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Droughts in East Africa: Causes, impacts and resilience

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Abstract:

East Africa (EA) has been the primary focus for various drought studies in recent years. However, a comprehensive analysis of droughts, including their evolution, complexity, social implications and people's vulnerability is currently lacking. Hence, there is a pressing need for an overview of drought studies in EA. Here, we present a state-of-the-art review of the causes and impacts of, and resilience to droughts in EA. Studies reveal that droughts tend to be more frequent, longer and more severe in the boreal spring and summer in EA, as the overall precipitation and water storage abruptly decline. A decrease in drought frequency is observed during the boreal autumn season (October–November). As these studies have only been analysed within the context of sparse and short-term regional climate data with very complex spatial and seasonal climate patterns, they are subject to uncertainties. The main causes for the changing pattern of droughts include climate variabilities and anthropogenic effects. Droughts have extensive impacts on human beings, environment, water resources and agriculture. Environmental rehabilitation involving the development of ecosystem services, biodiversity enhancement and soil and water conservation is found to be a suitable strategy to adapt to drought conditions. A better understanding of the causes and impacts of droughts, participatory management and community level actions are essential for building resilience to drought. Strong citizens–government–stakeholder cooperation is also valuable in monitoring and managing drought. The knowledge and insights gained from this review will help the countries in EA to build a drought-resilient society and will form a basis of information for other regions outside of EA.

Keywords: Drought; East Africa; anthropogenic activities; rainfall; Horn of Africa; climate variability

1. Introduction

Through its complex and hazardous effects, drought is challenging the environment and societies globally (Wilhite, 2000; Wilhite and Glantz, 1985). Most continents have experienced frequent droughts in the last three decades (Mishra and Singh, 2010, 2011). Drought has affected North America, such as the United States of America (Cook et al., 2007) and Canada (Wheaton, 2000), Europe (Demuth and Stahl, 2001), Asian countries such as Iran, Afghanistan, Tajikistan, Uzbekistan and Turkmenistan, Russia, China and India (Bates et al., 2008; Grumm, 2011; He et al., 2016), and Australia (Murphy and Timbal, 2007; Bond et al., 2008; McGrath et al., 2012). In Africa, various drought incidents have caused much devastation, including crop failures, livestock deaths and human losses at different spatiotemporal scales (Guha-Sapir et al., 2004; AghaKouchak, 2015; Mo and Lyon, 2015). Droughts resulted in around 450,000 deaths in Ethiopia and Sudan during 1984-1985 (Guha-Sapir et al., 2004; Vicente-Serrano et al., 2012), over 325,000 deaths during 1974-1975 in the Sahel (Benson and Clay 1998; Mortimore and Adams 2001; Guha-Sapir et al., 2004; Vicente-Serrano et al., 2012), and around 100,000 deaths in Mozambique (Guha-Sapir et al., 2004). Furthermore, the impacts of drought tended to be aggravated by deforestation, land degradation, growing water demand and climate change, as a result of climate variability, anthropogenic activities and increased global warming (Sheffield and Wood, 2011; Sheffield et al., 2012; IPCC, 2013; Trenberth et al., 2014; Zhao and Dai, 2015).

Droughts have occurred for millennia in East Africa (EA; Kiros, 1991), and often manifest as endemic events to the region (Lyon, 2014; Muller, 2014). In the last two decades, the region was marked by a number of prevailing dire drought events (Guha-Sapir et al., 2004; Funk, 2012; Hoell and Funk, 2013; Viste et al., 2013; Muller, 2014; AghaKouchak, 2015; Ayana et al., 2016; Nicholson, 2015, 2017). In EA, drought occurrence is frequent but has been difficult to forecast due to various natural and anthropogenic factors along with inefficient forecasting capacities. As a result, drought has had a severe impact on the environment and the socio-economic welfare of the societies in the region. Climate change, land use change and socio-political and institutional transitions in EA have caused recurrent droughts (IPCC, 2007; Meier et al., 2007; Trenberth et al., 2014; Zhao and Dai, 2015). Drought frequency in EA has doubled from once every six years to once every three years since 2005 (Guha-Sapir et al., 2004; Meier et al., 2007; Ayana et al., 2016). Over the past 16 years, EA has been struck by eight boreal spring droughts (Funk et al., 2014). In 2008-2010, drought hit EA and affected over 13 million people (Muller, 2014). Recently, the 2010-2011 Horn of Africa drought caused a wide range of dire situations in the region (Viste et al., 2013; AghaKouchak, 2015). In some countries such as Somalia, Kenya and Ethiopia, drought has been one of the main reasons for socio-economic instabilities (O'Loughlin et al., 2012; Ayana et al., 2016). For example, in Somalia alone, a wide range of food insecurity situations arose and around 250,000 deaths were registered during the 2010-2011 drought (Hillbruner and Moloney, 2012; Lyon and Vigaud, 2017). Drought is also becoming a menace to food supplies in EA (Meier et al., 2007; Muller, 2014; Zhao and Dai, 2015). This insidious phenomenon results in malnutrition, epidemics, displacement of populations, food insecurity, famine and death (Hillbruner and Moloney, 2012; Muller, 2014; Lyon and Vigaud, 2017). Drought is therefore considered as a strategic enemy in EA, and acute mitigation measures are required.

In parallel, past environmental, economic, political, and nomadic complexities have led the region to extremely high levels of poverty and vulnerability to natural and anthropogenic shocks (instabilities, floods and drought) (O'Loughlin et al., 2012; Shiferaw et al., 2014; Ayana et al., 2016). This chronic crisis is rooted in socio-economic issues and extreme climatic events (de Waal, 1997; Hillbruner and Moloney, 2012; Nicholson, 2014, 2015, 2017). At times, droughts and other climate extremes have occurred within the same year. For example, in 2006-2007, 2009 and 2010, droughts were followed by unprecedented flash floods (Nicholson, 2014). In addition, in recent years the EA long rains (during the rainfall season in March–May) have been subject to an abrupt decline due to climatic variations (Lyon and DeWitt, 2012; Tierney et al, 2015). As a result, the overall precipitation and total water storage are decreasing in EA (Omondi et al., 2014). This situation has been linked to the occurrence of repetitive drought conditions in EA with a significant humanitarian impact (Anderson et al., 2012). The region is known to be the most drought-prone in Africa, if not in the world (Tadesse, 2016).

EA has been the focus of various drought studies in recent years (e.g. Meier et al., 2007; Nicholson, 2014; Muller, 2014; Omondi et al., 2014; Sheffield et al., 2014; Zhao and Dai, 2015). There is a pressing need for a timely overview of drought studies in EA based on the evidence regarding regional droughts. In this review, in-depth assessment and discussion is presented in terms of practical existing conditions, as well as societal, governmental and stakeholders' efforts towards drought prevention. A comprehensive assessment of this literature could help capture collective regional information on the causes and impacts of, and resilience to EA droughts. For this review, studies were selected based on their relevant contents describing various aspects of EA drought conditions. To this end, drought results from various studies, experiments and models are presented and discussed in depth. This review includes drought events in EA and their characteristics, causes and impacts, as well as a discussion on resilience to droughts, along with the ongoing involvement of citizens, governments and stakeholders towards the goals of early warning, preparedness and mitigation. In addition, this review proposes a solid drought conceptual framework on the basis of the fundamental drought problems, including various drought management and monitoring approaches. Our intent is to summarise the ways for integrated drought monitoring and management, in order to benefit vulnerable societies through the delivery of solutions and solid mitigation measures.

This review is organised as follows. Following this introduction, Section 2 presents the geographical features of EA, Section 3 discusses the nature and causes of drought, Section 4 addresses the impacts of drought, Section 5 illustrates drought resilience and coping mechanisms, preparedness and early warning, and Section 6 reviews drought conditions, with particular reference to Somalia, Ethiopia and Kenya. The involvement of citizens and stakeholders in drought monitoring, preparation, prevention and relief is discussed in Section 7, followed by a summary of the findings and concluding remarks in Section 8.

2. Area description

The appellations EA (Nicholson, 2017) and Greater Horn of Africa (GHA; Anyah and Semazzi, 2006) represent the same geographical region and countries in Africa, which include Kenya, Uganda, Tanzania, Ethiopia, Eritrea, Djibouti, Somalia, South Sudan, Sudan, Rwanda and Burundi. This region covers the so-called Horn of Africa and surrounding countries in the eastern parts of Africa, and is located between the latitudes of 11°S and 23°N, and longitudes of 21°E and 51° E (Figure 1). EA covers an area of 6.22 million km^2 and comprises the Great East African Rift Valley, which is the source and largest part of the Nile River, as well as the highest mountains in Africa, such as Kilimanjaro, Mount Kenya and Ras Dashan. The hottest and lowest depressions such as Lake Assal in Djibouti (153 m below sea-level) and the Ethiopian Danakil Depression (100 m below sea-level) are also located in EA (Camberlin, 2018). Lake Victoria, the second largest freshwater lake in the world and one of the major sources of the Nile river, is also located in EA (Vanderkelen et al., 2018a, b).

Location of Figure 1

The climate and topography of EA vary from wet highlands to arid lowlands and coastal areas (Dinku et al., 2011). The mountainous physiography covers the Ethiopian highlands and parts of Kenya and Tanzania, while the arid region covers parts of the Eastern Ethiopian lowlands, Djibouti and Somalia (Dinku et al., 2011). Rainfall in EA is highly variable over short distances due to the complex influences of topography, lakes, seasonal dynamics of tropical circulation, as well as maritime influences (Benson and Clay, 1998; Funk et al., 2014; Liebmann et al., 2014; Nicholson, 2017). The mean annual rainfall ranges from 800 to 1200 mm, with higher rainfall over the highlands and lower rainfall over north-eastern Kenya and Somalia (Fenta et al., 2017).

The climate of EA comprises three rainy seasons (March–May, July–September, and October–November). Kenya, northern Tanzania, Somalia, southern Ethiopia, Rwanda, Burundi and most of Uganda receive bimodal rainfall during March–May (long rains in the boreal spring) and October–November (short rains in the boreal autumn) (Liebmann et al., 2014; Tierney et al., 2012). Eritrea, Djibouti, northern Ethiopia, northern Uganda and South Sudan receive most of the rainfall in the boreal summer (July–September) as a result of airflow from the Congo Basin and the Atlantic (Camberlin and Okoola, 2003; Dutra et al., 2013).

The population of EA was estimated at 330 million in the year 2015 (UNDESA, 2015). This population is mainly dependant on agriculture, complemented by crop production and livestock rearing (nomadism) (Shiferaw et al., 2014). The region is highly dependent on rainfall to feed its increasing human population, implying that EA is highly sensitive to drought events. Some key agricultural areas that are often affected by drought events include north-western South Sudan, north-eastern Eritrea, eastern Kenya, north-eastern Tanzania, southern Somalia, and northern (Kaabong) and south-eastern (Kiruhura) Uganda (Rojas et al., 2011; Cumani and Rojas, 2016), among others.

3. Existing drought patterns

Drought assessments prior to 1980 (especially during the instrumental period) are subject to uncertainties as observations are sparse and access to drought data is limited. During the last two decades, both the frequency and severity of droughts in EA have shown a significant increase (Guha-Sapir et al., 2004; Meier et al., 2007; Ayana et al., 2016). The duration of droughts and the impacted areas have also increased markedly in the region. In EA, many studies have suggested that droughts have become more frequent and severe, with evidentiary support (e.g. Meier et al., 2007; Funk, 2012; Lyon and DeWitt, 2012; Hoell and Funk, 2013; Omondi et al., 2014; Nicholson, 2015, 2017). For example, Funk (2012) identified a large number of below-normal rainfall seasons, which revealed more frequent droughts in EA since 1999. Nicholson (2015) concluded that a widespread condition of well below-average rainfall occurred in EA during 1998, 2000 and 2005, and this has condition occurred virtually every year since 2008. These droughts affect the summer and equatorial rainfall regions of EA. Similarly, Hoell and Funk (2013) analysed drought over EA during 1950-2010 and suggested that the Indo-Pacific sea surface temperatures (SSTs) have forced more frequent droughts in consecutive long and short rainy seasons since the 1980s. Nicholson (2017) reviewed the EA rainfall data and concluded that droughts have become longer and have occurred more frequently across the rainy seasons. Based on the assessments made in most of the recent studies in the last two decades, we conclude that droughts have become more frequent and severe in EA. In these studies, this drought condition is attributed to various drought causing factors, such as climate variability, anthropogenic factors or both.

In EA, there are variations in drought trends among the three rainy seasons: the boreal autumn (October–November, i.e. the short rains season), boreal spring (March–May; i.e. the long rains season) and boreal summer (June–September). The March–May long rains season is the primary rainy season in EA. In this season, EA has experienced a persistent decline in rainfall during the last 30 years (Funk et al., 2008; Lyon and DeWitt, 2012; Tierney et al., 2015). Similarly, Nicholson (2017) concluded that the greatest changes in drought appear to have occurred during the long rains, which have been declining over the past decades. A decline in the rains of the boreal spring (long rains season) has had major consequences for food security, as agriculture in the region is largely dependent on rainfall under the existing effects of climatic change (Viste et al. 2013; Liebmann et al. 2014; Nicholson 2017). Fewer studies have also considered the trends in the boreal summer season (June-September), but these have confirmed a similar decline to that observed in the boreal spring (Lyon and Dewitt, 2012; Viste et al., 2013). In the boreal autumn (short rains), however, there is a general increasing tendency in rainfall (Liebmann et al., 2014; Rowell et al., 2015; Tierney et al., 2015; Nicholson, 2017). For example, Tierney et al. (2015) projected an increase in rainfall during the short rains season. Liebmann et al. (2014) and Rowell et al. (2015) showed that the October–November season has become wetter i.e. the short rains have increased. However, the increase in the short rains has exacerbated the impact of the declining long rains, exhibiting a large variability in the region (Rowell et al., 2015). In summary, droughts are becoming more frequent, longer and more severe in the boreal spring (long rains) and summer in EA, but a decrease in drought frequency is observed in the October–November (short rains) season.

The studies described above have only been analysed within the context of sparse and short regional climatological data (Tierney et al., 2015). In addition, the rainfall over EA is characterised by very complex spatial and seasonal climate patterns and observations are subject to uncertainties (Liebmann et al., 2012; Nicholson, 2017; Funk et al., 2018). This uncertainty results from the lack of data and lower quality data, as well as the robustness of analysis and the diversity of time periods and geographical locations where the studies took place.

In the East African drought history, many drought events have been recorded, especially after the 1980s. For example, the years 1985, 2003 and 2010 are recorded as major drought years in specific parts of EA (Figure 2; Guha-Sapir et al., 2004; Wagaw et al., 2005; Degefu and Bewket, 2015). As illustrated in Figure 2, drought hit the northern parts of EA in 1985, including Northern Ethiopia, Southern Eritrea and Sudan. Most of these areas receive rainfall during the months of June–September. Similarly, in 2003 drought affected the central parts of EA and Ethiopia in particular. The severe drought in 2010 impacted the Horn of Africa, which includes Southern Somalia, Kenya, Ethiopia and some parts of Tanzania, due to the decline of the long rains in March–May.

Location of Figure 2

4. Causes of drought

The causes of drought in EA are diverse in nature, as this region is characterised by different geographical factors, regional oceanic circulations and coastal influences (Lyon, 2014; Ayana et al., 2016). The region is a focal point of important geographical areas including the Turkana channel, East African highlands, Lake Victoria and the Red Sea Trench (Lyon, 2014; Muller, 2014; Fenta et al., 2017; Vanderkelen et al., 2018a, b). Regional circulations, such as the tropical easterly jet, low-level Westerlies, localised convergence, monsoons and the Turkana jet, have important impacts on the occurrence of droughts. The climate system over EA is complex and heterogeneous, owing to a complex terrain (Lyon, 2014; Fenta et al., 2017). The natural vegetation land cover has been converted into farmlands, grazing lands and human settlements as a result of anthropogenic involvement. These factors exert direct and indirect influences on drought occurrences and create uncertainties for the characterisation and prediction of droughts (Muller, 2014; Hao and Singh, 2015).

4.1. Identifying the nature of drought

Droughts can be categorised into a number of types from various perspectives (Anderson et al., 2012; Nicholson 2014). A drought is usually identified based on indicators such as precipitation, temperature, evapotranspiration, streamflow or groundwater (Bachmair et al., 2016). The drought indicators are required to detect the evolving nature of a specific type of drought. For example, Anderson et al. (2012) explained the 2010-2011 Horn of Africa drought based on soil moisture data and indicated that the drought was a typical agricultural drought. Nicholson (2014) stated that droughts characterised as meteorological droughts dominate the droughts in EA due to anomalies in rainfall, temperature and evapotranspiration. Rulinda et al. (2012) used a Normalised Difference Vegetation Index (NDVI) to characterise and quantify vegetative drought in 2005–2006 and concluded that a severe drought had affected 60% of the vegetation. Ntale and Gan (2003) proposed that the standardised precipitation index (SPI) be used as an appropriate index for monitoring droughts in EA, as rainfall alone can explain most of the drought occurrences in the region. Hence, existing studies mostly focused on meteorological and agricultural droughts in EA. So far, studies associated with hydrological and other drought types are limited in the region, and more attention needs to be paid to these particular drought types.

4.2. Climate variability

One of the main driving forces of drought in EA is the high seasonal and interannual variability of the climate system (Haile, 2005). The complexity and variability of the El Niño–Southern Oscillation (ENSO), SSTs and land-atmosphere feedbacks are closely related to the occurrence of drought in EA (Zeng, 2003; Schreck et al., 2004; Liebmann et al., 2014; Masih et al., 2014; Hua et al., 2016). The climate of EA is associated with climate dynamics in the Indian Ocean, the Inter-tropical Convergence Zone (ITCZ), La Niña, the Mediterranean Sea and the Atlantic Ocean, exacerbated by local complex topographies (Shanko and Camberlin, 1998; Schreck et al., 2004; Tierney et al., 2013; Lyon, 2014; Cumani and Rojas, 2016). As a result, these factors have a direct or indirect impact on drought occurrences in EA. Lyon (2014) provided a review of the regional and large-scale SSTs and atmospheric circulation patterns on seasonal and longer timescales.

They noted that drought in EA is complicated by local rainfall regimes, generally consisting of unimodal and bimodal annual cycles.

The ITCZ sweeps across EA twice a year, significantly influencing the climatological rainfall patterns (Camberlin and Okoola, 2003; Anyah and Semazzi, 2006). This system is responsible for the bimodal rainfall pattern occurrence during March–May (long rains) and October–November (short rains) (Schreck et al., 2004; Anyah and Semazzi, 2006; Lott et al., 2013). Each rainy season coincides with the passage of the ITCZ as it migrates from the southern to the northern hemisphere. Camberlin and Okoola (2003) revealed that the average onset and cessation of long rains (in the boreal spring, March–May) in EA were March 25th and May 21st, respectively. The onset is associated with the SST and sea–level pressure (SLP) patterns. Regarding seasonal drought prediction, Schreck et al. (2004) and Nicholson (2017) stated that atmospheric variables such as zonal winds and low–level circulations provide more reliable seasonal drought forecasts compared to the SST, SLP and ENSO in EA. Generally, most severe droughts are attributed to the failure of the long rains in EA (Nicholson, 2016; Funk et al., 2018).

An accurate understanding of La Niña events is also important as it is one of the main reasons for drought in EA (Camberlin et al., 2001; Lott et al., 2013). La Niña is frequently associated with drought during the short rains in the central and eastern parts of EA (Funk, 2011; Lott et al., 2013). For example, the 2010–2011 Horn of Africa drought was attributed to a strong La Niña event (Funk, 2011; Dutra et al., 2013). The emerging La Nina event in summer 2010 originated from the steady Indian Ocean warming and caused reduced precipitation in EA (Funk, 2011; Souverijns et al., 2016). Limited precipitation in both the October–December 2010 and March–May 2011 rainy seasons were the main causes of this drought (Dutra et al., 2013; Lott et al., 2013; Souverijns et al., 2016). Hence, the drought was due to the failure of the October–December 2010 short rains and the delayed arrival of the April–June 2011 long rains, which are associated with La Niña (Anderson et al., 2012).

Increased warming of the Indian Ocean is considered to be another factor leading to drought in EA (Funk et al., 2008; Lyon, 2014). The warming of the Indian Ocean has led to decreased precipitation and terrestrial water storage, and has thereby induced drought

(Ahmed et al., 2014; Schubert et al., 2016). A number of studies have noted the relationship between Indian Ocean conditions and EA rainfall properties. Tierney et al. (2013) indicated that the multi-decadal variability/local Walker anomalies of Indian Ocean SSTs were the primary cause for the rainfall decline in the region. Warming of the central Indian Ocean, accelerated by the effects of climate change, also correlates with a decline in rainfall by affecting moisture transport (Funk et al., 2008; Yang et al., 2014; Tierney et al., 2015). Similarly, Funk et al. (2008) suggested that Walker cell-like anomalies may explain the observed rainfall declines over EA.

More importantly, Lyon et al. (2014), Lyon (2014), and Yang et al. (2014) provided evidence that most of the recent rainfall declines were driven by natural multi-decadal variabilities. Generally, on seasonal to interannual timescales, ENSO is the main reason for seasonal rainfall variability. In addition, La Niña is frequently associated with drought during the short rains. The ITCZ and the warming of the Indian Ocean are also linked to droughts through a decline of the long rains. In summary, climatic variability plays a vital role in the occurrence of droughts over EA.

4.3. Anthropogenic effects

Beyond the influence of climate variability, anthropogenic effects on the environment have also played a great role in changing drought patterns under conditions of burgeoning population growth (Zeng, 2003; AghaKouchak et al., 2015b; Schubert et al., 2016; Van Loon et al., 2016a). These effects include land use change, land degradation, deforestation, firing and mining (Zeng, 2003; Sheffield and Wood, 2011; Masih et al., 2014; Van Loon et al., 2016a; Ordway et al., 2017). Moreover, human activities such as the expansion of cultivation and grazing lands, overexploitation of water resources, new settlements and urbanisation, and investments in and construction of large-scale development projects have an impact on droughts (Bond et al., 2008; Masih et al., 2014; Schubert et al., 2016; Van Loon et al., 2016a; Huang et al., 2017). Hence, focusing on these factors to recognise human influence on drought is essential for understanding the driving mechanisms of drought. For instance, a study by Ordway et al. (2017) stated that land use changes through the expansion of commodity crops have increased the pressure on tropical forests. Similarly, Huang et al. (2017) and Wada et al. (2013) indicated that water withdrawal, especially for irrigation purposes, has shown a significant global increase. This may aggravate the competition for unsustainable natural resources utilisation and lead to drought. Hence, considering human influences as an integral part of drought management is vital, particularly in the human-influenced era (i.e. the Anthropocene) (Van Loon et al., 2016a, b).

Land surface changes due to anthropogenic activities have been observed to have an impact on altering underlying hydrological processes, which are directly linked to droughts (Zeng, 2003; Kiem et al., 2016; Van Loon et al., 2016a, b). Studies have reported that global warming is mainly attributed to human activities (e.g., Sheffield et al., 2012; Schubert et al., 2016; Souverijns et al., 2016). In addition, the Indian Ocean warming is also attributed to anthropogenic activities, and this causes rainfall and soil moisture deficits, thereby exacerbating drought (Schubert et al., 2016; Souverijns et al., 2016). A few studies (e.g., Lott et al., 2013; Rowell et al., 2015) also show that some droughts in EA, such as the 2010–2011 event, are likely due to anthropogenic influences. Rowell et al. (2015) hypothesised that anthropogenic aerosol emissions may have driven the recent droughts in EA due to the decline in long rains. Van Loon et al. (2016a) indicated that human-induced drought could emerge as a result of urbanisation, deforestation and reservoir construction. In addition, sectoral water withdrawals for irrigation, domestic use, electricity generation, livestock rearing, mining and manufacturing are also increasing (Van Loon., 2015; Huang et al. 2017). Wada et al. (2013) concluded that human water consumption has more than doubled, which has intensified the magnitude of global drought by 10–500% and the frequency by 27%. Pekel et al. (2016) stated that over 70% of the global net permanent water losses are due to drought and human activities such as river diversion or damming and withdrawals. Severe drought conditions are driven primarily by human water consumption in many parts of the world. As one of the main causative agents of drought, humans are suffering from lack of water driven by the complex and interacting effects of both natural and anthropogenic processes (Van Loon et al., 2016a). This indicates that humans are participating in causing droughts, suffering from their impact and coping with their effects.

4.4. Combined effects

Some studies discuss the droughts in EA by linking the causes emerging due to climate variations and anthropogenic activities (Kiem et al., 2016; Schubert et al., 2016; Souverijns et al., 2016). This indicates that both climate variability and anthropogenic activities have been important factors in causing droughts in the region (Hua et al., 2016; Van Loon et al., 2016a). Water resources, ecosystems, economies and societies have been hindered by the persisting severe droughts that are as yet poorly quantified and understood (Van Dijk et al., 2013; Van Loon., 2015; Van Loon et al., 2016b). Aggravated by global warming, the combined effects of climate variabilities and anthropogenic effects will likely remain as major driving factors that intensify drought severity and frequency in the future (Wada et al., 2013). For example, the frequency of agricultural and hydrological drought are projected to increase by 50–100% and 10–50%, respectively, by the 2090s (Zhao and Dai, 2015). Hence, the multidirectional relationship between natural climatic processes and the role of humans in causing drought should take priority in future drought studies (Van Loon et al., 2016b).

5. Impacts of drought

Drought was ranked first among all-natural hazards due to its severity, duration, spatial extent and severe consequences, including loss of life, economic loss and social effects, as well as its long-term impact (Bryant, 1991; Sivakumar et al., 2014; Kiem et al., 2016). As a result, drought has exerted a diverse impact on human beings, the environment, water resources and agriculture in EA (Mu et al., 2013; AghaKouchak et al., 2015b; Pozzi et al., 2016; Van Loon et al., 2016a). These effects are more pronounced due to the rapidly growing population along with the expansion of agriculture, and the energy and industrial sectors (Mondiale, 2008). The overall impacts of drought include, but are not limited to, land degradation, deforestation, reduced crop and rangeland productivity, reduced water levels, increased fire hazards, reduced energy production, increased livestock and wildlife death rates, and damage to marine and fish habitats (Sheffield and Wood, 2011; Sivakumar et al., 2014; Cumani and Rojas, 2016; Pozzi et al., 2016).

5.1. Impact on water resources

Water is a vital resource, the lack of which leads to the occurrence of drought (Mu et al., 2013). When water resources decline for various reasons, water shortages occur in time and space (Riebsame et al., 1991; Mu et al., 2013; AghaKouchak et al., 2015b; Van Loon et al., 2016a). In EA, water shortages have been observed and are closely related to drought events. Drought has been affecting water resources by reducing water supply and leading to the deterioration of water quality, which further induces crop failure, range productivity reduction, power generation diminishment, riparian habitat disturbances and the suspension of economic and social activities (Riebsame et al., 1991; Haile, 2005; Mishra and Singh, 2010, 2011). Moreover, water scarcity induced by frequent drought events and the overexploitation of water resources has been witnessed to impact surface and groundwater resources, by reducing groundwater levels, recharge and discharge (Riebsame et al., 1991; Van Loon and Lanen, 2013; Van Loon., 2015). Water scarcity tends to be exacerbated due to the unwise use of available water resources in the hydrological system (Van Loon., 2015).

The impacts of drought on water bodies are far reaching, both for human consumption uses and aquatic ecosystems (Verschuren et al., 2000; Bond et al., 2008; Van Loon et al., 2016). Hence, EA's water bodies have been suffering greatly under water deficit conditions, as they are used as sources of water for socioeconomic purposes such as agriculture and domestic use (Omute et al., 2012; Awange et al., 2013; Camberlin et al., 2017). There are a number of lakes in the Great Rift Valley system of East Africa and the Lakes region, including Victoria lake, Turkana lake and Lake Tana (Nicholson, 1998). The content and quality of these water bodies have direct and indirect linkages with drought events (Omute et al., 2012; Awange et al., 2013; Esfahanian et al., 2016, 2017). Drought affects both standing and flowing water systems by hindering the aquatic biota and ecosystem functions (Bond et al., 2008; Esfahanian et al., 2016, 2017). In addition, drought has had a substantial impact on marine ecosystem services (Esfahanian et al., 2016, 2017). This includes loss of habitat, water quality degradation and biotic interaction breakages (Nicholson, 1998; Bond et al., 2008; Van Loon et al., 2016). Drought occurs as surface water, lakes, runoff and streams decline, and under high temperatures at which evaporation increases. Under drought conditions, the water storage and elevation of the water bodies may decline sharply. In general, reductions in streamflow, groundwater, reservoir and lake levels are consequences of drought occurrences (Nicholson, 1998; Verschuren et al., 2000; Heim, 2002; Calow et al., 2010). Hence, there is an urgent need for effective monitoring and management of lake, river and stream resources so that they can be used for early warning and drought management.

More importantly, water resources over EA are unevenly distributed at the surface and in the subsurface (Riebsame et al., 1991; Heim, 2002; Haile, 2005; Calow et al., 2010; Camberlin et al., 2017). The intelligent use of surface and groundwater resources is important for managing and monitoring drought impacts (Van Loon., 2015). In various available forms of water (i.e. in the atmosphere, surface and subsurface), a reduced amount of water indicates an initial sign constituting an alert for drought (Van Loon and Lanen, 2013; Van Loon., 2015; Esfahanian et al., 2016, 2017).

5.2. Impact on agriculture

Agriculture and drought are two important issues that are tightly linked in EA. Around 40% of the Gross Domestic Product (GDP) of EA is from agriculture (FAO, 2014). In addition, 70-75% of EA labour forces are engaged in agricultural work (Dixon et al., 2001; Lyon, 2014). However, per-capita agricultural land has declined by 33% in EA, while the population has doubled in the past 25 years (Funk et al., 2008). Unless crop productions develop in parallel with the increasing population, EA farmers may become trapped into cycles of displacement, division and degradation when rain-fed agriculture diminishes due to drought episodes (Funk et al., 2008). In addition, agriculture, which is the mainstay of livelihoods in EA, is significantly impacted by recurrent droughts intertwined with climate variations and anthropogenic effects (Hayes et al., 2004; Lyon, 2014). In EA, rainfall receipts in the main crop-growing season have diminished by 15% along the western rim of the Indian Ocean (Funk et al., 2008). Drought was the main reason for the 2011 Somalia famine due to insufficient rainfall during the 2010 short rains (October–November) and 2011 long rains (March–May). This event resulted in very low cereal production and substantial livestock mortality (Hillbruner and Moloney, 2012).

Drought could result in deleterious effects that impede food security (Calow et al., 2010), as most of the agricultural production in EA is being affected by agricultural drought (Mondiale, 2008; IPCC, 2007, 2013). Livelihoods dependent on agriculture are suffering from a lack of sufficient food resources due to a reduction in crop biomass (Heim, 2002). Agricultural drought usually results in reduced income for farmers and becomes the main reason for hunger, increased food prices, unemployment and migration (Sivakumar et al., 2014). Food security in EA countries may face dangerous circumstances unless efforts are made to develop the agriculture (Haile, 2005; Mondiale, 2008).

5.3. Impact on human beings

In EA, a series of drought events have been registered during the past three decades (Kallis, 2008). Recently, below-average rainfall events have been increasing in the region (Nicholson, 2014; Fenta et al., 2017). Among the EA countries, Somalia, Ethiopia and Kenya have been affected by the worst drought events (Meier et al., 2007). According to Funk et al. (2013) and Bayissa et al. (2015), more frequent drought events over EA began in the early 1980s. Major drought periods in EA include 1978–1979, 1984–1985, 1994–1995 and 2003–2004 (Table1; Funk et al., 2013; Bayissa et al., 2015). According to Nicholson (2014), droughts occurred during 1998, 2000, 2005–2006, 2007, 2008, 2009 and 2010–2011 in EA. Severe droughts occurred in 2009, 2010 and 2011, and were most intense in Kenya, southern Somalia and southern Ethiopia (Funk et al., 2013; Nicholson, 2014, 2017). As per the data provided from the Emergency Events Database (EM-DAT) (http://www.emdat.be/database), which was based on long-term drought records with drought coverage and impacts, more than 216.9 million people were affected in EA and around 572,000 deaths occurred, along with 1.5 million USD in economic losses (Table 1; EM-DAT, 2018). Moreover, 100 drought events have been registered so far, as a result of the hydro-climatological, climatic, environmental and social factors/anomalies persisting in EA since the 1970s (Table 1; EM-DAT, 2018).

In EA, the number of people suffering from frequent drought events is increasing (Funk et al., 2013; Bayissa et al., 2015; Nicholson, 2014, 2017). According to FAO (2015), one in nine, i.e. 124.2 million people, were recently undernourished in EA. The famine of 1984–1985 led to around 450,000 deaths in Ethiopia and Sudan (Figure 2; Guha-Sapir et al., 2004; Vicente-Serrano et al., 2012). In Ethiopia alone, around 14 million people were affected by starvation during the 2002–2003 drought years (Figure 2; Haile, 2005; Wagaw et al., 2005). In the 2008-2010 drought, over 13 million people were affected in EA (Muller, 2014). The 2010-2011 drought was the most recent extreme event that led to severe food crises and a famine affecting around 12 million East African people (ACTED, 2011; AghaKouchak, 2015). This drought is recorded as the worst event in 60 years in EA (Figure 2; Pozzi et al., 2016), causing an estimated 250,000 fatalities in Somalia alone (Sheffield et al., 2014; Lyon and Vigaud, 2017). Moreover, flooding immediately followed the drought, and the abrupt conjunction of these events exacerbated the losses (Nicholson, 2014).

Location Table 1

6. Resilience and coping with drought

Global climate model simulations focusing on future EA drought prediction indicate a possible increase in extreme and widespread droughts (IPCC, 2013; Masih et al., 2014; Zhao and Dai, 2015; Kiem et al., 2016). In particular, the frequency, intensity and duration of droughts over the dry and semi-arid regions and mid to low latitudes are projected to increase due to an expected 10–13% reduction of available water in EA (IPCC, 2007; Pozzi et al., 2016). This constitutes a great challenge for EA due to slow progress in drought risk management, increased population growth, rapid land degradation and increased water demand (Masih et al., 2014). Efforts towards drought resilience via policy approaches, environmental rehabilitation, and agricultural productivity and water resources development are required (Benson and Clay, 1998). Maintaining soil health, water conservation, income diversification and the strengthening of local institutions are important coping strategies and can add value to the resilience (FAO, 2014). In addition, drought early warning facilities are important to improve drought resilience and coping strategies.

6.1. Drought management capabilities

For effective drought management and monitoring, designing clear response policies and strategies is needed. So far, drought mitigation and prevention measures at national, regional and international levels have been undertaken in EA (UNISDR, 2009). However, the corresponding implementations were not capable of executing consistent actions under drought management policies (Sivakumar et al., 2014). Designing active responses to droughts is more important than reactive responses, and the active responses should be based on risk management rather than crisis management (Tadesse et al., 2008; Sivakumar et al., 2014). Moreover, drought mitigation interventions should be made in terms of preparedness for coping, the creation of early warning awareness and the development of a trained experts (Solh and van Ginkel, 2014). Active and coordinated work towards drought prevention involves developing protection from the effects of climate variability and anthropogenic effects. The implementation of various drought mitigation strategies that consider grassroot problems is also necessary.

A drought-resilient economy is indispensable for drought-vulnerable societies in EA (United Nations, 2018). Sustainable drought management geared towards building social and economic security on local, regional and national levels is vital. This would help to develop the capacity to cope with the risk of drought through designing drought-resilient economies (UNISDR, 2009; Shiferaw et al., 2014). Drought-resilient economies can be achieved by implementing systematic, continuous and interdisciplinary efforts. These efforts include drought prevention policies, institutionalisation and synergy among possible stakeholders, the use of metadata and the adoption of standardised policy execution capacities and norms. Drought resilience and coping mechanisms vary due to the natural and anthropogenic responses to drought occurrences. Moreover, drought management programs should consider both short- and long-term approaches. Short-term approaches provide relief from the direct consequences of droughts in terms of distributing food to people in need, while long-term approaches focus on sustainable developmental measures (Tadesse et al., 2008; Shiferaw et al., 2014; Solh and van Ginkel, 2014).

In EA, governments have been working by designing drought management policies and strategies based on existing conditions. For example, the government of Ethiopia has introduced an initiative with numerous drought mitigation strategies, including the Productive Safety Net Program, which enables the rural-poor communities facing chronic food insecurity to resist shocks and become food self-sufficient (Shiferaw et al., 2014; FAO, 2015). Aiming to aid the most vulnerable groups to access food, the program enables the people to improve agricultural activities and invests in rural infrastructure (FAO, 2015). Similarly, Kenya's government has made plans to supply food to areas badly hit by drought (Abbass, 2009). In addition, the Kenyan government is working on sustainable long-term solutions, such as investing in community water resources development to reduce dependence on rain-fed agriculture.

6.2. Environmental rehabilitation

Combatting drought through environmental rehabilitation calls for both collective and individual efforts, which require intense behavioural changes based on a comprehensive understanding of the risks/shocks, as well as safety and resilience (Tadesse et al., 2008; Shiferaw et al., 2014). Changes can be realised by implementing structural, non-structural, infrastructural and environmental measures from local to national or regional levels (Tadesse et al., 2008; Muller, 2014; Shiferaw et al., 2014; Solh and van Ginkel, 2014). To reverse drought through environmental rehabilitation, the participation of relevant and responsible individuals, Non-Governmental Organisations (NGOs), aid agencies, donors, civil society members, public service organisers and community organisations are indispensable (Tadesse et al., 2008; Shiferaw et al., 2014). Environmental rehabilitation must be comprehensive, involving the development of ecosystem services, biodiversity enhancement and soil and water conservation works (Gebremeskel et al., 2018). Drought impacts can be reduced through various adaptation measures ranging from specific to more general measures. Improvements of land quality by soil and water conservation, area en/closure, afforestation, reforestation and agroforestry have significant benefits (Muller, 2014; Gebremeskel et al., 2018). Effective watershed-based soil and water conservation work by implementing physical/mechanical and biological measures through the active involvement of people and key stakeholders in the design and implementation is valuable (Gebremeskel et al., 2018). Such interventions have been observed to benefit farmers in Ethiopia, Kenya and Tanzania (FAO, 2015). For example, around 7.5 million drought-vulnerable people have risen out of poverty in Ethiopia through a cash/food-for-work approach to environmental rehabilitation from the Productive Safety Net Program (Shiferaw et al., 2014; FAO, 2015).

Various efforts have been undertaken to convert drought-prone degraded lands into well-established sustainable landscapes. Here, we present some case examples from EA countries where drought-resilience and coping mechanisms related to environmental rehabilitation have become successful. By applying conservation-based agricultural development policy, the Tigray region of Ethiopia recently won an international prize from the World Future Council (World Future Council, 2017). The prize was accompanied by the statement that these were the "world's best policies that combat desertification and land degradation with unique collective action, voluntary labour and the involvement of youth. The people of Tigray are restoring land on a massive scale" (World Future Council, 2017). Earlier, in 2012, the Abraha Atsbaha watershed (located in Tigray, Ethiopia) was placed among the worldwide Equator Prize winner watersheds by the United Nations Development Program at the Equator Prizing ceremony at the Rio+20, June 2012 conference (WFP, 2012). In this watershed, groundwater levels have increased and sustainable agricultural development practices have made a significant contribution to food self-sufficiency and economic growth in Tigray (Figure 3; World Future Council, 2017; Gebremeskel et al., 2018). These are demonstrations that one of the world's most drought-prone regions has been partly altered to be drought-resilient and has become a model for practical drought mitigation and coping strategies.

Location of Figure 3

Moreover, valuable lessons and experience of environmental rehabilitation may be taken from the Mwala area of Machakos County in Kenya. Through land restoration work via effective land management techniques, more land was gained for crop production (FAO, 2014). Drought-tolerant crops were used to cope with insufficient rainfall over the dry lands of the district (Cooper et al., 2008; FAO, 2014). In addition, the district has developed a response system of diversification that considers rainfall uncertainty and seasonal fluctuations. Machakos County has developed drought coping strategies to improve livelihood assets by implementing different adaptive capacities and strategies (Cooper et al., 2008). Another exemplary case is Kiroka village in Morogoro, Tanzania, where various climate change and drought mitigation measures were undertaken (FAO, 2014). In this village, different efforts towards sustainable land and water management, and the use of improved water management for rice intensification and paddy yield maximisation, have been carried out. Other beneficial actions include comprehensive soil and water conservation activities, deforestation reduction using energy saving stoves, the use of beekeeping as an incentive for participatory forest protection, and the use of capacity building towards the adoption of climate-smart agricultural innovations (Cooper et al., 2008; FAO, 2014).

6.3. Agricultural productivity

Around 30% of farmers living in developing countries are food-insecure (Brown and Funk, 2008). Around 80% of the EA population depends on agriculture (FAO, 2014). Hence, investing in agricultural productivity is equivalent to investing in the livelihoods of the population (Funk et al., 2008; Mondiale, 2008). Coping with agricultural drought depends on agricultural adaptations taking into account the start of the wet season, intra-seasonal rainfall, soil moisture and extreme temperatures (Sheffield et al., 2014). Further efforts should be made to enhance drought adaptive capacities by improving existing rain-fed agriculture through farm management and investment, and enhancing biotechnological inputs such as improved seeds/varieties is also important (Funk et al., 2008).

Seasonal rainfall lower than 500 mm is inadequate to sustain healthy agriculture (Sheffield et al., 2014). Hence, seasonal rainfall below 500 mm can serve as a rough indicator for possible drought occurrences. Rainfall data collection from representative areas is necessary for rapid decision making (Vicente-Serrano et al., 2012; Masih et al., 2014; Sheffield et al., 2014). The decision-making process could be more comprehensive if supported by data from remote sensing satellite products. Vicente-Serrano et al. (2012) suggested that for effective drought preparedness and mitigation, the involvement of drought information gathering tools is vital for early agricultural drought detection. These tools further benefit society through effective agricultural drought management and real-time decision-making in farmlands. Readiness towards early warning, building society's resilience, short-term relief, long-term planning and capacity building are key for urgent drought mitigation (Vicente-Serrano et al., 2012; Masih et al., 2014). Moreover, Funk et al. (2008), suggested that drought can be mitigated by intensive agricultural development programs.

The effects of drought vary with coping capabilities. For example, people living in regions with advanced irrigated agricultural systems are more resistant to drought than those without irrigation practices (Dai, 2011). In general, increasing agricultural productivity is essential for coping with famine due to drought. Innovative and promising crop management techniques such as crop breed enhancement can be adopted to produce moisture resistant and heat-tolerant crop varieties (Hansen et al., 2011; Shiferaw et al., 2014; Solh and van Ginkel, 2014). Moreover, development work towards drought mitigation could focus on crop and income diversification and planting drought-tolerant crop varieties (Shiferaw et al., 2014). Crop rotation, agroforestry practices and optimising crop calendars to avoid extreme soil heat are also among the best-adapted techniques in agricultural drought management (Shiferaw et al., 2014; Solh and van Ginkel, 2014). This could enable farmers to take early adaptive measures to cope with drought (Hansen et al., 2011; Solh and van Ginkel, 2014).

6.4. Water resources management

Exacerbation of drought by deforestation, land use change and unwise management of water resources leads to the alteration of inland water and corresponding hydrological processes (Sheffield et al., 2014; Van Loon, 2015). Hence, an effective water conserving and saving system is of paramount importance for drought mitigation (AghaKouchak et al., 2015b; Van Loon et al., 2016a). Appropriate water management activities in rain-fed and irrigation schemes present great advantages to overcome crop water shortages. The increase of soil moisture by reducing evaporation and implementing conservation agriculture is an important alternative, which conserves in-situ water for agricultural uses (Sheffield et al., 2014; Van Loon., 2015). Water management is implemented with the purpose of producing more crops using less water (Solh and van Ginkel, 2014; Giordano et al., 2017). Specifically, reducing irrigation water losses by converting surface irrigation schemes to pressured irrigation systems (e.g. drip or sprinkler systems) and shifting from more water-demanding to low water-demanding crops are among the best-adapted drought mitigation mechanisms in agriculture (Solh and van Ginkel, 2014). In addition, linking rainfed-irrigated systems (in conjunctive or alternating use of rainfall and irrigation), rainwater harvesting from catchments, supplementary irrigation and deficit irrigation are vital methods of water conservation (Muller, 2014; Solh and van Ginkel, 2014; Giordano et al., 2017). Moreover, the provision of water for irrigation via efficient water delivery and climate-smart technologies such as solar pumping and water filters are also very important (Muller, 2014).

The use of supplementary irrigation through adopting and diverting flood water is beneficial for both reducing downstream flood damages and for irrigation (Gebremeskel et al., 2018). To achieve water resources conservation, the management of flood water by converting sediment-carrying water for economic benefits should take priority. Hence, flood management involves appropriate protection techniques, such as placing rock-filled metal mesh gabions covered with earth, which can prevent rivers from bursting their banks (Cooper et al., 2008; FAO, 2014; Muller, 2014). Another useful technique is water harvesting from watersheds, roofs and rock surfaces (Sheffield et al., 2014; Van Loon., 2015; Gebremeskel et al., 2018). Using this technique, water can be harvested and used in cultivating horticultural crops, especially in backyards. Various types of reservoirs built for different purposes, including hydropower generation, are of substantial importance for conserving water (Tadesse et al., 2008; Shiferaw et al., 2014; Solh and van Ginkel, 2014; Gebremeskel et al., 2018). These could be used to obtain further economic benefits for the society beyond increasing drought resilience capacities. Overall, by default, conserving water constitutes an adaptation measure for drought, as all kinds of drought problems are characterised by a shortage of water.

6.5. Drought monitoring and forecasting

Better regional climate change and forecasting models, combined with effective agricultural development in the drought-threatened EA, can reduce the need for emergency drought responses (Funk, 2009, 2011; Kiem et al., 2016). For drought risk reduction, drought monitoring and forecasting systems must be developed so that essential early warning of drought occurrence can be achieved (UNISDR, 2009; Shukla et al., 2014; AghaKouchak et al., 2015b). Ahead of drought occurrences, relevant information on drought should be provided to people and concerned government bodies at the national and subnational levels. This drought information is often obtained from meteorological networks, hydrological modelling facilities and satellite remote sensing products (Mu et al., 2013; AghaKouchak et al., 2015a). Different organisations are providing drought information to the people, governments and stakeholders in EA (e.g. Ogallo et al., 2008; Mwangi et al., 2014; Sheffield et al., 2014; Shukla et al., 2014). For example, the Famine Early Warning System Network (FEWSNET; Shukla et al., 2014) provides drought forecasts based on local observers, market reports and remote sensing datasets. The initiations made by the Regional Climate Outlook Forum (RCOF) to forecast drought are also appreciated in the region (Ogallo et al., 2008). The Greater Horn of Africa Climate Outlook Forum (GHACOF) has also been established for precipitation and drought forecasts over EA (Mwangi et al., 2014). In line with drought forecasting and early warning, the African Drought Monitor (ADM) system in Kenya and Niger provides statistical and dynamic timely drought predictions using hydrological models and remote sensing data for end users across the region (Sheffield et al., 2014). Data used for drought forecasts are obtained from a combination of historical records, satellite data, reanalysis data, tree ring estimation and sediment measurements (Vicente-Serrano et al., 2013; Sheffield et al., 2012, 2014; Mwangi et al., 2014; Shukla et al., 2014; Schwalm et al., 2017; Mokria et al., 2017, 2018). The development of the internet, smartphones and social media have made the dissemination of drought information to end users easier (Funk, 2009, 2011; Vicente-Serrano et al., 2012). As a result, drought information will become widely accessible for societies in a more participatory and community-based way.

Drought monitoring and forecasting tools are increasingly helping decision-makers for handling future possible drought occurrences at various spatiotemporal scales (Anderson et al., 2012; Vicente-Serrano et al., 2012; Dutra et al., 2013). The African geospatial and temporal variation of droughts over the period 1900–2013 was reviewed by Masih et al. (2014). Accordingly, drought maps have been built at the continental, regional and country scales. The use of geospatial data and drought static and real-time information systems is important for coping with the challenges faced in drought mitigation in EA (Vicente-Serrano et al., 2012; Shukla et al., 2014). Shukla et al. (2014) described the development and implementation of a seasonal agricultural drought forecast system for EA, aimed at providing decision-making support to the FEWSNET science team. This forecast system produces baseline soil moisture estimates for the March–May growing season by forcing with high-quality atmospheric observations. The forecast results are able to provide the projected onset, duration and end of a drought event (DeChant and Moradkhani, 2015; Schwalm et al., 2017). Moreover, Funk and Michaelsen (2004) developed diagnostic models for data-poor regions and made improved satellite rainfall estimates for drought forecasts. Access to real-time satellite data enables drought forecasting though the use of hydrological models where ground measurements are limited (Mwangi et al., 2014; Sheffield et al., 2014). Hence, the use of satellite remote sensing datasets is particularly important in providing high spatial resolution and real-time inland forecasts of the water cycle components (Hansen et al., 2000; Tang et al., 2009). It is important to note that satellite observations and rainfall forecasts are important to provide earlier warning of EA droughts (Funk, 2009).

Moreover, accurate satellite measurements of land surface hydrological cycle components are essential for precise drought monitoring and forecasting (Ahmed et al., 2014; Sheffield et al., 2014; Van Loon., 2015). In addition, the use of remote sensing satellite products for drought monitoring and forecasting is useful to support humanitarian aid organisations (Anderson et al., 2012; Shukla et al., 2014; Enenkel et al., 2016). By applying drought indices such as the NDVI and Drought Severity Index (DSI), drought monitoring and forecasting can be achieved using data from remote sensing measurements (Omute et al., 2012; Mu et al., 2013; Abbas et al., 2014; AghaKouchak et al., 2015a; Zhao et al., 2017). For example, the Gravity Recovery and Climate

Experiment (GRACE) satellite data have been used to investigate water storage changes and water losses due to drought (Grippa et al., 2011; Ahmed et al., 2014; AghaKouchak et al., 2015a; Zhao et al., 2017). Similarly, remotely sensed vegetation cover maps (Rulinda et al., 2012; Mu et al., 2013; Abbas et al., 2014) show the vegetation responses to drought, which can further be used for drought monitoring and forecasting. Mu et al. (2013) used the DSI based on satellite evapotranspiration data to monitor and display the magnitude and spatial extent of drought over the global terrestrial land surface. The result captures the major regional droughts that have been reported over the last decade. Similarly, AghaKouchak et al. (2015a) conducted a comprehensive survey on current and emerging drought monitoring approaches using satellite remote sensing observations from climatological and ecosystem perspectives. The survey indicates that satellite observations can provide opportunities to improve early drought warning. Remote sensing satellite products can also be used to reflect lake inundation changes and processes under drought conditions (Wu and Liu, 2014). In general, in regions where in-situ climate observations are unavailable, remotely sensed satellite products are a valuable alternative for the monitoring and forecasting of droughts (Choi et al., 2013; Mu et al., 2013; Sheffield et al., 2014; AghaKouchak et al., 2015a).

Despite significant progress in drought monitoring and forecasting systems, drought forecasts have been hindered by unreliable monitoring networks, a lack of access to drought information, insufficient institutional capacities and a lack of integrated regional drought policies (Mu et al., 2013; Sheffield et al., 2014; AghaKouchak et al., 2015a). The use of satellite remote sensing products also faces major challenges, which include data continuity, unquantified uncertainty, sensor changes and community acceptability (AghaKouchak et al., 2015a). In addition, the region suffers from a lack of recorded long-term drought data and low rain gauge densities, along with complex topographies and climate variations (Nicholson et al., 2012; Sheffield et al., 2014; Funk et al., 2015; Enenkel et al., 2016; Zhan et al., 2016). As instrumental climate data recording started much later in Africa than in other continents (Nicholson et al., 2012), various scientific efforts have been undertaken to fill these gaps to forecast future droughts on the basis of the past records (Nicholson et al., 2012; Funk et al., 2015; Zhan et al., 2016). Under these conditions, remotely sensed drought information plays an important role in EA (Choi et al., 2013; AghaKouchak et al., 2015a; Enenkel et al., 2016). Indeed, care should be taken to minimise errors and inconsistencies that might occur in individual satellite products if datasets are not bias-corrected (Sheffield et al., 2009, 2014). The validation of satellite rainfall products over the complex topography of EA is therefore necessary (Dinku et al., 2007).

7. Country-specific case reviews

The EA region has suffered from the impacts of recurrent droughts to varying levels, including through abrupt changes in the length of growing periods, the timing and duration of wet and dry seasons, crop failures, livestock mortality and human death and displacement. Although global drought over the past 60 years has shown little change (Sheffield et al., 2012), the drought frequency and severity has highly increased in EA over the last two decades (Meier et al., 2007; Lyon and DeWitt, 2012; Lyon, 2014; AghaKouchak, 2015; Ayana et al., 2016; Nicholson, 2015, 2017). The drought events are widely distributed across all EA countries. Countries undergoing the most severe droughts in EA are Somalia, Ethiopia and Kenya (Lyon and DeWitt, 2012). In these countries, frequent droughts have resulted in the worst famine and poverty (Funk, 2009; FEWSN, 2011; Funk et al., 2013). Poor crop and pasture production, combined with civil conflict and insecurity, and abnormal inflation food prices have led to food crises in these countries (Funk, 2009; Lyon and DeWitt, 2012). For example, in 2008 Kenya faced unprecedented escalations in maize prices. In Ethiopia, a significant price inflation occurred in 2007, and in Somalia extreme food insecurity and civil unrest persist (Abbass, 2009; Funk, 2009; Zwaagstra, et al., 2010; Tadesse, 2016). Hence, a detailed discussion of drought issues will help to understand the overall drought effects in these particular countries.

7.1. Somalia

The most drought-prone country in EA is Somalia. Somalia has been facing chronic problems of food insecurity and high levels of malnutrition since the 1970s (Maxwell and Fitzpatrick, 2012; Menkhaus, 2012). International food relief and humanitarian aid have been playing a great role in sustaining livelihoods for decades (FEWSN, 2011; Funk et al., 2013). For several years the country was in a state of civil war and drought shocks (Maxwell and Fitzpatrick, 2012; Menkhaus, 2012). So far, Somalia is still not free from the effects of drought and existing conflicts. The UN declared a famine in southern Somalia on July 20, 2011 (Maxwell and Fitzpatrick, 2012). During this famine around 3.1 million people were affected, half a million children were malnourished and 1.46 million Somalis were displaced from their residences (Hillbruner and Moloney, 2012; Maxwell and Fitzpatrick, 2012). This famine has led to an estimated number of 258,000 deaths (FEWSN, 2011; Funk et al., 2013). Every day, nearly 2000 people from southern Somalia joined refugee camps in Ethiopia and Kenya in response to the famine (Hillbruner and Moloney, 2012). This famine was caused by manifold actors, including severe drought, conflict, rapidly-rising global food prices and long-standing instability in the country (Haan et al., 2012; O'Loughlin et al., 2012; Ayana et al., 2016).

Ahead of the 2010-2011 famine in Somalia, the joint technical analysis team from the USAID-funded Famine Early Warning Systems Network (FEWS NET) and the FAO-managed Food Security and Nutrition Analysis Unit (FSNAU) gave timely reports on the drought occurrence (Haan et al., 2012; Hillbruner and Moloney, 2012). However, help for the 2010-2011 famine victims from the International Committee of the Red Cross (ICRC), UN specialised agencies, Western NGOs, Islamic NGOs and Somali NGOs was denied by an Islamist Insurgent Group (*Al-Shabaab*) that controlled territories in the region (Haan et al., 2012; Menkhaus, 2012). Disagreements among the *Al-Shabaab*, the Transitional Federal Government (TFG), the UN and the USA, and a privilege gap in Somali society also exacerbated the famine (Haan et al., 2012; Menkhaus, 2012). Moreover, the crisis was aggravated by civil insecurity, lack of good governance, environmental degradation and increasing climate variability in the country (Haan et al., 2012; Maxwell and Fitzpatrick, 2012). More specifically, problems of humanitarian aid diversion, conflicts related to aid agencies' contracts and rents, the use of food as a weapon and an intention to harness humanitarian aid for political advantages also intensified the impacts of drought in Somalia (Haan et al., 2012; Hillbruner and Moloney, 2012; Menkhaus, 2012).

7.2. Ethiopia

Ethiopia has been challenged by severe droughts due to various climatic, environmental and social situations (Gebrehiwot et al., 2011; Viste et al., 2013; Bayissa et al., 2015). Drought in Ethiopia is cyclic, manifested by episodic events (Kiros, 1991; Shanko and Camberlin, 1998; Gebrehiwot et al., 2011; Bayissa et al., 2015). For these reasons, Ethiopia is highly vulnerable to drought (Gebrehiwot et al., 2011; Viste et al., 2013). According to long-term drought records, Ethiopia has frequently faced drought-induced famines (Viste et al., 2013). Drought in Ethiopia has been observed as early as 250 BC (Kiros, 1991; Degefu and Bewket, 2015).

Around 30 major drought events have struck Ethiopia in the last nine centuries, of which 13 were severe and affected the entire nation (Gebrehiwot et al., 2011; Bayissa et al., 2015). The first documented drought-induced famine in Ethiopia was in 1973-1975 (Wagaw et al., 2005). Since the 1970s, drought has hit the country approximately every 10 years. Recently, the frequency has increased to every two or three years, causing significant water shortages, economic losses and adverse social consequences (Wagaw et al., 2005; Gebrehiwot et al., 2011; Bayissa et al., 2015).

The droughts leading to the greatest loss of life occurred in 1973-1975 and 1984-1985, while drought affected the greatest number of people in 2002-2003 (Degefu and Bewket, 2015). During the 1973-1975 drought, the drought-induced famine took the lives of 250,000 people and countless domestic animals (Kebbede and Jacob 1988; Degefu and Bewket, 2015). The drought-induced great Ethiopian famine in 1984-1985 caused the deaths of between 250,000 to 750,000 people, and seven to ten million others suffered from severe starvation (Kebbede and Jacob 1988). This drought also forced 5.8 million people to become completely dependent on food aid (Wagaw et al., 2005; Gebrehiwot et al., 2011; Bayissa et al., 2015). During the 2002-2003 drought, around 14 million people were faced with hunger and starvation (Figure 2; Haile, 2005; Wagaw et al., 2005;). In Ethiopia, the government and international food aid agencies mitigated the impact of the severe drought in 2002–2003, which had a higher magnitude in severity and distribution than the costliest 1984–1985 drought (Wagaw et al., 2005; Funk, 2009). As part of the EA, Ethiopia also faced the 2010-2011 Horn of Africa drought, but the country resisted its impacts (Bayissa et al., 2015; Degefu and Bewket, 2015). The aforementioned drought events have driven the formation of a “drought early warning network”, which allows early forecasting and better preparedness for drought in Ethiopia (Wagaw et al., 2005; Gebrehiwot et al., 2011; Bayissa et al., 2015; Degefu and Bewket, 2015).

7.3. Kenya

In Kenya, around 72% of the country receives an average of less than 300 mm rainfall during the long March–May rainy season (Camberlin and Okoola, 2003). This amount of rainfall is insufficient to support crop productions. As a result, frequent droughts have occurred in the country (Abbass, 2009; Zwaagstra et al., 2010). Drought events have threatened Kenya more than 10 times since the 1970s (Abbass, 2009; Zwaagstra et al., 2010; Tadesse, 2016). During the 2010-2011 Horn of Africa drought, the people of Kenya were severely affected (Tadesse, 2016; Uhe et al., 2017; Funk et al., 2018). In 2012, Kenya also faced a severe rainfall deficit and more than 30% of the crops and pastures failed with subsequent high losses (Cumani and Rojas, 2016; Funk et al., 2018). Moreover, Kenya experienced drought in 2016 due to a shortage of rainfall, and more than 3 million people were in need of food aid (Uhe et al., 2017).

More specifically, drought is levelled as a primary recurrent natural disaster in the Arid and Semiarid Lands (ASAL) of Kenya (Zwaagstra, et al., 2010). The Kenyan ASAL is the most drought-prone region, where 25% of the Kenyan population and 50% of the national livestock are based (Abass, 2009; Uhe et al., 2017). The drought affected around 10 million livestock-dependent people in the ASAL (Zwaagstra, et al., 2010). In Kenya, a National Drought Management System dedicated to drought risk management was established and this system has been working actively for the last two decades (Abbass, 2009). Kenya is now becoming a more resistant country to drought, as its economy has reached the level of middle-income countries.

8. Government, citizen and stakeholder cooperation

To combat cycles of drought and control the hunger crisis in EA, regional cooperation among local and national governments, citizens, stakeholders, scientists and policymakers are vital (AghaKouchak et al., 2015b). Increasing strategic integration and coordination with the aim of helping people to become more resilient to drought are important. Indeed, many organisations have made important investments in building resilience to drought. In EA, countries including Sudan, South Sudan, Ethiopia, Eritrea, Djibouti, Somalia, Kenya and Uganda created the Intergovernmental Authority on Development (IGAD) in 1996 to deal with drought and desertification (https://igad.int/). This organisation was the first of its kind to tackle drought in EA. As a result, IGAD has made various drought mitigating efforts since its establishment. Similarly, the Nile Basin Initiative (NBI; http://www.nilebasin.org) is an intergovernmental partnership of regional cooperation established in 1999 to provide a forum for consultation and coordination for the sustainable management and development of the shared Nile Basin water for win-win benefits (Yohannes, 2009). The NBI comprises ten Nile Basin countries, namely Burundi, Ethiopia, Kenya, Rwanda, South Sudan, Sudan, Tanzania, Uganda, the Democratic Republic of Congo and Egypt, of which the last two are not a part of EA. These partnerships were established to strengthen the efficient use of water resources in an equitable way, targeting the minimisation of water resource competitions among the countries. Furthermore, these organisations have helped to develop cross-border linkages for better monitoring and assistance of the drought-vulnerable people in a coordinated way (Yohannes, 2009; O'Loughlin et al., 2012). A coordinated national and regional drought policy is important to respond to drought (Sivakumar et al., 2014). Hence, investing in short- and long-term actions, accompanied by well-planned and coordinated drought mitigation strategies is important for drought monitoring and management (Van Loon et al., 2016a). In addition, coping with drought is critical to address other challenges emerging in relation to drought, including environmental degradation, social conflicts, poverty and hunger (Solh and van Ginkel, 2014).

8.1. Governments

Governments have played a key role in monitoring and managing drought events, starting from designing drought prevention policies and laws, to transferring these into actions (Tadesse, 2016). The implementation of drought mitigation strategies and the development of various drought resilient infrastructures, especially in the agricultural sector, is significant for the societies in EA (Haile, 2005; Muller, 2014). In addition, governmental bodies' commitments in mobilising communities, civil society organisations and the private sector can further strengthen the support of funding and technical assistance from donors for drought alleviation strategies (Muller, 2014). Governments are also mandated to coordinate aid agencies, NGOs, donors and relevant stakeholders in collaboration with the local administrations to support vulnerable people and control drought risks and shocks. When a drought occurs, support from humanitarian and development agencies should be at the forefront to save lives and reduce risks (Haile, 2005; Tadesse, 2016). Large-scale emergency relief operations are often less relevant if they are not supported by development works towards drought alleviation. According to Muller (2014), the twin-track approach, i.e. combining emergency humanitarian assistance and development aid, is an appropriate way to build drought-resilient societies. Beyond active participation in an emergency framework, governments should play a vital role in designing and implementing sustainable development-oriented drought prevention strategies (Muller, 2014; Tadesse, 2016).

Having suffered from recurring droughts, African countries have adopted a strategic framework for drought risk management and enhanced resilience. The Windhoek declaration was proposed for a Drought Resilient and Prepared Africa (DRAPA), to be implemented at the national level starting from 2016 (Tadesse, 2016). The declaration comprises six important elements, which include: 1) drought policy and governance for drought risk management; 2) drought monitoring and early warning; 3) drought vulnerability and impact assessment; 4) drought mitigation, preparedness, and response; 5) knowledge management and drought awareness, and 6) reducing underlying factors of drought risk. This is a good step forward for the effective management and monitoring of drought in the drought-vulnerable EA region. The DRAPA strategic framework implementation is expected to produce a substantial reduction of drought impacts on human lives and economic and environmental assets (UNISDR, 2009; Tadesse, 2016). Similar frameworks are also being enacted worldwide to help populations living in drought-prone regions (e.g. Hyogo Framework for Action; UNISDR, 2009). These initiatives are particularly valuable for people facing recurrent shocks from drought episodes.

8.2. Citizens/people

Various actors should work together to take drought-preventive actions. Citizens/people can participate on a collective or individual basis for effective drought monitoring and management (Huddart et al., 2016; Tipaldo et al., 2017). Public service managers and community-based organisations are among the citizens who work in groups, whereas the individual actors are smallholder farmers, private sectors and local civil society members. These individuals are working individually to cope with possible drought incidents. Either individually or collectively, these actors are among the direct drought risk-takers, who benefit directly from preventing drought. Meanwhile, they can receive external help from their governments and relevant stakeholders. In addition, citizens can participate in various stages of drought protection measures from the early warning stage up to the relief stage. In addition, citizens can participate in research groups, traditional drought forecasting, and through the use of traditional drought-resistant crop varieties and transboundary husbandries so as to adapt to drought conditions and associated climatic challenges. Paul et al. (2017) noted that non-scientist citizens play a vital role in risk management and drought resilience-building. Citizens can enhance their innovation, adaptation, multidirectional information provision, risk management and local resilience-building (Huddart et al., 2016; Tipaldo et al., 2017). In addition, dissemination of available information via innovative methods can help farmers to mitigate the impact of cyclic drought. The use of local administration systems and religious networks can also contribute to delivering drought information to the farmers/citizens. This helps to equip citizens/farmers with more available information and solutions for drought mitigation (Huddart et al., 2016; Tipaldo et al., 2017).

8.3. Stakeholders

Coordinated direct and indirect involvement of drought stakeholders, such as partners, NGOs, donors, aid agencies and investors, has the potential to create great impacts in tackling drought episodes. When a lack of cooperation exists among these actors during a drought, the drought usually has more severe impacts on the society. A typical example occurred during the 2010-2011 Horn of Africa drought. Although the European Centre for Medium-Range Weather Forecasts (ECMWF) had predicted the drought (Funk, 2009; Pozzi et al., 2016), incapacitated preparedness and insufficient mitigation responses led to millions of people being critically affected in EA (Dutra et al., 2013; AghaKouchak, 2015). Meanwhile, a passive response from stakeholders led to increased drought severity.

Many stakeholders participate in drought prevention and associated developmental work (Muller, 2014; Shiferaw et al., 2014;). For example, Muller (2014) highlighted the experience of the Red Cross and Red Crescent in addressing drought in EA. The suggestions were that an effective implementation of national drought policy, an integrated approach and a strong linkage to drought adaptations are key for increasing early warning accuracy and reducing the risk of drought. Stakeholders should follow the rules and regulations of the countries where they are working, and services should be given to the vulnerable people. Moreover, these stakeholders should focus on sustainable drought resilience through further developmental work beyond the relief efforts.

9. Conclusions and further research priorities

We have reviewed the overall drought situation of EA, covering eleven countries. The causes and impacts of, and resilience to, drought are reviewed based on relevant literature. As a cross-cutting issue, a comprehensive synthesis of the complexities of drought in relation to its evolution, complexity, social implications and people's vulnerability is important in EA. Here, we draw the conclusions of this review and highlight possible research priorities for further drought mitigation in regards to drought monitoring and early warning.

In EA, drought has occurred every three years since 2005 (Meier et al., 2007; Funk, 2012; Hoell and Funk, 2013; Ayana et al., 2016; Nicholson, 2015, 2017). In addition, a drought event sometimes extends over two or more rainy seasons (Nicholson, 2017). So far, around 100 drought episodes have been recorded in EA since the 1970s (Guha-Sapir et al., 2004; Vicente-Serrano et al., 2012; EM-DAT, 2018). The failure of the EA long rains is the main cause of the droughts, as a result of climate variabilities and anthropogenic impacts. Human impacts that exacerbate drought in EA are increasing due to the improper use of natural resources. This includes the transformation of natural vegetation into farmlands, grazing lands and human settlements. Moreover, unless early warning systems and development programs are implemented, drought events are likely to increase food insecurity (Brown and Funk, 2008). Furthermore, EA drought monitoring is challenging as long-term drought data are lacking and rain gauge densities are low, along with high spatial climate variations (Funk et al., 2014; Sheffield et al., 2014). This has triggered research on the spatiotemporal behaviours of historical drought events to facilitate better drought adaptation and management. Hence, drought in EA is attracting attention from scientists, governments and stakeholders in order to implement effective mitigation measures.

Furthermore, governments, citizens and stakeholders should work together around the following key issues. Efficiency in service delivery to the drought-prone areas should be substantially improved. Respective governments' commitments and demonstrated leadership towards the overall functioning of drought prevention should be further strengthened. The active involvement and early actions of the partners are necessary for identifying drought vulnerable people and areas for practical actions. Moreover, designing and implementing drought risk reduction interventions and programmes/policies are the key necessities to minimise vulnerabilities and drought risks (Shiferaw et al., 2014). Governments should also focus on strengthening drought monitoring, forecasting, early warning and response systems for effective and efficient drought management. More transparent, coordinated and collaborated efforts in the preparation, prevention and relief of droughts are also vital for the affected societies.

Additional priority issues that should be solved through research are also recommended for further study. The overall precipitation, total water storage and occurrences of long rains have declining recently over EA (Ahmed et al., 2014; Liebmann et al., 2014; Omondi et al., 2014). Hence, droughts are becoming longer and more intense (Funk, 2012; Lyon and DeWitt, 2012; Hoell and Funk, 2013; Lyon, 2014; AghaKouchak, 2015; Nicholson, 2015, 2017), and these patterns are likely to continue across the region where the causes are still poorly understood. As a further consequence, food shortages may become more severe (Schreck et al., 2004; Liebmann et al., 2014; Masih et al., 2014; Sheffield et al., 2014; Hua et al., 2016). This requires further investigation through research concerning the individual and combined effects of anthropogenic activities and changes in the climate system.

To combat drought, knowledge of the links between drought, climate, oceanic and atmospheric circulations and any local factors such as government policies, and efforts of the people and stakeholders is valuable, and requires further composite investigation. Further study is needed to improve the accuracy of predictions of the severity, magnitude and coverage of droughts. Drought monitoring and forecast systems have been developed in many regions, including EA (Hao et al., 2014; Sheffield et al., 2014; Shukla et al., 2014; Tang et al., 2016; Zhang et al., 2017). These tools have been proven to be valuable for mitigating the socio-economic losses incurred by droughts. However, most of these approaches do not consider human activities such as water management and drought response measures. Future research should consider the impacts of human activities on drought to provide better tools for enhancing community drought preparedness.

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Table

Table 1: Summary of drought events recorded from 1900–2017 from EM-DAT database (EM-DAT, 2018) and from literature (e.g. Masih et al., 2014, Guha-Sapir et al., 2004)

Country	Drought years	Number of drought episodes	Number of deaths	Number of people affected (Million)	Economic loss (USD)
Burundi	1999, 2003, 2005, 2008, 2009, 2010	6	126	3.1	Not available
Djibouti	1980, 1983, 1988, 1996, 1999, 2005, 2007, 2008, 2010	9	0	1.2	Not available
Eritrea	1993, 1999, 2008	3	0	5.6	Not available
Ethiopia	1965, 1969, 1973, 1984, 1987, 1989, 1997, 1998, 1999, 2003, 2005, 2008, 2009, 2012 and 2015	15	402367	77.1	1492600
Kenya	1965, 1971, 1979, 1983, 1991, 1994, 1996, 1999, 2004, 2005, 2008, 2010, 2012, 2014 and 2016	15	196	50.2	1500
Rwanda	1976, 1984, 1989, 1996, 1999, 2003	6	237	4.2	Not available
Somalia	1964, 1969, 1973, 1980, 1983, 1987, 1988, 1999. 2004, 2005, 2008, 2010, 2012, 2014 and 2016	15	19673	18.4	Not available

South Sudan	2010, 2016	2	0	7.9	Not available
Sudan	1980, 1983, 1987, 1990, 1991, 1996, 1999, 2009, 2012 and 2015	10	150000	31.5	Not available
Tanzania	1967, 1977, 1984, 1988, 1990, 1996, 2003, 2004, 2006, 2011	10	0	12.7	Not available
Uganda	1967, 1979, 1987, 1998, 1999, 2002, 2005, 2008, 2010	9	194	5.0	1800
EA		100	572793	216.9	1495900

Figures

Figure 1

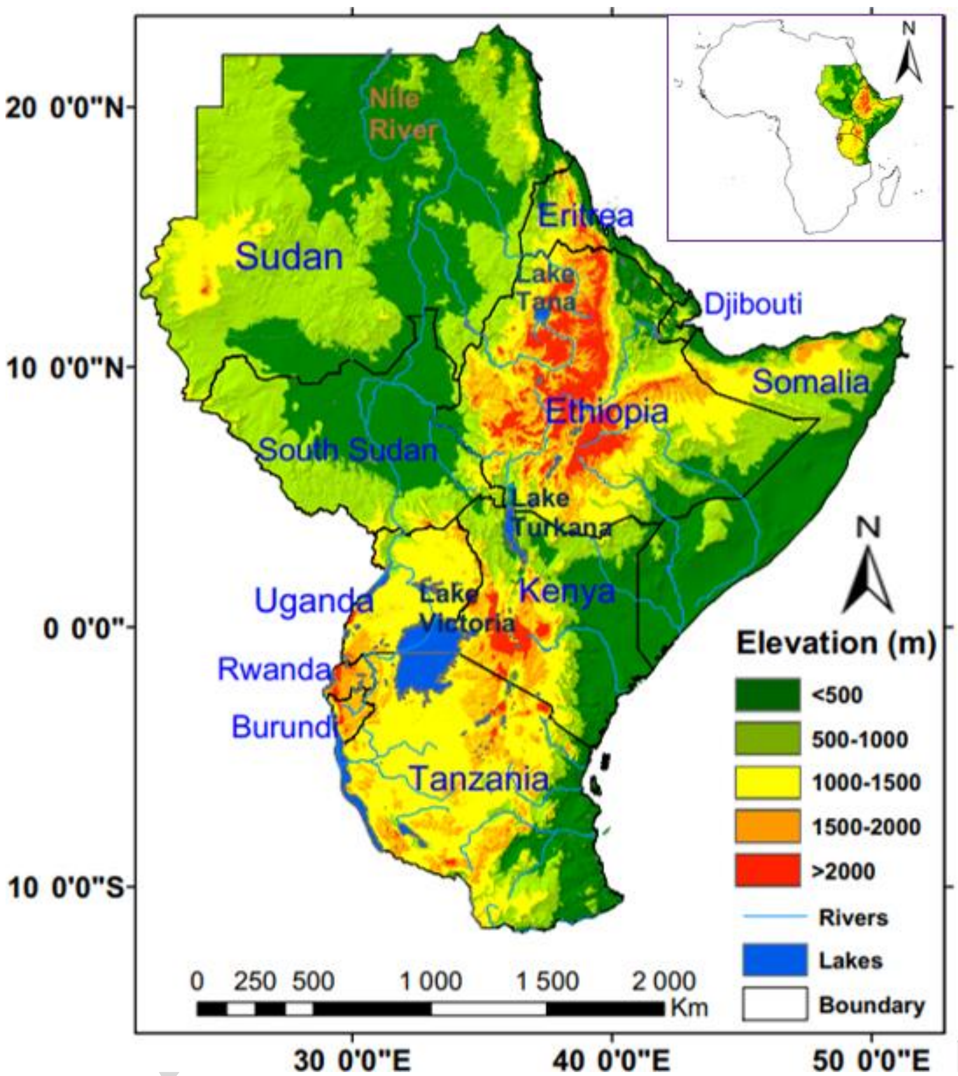

Figure 1: Geographical location of the East Africa

Figure 2

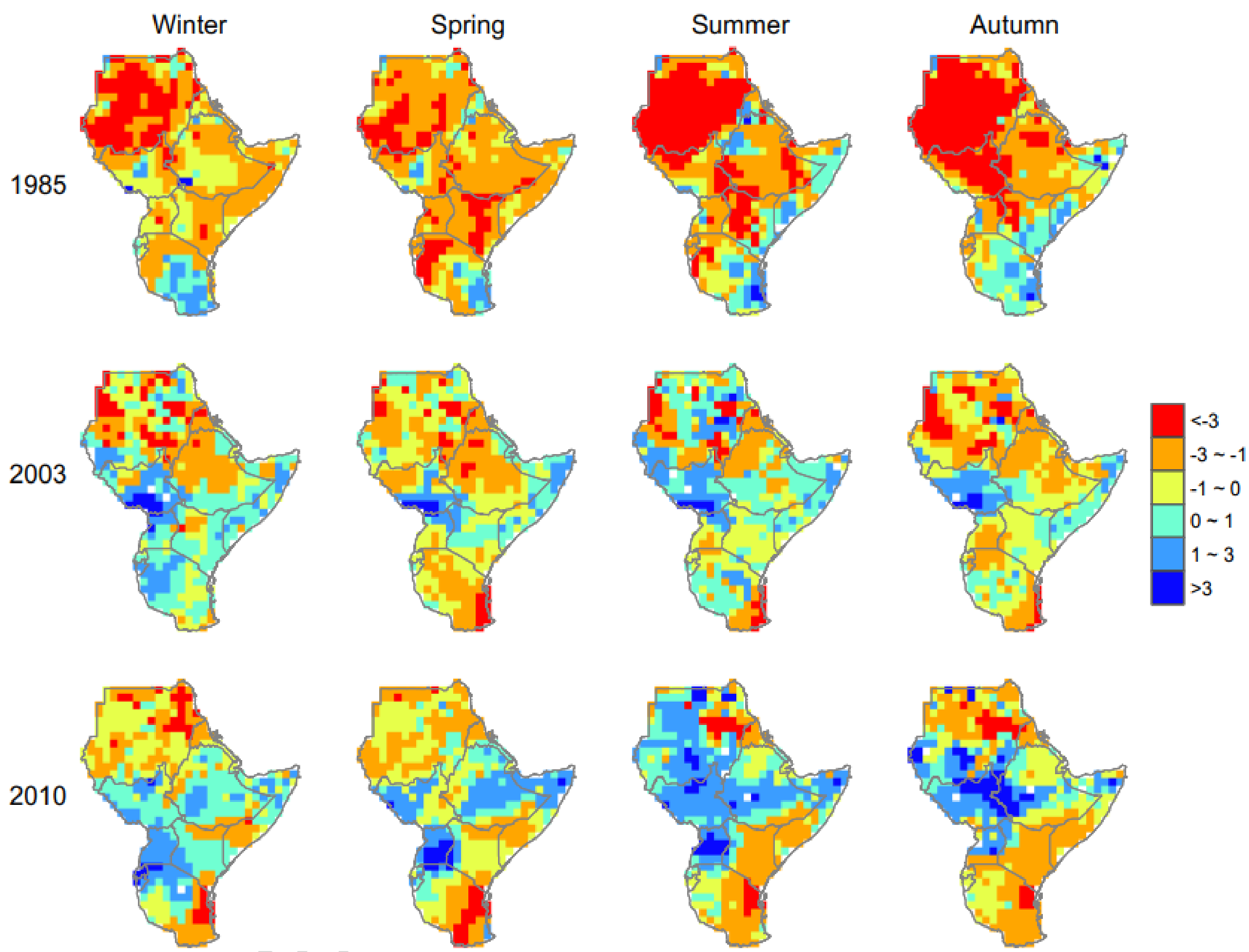

Figure 2: East African drought periods in 1985, 2003 and 2010 during the four seasons of each year. Data were used from a global dataset of Palmer Drought Severity Index (PDSI), a monthly 0.25-degree, resolution from the Princeton University Hydroclimatology Group (Sheffield et al., 2006, 2012). Note: The PDSI is a drought index used to estimate relative dryness/wetness by using temperature (in the form of potential evapotranspiration) and precipitation data as input (Sheffield et al., 2012). It is used to quantify long-term drought by capturing the basic effect of global warming. Values of PDSI ranges from -4 (extremely dry) and +4 (extremely wet)

Figure 3

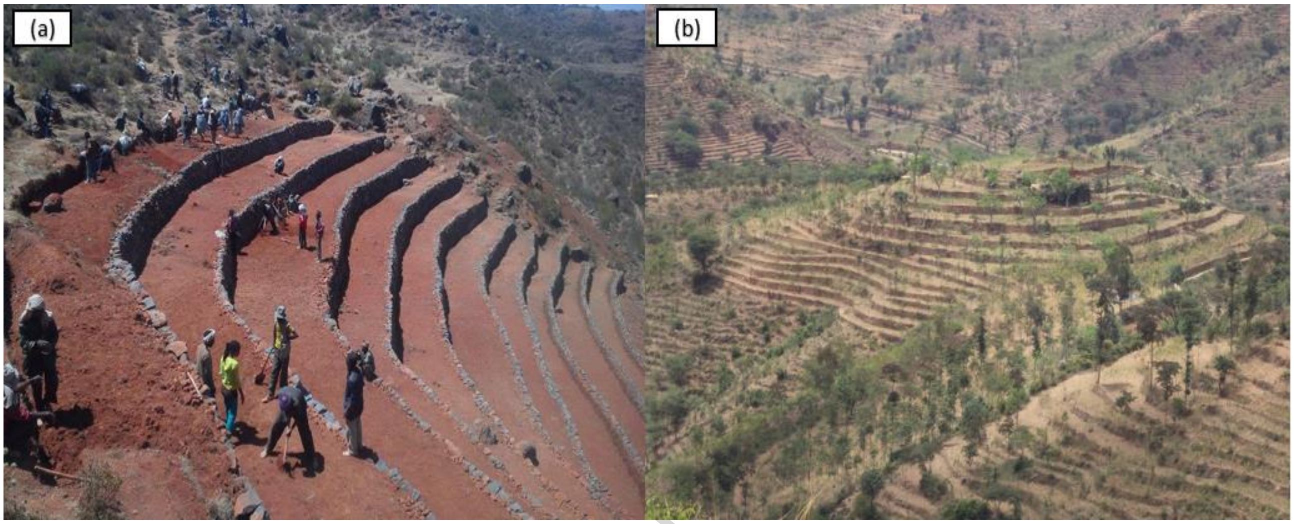

Figure 3: Drought mitigating efforts in Ethiopia, (a) efforts made to conserve soil and water and at the same time the benched terraces are used to harvest crops through distributing lands to non-land owner youths at Atsbi-Wonberta district, Tigray region, and (b) sustainable land management practices and enclosures at Adwa district, Tigray region.