Hydrol. Earth Syst. Sci. Discuss., 11, 2679–2718, 2014
www.hydrol-earth-syst-sci-discuss.net/11/2679/2014/
doi:10.5194/hessd-11-2679-2014

Hydrology and Earth System Sciences Discussions
Open Access

A review of droughts in the African continent: a geospatial and long-term perspective

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Received: 31 January 2014 – Accepted: 3 February 2014 – Published: 6 March 2014

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Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

This paper presents a comprehensive review and analysis of the available literature and information on droughts to build a continental, regional and country level perspective on geospatial and temporal variation of droughts in Africa. The study is based on the review and analysis of droughts occurred during 1900–2013 as well as evidence available from past centuries based on studies on the lake sediment analysis, tree-ring chronologies and written and oral histories and future predictions from the global climate change models. Most of the studies based on instrumental records indicate that droughts have become more frequent, intense and widespread during the last 50 yr. The extreme droughts of 1972–1973, 1983–1984 and 1991–1992 were continental in nature and stand unique in the available records. Additionally, many severe and prolonged droughts were recorded in the recent past such as the 1999–2002 drought in Northwest Africa, 1970s and 1980s droughts in West Africa (Sahel), 2010–2011 drought in East Africa (Horn of Africa) and 2001–2003 drought in Southern and Southeast Africa, to name a few. The available (though limited) evidence before the 20th century confirms the occurrence of several extreme and multi-year droughts during each century, with the most prolonged and intense droughts that occurred in Sahel and Equatorial East Africa regions. Complex and highly variant nature of many physical mechanisms such as El Niño-Southern Oscillation (ENSO), Sea Surface Temperature (SST) and land–atmosphere feedback adds to the daunting challenge of drought monitoring and forecasting. The future predictions of droughts based on global climate models indicate increased droughts and aridity at the continental scale but large differences exist due to model limitations and complexity of the processes especially for Sahel and North Africa regions.

However, the available evidence from the past clearly shows that the African continent is likely to face extreme and widespread droughts in future. This evident challenge is likely to aggravate due to slow progress in drought risk management, increased population and demand for water and degradation of land and environment.

HESSD

11, 2679–2718, 2014

Thus, there is a clear need for increased and integrated efforts in drought mitigation to reduce the negative impacts of droughts anticipated in future.

1 Introduction

Drought is a recurrent climatic phenomenon across the world. It affects human being in a number of ways such as causing loss of life, crop failures, food shortages which may lead to famine in many regions, malnutrition, health issues and mass migration. It also causes huge damage to the environment and is regarded as a major cause of land degradation, aridity and desertification. The impacts of droughts are witnessed at a range of geographical scales. For instance, individual families or communities may lose their livelihoods and source of water, subject to acute food shortages and health issues and the country's economy may be severely impacted. The available estimates on drought impacts suggest that, during the period 1900–2013, there were 642 drought events reported across the world resulting in huge toll to humanity killing about 12 million people and affecting over 2 billion (EM-DAT, 2014). The total economic damages are estimated at USD 135 billion (Table 1).

Drought remains a major disaster causing huge damages to people, environment and economy, despite making considerable progress on monitoring, forecasting and mitigation of droughts across the world. The lack of desired level of success could be attributed to many reasons. Drought is a complex phenomenon, which varies every time in terms of its onset, intensity, duration and geographical coverage. The capacity of people facing this hazard may be limited to avoid adverse impacts compounded by shortcomings in government capacity (e.g. financial, institutional and political) to provide short-term relieve and install long-term drought mitigation measures. There is an urgent and dire need to progress on various fronts of drought mitigation such as early warning and forecasting, building resilience of the societies, short-term relief efforts, long term planning and capacity building (e.g. Calow et al., 2010; Clarke et al., 2012; Dondero, 1985; Falkenmark and Rockström, 2008; GFDRR, 2011; IFAD, 2010,

HESSD
11, 2679–2718, 2014

2011a, b; Logar et al., 2013; Mishra and Singh, 2010; Msangi, 2004; Sehmi and Kundzewicz, 1997; Tadesse et al., 2008; Tøttrup et al., 2012; UNISDR, 2004 and 2010; Vicento-Serrano et al., 2012; Vogel et al., 2010; World Bank and GFDRR, 2010).

Understanding gained from detailed analysis of historic drought events offers enormous possibilities to carry out better drought management planning and to mitigate impacts of droughts (Vicente-Serrano et al., 2012). A sound science based geospatial analysis of the past drought events and their causes can facilitate the improvement of drought mitigation and preparedness plans. This can also guide in determining the spatial and temporal variability of drought hazard and the vulnerability of water resources, vegetation systems and society to drought. The analysis of historical droughts can provide information on deficits in water demand and likely impacts on water resources and environment, which is essential for drought risk reduction, planning new projects and reviewing the existing ones. Such studies can also provide necessary information on periodic nature of droughts and their relationship with increasing water demand or climate change (Mishra and Singh, 2010). Moreover, the outlook of the current and future drought events in the historic context could facilitate in applying low-risk and long-term plans to use, conserve and sustain water and other natural resources (Touchan et al., 2008). The current efforts by scientific community in this direction are very limited and require further attention (Mishra and Singh, 2010; Touchan et al., 2008; Vicente-Serrano et al., 2012; Vogel et al., 2010). The available scientific studies do not provide enough geospatial and long-term temporal coverage of the past drought events at global and continental levels. However, the increasing number of available studies offers great opportunity to conduct such an analysis. The major focus of this paper is to review the available literature in the context of Africa where droughts occur most frequently and cause significant loss of life, negative effects on people and damages to the economy and environment. Most countries in Africa also lack necessary capacity and resources to make required progress to address this catastrophic hazard (e.g. GFDRR, 2011; Tadesse et al., 2008; Vogel et al., 2010).

HESSD
11, 2679–2718, 2014

A recent global review on droughts and aridity by Dai (2011) indicated that large scale droughts have frequently occurred during the past 1000 yr across the globe. This review briefly reported few of these mega-droughts in North America, China and Africa, but does not provide the detailed review of the historic droughts across the world. For Africa, the focus was on the severe, widespread and prolonged droughts occurred during 1970s and 1980s in West Africa (Sahel region). The study mainly focused on aridity changes from 1950 to 2008 and provided foresight for the 21st century. One of the important conclusions of this paper is that the global aridity and drought areas have increased substantially during the 20th century and attributed to widespread drying since 1970s over Africa, southern Europe, East and South Asia, eastern Australia and many parts of the northern mid-high latitudes. The aridity trends are projected to continuously increase in the 21st century. However, study of Sheffield et al. (2012) shows that drought patterns are increasing over last 60 yr, though not as alarming as usually projected. Mishra and Singh (2010) conducted a comprehensive review on drought concepts and a critical evaluation of the most widely used indicators for drought assessment. But the review remains limited in terms of description of the historic droughts and only briefly mentions few of them with their main impacts. For Africa, the study only enlisted the severe droughts in Sahel occurred during 1910s, 1940s, 1960s, 1970s and 1980s. These droughts caused huge socio-economic and environmental impacts in this semi-arid region resulting in massive scale migration, famine and environmental degradation (desertification), especially during the last two drought episodes. The study noted that growing demand for water, limited sources of water and changes in spatio-temporal patterns of climate are aggravating the drought impacts in the world.

There are a growing number of studies addressing various drought related issues for Africa. Most of these studies focused on a specific region i.e., Southern Africa (e.g. Clarke et al., 2012; Cornforth, 2013; Dube et al., 2000, 2002, 2003; Green, 1993; Jager et al., 1998; Manatsa et al., 2008; O'Meagher et al., 1998; Richard et al., 2001; Unganai et al., 1998; Vogel et al., 2010), Sahel (West Africa) (e.g. Giannini et al.,

HESSD
11, 2679–2718, 2014

A review of droughts in the African continent

I. Masih et al.

2008; Govaerts et al., 2008; Kasei et al., 2010; Lebel et al., 2009; Lodoun et al., 2013; Traore et al., 2007; Zeng, 2003), East Africa (Horn of Africa) (e.g. Anderson et al., 2012; Dutra et al., 2013; Syroka and Nucifora, 2010) and Northwest Africa (e.g. Touchan et al., 2008 and 2010). There are few studies which attempt to cover more than one region (e.g. Calow et al., 2010; Herweijer and Seager, 2008; Rojas et al., 2011; Naumann et al., 2012; Tadesse et al., 2008; Verschuren, 2004). These and many other studies are comprehensively reviewed and discussed in the following sections. Most of them investigate one or more drought related subjects i.e., the study of a specific drought event or historic droughts in a country or regional perspective, methodological developments on drought indicators, causes of droughts, forecasting and early warning systems, impact analysis and drought risk reduction, drought planning and management and capacity building. None of them provide a long-term analysis of droughts considering past, present and future perspective at the continental scale.

There is growing number of global data sets which can facilitate continental scale analysis, along with growing number of literature. The few examples of these sources are EM-DAT data base[1], global scale estimation of various drought related indicators (e.g. Standardized Precipitation and Evaporation Index, SPEI) (Vicento-Serrano et al., 2010) and remote sensing data and products (e.g. Rojas et al., 2011).

The main objective of this study is to review available information and literature and conduct a detailed geospatial and long-term analysis of droughts across the African continent. We examine the major causes of droughts reported in the literature and present findings and important discourses on drought trends (including frequency, intensity and geospatial coverage), temporal variability, desiccation (aridity) and causes.

[1]http://www.emdat.be/database

HESSD
11, 2679–2718, 2014

2 Materials and methods

2.1 Study area

This study focuses on the whole African continent. However, analysis and discussion is also presented in the regional and country perspectives. It is important to note the differences in grouping various countries in different regions. For instance, EM-DAT groups African countries into North, Middle, South, East and West Africa. On the other hand, many regional studies are focused on Sahel (includes countries in West Africa between Sahara desert and Guinea coast rainforest, about 18–15° N), Horn of Africa (Ethiopia, Somalia, Kenya), Equatorial East Africa, Southern Africa. The special reference to countries in a given region is made wherever deemed necessary.

The rainfall depicts very high spatial and temporal variability across the African continent (Fig. 1). North Africa region receives very low rainfall and have a desert climate. The highest rainfall occurs in Middle African countries and some countries along with west coast of West Africa. These countries have (sub)-humid climatic characteristics. The highest variability of rainfall is found across the countries grouped under West, East and Southern Africa, but mostly have semi-arid climate. Variations within a country are also important to note, for instance, the eastern part of Ethiopia receives much less rainfall (semi-arid) compared to the Ethiopian Highlands (sub-humid) in the western part. There are distinct differences in intra-annual variability across the regions. Southern Africa receives most of the rainfall during October–March, whereas Sahel rainfall is concentrated during July–August summer monsoon period. Most countries in the Horn of Africa and Equatorial East Africa regions receive rainfall in two seasons: October–December (short rainfall season) and March–May (long rainfall season). The Northwest Africa receives most of the rainfall during October–April.

The earlier studies indicate that the semi-arid and sub-humid regions of Africa are the most drought prone regions (e.g. World Bank and GFDRR, 2010). These countries are highly vulnerable to drought owing to high climatic variability and also due to other reasons such as poverty, high dependency on rainfed agriculture and weak infrastructure to manage resources and recover from disasters. Moreover, vulnerability to drought varies per country. For instance the economic impact of the 1991–1992 drought was much higher on the GDP of Malawi and Zimbabwe compared to South Africa and Botswana (Benson et al., 1998). The lowest negative impacts in Botswana on people livelihoods and food security during drought periods of 1982–1987 and 1992 were mainly attributed to a small and largely accessible national population, availability of domestic and international resources, existence of rural infrastructure, government commitment, district-level capacity and a timely and fairly comprehensive food security and nutrition monitoring system (Belbase and Morgan, 1994).

2.2 Data and methods

The main data and information sources for this study are collected from the literature (e.g. published, peer and non-peer reviewed, unpublished sources). More than 100 literature sources were studied in detail, after initial skimming of over 500 articles searched from relevant international journals (individual journals and search engines), African Journals, donor reports and other sources. The list of reviewed material is not exhaustive, though an effort has been made to conduct a compressive coverage.

The global data set on droughts from EM-DAT website[2] were accumulated for the available period 1900–2013. This data set provides country/regional/continental level estimates on drought events, people killed and affected and economic damage. Additionally, a global database on SPEI was used to further analyse some of the selected droughts[3]. The SPEI is a widely used drought indicator estimated based on precipitation and potential evapotranspiration data. It has the ability to monitor onset, intensity and duration of drought. The indicator is very suitable to study geospatial and temporal variation of drought including the impact of global warming. This indicator is primarily related to meteorological drought and do not offer as such estimates on

[2]http://www.emdat.be/database

[3]http://sac.csic.es/spei/home.html

HESSD
11, 2679–2718, 2014

agricultural, hydrological and socio-economic aspects of droughts, though it could be seen as a proxy to these droughts as eventually they are caused by the deficit in precipitation. The detail discussion on comparison of various commonly used drought indicators, basic concepts and various perceptions on drought can be found in the literature (e.g. Dai, 2011; Mishra and Sing, 2010; Ntale and Gan, 2003; Smakhtin and Schipper, 2008; UNISDR, 2004). In this study drought is considered as a temporary, recurrent climatic event that is originally caused by lack of rainfall (Smakhtin and Schipper, 2008). This point of view is in general agreement with the understanding of drought by EM-DAT and most of the material used in this paper. For instance, the EM-DAT glossary considers drought as a long lasting event; triggered by lack of precipitation. Here a drought is stated as an extended period of time characterised by a deficiency in a region's water supply that is the result of constantly below average precipitation.

3 Results and discussion

3.1 Geospatial and temporal pattern of droughts during 1900–2013

The summary of the selected literature reviewed is presented in Table 2, indicating drought years, geographical location and key relevant findings. While preparing this Table, an effort was made to avoid duplication of similar studies and yet provide geospatial and temporal coverage. Another important consideration was to examine important discourses most relevant to the topic of this paper. There are a rapidly growing number of studies on various drought related issues, especially during the last decade. The available studies cover most parts of Africa, though coverage is low for middle Africa which is understandable as in this region climate is humid and droughts are not as catastrophic as in the other regions. Meteorological drought remains the main subject of most studies followed by agricultural drought. Studies examining hydrological droughts and the impacts of human uses of water on the assessment and intensification of these droughts are limited.

HESSD
11, 2679–2718, 2014

Table 3 provides a summary of the drought events recorded in the EM-DAT data base along with the number of people killed and affected and estimated economic damage. This widely used data base provides very useful information for this study. However, caution is required while using it for a specific purpose due to several reasons. First, the available information underestimates the total number of drought events per country and consequent impacts. Generally much lower number of droughts is recorded for many countries (e.g. Morocco, Tunisia, Algeria, Sudan, Zimbabwe and South Africa) for the period of 1900–2013, which prohibits formulating century scale picture of drought patterns for these countries. The information before 1960s is not available for most of the countries. Similarly, no information is available for many recorded drought events on number of people killed and affected and economic damage. Thus, aggregated values of these indicators, which are often used, give much lower estimates of drought affects. Second, in the aggregation of the number of events, the method used by EM-DAT and many users takes a country level perspective. In this way, a drought event occurred during one year in many countries in a region is counted more than once. This should be properly examined, especially when studying the region with similar climatic regimes. In the scientific literature, regional and multi-year droughts are often referred as one drought event (Table 2). This difference limits a straightforward comparison of the droughts given in Tables 2 and 3.

A number of inferences are drawn from the analysis of the available data and scientific evidence reviewed in this paper (Tables 2 and 3). The frequency, intensity and geospatial coverage of droughts have significantly increased across the whole African continent during the second half of the 1900–2013 period. This inference is supported by studies conducted at continental scale (e.g. Dai, 2011, 2013) as well as by most of the regional and country level studies (e.g. Quassou et al., 2007; Touchan et al., 2008, 2011; Elagib and Elhang, 2008; Kasei et al., 2010; Manatsa et al., 2008; Richard et al., 2001). The available data (though limited in temporal coverage) from EM-DAT also supports this observation (Table 2). This point is further substantiated by Figs. 2 and 3. Figure 2 shows the geospatial coverage of the three most extreme droughts occurred

HESSD
11, 2679–2718, 2014

during past 50 yr (1972–1973, 1983–1984 and 1991–1992 droughts). These droughts could be regarded continental in nature as they spanned over many sub-regions and covered wide areas of the African continent. None of the previous droughts during 20th century were as wide spread and intense compared to them (Fig. 3).

Most African countries are highly vulnerable to single and multi-year droughts when seen from purely hydro-climatic point of view. For instance, number of severe droughts occurred in Northern and Southern Africa during the 20th century are comparable to those observed in Eastern and Western Africa which are generally considered as the most vulnerable regions (Tables 2 and 3). However, distinct geospatial and temporal patterns exist in the drought episodes mainly driven by the diverse nature of the climate and drought inducing physical mechanisms (discussed later in this paper). The multi-year and prolonged droughts are more common in Sahel compared to any other region. In contrast, East Africa faces comparatively less prolonged but very extreme droughts.

The geospatial spread of drought depicts large variation within a country or a basin, beside regional heterogeneity. This point is clearly indicated by Figs. 2 and 3 and also highlighted by other studies (e.g. Anderson et al., 2012; Moeletsi and Walker, 2012; Mussá et al., 2014; Rojas et al., 2009; Rulinda et al., 2012; Trambuer et al., 2014). The increasingly available information and tools based on remote sensing, analysis of global climatic data sets (e.g. global SPEI products) and hydrological and climatic modelling offer great opportunity to identify these geospatial differences and drought hot spots. For instance, a remote sensing based study by Rojas et al. (2009) identified hot spots regions at sub-national level depicting higher probabilities of facing agricultural droughts. The most vulnerable regions identified by their study were: Tensift and Centre in Morroco, Brakna in Mauritania, North Darfur in Sudan, Samenawi Keith Bahri in Eritrea, Coast and Eastern in Kenya, Manyara, Tanga, Arusha and Kilimanjaro in Tanzania, Juba Hoose, Juba Dhexe and Shabelle Hoose in Somalia, Kaabong and Kiruhura in Uganda, Southern in Sierra Leone, Gbarpolu in Liberia and Otjozondjupa in Namibia.

HESSD
11, 2679–2718, 2014

There is increasing availability of drought monitoring and forecasting tools for decision making which can provide real time monitoring and forecasting of drought across the region (e.g. Tadesse et al., 2008; Anderson et al., 2009; Dutra et al., 2013; Vicento-Serrano et al., 2012). However, the use of these tools in decision making is still limited and could be promoted. For instance, despite inherent uncertainties in the available drought monitoring and forecasting systems, the 2010–2011 drought in the Horn of Africa was well predicted by European Centre for Medium-Range Weather Forecasts (ECMWF). But this information was not timely used for better preparedness and mitigation of the drought, which finally caused heavy toll affecting about 12 million people (Dutra et al., 2013).

3.2 Past, present and future pattern of droughts

There are few studies available to date which offer possibility of comparing droughts observed during 1900–2013 (instrumental era) with those witnessed in the past centuries. This comparison is important as African climate displays high decadal and century scale variability. The work of Touchen et al. (2008, 2011) provides a long term perspective on droughts in Northwest Africa (Morocco, Algeria and Tunisia). They used tree-ring records to construct the Palmer Drought Severity Index (PDSI) for the period AD 1179–2002. These studies reveal that the frequency of occurrence of a single drought event was 12–16 times per century before the 20th century, which was increased to 19 during the 20th century. The most severe multi-year drought occurred during 1999–2002, whereas 1847 and 2002 were identified as the driest single years with PDSI values of −3.74 and −3.90, respectively. The latter half of the 20th century is seen as the driest period in the last 9 centuries. This shift to drier conditions was attributed to anthropogenic climate change.

A number of researchers studied historic droughts in Africa based on lake sediment analyses. Evidence from the sediment analysis of the lake Bosumtwi, Ghana indicated several prolonged periods of drought during the last three millennia, most recent ones around 200–300 yr ago (Shanahan et al., 2009). Comparing 1970s droughts in Sahel

HESSD
11, 2679–2718, 2014

with earlier drought episodes, they concluded that these droughts were not anomalous and monsoon had generated even more severe and prolonged droughts in the past. Verschuren et al. (2000) investigated droughts over the period AD 900 to 2000 based on sediment analysis of Lake Naivasha Kenya in Equatorial East Africa. The period AD 1000–1270 (Medieval Warm Period) was found to be the driest one over the last 1100 yr. Additionally, dry conditions were found around AD 1380–1420, 1560–1620 and 1760–1840 during relatively wet period of AD 1270–1850 (Little Ice Age). These drought episodes were more severe than recorded droughts in the 20th century. Bessems et al. (2008) noted extreme droughts in Equatorial East Africa about 200 yr ago based on the sediment analysis of three lakes (Chibwera and Kanyamukali in western Uganda, and Baringo in central Kenya). The authors, Verschuren et al. (2000), and Bessems et al. (2008), compared their findings with the available evidence from the cultural history of east Africa and found consistency between two sets of observations.

Endfield and Nash (2002) described the discourse on long-term desiccation of the African continent emerged during 19th century. Their study is based on the analysis of the missionary documents from southern Africa (Botswana and South Africa). The authors constructed a chronology of intra-decadal climatic variability for the period 1815–1900 and showed that the major multi-year droughts occurred in 1820–1827, 1831–1835, 1844–1851, 1857–1865, 1877–1886 and 1894–1899. The study inferred that the discourse on long-term desiccation evolved during this period was merely triggered by these episodes of droughts rather than underpinned by long-term climatic deterioration. Nevertheless, the discourse on desiccation still remains an important subject in the current drought research. The evidence presented in the previous section pointed out to the increased aridity and intensification of droughts, especially during the second half of the 20th century (e.g. Dai, 2011; Elagib and Elhang, 2008; Kasei et al., 2010; Quassou et al., 2007; Manatsa et al., 2008; Touchan et al., 2008, 2011; Richard et al., 2001). Dai (2013) predicted likelihood of increased droughts and aridity over central and southern Africa during the 21st century. On the contrary, the Sahel region may receive more rainfall. Large uncertainties exist in these findings and thus

HESSD
11, 2679–2718, 2014

require caution in making regional or continental conclusions. Druyan (2011) reviewed 10 studies which are based on the simulations of atmosphere-ocean global climate models on future climate of Sahel. Some studies predicted wetter conditions and some predicted more frequent droughts, thus, no consensus was observed. The large uncertainties and differences in these predictions were attributed to model limitations and complexity of many physical mechanisms governing the precipitation trends.

3.3 Causes of droughts

It is important to acknowledge that droughts, at first, are part of natural climatic variability which is quite high at intra-annual, inter-annual, decadal and century time scales in the African continent. Many studies attempted to investigate the natural and anthropogenic causes that could be associated with droughts in Africa (Caminade and Terry, 2010; Dai, 2011, 2013; Dutra et al., 2013; Giannini et al., 2008; Herweijer and Seager, 2008; Jury et al., 1996; Kerr, 1985; Lebel et al., 2009; Manatsa et al., 2008; Hastenrath et al., 2007; Richard et al., 2001; Shanahan et al., 2009; Tierney et al., 2013; Vicente-Serrano et al., 2012; Zeng, 2003). The review of these studies revealed that there are complex array of factors inter-playing in an intricate manner. There is no unique set of factors responsible for geospatial and temporal variation of droughts across the continent. The physical mechanisms causing droughts differ by region, although ENSO and SSTs are regarded major influencing factors across the continent.

Droughts in Southern Africa occur most of the time during the warm phase of ENSO (El Niño). However, this does not happen always as there are many other local and global factors influencing the drought phenomenon. For instance, Richard et al. (2001) examined droughts during 1950–1988 in Southern Africa. They found that droughts during 1970–1988 were intense and widespread compared to those during 1950–1969. The El Niño was the main governing factor for droughts during 1970–1988. However, this observation require caution because droughts may not occur during El Niño periods, i.e., as happened during 1925–1926 and 1997–1998. For the droughts

HESSD
11, 2679–2718, 2014

during 1950–1969, regional oceanic and atmospheric anomalies (e.g. southwest Indian Ocean SST) were named as the main causes. Manatsa et al. (2008) suggested that El Niño alone is not a sufficient predictor of droughts in Southern Africa. They recommend that March to June extreme positive Darwin Sea Level Pressure anomalies are ideal additional candidate for drought monitoring and forecasting in Zimbabwe and Southern Africa.

Contrary to Southern Africa, East Africa region faces droughts during cold phase of ENSO (La Niña). For instance, Dutra et al. (2013) indicated that strong La Niña event was the main cause of 2010–2011 drought in the Horn of Africa. Hasternath et al. (2007) argue that the low rainfall in this region occurs during fast westerlies which are usually accompanied by anomalously cold waters in the northwestern and warm anomalies in the southeastern extremity of the equatorial Indian Ocean Basin. This mechanism was found responsible for 2005 drought in the Horn of Africa.

Droughts in Sahel are caused by an array of complex processes and feedback mechanisms. Caminade and Terry (2010) stated that conditions that favour lower summer rainfall in Sahel are: when Atlantic ocean north of equator is cool and the same is warm below the equator, El Niño events, increased vertical thermal stability from a warming troposphere and deterioration of vegetation cover, which increases albedo and decreases evapotranspiration. Most of the studies on Sahel droughts concur that the recent severe droughts in Sahel were caused by the ocean warming (southward warming gradient of the Atlantic ocean and steady warming of the Indian Ocean), southward shift of Inter Tropical Convergence Zone (ITCZ) (Caminade and Terry, 2010; Dai, 2011; Giannini et al., 2008; Kerr, 1985; Lebel et al., 2009; Zeng, 2003). The land-atmosphere feedbacks through natural vegetation and land cover change are also important factors. Anthropogenic contribution in land use change altering the land surface feedback mechanisms is also seen as a factor. Furthermore, human induced green house gas emission is also considered as a contributory factor to oceans warming. Despite recognition of these two anthropogenic factors, their relative

HESSD
11, 2679–2718, 2014

contribution in inducing Sahel droughts is debated and regarded as a minor factor, if so.

In Northwest Africa, neither SST nor ENSO shows a clear relationship with drought patterns (Touchan et al., 2008). Further research is required to understand mechanisms causing droughts in this region.

4 Conclusions

The climate of African continent exhibits large geospatial and temporal variability. Droughts are recurrent features varying from failure of rains in one season or up to one or more years. The vulnerability to droughts is high because of high frequency as well as due to poverty, and large dependency on rainfed agriculture and other factors. Therefore, droughts continue to incur heavy toll to people, animals, environment and economy. The planning and management of droughts requires a paradigm change shifting from crisis management to risk management. The comprehensive studies on the historic droughts event could significantly guide in better planning and mitigation of droughts. There is significantly increasing number of information and scientific studies on various aspects of drought. However, these studies do not provide a long-term and/or continental scale perspective. This study is a first of its kind to build such a perspective on droughts in Africa with the aim on conducting geospatial and long-term analysis of the droughts. The study is underpinned by a comprehensive review of available information and scientific literature and analysis of the EM-DAT and SPEI data sets.

The analysis of droughts during 1900–2013 indicated that droughts have been intensified in terms of their frequency, severity and geospatial coverage over the last few decades. The droughts that occurred in 1972–1973, 1983–1984 and 1991–1992 were most intense and widespread. All of the regions witnessed severe droughts in the last few decades, for instance, the 2010–2011 drought in East Africa (Horn of Africa), 1999–2002 drought in North Africa, 2001–2003 drought in Southern Africa and persistent droughts in Sahel during 1970s and 1980s. Few studies are available to construct drought chronologies before 20th century. However, studies based on lake sediment analysis indicated episodes of severe droughts prolonged for decades and even centuries in the past over West and Equatorial East Africa, which are also documented in the cultural histories of these regions. The studies underpinned by tree-ring chronologies in Northwest Africa indicated quite a number of moderate to severe droughts in the past, about 12–16 events per century which has increased to 19 during 20th century. Southern Africa also faced several single and multi-year droughts during 19th century, as indicated by the analysis of missionaries' correspondence.

The predictions on future drought patterns based on global climate model simulations remain uncertain for most of the regions, with the exception of likelihood of increased droughts in central and southern Africa. There is large number of complex factors responsible for causing the droughts across various regions of the continent (e.g. ENSO and SSTs, wind and pressure anomalies, land-atmospheric feedback mechanisms). Their complex interactions induce uncertainty in the drought predictions and require further efforts, though significant progress has been made in forecasting tools and global climate change simulation models.

The available evidence from the past clearly shows that the African continent is very likely to face extreme and widespread droughts in future. The vulnerability is likely to increase due to fast growing populations, increasing water demands and degradation of land and environmental resources. Addressing such a daunting and evident challenge calls for much more serious and committed action from communities, governments, regional bodies, international organizations and donors than that is witnessed at present. This review advances available information and scientific understanding of the droughts in Africa. The material presented in this paper will be very useful to guide long-term drought planning and mitigation approaches at country, regional and continental levels and will also serve as a guide to governments and regional organizations in Africa, international community and donors to (re)align their drought related policies and strategies.

HESSD
11, 2679–2718, 2014

Acknowledgements. This study was carried out in the scope of the DEWFORA (Improved Drought Early Warning and Forecasting to strengthen preparedness and adaptation to droughts in Africa) project which is funded by the Seventh Framework Programme for Research and Technological Development (FP7) of the European Union (Grant agreement no: 265 454).

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HESSD

11, 2679–2718, 2014

Table 1. Overview of number of droughts and their impact across the world during 1900–2013.

Continent	# of events	# of people killed	# of people affected	Damage ($\times 10^3$ USD)
Africa	291	847 143	362 225 799	2 920 593
Americas	134	77	69 505 391	50 471 139
Asia	153	9 663 389	1 707 836 029	44 251 865
Europe	42	1 200 002	15 488 769	25 481 309
Oceania	22	660	8 034 019	12 303 000
Total	642	11 711 271	2 163 090 007	135 427 906

Source: EM-DAT: The International Disaster Database. Centre for Research on the Epidemiology of Disasters-CRED; http://www.emdat.be/database, last accessed: 13 January 2014.

HESSD
11, 2679–2718, 2014

Table 2. Summary of the selected literature reviewed in this study.

Reference	Drought enlisted by region/country/basin during 1900–2013	Remarks
North Africa		
Quassou et al. (2007)	Morocco: 1904–1905, 1917–1920, 1930–1935, 1944–1945, 1948–1950, 1960–1961, 1974–1975, 1981–1984, 1986–1987, 1991–1993, 1994–1995, 1999–2003	The study shows that droughts of 1944–1945, 1982–1983, 1994–1995 and 1999–2000 were the driest agricultural seasons. Most severe hydrological droughts were 1980–1981, 1985–1986, 1991–1992, 2000–2001, 2002–2003. This study describes the institutional change in drought management in Morocco with progress, though slow, from crisis management to more risk management.
Touchan et al. (2011)	North Africa: Morocco, Algeria and Tunisia. 1945–1946, 1981–1982, 1999–2000	The study uses tree-ring chronologies to investigate climate of North Africa region and have constructed PDSI for Morocco, Algeria and Tunisia back to AD 1179. The later half of the 20th century emerged as the driest among last nine centuries.
Touchan et al. (2008)	Northwestern Africa: Algeria and Tunisia. 1920s, 1940s, 1945, 1999–2002	The study uses tree-ring chronologies to investigate climate of North Africa region and have constructed PDSI for Algeria and Tunisia for the period AD 1456–2002. The study mentions 19 droughts occurred during 20th century compared to 12 to 16 droughts per century during earlier periods. However, specific years or decades in which they occur are not given. The multi-year drought of 1999–2002 is the most severe in the last 5 centuries.
Elagib and Elhang (2011)	Sudan: 1969–1970, 1972–1973, 1979–1985, 1990–1991, 2002–2008	The study examines the drought episodes in Sudan using PDI drought index estimated from rainfall and temperature of 14 stations across Sudan for the period 1940s to 2008. The study shows several multi-year droughts after 1970s and suggested intensifying drought evidence. El Niño is a major driver of droughts in Sudan.

HESSD
11, 2679–2718, 2014

Table 2. Continued.

Reference	Drought enlisted by region/country/basin during 1900–2013	Remarks
West Africa		
Dai (2011)	West Africa, Sahel. 1970s, 1980s	These droughts were attributed to southward shift of the warmest SSTs in the Atlantic and warming in the Indian Ocean.
Druyan (2011)	West Africa-Sahel. 1970s, 1980s	No trend in future droughts in Sahel in late 21st century. Some studies say wet and some dry conditions.
Giannini et al. (2008)	West Africa, Sahel. 1970s, 1980s	The study investigates the droughts in Sahel during 1970s and 1980s using global climate models. The results suggest that the origin of these droughts is global in scale and external to the region. These droughts are attributed to warming of tropical oceans, especially the pacific and Indian Oceans, superimposed on an enhanced warming of the southern compared to the Northern Hemisphere most evident in Atlantic. Land surface changes, driven by precipitation changes and also anthropogenic activities, may have acted to amplify these droughts.
Kasei et al. (2010)	West Africa, Volta Basin. Burkina Faso, Ghana, Mali, Togo. 1961, 1970, 1983, 1984, 1992, 2001.	Using rainfall data of 1961 to 2005, intensity, extent and recurrence frequency was estimated using SPI as a drought indicator. 1983–1984 drought was most severe covering 90 % of the basin area. Akosombombo lake recorded lowest flows during 1983. The study show that dry years have become more frequent and occur at shorter intervals. Areal coverage of drought has also increased.

HESSD
11, 2679–2718, 2014

Table 2. Continued.

Reference	Drought enlisted by region/country/basin during 1900–2013	Remarks
Mishra and Singh (2010)	West Africa, Sahel. 1910s, 1940s, 1960s, 1970s, 1980s	The study reviews drought concepts and provide a critical evaluation of most widely used indicators for drought assessment. But the review remains limited in terms of description of the historic droughts and only briefly mentions few of them with their main impacts and recommends further work in this direction.
Lebel et al. (2009)	West Africa, Sahel. 1970s, 1980s	A wealth of data is collected under AMMA-Catch case sites in Mali, Niger and Benin on land surface processes and atmospheric dynamics. This will help to better understand the interactions between atmospheric, oceanic and terrestrial systems enabling a better understanding and prediction of rainfall in this region.
Shanahan et al. (2009)	West Africa, Lake Bosumtwi, Ghana. 1970s Sahel drought	The study indicates that the severe droughts of Sahel in 1970s is not anomalous in the context of past three millennia and monsoon is capable of longer and more sever future droughts. The findings are based on sediment analysis from Lake Bosumtwi in Ghana.
Zeng (2003)	West Africa, Sahel. Late 1960s onward.	The study shows lower rainfall in Sahel since 1960s but the exact drought years are not mentioned. The study focuses on reviewing the existing evidence on causes of droughts in Sahel. The study shows that combination of various factors are responsible of droughts in Sahel and are not yet fully understood and thus could not be adequately predicted. Therefore, combination of improved climatic predictions, sensible land use practices and green house gas emission reductions are very important for the future of this region.

HESSD
11, 2679–2718, 2014

Table 2. Continued.

Reference	Drought enlisted by region/country/basin during 1900–2013	Remarks
East Africa		
Anderson et al. (2012)	East Africa: 2010–2011 drought in Ethiopia, Somalia and Kenya	The study demonstrated the usefulness of remotely sensed data and hydrological modeling for tracking the progression and severity of drought.
Dutra et al. (2013)	Horn of Africa: 2010–2011 in Ethiopia and Somalia	The study shows that drought was caused by failure of rainfall in both October–December (short rainfall) and March–May (long rainfall) seasons. The drought was attributed to La Nina conditions. This drought was well forecasting by the ECMWF forecasting system.
Hastenrath and Polzin (2007)	East Africa. Kenya. 2005	Drought was attributed to increased pressure in the west and accelerated westerlies (wind) anomalies
Ntale and Gan (2003)	East Africa. Kenya and Tanzania. 1949–50.	The study reviewed various drought indicators and compared the performance of Palmer drought severity index (PDSI), Bhalme-Mooley Index (BMI) and Standardized Precipitation Index (SPI). Different indicators may yield different drought results. SPI was recommended for East Africa region.
Rulinda et al. (2012)	East Africa. Burundi, Kenya, Rwanda, Tanzania, Uganda. 2005–2006	Analyzed spatial propagation of vegetative drought during September 2005 to April 2006 using 10 day NOAA AVHRR images. The drought reached peak in January 2006.
Tierney et al. (2013)	East Africa, Horn of Africa. 2010–2011	This drought was regarded as the worst during past 60 yr. The study concluded that the Indian Ocean SSTs are the primary influence on East African rainfall over multidecadel and perhaps longer timescales.

HESSD
11, 2679–2718, 2014

A review of droughts in the African continent

I. Masih et al.

Table 2. Continued.

Reference	Drought enlisted by region/country/basin during 1900–2013	Remarks
Southern Africa		
Belbase and Morgan (1994)	Southern Africa: Botswana. 1978–1979, 1982–1987, 1991–1992.	The case study highlight the salient features of the relatively successful drought management experience in Botswana.
Manatsa et al. (2008)	Southern Africa: Zimbabwe: 1902–1903, 1911–1916, 1926–1927, 1941–1942, 1963–1964, 1972–1973, 1982–1984, 1986–1987, 1991–1992	The study identified droughts in Zimbabwe based on SPI estimation from the regionally averaged rainfall for the period 1900–2000. The moderate to severe droughts are noted here, with 1991–1992 as the most extreme drought of the 20th century. The study indicate that ENSO (El Niño) alone is not a sufficient predictor of droughts and show that March to June extreme positive Darwin Sea Level Pressure anomalies are ideal additional candidate for drought monitoring and forecasting in Zimbabwe and Southern Africa.
Msangi (2004).	Southern Africa. 1902, 1909–1911, 1917–1918, 1921–1922, 1925, 1929, 1933–1934, 1939–1940, 1953, 1969, 1972–1973, 1976, 1980–1982, 1984–1985	Information on drought years and respective country is not given. The study mainly focused on analyzing the drought management efforts by international and regional organizations, national institutions and NGOs and communities. The study stressed the need of adopting people centered mitigation measures and calling for informed global action as the success lies with people in the south and those in the north.
Mussá et al. (2014)	South Africa: Crocodile River catchment. 1945, 1951, 1958, 1966, 1970/71, 1978, 1983–1984, 1992–95 and 2003–04	The main focus of the study is to analyze whether groundwater can be used as an emergency source of water in cases of severe droughts in the Crocodile catchment. The study used the SPI and SRI drought indicators to identify meteorological and hydrological droughts, respectively. It implies that the 1992–1995 drought was the most severe one in the last 70 yr where the upper and lower areas of the catchments were the most affected.

HESSD
11, 2679–2718, 2014

Table 2. Continued.

Reference	Drought enlisted by region/country/basin during 1900–2013	Remarks
Richard et al. (2001)	Southern Africa. 1951, 1960, 1964, 1965, 1968, 1970, 1973, 1982, 1983, 1987	Droughts were not referred per country. The study focused on analyzing droughts during 1950–1988 during summer rainfall period January–March. Droughts during 1970–1988 period were intense and widespread compared to those during 1950–1969. The ENSO was the main governing factor for droughts during 1970–1988 (though not always), whereas, regional oceanic and atmospheric anomalies (e.g. southwest Indian Ocean SST) were the main causes of the droughts during 1950–1969.
Rouault and Richard (2005)	Southern Africa (South of 10° S). 1906, 1916, 1924, 1933, 1949, 1970, 1983, 1984, 1992, 1993, 1995, 1996, 2002, 2003, 2004.	The study discussed these droughts and corresponding area under them at an aggregated level of the African continent. Country or regional estimates are not available. SPI estimates for the period 1900–1999 are used. The ENSO (El Niño conditions) was attributed to 8 out of these 12 droughts occurred during 20th century. The area of the African continent under drought has significantly increased, especially after 1980s.
Vogel et al. (2010)	Southern Africa. 1982–1993, 1991–1992, 1994–1995, 2001–2003	This study stresses the need of learning from past drought events to better manage in future. The response to drought and general management options practiced in SADC countries are reviewed, in special reference to indicated droughts.

Table 2. Continued.

Reference	Drought enlisted by region/country/basin during 1900–2013	Remarks
More than one region		
Calow et al. (2010)	2002–03, 2004–05 and 2005–06 droughts in Ethiopia. 1991–1992 drought in Lesotho, Malawi, South Africa and Zimbabwe, Ghana.	The study shows the impacts of droughts on groundwater resources and consequently on water supply security. The communities enter into spiral of water insecurity when shallow groundwater supplies fail and additional demand on remaining resources causes mechanical failures. Declining access to food and access to safe water are interrelated, but the later usually receive less attention in drought management. Groundwater can act as buffer during droughts by increasing the coverage of groundwater supplies to rural communities underpinned by sound hydrological and socio-economic information.
Couttenier and Soubeyran (2013)	Sub-Saharan Africa. 1980s.	No country or year specific information presented, though droughts in Sudan in 1980s and in Uganda during 1980s and 2003–2005 are linked to civil war. Overall, link between drought and civil war was described as weak.
Rojas et al. (2011)	Morocco: 1992, 1995, 1997; Tunisia and Algeria: 1999–2002; Sahel: early-mid 1980s; Ethiopia and Kenya: 1984 and 2000; Ethiopia, Eritrea and Somalia: 1987; Southern Africa: 1982–1983 and 1991–1992 (most countries).	The study examined the major droughts occurred in African continent during 1980–2010. The study proposed that Pixed-Vegetation Health Index (VHI), estimated using remote sensing data (AVHRR) is a promising agricultural drought monitoring indicator and was able to track major droughts during 1981–2009 reported in the selected literature.
Tadesse et al. (2008)	Sub-Saharan Africa: 1972–1974 and 1984–1985 (Sahel and East Africa), 1992–1993 (southern Africa), 2000–2002 (Horn of Africa)	The droughts resulted in severe food shortages and famine are mentioned. The need of moving from a crisis management to risk management approaches is stressed and the use of the available drought and food security monitoring tools is recommended to reduce the impacts of droughts.
Vicento-Serrano et al. (2012)	Ethiopia, Sudan and Sahel region: 1974, Zimbabwe; 1990–1991; Kenya: 1999–2001; Many countries: 1984. Congo River: 1960s, 1970s. Orange River: 1980s, 1990s	The study demonstrated how the development of drought information systems based on geospatial technology, that combines static and real time information could improve the possibilities of drought mitigation in Africa.

HESSD
11, 2679–2718, 2014

Table 3. Summary of drought events recorded for 1900–2013 in EM-DAT data base.

Region/Countries	Drought Years	# of events	# of People killed	# of People affected	Economic Damage ($\times 10^3$ USD)
Overall African Continent		291	847 143	362 225 799	2 920 593
North Africa		18	150 012	31 153 400	900 100
Algeria	1981, 2005	2	12	0	0
Morocco	1966, 1971, 1983, 1984, 1999	5	0	412 000	900 100
Tunisia	1977, 1988	2	0	31 400	0
Sudan	1980, 1983, 1987, 1990, 1991, 1996, 1999, 2009, 2012	9	150 000	30 710 000	0
Middle Africa		25	3058	11 379 800	84 500
Angola	1981, 1985, 1989, 1997, 2001, 2004, 2012	7	58	4 443 900	0
Cameroon	1971, 1990, 2001, 2005	4	0	586 900	1500
Central Africa Republic	1983	1	0	0	0
Chad	1910, 1940, 1966, 1969, 1980, 1993, 1997, 2001, 2012	9	3000	5 456 000	83 000
Congo	1983	1	0	0	0
Sao Tome et Principe	1983	1	0	93 000	0
Zaire/Congo Dem Rep	1978, 1983	2	0	800 000	0

HESSD
11, 2679–2718, 2014

Table 3. Continued.

Region/Countries	Drought Years	# of events	# of People killed	# of People affected	Economic Damage ($\times 10^3$ USD)
West Africa		94	170 012	74 500 255	507 354
Benin	1969, 1980	2	0	2 215 000	651
Burkina Faso	1910, 1940, 1966, 1969, 1976, 1980, 1988, 1990, 1995, 1998, 2001, 2011	12	0	8 413 290	0
Cape Verde Is	1900, 1910, 1920, 1940, 1946, 1969, 1980, 1992, 1998, 2002	10	85 000	40 000	0
Cote d'Ivoire	1980	1	0	0	0
Gambia The	1910, 1940, 1968, 1969, 1976, 1980, 2002, 2012	8	0	1 258 000	700
Ghana	1971, 1977, 1980	3	0	12 512 000	100
Guinea	1980, 1998	2	12	0	0
Guinea Bissau	1910, 1940, 1969, 1980, 1980, 2002, 2006	6	0	132 000	0
Liberia	1980	1	0	0	0
Mali	1910, 1940, 1966, 1976, 1980, 1991, 2001, 2005, 2006, 2010, 2011	11	0	6 927 000	0
Mauritania	1910, 1940, 1965, 1969, 1976, 1978, 1980, 1993, 1997, 2001, 2010, 2011	12	0	7 398 907	59 500
Niger	1903, 1906, 1910, 1940, 1966, 1980, 1988, 1990, 1997, 2001, 2005, 2009, 2011	13	85 000	23 655 058	0

HESSD
11, 2679–2718, 2014

A review of droughts in the African continent

I. Masih et al.

Table 3. Continued.

Region/Countries	Drought Years	# of events	# of People killed	# of People affected	Economic Damage ($\times 10^3$ USD)
Nigeria	1981	1	0	3 000 000	71 103
Senegal	1910, 1940, 1966, 1969, 1976, 1979, 1980, 2002, 2011	9	0	8 399 000	374 800
Togo	1971, 1980, 1989	3	0	550 000	500
East Africa		122	523 561	220 892 229	371 900
Burundi	1999, 2003, 2005, 2008, 2009, 2010	6	126	3 062 500	0
Comoros	1981	1	0	0	0
Djibouti	1980, 1983, 1988, 1996, 1999, 2005, 2007, 2008, 2010	9	0	1 188 008	0
Eritrea	1993, 1999, 2008	3	0	5 600 000	0
Ethiopia	1965, 1969, 1973, 1983, 1987, 1989, 1997, 1998, 1999, 2003, 2005, 2008, 2009, 2012	15	402 367	66 941 879	92 600
Kenya	1965, 1971, 1979, 1983, 1991, 1994, 1996, 1999, 2004, 2005, 2008, 2010, 2012	13	196	47 200 000	1500
Madagascar	1981, 1988, 2000, 2002, 2005, 2008	6	200	3 515 290	0
Malawi	1987, 1990, 1992, 2002, 2005, 2007, 2012	7	500	21 578 702	0
Mauritius	1999	1	0	0	175 000

HESSD
11, 2679–2718, 2014

A review of droughts in the African continent

I. Masih et al.

Table 3. Continued.

Region/Countries	Drought Years	# of events	# of People killed	# of People affected	Economic Damage ($\times 10^3$ USD)
Mozambique	1979, 1981, 1987, 1990, 1998, 2001, 2003, 2005, 2007, 2008, 2010	12	100 068	17 757 500	50 000
Rwanda	1976, 1984, 1989, 1996, 1999, 2003	6	237	4 156 545	0
Somalia	1964, 1969, 1973, 1980, 1983, 1987, 1988, 1999. 2004, 2005, 2008, 2010, 2012	13	19 673	13 183 500	0
Tanzania Uni Rep	1967, 1977, 1984, 1988, 1990, 1996, 2003, 2004, 2006, 2011	10	0	12 737 483	0
Uganda	1967, 1979, 1987, 1998, 1999, 2002, 2005, 2008, 2010	9	194	4 975 000	1800
Zambia	1981, 1983, 1990, 1995, 2005	5	0	4 173 204	0
Zimbabwe	1981, 1990, 1998, 2001, 2007, 2010	6	0	14 822 618	51 000

HESSD
11, 2679–2718, 2014

Table 3. Continued.

Region/Countries	Drought Years	# of events	# of People killed	# of People affected	Economic Damage ($\times 10^3$ USD)
Southern Africa		32	500	24 300 115	1 056 739
Botswana	1965, 1968, 1970, 1981, 1990, 2005	6	0	1 344 900	3000
Lesotho	1968, 1983, 1990, 2002, 2007, 2011	6	0	2 736 015	1000
Namibia	1981, 1990, 1995, 1998, 2001, 2002, 2013	7	0	1 114 200	51 000
South Africa	1964, 1980, 1981, 1986, 1988, 1990, 1995, 2004	8	0	17 475 000	1 000 000
Swaziland	1981, 1984, 1990, 2001, 2007	5	500	1 630 000	1739

HESSD
11, 2679–2718, 2014

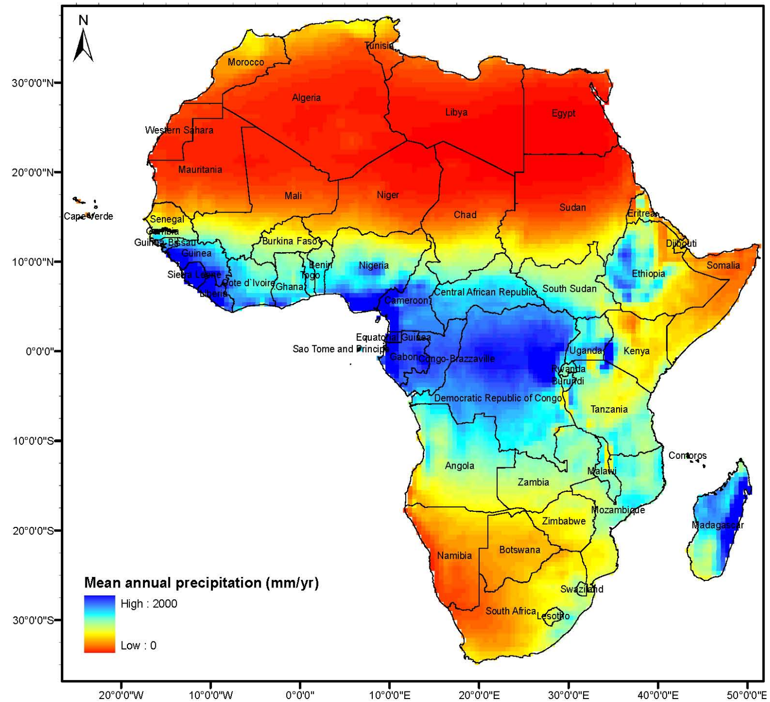

Fig. 1. Map of the African continent with country names and rainfall pattern. (Data source: ERA-Interim corrected with GPCP v2.1, period: 1979–2010. See Trambauer et al., 2014 for detailed explanation.)

HESSD
11, 2679–2718, 2014

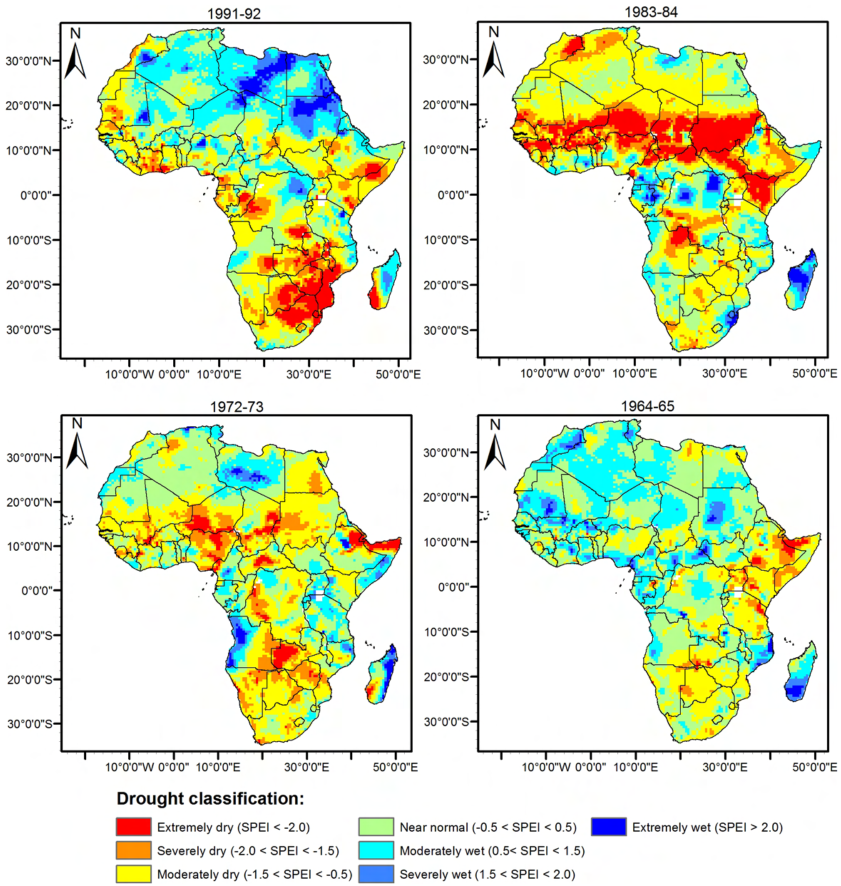

Fig. 2. Geospatial coverage of extreme droughts of 1964–1965, 1972–1973, 1983–1984 and 1991–1992 indicated by 12 months SPEI (October–September). (Data source: Global SPEI database available at http://sac.csic.es/spei/database.html, version 2.2 retrieved in January 2014.)

HESSD
11, 2679–2718, 2014

A review of droughts in the African continent

I. Masih et al.

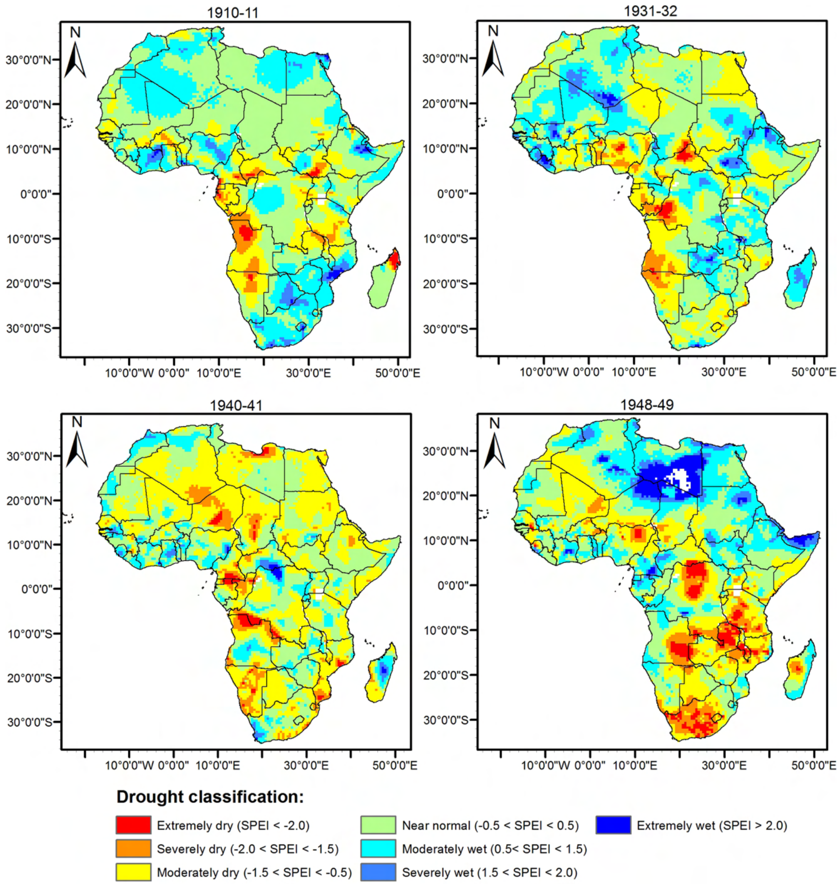

Fig. 3. Geospatial coverage of selected droughts 1910–1911, 1931–1932, 1940–1941 and 1948–1949 indicated by 12 months SPEI (October–September). (Data source: Global SPEI database available at http://sac.csic.es/spei/database.html, version 2.2 retrieved in January 2014.)

HESSD
11, 2679–2718, 2014

A review of droughts in the African continent

I. Masih et al.