

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

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## **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 years. The extreme droughts of 1972-73, 1983-84 and 1991-92 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), 2010-11 drought in East Africa (Horn of Africa) and 2001-03 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

1 predictions of droughts based on global climate models indicate increased droughts and  
2 aridity at the continental scale but large differences exist due to model limitations and  
3 complexity of the processes especially for Sahel and North Africa regions.

4 However, the available evidence from the past clearly shows that the African continent is  
5 likely to face extreme and widespread droughts in future. This evident challenge is likely to  
6 aggravate due to slow progress in drought risk management, increased population and  
7 demand for water and degradation of land and environment. Thus, there is a clear need for  
8 increased and integrated efforts in drought mitigation to reduce the negative impacts of  
9 droughts anticipated in future.

10 **Key words:** Drought, Africa, geospatial coverage, temporal variability, causes of drought,  
11 drought mitigation

12

## 13 **1 Introduction**

14 Drought is a recurrent climatic phenomenon across the world. It affects human being in a  
15 number of ways such as causing loss of life, crop failures, food shortages which may lead to  
16 famine in many regions, malnutrition, health issues and mass migration. It also causes huge  
17 damage to the environment and is regarded as a major cause of land degradation, aridity and  
18 desertification. The impacts of droughts are witnessed at a range of geographical scales. For  
19 instance, individual families or communities may lose their livelihoods and source of water,  
20 subject to acute food shortages and health issues and the country's economy may be severely  
21 impacted. The available estimates on drought impacts suggest that, during the period 1900-  
22 2013, there were 642 drought events reported across the world resulting in huge toll to  
23 humanity killing about 12 million people and affecting over 2 billion (EM-DAT, 2014). The  
24 total economic damages are estimated at 135 billion US\$ (Table 1).

25 Drought remains a major disaster causing huge damages to people, environment and  
26 economy, despite making considerable progress on monitoring, forecasting and mitigation of  
27 droughts across the world. The lack of desired level of success could be attributed to many  
28 reasons. Drought is a complex phenomenon, which varies every time in terms of its onset,  
29 intensity, duration and geographical coverage. The capacity of people facing this hazard may  
30 be limited to avoid adverse impacts compounded by shortcomings in government capacity  
31 (e.g. financial, institutional and political) to provide short-term relieve and install long-term

1 drought mitigation measures. There is an urgent and dire need to progress on various fronts of  
2 drought mitigation such as early warning and forecasting, building resilience of the societies,  
3 short-term relief efforts, long term planning and capacity building (e.g. Calow et al., 2010;  
4 Clarke et al., 2012; Dondero, 1985; Falkenmark and Rockström, 2008; GFDRR, 2011; IFAD,  
5 2010; 2011a and 2011b; Logar et al., 2013; Mishra and Singh, 2010; Msangi, 2004; Sehmi  
6 and Kundzewicz, 1997; Tadesse et al., 2008; Tøttrup et al., 2012; UNISDR, 2004 and 2010;  
7 Vicente-Serrano et al., 2012; Vogel et al., 2010; World Bank and GFDRR, 2010).

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

1 A recent global review on droughts and aridity by Dai (2011) indicated that large scale  
2 droughts have frequently occurred during the past 1000 years across the globe. This review  
3 briefly reported few of these severe and multi-year droughts in North America, China and  
4 Africa, but does not provide the detailed review of the historic droughts across the world. For  
5 Africa, the focus was on the severe, widespread and prolonged droughts occurred during  
6 1970s and 1980s in West Africa (Sahel region). The study mainly focused on aridity changes  
7 from 1950 to 2008 and provided foresight for the 21st century. One of the important  
8 conclusions of this paper is that the global aridity and drought areas have increased  
9 substantially during the 20th century and attributed to widespread drying since 1970s over  
10 Africa, southern Europe, East and South Asia, eastern Australia and many parts of the  
11 northern mid-high latitudes. The aridity trends are projected to continuously increase in the  
12 21st century. However, study of Sheffield et al. (2012) shows that drought patterns are  
13 increasing over last 60 years, though not as alarming as usually projected. Mishra and Singh  
14 (2010) conducted a comprehensive review on drought concepts and a critical evaluation of the  
15 most widely used indicators for drought assessment. But the review remains limited in terms  
16 of description of the historic droughts and only briefly mentions few of them with their main  
17 impacts. For Africa, the study only enlisted the severe droughts in Sahel occurred during  
18 1910s, 1940s, 1960s, 1970s and 1980s. These droughts caused huge socio-economic and  
19 environmental impacts in this semi-arid region resulting in massive scale migration, famine  
20 and environmental degradation (desertification), especially during the last two drought  
21 episodes. The study noted that growing demand for water, limited sources of water and  
22 changes in spatio-temporal patterns of climate are aggravating the drought impacts in the  
23 world.

24 There are a growing number of studies addressing various drought related issues for Africa.  
25 Most of these studies focused on a specific region i.e., Southern Africa (e.g. Clarke et al.,  
26 2012; Cornforth, 2013, Dube et al., 2000, 2002 and 2003; Green, 1993; Jager et al., 1998;  
27 Manatsa et al., 2008; O'Meagher et al., 1998; Richard et al., 2001; Unganai et al., 1998; Vogel  
28 et al., 2010), Sahel (West Africa) (e.g. Giannini et al., 2008; Govaerts et al., 2008; Kasei et  
29 al., 2010; Lebel et al., 2009; Lodoun et al., 2013; Traore et al., 2007; Zeng, 2003), East Africa  
30 (Horn of Africa) (e.g. Anderson et al., 2012; Dutra et al., 2013; Syroka and Nucifora, 2010)  
31 and Northwest Africa (e.g. Touchan et al., 2008 and 2010). There are few studies which  
32 attempt to cover more than one region (e.g. Calow et al., 2010; Herweijer and Seager, 2008;  
33 Rojas et al., 2011; Naumann et al., 2012; Tadesse et al., 2008; Verschuren, 2004). These and

1 many other studies are comprehensively reviewed and discussed in the following sections.  
2 Most of them investigate one or more drought related subjects i.e., the study of a specific  
3 drought event or historic droughts in a country or regional perspective, methodological  
4 developments on drought indicators, causes of droughts, forecasting and early warning  
5 systems, impact analysis and drought risk reduction, drought planning and management and  
6 capacity building. None of them provide a long-term analysis of droughts considering past,  
7 present and future perspective at the continental scale.

8 There are a growing number of continental and global data sets on drought. For instance,  
9 there are specific continental drought monitoring and forecasting systems that deal with  
10 specific drought related information in real time as well as historical data. The examples are  
11 the African drought monitor: <http://hydrology.princeton.edu/adm> (Sheffield et al., 2013) and  
12 the DEWFORA African drought observatory: <http://edo.jrc.ec.europa.eu/dewfora/> (Barbosa et  
13 al., 2013). Moreover, the EM-DAT data base (<http://www.emdat.be/database>) provides  
14 information on historic droughts recorded across the world along with their impacts.  
15 Significant advances have been made on the global scale estimation of various drought related  
16 indicators (e.g. Standardized Precipitation and Evaporation Index, SPEI) (Vicento-Serrano et  
17 al., 2010). Several remote sensing based data and products have been developed over time  
18 (e.g. Rojas et al., 2011; Sheffield et al., 2013). These efforts have resulted in significant  
19 increase in the scientific literature and data bases, which can facilitate continental scale  
20 analysis of droughts in terms of severity, spatial and temporal coverage.

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

26

## 27 **2 Materials and Methods**

### 28 **2.1 Study Area**

29 This study focuses on the whole African continent. However, analysis and discussion is also  
30 presented in the regional and country perspectives. It is important to note the differences in  
31 grouping various countries in different regions. For instance, EM-DAT groups African

1 countries into North, Middle, South, East and West Africa). On the other hand, many regional  
2 studies are focused on Sahel (includes countries in West Africa between Sahara desert and  
3 Guinea coast rainforest, about 18°N to 15°N), Horn of Africa (Ethiopia, Somalia, Kenya),  
4 Equatorial East Africa, Southern Africa. The special reference to countries in a given region is  
5 made wherever deemed necessary. In this study, the continent is grouped into North, West  
6 (Sahel), East, Middle and Southern Africa regions (Table 2).

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

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## 23 **2.2 Data and Methods**

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

30 The global data set on droughts from EM-DAT website (<http://www.emdat.be/database>) were  
31 accumulated for the available period 1900-2013. This data set provides

1 country/regional/continental level estimates on drought events, people killed and affected and  
2 economic damage. Additionally, a global database on SPEI was used to analyse droughts  
3 with the aim to substantiate the findings of this review (<http://sac.csic.es/spei/home.html>). It is  
4 acknowledged that a number of drought indicators are available, each with own strengths and  
5 weaknesses (e.g. Mishra and Singh, 2010; Dai, 2011; Zargar et al., 2013). For example, the  
6 Decile Index (Gibbs and Maher, 1967) is easy to compute, however it requires a long time  
7 series of data to have accurate results. With the Palmer Drought Severity Index (Palmer,  
8 1968), abnormality of agricultural droughts can be identified and it also shows historical  
9 aspects of current conditions. The disadvantage of this method is that as it depends on soil  
10 moisture data and its properties which are often very difficult to assess, especially at a larger  
11 spatial scale and in spatially distributed manner. The widely used Standardized Precipitation  
12 Index (Mckee et al., 1993; Zargar et al., 2011) seems to have advantages because it is a  
13 simple method that requires few data (only precipitation) for its computation. The SPEI is a  
14 widely used drought indicator which uses precipitation and potential evapotranspiration for its  
15 computation. It has the ability to monitor onset, intensity and duration of drought. The  
16 indicator is very suitable to study geospatial and temporal variation of drought including the  
17 impact of global warming. This indicator is primarily related to meteorological drought and  
18 do not offer as such estimates on agricultural, hydrological and socio-economic aspects of  
19 droughts, though it could be seen as a proxy to these droughts as eventually they are caused  
20 by the deficit in precipitation. The detail discussion on various drought indicators and their  
21 comparison basic concepts and various perceptions on drought can be found in the literature  
22 (e.g. Dai, 2011; Mishra and Sing, 2010; Ntale and Gan, 2003; Smakhtin and Schipper, 2008;  
23 UNISDR, 2004; Zargar et al., 2011).

24

25

26

## 27 **3 Results and Discussion**

### 28 **3.1 Geospatial and Temporal Pattern of Droughts during 1900-2013**

29 The summary of the selected literature reviewed is presented in Table 2, indicating drought  
30 years, geographical location and key relevant findings. . While preparing this Table, an effort  
31 was made to avoid duplication of similar studies and yet provide geospatial and temporal

1 coverage. Another important consideration was to examine important discourses most  
2 relevant to the topic of this paper. There are a rapidly growing number of studies on various  
3 drought related issues, especially during the last decade. The available studies cover most  
4 parts of Africa, though coverage is low for middle Africa which is understandable as in this  
5 region climate is humid and droughts are not as catastrophic as in the other regions..  
6 Meteorological drought remains the main subject of most studies followed by agricultural  
7 drought. Studies examining hydrological droughts and the impacts of human uses of water on  
8 the assessment and intensification of these droughts are limited.

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

27 A number of inferences are drawn from the analysis of the available data and scientific  
28 evidence reviewed in this paper (Table 2 and Table 3). The frequency, intensity and  
29 geospatial coverage of droughts have significantly increased across the whole African  
30 continent during the second half of the 1900-2013 period. This inference is supported by  
31 studies conducted at continental scale (e.g. Dai 2011 and 2013) as well as by most of the  
32 regional and country level studies (e.g. Quassou et al., 2007, Touchan et al., 2008 and 2011,



1 Elagib and Elhang, 2008; Kasei et al., 2010; Manatsa et al., 2008; Richard et al., 2001). The  
2 available data (though limited in temporal coverage) from EM-DAT also supports this  
3 observation (Table 2).

4 This point is further substantiated by Figures 2, 3 and 4. The drought shown in Figure 2 and 3  
5 were reported by most of the reviewed literature and thus were chosen for the illustration.  
6 Figure 2 shows the geospatial coverage of the four most extreme droughts occurred during  
7 past 50 years. Three out of these four droughts (1972-73, 1983-84 and 1991-92) were most  
8 severe and could be regarded continental in nature as they spanned over many sub-regions  
9 and covered wide areas of the African continent. None of the previous droughts during 20th  
10 century were as wide spread and intense compared to them (Figure 3). Figure 4 show the area  
11 of the African content under different drought categories based on SPEI data analysis  
12 conducted in this study. On this data, the widely used non-parametric Spearman Rank test  
13 (e.g. Masih et al., 2011) was applied to test the statistical significance of the trends. The  
14 results revealed statistically significant increase (at 99% significance level) in the area under  
15 all categories of drought (e.g. moderate, severe and extreme droughts) for the African  
16 continent during 1901-2011. Figure 4 exhibits these findings and the visual inspection also  
17 indicates the increasing trend in the geospatial extent of the African continent under drought.

18 Most African countries observe single and multi-year droughts when seen from purely hydro-  
19 climatic point of view. For instance, number of severe droughts that occurred in Northern and  
20 Southern Africa during the 20th century are comparable to those observed in Eastern and  
21 Western Africa where comparatively more droughts are reported in literature and available  
22 data bases (Table 2 and Table 3). However, distinct geospatial and temporal patterns exist in  
23 the drought episodes mainly driven by the diverse nature of the climate and drought inducing  
24 physical mechanisms (discussed later in this paper). It can be inferred from the studies  
25 reviewed in this paper (Table 2) that the multi-year and prolonged droughts are more common  
26 in Sahel compared to any other regions (e.g. Mishra and Singh, 2010; Rojas et al., 2011). In  
27 contrast, studies for the East Africa region report mostly very severe seasonal droughts often  
28 not spanning over many years (e.g. Dutra et al., 2013).

29 The geospatial spread of drought depicts large variation within a country or a basin, beside  
30 regional heterogeneity. This point is clearly indicated by Figure 2 and 3 and also highlighted  
31 by other studies (e.g. Anderson et al., 2012; Moeletsi and Walker, 2012; Mussá et al., 2014;  
32 Rojas et al., 2009; Rulinda et al., 2012; Trambuer et al., 2014). The increasingly available

1 information and tools based on remote sensing, analysis of global climatic data sets (e.g.  
2 global SPEI products) and hydrological and climatic modelling offer great opportunity to  
3 identify these geospatial differences and drought hot spots. For instance, a remote sensing  
4 based study by Rojas et al. (2009) identified hot spots regions at sub-national level depicting  
5 higher probabilities of facing agricultural droughts. The studies indicate that the semi-arid and  
6 sub-humid regions of Africa are the most drought prone regions (e.g. World Bank and  
7 GFDRR, 2010). These countries are highly vulnerable to drought owing to high climatic  
8 variability and also due to other reasons such as poverty, high dependency on rainfed  
9 agriculture and weak infrastructure to manage resources and recover from disasters.  
10 Moreover, vulnerability to drought varies per country. For instance the economic impact of  
11 the 1991-92 drought was much higher on the GDP of Malawi and Zimbabwe compared to  
12 South Africa and Botswana (Benson et al., 1998). The lowest negative impacts in Botswana  
13 on people livelihoods and food security during drought periods of 1982-87 and 1992 were  
14 mainly attributed to a small and largely accessible national population, availability of  
15 domestic and international resources, existence of rural infrastructure, government  
16 commitment, district-level capacity and a timely and fairly comprehensive food security and  
17 nutrition monitoring system (Belbase and Morgan, 1994).

18 There is increasing availability of drought monitoring and forecasting tools for decision  
19 making which can provide real time monitoring and forecasting of drought across the region  
20 (e.g. Tadesse et al., 2008; Anderson et al., 2009; Dutra et al., 2013; Vicente-Serrano et al.,  
21 2012). However, the use of these tools in decision making is still limited and could be  
22 promoted. For instance, despite inherent uncertainties in the available drought monitoring and  
23 forecasting systems, the 2010-11 drought in the Horn of Africa was well predicted by  
24 European Centre for Medium-Range Weather Forecasts (ECMWF). But this information was  
25 not timely used for better preparedness and mitigation of the drought, which finally caused  
26 heavy toll affecting about 12 million people (Dutra et al., 2013).

27

### 28 **3.2 Past, present and future pattern of droughts**

29 There are few studies available to date which offer possibility of comparing droughts  
30 observed during 1900-2013 (instrumental era) with those witnessed in the past centuries. This  
31 comparison is important as African climate displays high decadal and century scale

1 variability. The work of Touchen et al. (2008 and 2011) provides a long term perspective on  
2 droughts in Northwest Africa (Morocco, Algeria and Tunisia). They used tree-ring records to  
3 construct the Palmer Drought Severity Index (PDSI) for the period A. D. 1179 to 2002. These  
4 studies reveal that the frequency of occurrence of a single drought event was 12 to 16 times  
5 per century before the 20th century, which was increased to 19 during the 20th century. The  
6 most severe multi-year drought occurred during 1999-2002, whereas 1847 and 2002 were  
7 identified as the driest single years with PDSI values of -3.74 and -3.90, respectively. The  
8 latter half of the 20th century is seen as the driest period in the last 9 centuries. This shift to  
9 drier conditions was attributed to anthropogenic climate change.

10 A number of researchers studied historic droughts in Africa based on lake sediment analyses.  
11 Evidence from the sediment analysis of the lake Bosumtwi, Ghana indicated several  
12 prolonged periods of drought during the last three millennia, most recent ones around 200 to  
13 300 years ago (Shanahan et al., 2009). Comparing 1970s droughts in Sahel with earlier  
14 drought episodes occurred during the past three millennia, they concluded that more severe  
15 and prolonged droughts were recorded in the past centuries. Verschuren et al. (2000)  
16 investigated droughts over the period A.D 900 to 2000 based on sediment analysis of Lake  
17 Naivasha Kenya in Equatorial East Africa. The period AD 1000 to 1270 (Medieval Warm  
18 Period) was found to be the driest one over the last 1100 years. Additionally, dry conditions  
19 were found around AD 1380-1420, 1560-1620 and 1760-1840 during relatively wet period of  
20 AD 1270-1850 (Little Ice Age). These drought episodes were more severe than recorded  
21 droughts in the 20th century. Bessems et al. (2008) noted extreme droughts in Equatorial East  
22 Africa about 200 years ago based on the sediment analysis of three lakes (Chibwera and  
23 Kanyamukali in western Uganda, and Baringo in central Kenya). The authors, Verschuren et  
24 al. (2000), and Bessems et al. (2008), compared their findings with the available evidence  
25 from the cultural history of east Africa and found consistency between two sets of  
26 observations.

27 Endfield and Nash (2002) described the discourse on long-term desiccation of the African  
28 continent emerged during 19th century. Their study is based on the analysis of the missionary  
29 documents from southern Africa (Botswana and South Africa). The authors constructed a  
30 chronology of intra-decadal climatic variability for the period 1815-1900 and showed that the  
31 major multi-year droughts occurred in 1820-7, 1831-5, 1844-51, 1857-65, 1877-86 and 1894-  
32 9. The study inferred that the discourse on long-term desiccation evolved during this period

1 was merely triggered by these episodes of droughts rather than underpinned by long-term  
2 climatic deterioration. Nevertheless, the discourse on desiccation still remains an important  
3 subject in the current drought research. The evidence presented in the previous section  
4 pointed out to the increased aridity and intensification of droughts, especially during the  
5 second half of the 20th century (e.g. Dai 2011; Elagib and Elhang, 2008; Kasei et al., 2010;  
6 Quassou et al., 2007; Manatsa et al., 2008; Touchan et al., 2008 and 2011; Richard et al.,  
7 2001). Dai (2013) predicted likelihood of increased droughts and aridity over central and  
8 southern Africa during the 21st century. On the contrary, the Sahel region may receive more  
9 rainfall. Large uncertainties exist in these findings and thus require caution in making regional  
10 or continental conclusions. Druyan (2011) reviewed 10 studies which are based on the  
11 simulations of atmosphere-ocean global climate models on future climate of Sahel. Some  
12 studies projected wetter conditions and some projected more frequent droughts, thus, no  
13 consensus was observed. The large uncertainties and differences in these predictions were  
14 attributed to model limitations and complexity of many physical mechanisms governing the  
15 precipitation trends.

16

### 17 **3.3 Causes of droughts**

18 Drought is a part of natural climatic variability in the African continent, which is quite high at  
19 intra-annual, inter-annual, decadal and century time scales (e.g. Nicholson, 2000).. Many  
20 studies attempted to investigate the natural causes that could be associated with droughts in  
21 Africa (Caminade and Terray 2010; Dai 2011 and 2013; Dutra et al., 2013; Giannini et al.,  
22 2008 and 2013; Hastenrath et al., 2007; Herweijer and Seager, 2008; Jury et al., 1996; Kerr,  
23 1985; Lebel et al., 2009; Manatsa et al., 2008; Nicholson, 2000; Richard et al., 2001;  
24 Shanahan et al., 2009; Tierney et al., 2013; Vicente-Serrano, 2012; Zeng, 2003). Some of  
25 them also focus on anthropogenic factors, such as climate change, aerosol emissions, land use  
26 practices and resulting land-atmosphere interactions, contributing to drought inducing  
27 mechanisms (e.g. Dai 2011 and 2013; Hwang et al., 2013; Lebel et al., 2009; Zeng, 2003).  
28 The review of these studies revealed that there are a number of factors contributing in  
29 inducing drought conditions. However, despite regional differences in the factors causing  
30 droughts in a specific region, ENSO and SSTs are regarded major influencing factors across  
31 the continent. For instance, Nicholson (2000) demonstrates that ENSO, SST and land-  
32 atmospheric feedback are the major governing factors on the rainfall variability in Africa. The

1 author states that these factors alone or in combination can change the atmospheric dynamics  
2 and circulation patterns, for instance, causing changes in the Hadley and Walker circulations  
3 or upper level jet streams.

4 Droughts in Southern Africa occur most of the time during the warm phase of ENSO (El Niño  
5 Southern Oscillation). Nicholson and Kim (1997) studied the correlation between  
6 precipitation and ENSO (El Niño Southern Oscillations) in the Pacific. They found that  
7 among the 20 extreme rainfall events analyzed, 15 events appeared to be modulated by the  
8 ENSO. Their results suggest that the southern part of Africa is negatively correlated with  
9 warm ENSO. Phillips et al. (1998) studied the possibility of using ENSO predictions to  
10 reduce the risks associated with rainfall variability in agricultural production in Zimbabwe.  
11 The analysis showed that during the El Niño phase a decrease on the precipitation was  
12 noticed, which is in agreement with the findings of (Nicholson and Kim 1997). Rouault and  
13 Richard (2005) studied the temporal and spatial extent of the droughts in South Africa based  
14 on the SPI (Standardized Precipitation Index) from 1900 to 2004. Their results show that 8  
15 out of 12 droughts detected coincide with El Niño years, which confirms the strong  
16 relationship between the ENSO and the droughts events in southern Africa. However, some  
17 studies point that the occurrence of droughts during El Niño years does not happen always as  
18 there are many other local and global factors influencing the drought phenomenon. Richard et  
19 al. (2001) examined droughts during 1950 to 1988 in Southern Africa. They found that  
20 droughts during 1970-88 were intense and widespread compared to those during 1950-1969.  
21 The El Niño was the main governing factor for droughts during 1970-88. However, this  
22 observation require caution because droughts may not occur during El Niño periods, i.e., as  
23 happened during 1925-26 and 1997-98. For the droughts during 1950-1969, regional oceanic  
24 and atmospheric anomalies (e.g. southwest Indian Ocean SST) were named as the main  
25 causes. Manatsa et al. (2008) suggested that El Niño alone is not a sufficient predictor of  
26 droughts in Southern Africa. They recommend that March to June extreme positive Darwin  
27 Sea Level Pressure anomalies are ideal additional candidate for drought monitoring and  
28 forecasting in Zimbabwe and Southern Africa.

29 Contrary to Southern Africa, East Africa region faces droughts during cold phase of ENSO  
30 (La Niña). For instance, Dutra et al. (2013) indicated that strong La Niña event was the main  
31 cause of 2010-11 drought in the Horn of Africa. Lott et al. (2013) investigated whether the  
32 2010-11 drought was caused by human intervention or not. They did not find any evidences

1 of human activities on this event and also attributed this with La Niña events. Tierney et al.  
2 (2013) also suggested that the recent drought in the Horn of Africa, was partly due to the  
3 prevailing La Niña conditions in the tropical Pacific. On the other hand, Hasternath et al.  
4 (2007) argue that the low rainfall in this region occurs during fast westerlies which are usually  
5 accompanied by anomalously cold waters in the northwestern and warm anomalies in the  
6 southeastern extremity of the equatorial Indian Ocean Basin. This mechanism was found  
7 responsible for 2005 drought in the Horn of Africa. Tierney et al. (2013) suggested that the  
8 Indian Ocean drives rainfall variability in East Africa by altering the local Walker circulation.  
9 Moreover, it is argued that warming of the central Indian Ocean accelerated by greenhouse  
10 gas and aerosol emissions after later half of the 20th century are correlated with the decline in  
11 precipitation over Eastern Africa (Funk et al., 2008; Williams and Funk, 2011). These studies  
12 suggested that warming of the central Indian Ocean drives changes in the local Walker  
13 circulation causing reduction in the seasonal rainfall and inducing drought conditions in the  
14 region.

15 Droughts in Sahel are caused by an array of complex processes and feedback mechanisms.  
16 Caminade and Terray (2010) stated that conditions that favour lower summer rainfall in Sahel  
17 are: when Atlantic Ocean north of equator is cool and the same is warm below the equator, El  
18 Niño events and increased vertical thermal stability from a warming troposphere. Most of the  
19 studies on Sahel droughts concur that the recent severe droughts in Sahel were caused by the  
20 ocean warming (southward warming gradient of the Atlantic ocean and steady warming of the  
21 Indian Ocean), southward shift of Inter Tropical Convergence Zone (ITCZ) (Caminade and  
22 Terry 2010; Dai, 2011; Giannini et al., 2008; Janicot et al., 1998; Kerr, 1985; Lebel et al.,  
23 2009; Zeng, 2003). The land-atmosphere feedbacks through natural vegetation and land cover  
24 change are also important factors. Anthropogenic contribution in land use change altering the  
25 land surface feedback mechanisms is also seen as a factor. Some studies were done with the  
26 objective of examining whether the climate in the Sahel region is sensitive to land use  
27 changes or not. For instance, Zheng and Eltahir (1997) investigated the interaction between  
28 vegetation and climate in the Sahel region by means of simulations of the West African  
29 monsoons with a simple zonally-symmetric model. Their results show that the impacts of land  
30 cover changes in the Sahel region along the border with Sahara are insignificant. However,  
31 deforestation along the southern coast of West Africa can cause significant reduction of the  
32 rainfall and affect on the monsoon circulation. Several studies suggested aerosol emissions  
33 were an important driver of the recent Sahel droughts (e.g. Desboeufs et al., 2010; Hwang et

1 al., 2013; Moulin and Chiapello, 2004; Prospero and Lamb, 2003). Furthermore, human  
2 induced green house gas emission is also considered as a contributory factor to oceans  
3 warming (e.g. Dai, 2013). Despite recognition of these anthropogenic factors, their relative  
4 contribution compared to natural factors in inducing Sahel droughts is debated and regarded  
5 as a secondary factor.

6 The limited studies are available on causes of droughts in Northwest Africa. The North  
7 Atlantic Ocean SST does influence on rainfall variability in the region but this relationship is  
8 rather weak and could not explain major droughts in the region (Li et al., 2003; Touchan et  
9 al., 2011). Similarly, ENSO is seen as a potential factor, but a strong relationship is not  
10 demonstrated by ENSO about modulating droughts in this region (Esper et al., 2007; Touchan  
11 et al., 2008). The North Atlantic Oscillation (NAO) indicates variable influence on the rainfall  
12 in the region, with negative correlation with western parts but no correlation with eastern  
13 parts (Touchan et al., 2013). However, no relationship is found between NAO and droughts in  
14 the region. Touchan et al. (2013) argued that anthropogenic green house gas emission is an  
15 important factor causing drying in this region. The review of these studies suggested that the  
16 causes of droughts in the Northwest Africa are not well established and require further  
17 research.

18

19

## 20 **4 Conclusions**

21 The climate of the African continent exhibits large geospatial and temporal variability.  
22 Droughts are recurrent features varying from failure of rains in one season or up to one or  
23 more years. The vulnerability to droughts is high due to poverty, large dependency on rainfed  
24 agriculture and other factors. Therefore, droughts continue to incur heavy toll to people,  
25 animals, environment and economy. The planning and management of droughts requires a  
26 paradigm change shifting from crisis management to risk management. Comprehensive  
27 studies on historic drought events could significantly guide in better planning and mitigation  
28 strategies of droughts. There is significantly increasing number of information and scientific  
29 studies on various aspects of drought. However, these studies do not provide a long-term  
30 and/or continental scale perspective. This study is a first of its kind to build such a perspective  
31 on droughts in Africa with the aim on conducting geospatial and long-term analysis of the

1 droughts. The study is underpinned by a comprehensive review of available information and  
2 scientific literature and analysis of the EM-DAT and SPEI data sets.

3 The analysis of droughts during 1900-2013 indicated that droughts have been intensified in  
4 terms of their frequency, severity and geospatial coverage over the last few decades. The  
5 droughts that occurred in 1972-73, 1983-84 and 1991-92 were most intense and widespread.  
6 All of the regions witnessed severe droughts in the last few decades, for instance, the 2010-11  
7 drought in East Africa (Horn of Africa), 1999-2002 drought in North Africa, 2001-03 drought  
8 in Southern Africa and persistent droughts in Sahel during 1970s and 1980s. Few studies are  
9 available to construct drought chronologies before 20th century. However, studies based on  
10 lake sediment analysis indicated episodes of severe droughts prolonged for decades and even  
11 centuries in the past over West and Equatorial East Africa, which are also documented in the  
12 cultural histories of these regions. The studies underpinned by tree-ring chronologies in  
13 Northwest Africa indicated quite a number of moderate to severe droughts in the past, about  
14 12-16 events per century which has increased to 19 during 20th century. Southern Africa also  
15 faced several single and multi-year droughts during 19th century, as indicated by the analysis  
16 of missionaries' correspondence.

17 Drought predictions based on the global climate models simulations show varying results and  
18 thus remain uncertain for most of the African continent. However, the results of simulation  
19 models suggested high likelihood of increased droughts in central and southern Africa.  
20 Despite considerable improvements in these models, they are still not able to accurately  
21 represent the large number of complex factors responsible for causing the droughts across  
22 various regions of the continent (e.g. ENSO and SSTs, wind and pressure anomalies, land-  
23 atmospheric feedback mechanisms). Their complex interactions induce uncertainty in the  
24 drought predictions.

25 The available evidence from the past clearly shows that the African continent is very likely to  
26 face extreme and widespread droughts in future. The vulnerability is likely to increase due to  
27 fast growing populations, increasing water demands and degradation of land and  
28 environmental resources. Addressing such a daunting and evident challenge calls for much  
29 more serious and committed action from communities, governments, regional bodies,  
30 international organizations and donors than that is witnessed at present. This review advances  
31 available information and scientific understanding of the droughts in Africa.

32



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23

1 Table 1. Overview of number of droughts and their impact across the world during 1900-  
 2 2014.

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

3 Source: EM-DAT: The International Disaster Database. Centre for Research on the  
 4 Epidemiology of Disasters-CRED. <http://www.emdat.be/database> (accessed on 13th January  
 5 2014).

6

7

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

Reference	Drought enlisted by region/country/basin during 1900 to 2013	Remarks
<b>North Africa</b>		
Quassou et al. (2007)	Morocco: 1904-05, 1917-20, 1930-35, 1944-45, 1948-50, 1960-61, 1974-75, 1981-84, 1986-87, 1991-93, 1994-95, 1999-2003	The study shows that droughts of 1944-45, 1982-83, 1994-95 and 1999-2000 were the driest agricultural seasons. Most severe hydrological droughts were 1980-81, 1985-86, 1991-92, 2000-01, 2002-03. 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. 1945-46, 1981-82, 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 A.D. 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: 1969-70, 1972-73, 1979-85, 1990-91, 2002-08	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.
<b>West Africa</b>		
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.

Reference	Drought enlisted by region/country/basin during 1900 to 2013	Remarks
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. 1983-84 drought was most severe covering 90% of the basin area. Akosomombo 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.
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.
<b>East Africa</b>		
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: 2010-11 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

Reference	Drought enlisted by region/country/basin during 1900 to 2013	Remarks
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. 2010-11	This drought was regarded as the worst during past 60 years. The study concluded that the Indian Ocean SSTs are the primary influence on East African rainfall over multidecadal and perhaps longer timescales.
<b>Southern Africa</b>		
Belbase and Morgan (1994)	Southern Africa: Botswana. 1978-79, 1982-87, 1991-92.	The case study highlight the salient features of the relatively successful drought management experience in Botswana.
Manatsa et al. (2008)	Southern Africa: Zimbabwe: 1902-03, 1911-16, 1926-27, 1941-42, 1963-64, 1972-73, 1982-84, 1986-87, 1991-92	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 1991-92 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, 1909-11, 1917-18, 1921-22, 1925, 1929, 1933-34, 1939-1940, 1953, 1969, 1972-73, 1976, 1980-82, 1984-85	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. (2013)	South Africa: Crocodile River catchment. 1945, 1951, 1958, 1966, 1970/71, 1978, 1983-84, 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 1992-95 drought was the most severe one in the last 70 years where the upper and lower areas of the catchments were the most affected.

Reference	Drought enlisted by region/country/basin during 1900 to 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 to 1988 during summer rainfall period January-March. Droughts during 1970-88 period were intense and widespread compared to those during 1950-1969. The ENSO was the main governing factor for droughts during 1970-88 (though not always), whereas, regional oceanic and atmospheric anomalies (e.g. southwest Indian Ocean SST) were the main causes.
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. 1982-93, 1991-92, 1994-95, 2001-03	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.
<b>More than one region</b>		
Calow et al. (2010)	2002-03, 2004-05 and 2005-06 droughts in Ethiopia. 1991-92 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 2003-5 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: 1982-83 and 1991-92 (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.

Reference	Drought enlisted by region/country/basin during 1900 to 2013	Remarks
Tadesse et al. (2008)	Sub-Saharan Africa: 1972-74 and 1984-85 (Sahel and East Africa), 1992-93 (southern Africa), 2000-02 (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; 1990-91; 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.

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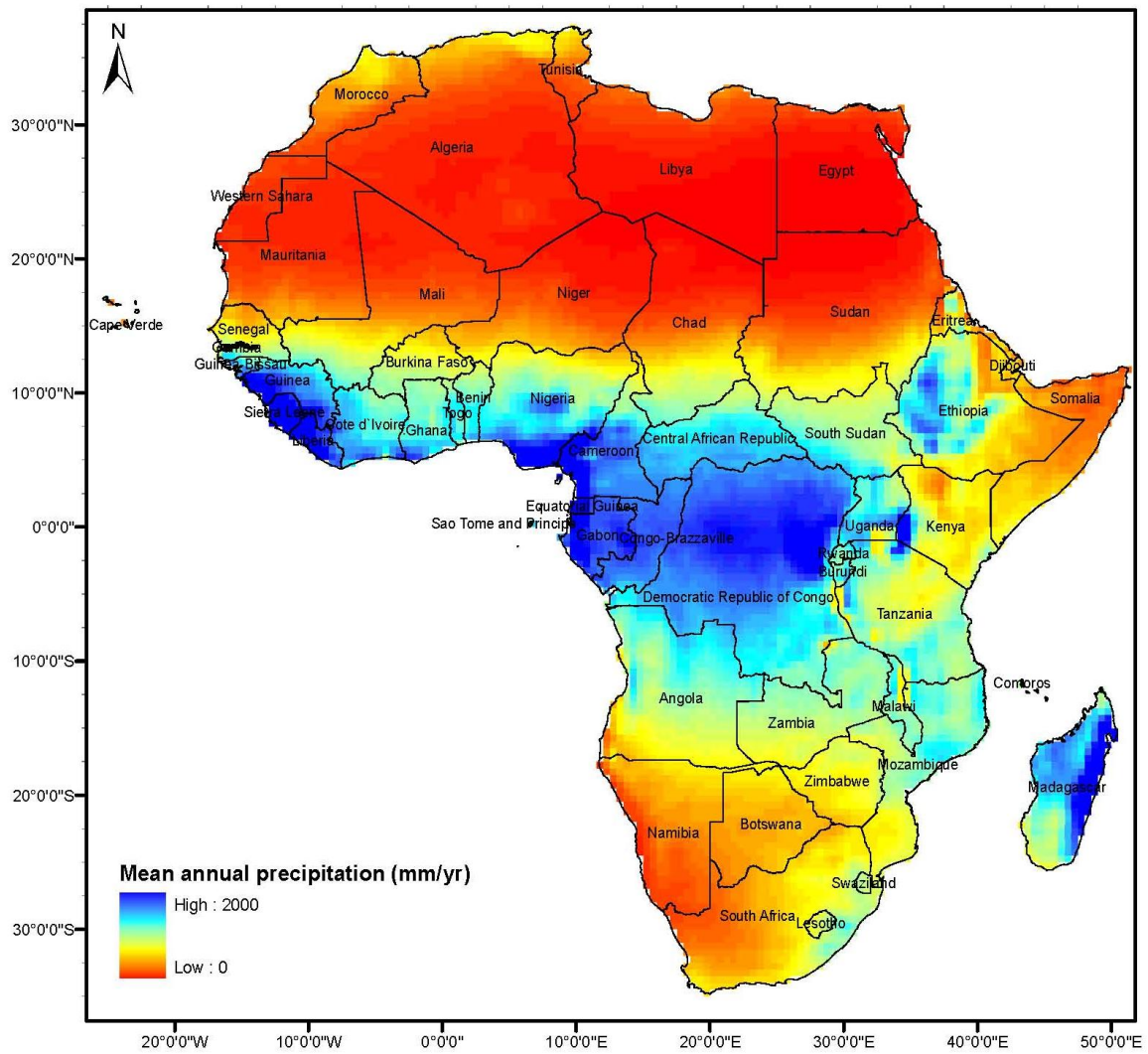


1 Table 3. Summary of drought events recorded for 1900-2013 in EM-DAT data base.

Region/Countries	Drought Years	# of events	# of People Killed	# of People affected	Economic Damage ( × 10 <sup>3</sup> USD)
<b>Overall African Continent</b>		<b>291</b>	<b>847143</b>	<b>362225799</b>	<b>2920593</b>
<b>North Africa</b>		<b>18</b>	<b>150012</b>	<b>31153400</b>	<b>900100</b>
Algeria	1981, 2005	2	12	0	0
Morocco	1966, 1971, 1983, 1984, 1999	5	0	412000	900100
Tunisia	1977, 1988	2	0	31400	0
Sudan	1980, 1983, 1987, 1990, 1991, 1996, 1999, 2009, 2012	9	150000	30710000	0
<b>Middle Africa</b>		<b>25</b>	<b>3058</b>	<b>11379800</b>	<b>84500</b>
Angola	1981, 1985, 1989, 1997, 2001, 2004, 2012	7	58	4443900	0
Cameroon	1971, 1990, 2001, 2005	4	0	586900	1500
Central Africa Republic	1983	1	0	0	0
Chad	1910, 1940, 1966, 1969, 1980, 1993, 1997, 2001, 2012	9	3000	5456000	83000
Congo	1983	1	0	0	0
Sao Tome et Principe	1983	1	0	93000	0
Zaire/Congo Dem Rep	1978, 1983	2	0	800000	0
<b>West Africa</b>		<b>94</b>	<b>170012</b>	<b>74500255</b>	<b>507354</b>
Benin	1969, 1980	2	0	2215000	651
Burkina Faso	1910, 1940, 1966, 1969, 1976, 1980, 1988, 1990, 1995, 1998, 2001, 2011	12	0	8413290	0
Cape Verde Is	1900, 1910, 1920, 1940, 1946, 1969, 1980, 1992, 1998, 2002	10	85000	40000	0
Cote d'Ivoire	1980	1	0	0	0
Gambia The	1910, 1940, 1968, 1969, 1976, 1980, 2002, 2012	8	0	1258000	700
Ghana	1971, 1977, 1980	3	0	12512000	100
Guinea	1980, 1998	2	12	0	0
Guinea Bissau	1910, 1940, 1969, 1980, 1980, 2002, 2006	6	0	132000	0
Liberia	1980	1	0	0	0
Mali	1910, 1940, 1966, 1976, 1980, 1991, 2001, 2005, 2006, 2010, 2011	11	0	6927000	0
Mauritania	1910, 1940, 1965, 1969, 1976, 1978, 1980, 1993, 1997, 2001, 2010, 2011	12	0	7398907	59500
Niger	1903, 1906, 1910, 1940, 1966, 1980, 1988, 1990, 1997, 2001, 2005, 2009, 2011	13	85000	23655058	0
Nigeria	1981	1	0	3000000	71103

Region/Countries	Drought Years	# of events	# of People Killed	# of People affected	Economic Damage ( × 10 <sup>3</sup> USD)
Senegal	1910, 1940, 1966, 1969, 1976, 1979, 1980, 2002, 2011	9	0	8399000	374800
Togo	1971, 1980, 1989	3	0	550000	500
<b>East Africa</b>		<b>122</b>	<b>523561</b>	<b>220892229</b>	<b>371900</b>
Burundi	1999, 2003, 2005, 2008, 2009, 2010	6	126	3062500	0
Comoros	1981	1	0	0	0
Djibouti	1980, 1983, 1988, 1996, 1999, 2005, 2007, 2008, 2010	9	0	1188008	0
Eritrea	1993, 1999, 2008	3	0	5600000	0
Ethiopia	1965, 1969, 1973, 1983, 1987, 1989, 1997, 1998, 1999, 2003, 2005, 2008, 2009, 2012	15	402367	66941879	92600
Kenya	1965, 1971, 1979, 1983, 1991, 1994, 1996, 1999, 2004, 2005, 2008, 2010, 2012	13	196	47200000	1500
Madagascar	1981, 1988, 2000, 2002, 2005, 2008	6	200	3515290	0
Malawi	1987, 1990, 1992, 2002, 2005, 2007, 2012	7	500	21578702	0
Mauritius	1999	1	0	0	175000
Mozambique	1979, 1981, 1987, 1990, 1998, 2001, 2003, 2005, 2007, 2008, 2010	12	100068	17757500	50000
Rwanda	1976, 1984, 1989, 1996, 1999, 2003	6	237	4156545	0
Somalia	1964, 1969, 1973, 1980, 1983, 1987, 1988, 1999, 2004, 2005, 2008, 2010, 2012	13	19673	13183500	0
Tanzania Uni Rep	1967, 1977, 1984, 1988, 1990, 1996, 2003, 2004, 2006, 2011	10	0	12737483	0
Uganda	1967, 1979, 1987, 1998, 1999, 2002, 2005, 2008, 2010	9	194	4975000	1800
Zambia	1981, 1983, 1990, 1995, 2005	5	0	4173204	0
Zimbabwe	1981, 1990, 1998, 2001, 2007, 2010	6	0	14822618	51000
<b>Southern Africa</b>		<b>32</b>	<b>500</b>	<b>24300115</b>	<b>1056739</b>
Botswana	1965, 1968, 1970, 1981, 1990, 2005	6	0	1344900	3000
Lesotho	1968, 1983, 1990, 2002, 2007, 2011	6	0	2736015	1000
Namibia	1981, 1990, 1995, 1998, 2001, 2002, 2013	7	0	1114200	51000
South Africa	1964, 1980, 1981, 1986, 1988, 1990, 1995, 2004	8	0	17475000	1000000
Swaziland	1981, 1984, 1990, 2001, 2007	5	500	1630000	1739

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

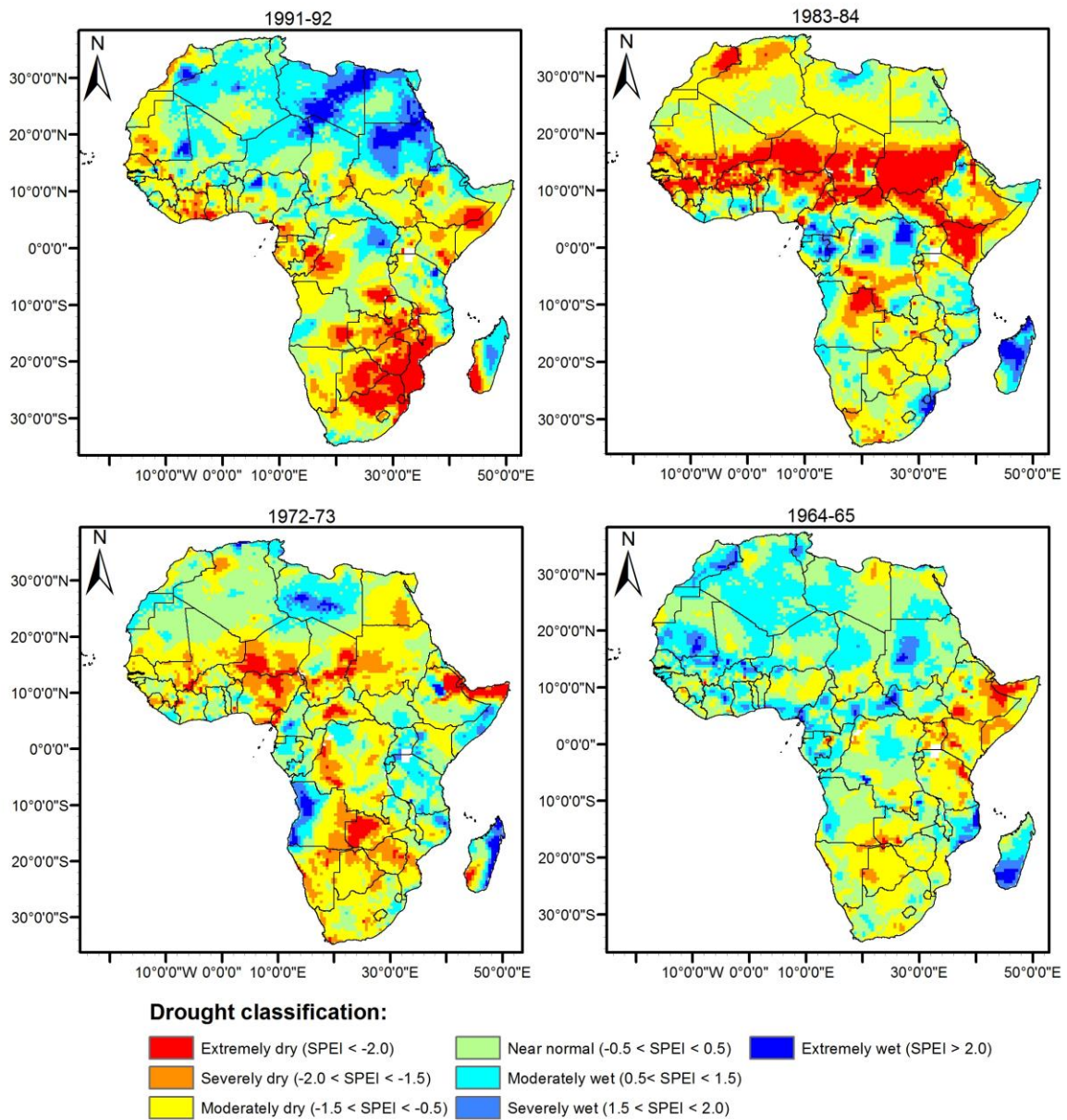
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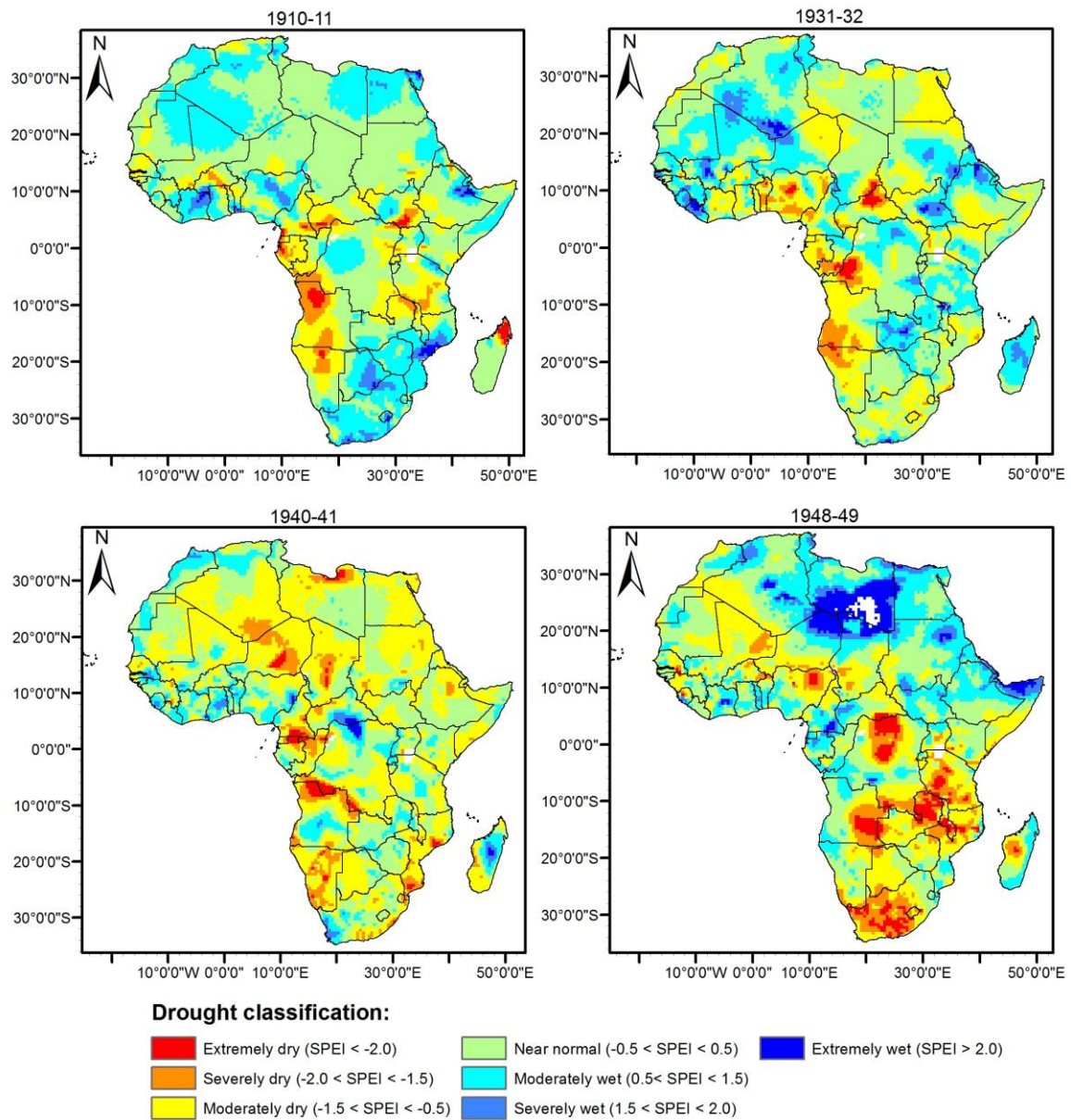
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2 Figure 2. Geospatial coverage of extreme droughts of 1964-65, 1972-73, 1983-84 and 1991-  
 3 92 indicated by 12 months SPEI (October to September). (Data source: Global SPEI database  
 4 available at <http://sac.csic.es/spei/database.html>, version 2.2 retrieved in Jan 2014)

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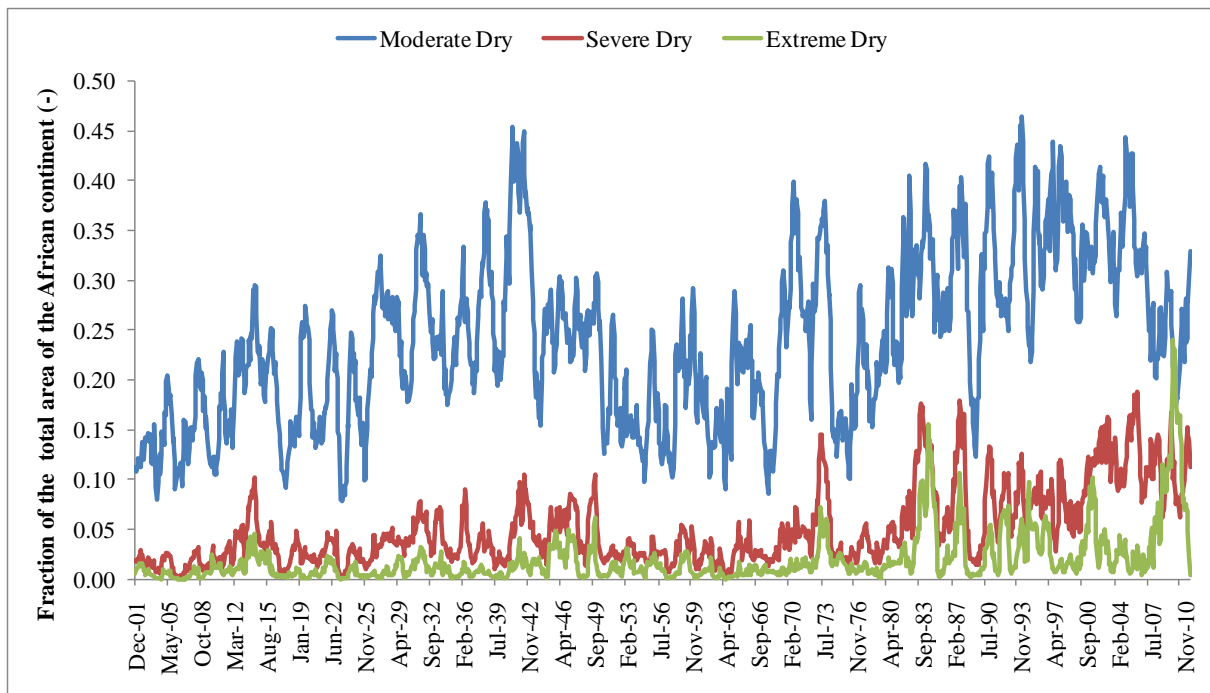


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2 Figure 3. Geospatial coverage of selected droughts 1910-11, 1931-32, 1940-41 and 1948-49  
 3 indicated by 12 months SPEI (October to September). (Data source: Global SPEI database  
 4 available at <http://sac.csic.es/spei/database.html>, version 2.2 retrieved in Jan 2014).

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 2 Figure 4. Fraction of the African continent under different drought conditions computed from  
 3 the 12 month SPEI dataset. (Data source: Global SPEI database available at  
 4 <http://sac.csic.es/spei/database.html>, version 2.2 retrieved in May 2014). Note: Moderate dry  
 5 ( $-1.5 < \text{SPEI} < -0.5$ ); Severe Dry ( $-2.0 < \text{SPEI} < -1.5$ ); Extreme Dry ( $\text{SPEI} < -2.0$ ).