African Journal of Rural Development, Vol. 8 (2): April-June 2023: pp. 73-79 ISSN 2415-2838

Drought Hazard Modelling: Exploring a drought index for Malawi

KAPICHI, T.[1,2], ISABIRYE, M.[1]. and TCHUWA, I[2]

[1]Faculty of Natural Resources and Environmental Sciences, Busitema University, P.O Box 236, Tororo, Uganda

[2]Ndata School of Climate and Earth Sciences, Malawi University of Science and Technology

Corresponding author: thokokapichi@gmail.com

ABSTRACT

With a single growing season, drought as a consequence of climate change has taken a toll on Malawi's agro-based economy. In the context of climate change, an accurate and comprehensive assessment of drought at regional level is very necessary to sustain agricultural development and manage natural disasters. Despite considerable improvements, world drought models are still not able to accurately represent the large number of factors that are responsible for causing droughts across different regions of Africa such as Malawi. This study deployed a number of drought input variables, i.e., precipitation, minimum temperature, maximum temperature and potential evapotranspiration to construct a Malawi Drought Index (MaDI) using multiple linear regression and GIS in order to best explain the complex interaction of major drought indicators, as well as to validate the accuracy of global drought models in the country. A strong positive correlation was observed between the Malawi Drought Index (MaDI) and the Standardized Precipitation Index (SPI) suggesting that the MaDI does not depart very much from the existing drought models. This paper therefore promotes the improvement of the MaDI as a new, easier and better local drought prediction and assessment method in Malawi.

Key words: Climate Change, Drought Indicator, Drought Model, MaDI, Malawi

RÉSUMÉ

Avec une seule saison de culture, la sécheresse, conséquence du changement climatique, a fortement impacté l'économie agricole du Malawi. Dans ce contexte, une évaluation précise et complète de la sécheresse au niveau régional est cruciale pour soutenir le développement agricole et gérer les catastrophes naturelles. Malgré des améliorations considérables, les modèles mondiaux de sécheresse ne parviennent toujours pas à représenter avec précision le grand nombre de facteurs responsables des sécheresses dans différentes régions d'Afrique, comme le Malawi. Cette étude a utilisé plusieurs variables d'entrée de la sécheresse, à savoir les précipitations, la température minimale, la température maximale et l'évapotranspiration potentielle pour construire un Indice de Sécheresse du Malawi (MaDI) en utilisant la régression linéaire multiple et les SIG, afin d'expliquer au mieux l'interaction complexe des principaux indicateurs de sécheresse et de valider l'exactitude des modèles de sécheresse globaux dans le pays. Une forte corrélation positive a été observée entre le MaDI et l'Indice de Précipitation Standardisé (SPI), suggérant que le MaDI ne s'écarte pas beaucoup des modèles de sécheresse existants. Cet article promeut donc l'amélioration du MaDI comme une nouvelle méthode locale de prédiction et d'évaluation de la sécheresse plus facile et meilleure au Malawi.

Mots-clés : Changement climatique, Indicateur de sécheresse, Modèle de sécheresse, MaDI, Malawi

Cite as: Kapichi, T., Isabirye, M.. and Tchuwa, I. 2023. Drought Hazard Modelling: Exploring a drought index for Malawi. *African Journal of Rural Development* 8 (2):73-7.9

Background

Being an agro-based economy, drought occurrences have been one of the costliest disasters in Malawi. Drought in Malawi is said to occur when seasonal rainfall is lower than 75% of the normal rainfall that the country receives. The whole country is vulnerable to droughts, however, Karonga, Salima, Zomba and Shire Valley are the major drought prone areas (Chabvungma *et al*., 2010).

The occurrence of drought phenomenon is increasing in Malawi, for instance, between 1980 and 2019 alone, Malawi experienced eight major droughts, in total affecting over 24 million people (World Bank, 2016). Data from WorldClim (1970-2000) show that many areas in Malawi have been receiving rainfall of above 2000mm in the past few decades, but currently Malawi's rainfall can hardly reach 2000mm. The impact, frequency and spread of drought in Malawi are likely to worsen with the changing climate, hence it is major source of worry in the country. More recently the impacts of drought and resultant food security crisis overwhelmed Malawi's national response capacity to the extent that the Government of Malawi declared a national drought emergency in April 2016. As a consequence, droughts and dry spells in Malawi cause, on average, 1 percent loss of Gross Domestic Product (GDP) annually (Chabvungma *et al*., 2010). Agriculture for example, contributed 26 percent of GDP in 2017 which was about 40 percent lower than in 2002. This was largely due to repeated episodes of delayed rains and prolonged dry spells (Coulibaly *et al*., 2015; USAID, 2019b).

Drought models or indicators are simulations based on climate data that seeks to explain the relationship between drought occurrence and its causative factors. Due to differences in methods of observation, drought indices are divided into two: one based on observed data from actual ground stations, and the other based on satellite remote sensing data. Ground based drought modelling has developed for a long time, and was extensively used as early as 1900s when the Precipitation Anomaly (PA) was developed to categorize the wet and dry conditions.

After a number of substantial improvements, indices to represent the PA were developed which among others included: Palmer Drought Severity Index (PDSI); Standardized Precipitation Index (SPI); and Composite Index of meteorological drought (CI).

The SPI index was based on the precipitation sequenced data, which is used to calculate different scales, each of which can reflect different types of drought. The use of a single factor to model drought has been the prime challenge faced by the SPI bearing in mind that drought incident is multivariate in nature. The CI index was precise to the Chinese National Standard for Meteorological Drought. Though the CI index considers both the precipitation and evaporation factors and has superiority over SPI drought index that simply used precipitation, it has been well applicable and widely used in China only (Yu *et al*., 2019). PSDI tries to take into account several factors including precipitation, temperature and soil effective water content, which was a significance development at that time, but the index was mainly used in the United States only (Yu *et al*., 2019).

Remote sensing-based drought modelling on the other hand have the advantages of wide coverage, fast information acquisition, and real-time dynamic and high efficiency as compared to the early ground based models. With the development of the remote drought sensing-based monitoring models, many drought indices have been produced. The major disadvantage of the satellite based models is that most indices have been modelled from the vegetation index and surface temperature data only (Chen *et al*., 2020). A large number of multivariate drought indices have been developed in recent years with notable examples that includes a research by Yu *et al*. (2019) that constructed a Comprehensive Drought Monitoring Model (CDMM) in Jing-Jin-Ji region based on Multisource Remote Sensing Data; and Chen *et al*. (2020) who developed a Modified Composite Drought Index (MCDI) using a case study of Hubei Province, China. Basically, the CDMM is a satellite based model which classifies drought largely between -2 and 1 which may present challenges to distinguish and isolate different drought levels. Although the model took into account the factors such as vegetation growth and atmospheric precipitation, drought is still a complex natural phenomenon, other relative factors, such as evapotranspiration and land use are supposed to be taken into consideration. The study by Chen *et al*. (2020) is limited also as it broadly used temperature based on average calculations, the study did not look at the independent influence of maximum and minimum temperature when developing the model. The research also only considered evaporation but did not take into account the contribution of transpiration. which is significant in many tropical countries such as Malawi.

At national level, research on drought modelling is almost non-existent in Malawi. The few that are available have focussed on drought mitigation and recovery. monitoring in Malawi. The Department of Climate Change and Meteorological Services (DCCMS) in Malawi does release weather forecasts that includes drought occurrences, but they too are using global and not national

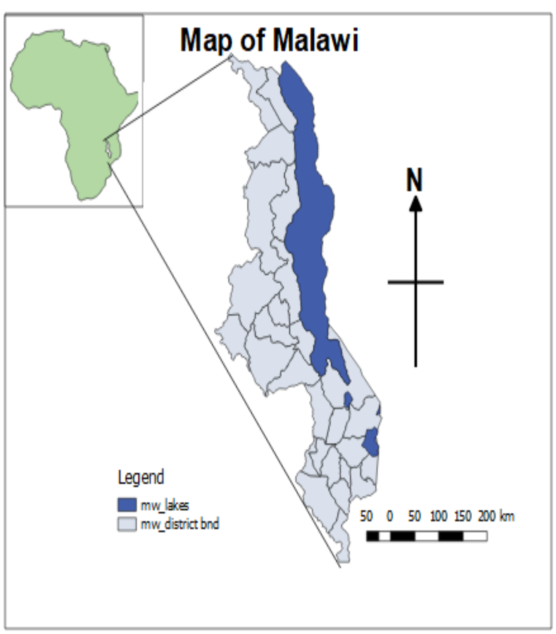

Figure 1. Map of the study area

It is against this background that this study modelled a drought index for Malawi that best explains the complex interaction of drought with its major factors in the country. The research further provides an interactive and easy to used web based platform for drought

Materials and Methods

Study area. Malawi occupies the southern part of the East African Rift Valley and lies between latitude 9 and 17 degrees South and longitude 32 and 36 degrees East. It is bordered by Mozambique to the south and east, Zambia to the west and Tanzania to the east and north east (Figure 1). With a total territorial area of 119140 square kilometres, the country varies in altitude from near sea level to well over 2000 meters above mean sea level. Of this area one fifth is water bodies largely dominated by Lake Malawi which is Africa's third largest lake.

Model development

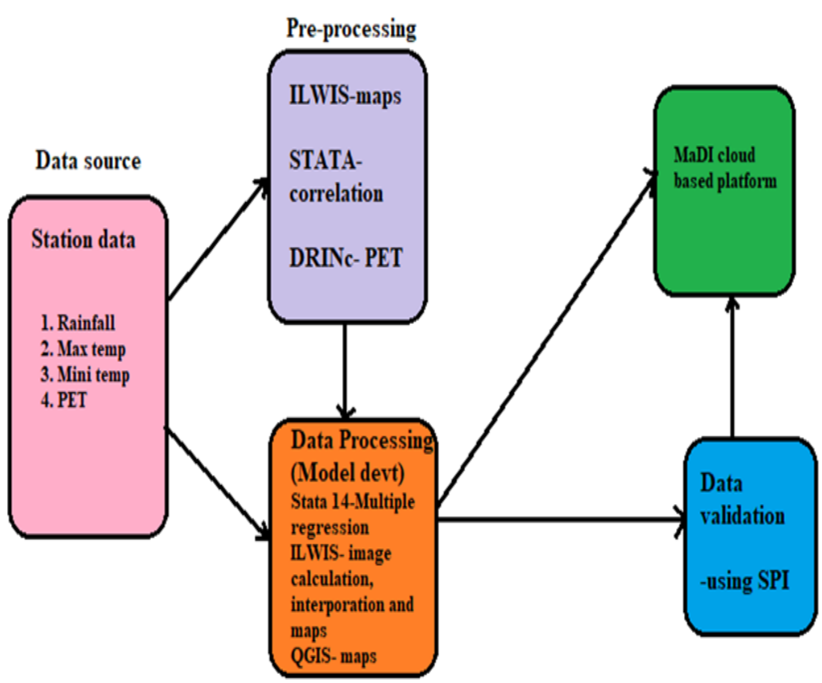

Figure 2. Framework for the methodology

Actual weather observations from 69 weather stations distributed over Malawi was used to model Malawi Drought Index (MaDI). This dataset comprised five-year monthly observations for rainfall and maximum and minimum temperatures. Potential Evapotranspiration (PET) for all the stations was calculated using DrinC software and extrapolated over the whole country. Difference between rainfall and PET for humid months (November-March) was logged to base 10 in order to obtain an index with values between 0 and 10. Then multi-linear regression was computed to obtain an equation using the MaDI as dependent variable and Rainfall (R); Maximum Temperature (Tmax); Minimum Temperature (Tmin); and PET as independent variableinSTATA14.

The equation $lnY_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + U_i$ was modified with the coefficients of the independent variables from the STATA output to come up with the model. In order to create a web based MaDI platform, Laravel framework version 6.18.35 running on PHP 7.2 was used. Plain Javascript and JQuery were used for the visualisation.

Results and Discussion

Malawi Drought Index (MaDI). Table 1 is a STATA output for regressing MaDI with annual rainfall (AnnualRain), minimum temperature (Tmin), maximum temperature (Tmax) and potential evapo-transpiration (PET). The model used 95% confidence interval. The coefficient of determination (R-squared) of this model is 0.7033 meaning that about 70% of the variation in the MaDI is explained by the regression model. From the STATA output in Table 4 MaDI model was developed using the coefficients of the independent variables as $MaDI = 0.004r + 0.1tmax - 0.094tmin - 0.016pet + 11.204$, where **r** is the Annual rainfall; tmax is the Maximum temperature; tmin is the Minimum temperature; pet is Potential Evapotranspiration; and 11.204 is a constant. Cut off points for the MaDI were developed in comparison with SPI classification as shown in Table 2. MaDI values range from 0 to 10, values greater than 6.0 indicate severe wet condition, values between 5.0 and 6.0 indicate moderately wet (near normal) condition, 3.5 – 4.9 values show moderately dry conditions, and values less than 3.5 indicate severe dry conditions.

Table 1. Regression STATA output

```
. regress MaDI AnnualRain PET Tmin Tmax
```

Source	SS	df	MS
Model	108.912714	4	27.2281784
Residual	45.9359821	64	.717749721
Total	154.848696	68	2.2771867

Number of obs	=	69
F(4, 64)	=	37.94
Prob > F	=	0.0000
R-squared	=	0.7033
Adj R-squared	=	0.6848
Root MSE	=	.8472

MaDI	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AnnualRain	.0042384	.0004297	9.86	0.000	.0033801	.0050968
PET	-.0160985	.0036797	-4.37	0.000	-.0234495	-.0087475
Tmin	-.094993	.0730047	-1.30	0.198	-.2408366	.0508506
Tmax	.1008836	.0830694	1.21	0.229	-.0650665	.2668337
_cons	11.20376	1.705648	6.57	0.000	7.796341	14.61119

Model validity

All values of independent variables for the five-year period were substituted into the model to come up with the MaDI map for the period and compared with SPI computed from the same dataset as well as the flood and drought risk map produced by World Food programme, 2010 as shown in Figure 3 where a strong correlation was observed. This suggests that the MaDI does not depart very much from the existing models. The existing model such as SPI however seems to overestimate the occurrence of drought as they usually depend on secondary data.

Table 2. MaDI cut off points

MaDi	SPI	class
>6	>2	Extremely wet
	1.5 to 1.99	Very wet
5.0-6.0	1.0 to 1.49	Moderate wet
	-0.99 to 0.99	Near normal
3.5-4.9	-1 to -1.99	Moderately dry
<3.5	-1.5 to -1.99	Severely dry
	<-2	Extremely dry

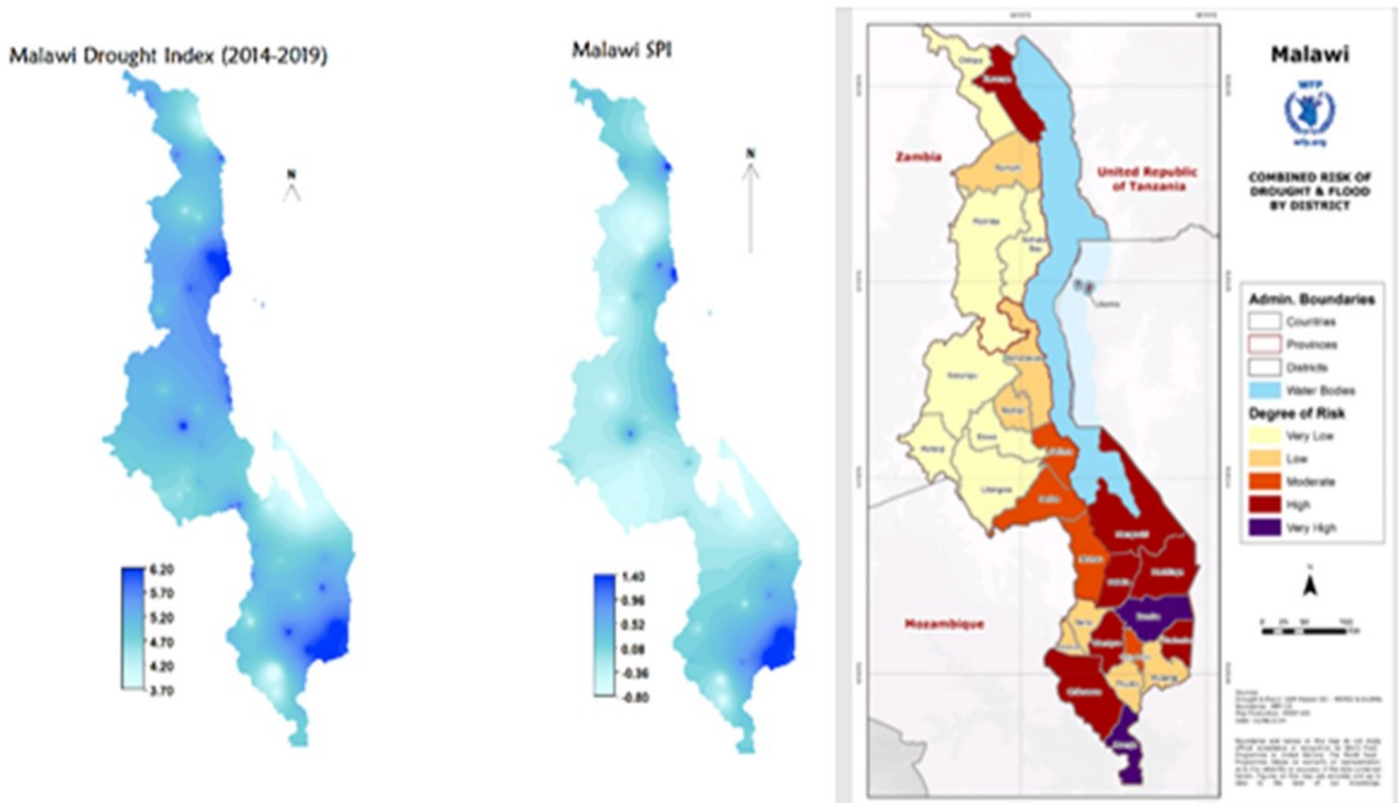

Figure 3: Model comparison

Conclusion and Recommendation

Drought Indices can simplify complex relationships and provide useful communication tools for diverse users and the public. This paper agrees with Yu *et al.* (2019), World Bank (2019) and Chen *et al*. (2020) that drought is very complex in nature, and the use of a few indicators may result in not representing all aspects of the drought situation correctly.

A large number of studies have also reached a consensus that constructing drought indices based on a single variable is likely to be insufficient for accurate drought risk assessment.

Due to the complex physical interactions among drought indicators, investigation of drought phenomenon based on an integrated multivariate factors deserves more attention. To a greater extent the MaDI agrees with SPI, however the MaDI is an improvement as it incorporates a greater number of variables to model drought. There is still room for improvement for the model to be more accurate and reliable, for example the proposed MaDI can be improved by using additional input variables for considering local hydrological conditions as well as collecting more data from a several years in future research work. MaDI will help to effectively mitigate the impacts of drought in Malawi by providing an effective and timely monitoring system for drought occurrences. This study provides a good starting off point to develop further comprehensive drought models for Malawi.

Declaration of Conflict of Interest

The authors declare no conflict of interest in this paper.

References

ADRA Intertnational. 2017. Inter-Sectoral Response to Drought in Southern and Eastern Africa. May.

Agwata, J. F. 2014. A Review of Some Indices used for Drought Studies. *Civil and Environmental Research,* 6 (2):14–21.http://www.iiste.org/Journals/index.php/CER/article/view/10842%0Ahttps://www.uonbi.ac.ke/agwatas/files/10842-13144-1-pb.pdf%5Cnhttp://www.iiste.org/Journals/index.php/CER/article/view/10842/11145

Benson, C. and Clay, E. 1994. The Impact of Drought on Sub-Saharan African Economies. *Ids Bulletin* 25 (4):24-32.

Burke, E.J., Brown, S.J. and Christidis, N. 2006. Modeling the recent evolution of global drought and projections for the twenty-first century with the Hadley Centre climate model. *Journal of Hydrometeorology* 7 (5):1113-1125.

Chabvungma, S.D., Mawenda, J. and Kambauwa, G. 2010. Drought conditions and management strategies in Malawi. 1–9.

Chen, S., Zhong, W., Pan, S., Xie, Q. and Kim, T.W., 2020. Comprehensive drought assessment using a modified composite drought index: A case study in Hubei Province, China. *Water* 12 (2):462.

Coulibaly, J. Y., Gbetibouo, G. A., Kundhlande, G., Sileshi, G. W. and Beedy, T. L. 2015. Responding to crop failure: Understanding farmers' coping strategies in Southern Malawi. *Sustainability* 7 (2):1620–1636. https://doi.org/10.3390/su7021620.

Fasemore, O. A. 2019. The impact of drought on groundwater resources. *Water Sewage and Effluent* 39 (3):37–38.

Fuchs, B. 2012. Drought Indices and Indicators in use around the world. Caribbean Drought WorNshop pp.22-24.

Gan, T.Y., Ito, M. and Hülsmann, S. 2013. Drought, climate and hydrological conditions in Africa: An assessment based on the application of remotely sensed geospatial data and various models. United Nations University, Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES).

Hao, Z., Singh, V.P. and Xia, Y. 2018. Seasonal drought prediction: Advances, challenges, and future prospects. *Reviews of Geophysics* 56 (1):108-141.

Hisdal, H., Tallaksen, L.M., Demuth, S., van Lanen, H.A.J., Peters, E. and Stahl, H. 2000. Technical Report No .6 Drought Event Definition. 6.

Horion, S., Carrão, H., Singleton, A., Barbosa, P. and Vogt, J. 2012. JRC experience on the development of Drought Information Systems. Europe, Africa and Latin America. *EUR* 25235.

Jayanthi, H., Husak, G. J., Funk, C., Magadzire, T., Chavula, A. and Verdin, J. P. 2013. Modeling rain-fed maize vulnerability to droughts using the standardized precipitation index from satellite estimated rainfall-Southern Malawi case study. *International Journal of Disaster Risk Reduction* 4:71–81. https://doi.org/10.1016/j.ijdrr.2013.02.001

Kumbuyo, C. and Yasuda, H. 2015. Study on Rainfall Time Series in Malawi: An Analysis of the Temporal and Spatial Fluctuation, Linkage with Global Sea Surface Temperature. *Nhk技研* 151:10–17.

Malawi Government. 2016.Malawi drought 2015-2016.

Mawenda, J.S.C. and Kambauwa, G. 2015. Drought Conditions and Management Strategies in Malawi. https://www.ais.unwater.org/ais/pluginfile.php/601/mod_page/content/29/Malawi.pdf

Munthali, G., Saka, J., Kamdonyo, D., Kasulo, V., Nkhokwe, J. and Kainja, S. 2003. Drought Case Study for Malawi. *The British Journal of Psychiatry* 111 (479):1009–1010.https://doi.org/10.1192/bjp.111.479.1009-a

National Weather Service. 2006. What is Drought? Public Fact Sheet. August.

Nhamo, L., Mabhaudhi, T. and Modi, A. T. 2019. Preparedness or repeated short-term relief aid? Building drought resilience through early warning in southern Africa. *Water SA* 45 (1):75–85. https://doi.org/10.4314/wsa.v45i1.09

Panis, M. 2019. Assessing the forecast skill of agricultural drought forecast from satellite-derived products in the Lower Shire River Basin. http://resolver.tudelft.nl/uuid:18ac68f0-e913-4faa-a330-aa7888fb8e47

Pauw, K., Thurlow, J. and van Seventer, D. 2010. Droughts and Floods in Malawi: Assessing the Economywide Effects. IFPRI Discussion Paper, 00962. http://www.ifpri.org/publication/droughts-and-floods-malawi?print

Reichhuber, A., Gerber, N., Mirzabaev, A., Svoboda, M., Santos, A. L., Graw, V., Stefanski, R., Davies, J., Vuković, A., García, M. A. F., Fiati, C. and Jia, X. 2019. The Land-Drought Nexus: Enhancing the role of land-based interventions in drought mitigation and risk management. A Report of the Science-Policy Interface.

Save the Children and UNICEF. 2017. Adaptation and response for children affected by droughts and disasters: how national social protection systems are responding to El Niño in Eastern and Southern Africa.

Serdeczny, O., Adams, S., Baarsch, F., Coumou, D., Robinson, A., Hare, W., Schaeffer, M., Perrette, M. and Reinhardt, J. 2017. Climate change impacts in Sub-Saharan Africa: from physical changes to their social repercussions. *Regional Environmental Change* 17 (6):1585–1600. https://doi.org/10.1007/s10113-015-0910-2

Sheffie, J. 2016. Drought monitoring and forecasting in Sub-Saharan African. *Bulletin of the American Meteoro logical Society* 95 (6). https://www.doi.org/10.1175/ BAMS-D-12-00124.1

Syroka, J. and Nucifora, A. 2010a. National drought insurance for Malawi. pp.1997–2007. In: *World* (Issue January).http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1536982

Syroka, J. and Nucifora, A. 2010b. National drought insurance for Malawi. *World January*. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1536982

Tadesse, T.2018. Strategic Framework for Drought Risk Management and Enhancing Resilience in Africa. https://www.unccd.int/sites/default/files/relevant-links/2018-04/DRAPA_strategic_framework_final_ttadesse2.pdf

Tadesse, T., Senay, G., Wardlow, B. D., Knutson, C. L., Tadesse, T., Haile, M., Senay, G., Wardlow, B. D. and Knutson, C. L. 2008. DigitalCommons @ University of Nebraska - Lincoln The Need for Integration of Drought Monitoring Tools for Proactive Food Security Management in Sub-Saharan Africa

UNDP. 2011. Mainstreaming Drought Risk Management- a primer. UNDP.

UNDP. 2015. Drought risk reduction training manual in integrated water resources management. UNDP.

United Nations.2012. Drought Contingency Plans and Planning in the Greater Horn of Africa. UN.

USAID. 2019. Climate risks in food for peace geographies: Malawi. March. USAID.

Warnatzsch, E.A. and Reay, D.S. 2019. Temperature and precipitation change in Malawi: Evaluation of CORDEX-Africa climate simulations for climate change impact assessments and adaptation planning. *Science of the Total Environment* 654:378–392.https://doi.org/10.1016/j.scitotenv.2018.11.098

Wilhite, D.A. 2000. Drought as a natural hazard. Concepts and definitions. Published in Drought: A Global Assessment, Vol I, In: Donald A. Wilhite chap. 1 (London: Routledge, 2000).

Wilhite, D A. and Knutson, C.L. 2006. Drought management planning : Conditions for success. *Options Méditerranéennes* Series A 80:141–148.

WMO. 2016. Handbook of Drought Indicators and Indices (Issue 1173). WMO

World Bank. 2016. Malawi Drought Recovery and Resilience. World Bank.

World Bank. 2019. Assessing Drought Hazard and Risk. World Bank.

World Meteorological Organization. 2005. Drought assessment and forecasting. 8.

Yu, H., Li, L., Liu, Y. and Li, J. 2019. Construction of Comprehensive Drought Monitoring Model in Jing-Jin-Ji Region Based on Multisource Remote Sensing Data. 1–17. *Water,* 11 (5):1077.