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Geographical Variability of Drought in Northern South Africa

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Abstract

This study focuses on the geographical variation of drought in northern South Africa (hereafter NSA). It assesses seasonal rainfall characteristics to determine drought occurrence and persistence in NSA. Seasonal rainfall data for the period 1960-2009 is used and was obtained from the South Africa Weather Service (SAWS). Rainfall stations in NSA are well distributed, forming a dense network of point-source data samples. Standardised Precipitation Indices (SPIs) are employed to detect drought occurrence and intensity at different locations. Analysis of SPIs with respect to time suggests that the severity of drought results from the accumulation of consecutive dry spells within a rainfall season and sometimes even consecutive dry rainfall seasons. It also shows the intensity and frequency of drought has increased in recent years. The trend towards worsening drought conditions has significant socioeconomic implications for the region and other areas with similar geographical settings.

Keywords: drought variation, seasonal rainfall, SPI, South Africa

1. Introduction

This paper assesses droughts in NSA (Fig. 1) over the long term, examining the duration, frequency and intensity of dry spells, and their changes over a 50-year period. When a dry spell lasts an abnormally long time, then it becomes a drought. Drought timescales are particularly important, according to Vicente-Serrano and López-Moreno (2008), since the responses of various systems to drought are different at each scale. Spatial variation is similarly important; a particular intensity of drought might affect the entire region or just a localized area [or ‘part of it’]. Despite this, local scale drought has not been given much attention in the field of climate studies; according to Wilbanks and Kates (1999), understanding of linkages between large scale and local scale developments is important in a wide range of sciences, since local scale changes affect large scale and vice versa.

The people of NSA are mainly subsistence farmers who depend on rain-fed agriculture for crop and livestock production. The rainfall is seasonal, so the drought timescale considered in this study is that which affects the rainfall season – October to March. Drought in NSA is associated with food shortages, livestock losses, disruption of farming activities and outward migration, especially of able-bodied manpower (Vogel & Drummond, 1993; Vogel, 1994; Omara-Ojungu, 1999). During the summers of 1982, 1983 and 1984 the region experienced extended droughts that severely diminished agricultural production and water reserves (Schulze, 1984; Rocha & Simmonds, 1997; Dube & Jury, 2000). Records for that period showed rainfall to be 60% below normal over the entire region (Jury & Lyons, 1994). Extended droughts in South Africa were observed in 1991-93 and 1994-95 (Joubert, Mason, & Galpin, 1996; Rocha & Simmonds, 1997). These added further stress to the area, which had not recovered economically from the prolonged 1981-84 drought.

The frequency of droughts in the past forty years in Africa as a whole has added to concern about possible anthropogenic climate change such as through poor agricultural practices and overgrazing by livestock (Adedoyin, 1997). Other anthropogenic factors that might have contributed to the recurrence of droughts in Africa and other developing nations include planned population redistribution that has taken place in those areas over time (e.g. areas such as Tanzania in Villagisation programs, or resettlement in connection with Kariba Dam in Zambia). Migration and population movements have always taken place in many African countries, from pre-colonial times to the present day (Kikula, 1986). In South Africa, and especially in NSA, recorded forced removals took place from the 1920s to the 1960s. Today in NSA, 87% of the population is concentrated in 9% of the total land. Despite the apparent conservation value to the environment of the scattered traditional population distribution, the government of the day forced people to live in clustered settlements; Kikula (1986) maintain that the population distribution was mainly for administrative convenience, to ensure easy supply of labour or even to facilitate quick suppression of any possible indigenous opposition to the administration.

Aside from the Western and Eastern Cape, much of South Africa is climatologically disadvantaged in that it receives a unimodal rain season centred on January. As Rocha and Simmonds (1997) pointed out, the failure of seasonal rains in a unimodal rainfall area leaves the area water stressed until the next wet season. By contrast, areas such as Western Cape and Eastern Cape that receive more than one mode of rain tend to recover from the failure of rains in one mode when the next mode is normal or above normal.

Drought problems in NSA arise not simply from a lack of rainfall during the dry season, but from the variability and unpredictability of drought events (in terms of their frequency, severity and persistence), and also the variability of rainfall in the rainy season. Drought prone areas need proper drought diagnosis and mitigation of the impacts, and these are impossible without detailed information about drought (Unganai, 1993). Currently, there is a lack of detailed understanding of the duration, persistence, spatial coverage, frequency and intensity of inter-annual and seasonal droughts in NSA. This study aims to fill these gaps in the current knowledge. It categorises drought events ranging from near-normal to extreme – the categories as used by McKee, Doesken, & Kleist (1993).

2. Data and Methods

The rainfall data used in this study consist of monthly means for the 49 stations in NSA (22–24° S, 29–32° E) identified in Fig. 1. It was provided by SAWS. Only stations with a recording period of 50 years (1960-2009) or more were used. This exceeds the 30-year span considered sufficient for climatic changes of significance (WMO – No 335, 1972). Data series from different stations are significantly cross correlated ($r > 0.80$, $n = 98$).

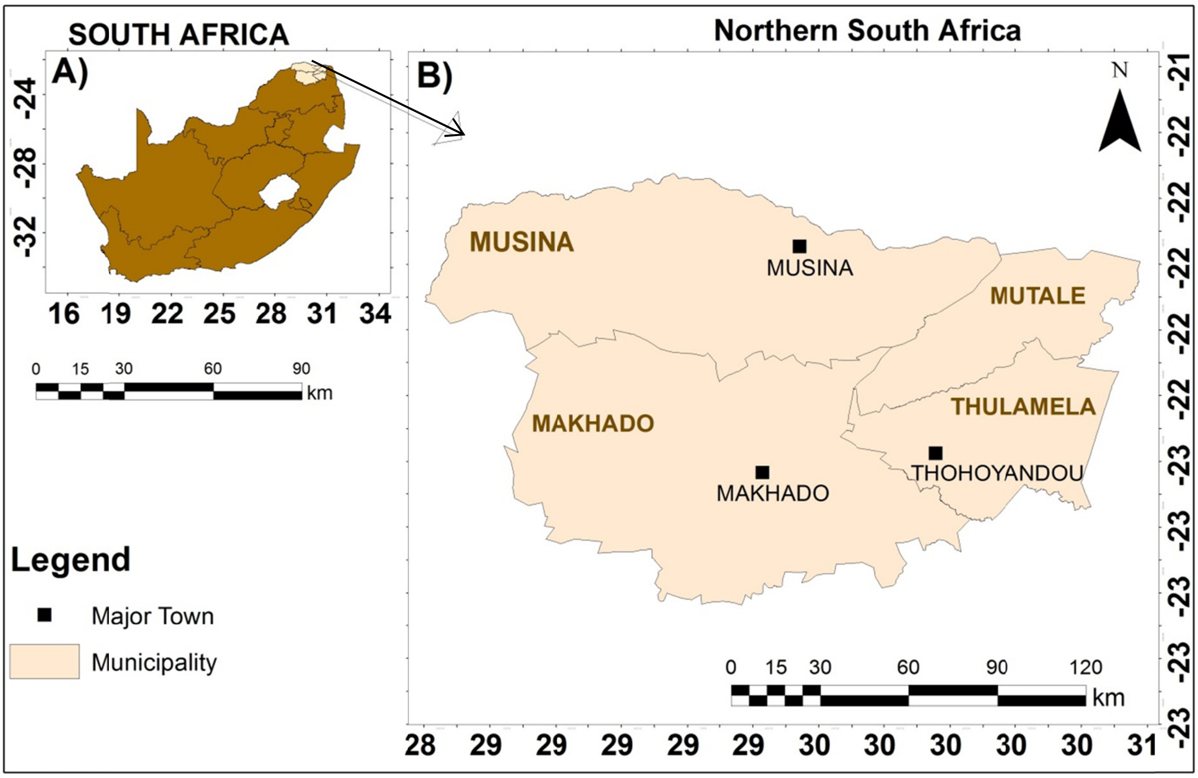

Figure 1. Location of the study area– Northern South Africa (NSA)

This study uses the Standardized Precipitation Index (SPI), which was developed by McKee et al. (1993) and has been found suitable in many studies since then (Guttman, 1998; Vicente-Serrano, Gonzalez-Hidalgo, de Luis, & Raventos, 2004; Giddings, Soto, Rutherford, & Maarouf, 2005; Goodrich & Ellis, 2006; Wu, Svoboda, Hayes, Wilhite, & Fujiang, 2006; Li, Fu, Juarez, & Fernandes, 2007).

Other indices – such as the Palmer Drought Severity Index (PDSI) (Palmer, 1965), Surface Water Supply Index

(SWSI) (Shafer & Dezman, 1982), and Crop Moisture Index (CMI) (Palmer, 1968) – were rejected: firstly, the study area is not topographically uniform, but has complex terrain with valleys and elevated areas, and secondly, it has highly variable rainfall (Nenwiini & Kabanda, 2013). Many indices do not function well in such circumstances.

The SPI was developed using precipitation only (Hayes et al. 1999; Mckee et al. 1993; McKee et al. 1995) and it classifies rainfall as a standardised departure with classifications ranging from < -3 (extremely dry) to > +3 (extremely wet). Since precipitation is not normally distributed, it is therefore, first transformed so that precipitation values follow a normal distribution (Edwards and McKee 1997). In this study, all the rainfall seasons under consideration exceed six months and in some cases drought events overlap two or more rainfall seasons. Therefore, according to the central limit theorem, as one moves to extended time periods in excess of 6 months, the resultant time averaging will tend to shift the observed probability distributions towards normal. The SPI is computed by fitting a gamma probability density function to a given rainfall time series. However, since the time series used is long, it is possible to use the normal probability distribution instead of gamma, which is computationally easier to calculate and maybe more accurate, because of a better fitting to the data. In this case, the SPI index becomes simply:

$$SPI = Z = (x - \mu)/\sigma \quad (1)$$

Where μ and σ are the sample estimates of the population mean and standard deviation, respectively.

Equation 1, is the simplified version of the SPI. According to Hayes et al. (1999) SPI is used to measure the precipitation changes, define drought intensities and the criteria for a drought event.

3. Results

3.1 Onsets and Cessation of Drought

SPI is used to monitor rainfall over a short time periods (such as a month) (Lloyd-Hughes & Saunders, 2002). Dry seasons (non-rainfall season) are included in this analysis, in order to give a clear picture on when the rainfall deficiency begins. This approach is justified since no month of the year in NSA is ever completely dry, even in a drought.

Looking at the drought of 1963-64, Figure 2 shows the onset of drought, which is July 1963, and its end in October 1964. Maximum intensity was reached in November 1963 when the SPI record was -1.6. Another low SPI occurred in March 1964 with an SPI of -1.2. In total, 15 consecutive months from July 1963 to September 1964 recorded rainfall amounts that were below the normal precipitation.

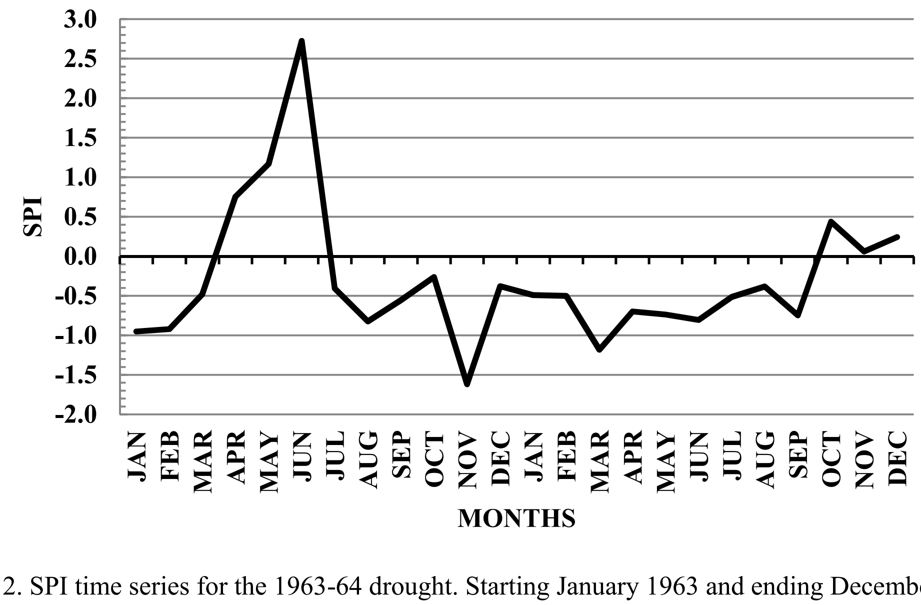

Figure 2. SPI time series for the 1963-64 drought. Starting January 1963 and ending December 1964

Figure 3 shows the time series of monthly SPI for the1981-83 drought. During 1981, low SPI values were recorded in April, June and July, followed by three months of above-normal rains (August to November). From December 1981 to June 1983, all months had low SPI except for April and May 1982, which recorded SPI of 0.3

and 1.2 respectively. However, the period was too short and isolated to offset the drought (and May is normally a low-rainfall month). Drought ended in June 1983. This was the longest drought in the 50-year study period; it lasted a total of 18 months and included 16 consecutive months of below-normal rainfall.

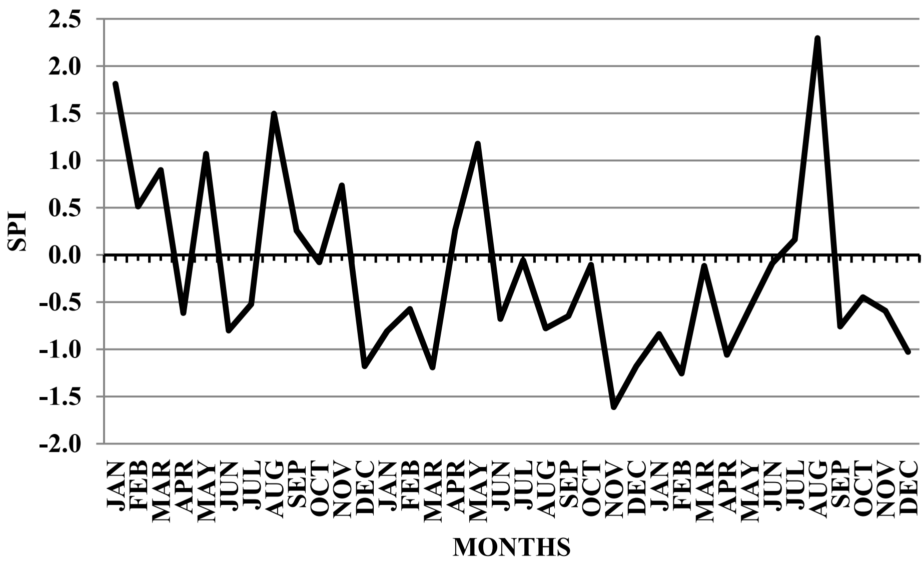

Figure 3. SPI time series for the 1981-83 drought. Starting January 1981 and ending December 1983

Figure 4 illustrates the 1991-92 drought. There were negative SPI values for 12 consecutive months (reaching a minimum of -1.4 in November 1991), followed by a single positive value (1.4 for June 1992) and negative values for a further five months. The above-average rainfall for June 1992 had no significant impact on the drought, which continued to ravage NSA; in total, the drought ran for 18 months, from June 1991 to December 1992.

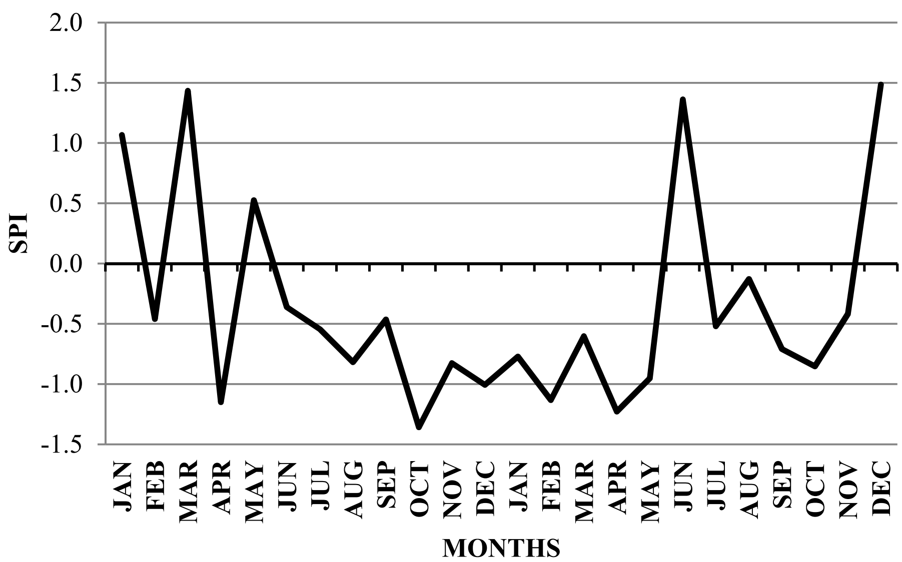

Figure 4. SPI time series for the 1991-92 drought. Starting January 1991 and ending December 1992

Looking at the drought of 1997-98, Figure 5 shows that the first eight months of 1997 were characterised by alternating events of above and near-normal SPI. However, April, June and August values were lower than -0.5 which can be categorised as near-normal drought. From September to November, higher SPI values were observed, followed by -1.0 SPI in December 1997. A small increase in SPI was recorded in January 1998, followed by five months of low SPI that continued till June 1998.

From the SPI pattern in Figure 5, it follows that drought began in December 1997 and ended in June 1998. The January 1998 positive event was not large enough to impede the drought.

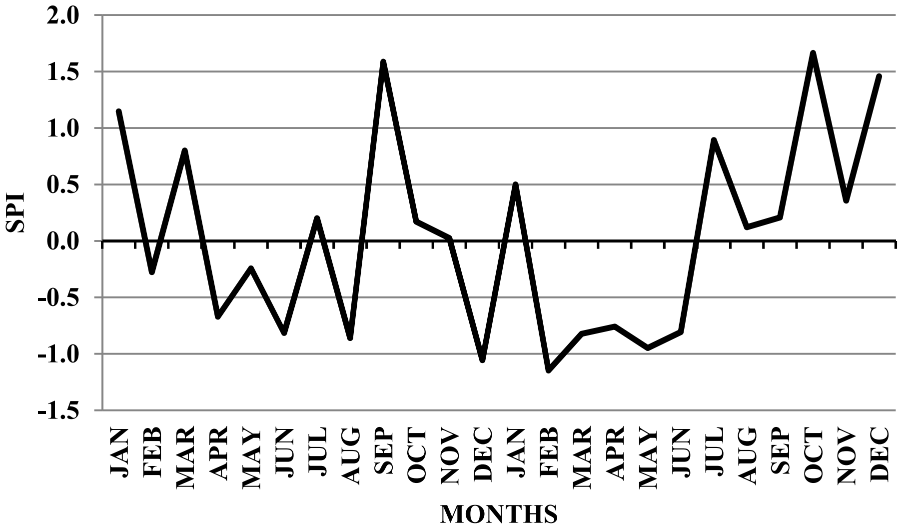

Figure 5. SPI time series for the 1997-98 drought. Starting January 1997 and ending December 1998

Table 1 shows the onset and cessation of drought, which were obtained using SPI as presented in Figures. 2 - 5. It is seen from the table that the period of start and end are different from one drought to another. The 1981/83 drought involved two consecutive rainfall seasons, making it the longest drought since the sixties.

Table 1. Drought onset and cessation time in NSA

Drought Period	Onset	Cessation
1963/64	July 1963	October 1964
1981/83	December 1981	June 1983
1991/92	June 1991	December 1992
1997/98	December 1997	June 1998

3.2 Drought Categories, Occurrences and Persistence

The drought categories used in this study – near-normal, moderate, severe and extreme – are the same as those used by McKee et al. (1993). Attempting to tailor the SPI to the specific region would destroy the primary advantage of the SPI index, which is its universality.

Table 2 indicates drought categories, their corresponding range of values of the SPI, probabilities of occurrence and the anticipated frequencies of occurrence in NSA.

Table 2. Drought Criteria in NSA

Drought Index (SPI)	Drought Category	Frequency years in 50 year sample	Probability
-.99 to .99	Near normal	1.5	**P = 0.680**
-1.0 to -1.49	Moderately dry	11.0	P = 0.091
-1.5 to -1.99	Severely dry	22.7	P = 0.044
-2 and less	Extremely dry	43.5	P = 0.023

Droughts observed in 1981 and 1991 belong to the severe category (Table 3). In the extended drought episode that started in 1981, 63% of the total area of NSA experienced drought magnitude of $-1.99 < Z < -1.5$, and 12% experienced drought with the $Z \leq -2.1$. The rest of the area (25%) reported moderate levels ($-1.49 < Z < -1.0$).

Table 3. Drought categories during 1960-2009

Period	Length in rainfall seasons (Consecutive below normal)	Category severity
1963-64	2	Moderate drought
1981-83	2	Severe drought
1991-92	2	Severe drought
1997-98	1	Moderate drought

Areal drought severity, coverage and intensities for 1981/83 and 1991/92 drought are presented in Fig. 6 and Fig. 7. During those drought episodes more than two thirds of the total area was affected. Both seasons reached a threshold of SPI value of -1.5, which qualifies them as severe drought.

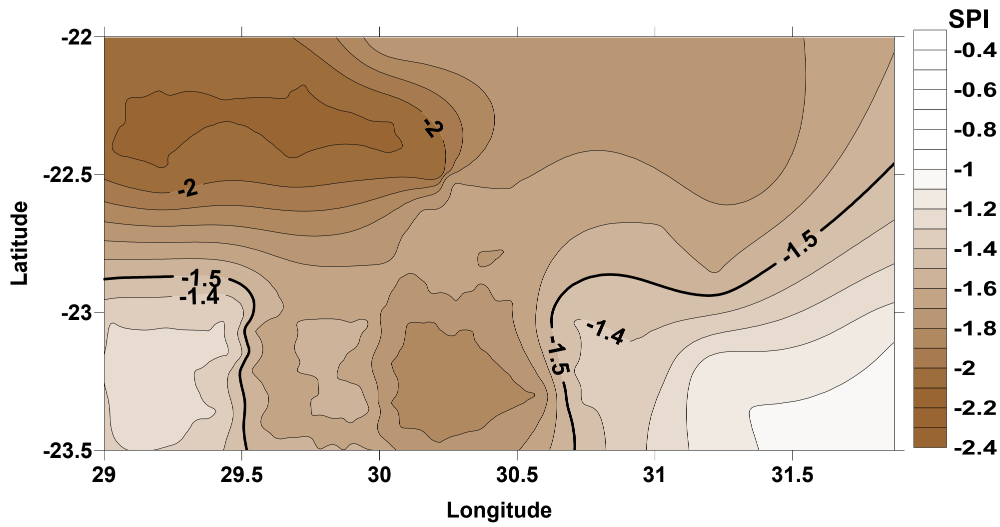

Figure 6. Spatial variability of 1981-83 drought patterns in SPI values for NSA. SPI contour intervals are 0.1.

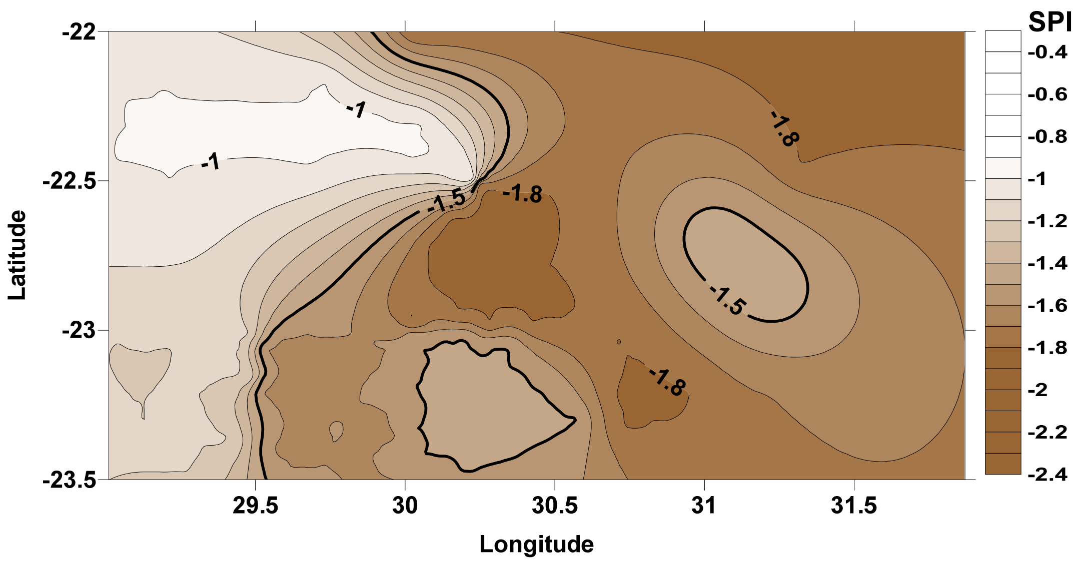

Figure 7. Spatial variability of 1991-92 drought patterns in SPI values for NSA. SPI contour intervals are 0.1.

Using the SPI value obtained for the severe drought, the probability of occurrence (P) of that magnitude in NSA can be computed from statistical tables (Norcliffe, 1977), which represent normalised statistics as follows:

$$P(-1.99 < Z < -1.5) = 0.044 = 4.4\%$$

More than 60% of NSA experienced this drought type in both the 1981/83 and 1991/92 rainfall seasons. These results are in general agreement with the time spell that was suggested by Agnew (2000), as well as Santos and Henriques (2000), for defining severe drought. They suggested that severe drought does not happen very often; the probability of such a drought starting in any given year would be approximately 4%. Moderate droughts occurred in the 1963/64 season (Fig. 8) and the 1997/98 season (Fig. 9). The probability of occurrence of this type of drought is given as:

$$P(-1.49 < Z < -1.0) = 0.091. \approx 9\%$$

The SPI indicates a moderate drought 9 per cent of the time. Drought severity, as classified from the SPI values, also correlates with areal coverage, with severe droughts affecting larger areas than moderate or near-normal ones.

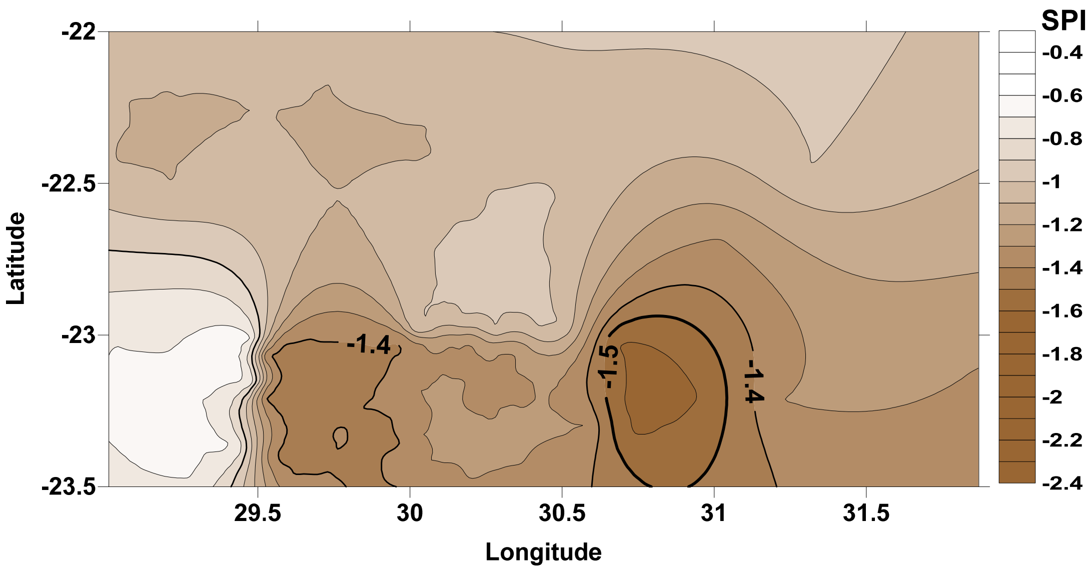

Figure 8. Spatial variability of 1963-64 drought patterns in SPI values for NSA. SPI contour intervals are 0.1

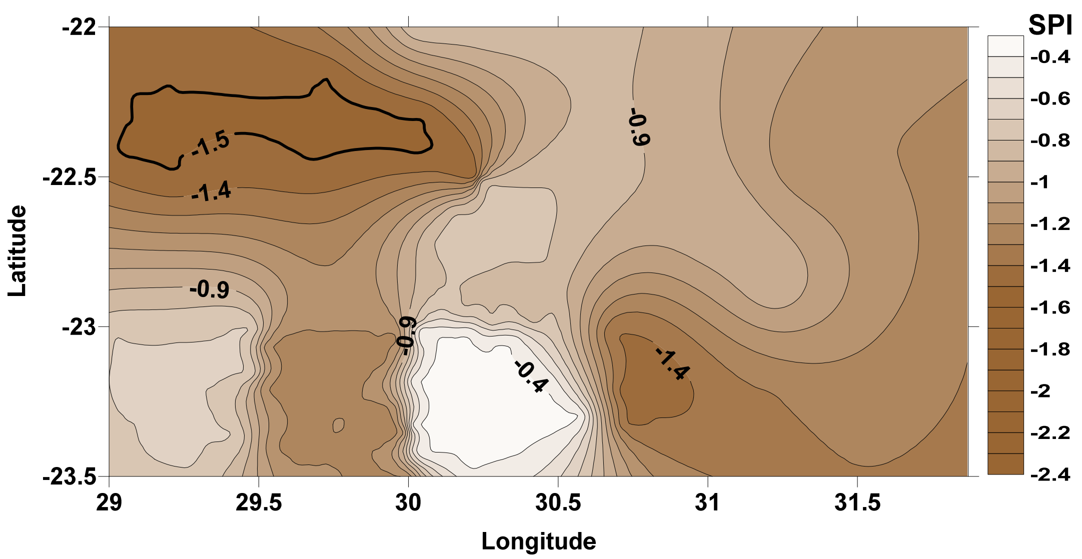

Figure 9. Spatial variability of 1997-98 drought patterns in SPI values for NSA. SPI contour intervals are 0.1

The third class of drought is the near-normal category P (-0.99 > Z > 0.99) = 0.68. This class is the most common. NSA is not a rainy area, and deficiency of rain is common, but this does not necessarily mean a widespread drought exists all the time. The results for this class suggest that the SPI is in the near-normal category 68% of the time, or such events occur on average once in one and half years. This category is not listed in Table 3 or in any figures because of the high frequency of occurrence during the period of study. These frequent events are characterised by very variable area coverage. When considering all the criteria needed to categorise this event, it becomes difficult to separate them from normal rainfall events – after all, NSA is a semi-arid area with generally low rainfall and frequent dry spells.

4. Discussion and Conclusions

Climate-dependent agriculture that includes raising cattle and commercial and subsistence crop farming – is the economic mainstay of NSA and accounts for most employment in the region.

The region suffers from a relatively limited supply of both ground and surface water resources, leaving the agricultural sector largely dependent on rainfall. As a result, it is susceptible to the droughts that periodically affect this semi-arid region, such as the 1963-64, 1997-98, 1981-83 and 1991-92 droughts. The 1992 drought was recorded as the worst drought in Southern Africa (Maphosa, 1994; Laing, 1994). It was experienced throughout summer rainfall areas in South Africa and the whole of Zimbabwe. Apart from direct food shortages, the drought caused significant impact on the overall performance of water resources and agricultural based economy. The 1981–83 and 1991–92 seasons were the only occasions in the last 70 years or so, that two consecutive summer-rainy seasons have had seriously inadequate rainfall (only 75% of normal rainfall) (Laing, 1994). These droughts were more extended and intense and covered a large part of NSA. The decrease in rainfall over this area was also observed by Mason (1996) and Fauchereau, Trzaska, Rouault, & Richard, (2003). Both periods of droughts coincided with significant ENSO anomalies (Goddard & Graham, 1999) which were associated with warm and widespread SST anomalies in the subtropical Southwest Indian Ocean.

The 1963/64 drought had low variability and its spatial extent was not homogeneous; the worst rainfall deficits were found over Zimbabwe, with less severe effects over South Africa (Fauchereau et al., 2003). However, in NSA the spatial patterns of drought show areas of significant rainfall deficit which extended from the Zimbabwe border and climaxed in the south (Fig.8). This drought was associated with abnormally cold sea surface temperatures (SST) in the subtropical Southwest Indian Ocean (Fauchereau et al., 2003). The cold Southwest Indian Ocean SST brings dry conditions over Southern Africa due to the reduction of deep convective activities over the sub-continent (Reason and Mulenga 1999).

On the other hand, mild drought conditions were experienced in 1997/98. They were attributed to the anomalous warming of the West Indian Ocean and the equatorial eastern Atlantic Ocean basin. It is believed (Anyamba, Tucker, & Eastman, 2001) that this could have been in part a direct result of strong equatorial easterly winds dumping excess moisture from a warmer than normal equatorial West Indian Ocean, thus dampening the expected severe drought response.

This study addressed some of the essential aspects of drought climatology in NSA and presented local scale drought distribution. It utilised the Standardised Precipitation Index (SPI). Globally, local-scale drought has received relatively little research attention compared to the regional scale. Therefore, this study has explored spatial and temporal changes of drought features at a local-scale setting which is very important - because multiple socio-economic impacts such as rain-fed-based agriculture, water supply, and stream health occurs individually or in combination at local scales.

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