Decadal Spatio-Temporal Dynamics of Drought in Semi-Arid Farming Regions of Zimbabwe between 1990 and 2020. A Case of Mberengwa and Zvishavane Districts.

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Abstract

Drought severity and frequency is increasing in tropical regions and its occurrence is not uniform in space and time. The study assessed spatio-temporal dynamics of agrometeorological drought in Mberengwa and Zvishavane Districts between 1990 and 2020. An empirical research design was adopted in this study. GIS and remote sensing techniques were used to determine and analyse agricultural drought conditions and the Standardized Precipitation Generator was used to compute SPI for meteorological drought monitoring and analysis. Microsoft excel 2011 was adopted for analysis of drought coverage and performing the Mann Kendall trend test for precipitation trend analysis. Results indicated that area covered by drought declined between the 1990 and 2000 and 2001-2010 decade before increasing during the 2011-2020 decade. Results indicated significant spatial dynamics of drought severity and frequency in Mberengwa and Zvishavane Districts and the majority of wards experienced increased frequency of severe droughts during the 2011-2020 decade. It was highlighted that meteorological drought was not evenly distributed across all decades. Dry conditions in the first months (October and November) of the rain season have been indicated during the 1990-2000 decade, followed by wetter conditions during the 2001-2010 decade and comparatively drier conditions in the same months during the 2011-2020 decade. This indicated late onset of the rainfall season during the 1990-2000 and 2011-2020 decades compared to the 2001-2010 decade. It was also shown that rainfall cessation was earlier during the 2001-2010 and 2011-2020 decades and late during the 1990-2000 decade. The study concludes that drought has increased both in severity and frequency in Mberengwa and Zvishavane Districts hence there is need for more support to drought resilience building initiatives in these areas. The government of Zimbabwe is advised to set up climate research centres in all provinces of the country to improve availability of climate change related data which is useful when addressing the impacts of climate change.

1. Introduction

Due to climate change, drought incidence and severity have increased and myriads of social and economic sectors are being affected. Definitions have been advanced and shaped by systems and contexts in which drought impacts are perceived and felt. Drought manifest with varying frequency almost in all parts of the world and in all types of economic systems of both developed and the developing world (Wilhite, 1992; Frischen et al., 2020). Drought was classified by Wilhite and Glantz (1985) as meteorological, agricultural, socioeconomic, and hydrological drought. Wilhite (2000) further stressed that these droughts are linked in some way. Despite the fact that temperature, wind speed, evapotranspiration, and soil moisture have a role in the incidence and progression of drought, the fundamental driver of every drought event is a lack of precipitation (Heim, 2002; Smakhtin and Schipper, 2008; Kumar et al., 2009; Vicente-Serrano et al., 2010; Mishra and Singh, 2011). Drought is a severe climatic hazard and an extreme meteorological phenomenon that results from a lack of precipitation, resulting in a water scarcity for certain applications (Szinell et al., 1998). Precipitation deficit over a short period of time can be a meteorological drought but not agricultural or hydrological drought. When this deficit prolongs, it leads to soil moisture deficit (agricultural drought) and another period beyond may result in hydrological drought (Wilhite, 2000).

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 (Kogan et al., 2013). Several droughts affected key agricultural regions in the northern hemisphere from 2000 to 2012, notably from 2010 to 2012. The area affected by severe drought grew from 8% in 2014 to 14% by the end of 2015 (Greenhalgh, 2016). By the end of 2015, 30% of the world's land was experiencing drought, with 14% experiencing severe or extreme drought (Osborn et al., 2016). Between 2011 and 2012, the United States of America was hit by severe droughts. Combined drought index for Europe in the 2019/2020 season showed drought conditions over few core regions including Ireland and the UK, Belgium, the Netherlands and Germany, north-west Balkans and Scandinavia. Some of the affected areas were in the peripherals located in central Italy, eastern France, Poland, Belarus and Greece. However, parts of Romania, Moldova and north-west Ukraine showed signs of recovery compared to previous years. Western and central Europe also suffered severe drought from 2018 to 2020 (Barbosa, 2020).

Literature on droughts in Asia shows that several droughts affected northern China which also experienced one of the most severe drought that led to drying up of the Yellow river in 1997 (Zhang et al., 2009). This was the worst drought in Pakistan and Afghanistan in 50 years (Barlow et al., 2002; 2016; Zhang and Zhou, 2015). An extreme drought hit Sichuan and the Yangtze River basin in 2006–07, causing a drop in rice, potato, and bean production. In 2008–09, the drought also hit Yunnan and Southwestern China, causing agricultural losses (Barriopedro et al., 2012; Yang et al., 2014). North China was also hit by a severe drought that lasted from the autumn of 2009 to the spring of 2010. (Yang et al., 2012). Since the 1970s, aridity has worsened over Northern China, and the occurrence of extreme droughts in the Central part of Northern China, North East China, and the eastern part of North West China has also increased.

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 (Calow et al., 2010; Zhou et al., 2014). The period 2008-2010 saw another drought hitting most countries in East Africa especially countries within the horn of Africa. According to Zaitchik et al. (2012), 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 (Masih et al., 2014; Nicholson, 2014). 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 were experienced in North Namibia, South Angola, North Zimbabwe, the whole of Lesotho and South Botswana during the 2018/2019 season (Masante et al., 2019). Negative anomalies of rainfall worsened over the whole of Zimbabwe, southern Mozambique, Zambia and north-east Botswana during the 2019/2020 season. Given these spatial and temporal dynamics of drought in different parts of the globe, it can be noted that past decades have been experiencing severe droughts which threatened livelihoods of many people especially in developing countries thus affecting the achievement of sustainable development goals 1 and 2. This is because majority of population in developing countries are in rural areas where they depend on rain-fed agriculture hence frequent droughts

compromise livelihood sources of these people. However, mitigating the impacts of drought require information of historical droughts, their trajectories, severity as well as spatio-temporal distribution so as to come up with informed decision to counter associated impacts. Southern Zimbabwe is largely arid-semi-arid where precipitation is so erratic (450-500mm) and temperatures are high (averaging 28 degree Celsius) (Manatsa et al., 2020). These characteristics already makes this area drought prone hence the need to study drought spatial and temporal distribution at district level for informed planning for drought resilience building. Mberengwa and Zvishavane Districts are part of this area, however, their selection was based on grounds that they have similar climatic conditions but dominated by soils of different water retention capacity (Mupepi and Matsa, 2021). Therefore the need to confirm the perceived similar climatic conditions and whether different soils have an influence on drought severity motivated selection both districts for this study. Against this background, this article assesses decadal spatio-temporal dynamics of drought in Mberengwa and Zvishavane Districts if Zimbabwe between 1990 and 2020 with the main thrust of the study being to: 1) determine the temporal coverage and severity of drought in Mberengwa and Zvishavane Districts; 2) analyse the spatial severity of drought in Mberengwa and Zvishavane wards between 1990 and 2020 and 3) to assess seasonal distribution of meteorological drought in Mberengwa and Zvishavane Districts between 1990-2020.

2. Study Area

The study was conducted in the Midlands province's adjacent districts of Zvishavane and Mberengwa, at an elevation of 1,039 meters above sea level. The total areas of Mberengwa and Zvishavane are 5066 km² and 2476 m², respectively (Zimbabwe national population statistics, 2012). According to FAO (2016), Zimbabwe's total area is 390 760 km², making Mberengwa and Zvishavane districts 1.93 percent of the total size of Zimbabwe. Zvishavane is located 97 kilometers west of Masvingo on the main Bulawayo-Masvingo route (20° 20'S; 30° 02'E) (Figure 1), while Mberengwa is located approximately 24 kilometers south of Zvishavane (20° 29' 0" S, 29° 55' 0" E). Both districts are in agro-ecological zones 4 and 5a, with annual rainfall of 450-650 mm and less than 650 mm, respectively, and an annual average temperature of about 28°C (Manatsa et al., 2020). High temperatures in these areas increase evapotranspiration, increasing the likelihood of agricultural droughts. Seasonal moisture deficits and severe mid-season dry spells are common in these regions due to the unpredictable nature of precipitation, resulting in increased agro-meteorological drought occurrences.

Soils in Mberengwa and Zvishavane districts are Sandy Ustalfs which require consistent moisture to maintain agricultural production; however, the unpredictable and sparse rainfall puts crop and animal production at risk, as moisture required to support crops and pastures for livestock is rarely available. The geology of the area is linked to the Great Dyke, which consists of layered mafic intrusions linked to economically important metals like platinum, chromium, nickel, vanadium, copper, titanium, iron, and tin, providing communities in these areas with alternative livelihood sources through mining activities (Badlock et al., 1991)

Figure 1: Map of Zvishavane and Mberengwa Districts

Source: Authors

Zvishavane has a population of 52 734 people, with 27 815 women and 24 919 men (Zimbabwe Central Statistical Office (CSO) 2012 report), while Mberengwa has a population of 185,757 people, with males accounting for 86,764 and females accounting for 98,993. In Zvishavane and Mberengwa, mining is one of the main sources of income (Zimbabwe Poverty Assessment Study Survey Summary, 2003). Despite the challenges posed by changing climatic conditions, rural residents in both districts continue to grow cash crops such as cotton, sunflowers, staple cereals maize and sorghum, and vegetables, as well as livestock for survival.

Agriculture is vulnerable in Mberengwa and Zvishavane districts due to erratic or unreliable precipitation, as communities rely on rainfall for crop and livestock production. As a result of frequent crop failures and livestock deaths, primarily due to water scarcity, the majority of people are at risk of food insecurity and starvation. Large deposits of minerals such as platinum, gold, and asbestos, which are found in Zvishavane, and gold, tantalite, and emeralds, which are abundant in Mberengwa, however, provide an alternative source of income through employment in mining companies as well as participation in small-scale and artisanal mining activities.

3. Methodology

This study employed the empirical research design which is based on use of verifiable evidence in order to arrive at research outcomes. Empirical research design was adopted because it is based on evidence obtained through scientific data collection methods (Borry et al., 2006). In this study, scientific measurements of drought in both Mberengwa and Zvishavane Districts using Geographic information system (GIS) and remote sensing techniques were employed. These constituted computation of Vegetation Condition Index (VCI) and Temperature Condition Index (TCI) using ArcMap 10.5 software and computation of Standardized precipitation Index (SPI) using the SPI generator software. These mathematically computed indices allowed for the determination of agricultural and meteorological droughts in Mberengwa and Zvishavane districts between 1990 and 2020. GIS and remote sensing were found ideal for assessing surface water dynamics in Mberengwa and Zvishavane due to their ability to provide a synoptic spatial and temporal visualization of drought.

Landsat images with a spatial resolution of 30m were acquired from the United States Geological Survey (USGS) website for the period 1990 to 2020. Landsat 4-5 images were downloaded for the period 1990 to 2014 and Landsat 8 images were downloaded for the period 2015 to 2020.

Table 1: Satellite data sets used and their meta-data

Source: Authors

The research maintained consistency in using Landsat images for the whole study period in order to maintain mapping uniformity using images of same spatial resolution. Landsat 4-5 images were used for the period 1990 to 2014 because it was the only Landsat satellite platform that was perfectly functional during this period and Landsat 8 images were acquired for the period 2015 to 2020 because this satellite was launched to succeed Landsat 4-5 thus available to provide images of improved quality for this period (USGS, 2015). These Landsat images were used for the computation of NDVI, VCI and TCI for characterisation of agricultural drought. Images for the month of March were used for drought monitoring because maximum chlorophyll in vegetation and croplands is experienced in March when peak growth is attained (Yang et al., 2015; Alemayehu et al., 2017) hence deviations from normal vegetation condition during this month would be a reliable depiction of drought due to moisture deficit even during the previous months.

Removal of the no data value region and conduction of geometric and radiometric corrections to remove distortions and radiometric noise constituted the pre-processing stage (data cleaning). Mberengwa and Zvishavane district shapefiles were created and used to extract study areas from Landsat images. Image mosaicking was done for Landsat 4/5 images since these images could not cover the whole study area in a single swath.

Many researchers (Di et.al, 1994; John et.al, 1998) who studied drought employed NDVI to monitor vegetation status that shows whether there is drought or not. Use of NDVI is based on differences in spectral responses of health and unhealthy vegetation. Healthy vegetation reflects less in the visible electromagnetic spectrum due to chlorophyll absorption in this region while it reflects more in the near infrared spectrum due to internal reflectance of the mesophyll spongy tissue of health green leaf. In contrast, stressed vegetation reflects more in the visible electromagnetic spectrum and less in the near infrared spectrum (Campbell, 1987). These differences in spectral response by both drought stressed and healthy vegetation assists determining drought and its spatial extent. NDVI can be calculated as the ratio of red and the NIR bands of a sensor system and is represented by the following equation:

$$NDVI = \frac{NIR - RED}{NIR + RED} \dots\dots\dots (1)$$

Where RED and NIR are reflectance in the red and near infrared bands respectively. Due to difficulties in accurately interpreting NDVI values in heterogeneous terrains (Kogan, 1987) as the case in both Zvishavane and Mberengwa districts and the weakness that NDVI doesn't clearly show the weather impact separately, VCI as suggested by Kogan (1997) was adopted in this research. Calculated NDVI was used to compute VCI in this research.

Vegetation condition index was first suggested by Kogan (1993) to indicate the status of vegetation cover as a function of maximum and minimum NDVI experienced in a specific area over a specific period of time. Vegetation condition presented by VCI was in the form of percentage with values ranging from 0-100%. Values from 50-100% indicate optimum to above normal conditions while values close to 0% signify extremely dry conditions. These values assisted in determining agrometeorological drought severity in different areas of Mberengwa and Zvishavane Districts as they showed how much vegetation has responded to climate. Vegetation condition index was computed as:

$$VCI = \frac{NDVI_j - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \times 100 \dots\dots\dots (2)$$

Where $NDVI_j$ is current year NDVI, $NDVI_{min}$ is multi-year minimum NDVI and $NDVI_{max}$ is multi-year maximum NDVI.

According to Thenkabail et.al (2004), Temperature condition index was suggested by Kogan (1997) to reflect vegetation response to temperature. When using TCI, higher temperature corresponds to severe drought conditions, moderately high temperatures corresponds to mild drought and optimum temperatures corresponds to normal conditions. In this research TCI was used to confirm drought conditions detected using VCI and SPI. TCI was computed as:

$$TCI = \frac{BT_{max} - BT_j}{BT_{max} - BT_{min}} \times 100 \dots\dots\dots (3)$$

Where BT is the brightness temperature, BT_{max} is multi-year maximum brightness temperature, BT_{min} is multi-year minimum brightness temperature and BT_j is current year brightness temperature. Maximum and minimum BT was calculated basing on long-term records of remote sensing images for particular periods. Low TCI values indicate hot weather conditions and high values show milder conditions.

The standardised precipitation index was developed by McKee et.al (1993) for characterisation of drought. SPI is the number of standard deviations that the observed value would experience from the long term mean of a normally distributed random variable. This index was adopted to determine deviations of precipitation from the normal expected from 1990 to 2020 in Mberengwa and Zvishavane districts. SPI was used to quantify precipitation deficits over the studied period thus determining meteorological drought. Six-month SPI (SPI-6) was adopted in this research to incorporate all months within the rainfall season (October -March) in Zimbabwe. This SPI was computed using 1990-2020 monthly precipitation records obtained from the Meteorological Services Department. The standardised precipitation index (SPI) was computed using the SPI generator software:

$$SPI = \frac{P_i - P_m}{SD} \dots\dots\dots(4)$$

Where Pi is seasonal precipitation, Pm is the seasonal mean and SD is the standard deviation of the long-term record.

The study produced average Vegetation Condition and Temperature Condition Index maps for 1990-2000, 2001-2010 and 2011-2020 decades and seasonal SPI-6 (for October –March) and 1990-2020. Therefore, each decade had 2 maps showing average TCI and VCI. Average TCI and VCI per decade were determined by finding mean cell statistics for 10 year TCI and VCI raster images within each decade using the cell statistics function of Arc Map 10.5 software. Therefore, TCI and VCI for all years within each of the study decades were averaged to get average TCI and VCI for each decade.

Figure 2: Agro-meteorological drought determination procedures

Source: Authors

Spatial and temporal severity of drought in both Zvishavane and Mberengwa districts was analysed in ArcMap 10.5 software using raster calculator and spatial analyst tools to produce VCI and TCI thematic maps showing the distribution of drought in Zvishavane and Mberengwa districts. The raster calculator and cell statistics tools were used to compute TCI and VCI for characterising drought conditions. The cell statistics function was used to average TCI and VCI to determine average decadal drought conditions for presentation in the form of thematic maps. The Mann Kendall trend test was used to determine trends in precipitation distribution in Mberengwa and Zvishavane Districts. Microsoft excel 2013 was used to analysed drought coverage statistics and creation of graphs for presentation of decadal drought area coverage.

4. Results

4.1 Temporal coverage and severity of drought in Mberengwa and Zvishavane Districts between 1990 and 2020

Based on VCI and TCI indices, drought conditions were categorized into extreme-severe, moderate and mild-no drought classes using the Kogan (2002) guidelines (Table 2). Thermal stress (indicated by TCI) and water deficit stress (indicated by VCI) were used to detect drought conditions (Kogan, 2002; Wnkler et al., 2017) in Mberengwa and Zvishavane districts. Average drought conditions per each decade have been determined through finding the mean VCI and TCI values of each year's image pixels over the 10-year period in each decade so as to come up with average drought conditions experienced by each image pixel during each decade (Liang et al., 2017). This allowed for analysis of average drought conditions for areas in both Mberengwa and Zvishavane districts during each of the three studied decades (1990-2000, 2001-2010 and 2011-2020)

Table 2: Vegetation Condition Index and Temperature Condition Index value interpretation

Source: Kogan (2002)

For the purpose of analyzing spatial coverage and severity of drought between 1990 and 2020, area under each drought category was calculated and compared across decades (table 4.3).

4.1.1 Spatio-temporal coverage of drought in Mberengwa and Zvishavane Districts based on VCI

Based on average Vegetation Condition Index values, area under mild-no drought conditions dominated in both Mberengwa and Zvishavane districts during the 1990 to 2000 decade as it constituted 47.2% in Mberengwa District and 35% in Zvishavane District. This was followed by the area under moderate drought conditions which constituted 31.6% of Mberengwa and 33.1% of Zvishavane districts respectively. Area under severe drought conditions during the same decade was 21.2% in Mberengwa and 31% in Zvishavane District. This signifies that greater parts of Mberengwa and Zvishavane Districts experienced drought during the 1990-2000 decade despite that considerable proportions of these districts experienced mild to no drought conditions. When comparing the two districts, Mberengwa had larger proportion of its area under mild-no drought conditions whereas Zvishavane had larger proportion of its area under drought. Dominance of soils with less clay content in Zvishavane than in Mberengwa (Mupepi and Matsa, 2021) can be one of main reasons why Zvishavane is comparatively drier than Mberengwa District. These kind of soils according to Balasubramanian (2017), have poor moisture retention capacity hence they quickly dry up when exposed to high temperature and less precipitation over long period of time.

Figure 3.: Decadal dynamics of drought spatial severity between 1990 and 2020

Source: Remote sensing data

Average Vegetation Condition Index (VCI) values during the 2001-2010 decade confirmed that area that experienced mild-no drought conditions was the largest in Mberengwa constituting 49.4% followed by area under moderate drought condition (46.5%) and area under severe-extreme drought condition (4.1%). In Zvishavane, area under moderate drought condition dominated, constituting 53.4% of the total area, followed by area under moderate drought (41%) and severe-extreme drought condition (5.5%). In Mberengwa District, despite the dominance of area that experienced mild-no drought conditions, total area under drought (both moderate and severe-extreme) constituted the greater part of the district. However, in Zvishavane, overall, the proportion of area under drought conditions was larger than that of Mberengwa, a scenario likely to be driven by the dominance of sandy soils in Zvishavane which are poor in terms of moisture storage thus exposing them to more agricultural drought (Balasubramanian, 2017). In general, area under severe to extreme

drought was the smallest in both districts but combined area under drought conditions in these districts was larger than that which experienced mild-no drought condition.

During the 2011-2020 decade, average VCI values indicated that both Mberengwa and Zvishavane districts, had larger proportion of their area under severe-extreme drought condition (40% in Mberengwa District and 41% in Zvishavane District). In both districts, area under moderate drought was the second largest, constituting 35% in Mberengwa and 34.6% in Zvishavane District. Area that experienced mild-no drought conditions was smallest in both districts that is 25.1% in Mberengwa and 24.4% in Zvishavane. Overall, area under drought conditions in this decade was largest with severe-extreme drought conditions dominating in both districts.

4.1.2 Spatio-temporal coverage of drought in Mberengwa and Zvishavane Districts based on TCI

Based on average Temperature Condition Index values for both Mberengwa and Zvishavane districts during the 1990-2000 decade, area that experienced moderate drought conditions was dominant. For Mberengwa, 48.2% of the area experienced moderate drought whilst in Zvishavane, 41.3% of the area experienced moderate drought conditions during this decade. In Mberengwa District, area that experienced mild-no drought conditions during this decade was second largest constituting 32.2% whereas the remaining 19.6% experienced severe-extreme drought conditions. In Zvishavane, area that experienced severe-extreme drought conditions was second largest constituting 33.5% of the total area whilst 25.5% of the area experienced mild-no drought conditions. This shows that largest proportion of both Mberengwa and Zvishavane districts experienced drought conditions whilst smaller area experienced mild-no drought conditions. When comparing the two districts, Zvishavane had more of its area under drought compared to Mberengwa though both of them were dominated by drought conditions.

Figure 4...: Decadal dynamics of drought spatial severity between 1990 and 2020

Source: Remote sensing data

During the 2001-2010 decade, average Temperature Condition Index (TCI) indicated that more than half of both Mberengwa (52%) and Zvishavane (54.9%) area experienced moderate drought conditions. This was followed by area that experienced mild-no drought conditions during the decade which accounted for 34.6% in Mberengwa and 28.9% in Zvishavane district. Only 13.5% and 16.2% of the area experienced severe-extreme drought conditions in Mberengwa and Zvishavane districts respectively. Both districts were dominated by moderate drought with considerable area under mild-no drought and very small proportions that experienced severe-extreme drought between 2001 and 2010. Overall, both districts were dominated by drought but Zvishavane had more of its area under drought conditions compared to Mberengwa District.

During the 2011-2020 decade, average Temperature Condition Index (TCI) showed that 48.1% of Mberengwa area experienced severe-extreme drought conditions compared to 41.6% in Zvishavane. For Zvishavane District, it was indicated that 44.3% of the area experienced moderate drought whereas in Mberengwa, 38.3% of the area experienced same drought conditions. This was followed by only 13.6% and 14.1% of Mberengwa and Zvishavane area respectively which experienced mild-no drought conditions during this decade. Overall, average temperature condition index indicated that Mberengwa experienced more severe drought conditions than Zvishavane during this decade though the margin of difference was slight.

These findings indicate fluctuations in drought severity across the three study decades (1990-2000, 2001-2010 and 2011-2020). Both VCI and TCI drought indices showed that drought declined during the 2000-2010 decade before a phenomenal surge during the 2011-2020 decade. When compared to the 2001-2010 decade, the 1990-2000 decade experienced more drought. This can be attributed to the most severe drought of all time that affected Mberengwa and Zvishavane during the 1991/92 season (Sachikonye, 1992), followed by the 1993/94 and the 1997/98 season drought which are among most severe droughts in Zimbabwe. These droughts were due to the El Nino phase of the El Nino Southern Oscillation (ENSO) cycle that affects drought occurrence in Zimbabwe and other southern African countries (Tadross et al., 2005; Manatsa et al., 2008). These and other less severe droughts during this decade made average drought conditions of this decade more exceptional than the 2001-2010 decade. Conversely, the 2001-2010 decade was wetter mainly because it was dominated by La Nina episodes and events of the (ENSO) cycle. Examples of confirmed La Nina episodes during these decade includes the 2000-2001, 2005-2009 and the 2010 La Nina events (NOA, 2021).

All these La Nina episodes and events resulted in more precipitation in Zimbabwe and other southern African countries thus less average drought conditions during this decade. Only the 2001/02 drought was so salient during this decade hence when it comes to average drought condition during this decade, non-drought conditions dominated in both Mberengwa and Zvishavane. The dominance of drought during the 2011-2020 decade in both Mberengwa and Zvishavane districts can be linked to the increased frequency of drought between 2011 and 2020 in Zimbabwe which have been affecting agro-ecological regions 4 and 5 more than others. El Nino events like 2011-2012, 2014-2016 and 2019/2020 (Adames, 2020) had significant contribution to drought conditions in Zimbabwe with 2011/12 and 2015/16 seasons being among the worst seasons in terms of drought severity in Zimbabwe. Mushore (2013) confirmed the 2011/12 and 2012/13 heat waves that were rampant in Zimbabwe. These should have worsened agricultural drought conditions in Mberengwa and Zvishavane Districts which already are characterized by high temperatures averaging 28 degrees Celsius (Mgandani et al., 2012; Manatsa et al., 2020).

4.2 Decadal spatial dynamics of drought in Mberengwa and Zvishavane districts between 1990 and 2020

Despite some variations in area covered by mild-no drought, moderate drought and severe-extreme drought as indicated by Vegetation Condition Index (VCI) and Temperature Condition Index (TCI), the general pattern of drought conditions was the same in both districts. Both indices indicated a decline in area covered by severe-extreme drought, increase in area under moderate drought and increase in area under mild-no drought conditions between 1990-2000 and 2001-2010 decades. Both indices also indicated an increase in area under severe - extreme drought conditions and decline in area under moderate and mild-no drought conditions between 2001-2010 and 2011-2020 decades. In as far as average drought conditions per decade is concerned, results indicated changes in spatial severity of drought conditions in both Mberengwa and Zvishavane districts over the past three decades. However, some areas indicated to have been constantly affected by specific drought conditions.

During the 1990-2000 decade, average TCI and VCI agreed in indicating that wards 36, 13 and 34 to the west, south-western parts of ward 32, most of ward 2 to the north, wards 25, 24 and parts of ward 26 to the south and parts of ward 21 and 22 to the south east of Mberengwa experienced severe-extreme drought conditions. In Zvishavane, wards 6, 3 and northern parts of ward 5 to the west, wards 2, 4 and 9 to the north, and ward 15 to the south east of the district experienced severe-extreme drought conditions. Both indices indicated that some parts of central (including wards 7, 8, 17) and eastern (including wards 5, 6 and 19) Mberengwa experienced moderate drought conditions during the 1990-2000 decade.

Figure 5: Average VCI and TCI in Mberengwa and Zvishavane districts between 1990 and 2020

Source: Remote sensing data

For Zvishavane, it was highlighted that wards 5 and 11 to the west and ward 18 to the south east experienced moderate drought conditions. Both VCI and TCI indicated mild-no drought conditions in parts of wards 2, 6, 20 and 30 in Mberengwa District. In Zvishavane they agreed that eastern part of ward 3, most parts of ward 7, eastern parts of ward 17 and western parts of ward 18 experienced mild-no drought conditions during the 1990-2000 decade.

Since VCI is more based on vegetation response to moisture deficit (Kogan, 1993; 97) and TCI is based on vegetation response to thermal stress (Thenkabail et al., 2004), some differences were noted in severity of drought conditions in some parts of both Zvishavane and Mberengwa Districts. During the 1990-2000 decade, TCI indicated that most wards to the south east of Mberengwa were in mild-no drought conditions in as far as thermal stress is concerned whereas VCI indicated moderate drought conditions based on moisture deficit response of vegetation. In wards 30, 31 and 29 to the south west, ward 4 to the north east and ward 35 to the west of Mberengwa there was higher thermal stress than moisture deficit as TCI indicated severe-extreme drought whereas VCI indicated moderate drought conditions. Some areas experienced more of moisture deficit than thermal stress as the case with wards 14 and 1 of Zvishavane where VCI indicated moderate drought conditions with TCI indicating mild-no drought conditions.

Average VCI and TCI for the 2001-2010 decade indicated that all wards to the south, south east, south west and central parts of Mberengwa except wards 11, 12 and Southern parts of ward 35 experienced moderate drought conditions. Both indices agreed on the dominance of moderate drought conditions in most of southern, south-western, western, northern, north western and central parts of Zvishavane District. Both TCI and VCI indicated that most wards to the western part of Mberengwa including wards 1, 36, 13, 34, parts of ward 11 and 37, ward 2 and parts of ward 3 to the north and wards 31 and 32 to the south west experienced severe extreme drought conditions during the 2001-2010 decade. In Zvishavane, greater parts of ward 14 to the east, wards 16, 15, 17 and 18 to the south east experienced severe to extreme drought conditions. These indices also confirmed that parts of ward 4 and 6 to the north east, wards 9, 17 and 35 at the central part, wards 14, parts of ward 11, 30 and 34 to the south west of Mberengwa experienced mild-no drought conditions during the 2001-2010 decade. In Zvishavane, wards 1 and 2 to the north, some parts of ward 15 and parts of ward 19 to the south experienced mild-no drought conditions as indicated by both indices.

Despite both indices agreeing on the spatial distribution of drought in Mberengwa and Zvishavane districts, some areas experienced more thermal stress than moisture deficit stress and others suffered more moisture deficit stress than thermal stress. Parts of wards 14, 30 and 34 south-west of Mberengwa District and parts of ward 9 to the south of Zvishavane, wards 7, 12 and 10 at the center and wards 4, 3, 2 and 1 to the north of Zvishavane experienced moderate moisture deficit stress as shown by VCI. In Mberengwa District, ward 5 proved to have experienced more thermal stress than moisture deficit as TCI indicated severe-extreme drought whereas VCI indicated mild-no drought conditions in most parts of this ward.

During the 2011-2020 decade, both VCI and TCI values indicated that most wards to the west (1, 36, 13, 34, 11 and 37) and east (6, 19, 20 and 21), wards 24 and 22 to the south and ward 2 to the north of Mberengwa District experienced severe-extreme drought conditions. For Zvishavane, all western wards except wards 12, 11 and 5 and all central and eastern wards experienced severe-extreme drought conditions. Wards to the southern parts of the district, and ward 18 to the south east of the district also experienced severe-extreme drought conditions. Both indices agreed that some parts of ward 36 to the east of Mberengwa, parts of ward 2 to the north and parts of ward 17 at the center experienced moderate drought conditions. In Zvishavane, it was indicated that some parts of ward 19 to the south, parts of ward 4 to the north, parts of ward 17 and 14 to the south east and east respectively experienced moderate drought during the 2011-2020 decade.

However, wards 14, 33, 30, 29 and 32 to the south west, ward 35 to the east, ward 3 to the north and parts of wards 22 and 28 to the south east of Mberengwa, wards 1 and 2 of Zvishavane to the north and most parts of ward 17 to the south east of Zvishavane experienced less thermal stress than moisture deficit as TCI and VCI indicated mild-no drought conditions and severe to extreme drought conditions respectively. Conversely, wards 25 and 26 to the south, ward 4 to the north east of Mberengwa and ward 19 to the south and parts of 5 of Zvishavane experienced more thermal stress than moisture deficit stress as TCI indicated severe to extreme drought conditions whilst VCI indicated moderate drought conditions in these areas.

Findings revealed that none of the wards in both Mberengwa and Zvishavane Districts frequently experienced moderate drought conditions during all study decades, an indication of dynamics of droughts biased more towards severe-extreme drought conditions. Wards 5,6,7,8 and 19 of Mberengwa District experienced moderate drought more frequently during the 1990-2000 and 2001-2010 decade whilst wards 2, 17 and 36 experienced this moderate drought more frequently during the 2001-2010 and 2011-2020 decades. Wards 4, 14, 17 and 19 of Zvishavane experienced moderate droughts more frequently during the 2001-2010 and 2011-2020 decades whilst wards 11 and 18 experienced these conditions during the 1990-2000 and 2001-2020 decades.

All remaining wards of Zvishavane only experienced moderate drought on average during the 2001-2010 decade. This shows that moderate and no drought conditions were experienced by many wards only during the 2001-2010 decade when La Nina events were more frequent (2001, 2005-6, 2007-2011) than the 1990-2000 and 2011-2020 decades (NOAA, 2021). These were confirmed by the U.S National Oceanographic and Atmospheric Administration and usually these conditions are associated with drought events in Southern Africa including Zimbabwe (Manatsa et al., 2008). Generally, the findings signify that there were some changes in drought conditions of most wards during the study period as indicated by shifts from one drought condition to another in most areas of both Mberengwa and Zvishavane Districts. Spatial and temporal variability in ward level drought severity in Mberengwa and Zvishavane has been confirmed by precipitation records obtained from AGRITEX which indicated variations in monthly precipitation from ward to ward thus indicating localized precipitation variability as one of key factors that determine spatial and temporal variability in drought at local scale (Manjowe et al., 2018). These results show that drought is now highly variable in terms of place and time within different areas (wards) of same districts.

4.3 Seasonal distribution of meteorological drought between 1990 and 2020 (based on Standardized Precipitation Index)

Drought categorization was done based on McKee et al (1993) interpretation values (**Table 3**)

Table 3: SPI interpretation

Source McKee et al. (1993)

Standardized Precipitation Index for 6 months (SPI-6) (October to March) was computed to indicate temporal distribution of meteorological drought during cropping seasons from 1990-2020.

Standardized Precipitation Index (SPI) values for Mberengwa and Zvishavane districts during the 1990-2000 decade indicated significant temporal dynamics of meteorological drought during the 1990-2000 decade. During this decade, the month of October experienced moderately dry conditions on average, both in Mberengwa and Zvishavane districts. However, extremely dry conditions were experienced during 1991/2 and 1993/94 seasons in both districts.

Table 4: SPI-6 for October to March during 1990-2000 decade in Mberengwa and Zvishavane districts

Source: Meteorological service department (2021)

Mberengwa District also experienced extreme drought during October of the 1996/97 season. For Zvishavane, October of the 1994/95 season was in moderately wet conditions whilst in Mberengwa moderately wet and very wet conditions were detected during the 1999/2000 and 1994/95 respectively. The remaining years had near-normal drought conditions during the same month.

For the month of November, no year experienced extremely dry conditions but moderately dry conditions to wet conditions were experienced in all years. In Zvishavane 1992/1993 and 1996/97 seasons experienced extremely wet conditions whilst 1995/96 and 1998/99 seasons had very wet conditions during the month of November. For Mberengwa, season 1998/99 experienced very wet conditions whilst seasons 1994/95 and 1999/2000 had moderately wet conditions. On average, during this decade, both districts were in near-normal but wetter conditions during the month of November.

As for the month of December, on average, both districts experienced near-normal but drier than normal conditions as indicated by negative SPI values (0.59 for Zvishavane and 0.37 for Mberengwa). However, in Zvishavane, December of seasons 1991/92, 1994/95, and 1997/98 was extremely dry whilst in Mberengwa these same conditions were experienced during the 1997/98 season with season 1991/92 comparatively better as it experienced severely dry conditions. In Zvishavane, the month of December had very wet conditions during 1992/93 and 1996/97 seasons whereas moderately wet conditions were experienced during the 1995/96 season. In Mberengwa District, only seasons 1992/93, 1996/97 and 1998/99 experienced moderately wet month of December.

For the month of January, Zvishavane experienced moderately dry January (-0.11) on average whilst Mberengwa had near normal but drier conditions (-0.29). Severely dry conditions were experienced during 1990/91, 1991/2 and 1998/99 seasons in Zvishavane whereas very wet conditions were experienced during 1996/97, 1997/98 and 1999/2000 seasons with season 1995/96 experiencing extremely wet conditions. During the same period, Mberengwa also experienced severely dry January during 1992/93 and 1998/9 seasons. Compared to Zvishavane, Mberengwa had an extremely dry January during the 1991/92 season.

For February, both districts had extremely dry conditions during 1991/92, 1994/94 and 1997/98 seasons. More so, both districts experienced extremely wet January during the 1999/2000 season. Comparatively, Zvishavane had wetter conditions (moderately wet) during the 1992/93 and 1996/97 season.

On average, during this decade the month of February experienced near-normal but dryer conditions in both Mberengwa (-0.28) and Zvishavane districts (-0.55).

As for the month of March, during the 1990-2000 decade, both Zvishavane (-0.09) and Mberengwa (-0.24) Districts experienced near normal but drier drought conditions though Zvishavane was comparatively wetter. Both districts experienced extremely dry March during the 1992/93 season. Zvishavane experienced severely dry March during 1997/98 season, moderately dry conditions during 1993/94 season and very wet conditions between 1994/95 and 1996/97 seasons. However, Mberengwa had another extremely dry March during 1993/94 season, and very wet month of March during 1994/95, 1996/97 and 1999/2000 seasons.

Table 5: SPI-6 for October to March during 2001-2010 decade in Mberengwa and Zvishavane districts

Source: Meteorological service department (2021)

During the 2001-2010 decade, SPI values indicated variations in drought conditions in both Mberengwa and Zvishavane Districts. On average, the month of October experienced near normal but drier conditions in both Zvishavane (-0.05) and Mberengwa (-0.43) districts between 2001 and 2010. However, the 2005/06 and 2008/09 seasons experienced extremely dry conditions whilst season 2002/03 and 2003/04 experienced extremely wet October in Zvishavane. In Mberengwa, 2000/01, 2005/06, 2006/07 and 2008/09 seasons experienced extremely dry conditions in the month of October whilst extremely wet conditions were in the same month for 2003/04 and 2004/05 seasons.

For the month of November, on average, both Zvishavane and Mberengwa districts experienced near normal but wetter conditions as shown by 0.16 and 0.12 SPI values respectively. For Zvishavane, season 2004/05 was the driest whilst the 2001/02 season experienced severely wet conditions. For Mberengwa, 2005/06 season had the driest November whereas the wettest November was experienced during 2008/09 season.

For the month of December, both districts experienced near normal but wetter conditions as shown by average SPI values of 0.60 and 0.13 for Zvishavane and Mberengwa districts respectively. Seasons 2002/03 and 2009/2010 had driest month of December in the category of severely dry conditions according to SPI values whereas wettest conditions were experienced in December of the 2001/02 season in Zvishavane. However, in Mberengwa the driest December was experienced during the 2002/03 season with SPI value indicating severely dry conditions whilst the 2007/2008 season had the wettest December with an SPI value indicating extremely wet conditions.

During this decade, the month of January was in near-normal but drier conditions on average, as indicated by SPI values of -0.45 and -0.33 for Zvishavane and Mberengwa districts respectively. In Zvishavane, January of the season 2001/02 was the driest with SPI values in the extremely dry condition category whereas January of seasons 2006/07 and 2007/08 were the wettest with SPI values indicating very wet conditions. For Mberengwa, driest January was experienced during 2001/02 and 2006/07 seasons with SPI values in the extremely dry conditions whilst the wettest January was experienced during the 2007/08 season with SPI values indicating very wet conditions.

On average, during the 2001-2010 decade, both districts experienced near normal February but Zvishavane experienced slightly drier than normal (-0.36) whilst Mberengwa had slightly wetter than normal (0.35) conditions. For Zvishavane, season 2007/08 had the driest February with SPI values indicating extremely dry conditions whilst the 2000/01 season had the wettest February. In Mberengwa, 2001/02 and 2007/08 seasons had driest month of February with SPI values indicating extremely dry conditions whilst season 2000/01 had the driest February.

For the month of March, both districts experienced an average of near normal drought conditions with Zvishavane District being slightly drier than normal (-0.34) whilst Mberengwa was slightly wetter than normal (0.89). For Zvishavane, seasons 2001/02 and season 2008/09 had driest month of March with SPI values indicating extremely dry conditions whereas seasons 2000/03 and 2003/04 had wettest month of March. For Mberengwa, seasons 2001/02, 2004/05, 2005/06, 2006/07 and 2007/08 had extremely dry conditions in March as per SPI value indications which were the driest during this decade whilst season 2002/03 had the wettest month of March.

Table 6: SPI-6 for October to march during the 2011-2020 decade in Mberengwa and Zvishavane districts

Source: Meteorological service department (2021)

During the 2011-2020 decade, on average, Zvishavane experienced moderately dry October with an SPI value of -1.08 whereas Mberengwa district experienced near-normal but drier conditions as shown by an SPI value of -0.78. Driest conditions during the month of October were experienced during seasons 2018/19 and 2019/20 seasons in Zvishavane whilst wettest conditions during the same month were experienced during 2012/13 season when SPI value indicated moderately wet conditions. In Mberengwa, driest conditions in same month were experienced during seasons 2014/15, 2017/18 and 2019/20 when SPI values showed extremely dry conditions whereas wettest conditions during this month were experienced during season 2012/13.

On average the decade 2011-2020 experienced near normal but drier November conditions in both Zvishavane (-0.70) and Mberengwa (-0.01) districts. For Zvishavane, driest conditions in the month of November were experienced during the 2016/2017 season when SPI values showed severely dry conditions, whilst wettest conditions in the same month were experienced during 2010/11 and 2017/18 seasons with SPI values indicating moderately wet conditions. However, for Mberengwa, all seasons experienced near normal conditions except 2017/18 season which experienced moderately wet conditions. During this decade, the month of December on average, experienced near normal conditions though slightly drier than normal conditions in both Zvishavane (-0.29) and Mberengwa (-0.08) districts. For Zvishavane, driest conditions in this month were experienced during the 2019/2020 season

when SPI values showed extremely dry conditions whereas wettest conditions during the same month were experienced during 2014/2015 and 2016/2017 seasons with SPI values indicating extremely wet conditions. In Mberengwa, driest conditions in December were experienced during 2012/13, 2015/16 and 2019/20 seasons when SPI values indicated very dry conditions whereas wettest conditions in this month were experienced during 2014/15 and 2016/17 seasons when SPI values indicated very wet conditions.

Average drought conditions for the month of January during the 2011-2020 decade were near normal but wetter than normal in both Zvishavane (0.16) and Mberengwa (0.10) districts. In Zvishavane, driest conditions in this month were experienced during the 2015/16 season when SPI value indicated extremely dry conditions whereas wettest conditions in this month were experienced during the 2010/11. For Mberengwa, SPI values indicated that the driest January was the one during the 2015/2016 season whilst the wettest was during the 2010/11 season. For the month of February, both districts experienced near normal but slightly drier conditions as indicated by SPI values of -0.05 and -0.04 for Zvishavane and Mberengwa districts respectively. These findings are in tandem with findings by Mberego and Gwenzi (2014) and Winkler et al. (2017) who confirmed severe drought conditions throughout Zimbabwe during the 2011/12 and 2015/16 thus tallying with confirmed drought condition in Mberengwa and Zvishavane Districts during this period. In Zvishavane, during this decade, the driest conditions during February were experienced during the 2010/11 season when extremely dry conditions were confirmed by SPI whilst wettest conditions were experienced during 2016/2017 and 2018/19 seasons when SPI showed extremely wet conditions. For Mberengwa, driest conditions in the month of February were experienced during 2010/11 and 2012/13 seasons whilst wettest conditions were experienced during the 2017/18 season. This is against the findings by Manatsa et al. (2008) and Frischen et al. (2020) who omitted the 2010/11 season among drought years in Zimbabwe. This is because these scholars were more focused on agriculturally significant drought that affected the whole rainfall season not just precipitation shortage within specific months.

Zvishavane had near normal but drier conditions (-0.16) on average, during the 2011-2020 decade whilst Mberengwa experienced moderately dry conditions (-1.45) on average. In Zvishavane, driest conditions in the month of March were experienced during the 2010/11 season (extremely dry conditions) whilst wettest conditions were experienced during the 2015/16 season when SPI showed extremely wet conditions. For Mberengwa, driest conditions in the month of March were experienced during 2010/11, 2011/12, 2012/13, 2017/18 and 2019/20 seasons. This made the decade 2011-2020 the driest in as far as the month is concerned. This indicates early rainfall season cessation in Mberengwa and Zvishavane Districts, a scenario also observed by Tadross (2018) in the whole of southern Africa and Zimbabwe as a whole. Overall, seasonal drought conditions from 1990-2020 showed increasing frequency as shown by decline in frequency of extremely wet and very wet conditions at the expense of extremely dry to moderately dry conditions.

The month of March in both Districts proved to be dry though the 1990-2000 decade was comparatively better (near normal but drier than normal conditions). When comparing the two districts regarding drought conditions for the month of March, Mberengwa was drier than Zvishavane throughout the study period. This was due to lower precipitation in Zvishavane compared to Mberengwa as indicated by precipitation records from the meteorological service department. Low precipitation during the month of March in Mberengwa might have been due to 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 in the far south and south-western Zimbabwe (Manjowe et al., 2018). Therefore precipitation gradient in these cases lowers towards Mberengwa which is south of Zvishavane. However higher precipitation and comparatively less drought conditions in Zvishavane during October and November can be attributed to movement of the ITCZ from north to south as the summer begins (Manjowe et al., 2018) hence Zvishavane received precipitation inducing conditions first than Mberengwa which experiences these conditions latter.

Results of the Mann Kendall trend test showed that the p-values for all months are greater than the significance level $\alpha=0.05$, which indicates no statistically significant trend in precipitation distribution between 1990 and 2020. This indicates that precipitation distribution during months within the cropping season in both Mberengwa and Zvishavane districts did not follow a well-defined statistically positive or negative trend but fluctuated over the study period.

5. Conclusion

The study assessed spatio-temporal dynamics of agrometeorological drought in Mberengwa and Zvishavane Districts between 1990 and 2020. Both VCI and TCI drought indices showed the same drought trajectory between 1990 and 2020. It was shown that area covered by drought conditions declined between the 1990 and 2000 and 2001-2010 decade before increasing during the 2011-2020 decade. Findings indicated that the 2011-2020 decade experienced more droughts followed by the 1990-2020 decade whilst the 2001-2010 decade was comparatively less droughty. This was an indication of an increase in drought frequency in both Mberengwa and Zvishavane Districts between 2011 and 2020 after a decline between 2001 and 2010.

Results indicated that none of the wards in Mberengwa and Zvishavane districts have been constantly under moderate or no drought conditions which shows that all wards experienced mostly severe-extreme drought conditions. However the majority of wards experienced moderate drought conditions only during the 2001-2010 decade. Almost all wards have been in severe to extreme drought conditions more frequently during the 2011-2020 decade. Findings therefore indicate significant spatial dynamics of drought conditions in both Mberengwa and Zvishavane District wards.

It was highlighted that meteorological drought was not evenly distributed across all decades. Dry conditions in the first months (October and November) of the rain season have been indicated during the 1990-2000 decade, followed by wetter conditions during the 2001-2010 decade and comparatively drier conditions during the same months during the 2011-2020 decade. This indicated late onset of the rainfall season during the 1990-2000 and 2011-2020

decades compared to the 2001-2010 decade. It was also shown that rainfall cessation was earlier during the 2001-2010 and 2011-2020 decades and late during the 1990-2000 decade. Therefore, drought was heterogeneously distributed both spatially and temporally in Zvishavane and Mberengwa Districts.

6. Recommendation

In light of the findings from this study, the following recommendations are suggested:

- The Meteorological Services Department of Zimbabwe is encouraged to improve the spatial distribution and number of rain gauges in all districts of Zimbabwe so as to improve spatial analysis of meteorological drought in Zimbabwe.
- The government of Zimbabwe is advised to set up climate research centres in all provinces of Zimbabwe with a mandate to conduct climate change and associated impact researches. This will improve availability of climate change related data which is useful when addressing the impacts of climate change.
- The Meteorological Services Department of Zimbabwe is also advised to consider remote sensing methods of precipitation measurement which will improve meteorological data availability as well as reducing gaps in meteorological data like missing precipitation records.
- The Government of Zimbabwe is encouraged to support scientific monitoring of drought in the country through ensuring the availability of software and high quality datasets that allow for more detailed mapping of drought.
- Drought researchers are advised to adopt both meteorological and remote sensing methods of drought mapping which ensures solid mapping of drought since these methods complement each other in drought mapping.

Declarations

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The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript

Conflicts of interests

This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue.

Availability of data and material

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Code availability

Not applicable

Author's contributions

Oshneck Mupepi was responsible for coming up with the idea, doing data compilation and analysis under supervision of Prof Mark Makomborero Matsa. Oshneck Mupepi developed the final draft and proof reading and further adjustments were done by mark Makomborero Matsa.

Ethics approval

Approval was granted by Midlands state university to carry out the research as well as to publish under its name. All sources were properly cited to avoid plagiarism.

Consent to participate

All authors participated and agreed to participate up to final revision of the manuscript

Consent for publication

Authors agreed to let the paper published when considered for publication.

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Tables

Table 1: Satellite data sets used and their meta-data

Period	Satellite platform	Resolution (meters)	Path	Row	Month
1990-2000	Landsat 4/5 TM	30	170	73& 74	March
2001-2010	Landsat 4/5 TM	30	170	73& 74	March
2011-2014	Landsat 4/5 TM	30	170	73& 74	March
2015-2020	Landsat 8 OLI	30	170	74	March

Source: Authors

Table 2: Vegetation Condition Index and Temperature Condition Index value interpretation

VCI / TCI values (%)	Drought category
>30	Mild-no drought
20-30	Moderate drought
0-20	Severe-extreme drought

Source: Kogan (2002)

Table 3: SPI interpretation

Drought category	SPI value
≥ 2.0	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Very dry
≤ -2	Extremely dry

Source McKee et al. (1993)

Table 4: SPI-6 for October to March during 1990-2000 decade in Mberengwa and Zvishavane districts

	ZVISHAVANE						MBERENGWA					
	OCT	NOV	DEC	JAN	FEB	MAR	OCT	NOV	DEC	JAN	FEB	MAR
1990/91	-1.45	-1.48	-1.05	-1.76	-0.91	0.42	-0.91	-1.11	-1.38	-0.55	-0.53	1.02
1991/92	-3.45	0.85	-2.1	-1.84	-2.73	-0.57	-2.99	-0.72	-1.76	-2.32	-2.61	-0.23
1992/93	-0.62	-1.41	1.95	-1.31	1.43	-2.43	-0.61	-0.70	1.34	-1.59	0.15	-2.92
1993/94	-3.50	2.33	0.20	-1.44	-2.11	-1.24	-2.99	1.12	-0.24	-1.44	-2.42	-2.41
1994/95	1.23	-1.39	-2.42	-1.11	1.01	1.58	1.78	0.99	-0.39	-1.49	0.11	-1.82
1995/96	-1.38	1.59	1.04	2.01	-0.73	1.63	-1.32	0.84	-0.35	1.79	1.43	0.17
1996/97	-0.81	2.21	1.9	1.97	-0.73	1.63	-2.51	1.10	1.15	1.43	-0.47	1.96
1997/98	-0.69	-0.77	-3.1	1.99	-2.01	-1.97	-0.31	-0.21	-2.8	1.86	-2.43	-0.39
1998/99	-0.49	1.61	-1.31	-1.61	-1.38	-0.41	-2.3	0.63	1.1	-1.87	1.29	0.18
1999/2000	-3.45	-1.39	-1.02	1.98	2.71	0.51	1.43	1.99	-0.39	1.21	2.64	1.96
AVERAGE	-1.46	0.22	-0.59	-0.11	-0.55	-0.09	-1.075	0.393	-0.37	-0.29	-0.28	-0.24
KEY												
			Extremely dry	Severely dry	Moderately dry	Near normal	Moderately wet	Very wet	Extremely wet			

Source: Meteorological service department (2021)

Table 5: SPI-6 for October to March during 2001-2010 decade in Mberengwa and Zvishavane districts

	ZVISHAVANE						MBERENGWA					
	OCT	NOV	DEC	JAN	FEB	MAR	OCT	NOV	DEC	JAN	FEB	MAR
2000/01	-0.45	0.99	1.85	-1.96	2.32	-0.21	-2.99	0.792	-0.15	-1.90	2.13	0.99
2001/202	-0.54	2.33	2.11	-2.51	-1.93	-2.38	-0.42	1.23	-0.28	-2.98	-2.10	-2.79
2002/203	3.30	-1.44	-1.86	-1.69	-0.89	2.41	1.6	-1.43	-1.54	0.98	-0.33	3.13
2003/04	3.10	-1.39	-0.22	0.48	-1.42	2.25	2.43	-0.59	-0.35	1.32	1.43	0.23
2004/05	1.11	-1.56	1.22	-0.52	0.95	-1.21	2.11	-1.00	-0.12	-1.62	1.39	-2.73
2005/06	-3.43	-1.11	1.96	0.63	0.99	0.63	-2.99	-2.11	1.29	1.01	-0.25	-2.32
2006/07	1.25	1.62	-0.34	1.89	-1.32	-1.99	-2.99	1.53	-0.26	-2.32	1.25	-2.67
2007/08	-0.82	-1.11	2.13	1.67	-2.54	-2.51	-0.10	1.18	2.77	1.59	-2.61	-2.54
2008/09	-3.40	1.69	0.95	-0.45	-0.79	0.23	-2.35	2.12	-0.42	-0.41	1.25	-1.62
2009/10	-0.59	1.55	-1.82	-1.99	1.03	-0.59	1.43	-0.52	0.33	0.99	1.30	1.45
AVERAGE	-0.05	0.16	0.60	-0.45	-0.36	-0.34	-0.43	0.12	0.13	-0.33	0.35	-0.89
KEY												
		Extremely dry	Severely dry	Moderately dry	Near normal	Moderately wet	Very wet	Extremely wet				

Source: Meteorological service department (2021)

Table.6: SPI-6 for October to march during the 2011-2020 decade in Mberengwa and Zvishavane districts

S	ZVISHAVANE						MBERENGWA					
	OCT	NOV	DEC	JAN	FEB	MAR	OCT	NOV	DEC	JAN	FEB	MAR
2010/11	-0.73	1.22	1.21	2.13	-2.0	-2.01	-1.99	-0.21	0.34	2.11	-1.97	-2.21
2011/12	-0.71	-0.77	-0.25	1.67	-0.81	-0.64	-0.10	-0.23	0.22	-1.49	-0.24	-2.32
2012/13	1.22	-1.12	-1.84	1.72	-1.56	-0.64	1.61	-0.41	-1.52	1.87	-1.73	-2.98
2013/14	-0.31	-1.45	0.23	0.49	0.98	0.72	0.20	0.34	0.42	1.19	-0.28	-1.91
2014/15	-1.51	-1.12	2.01	-1.63	-1.49	1.31	-2.4	-0.21	1.56	-0.98	-1.45	1.57
2015/16	-1.30	-1.32	-1.82	-2.01	-1.41	2.31	-0.22	-0.21	-1.64	-1.61	-0.43	2.14
2016/17	-0.82	-1.59	2.01	1.82	2.53	-0.32	1.38	0.93	1.56	1.54	1.57	-1.82
2017/18	0.21	1.27	-1.03	-0.62	2.66	0.34	-2.99	1.12	0.39	-0.42	2.55	-2.90
2018/19	-3.30	-1.32	-1.33	-1.35	1.38	-1.33	-0.25	-0.99	-0.42	-0.68	1.62	-1.82
2019/20	-3.50	-0.76	-2.09	-0.62	-0.75	-1.34	-2.99	-0.21	-1.74	-0.51	-0.01	-2.21
AVERAGE	-1.08	-0.70	-0.29	0.16	-0.05	-0.16	-0.78	-0.01	-0.08	0.10	-0.04	-1.45
KEY												
		Extremely dry	Severely dry	Moderately dry	Near normal	Moderately wet	Very wet	Extremely wet				

Source: Meteorological service department (2021)

Figures

Figure 1

Map of Zvishavane and Mberengwa Districts

Source: Authors

Figure 2

Agro-meteorological drought determination procedures

Source: Authors

Figure 3

Decadal dynamics of drought spatial severity between 1990 and 2020

Source: Remote sensing data

Figure 4

Source: Remote sensing data

Figure 5

Average VCI and TCI in Mberengwa and Zvishavane districts between 1990 and 2020

Source: Remote sensing data