storms, floods, drought, and varying onset, length, and cessation of rainy seasons, are likely to arise due changing climatic conditions (Thornton et al., 2013; USAID, 2011). In Sub-Saharan Africa, many countries are already experiencing increasing water stress due to unreliable rainfall and changes in patterns and intensity of rainfall. According to (Sarr et al., 2015), in West Africa, flood events have increased in average from less than two in a year during the period before 1990 to more than eight to twelve in the 2000s with a significant loss in crop production and crop income. The increased frequency of heavy precipitation has caused sudden floods and an increase in the occurrence of diseases in livestock and humans (Tog-Noma et al., 2015). Rising temperatures have led to high rates of evaporation and drying out of water, reducing the rate of recharge of groundwater. Frequency and intensity of droughts have continued to increase in the last 50 years (Masih et al., 2014).. Rainfall amount and distribution during farming season profoundly determines agricultural productivity. It also influences the agricultural calendar as well as the type of crops that farmers can grow and activities such as irrigation (Yengoh et al., 2010).

Changes in the intensity and variability of precipitation are projected to increase the risks of flooding and drought in many parts of the world (IPCC, 2008). Floods and droughts have both environmental and economic implications, which can be direct or indirect. Flood incidences lead to crop destruction, runoff and water erosion, death, and injuries to people and animals, prevalence and spread of water-borne diseases and exposure to toxic substances. Also, new diseases that emerge due to temperature and precipitation changes could affect food chains and the ability of people to obtain enough nutrients from the foods that they consume resulting to malnutrition and other health issues (Tadesse 2010). Rising water levels further destroys farms located close to rivers and crops causing soil erosion and in some cases creation of galleys. Floods also wash out unpaved roads leading to inaccessibility especially in rural areas by other actors such as transporters and input suppliers (Monastyrnaya et al., 2016).

Prevalence of droughts result in a reduced amount of water available for crops due to increased evapotranspiration, which lessens soil moisture. Droughts have negative implications on agricultural output with an added risk of extinction of some crop species and surges in pest and diseases. Impacts of droughts are also felt in the livestock sector where the prevalence of drought leads to fodder deficiency and thus loss of livestock and drop in productivity (Lambert 2014; Thornton et al., 2013). Devastating famines are likely to lead to water scarcity and poor health among people due to lack of proper nutrition and economic hardship (Economic Commision for Africa, 2007). These according to (Tog-Noma et al., 2015) are likely to lead to crop destruction thus drop in yields, a decline in soil fertility, gradual loss of biodiversity and hence influencing food security. Variability in weather patterns and frequency in extreme events may have significant impacts on the prevalence of weeds, pests, and diseases in crops and livestock. For instance, outbreak and spread of diseases such as Rift valley fever in East Africa and African horse sickness have been triggered by the combination of drought followed by heavy rainfall (Thornton et al., 2013). A study by (Yéo et al., 2016) in Burkina Faso cited that farmers were noticing new pests and diseases such as swollen-shoot in cocoa and an increase in the incidence of malaria among humans. These shocks are predicted to lower the amount of land that is suitable for rain-fed agriculture by 6 percent and cut down the total agricultural GDP in Africa by 2 to 9 percent (Terr Africa, 2009).

Changing rainfall patterns has brought about shifts in the onset and length of growing seasons. Thornton et al., (2011) projected changes in the period of crop growing season up to 2090 and found that a significant portion of rangeland and cropping area in sub-Saharan Africa will experience a decline in the length of growing season and the southern part of the continent will experience at least 20 percent losses. Late onset of rainfall leads to delay in cropping season and changes in cropping patterns. Farmers cited that rainy seasons had changed over the years and the untimeliness of the rainfall patterns poses significant challenges in determining sowing dates. Farmers predict the start and end of the rainy season from trends of previous seasons but sometimes end up replanting when there are longer rainfall delays. For instance in Ghana, farmers experienced delayed onset and early cessation of rainfall, resulting in shorter crop cycles (Nyadzi, 2016). The Northern part of Ghana experienced highly variable rain over the last 20th century with a delay in onset of the rainy season shifting from April to May and sometimes to June disrupting agricultural calendar and forcing farmers to replant hence increased production costs (Adaawen, 2016a). Analysis of agro climatic data in Côte d'Ivoire by (Goula et al., 2010) showed that the onset and cessation of rainfall in the country remains variable from year to year and from one ecological zone to another. The Northern region experiences rainfall onset from April to May and cessation from October to November The area with two growing seasons, onsets are from March, April up to May. Cessation occurs in July in many parts. Rainfall patterns show that there has been a delay in the whole country during the onset of growing season. Most parts of the country experience a delay of 1 to 10 days while delays of more than 10 days have been observed at the centre, the Northern part and some areas in the South. However, in the North and West early onset are experienced 1 to 10 days. Cessation of the rainy season has also had significant changes. Cessation occurred 1 to 10 days earlier but with time, 11 to 20 days of early cessation are being observed and late cessations of 1 to 10 days.

These effects of variable and unpredictable climatic conditions finally manifest themselves in the form of increased food prices and reduced income for farmers and the agribusiness sector. Other ways include; reduced tax revenues for the government, malnutrition and famine, unemployment and increased conflict and out-migration (Shiferaw et al., 2014). The population in Sub Saharan Africa is expected to reach up to 1500 million people by 2050, which means the overall water, and food demand will increase. The agricultural sector, which provides livelihoods to a majority of the African population, is mainly rain-fed. Climate extremes such as prolonged drought periods, severe floods, variability in onset and cessation of rainfall and land degradation have led to significant reduction in crop yields and loss of livestock. Rural livelihoods in many developing countries which are mainly dependent on natural resources have become endangered (Tadesse, 2010).

3 The vulnerability of food security to water variability

According to the World Food Summit (2009) “Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food, which meets their dietary needs and food preferences for an active and healthy life." Achieving food security is one of the primary goals of the 2030 Agenda for Sustainable development. However, ensuring global food security remains a great challenge due to the complexities of climatic, environmental, socio-economic and institutional factors across different scales (FAO, 2008). The latest global assessment of the state of food security and nutrition shows that after a prolonged decline, world hunger appears to be on the rise again. Up to 815 million people are said to be chronically undernourished, out of which 489 million live in countries struggling with conflict and violence (FAO, IFAD, UNICEF, WFP, 2017). With the growing global population, food price volatility, increasing inequalities, climate and environmental changes, this trend is expected to heighten. Given these trends, the future of food production is likely to be challenged. The majority of the population in Sub Saharan Africa (SSA) depends on agriculture and natural resources for their livelihoods. Aspects of weather fluctuations such as rainfall variability highly impact on agricultural activities with huge implications on the food security status of the people (FAO, 2016b). Agriculture in SSA remains quite sensitive to weather extremes such as droughts and floods due to lack of resources for mitigation. This means that seasonal rainfall variability poses enormous impacts on production and food security levels of households in Africa (Kotir, 2010).

Food security is comprised of four dimensions which include: food availability (production, distribution, trade and exchange, food accessibility (allocation, affordability, and preference), food utilization (safety, nutritional and societal values), and food stability (Kotir, 2010). These four dimensions of food security are likely to be compromised by water variability in the following ways.

Food availability

The most direct and immediate effect that rainfall changes are expected to have on food security is through availability because of changes in crop productivity. Changes in precipitation affect the production of some staple crops, and future changes in frequency and amount threaten to exacerbate this. Rainfall changes will have an impact on yields and also affect both crop quality and quantity (WFP, 2017). Lower and unpredictable rainfall patterns will have an adverse effect on crop productivity through reduced crop growth and duration. For example in Cameroon, a 7% decrease in precipitation causes a US$ 2.86 Billion reduction of net revenue (Molua, 2009). According to (Lotsch, 2007) up to 40% of SSA countries will face a significant decline in rainfed crop and pasture production due to weather changes.

This is mainly due to the vulnerability of subsistence farmers whose capacity to cope with environmental stressors is quite low. Reduction in yields relates to rainfall variability on both water and soil. Rainfall deficits bring about drought, sporadic and high-intensity rainfall contributes to soil degradation and desertification. Increased levels of soil erosion reduce the viability of land for agriculture due to depletion of nutrients. This directly reduces yields and limits the potential of the land, as the soil would require higher quantities of inputs to make it productive. Land degradation also limits the types of crops that can be grown permitting production of crops that are more resilient to poor conditions. Crop diversification is lowered which reduces food sources with implications on health. Soil degradation lowers the capacity of the soil to absorb water leading to runoff and draining of the essential nutrients in the soil which further increases soil degradation and reduces the availability of soil water for crop growth (Kotir, 2010). Furthermore, droughts increase competition for water resources with higher potential of diversion of water for industrial and domestic use limiting access for agricultural purposes. As water becomes scarce, the cost of installation and maintenance of irrigation systems will continue to increase which reduces potential benefits from irrigation. Stress on water availability will have a tremendous impact on crop productivity and food productivity (Thompson et al., 2010). Rainfall variability results in increased risks among rural communities, which include recurrent crop failure, loss of livestock and reduced availability of fisheries and forest products.

For example, in Ghana according to (Kasei et al., 2014) droughts have led to lower production of some sorghum varieties while other varieties have been abandoned. Late varieties cowpea and bambara beans have also been abandoned. A study carried out in Tanzania in 2050 indicates that by 2050, there will be a 20% increase variability in intraseasonal precipitation which will reduce agricultural yields by 4.2%, 7.2%, and 7.6% respectively for maize, sorghum and rice (Zewdie and Markos, 2014). Specifically, water variability will lead to lower food availability because the primary means of food production which include soil, water and biodiversity will be negatively affected (Black et al., 2008).

Food access

Access is based on the ability to procure food. Markets are essential secondary sources of food especially during the hungry season when crop yields do not meet demand, and food must mostly be bought from the market. As droughts continue to become a regular phenomenon, hungry seasons are said to become longer, and reliance on food purchases will increase. Droughts lead to loss of agricultural incomes resulting in the reduced ability of households to access food. When food supply is reduced, food prices increase. A rise in food prices will increase due to population growth and reduced food production. Reliance on food purchases is likely to increase as drought, and reduced crop productivity becomes a common phenomenon. Rising food prices and reduced agricultural income will strain the ability of people to access food. These conditions may force the low-income earners who use a high percentage of their income on food, to sacrifice more assets to meet their nutritional requirements resulting in depletion of household assets. In turn, this will reduce the ability of people to access food resources (Thompson et al., 2010).

Due to the impacts of droughts, many African countries are not able to produce enough food for their own needs putting their food security at risk. These countries have to rely on imports to feed their population. According to (Bren d'Amour et al., 2016) a 5% drop in the volume of rice in a developing country's market could lead to a price increase of up to 17%, reducing the ability of households to access food. Unexpected increases in prices of food decrease the purchasing power of consumers pushing households closer to or below the poverty line. This profoundly impacts the food security levels of urban families, rural households that are net consumers, and female-headed households. This may mean reduced dietary quality and reduced total energy intake, which leads to micronutrient deficiencies for all family members and sometimes leads to increased infant mortality. It also means that at the national level, the prevalence of stunting, underweight and other forms of malnutrition may increase, slowing human development and economic growth. Food imports can help ensure that food is readily available in the market at affordable prices, which also improves accessibility to households that are net buyers. Imports help to smooth out and curb food price spikes during times of droughts and other climatic hazards such as floods that lead to reduced food availability in the markets (Meerman and Aphane, 2012).

Food utilization

Food utilization refers to the dietary intake of an individual and ability of the nutrients contained in the foods to be absorbed by his/her body. Hence, food utilization includes both the diet quality and also the quantity of food consumed (Pieters et al., 2013). Risks that are related to climate severely affect calorie intake, particularly in areas where chronic food insecurity is already a significant problem. Changing climatic conditions could also create a vicious cycle of disease and hunger. Nutrition is likely to be affected by rainfall variability through related impacts on food security, dietary diversity, care practices and health (WFP, 2017). Food sources that are not able to provide a balanced and nutritious diet are likely to have significant adverse implications on productivity and health of populations. The ability of people to engage in valuable contribution and livelihood activities depends on the good health of the individuals (Thompson et al., 2010). Food safety conditions and changing disease pressure from water, vector and food-borne due to droughts and floods will affect the ability of individuals to utilize food efficiently. For instance, extended droughts can increase risks of meningitis outbreak or floods can lead to cholera outbreak, lowering the ability of those affected to utilize food efficiently. Areas that lack basic infrastructure and sanitation facilities will be impacted by aspects such as flooding raising the number of people exposed to water-borne diseases and thus lowering their productivity levels and capacity to utilize food (Schmidhuber and Tubiello, 2007). Reduced agricultural incomes due to reduced production affect the ability of households to purchase a diversity of food items that constitute a balanced diet. Food prices in SSA have continued to increase since 2006 and by almost 50 percent from 2010 to 2011 with a decrease in supply being one of the causes (Zewdie and Markos, 2014). Due to the high prices of food, many households may be forced to reduce both their quality and quantity of food that they consume.

Food stability

Households' or individuals' food stability is ensured when they have adequate access to food at all times. For example, if unexpected shocks such as economic crisis and poor climatic conditions take place, individuals and households need to acquire the measures that protect them to have stable food access (Uribe et al., 2010). Intense and unpredictable rainfall events can upset the stability of individuals' and government food security strategies, creating fluctuations in food availability, access, and utilization (WFP, 2017). Increase in the frequency and severity of events such as floods and droughts and changes in the amount and timing of rainfall within the season can bring high fluctuations in crop yields and food supplies (Chijioke et al., 2011). Rainfall variability is likely to increase across many regions with short-term fluctuation in food production being more pronounced in arid and semi-arid areas. This means that there will be greater instability in food production and income generation in the poorest regions of the world (Schmidhuber and Tubiello, 2007).

In summary, changes in rainfall affects food production either directly through changes in agro-ecological conditions and indirectly by affecting distribution and generation of incomes, therefore the demand for agricultural produce. Due to changes in amount and frequency of precipitation, arable land may become increasingly arid and unsuitable for cropping and hence reducing the amount of yields produced. The increase in agricultural pests, and diseases will also lead to the loss in agricultural produce (Tubiello et al., 2008).

4 Impact of water variability on household capital endowment

Household livelihood security is said to be mainly affected by various resource endowment. The livelihood of a given household is primarily dependent on its asset endowment, which enables it to have a sustainable living. Climatic shocks that directly affect household endowments has indirect impacts on the households' food security (Geffersa & Berhane, 2015). Ownership of different forms of capital plays a huge role in sustaining livelihoods, enhancing the ability to manage risks and securing food for the household (Ramírez, 2002). A household's livelihood is hypothesized to be dependent on its resource endowment, which is broadly summarized in the following categories: human, financial, social, natural, physical, infrastructural as well as political and institutional capital. Availability of these different forms of capital enables households to attain sustainability in their livelihoods. Food security, as being a significant part of one's livelihood is majorly determined by the level of resource endowment a household owns (Demeke et al., 2011). Variability in water availability has severe impacts on livelihood assets in both rural and urban areas and threaten the stability of food supply (Black et al., 2008).

Table 1 below presents the various forms of capital owned by households and examples for each at the household level.

Table 1: Household capital endowment

Asset category	Examples at the household level
Natural	Private land and pasture, forests, fisheries, water: quantity and quality.
Human	Household size and composition, nutritional and health status, dependency ratio, education, and skills.
Physical	Productive assets (tools, equipment, work animals), household assets (e.g., housing, household goods), stocks (e.g., livestock, food, and jewellery).
Financial	Cash, credit access, savings, and insurance markets.
Social	Intra-household dynamics, household social ties, and networks.
Infrastructure	Sanitation, access, and proximity to clean and safe water, education, health, marketplace, storage, and roads.

Physical capital

Physical capital refers to productive assets that enable a household to have a sustainable livelihood. They include livestock, land, machinery and other movable assets. These can be converted into cash or exchanged for goods or services (USAID, 2012).

Garrett et al., (1999) and Grootaert et al., (2004) found that the size of land that a household cultivates affects its food security level. This is because land is the primary resource input in the production of food. As the size of farmland increases, a household is likely to get more output. Thornton et al., (2013) describes that with extreme climatic conditions, large parts of the cropping and rangeland area of sub-Saharan Africa are projected to experience a decrease in growing season length, meaning that these lands will start to lose their productivity. Shortage of water in irrigated areas may result in a massive reduction of the irrigated share of agricultural production, heightening direct impacts of weather-induced variability on production in these regions (FAO, 2016; Chijioke et al., 2011). According to (Zewdie and Markos, 2014) projections show that by 2025 two thirds of the land in Africa that is suitable for arable farming is expected to be lost due to decreased rainfall and reduced yields. Lotsch (2007) projected that by 2039 the continent is expected to have lost on average 4.1% of its cropland. The northern and eastern parts of Africa will lose 15% cropland in the next 30 years. Eritrea, Ethiopia, Kenya, and Sudan will experience a loss of more than 20% in the length of growing seasons (Shah and Velthuizen, 2002).

Livestock possession can act as a coping mechanism by helping households reduce vulnerability to food insecurity (Little et al., 2006). When crops fail due to drought, households with substantial livestock sizes can sell some of their livestock to purchase food or slaughter for meat. Livestock production is severely affected by droughts, which leads to a reduction in forage quality and quantity and drinking water. Pastures also start to lose their nutritive value. Increased disease and pest attacks lead to reduced yields and mortality. The carrying capacity of grasslands and rangelands, as well as feed production for non-grazing systems are negatively affected. These in return lead to reduced milk production, livestock reproduction and increased animal mortality (Akudugu et al., 2012; FAO, 2016).

A household's level of asset ownership can affect its ability to withstand risks such as crop failure or situations that require additional expenses. Sale of an asset can help combat risks, act as collateral to secure a loan or can be sold to buy food in times of drought (Maxwell and Smith1992). Climatic events such as floods can lead to destructions of property that constitute household assets hence adverse effects on livelihoods. Degradation of arable lands and loss of biodiversity in terms of animals and plants through floods and droughts leads to immense depletion of natural capital. Drying up of rivers and streams used for irrigation and animal watering has severe implications on livelihoods of those who depend on these capitals as this increases their vulnerability. Reduction in rainfall also adversely affects hydroelectric production and the energy that is used in the production of goods (Akudugu et al., 2012). Severe droughts can make farmers sell their productive capital such as cattle to compensate for income shocks. This in return has a direct impact on farming households which limits their capacity to meet expenditures such as education and health (FAO, 2016b).

Social capital

Social capital is generated by the household's connections in a social network, and the trust, reciprocity, and resource sharing qualities of those connections. It encompasses the network of people and institution a household can resort to in case help is needed or where a household can get information. Social capital helps farmers to acquire social support networks, which also works as an insurance mechanism (Ellis, 2000). Since formal insurance and finance markets are not common in developing countries, informal arrangements play a crucial role (Alderman et al., 1992). Farmers exchange information within farmer organizations about new technology and new ways of farming. Difficulties to access the diminishing natural resources like pasture lands and water by pastoralists, which continue to become bare due to droughts leads to conflicts and breakdown of social cohesions. Also, competitions and conflicts are likely to arise between crop farmers and animal herders that quickly lead to disputes (Akudugu et al., 2012). In Burkina Faso for example, because of the loss of livelihoods, migration movements are triggered, mainly from the central plateau to eastern and western areas of the country. Droughts also affect nomadic patterns, which have indeed expanded beyond their traditional geographical regions of destination. Resource scarcity and possible competition for its access may induce and create tensions between sedentary and nomadic communities. Conflicts occasionally arise from migrations and also due to land tenure issues (Nielsen, 2016). In Cote d'Ivoire, due to reducing rainfall in the Northern part, movement of farmers towards forest regions to practice their agricultural activities has led to a high concentration of population in these regions resulting in conflicts between natives and farmers. There has also been a movement of cattle farmers towards the South (forest region) to look for green fodder crops causing conflicts between pastoralists and farmers (Danumah et al. 2016; Alama 2009).

Human capital

This refers to the livelihood knowledge and capabilities possessed by individuals as well as the health status that determine how effectively individuals apply their knowledge and skills to livelihood activities. Critical determinants of human assets include individuals' access to education and training, health services, gender, number of people in a household and adequate amounts of nutritious food (USAID, 2012b).

Men and women have access to a different combination of livelihood assets (human, natural and social). In SSA female smallholder farmers, face higher barriers to access credit compared to their male counterparts. Men and women also have varying degrees of power in decision making which affects their level of vulnerability. Women face more constraints than men on formal legal and regulatory issues, especially on land tenure. Additionally, social norms and time constraints may prevent women from participating in off-farm activities and access to markets, which influences their incomes and ability to adjust their agricultural production. Women's' access to credit facilities becomes limited due to lack of assets that can act as collateral. This results in their inability to undertake agricultural investments that require money and labour (Lambrou and Nelson, 2010). During times of drought, women are forced to travel long distance spending a lot of their time in search of drinking water which affects their ability to engage in productive labour (USAID, 2012a).

Educated (with formal education) household heads are more likely to manage their farm well by adopting new and improved technologies and inputs, which in turn leads to increased total yield. They are more likely to access knowledge on ways of mitigation such as obtaining credit and installing technologies such as irrigation systems and greenhouses (Garrett et al., 1999).

Looking at the size of households, large households are likely to suffer more from food poverty. Climate stress on livelihoods such as floods, droughts, and unpredictable weather patterns may force people to migrate. As land and soil degradation increases, production and incomes start to decline. Water scarcity and conflicts caused by extended droughts makes people abandon their land (FAO, 2017). Most people carry out migration as a mitigation strategy. In many cases, migration involves the most active and most educated members of the family. More responsibility for raising crops and livestock is put on the old people and children left behind. The workload of those left behind greatly increases to the extent that there could be severe labour shortages at critical times in the agricultural calendar, especially during times of harvest, cultivation, and planting when the demand for labour is high. These shortages also limit the land size that households can cultivate, resulting in lower production (IUCN, 1989). In addition, those left behind due to inadequate education may lack necessary skills especially on modern technologies such as improved sustainable land management strategies against poor weather conditions and soil degradation. Migration of mostly economically active persons from rural areas brings about changes in household structure with implications on labour availability and hence agricultural productivity (Adaawen, 2016b).

The health of household members is also paramount. The sickness of working household members is likely to result in reduced income since a significant fraction household income is used for medication and the loss of income contribution and farm labour from the sick person. The flow of income as well as farm productivity of the household are affected, compromising the households' food security (Kayunze and Mwageni 2013). Climatic aspects such as drought and floods may result in poor health among household members. Shortages of food due to drought may cause malnutrition and lack of physical energy while floods may lead to aspects such as diarrhoea and cholera, which limit the ability of people to engage in productive activities.

Infrastructural capital

Access to transportation and communications systems, water and power lines, increases accessibility to markets and enables efficient flow of information. Access to information on inputs, output prices and, markets is fastened which create additional income from non-farm employment opportunities (Tembo and Simtowe 2009). Households that have access to infrastructural facilities have a higher chance to be food secure. Infrastructure increases the access of rural populations to markets where they can purchase different types of food and sell their surplus. Extreme weather events such as floods can pose threats to rural roads inhibiting access of rural households to markets which limits their food base and nutritional intake (Chijioke et al., 2011).

Financial capital

Access to financial capital such as credit helps to increase production by enabling a household to purchase inputs and expanding income-generating activities. Having access to credit by households gives them, a way to invest in the farm and non-farm activities and generate more income, which supports them achieve food security and diversify their livelihood (Diagne, 1998; Devereux, 2001). Access to finance gives farmers the ability to purchase and invest in sustainable land management practices and technologies such as irrigation technologies and greenhouses that can aid in mitigating climatic shocks. Households that have access to credit are less likely to be vulnerable to climatic hazards. Prolonged climatic shocks such as drought and floods can lead to depletion of household assets that can be used as collateral to procure credit undermining the ability of households to access credit.

Table 2: Impact of climate variation on household assets

Household asset ownership	**Prolonged drought**	**Delayed onset of rains**	**Above-normal rains**
Physical assets	Crop failure, erosion of savings, death of livestock, depletion of seed resources in granaries, trees cut down for income generation, wealth and productive resources liquidated, reduced animal feed	Shortage of water resources, delayed planting leads to short maturing and lower yielding varieties and fewer sales, animals get weak and sick, wealth resources liquidated	Waterlogging and increased pests destroy crops, increased diseases affect humans and livestock, water damages housing and grain stores, increased pests in grain stores, small animals drown or washed away, disrupted transport reduces the sale of goods
Human capital	Increased labour migration, malnutrition, undernutrition, disease epidemics (cholera, dysentery) due to poor sanitary conditions, morbidity and mortality of income earners	Hunger, undernutrition, education suffers as children sometimes have to stop school until money is acquired to pay school fees	Disease epidemics, stagnant water, flooding, and poor sanitation leads to disease outbreaks, including malaria, cholera, and diarrhoea, respectively. Schools and health centres might be structurally damaged or closed because of restricted access
Natural capital	Firewood depleted, poor pastures, limited water supply, dry soils, increased erosion, gathering of wild food	Firewood depleted, poor pastures, limited water supply, dry soils, increased erosion, gathering of wild food	Increased flooding and waterlogging, increased pests
Social capital	Kinship networks weaken as resources depleted (claims not met) and increased migration, exploitation of common property resources increased conflict	Temporary exploitation of communal resources	Kinship networks weaken as resources are depleted (claims not being met), increased conflict, safety nets destroyed, employment opportunities decrease, increased migration for work

Adapted from (Ziervogel and Calder, 2003)

5 Water variability, production risks, and behavioral responses

In the face of increasingly unpredictable onset of the rainfall (Olabisi et al., 2017) and water variability during the crop cycle, farmers are confronted with risks of crop failure (Sonwa et al., 2017) or a variable outcome of their investment that threaten food security at household level. Deterioration of the environment has increased pressure on the available natural resources especially farmland. In return, this affects the capacity of farming households to carry out sufficient agricultural production and increases costs of production contributing to increased poverty levels, which trigger migration. Farmers respond to these risks with shifts in their production system, opting either to reduce the hazard (Perez et al., 2015) or building/increasing resilience (Guan et al., 2017). Risk management strategies depend not only on the frequency and intensity of hydrological hazards and farmers' vulnerability but also on the availability of production factors at the household level and access to markets.

Generally, in Africa, poor rural households improve their livelihoods through the following ways; expansion of the agricultural area, change of cropping systems, diversification into non-agricultural sources and migration into urban areas or to other rural areas. Migration usually makes a household member unavailable and reduces the labour force available for farm activities, which may also reduce the amount of farmland that is cultivated. Due to reduced labour, farm output declines, however, it can be compensated by remittance send back by the household members (Tsegai 2005). Water variability induces response mechanisms, which include shifts in cropping systems and wider livelihood options. Some examples are income-generating opportunities such as a shift of labour from agricultural to non-agricultural activities that can be understood through their respective labour allocation, or as strategies of mobility (migration). Industrial crops (cash crops) and mining represent alternative livelihood strategies to food crops that are less sensitive to variable water availability. Such response strategies to variable water availability may enhance existing conflicts or create new tensions if groups of farmers decide to move into economic sectors or geographic space that is occupied by other actors. As such, social conflict can be seen as an unintended feedback loop of adaptation.

5.1 The vulnerability of food value chains to water variability

Development of value chains is one of the primary strategies in integrating smallholder farmers into trade processes. Well-developed value chains bring about an increase in productivity, quality enhancement, and efficient marketing, leading to increased incomes to the target groups. Poorer households and marginalized groups can be easily integrated into staple food crop value chains due to lower barrier. Their promotion would have a direct impact on food availability of the majority of populations engaged in small-scale agriculture which is an essential aspect in achieving food security (Fritz-Sch and Bon, 2016). Variable weather conditions can affect the whole chain and value adding activities for agricultural commodities from production to consumption of the final good. Weather shocks lead to a loss of production, destruction of infrastructure in both processing and transport. This may increase food supply shortages, increase in transport costs which leads to rise in price of the final good (Dekens and Bagamba, 2014). These shocks affect all actors in the agricultural value chain such as farmers demand fewer inputs with reduced income to private input dealers and other actors in the agricultural produce marketing chain for instance transporters also end up losing business (Monastyrnaya et al., 2016).

The resilience of the value chain remains crucial to ensuring food security in SSA. Resilience of food value chains refers to the "capacity over time of a food system and its units at multiple levels, to provide sufficient, appropriate and accessible food to all, in the face of various and even unforeseen disturbances" (Tendalla et al., 2015). This includes the capacity of the system to minimize food insecurity when faced with persistent disturbance and changing environment. Some of the impacts of water variability on value chains include; reduction of usable area for cultivating due to drought, reduction in rice yield and grain quality (Rowhani et al., 2011), decline of crop productivity with higher negative impacts on irrigated fields and significant crop and income losses among smallholder farmers (Terdoo and Feola, 2016). The shocks caused by water variability leads to increased production risks. Farmers start to experience unstable incomes and food supply (Ray et al., 2015). Due to increased production risks, the vulnerability of food value chains also increases. Increased post-harvest losses during storage and distribution as a result of infestation by pests and diseases add more burden to supply chains (Pinto et al., 2012).

Farmers in SSA countries are more likely to suffer due climatic shocks especially because of the unfavourable environment compounded by the fact that they sell their products as raw materials or with limited value addition (Terdoo and Feola, 2016b). They also lack the infrastructure that enhances resilience to climate weather shocks such as irrigation systems, early warning systems, hydrological systems and telecommunication facilities for information transfer. Inadequate financing mechanisms in many countries inhibit farmers from investing on climate-smart agriculture infrastructure. For instance; farmers are unable to manage risks associated with adoption of new technologies such as agroforestry and conservation agriculture since their benefits come in several years. Farmers also lack access to credit and insurance. To market their products, farmers tend to depend heavily on intermediaries who eat into profits. They are therefore unable to earn enough to invest to climate resilient infrastructure (Dekens & Bagamba, 2014) with climatic shocks increasing these powers inequalities and asymmetries. Distrust among actors in the value chain is a major concern, such as lack of trust between farmers and input suppliers who sell low-quality inputs to farmers (Dekens and Bagamba, 2014). Counterfeit inputs erode trust between farmers and input dealers making farmers hesitant to buy inputs from local markets. As a result, the information flow between input dealers and farmers is hindered due to bad experiences with counterfeit inputs. Farmers become suspicious towards the input dealers, and in turn, input dealers opt not to sell their products on credit to farmers in fear of non-repayment (Monastyrnaya et al., 2016).

Women are more vulnerable to the impacts of rainfall variability because often they cannot participate in the agricultural value chains effectively as men. This can be due to inadequate access to land (land tenure rights), biased inheritance patterns that favour men, gender biased cultural norms, poor credit access due to lack of collateral and discrimination in the decision making process (Demont, 2013). Lack of proper land rights also hinders farmers from investing in sustainable land management practices such as soil and water conservation. With lower yields, the income for farmers is reduced that they can afford cheaper inputs This results in low-quality products, which further reduces their yields and income. Payment of farming loans also becomes a challenge (Dekens and Bagamba, 2014).

5.2 Change in value chains and agronomic practices as an adaptation strategy

As water variability continues to become a normal climatic condition, farmers have been forced to make adjustments in their agricultural systems. To ensure resilience, farmers diversify their crops so that in case one crop fails, yields of another crop can compensate it. For instance in Burkina Faso farmers grow cocoa and plantain, cashew nut and teak. Farmers tend to adjust their crops to varieties that can withstand variable climatic conditions such as drought tolerant, short cycle cultivars and abandon longer-cycle crops to secure their incomes. In Ghana, cocoa and coffee is replaced with cashew nut and teak. Additionally, a cocoa variety known as French cocoa are being replaced by Mercedes cocoa variety. Agroforestry is another major adaptation strategy using fast-growing tree species (Yéo et al., 2016). Communities also undertake and invest in soil and water conservation measures such as micro water harvesting techniques, stone lines, conservation of crop residues and use organic matter. With the extended dry periods and decreased rainfall amounts communities are growing more heat tolerant crop varieties. Adoption of early maturing and supplemental irrigation are other strategies adopted by farmers. Shifting of planting dates also helps farmers to cope with changing onset and cessation periods of rainfall (Sarr et al., 2015a). Farmers also engage in intercropping to minimize the risk of crop failure. In Ghana, cocoa farmers preserve parts of their land to grow food crops for their households (Asante and Amuakwa-Mensah, 2014b). In Burkina-Faso, the reduction of seasonal rainfall has enabled households to cultivate lowland areas. Households in most of the dry regions adapt to reduced production by the expansion of the area cultivated, diversification into livestock farming and increase in fertilizer use. Construction of stone bunds is also a widely practiced technique to combat run-off and erosion by farmers. The stone bunds contribute to conserving more moisture in the soil thereby helping to alleviate water stress during dry spells (Sarr et al., 2015b). Commonly-encountered measures to reduce drought hazards include investment in irrigation, the building of field bunds (Touré et al., 2009) or shifting the production from vulnerable upland to more favorable lowland fields (Shiferaw, et al., 2014). The adoption of drought-tolerant genotypes or crop species is a short-term response while building soil organic matter or other buffering measures require longer time horizons. Investment in perennial cash crops or high-value species (i.e., vegetables) can generate income, providing indirect strategies to ensure food security locally (Afari-Sefa et al., 2012). The type of system shifts also depends on market access and the structure of value chains and thus differs between rural and peri-urban areas. Therefore, changes in production systems and cropping strategies at the plot and the farm levels may differentially affect food security at the household and the regional level (Demont and Ndour, 2015).

5.3 Adaptation through migration

Environmental conditions are paramount to the extent that people are likely to migrate from areas with unfavourable conditions such variable and insufficient rainfall, degraded and land-scarcity. People from drier rural areas move to wetter regions temporarily or permanently with short-term rainfall deficits increasing the risk of long-term migration to other rural areas (Brücker and Gemenne, 2013). Labour adaptation measures include a move to salaried agricultural activities. Households that are rich in labour engage in casual day labour in exchange for money or food on someone's farm. Many households result to salaried non-agricultural activities, which in most cases involves migrating outside the village to cities. Households that possess large parcels of land during climatic shocks in most cases are found to engage only in short-term migration and do return to the village after the shock, while land-poor households are more likely to engage in permanent migration in the course of climatic shock. Migration acts as a risk management strategy whereby people carry out migration as a way to diversify their portfolio of economic activities and improve their living standards (Waldinger and Fankhauser, 2015). In Tanzania (Beegle et al., 2011) cited that migration increased consumption growth by 26 percent while the most vulnerable and poorest because of lack of resources may not be able to migrate (trapped). Belayneh, (2017) found that rainfall variability and inconsistent onset and cessation dates are likely to increase migration by 13 percent within the following year.

A study on "Migration and self-protection against climate change" in Northern Kenya showed that migration of labor could serve as a way to mitigate the impacts of climate change, especially for pastoral communities. Households which have at least one member who has migrated to seek off-farm employment receive remittances which enable them to purchase high-cost innovations such as irrigation systems (Ng'ang'a et al., 2016). However, migration involves men more than women leading to increased male absentee rates in rural areas. More responsibility for raising crops and livestock is put on the women and children left behind. The workload of those left behind greatly increases to the extent that there could be severe labour shortages at critical times in the agricultural calendar especially during times of harvesting, cultivation, and planting when the demand for labour is high. These shortages also limit the land size that households can cultivate leading to lower production (IUCN, 1989).

Many countries in SSA are faced with a strong climate uncertainty, for example in Burkina Faso, apart from droughts and floods, desertification remains a major challenge due to its close vicinity to the Sahel. Droughts and floods account for 45 percent of natural disasters occurring in the country and often lead to displacement and migration. Droughts reduce yields in certain crops such as cotton and yam, which require a significant amount of water. As a result of the loss of livelihoods, migration movements are triggered. Droughts also affect nomadic patterns who have indeed expanded beyond their traditional geographical areas of destination. Resource scarcity and possible competition for its access induce and creates tensions between sedentary and nomadic communities. Conflicts occasionally arise from migrations also due to land tenure issues. Migration remains one adaptation strategy especially amongst the youth but only applies to households that can afford the migration costs. In Burkina Faso, internal migration is mostly directed to rural areas, secondary towns and to major urban centres such as Ouagadougou and Bobo Dioulasso (Brücker and Gemenne, 2013). Climate variability plays a major role regarding migration decisions as agricultural production starts to decline due to unfavourable weather conditions return migrations continue to be less attractive because of environmental damage. Poor and unpredictable rainfall remains a challenge with either too little rainfall, rainfall falling at the wrong time, prolonged droughts, heavy rainfall and false starts whereby the rainfall starts but stops abruptly and unexpectedly (Nielsen, 2016). In Ghana migrations which used to be a circulatory seasonal migration to work in the mines and cocoa producing areas of southern Ghana, has seen people moving to the urban centres with Accra and Kumasi being the major destination areas (Adaawen and Owusu, 2013). Although men dominate the movement, women and children are also migrating in large numbers to work in the south of the country. Movements include massive rural-rural migration of workers to look for employment in plantation farms in the south of the country, migration to the gold mining areas and substantial movement of children and young adults from the north to work in commerce and trade in the cities of Accra and Kumasi (Anarfi et al., 2003). Migration of mostly economically active persons in the area brings about changes in household structure affecting labour availability and in return agricultural productivity. At the same time, the cash and social remittances that migrants send or bring along have brought some level of development and social transformation in the rural areas (Adaawen, 2016b).

Migration acts a major adaptation strategy whereby agricultural workers who shift to non-agricultural labour as a way of survival experience lower cutback in their wages since droughts result to long-term losses on agricultural wages. On the other hand, investment in irrigation and alternative crops that are more tolerant to drought decrease vulnerability to climatic changes in the long run (Wilkinson et al., 2016).

6 Conclusion

In SSA variability in water availability and extreme weather events such as floods and droughts are the main risks affecting agricultural productivity and household food security, especially in rural areas. A large percentage of the population in Africa remain rural and tend to be highly vulnerable to climatic shocks as their livelihoods depend to a great extent on environmental conditions. Food insecurity remains a common phenomenon coupled with rapid population growth and limited institutional capacity to cope and adapt to variable rainfall conditions. This has lead to regular food crises due to a reduction in crop productivity.

A failure of the rainy season leads to loss in agricultural production and hence the subsequent reduction of the availability of food at the household level. The decline in food production, rise in food prices and a decrease in purchasing power compromises access to food. Impacts of climate change will have negative implications on crop productivity in many parts of the world. Cropland area in Africa is likely to decrease significantly. SSA will continue to experience an increase in the land with moisture stress and expansion of land with climatic and soil constraints and hence a significant loss in yields and increased risk of hunger. As precipitation falls, net revenues from agriculture will also continue to fall. With the increase in migration of farmers from rural to urban areas in search of off-farm employment, there is an unlikelihood that cities can absorb the increasing number of rural-urban immigrants. The displaced populations often end up living in risky areas in the urban areas. They also take essential knowledge and skills with them leaving the communities behind with insufficient capacity to carry out farming. Measures of mitigation and adaptation to the changing climatic conditions need to be put in place to reduce forced migration. This includes promoting means to a livelihood that are less risky which consist of switching to off-farm activities and improving market linkage to people living in rural areas. Policies that work to create economic opportunities can sustain livelihoods, increase resilience and reduce farmer's vulnerability.

It is vital to help smallholder farmers to build resilience and adaptive capacity to cope with current weather-induced risks. Activities that have shown to increase productivity such as facilitating access to fertilizers, irrigation, improved and drought tolerant seeds among other inputs should be supported. Improving market access and road infrastructure. The most important is facilitating access to timely climate information. This would inform farmers on crop choice, planting dates and other management strategies to avoid losses like replanting due to rainfall delays. Additionally, access to irrigation infrastructure would reduce overreliance on rain-fed agriculture. Agroforestry techniques would also play various roles such as enhancing the resilience of agricultural systems against increased temperatures, soil erosion, as well as act as carbon stocks. Better tenure rights would help farmers in investing in sustainable land management practices. Agronomical practices and use of cultivars that are more suitable to the new climatic regimes remain to be the major adaptation strategies to the intensified and shortened rainy seasons in these areas.

In addition, policymakers will have to consider whether adaptation policy should work towards making people more resilient at their location or facilitate people in leaving to look for other means of livelihood. For example, smallholder farmers living in extremely fragile environments where water scarcity has become a significant constraint will experience even bigger challenges in the future as their harvests will continue to decrease. There is a need to consider whether investments in drought-tolerant crop varieties and irrigation technologies will be sufficient to reduce vulnerability in the long run for example if the new crop varieties fail. Farmers might find themselves struggling to repay for their loans if they had taken credit to purchase these new interventions. Rainfall variability will negatively affect food security at the global level. This is because there will be a reduction in crop yields and the land suitable for agricultural production especially in the tropics where already high levels of food insecurity persist. Food prices will increase affecting the ability of poor farmers to purchase food. Disease outbreaks will affect the ability of the body to absorb and utilize nutrients. In the least developed countries levels of malnutrition among children is said to increase. Ultimately, the level of impacts of water variability will depend on the ability to adapt to these changes. Changing weather conditions will lead to decreased production in lower latitude areas while higher latitudes would even benefit from increased temperatures leading to increased production. These different regional implication implies that trade could play a major role to lower potential shortages in low altitude areas. Trade could help stabilize food supplies from food surplus to food deficit areas. Trade, therefore, can act as an adaptation mechanism to changes in climate by stabilizing prices and become a contributor to food security in countries that experience reduced production (FAO, 2017). From the literature, the role of trade in helping to minimize the impacts of water variability still requires further research. Also, studies need to look into the effects of water variability on the functioning of existing value chains and how to ensure resilience either through sustainable land management strategies or other measures.

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