ISSN: 2469-4134
Journal of Remote Sensing & GIS

OPEN ACCESS Freely available online

Research Article

Remote Sensing Drought Indices and their Application in Mapping Spatial and Temporal Variations of Drought in Zimbabwe

Oshneck Mupepi*

Department of Geography, Environmental Sustainability and Resilience Building, Midlands State University, Gweru, Zimbabwe

ABSTRACT

Drought is increasing in severity and frequency in Southern African countries hence there is need to assess its spatial and temporal patterns for the purpose of easing decision making on resilience building. The paper sought to assess the spatial and temporal variations of drought in Zimbabwe between 2015 and 2021. TCI, VCI and VHI indices were used to map drought in this study. ArcMap 10.5, SPSS and Microsoft excel were used for data analysis. The findings indicated that drought varied from district to district or province to province as well as from year to year across the study years. Fluctuation were noted as years 2015 and 2016 were drought years when most parts of the country were affected followed by mild droughts in 2017 and 2018. Years 2019 and 2020 registered severe drought in most parts of the country whilst year 2021 was mildly affected. Drought frequency analysis over the past years showed that most southern, south western and western Zimbabwe districts were the most affected, an indication of aridity influence on drought severity. However, despite drought fluctuation during the study period, some southern and western parts of the country were in constant severe drought conditions as they got affected more than 5 times in 7 years. Therefore arid areas need to be prioritized for drought resilience capacities to make them not lag behind with regards to achieving sustainable development. The study recommends Southern African countries to prepare communities in dry areas for drought resilience as the general trends in drought despite some fluctuations indicate increasing spatial coverage and severity of droughts especially in arid areas.

Keywords: Drought resilience; Remote sensing; Fluctuations; Climatological conditions

INTRODUCTION

The 21st century began with series of droughts that affected the whole globe. Severe to exceptional intensity droughts covered 7%-16% and extreme droughts affected 2%-6% of the world land area [1]. From 2000 to 2012, several droughts affected important agricultural regions in the northern hemisphere especially from 2010-2012. From 2015, the world experienced expansion of area under drought conditions with the area under severe drought increasing from 8% to 14% [2]. After 2015, 30% of the global land was in drought, with 14% in a severe or extreme drought. Kazakhstan was affected in 2012 whilst Ukraine was affected in 2010 and 2012 and Russia in 2010. Vegetation Health (VH) records by NOAA global monitoring satellite indicated that drought reappears every 9 years in western US [3]. The 2012 drought was observed during the growing season in the southern hemisphere, affecting Eastern Brazil, Northern Argentina and Southern Australia for a short time (UNDP, 2012). Other droughts were experienced in US and California's New Mexico and Northern Mexico (2011-2014), East Australia (mostly over Queensland) (between 2013-2016) and Amazonia due to long term rainfall deficits [3].

Historical droughts over Asia indicates that consecutive droughts have been experienced since 1960s especially northern China which experienced a severe drought that led to drying up of the Yellow river in 1997 [4]. From 1999-2003, another severe drought hit Central Asia, Pakistan and China. This drought was the worst in Pakistan and Afghanistan in 50 years [5]. In 2006-07 an extreme drought hit Sichuan and the Yangtze River Basin, causing a fall in production of rice, potatoes, and beans. The drought moved to Yunnan and Southwestern China in 2008-09 where it also caused agricultural losses [6]. North China also experienced severe drought which lasted from the autumn of 2009 to the spring of 2010 [7]. The aridity is worsening over Northern China and extreme drought recurrence in the Central part of Northern China, North east China and the eastern part of North West China is also increasing. From 2011-2014, China experienced another once in a 50-year period drought over the Yangtze River basin which led to

Correspondence to: Oshneck Mupepi, Department of Geography, Environmental Sustainability and Resilience Building, Midlands State University, Gweru, Zimbabwe, E-mail: omupepi@gmail.com

Received: 16-Aug-2022, Manuscript No.JGRS-22-17804; **Editor assigned:** 19-Aug-2022, PreQC No. JGRS-22-17804 (PQ); **Reviewed:** 02-Sep-2022, QC No JGRS-22-17804; **Revised:** 13-Sep-2022, Manuscript No. JGRS-22-17804 (R); **Published:** 21-Sep-2022, DOI: 10.35248/2469-4134.22.11.251

Citation: Mupepi O (2022) Remote Sensing Drought Indices and their Application in Mapping Spatial and Temporal Variations of Drought in Zimbabwe. J Remote Sens GIS. 11:251.

Copyright: © 2022 Mupepi O. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

severe water shortages and crop failure [8].

In Tropical Africa, the Congo River basin and most of Central Africa experienced a severe drought which lasted from 2000 to 2006. Remote sensing images showed severe vegetation stress over the Congo River Basin and Central Africa during this time period [9]. The period 2008-2010 saw another drought hitting most countries in East Africa especially countries within the horn of Africa. The drought between 2008 and 2010 in the lower eastern part of the horn of Africa was characterised by prolonged rainfall deficits which actually pushed this drought to 2011 [10,11]. During the 2018/2019 season, South-West Ethiopia, Western Kenya, Northern Uganda and South Sudan experienced drought but Kenya and Uganda were severely affected [12].

Southern Africa experienced drought during the 2018/2019 season and only North Eastern South Africa and southern Mozambique experienced floods during that season. Worst drought conditions (less than 300 mm rainfall) were experienced in North Namibia, South Angola, North Zimbabwe, the whole of Lesotho and South Botswana with SPI values ranging between 1.5 to 2 [12]. Negative anomalies of rainfall worsened over the whole of Zimbabwe, southern Mozambique, Zambia and north-east Botswana during 2019/2020 season. Based on this literature, it can be noted that drought has been phenomenal during the 21st century and it spatially and temporally varied from region to region without any of the world regions being spared. Southern Africa and Zimbabwe are dominantly arid-semi-arid where drought conditions are increasing in severity due to global warming and precipitation anomalies accruing to changing climatological conditions.

This becomes one of the major threats to livelihoods of agrarian communities in this region who are greatly dependent on rain-fed agriculture and already impoverished. At national level, within southern African countries, some spatial and temporal variations in drought do exist as is the case at regional and global level. Hence monitoring the spatial severity of drought across a country like Zimbabwe over the past few years helps to track the trends in drought severity which guides drought resilience building when the at risk districts and provinces are to be assisted. Against this background, this study seeks to assess drought spatial and temporal severity across Zimbabwe and determine drought frequency across districts and provinces in Zimbabwe over the same time period. This will inform decision making on building drought resilience in vulnerable communities, a step towards enhancing achievement of Sustainable development goals 1, 2 and 13 in Zimbabwe and Southern Africa at large.

Description of study area

Zimbabwe is a sub-tropical country situated between 15° and 23° south of the Equator and 25° and 34° east of the Greenwich Meridian in southern Africa. The country is bordered to the east by Mozambique, to the south by South Africa, to the west by Botswana, and to the north and north-west by Zambia. Zimbabwe's boundaries with Zambia and South Africa are formed by the Zambezi River in the north and the Limpopo River in the south, respectively. It has a total land area of 391,757 km^2, of which 43% is covered in forests and woodlands. The country is severely affected droughts [13]. There are four distinct seasons which include a warm wet season from November to March, a transitional season from April to May, a cool dry winter season from May to August and a warm dry season from August to October (Figure 1) [14].

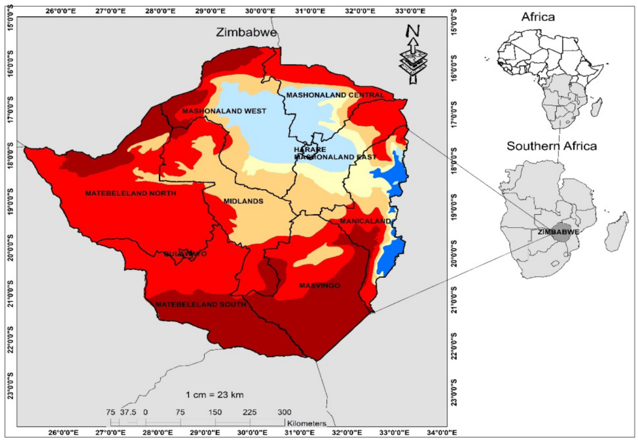

Figure 1: The location of Zimbabwe. **Note:** ( ) Provincal boundary, ( ) I, ( ) IIa, ( ) IIb, ( ) III , ( ) IV, ( )V, ( ) Zimbabwe, ( ) Southern African Countries.

The country is divided into 5 agro-ecological zones which are grouped based on the geographical distribution of average rainfall [15]. The soil type and agro-climate influence agricultural operations in these agro-climatological zones. Region 1 (to the east of the country) has the highest agricultural adaptability and receives highest annual precipitation (1020 mm) while region 4-5 (to the south, south west and western parts of the country) receive lowest annual precipitation (<500 mm) and have the worst agricultural adaptability [13]. However, the nation is prone to inter and intra-seasonal droughts, which impact even the better-suited regions for agricultural purposes. The quantity of rainfall received in the country has consistently dropped from the multi-decadal mean during the 2000-2010 [16]. In the latter half of the twentieth century, runoff in the country fell by 20% to 30%. This has an impact on water supplies, as well as human activities and livelihoods in the country.

MATERIALS AND METHODS

Data collection in this study included acquisition of satellite images for the study period from USGS website for the computation of Vegetation Condition Index (VCI), Temperature Condition Index (TCI) and Vegetation Health Index (VHI). Eros Moderate Resolution Imaging Spectoradiometer (MODIS) Global Land Surface Temperature version 6.1 and Eros MODIS Normalized Difference vegetation Index version 6 satellite images were adopted for computation of these indices [17]. Land surface temperature and normalized difference vegetation index data sets for Zimbabwe were derived from these global data sets and they had spatial resolution of 250 m. These datasets were used despite course resolution since the study was at the national scale hence they would be representative of larger areas like districts and provinces thus giving a clear depiction of drought variability from district to district and province to province. The period 2015-2021 was prioritized because drought have been reportedly increased and severity over the past few years in Southern Africa including Zimbabwe due to increasing climate change and associated global warming. Since the study period spanned from 2015 to 2021, MODIS data sets were downloaded for each study year that is 2015-2021 (Table 1).

Table 1: Satellite datasets used.

Year	Satellite platform	Spatial resolution (m)	Date of acquisition
2015	MODIS	250	15-03-2015
2016	MODIS	250	15-03-2016
2017	MODIS	250	15-03-2017
2018	MODIS	250	15-03-2018
2019	MODIS	250	15-03-2019
2020	MODIS	250	15-03-2020
2021	MODIS	250	15-03-2021

Geometric errors were corrected by performing the re-projection process to ensure that satellite images and study area boundary shapefiles share the same map projection (Universal Mercator Projection). Radiometric errors were corrected by performing radiometric calibration, image enhancement (improving image contrast and brightness using the image analysis function) as well as using the reflectance rescaling coefficients provided in the metadata files of the images. Masking of the images was then done using the Zimbabwe national boundary shapefile. Temperature and NDVI images were used to calculate TCI and VCI whilst VHI was derived from a combination of TCI and VCI [18].

Computation of drought indices

Vegetation condition index was first suggested to indicate the status of vegetation cover as a function of maximum and minimum NDVI experienced in specific area over a specific period of time [19]. Vegetation condition presented by VCI results are in form of percentage with values ranging from 0%-100%. Values form 50-100% indicates optimum to above normal conditions yet values close to 0% signify extremely dry conditions. These values were used to determine drought severity in different areas in Zimbabwe as they showed how much vegetation has responded to drought. Vegetation condition index was computed using the following formulae:

$$VCI = \frac{NDVIj - NDVI\min}{NDVI\max - NDVI\min} * 100 \text{.............}(1)$$

Where NDVIj is current year NDVI, NDVI min is multi-year minimum NDVI and NDVImax is multi-year maximum NDVI.

Temperature Condition Index (TCI)

According to temperature condition index was suggested by to reflect vegetation response to temperature [16]. When using TCI, a range of values in the form of percentage is produced whereby higher lower TCI values close to 0% corresponds to severe drought conditions, moderately high values corresponds to mild drought and higher values close to 100% corresponds to normal conditions. In this research TCI was be used to confirm drought conditions detected using VCI and VHI and the following formula will be used to compute TCI [20].

$$TCI = \frac{LST\max - LSTj}{LST\max - LST\min} * 100 \text{..................}(2)$$

Where LST is the land surface temperature, LSTmax. Is multi-year maximum land surface temperature, LSTmin is multi-year minimum land surface temperature and LSTj is current year land surface temperature. Maximum and minimum land surface temperature was computed based on long-term records of remote sensing images for 2015 to 2021 [21].

VHI was derived based on both the Land Temperature Surface (LST) and Normalized Differenced Vegetation Index (NDVI). In this study the VHI was computed using Temperature Condition Index derived from land surface temperature and Vegetation Condition Index derived from the Normalized Vegetation Index (NDVI). VHI values, just like TCI and VCI they range from 0-100%, with values close to 0% depicting extreme drought and those close to 100% depicting non-drought conditions. This index was more comprehensive as it incorporate both TCI and VCI in coming up with solid results. VHI formula is combination of VCI and TCI that has a constant α of 0.5. VHI was computed using the following formula.

$$VHI = \alpha.VCI + (1-\alpha)TCI \cdots\cdots\cdots\cdots(3)$$

Where α is the constant with value of 0.5, VCI is computed Vegetation Condition Index and TCI is computed Temperature Condition Index.

Arc map 10.5 software was used during computation of drought indices. The cell statistics function was used to find maximum and minim values for Normalized Difference Vegetation Index and land surface temperature which were used to compute TCI and VCI using the raster calculator. Vegetation Health Index was computed based on TCI and VCI values using the raster calculator. Thematic maps showing the spatial distribution of drought in Zimbabwe were developed to present spatio-temporal dynamics of drought between 2015 and 2021. Pearson correlation was adopted to determine the relationship between the TCI, VCI and VHI in drought detection in Zimbabwe in the spatial context. This was done by extracting cell values from TCI, VCI and VHI images to 97 randomly scattered points across the country. After this, values of sampled pixels were exported to Microsoft Excel before being imported into SPSS v 20.0 for correlation analysis [22].

RESULTS

Spatio-temporal distribution of drought in Zimbabwe between 2015 and 2021

Results of spatial and temporal dynamics of drought in Zimbabwe illustrate that significant proportion of Zimbabwe's land suffered severe to extreme drought conditions in 2015. Vegetation Condition Index (VCI), Temperature Condition Index (TCI) and Vegetation Health Index (VHI) agreed significantly on the general distribution of drought across the country during this year. All drought indices indicated the dominance of extreme drought conditions in southern (Beitbridge, Mwenezi, Gwanda, Mberengwa, Zvishavane among other districts), south-western (Mangwe, Matobo, Bulilima and Insiza districts) south eastern (Chipinge, Zaka and Bikita and some parts of Gutu District) and central (parts of Shurugwi, western Gweru and parts of Chegutu and kwewe), and western parts (hwange, Tsholotsho, Lupane and Binga districts) of Zimbabwe (Figure 2).

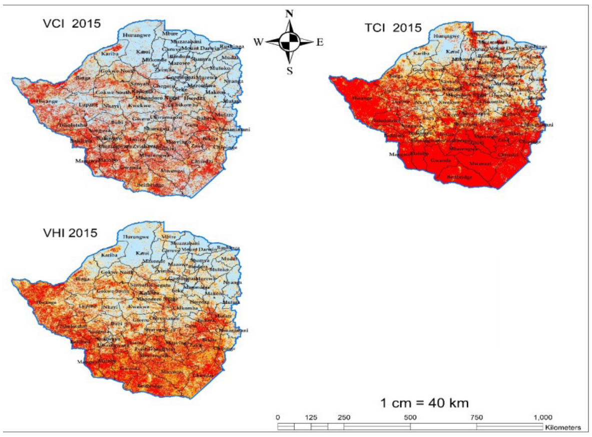

Figure 2: Spatial distribution of drought according to VHI, TCI and VCI in 2015. **Note:** ( ) National Boundary, ( ) District Boundary, ( ) Extreme Drought, ( ) Severe Drought, ( ) Moderate Drought, ( ) Normal-above normal condition.

Severe drought was detected also by all indices especially in the same areas that were affected by extreme drought conditions but its spatial coverage was not that significant. All indices showed that northern Zimbabwe (Hurungwe, Karoyi, Makonde, Mbire, Muzarabani, Shamva and Mazowe districts) some parts of north western (parts of Kariba, North eastern and northern Binga) and north eastern Zimbabwe (Mudzi, Mutoko Rushinga) experienced normal to above normal conditions. Greater parts of Mutare, eastern Chimanimani, Makoni and Nyanga districts to the east were not much affected by extreme drought but partially by severe to moderate drought conditions (Figure 3).

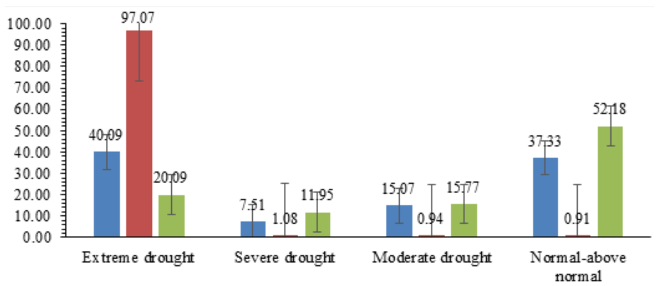

Figure 3: Spatial coverage of drought severity according to VHI, TCI and VCI in 2015. **Note:** ( ) VHI, ( )TCI, ( )VCI.

Statistical analysis of spatial severity of drought during 2015 indicated that 40.09%, 97.07% and 20.09% was covered by extreme drought as per VHI, TCI and VCI respectively. VHI and VCI indicated that 37.33% and 52.18% of the total area of Zimbabwe was covered by normal to above normal conditions. These two indices (VHI and VCI) also indicated that a considerable area of Zimbabwe was covered by moderate drought conditions that is 15.07% and 15.77% respectively [23,24]. This indicates that VHI and VCI were agreement when it comes to the spatial coverage of moderate drought and normal to above normal condition whilst TCI alone exaggerated the dominance of extreme drought coverage by a greater margin. Severe drought proved to have been out powered by extreme drought during this year as VHI, TCI and VCI indicated that only 7.51%, 1.08% and 11.95% was covered by severe drought. This shows that areas which suffered drought conditions during this years were severely affected [25].

Significant correlation was confirmed at 0.01 which indicates that detection of the spatial distribution of drought using TCI, VCI and VHI is not too much different thought some differences do exist. This is shown by the level of agreement between TCI and VCI (0.592), TCI and VHI (0.829) and VHI and VCI (0.700). However, this shows that VHI and TCI had a stronger agreement in spatial distribution of drought in 2015 (Figure 4).

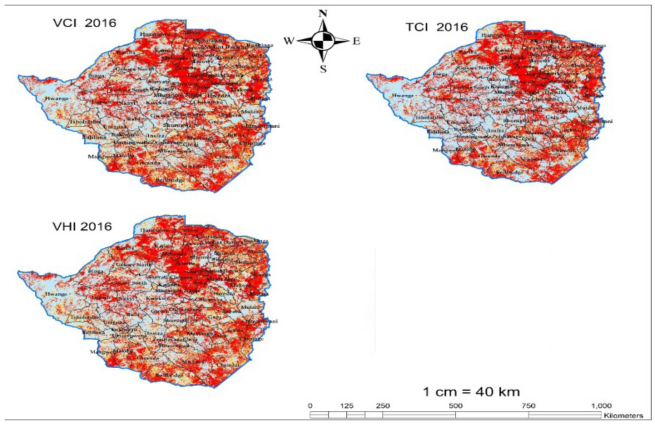

Figure 4: Spatial distribution of drought according to VHI, TCI and VCI in 2016. **Note:** ( ) National Boundary, ( ) District Boundary, ( ) Extreme Drought, ( ) Severe Drought, ( ) Moderate Drought, ( ) Normal-above normal condition.

Results indicated that the year 2016 was severely affected by drought as the whole country was affected by severe to extreme drought except some few parts of specific districts which were moderately or not affected [26]. Findings as per VHI, TCI and VCI indicated that Southern Zimbabwe (Beitbridge, Chiredzi, Mwenezi, Gwanda, Mangwe and Matobo districts), Northern (Hurungwe, Mbire, Kariba, Makonde, Muzarabani and Zvimba districts) and, North-eastern Zimbabwe (Mutoko, Mudzi and Murehwa districts) were severely affected by drought. During this year, western Zimbabwe (Hwange, Binga and Tsholotsho districts) were moderately affected (Figure 5).

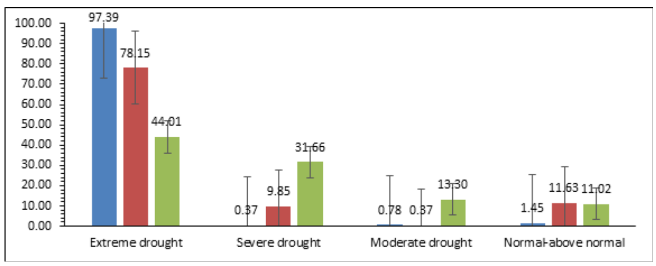

Figure 5: Spatial coverage of drought severity according to VHI, TCI and VCI in 2016. **Note:** ( ) VHI, ( )TCI, ( )VCI.

Statistical calculations of the spatial coverage of each drought category according to the VHI, TCI and VCI indicated that extreme drought covered 97.39, 78.15 and 44.01 respectively. TCI and VCI showed that 9.85% and 31.66% of the countries area was affected by severe drought whilst VHI indicated only 0.37% for this drought severity category. Moderate drought proved to have affected very small area of the nation as VHI, TCI and VCI indicated that it covered 0.87%, 0.37% and 13% respectively. These results shows that the greater part of the country was affected by severe-extreme drought conditions whilst very few areas were spared [27].

Significant correlation was confirmed at 0.01 which indicates that detection of the spatial distribution of drought using TCI, VCI and VHI did not differ by large margins. This is shown by the level of agreement between TCI and VCI (0.600), TCI and VHI (0.712) and VHI and VCI (0.720). However, this shows that VHI and VCI had a stronger agreement in spatial distribution of drought in 2015 (Figure 6).

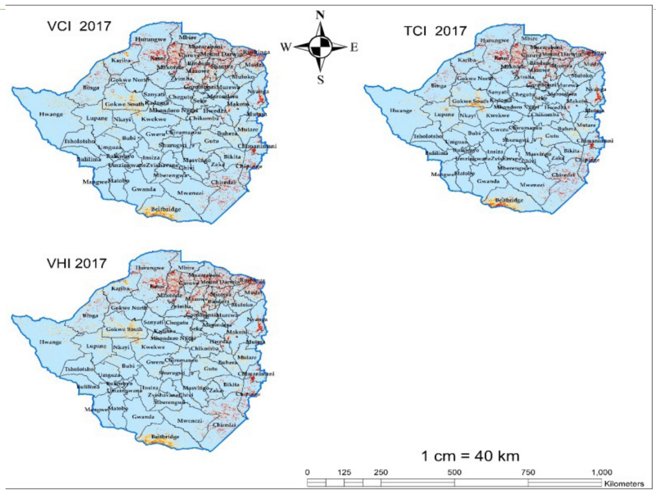

Figure 6: Spatial distribution of drought according to VHI, TCI and VCI in 2017. **Note:** ( ) National Boundary, ( ) District Boundary, ( ) Extreme Drought, ( ) Severe Drought, ( ) Moderate Drought, ( ) Normal-above normal condition.

Findings showed that the country experienced good rains in 2017 as the greater part of the country experienced normal to above normal conditions as agreed upon by VHI, TCI and VCI. All indices agreed that a mixture of moderate and severe drought affected Makonde, central parts of Karoi, and parts of Makoni, Guruve and Mt Darwin districts to the north of the country. South western Nyanga, some part of southern Nyanga in Eeastern Zimbabwe, and southern parts of Beitbridge experienced severe drought [28]. However, VCI indicated that most of central, eastern and western Zimbabwe were moderately affected. However, the country was not much affected by drought during this year (2017) (Figure 7).

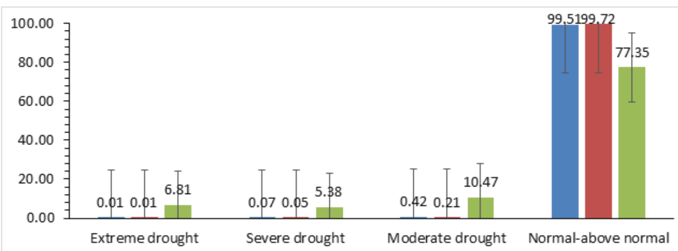

Figure 7: Spatial distribution of drought according to VHI, TCI and VCI in 2017. **Note:** ( ) VHI, ( )TCI, ( )VCI.

Drought spatial coverage statistics showed that Zimbabwe was dominated by normal to above normal conditions as VHI, TCI and VCI indicated that 99.51%, 99.72% and 77.35% of the country were under normal to above normal conditions. This clearly indicates that drought affected very small proportion of the country (less than 1% for other drought categories except for VCI which indicated 10.7% moderate drought, 5.38% severe drought and 6.81% extreme drought. Combined analysis of the two indices through VHI however showed that less than 1% of the country area was affected by drought [29].

The Pearson correlation test confirmed very strong relationships among all three indices significant at 0.01 which indicates that detection of the spatial distribution of drought using TCI, VCI and VHI greatly agreed. This is shown by the level of agreement between TCI and VCI (0.870), TCI and VHI (0.912) and VHI and VCI (0.800). However, this shows that all drought indices agreed in spatial distribution of drought in 2017 through a stronger agreement was shown between TCI and VHI (Figure 8).

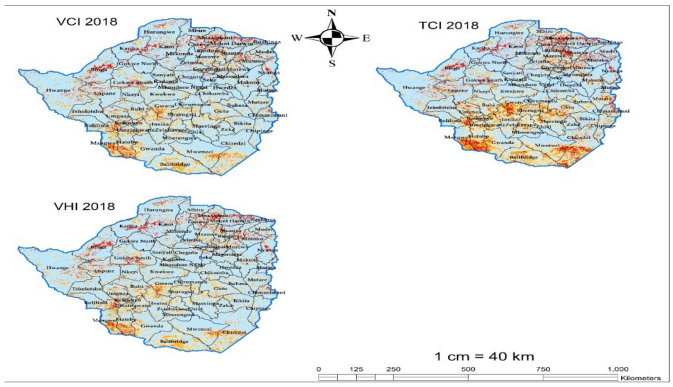

Figure 8: Spatial distribution of drought according to VHI, TCI and VCI in 2018. **Note:** ( ) National Boundary, ( ) District Boundary, ( ) Extreme Drought, ( ) Severe Drought, ( ) Moderate Drought, ( ) Normal-above normal condition.

VHI, TCI and VCI indicated that the country was dominated by a mixture of moderate and normal to above normal conditions which made year 2018 moderately affected. However, some areas were severely to extremely affected by drought during the same year. Some parts of Binga and Kariba to the west and north west respectively, Muzarabani, Rushinga, Makoni and Guruve to the north, Sothern parts of Gweru in central Zimbabwe, southern parts of Matobo and Mangwe to the south west and southern parts of Beitbridge and Chiredzi were extremely affected. The rest of the country was either under moderate or normal to above normal conditions (Figure 9).

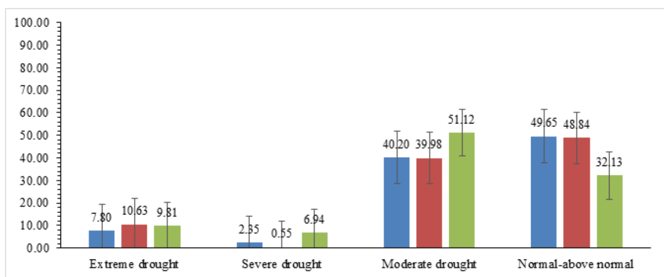

Figure 9: Spatial coverage of drought severity according to VHI, TCI and VCI in 2018. **Note:** ( ) VHI, ( )TCI, ( )VCI.

VHI, TCI and VCI indicated that 49.65%, 48.84% and 32.13% of the country was under normal to above normal conditions whilst 40.2%, 39.98% and 51.12% was under moderate drought conditions respectively in 2018 [30]. However, VHI, TCI and VCI showed that 7.80%, 10.63% and 9.81% of the country was affected by extreme drought. Very small area was affected by severe drought as VHI, TCI and VCI indicated that 2.35%, 0.55% and 6.94% was affected by severe drought. This shows that the bulk of the country's landmass was moderately or not affected by drought [31].

The Pearson correlation test confirmed strong relationships among all three indices significant at 0.01 which indicates that detection of the spatial distribution of drought using TCI, VCI and VHI greatly agreed. This is shown by the level of agreement between TCI and VCI (0.655), TCI and VHI (0.702) and VHI and VCI (0.790). However, this shows that all drought indices agreed in spatial distribution of drought in 2018 with the strongest agreement VHI and VCI (Figure 10).

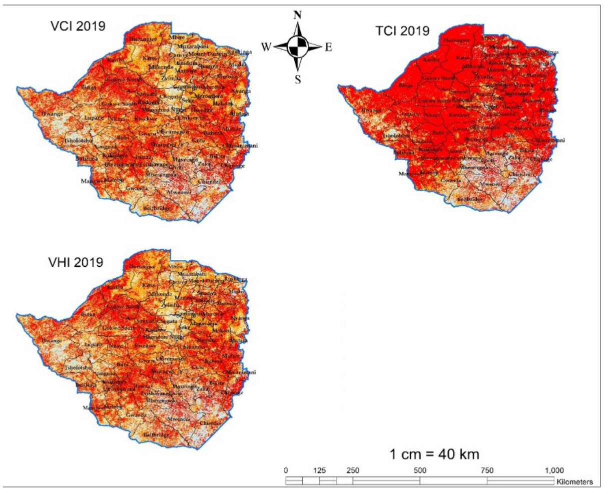

Figure 10: Spatial distribution of drought according to VHI, TCI and VCI in 2019. **Note:** ( ) National Boundary, ( ) District Boundary, ( ) Extreme Drought, ( ) Severe Drought, ( ) Moderate Drought, ( ) Normal-above normal condition.

Most of the areas in Zimbabwe were affected by drought in 2019, with all drought indices indicating severe to extreme drought conditions in almost all districts except for some few areas that were moderately or not affected. TCI confirmed severe to extreme drought throughout the country with only southern parts being moderately to mildly affected. However, VCI, thought it agreed with TCI on spatial distribution of drought, it indicated that Mbire, Guruve, Makonde, Zvimba and some parts of Karoi districts were moderately affected whilst some parts of these districts did not suffer drought. The same applies to Lupane, parts of Nyanga and Chegutu districts which were moderately affected. However, VHI showed that the whole country was affected by extreme drought except for parts of Chiredzi, Hwange, Chegutu and Zvimba which were moderately affected. These findings indicate that the year 2019 was bad for all districts in Zimbabwe (Figure 11).

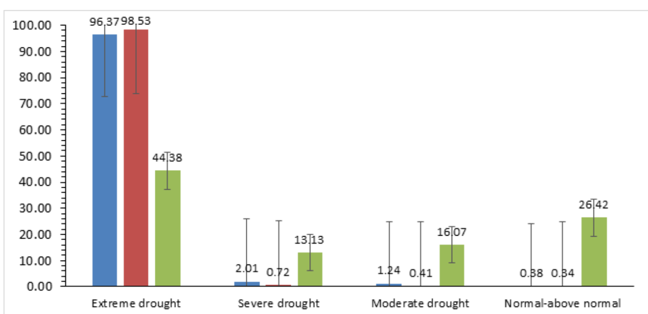

Figure 11: Spatial coverage of drought severity according to VHI, TCI and VCI in 2019. **Note:** ( ) VHI, ( )TCI, ( )VCI.

Generally, results indicated that extreme drought dominated in the country as VHI, TCI and VCI showed that 96.3%, 98.58% and 44.38% of the national land was affected by extreme drought. However, VCI indicated that significant proportion of the country was affected by moderate drought (16.07%) whilst 26.42% was under normal to above normal conditions. TCI and VHI indicated that the other three drought categories combined did not cover much area as they constituted less than 3% of the landmass. Therefore, the greater part of the country experienced extreme drought.

The Pearson correlation test confirmed significant relationships among all three indices s at 0.02. However, the relationship between TCI with other two indices was comparatively poor which shows a weaker relationship between TCI and other indices. Despite this, VHI and VCI agreed strongly at 0.780. This shows that vegetation condition and health may have not been much influenced by temperature in 2019 (Figure 12).

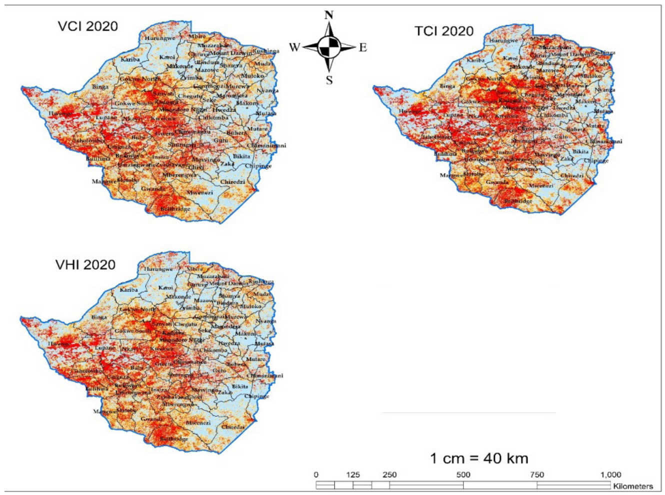

Figure 12: Spatial distribution of drought according to VHI, TCI and VCI in 2020. **Note:** ( ) National Boundary, ( ) District Boundary, ( ) Extreme Drought, ( ) Severe Drought, ( ) Moderate Drought, ( ) Normal-above normal condition.

Results from all drought indices (VHI, TCI and VCI) indicated that extreme drought ravaged central, southern, south western and western Zimbabwe in 2020. However, TCI indicated that some areas in northern and north eastern Zimbabwe were affected by extreme drought too. Gokwe, Kwekwe, Gweru, Chegutu, Sanyati, Mhondoro and southern Zvimba were affected by extreme drought. In Southern Zimbabwe, Beitbridge, western Mwenezi, Gwanda, parts of Mberengwa and Zvishavane were extremely affected. To the west, the eastern half of Hwange and other districts except some parts of Lupane were also extremely affected. However, most parts of Northern Zimbabwe including Karoi, Hurungwe, Kariba, Makonde, Northern Zvimba and some parts of Mazowe, and Guruve were comparatively safe as they got most of their parts under normal and above normal conditions. More so, during this year, most of eastern Zimbabwe was safe from drought except some few area that experienced moderate drought conditions. When compared to 2019, years 2020 was less affected thought significant proportion of the area was affected (Figure 13).

VHI, TCI and VCI highlighted that 95.55%, 41.87% and 25.18% of Zimbabwe was affected by severe drought respectively whilst 1%, 6.77% and 16.32% were under severe drought respectively. More so, 1.45%, 30.17% and 30.82% of the area was affected by moderate drought as per VHI, TCI and VCI respectively whereas 2.01%, 21.19% and 27.69% was under normal to above normal drought conditions respectively. These findings indicates that despite VHI indicating the dominance of extreme drought, the other two indices showed almost an even distribution of drought severity categories. These results shows that areas that were affected by drought were extremely affected as severe drought covered a smaller proportion of the country's landmass. Moreover, TCI and VCI indicated that a significant portion (over 50% of the country) was not severely or extremely affected but at least moderately affected with some areas being free from drought.

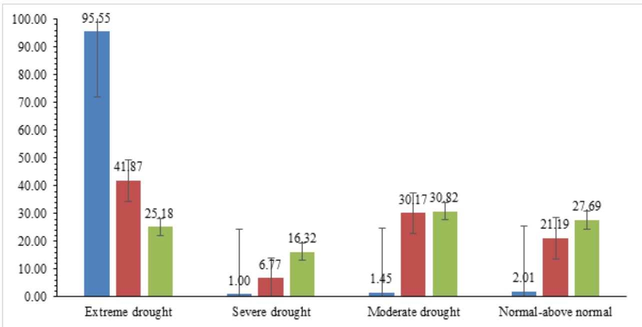

Figure 13: Spatial coverage of drought severity according to VHI, TCI and VCI in 2020. **Note:** ( ) VHI, ( )TCI, ( )VCI.

The Pearson correlation test confirmed very strong relationships among all three indices significant at 0.01 which indicates that detection of the spatial distribution of drought using TCI, VCI and VHI greatly agreed. This is shown by the level of agreement between TCI and VCI (0.900), TCI and VHI (0.843) and VHI and VCI (0.880). However, this shows that all drought indices agreed in spatial distribution of drought in 2020 through a stronger agreement was shown between TCI and VCI (Figure 14).

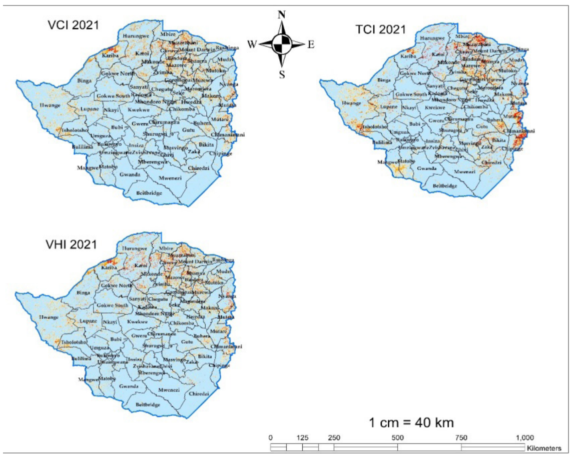

Figure 14: Spatial distribution of drought according to VHI, TCI and VCI in 2021. **Note:** ( ) National Boundary, ( ) District Boundary, ( ) Extreme Drought, ( ) Severe Drought, ( ) Moderate Drought, ( ) Normal-above normal condition.

The country experienced one of the best seasons in the 21st century in 2021 as most of the areas in Zimbabwe experienced above to above normal conditions. Southern, central, western and most of eastern Zimbabwe experienced normal to above normal conditions. However, some parts of northern Zimbabwe (northern parts of Kariba, Muzarabani, Guruve, parts of Bindura and southern Mazowe districts) were partially affected by extreme drought. Eastern parts of Chimanimani, Chipinge and Mutare also had some parts affected by extreme drought. However, some areas experienced a mixture of moderate and normal conditions with normal to above normal conditions dominating (Figure 15).

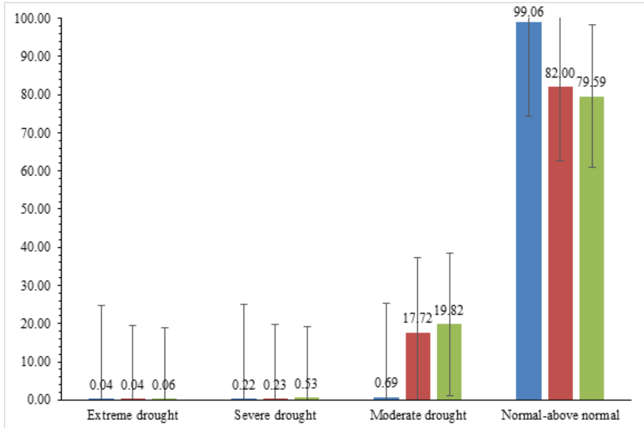

Figure 15: Spatial coverage of drought severity according to VHI, TCI and VCI in 2021. **Note:** ( ) VHI, ( )TCI, ( )VCI.

VHI, TCI and VCI indicated that 99.06%, 82% and 79.59% of the country experienced normal to above normal conditions whilst 0.69%, 17.72% and 19.82% experienced moderate drought conditions. All indices agreed that less than that extreme and severe drought combined affected less than 1% of the country which shows that the majority of landmass was less affected or free of drought.

Throughout the study period, Temperature Condition Index (TCI) detected comparatively greater spatial coverage of severe and extreme drought in southern, western and parts of central Zimbabwe. This might be due to the high temperature experiences that drives drought conditions in these parts of the country. This agrees with the postulation that temperature condition index is an indication of vegetation response to temperature stress. The difference in spatial severity of drought based on VCI and TCI is a function of what each of these indices focuses on. VCI concentrates on soil moisture deficit due to precipitation deficit whilst TCI majors on the influence of temperature and associated heat induced vegetation stress. Vegetation Health Index moderated drought conditions based on both indices hence it indicated less severe droughts in areas where temperature condition index had exaggerated. However, VHI agreed with both indices on the spatial severity of drought across Zimbabwe during the study period (2015-2021) since it was developed from a combination of these indices.

The Pearson correlation test confirmed very strong relationships among all three indices significant at 0.01 which indicates that detection of the spatial distribution of drought using TCI, VCI and VHI agreed. However, during this year (2021), TCI's relationship with VCI (0.601) and VHI (0.592) was weak compared to the relationship between VHI and VCI (0.830).

Spatial distribution of drought frequency between 2015 and 2021 in Zimbabwe

Results showed that there are some areas which experienced drought more frequently that others during the study period. However, the whole country has been experiencing droughts despite some being less frequently affected (Figure 16).

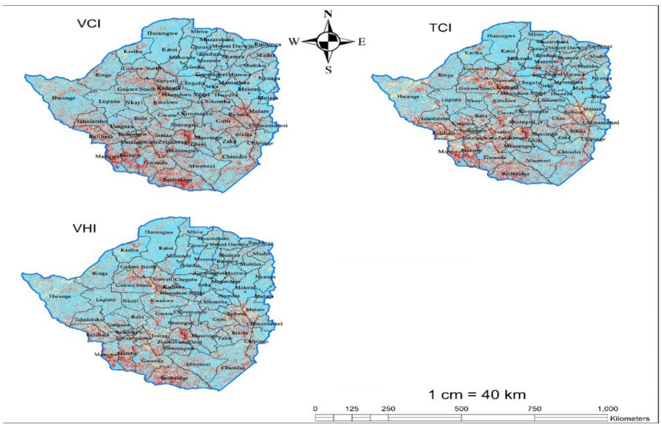

Figure 16: Spatial distribution of drought frequency in Zimbabwe between 2015 and 2021. **Note:** ( ) National Boundary, ( ) District Boundary, **Drought Frequency:** ( )1-2, ( )3-4, ( ) 5-7.

It was shown that districts in southern, south-western, south eastern and western Zimbabwe experienced more droughts during the study period. Districts like Beitbridge, Mangwe, Bulilima, Parts of Chivi, Chiredzi and Chipinge in southern Zimbabwe experienced droughts in 5-7 years which indicates that these areas have been affected on a yearly basis despite differences in spatial distribution of these droughts within district boundaries. The same happened in Buhera, estern parts of Gutu and south-western parts of Mutare in eastern Zimbabwe. This was shown by VCI, TCI and VHI though there were some few spatial differences among these indices. The indices especially TCI and VHI indicated that Hwange, parts of Mutare and Buhera and some areas within Insiza, and Zvishavane districts experienced between 3-4 droughts during the study period. Parts of most districts in Northern Zimbabwe proved to have been affected by 3-4 droughts whilst their greater parts were affected by 1-2 droughts. This is the same for districts in eastern Zimbabwe except Bikita, greater parts of Gutu and Buhera. These findings confirms the dominance of droughts in southern, south-western, south-eastern and western Zimbabwe.

DISCUSSION

Findings indicated great spatial variations in drought over Zimbabwe between 2015 and 2021. However the findings confirmed the postulation hat dry regions of the country especially agro-ecological 4 and 5 are more prone to drought as they were really more frequently affected during the study period. Arid regions that include most of Southern Zimbabwe, Western Zimbabwe and parts of North Western Zimbabwe were severely affected as indicated by high frequency (5-7 times) of drought over the past 7 years [32]. Also confirmed drought proneness of districts that are in southern Zimbabwe during the last 6 years [33]. Low precipitation in the far south and southern western parts of Zimbabwe especially during dry years were associated with the weakening of the ITCZ more than westerly cloud bands during dry years in Zimbabwe, a scenario that induces more severe drought conditions especially for mid-summer [34]. One of the main reasons that resulted in comparatively less drought in 2017, 2018 and 2021 was the LA Nina episode of 2017-2018 (NOA, 2021) and 2021 which resulted in better precipitation compared to years 2019 and 2020 which have been confirmed as El Nino years (FAO, 2019; WMO, 2012). This shows that drought conditions in Zimbabwe are mainly driven by the El Nino Southern Oscillation though the ITCZ shifts have significant influence as well [35]. A study in Mberengwa and Zvishavane districts in Southern Zimbabwe indicated severe droughts during 2018, 2019 and 2020. This is in tandem with several studies on drought in Zimbabwe which confirmed droughts in 2018, 2019 and 2020 [36]. Vulnerability of dry regions of the country to drought calls for various drought resilience actors to cooperate in building capacities of communities in Southern Zimbabwe, South Western Zimbabwe and most of western Zimbabwe. These are agrarian regions where people rely on rain-fed agriculture which under such drought condition cannot sustain livelihoods of communities. This hinders the achievement of Sustainable development goals especially climate action (SDG13), Poverty reduction (SDG1) and Hunger reduction (SDG 2). Therefore, given the increasing uncertainty of crop growing seasons in Zimbabwe in terms of drought occurrence there is need to reinforce livelihoods of communities in dry or arid areas of the country.

CONCLUSION

The paper sought to assess the spatial and temporal variations of drought in Zimbabwe between 2015 and 2021. The findings indicated that drought varied from district to district or province to province as well as from year to year across the study years. Fluctuation were noted as years 2015 and 2016 were drought years when most parts of the country were affected followed by mild droughts in 2017 and 2018. Years 2019 and 2020 registered severe drought in most parts of the country whilst year 2021 was mildly affected. Drought frequency analysis over the past years showed that most southern, south western and western Zimbabwe districts were the most affected, an indication of aridity influence on drought severity. However, despite drought fluctuation during the study period, some southern and western parts of the country were in constant severe drought conditions as they got affected more than 5 times in 7 years. Therefore arid areas need to be prioritized for drought resilience capacities to make them not lag behind with regards to achieving sustainable development.

RECOMMENDATIONS

Southern African countries need to prepare communities in dry areas for drought resilience as the general trends in drought despite some fluctuations indicate increasing spatial coverage and severity of droughts especially in arid areas.

Use of more than one index to monitor drought is recommended in future researches on drought as it allows for critical analysis of drought based on both temperature and soil moisture dimensions which are major drivers and indicators of drought respectively.

REFERENCES

1. Adames B. How droughts in Zimbabwe affect the hunger crisis. The Borgen project. 2020.
2. Barlow M, Cullen H, Lyon B. Drought in Central and Southwest Asia: La Niña, the warm pool, and Indian Ocean precipitation. J Clim. 2002;15(7):697-700.
3. Barlow M, Zaitchik B, Paz S, Black E, Evans J, Hoell A. A review of drought in the Middle East and southwest Asia. J Clim. 2016;29(23):8547-8574.

4. Barriopedro D, Gouveia CM, Trigo RM, Wang L. The 2009/10 drought in China: Possible causes and impacts on vegetation. J Hydrometeorol. 2012;13(4):1251-1267.

5. Brazier A. Climate change in Zimbabwe: Facts for planners and decision makers. Konrad-Adenauer-Stiftung. 2015.

6. Calow RC, MacDonald AM, Nicol AL, Robins NS. Ground water security and drought in Africa: Linking availability, access, and demand. Ground water. 2010;48(2):246-256.

7. Chifurira R, Chikobvu D. Predicting rainfall and drought using the Southern Oscillation Index in drought prone Zimbabwe. 2010.

8. Food and Agriculture Organisation. The 2019 humanitarian appeal: 2018/19 El Niño Response Plan for Southern Africa. 2019.

9. Frischen J, Meza I, Rupp D, Wietler K, Hagenlocher M. Drought risk to agricultural systems in Zimbabwe: A spatial analysis of hazard, exposure, and vulnerability. Sustainability. 2020;12(3):752.

10. Greenhalgh E. 2015 state of the climate: Drought conditionds expand across the globe. 2016.

11. Griffin D, Anchukaitis KJ. How unusual is the 2012–2014 California drought? Geophys Res Lett. 2014;41(24):9017-9023.

12. Kogan F, Guo W. Early twenty-first-century droughts during the warmest climate. Geomat Nat Hazards Risk. 2016;7(1):127-137.

13. Kogan F, Adamenko T, Guo W. Global and regional drought dynamics in the climate warming era. Remote Sens Lett. 2013;4(4):364-372.

14. Ma Z, Fu C. Some evidence of drying trend over northern China from 1951 to 2004. Sci Bull. 2006;51(23):2913-2925.

15. Makaudze EM, Miranda M. Using remotely-sensed vegetation condition index to investigate the feasibility of Drought Insurance for Smallholder Farmers in Zimbabwe. In University of Oxford Conference on Economic Development in Africa. 2008.

16. Manatsa D, Mukwada G, Siziba E, Chinyanganya T. Analysis of multidimensional aspects of agricultural droughts in Zimbabwe using the Standardized Precipitation Index (SPI). Theor Appl Climatol. 2010;102(3):287-305.

17. Manatsa D, Mushore TD, Gwitira T, Wuta M, Chemura A, Shekede M, et al. Report on revised agroecological zones of Zimbabwe. 2020.

18. Manjowe M, Mushore TD, Gwenzi J, Mutasa C, Matandirotya E, Mashonjowa E. Circulation mechanisms responsible for wet or dry summers over Zimbabwe. AIMS Environ Sci. 2018;5(3):154-172.

19. Masante D, Magni D, Vogt J, Cammalleri C. Analytical report global drought observatory. 2019.

20. Masante D, Magni D, Vogt J, Cammalleri C. Global drought observatory analytical report: Drought in Zimbabwe. 2020.

21. Masih I, Maskey S, Mussá FE, Trambauer P. A review of droughts on the African continent: a geospatial and long-term perspective. Hydrol Earth Syst Sci. 2014;18(9):3635-3649.

22. Matyas D, Pelling M. Positioning resilience for 2015: The role of resistance, incremental adjustment and transformation in disaster risk management policy. Disasters. 2015;39(s1):s1-8.

23. Mberego S, Gwenzi J. Temporal patterns of precipitation and vegetation variability over Zimbabwe during extreme dry and wet rainfall seasons. J Appl Meteorol Climatol. 2014;53(12):2790-2804.

24. Mugandani R, Wuta M, Makarau A, Chipindu B. Re-classification of agro-ecological regions of Zimbabwe in conformity with climate variability and change. Afr Crop Sci J. 2012;20:361-369.

25. Mutowo G, Chikodzi D. Remote sensing based drought monitoring in Zimbabwe. Disaster Prev Manag. 2014.

26. Nangombe SS. Drought conditions and management strategies in Zimbabwe. 2015; 5-8.

27. National Oceanographic and Atmospheric Administration. LA Nina years. 2021.

28. Osborn T, Barichivich J, Harris I, Van Der Schrier G, Jones P. Monitoring global drought using the self-calibrating Palmer Drought Severity Index. Bull Am Meteorol Soc. 2018;99(8):S36-S37.

29. Otkin JA, Anderson MC, Hain C, Svoboda M, Johnson D, Mueller R, et al. Assessing the evolution of soil moisture and vegetation conditions during the 2012 United States flash drought. Agric For Meteorol. 2016;218:230-242.

30. Seager R, Hoerling M, Schubert S, Wang H, Lyon B, Kumar A, et al. Causes of the 2011–14 California drought. J Clim. 2015;28(18):6997-7024.

31. United Nations Development Programme. Drought in Russia and Kazakhstan. 2012.

32. World Meteorological Organization. SPI userguide. 2012.

33. Yang J, Gong D, Wang W, Hu M, Mao R. Extreme drought event of 2009/2010 over southwestern China. Meteorol Atmospheric Phys. 2012;115(3):173-184.

34. Anderson WB, Zaitchik BF, Hain CR, Anderson MC, Yilmaz MT, Mecikalski J, et al. Towards an integrated soil moisture drought monitor for East Africa. Hydrol Earth Syst Sci. 2012;16(8):2893-2913.

35. Zhang Q. Drought (in Chinese). China Meteorological Press. 2009;199.

36. Zhou L, Tian Y, Myneni RB, Ciais P, Saatchi S, Liu YY, et al. Widespread decline of Congo rainforest greenness in the past decade. Nature. 2014; 509(7498):86-90.