A new early warning drought index for Ethiopia

Yonas Tadesse, Aklilu Amsalu, Paolo Billi and Massimiliano Fazzini

ABSTRACT

This study investigates the occurrence of droughts in the Dire Dawa area of eastern Ethiopia. A new index based on the rainfall delay (*Rd*) with respect to the expected onset (and traditional) seeding time and other indices, i.e., the aridity index and the Z-score, alternatives to the Standard Precipitation Index (SPI), are used to test the validity of the new *Rd* index in identifying severe droughts extending back to 1955. Although only data of rain gauges located in the district of Dire Dawa were used, they proved, albeit with different accuracies, able to identify nation-wide droughts.

Key words | aridity index, drought, dryland, Ethiopia, rain delay, SPI

Yonas Tadesse
Department of Environmental Science,
University of South Africa,
Pretoria, South Africa

Aklilu Amsalu
Department of Geography & Environmental Studies,
Addis Ababa University, Ethiopia

Paolo Billi (corresponding author)
International Platform for Dryland Research and Education,
University of Tottori,
1390 Hamasaka, Tottori, 680-0001, Japan
E-mail: *bli@unife.it*

Massimiliano Fazzini
Department of Physics and Earth Sciences,
University of Ferrara, Italy

INTRODUCTION

The history of climate extremes, especially drought, is not new in Ethiopia. Records of drought in Ethiopia date back to 250 BC and since then they have been a recurring phenomenon (Kiros 1991; Edossa *et al.* 2010). Recent studies have shown that the frequency of drought has increased over the past few decades, especially in the lowlands (Lautze *et al.* 2003; Viste *et al.* 2012). Major droughts occurred in 1957–1958, 1964–1966, 1972–1974, 1982–1984, 1987–1988, 1990, 1999, 2000, 2002–2003, 2006, 2009 and 2011 (Edossa *et al.* 2010; Degefu & Bewket 2015).

The greatest losses of life associated with drought in Ethiopia occurred in 1888, 1957–1958, 1972–1973 and 1983–1984, affecting as many as one million people (Degefu & Bewket 2015). Similarly, the 1972–1973, 2006 and 2008 droughts caused the death of 30% of the livestock population in Tigray and Wollo and several thousands of livestock in Southern Ethiopia (Degefu & Bewket 2015). The greatest number of affected people was 14.2 million in 2002, who needed emergency food assistance (EEPRI 2003 in Bewket 2012).

Ethiopia is an agricultural and agro-pastoral country and its economy is mainly dependent on rain-fed agriculture. Chronic food insecurity affects 10% of the population, even in average rainfall years. Future climate variability is expected to worsen these conditions. About a century ago, the frequency of droughts used to be once every 10–15 years but recent records indicate an increased frequency of once every five years or even less (Edossa *et al.* 2010; Block 2008 in Degefu & Bewket 2015).

Viste *et al.* (2012), in their vast and comprehensive work on drought and precipitation variability in Ethiopia, have shown that rainfalls are highly variable and drought conditions are common in Ethiopia at both seasonal and annual time scales, and concluded that Ethiopia as a whole is particularly prone to droughts. Ethiopia has a predominantly rain-fed agricultural system and rainfall is a crucial factor in determining food production. Farmers indicate the erratic nature of rainfall as a primary cause of food insecurity and vulnerability. In Ethiopia, drought is commonly followed by famine to such an extent that, although famine may have many other causes, the two terms have become almost synonymous.

In spite of the many efforts made by the Ethiopian Government to develop strategic plans to mitigate the impact of

doi: 10.2166/wcc.2018.105

climate change, early warning systems are not yet effective and drought risk management is still implemented with difficulties and often belatedly. Although some teleconnections between ENSO and the pattern of seasonal rainfall in Ethiopia have been recognized (e.g., Lanckriet *et al.* 2015; Degefu & Bewket 2017), given the strict dependence of agriculture on rainfall variability, the possibility of defining a simple method to anticipate drought, even by a short time but sufficient to activate effective drought mitigation countermeasures, could bring about a substantial benefit to the local farmers. Jury (2013) developed an interesting method to predict climate-driven local crop yields, but it implies four variables, the data of which cannot be easily obtained, especially in developing countries.

The main aim of this paper is to present a very simple agricultural drought index based on the delay of the rainy seasons onset with respect to the traditional seeding time. Commonly, in fact, famine conditions are not caused simply by a reduction in rainfall amounts, but primarily by rainfall occurring with substantial delay in comparison with the average date. Such a new index is tested against other common indices (such as the Standard Precipitation Index (SPI) – McKee *et al.* 1993) and the results are compared with the time series of droughts in Ethiopia. As a complementary, secondary output, the capacity of at-site drought identification of regional episodes is verified.

STUDY AREA, DATA AND METHODS

The study was conducted in the area of Dire Dawa (eastern Ethiopia), whose major topographic features consist of the plateau, at an elevation of about 2,300 m asl, the main Ethiopian Rift escarpment, linking the plateau to the lowland north of Dire Dawa and the lowland, at an elevation around 800 m asl (Figure 1).

Mean annual air temperature is 25.1 °C in Dire Dawa (lowland) and around 17 °C on the plateau. Rainfall has a bimodal distribution with two, distinct main rainy seasons, spring (March, April, May) and summer (July, August, September), locally called '*belg*' and '*kiremt*', respectively, separated by a short dry spell in June. Mean annual rainfall is about 638 mm in Dire Dawa and 800–1,000 mm on the plateau (Fazzini *et al.* 2015). Monthly rainfall data were obtained from the National Meteorological Agency of Ethiopia (NMA) for five meteo-stations in the study area: Combolcha, Dengego, Dire Dawa, Haramaya and Kulubi (Figure 1). The data from Combolcha, Dengego and Kulubi cover the 1985–2014 interval, whereas the data from Dire Dawa and Haramaya have a much longer record, starting in 1953 and 1955, respectively. Kulubi is the highest rain gauge at an elevation of 2,436 m asl and Dire Dawa is the least elevated at 1,180 m asl. The elevations of the other meteo-stations, namely Combolcha, Dengego and Haramaya, are 2,122, 2,078 and 2,020 m asl, respectively.

Drought indices

A few, simple indices among the most used in the literature were considered. They are the SPI (McKee *et al.* 1993), the standard Z-score (Z), the aridity index (Ai) (UNEP 1992) and the newly defined Rainfall Delay index (Rd). The Percent of Normal was initially considered as well, but its poor performance suggested it should not be included in our analysis. Rd was not calculated for Combolcha because daily rainfall data are missing, and Ai was not calculated due to unavailable temperature data.

The Standard Precipitation Index

The SPI (McKee *et al.* 1993) is probably the most widely used drought index (e.g., Lloyd-Hughes & Saunders 2002; Knutson & Fuchs 2016). The SPI has advantages in its simplicity since it is based solely on rainfall and requires only the computation of two parameters, compared with the 68 computational terms needed to calculate the Palmer Drought Severity Index (PDSI) (Palmer 1965). The SPI variable time scale allows drought conditions to be described for a range of meteorological, agricultural and hydrological applications. This temporal versatility is also helpful to determine drought onset and cessation, which have always been difficult to track with other indices. The robustness of SPI over the other drought indices has been reported in many studies (e.g., Guttman 1998; Wu *et al.* 2001; Mpelasoka *et al.* 2008 in Degefu & Bewket 2015). The index is computed by considering the precipitation anomaly with respect to the mean value for a given time scale, divided by its standard deviation. SPI values were computed to quantify drought events at 3-, 6- and 12-month

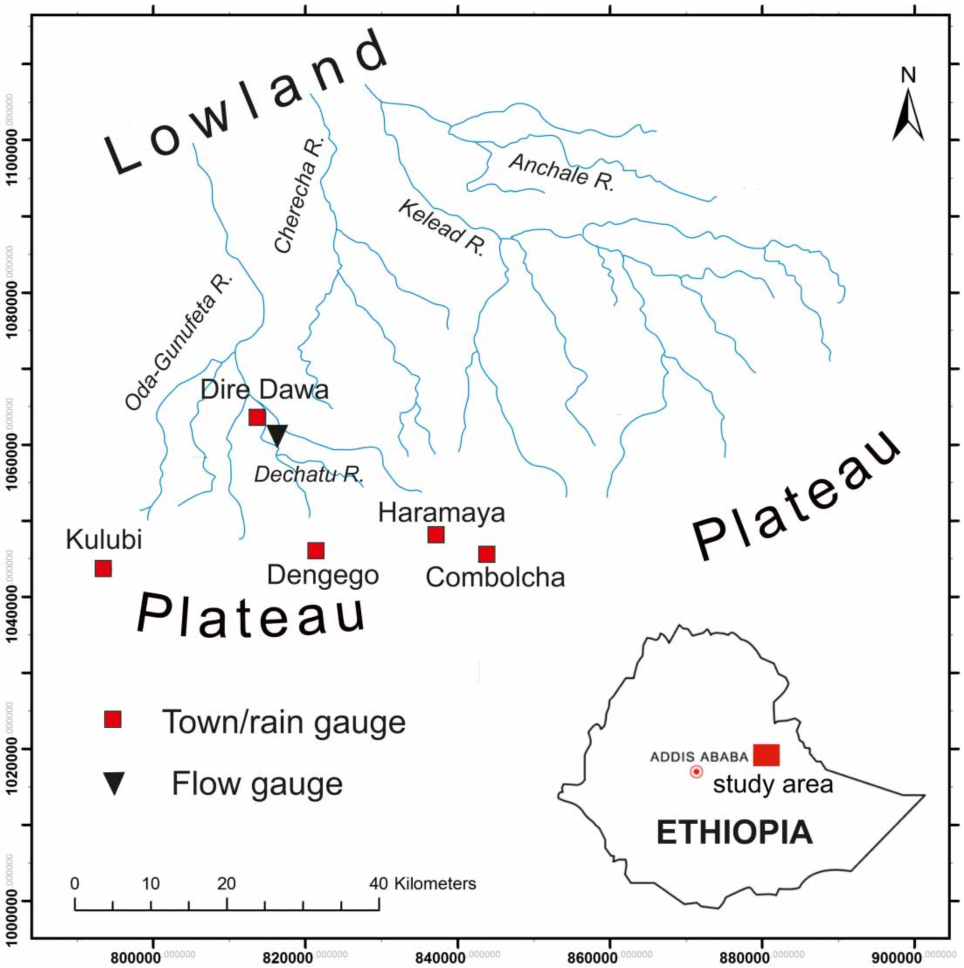

Figure 1 | Location map of the study area.

time scales, but in this short paper only the 12-month scale is considered.

Alternative indices

Although the SPI is widely accepted by climatologists, Viste *et al.* (2012), also quoting McKee *et al.* (1993), pointed out that the SPI values are normally distributed and, hence, wet and dry periods are represented in a similar way. For this reason, the SPI should not be used to identify areas that are more drought-prone than others because the frequency of extreme droughts is the same for both wet and dry areas. For these reasons, other alternative methods were used and tested against the drought/famine sequence recorded in Ethiopia.

Aridity is a climatic characteristic of a region and it is defined in several ways (e.g., the duration and frequency of dry intervals; the shortage of moisture depending on the ratio between precipitation and evapotranspiration; if the precipitation is greater or less than the water needed to offset evaporation and plant transpiration). Several indices have been proposed by scientists but the UNEP (1992) aridity index (*Ai*), also known as the desertification index, is one of the most used. It is defined as follows:

$$Ai = \frac{P}{PET} \tag{1}$$

where *P* is annual precipitation and *PET* is potential evapotranspiration, calculated by Thornthwaite's method. Four classes of aridity are defined: hyper-arid ($Ai < 0.05$); arid ($0.05 < Ai < 0.20$); semi-arid ($0.20 < Ai < 0.50$); and dry sub-humid ($0.50 < Ai < 0.65$). In this study, values of Ai less than 0.50 were considered as an indicator of potential drought conditions.

Famine is a typical consequence of drought in Ethiopia and although famine is also caused by other reasons, drought and famine are often considered as synonymous. Wood (1977) and Pankhurst & Johnson (1988) stated that, historically, rainfall variability and associated droughts have been major causes of food shortages and famine in Ethiopia.

In areas of Ethiopia with bimodal distribution of monthly precipitation (a larger proportion of the country – Fazzini *et al.* 2015), the dates of onset and end of the two rainy seasons represent the most significant variable for agriculture. Although the main growing season is summer, spring rains (*belg*) allow a smaller, but often significant crop, which is harvested just prior to summer planting. The high variability of *belg* rainfall is well documented (e.g., Fazzini *et al.* 2015). When spring rains fail, farmers commonly suffer from a shortage of food and have to borrow new seeds. During spring droughts, poor farmers must face the classic dilemma of whether to plant spring crops or to allow their fields to regenerate as pasture to sustain livestock into the main ploughing season. Although the *belg* rains account, on average, for only 5 to 15% of the annual crop, poor farmers depend on the spring rains to provide a critical margin of productivity. Farmers can manipulate other factors under their control, but the failure of rainfall is a given risk. If we consider the combined occurrence of both *belg* and *kiremt* droughts, the probability of a famine outbreak is high. Therefore, in order to indicate the rain variability of the two main crop seasons a simple precipitation analysis was carried out using the standard Z-score for both the *belg* and *kiremt* rainfall. Z is defined as:

$$Z = \frac{(x_i - x_m)}{s} \quad (2)$$

in which x_i is the total rainfall amount for *belg* or *kiremt* in a given year; x_m is the long-term seasonal average; and s is the standard deviation. A Z time series is then constructed and pairs (*belg* and *kiremt*) of values lower than -1 or individual peaks lower than -2 are considered and compared with the sequence of known drought/famine. According to Wu *et al.* (2001), the flexibility of Z-score is particularly important for regions where weather data are often incomplete, as is the case in Ethiopia.

In Ethiopia, crop yields are particularly sensitive to precipitation (WFP 2016) and wetter years are associated with higher yields. Although in Ethiopia cereal (*teff*, wheat, barley and maize) production almost quadrupled between 1961 and 2010, the frequency and magnitude of droughts in this period markedly affected agricultural viability (WFP 2016).

Several years of field work in Ethiopia and discussions with local farmers and relief managers led us to note that in years with relatively abundant precipitation the crop yield was also far below expectations, and hot spots of famine were reported by the media. In Ethiopia, farmers follow a millennial tradition of adaptation to rainfall seasonality and sow their crops at the end of February (just before the beginning of *belg*) and at the end of June to beginning of July for *kiremt* crops. The sooner the rainfall comes the better it is for seed germination. If, instead, the rain comes several days after the seeds' placement, their germination will be at risk or significantly reduced. A delay in the rainy season onset can be disastrous, as proved by some of the worst famines of southern Asia caused by delay in the summer monsoon (Critchfield 1983). Moreover, a bird of the francolin family, rather common in Ethiopia, is able to find the seeds under 2–3 cm of soil. Even though farmers use different means to keep these birds away, the longer the time between sowing and germination the more seeds are eaten by these birds. On the basis of such considerations, a new, very simple parameter was developed to take into account the delay of rain onset with respect to sowing. For each of the study meteo-stations, the number of days to reach a rainfall amount of 20 mm after March 1 and July 1 were counted and then summed. In fact, if the rainfall delay of the main crop season is enough to threaten agriculture, the delay in the *belg* rains may also lead to drought or, at least, to famine conditions. Time series diagrams of rain delay data (*Rd*) for both *belg* and *kiremt* and their sum were constructed and the occurrence of peaks compared with drought/famine occurrence since 1955 for Dire Dawa and Haramaya and since 1981 for the other meteo-stations, respectively, with the exception of Combolcha, as already explained.

The 'good' rainfall is the adequate amount of precipitation, i.e., neither too much nor too little, for crop growing. According to USAID (2000), for regions in Africa this amount is in the range of 41–75 mm in ten days. On the basis of this study, Lemi (2005) suggests an amount of about 35 mm of rain in ten days for Ethiopia. The amount of 20 mm, taken in this study as a reference to calculate the rain delay, is about half of USAID and Lemi's 'good' rain but, given the different purpose, 20 mm can be considered appropriate to indicate the minimum rain necessary for seed germination. Moreover, since the rainfall data available are expressed as daily values, it was possible to calculate the return time of an intensity of 20 mm in 24 hours, which ranges from 0.3 to 0.6 years. This suggests that a daily rainfall of 20 mm has almost the same probability of occurring during both the *belg* and the *kiremt*. From the comparison with the historical drought series, cumulative rain delays in excess of 40–50 days (depending on annual precipitation) can be considered as indicative of drought conditions.

RESULTS AND DISCUSSION

According to some authors and international institutions (Edossa *et al.* 2010; Degefu & Bewket 2015), in Ethiopia, major droughts have occurred in 1957–1958, 1964–1966, 1972–1974, 1982–1984, 1987–1988, 1990, 1999, 2000, 2002–2003, 2006, 2009 and 2011. This sequence is compared with the peaks of the aridity/drought parameters considered in this study, i.e., SPI, the UNEP's (1992) aridity index (*Ai*), the Z-score (*Z*) and the rain delay (*Rd*) (Table 1). The results indicate the best performance is given by *Rd* with about 65% of matches. The other parameters have lower percentages of correspondence with the drought/famine episodes, i.e., about 49% for the Z-score, 45% for SPI and 36% for *Ai*. The good performance of *Rd* is particularly important as this index can be used in a warning procedure to alert farmers of drought onset probability and to deploy the necessary countermeasures at both local and central level. The combination of the four parameters (and in particular *Rd*) were also able to point out other, likely, minor drought episodes, the strongest of which seems to have occurred in 2012 and a milder one in 1994.

The average angular coefficient of the *Rd* trend lines for the spring rains indicates an increase in the delay of the *belg* rainfall onset and confirms the conclusions of other authors (e.g., Seleshi & Camberlin 2006; Williams & Funk 2011) who have documented a marked spring season precipitation decrease in southern and eastern Ethiopia.

Table 1 | Results of different indices (see text for explanations) matching drought/famine episodes (x = matches: o = does not match; md = missing data)

		1957–58	1964–66	1972–74	1982–84	1987–88	1990	1999	2000	2002-03	2006	2009	2011	Total (%)
Dire Dawa	SPI	md	md	md	md	x	o	o	x	x	x	x	x	**75**
	Z	x	x	x	x	x	x	o	x	x	o	x	o	**75**
	Ai	x	x	x	x	x	x	x	x	x	x	md	md	**83**
	Rd	x	x	x	x	x	o	o	x	o	o	o	x	**58**
Haramaya	SPI	md	md	md	md	o	o	o	x	x	o	o	o	**25**
	Z	x	x	o	x	o	o	o	o	o	x	o	o	**33**
	Ai	md	md	o	o	o	o	o	md	o	md	o	md	**0**
	Rd	x	x	x	x	o	x	o	x	x	md	x	x	**82**
Dengego	SPI	md	md	md	md	x	x	o	o	x	o	o	x	**50**
	Z	md	md	md	x	x	o	o	o	x	md	o	x	**50**
	Ai	md	md	md	x	o	md	o	o	o	md	md	md	**25**
	Rd	md	md	md	x	md	o	o	x	o	x	x	x	**63**
Kulubi	SPI	md	md	md	md	x	o	o	o	o	x	x	x	**50**
	Z	md	md	md	o	x	o	x	o	x	o	x	o	**44**
	Rd	md	md	md	x	x	o	o	md	o	md	x	x	**57**
Combolcha	SPI	md	md	md	md	x	o	o	o	x	o	o	o	**25**
	Z	md	md	md	md	x	o	o	o	x	o	x	o	**43**
Total match (%)		**100**	**100**	**67**	**82**	**67**	**25**	**12**	**50**	**62**	**42**	**57**	**61**	

The best performance of all indices, except *Rd*, at Dire Dawa, the hottest and driest meteo-station, apparently seems to indicate that the indices considered provide better predictions in drier, hotter and likely more drought-prone areas. However, as already pointed out by Viste *et al.* (2012), that could be due to an over-assessment of drought that may result, especially when using the SPI, in areas more drought prone than others.

Although the *Rd* index proved to give the best predictions of droughts, more extensive studies, with larger data sets and in different part of Ethiopia – including for instance the zones with unimodal rains – should be undertaken to confirm the efficiency of this new agricultural drought index. After additional verification, the new *Rd* parameter could be used as a short-term predictor of drought/famine conditions. The new index has practical application potential, while it is a very cheap and effective tool in early warning systems. In fact, it is also very easy to measure the *Rd* parameter from class C meteo-stations or individual rain gauges. The onset of drought/famine risk condition could be reported to regional relief agencies through a down-up information transfer process, improving the speed and effectiveness of mitigation interventions. An example of the *Rd* index implementation could be the prolonged droughts that threatened the Horn of Africa in early 2017 (UN-ISDR 2017). Other countries in the region, such as Eritrea and Somalia, have experienced severe droughts. Furthermore, in these countries precipitation follows a seasonal pattern with distinct rainy season and the delay in the seasonal rainfall onset is commonly the main cause of agricultural drought.

CONCLUSIONS

Droughts are the greatest and most recurrent climate hazard in Ethiopia, particularly for pastoral and agro-pastoral communities. The results of the analysis presented in this study confirm that a new parameter, the days of rainfall delay (*Rd*) with respect to the expected onset of seasonal rainfall, is a reliable index to identify and characterize both local and regional droughts. The *Rd* performed better than the Z-score which, in its turn, proved to be more accurate than the Standardized Precipitation Index (SPI). These methods were also able to indicate smaller drought conditions not reported in official documents, but likely characterized by hard consequences for a few rural communities. The rain delay index is a simple method that could allow local authorities to set up drought mitigation countermeasures in due time. The *Rd* time series analysis also confirms the increasing importance of spring rain shortage in determining drought and famine.

By contrast, the poor matches of the aridity index (*Ai*) suggest this is not a reliable tool for drought analysis.

While the new parameter, rainfall delay, provides relatively better results compared to other predictors, further studies based on data from areas with similar climate conditions are needed to verify the predicative performance of the parameter, especially in regions with distinct seasonal rainfall.

ACKNOWLEDGEMENTS

This research was supported by the Universities of Dire Dawa and Addis Ababa, Ethiopia, and by the University of Tottori, Japan.

REFERENCES

Bewket, W. 2012 Climate change perceptions and adaptive responses of smallholder farmers in central highlands of Ethiopia. *International Journal of Environmental Studies* **69**, 507–523.

Block, P. J. 2008 *Mitigating the effects of hydrologic variability in Ethiopia: an assessment of investments in agricultural and transportation infrastructure, energy and hydroclimatic forecasting*. CPWF Working Paper 01, The CGIAR Challenge Program on Water and Food, Colombo, Sri Lanka, 53 pp.

Critchfield, H. J. 1983 *General Climatology*. Prenctice-Hall, Englewood Cliffs, NJ, USA.

Degefu, M. A. & Bewket, W. A. 2015 Trends and spatial patterns of drought incidence in the Omo-Ghibe river basin, Ethiopia. *Geografiska Annaler: Series A, Physical Geography* **97** (2), 395–414.

Degefu, M. A. & Bewket, W. A. 2017 Variability, trends, and teleconnections of stream flows with large-scale climate signals in the Omo-Ghibe River Basin, Ethiopia. *Environmental Monitoring and Assessment* **189** (4), 142.

Edossa, D. C., Babel, M. S. & Gupta, A. D. 2010 Drought analysis in the Awash River Basin, Ethiopia. *Water Resources Management* **24**, 1441–1460. DOI 10.1007/s11269-009-9508-0.

EEPRI (Ethiopian Economic Policy Research Institute) 2003 Quarterly report on the macroeconomic performance of the Ethiopian economy. Unpublished report, EEPRI, Addis Ababa.

Fazzini, M., Bisci, C. & Billi, P. 2015 The climate of Ethiopia. In: *Landscapes and Landforms of Ethiopia* (P. Billi, ed.). Springer, Heidelberg, Germany, pp. 65–88.

Guttman, N. B. 1998 Comparing the palmer drought index and the standardized precipitation index. *Journal of American Water Resources Association* **34** (1), 113–121.

Jury, M. R. 2013 Ethiopian highlands crop-climate prediction: 1979-2009. *Journal of Applied Meteorology and Climatology* **52** (5), 1116–1126.

Kiros, F. G. 1991 Economic consequences of drought, crop failure and famine in Ethiopia, 1973-1986. *Ambio* **20**, 183–185.

Knutson, C. & Fuchs, B. 2016 New tools for assessing drought conditions for rangeland management. *Rangelands* **38** (4), 77–182.

Lanckriet, S., Frankl, A., Adgo, E., Termonia, P. & Nyssen, J. 2015 Droughts related to quasi-global oscillations: a diagnostic teleconnection analysis in North Ethiopia. *International Journal of Climatology* **35** (7), 1534–1542.

Lautze, S. Y., Aklilu, A., Raven-Roberts, A., Kebede, G. & Learning, J. 2003 *Risk and Vulnerability in Ethiopia: Learning From the Past, Responding to the Present, Preparing for the Future*. Report for the US Agency for International Development, Addis Ababa, Ethiopia.

Lemi, A. 2005 Rainfall probability and agricultural yield in Ethiopia. *Eastern Africa Social Science Research Review* **21**, 1–41.

Lloyd-Hughes, B. & Saunders, M. A. 2002 A drought climatology for Europe. *International Journal of Climatology* **22** (13), 1571–1592.

McKee, T. B., Doesken, N. J. & Kleist, J. 1993 The relationship of drought frequency and duration to time scale. *Proceedings of the Eighth Conference on Applied Climatology, American Meteorological Society*, Anaheim, CA, USA, pp. 179–184.

Mpelasoka, F., Hennessy, K., Jones, R. & Bates, B. 2008 Comparison of suitable drought indices for climate change impacts assessment over Australia towards resource management. *International Journal of Climatology* **28**, 1283–1292.

Palmer, W. C. 1965 *Meteorologic Drought*. US Weather Bureau, Res. Paper No. 45. Silver Spring, MD, USA.

Pankhurst, R. & Johnson, D. H. 1988 The great drought and famine of 1888–92 in northeast Africa. In: *The Ecology of Survival: Case Studies From Northeast African History* (D. H. Johnson & D. M. Anderson, eds). Lester Crook Academic Publishing, London, UK, pp. 47–72.

Seleshi, Y. & Camberlin, P. 2006 Recent changes in dry spell and extreme rainfall events in Ethiopia. *Theoretical and Applied Climatology* **83**, 181–191.

UNEP 1992 *Status of Desertification and Implementation of the United Nations Plan of Action to Combat Desertification*. Report of the Executive Director, United Nations Environment Programme, Nairobi, Kenya.

UN-ISDR 2017 *Prolonged Drought Threatens Greater Horn of Africa*. https://www.unisdr.org/archive/52011.

USAID 2000 *Famine Early Warning System, Weather Analysis Defined, Regional Weather Page*. Famine Early Warning Systems Network, Washington, DC, USA.

Viste, E., Korecha, D. & Sorteberg, A. 2012 Recent drought and precipitation tendencies in Ethiopia. *Theoretical and Applied Climatology* **112**, 535–551.

WFP (World Food Programme) 2016 *Climate Risk and Food Security in Ethiopia: Analysis of Climate Impacts on Food Security and Livelihoods*. WFP-UN, New York, USA.

Williams, A. & Funk, C. 2011 A westward extension of the warm pool leads to a westward extension of the Walker circulation, drying Eastern Africa. *Climate Dynamics* **37**, 2417–2435.

Wood, A. 1977 A preliminary chronology of Ethiopian droughts. In: *Drought in Africa* (D. Dalby, R. J. H. Church & F. Bezzaz, eds). International African Institute, London, UK, Vol. 2, pp. 68–73.

Wu, H., Hayes, M. J., Weiss, A. & Hu, Q. 2001 An evaluation of the standardized precipitation index, the China-Z index and the statistical Z-score. *International Journal of Climatology* **21**, 745–758.

First received 29 June 2017; accepted in revised form 26 March 2018. Available online 17 April 2018