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ORIGINAL PAPER

Spatiotemporal characteristics of severe dry and wet conditions in the Free State Province, South Africa

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Abstract

This paper assesses the spatiotemporal characteristics of agricultural droughts and wet conditions in the Free State Province of South Africa for the period between 1960 and 2013. Since agriculturally, the Free State Province is considered the bread basket of the country, understanding the variability of drought and wet conditions becomes necessary. The Standardised Precipitation Index (SPI) computed from gridded monthly precipitation data was used to assess the rainfall extreme conditions. Hot spot analysis was used to divide the province into five homogenous clusters where the spatiotemporal characteristics for each cluster were analysed. The results show a west to east increase in seasonal average total precipitation. However, the eastern part of the province demonstrates higher occurrences of droughts, with SPI ≤ -1.282. This is despite the observation that the region shows a recent increase in droughts unlike the western region. It is also noted that significant differences in drought/wet intensities between clusters are more pronounced during the early compared to the late summer period.

1 Introduction

Drought occurrence is among the most devastating phenomena in the world, costing billions of dollars to governments. While climate models show that eventually, no area is going to be spared by the effects of future climate change, Africa is among the continents that have been identified as the most vulnerable. Southern Africa's droughts, in particular, are projected to intensify not only in frequency but also in their spatial extent (Buckland et al. 2000). Because the impact of natural disasters is much greater for developing countries than developed countries (Spencer and Urquhart 2016), most countries in southern Africa will be exceedingly vulnerable because of their economies which are not strong enough to cushion them enough from the impacts. South Africa has suffered multiple effects of drought, varying from dwindling water supplies, effects on staple crops and increased government expenditure on food importation. Population migration, company closures and reduced living conditions are among other impacts. For example, the 1992/1993 drought forced the government to import food, which weighed heavily on the trade deficit of the country (South African Weather Services 2017). The knock-on effect of crop failure was seen in the population drift from rural areas into the cities, farm labour lay-offs and farm closures. There was also an increase in indebtedness in the agricultural sector (South African Weather Services 2017). South Africa is one of the top ten maize producers in the world (12,365,000 tons as of 2013). Most of this maize is produced by the Free State Province under rain-fed conditions (Moeletsi and Walker 2012; DAFF 2010) and hence making the province to be regarded as the country's granary. Although the contribution of agriculture to the country's gross domestic product is small and declining, it still plays an important role in the creation of wealth and safety nets, especially in the rural areas (Filtane 2016).

Many aspects and implications of drought have been researched on in southern Africa (Ujeneza and Abiodun 2015; Manatsa et al. 2010 and Africa at large (Glantz 1987; Vicente-Serrano et al. 2012). However, little research has been done to analyse droughts at smaller scale like the provincial level. Shortage of data due to sparsity of meteorological stations in southern Africa has made this type of research

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difficult. As recommended by the World Meteorological Organization (Hayes et al. 2011), the South African Weather Services has embraced the Standardised Precipitation Index (SPI) as an index to determine the severity of dry and wet conditions in the country. The SPI, developed by McKee et al. (1993), is a multi-scalar index based on a precipitation frequency approach. It has been widely accepted for its solid theoretical development, robustness and versatility in drought analyses (Redmond 2002). While it is simple in its calculation as it requires precipitation data only, its ability to attain unprecedented values if the same magnitude of 'climatic shocks' occurs in future gives it a unique 'open ended' characteristic feature absent in other indices. The SPI has been extensively used in many research work across the world, for example in Kuwait (Almedeij 2014; Ntale and Gan 2003), Argentina (Seiler et al. 2002), Canada, Spain (Lana et al. 2001), Korea (Min et al. 2003), Hungary (Domonkos 2003), China (Wu et al. 2001), East Africa (Ntale and Gan 2003) and Europe (Lloyd-Hughes and Saunders 2002), for real-time monitoring or retrospective analysis of droughts. The index, however, does not capture the influence of other factors, other than precipitation, that may determine drought conditions such as temperature, wind speed and water-holding capacity of the soil (Vicente-Serrano and López-Moreno 2011). For example, given that global temperature has increased by between 0.5 and 2 °C during the last 150 years, it can be expected that such increases have had consequences for drought conditions (Vicente-Serrano et al. 2012).

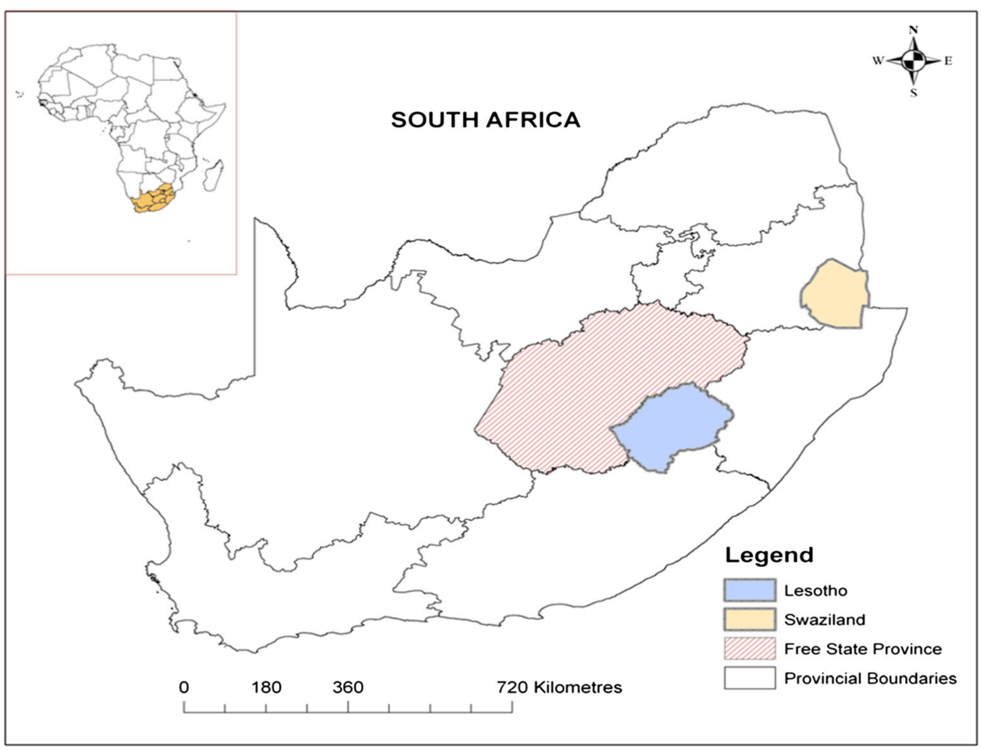
In this study, we analysed drought at 3 and 6 months scale as SPI at short-time scale can be used to identify agricultural drought. Agricultural drought or soil moisture drought (Gao et al. 2016) occurs when there is insufficient moisture in the soil to sustain crops and forage leading to a decrease in agricultural productivity. These short-term scales were also used in previous work and are recommended as adequate for part and overall monitoring of the growing season's performance (Manatsa et al. 2010; Rouault and Richard 2005; Edwards and Mckee 1997). The Free State Province is important for its contribution to food security in the country. As such, an assessment of the evolution of agricultural droughts and mapping of drought-prone areas within the province was done and this knowledge will assist in planning for drought mitigation strategies.

2 Data and methods

2.1 Study area

Figure 1 shows the location of the Free State in South Africa. The province is situated between latitudes 26.6 °S and 30.7 °S and between longitudes 24.3 °E and 29.8 °E sprawling over high plains and stretching along the Maluti-Drakensburg Mountains bordering Lesotho. The province covers an area of 129,825 km^2.

Fig. 1 Location of the Free State Province, South Africa



Cultivated land covers approximately 32,000 km^2 with natural veld and grazing land covering a further 87,000 km^2 of the province (Department of Agriculture, Forestry and Fisheries, DAFF 2010). Field crops yield almost two-thirds of the gross agricultural income of the province although mining on the rich goldfields reef is its largest employer. The Free State Province is also the country's leader in the production of bio-fuels, that is fuel from agricultural crops, with a number of ethanol plants under construction in the grain-producing western region. Animal products contribute a further 30%, with the balance generated by horticulture (DAFF 2010).

2.2 Seasonal climatic characteristics

The Free State Province experiences a continental climate that is characterised by warm to hot summers and cool to cold winters. The rainfall season spans from October to March; thus, water availability for crop production is determined by the amount received during this period. Seasonal rainfall varies considerably over the province. Several factors determine the amount of precipitation an area receives, including altitude, distance from the sea and aspect, among other factors. The dominant factor influencing the variability of precipitation in the province is yet to be established.

The forces that control the summer season rainfall in southern Africa vary within this season. Between October and December, usually regarded as early summer, the atmosphere has a distinct extratropical nature with frequent cut-off lows while during late summer period (January–March), tropical circulation systems are much more prevalent over southern Africa (Dyson and Van Heerden 2002; Manatsa and Reason 2016; D'Abreton and Lindesay 1993). Thus, the season was analysed in three parts, October to December (OND), January to March (JFM) and a complete season which merges OND to JFM of the succeeding year (ONDJFM). Hence in this work, the 1991/1992 period represents the OND of 1991 and the JFM of 1992. In cases where the OND period only was made reference to, the complete season identity was used but taking into consideration that the OND sub-season would be for the year 1991. The 3 and 6-month scales were selected because they have an appropriate estimation of seasonal precipitation which has a significant progressive effect on crop yield.

Monthly mean precipitation (mm) covering the 1960–2013 period was extracted from Climate Explorer's Climate Research Unit (CRU) gridded data file from Climate Explorer at 0.5° × 0.5° spatial resolution (available from https://climexp.knmi.nl). The selected period of 54 years is well beyond the minimum climatic analysis duration of 30 years recommended in the WMO guidelines (Sivakumar et al. 2011). Using this data, the province was divided into five homogenous sub-regions or clusters (Fig. 2) based on the average total precipitation for the October to March rainfall season. This was done using Hot Spot Analysis in ArcGIS (version 10.3). Hot Spot Analysis is a local spatial pattern analysis tool which works by considering each feature within the context of neighbouring features and determining if the local pattern (a target feature and its neighbours) is statistically different from the global pattern (all features in the dataset). The z-score and p value results associated with each feature determine if the difference is statistically significant or not. This enabled the comparison of droughts and wet characteristics between and among the different areas within the province. Data from the grid points that are located in the immediate surroundings of the province were also included in the analysis for purposes of interpolation during spatial analysis.

The drought index calculator (DrinC) was used to calculate the SPI for each of the grid points included in the study. Details on SPI calculation using DrinC can be found in Tigkas et al. (2015). The SPI calculation for any location is based on the long-term precipitation record for a desired period, which is then fitted to a probability distribution and converted into a normal distribution. According to this distribution, the mean SPI for the location and desired period is zero (Edwards and Mckee 1997). Positive SPI values indicate greater than median precipitation while negative values indicate less than median precipitation (Dlamini 2013). Several research work have used the DrinC, for example those undertaken in Italy (Capodici et al. 2008); Malta (Borg 2009) and Iran (Darani et al. 2011). Yevjevich et al. (1978) suggest that for a drought index to be effective, it should be derived locally, be adapted to the climate of the territory and be conceptually and comprehensively used to describe droughts in the region. Therefore, the SPI classification that was developed by Agnew (2000) and modified by Manatsa et al. (2010) was adopted, to meet the southern Africa Regional Climate Outlook Forum (SARCOF) guidelines (Table 1). Three essential elements which distinguish droughts from one another were analysed: intensity, duration and spatial extent (White 2010). The scope of this study was limited to severe and extreme droughts and wet conditions within the Free State Province as these have a greater impact on agricultural yield. A study on the impact of drought on grape yield in the Western Cape Province of South Africa revealed that years of poor yield coincide with moderate or severe drought periods with ($r \approx -0.9$) (Araujo et al. 2016).

2.3 Computing SPI

The SPI is equivalent to z-score used in statistics (Almedeij 2014). It is based on the conversion of the precipitation data to

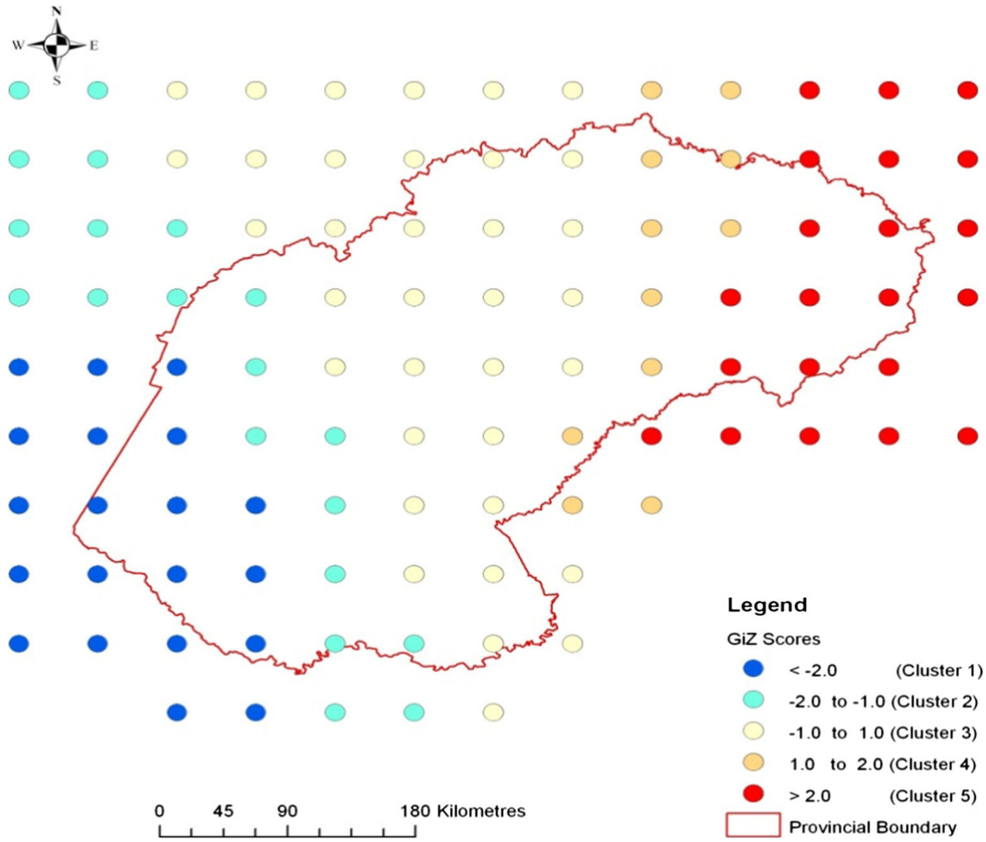


Fig. 2 Locations of sub-regions/ clusters in the Free State Province [cluster 1 (blue), cluster 2 (turquoise), cluster 3 (cream), cluster 4 (brown) and cluster 5 (red)] from Hot Spot Analysis performed using average total precipitation between October and March

probabilities, based on long-term precipitation records which are computed at different time scales. Compared to other drought indices, for example the Palmer Drought Severity Index, the SPI gives a better representation of abnormal wetness and dryness (Guttman 1999). The multi-scalar characteristic of the SPI enables the identification of different types of droughts (Edwards and Mckee 1997). Details about the theoretical background of SPI can be found in (Lloyd-Hughes and Saunders 2002). SPI trends were investigated using the linear regression model. We plotted the Kernel densities on the data according to each cluster to check whether the data is normally distributed. As shown in Fig. 3, the data show a fair approximation to normal distribution. As such, parametric test (ANOVA) was performed to check for any significant differences in the drought and wet characteristics between clusters.

Since the SPI is normalised, it represents wetter and drier climates in the same way. The trend analysis was performed for the province as a whole, and then separately for each of the clusters. Annual drought/wet percentage of area for each cluster was calculated based on the ratio of the number of grid points with SPI ≤ -1.282 to the number of grid points in that particular sub-region/ cluster. For any area, a drought year is defined as a year in which at least 40% of the area (in this case, expressed as the number of grid points) is affected by the drought (Yu et al. 2014).

3 Results and discussion

3.1 Distribution of seasonal average rainfall in the Free State

Figure 4 illustrates the distribution of seasonal average precipitation (October–March) over the Free State Province. There is a clear west-east gradient in average total precipitation received in the Free State Province.

Table 1 Categorisation of dryness/wetness

SPI value occurrence	% Occurrence	Nominal SPI class
> 1.645	≤ 5	Extremely wet
1.644 to 1.282	6–10	Severely wet
0.842 to 1.281	11–20	Moderately wet
0.524 to 0.841	21–33	Slightly wet
−0.523 to 0.523	34–50	Normal
−0.841 to 0.524	21–33	Slight drought
−1.281 to −0.842	11–20	Moderate drought
−1.644 to −1.282	6–10	Severe drought
< -1.645	≤ 5	Extreme drought

(Adapted from by Agnew (1999) and modified by Manatsa et al. 2010: p. 291)

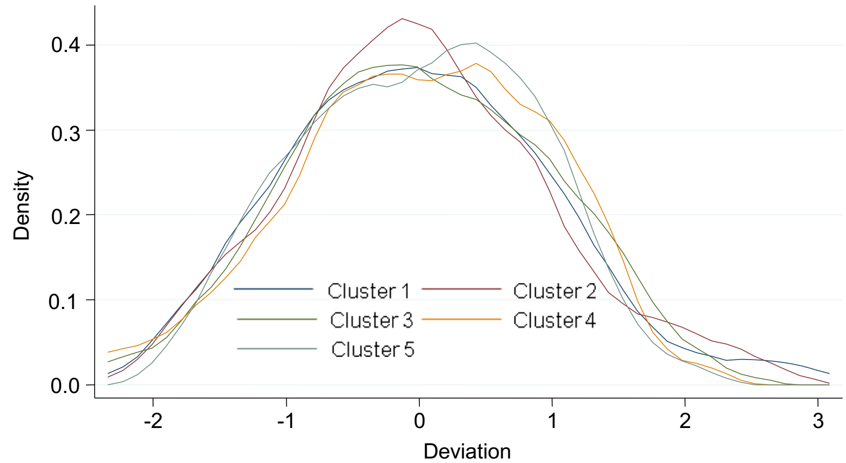
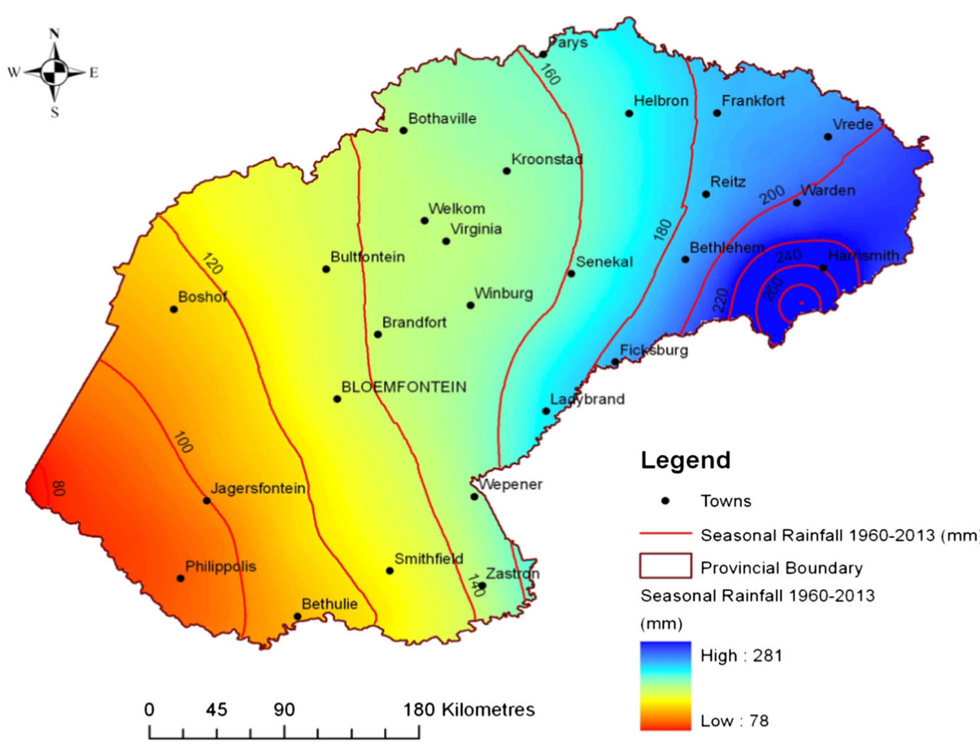


Fig. 3 Distribution of the provincial averaged 6-month SPIs expressed in kernel densities versus standard deviation for clusters 1–5

3.2 Drought intensity variations

The seasonal averaged SPIs for the Free State region were plotted for the three seasons: OND, JFM and ONDJFM for the 1960–2013 period from a regional perspective down to cluster level. Figure 5 shows the SPI variations over time for all the seasons analysed. The most intense drought was experienced during the OND season in the 1994/1995 season with SPI value of − 1.98. The second most intense drought occurred during the JFM period of the 1991/1992 rainfall season with SPI value of − 1.755. The other two JFM seasons that experienced severe droughts were recorded in 2006/2007 and 1982/1983. In total, SPI_3 OND identified five seasons whose droughts were in severe category, including 1994/1995, 1990/1991, 1972/1973, 1965/1966 and 1997/1998, all of which were either severe or extreme. There were no droughts (SPI ≤ − 1.282) identified by the SPI_6 ONDJFM. This was despite the fact that 1994/1995 OND sub-season was the driest for the entire study period. The 1994/1995 JFM SPI of − 0.127 contributed to the reduction of the seasonal SPI. This suggests that while the season started off as dry, the later summer sub-season was generally wet. The South African Weather Services (SAWS) records show that there were droughts that affected South Africa during the whole season, for example 1991/1992, 1969/1970 and 1982/1983, but these were not identified in the Free State at the 6-month scale. This deviation can be explained as the effect of using averages. Extremely low SPI values and extremely high values when

Fig. 4 Seasonal average rainfall distribution over the Free State Province (season covers October–March). The data is averaged for the period 1960–2013



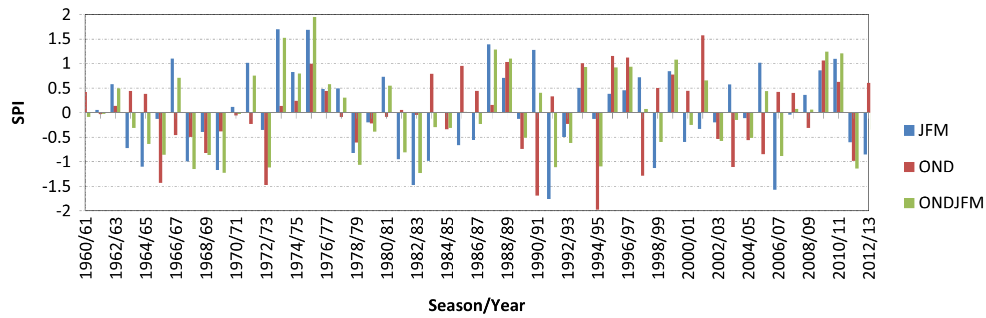


Fig. 5 Annual variation of averaged SPIs for the Free State Province for OND (SPI_3), JFM (SPI_3) and ONDJFM (SPI_6). Data is from 1960 to 2013

averaged result in near zero values. This problem can be overcome by first performing a hot spot analysis in order to delineate homogeneous regions, whose SPI characteristics were analysed separately.

On the other end, the wet years that recorded SPIs ≥ 1.282, at the 6-month scale were 1987/1988, 1973/1974 and 1975/1976. SPI_3 OND identified only 2001/2002 and SPI_3 JFM identified 1987/1988, 1975/1976 and 1973/1974. What is interesting about the wet years is that the seasons identified by SPI_3 JFM are identical in intensity to those identified by SPI_6 ONDJFM. Overall, the dominant rainfall systems for the region are of tropical origin that moves in sympathy with the Intertropical Convergence Zone during the late part of the rainfall season. The rest of the results are displayed in Tables 2, 3 and 4 while Fig. 6a–c shows temporal variations of drought/wet intensity per cluster over the 53 years for each of the seasons. At

Table 2 Distribution of severe and extreme dry/wet seasons at 6-month scale across clusters of the Free State Province between 1960 and 2013

Dry seasons					Wet seasons			
Cluster	Total number of drought seasons (SPI ≤ − 1.282)	Year	SPI value	Drought description	Total number of wet seasons SPI ≥ 1.282	Years	SPI value	Wetness description
1	2	1998/1999	− 1.89361	Extremely dry	5	1993/1994	1.411	Severely wet
		1969/1970	− 1.32885	Severely dry		1987/1988	1.4325	Severely wet
						2010/2011	1.5837	Severely wet
						1975/1976	2.4222	Extremely wet
						1973/1974	2.6752	Extremely wet
2	2	1969/1970	− 1.51883	Severely dry	4	2010/2011	1.5	Severely wet
		1967/1968	− 1.40239	Severely dry		1987/1988	1.6265	Severely wet
						1975/1976	2.3447	Extremely wet
						1973/1974	2.3836	Extremely wet
3	3	1991/1992	− 1.5576	Severely dry	4	1973/1974	1.400392	Severely wet
		1969/1970	− 1.35439	Severely dry		1988/1989	1.428666	Severely wet
		1967/1968	− 1.32612	Severely dry		2009/2010	2.55537	Extremely wet
4	3	1982/1983	− 1.88074	Extremely dry	2	2009/2010	1.510758	Severely wet
		1991/1992	− 1.66856	Extremely dry		1995/1996	1.799828	Extremely wet
		2011/2012	− 1.5523	Severely dry				
5	4	1981/1982	− 1.69535	Extremely dry	2	1999/2000	1.350926	Severely wet
		1982/1983	− 1.57855	Severely dry		1995/1996	2.282034	Extremely wet
		2011/2012	− 1.41806	Severely dry				
		1965/1966	− 1.37732	Severely dry				

Table 3 Distribution of severe and extreme dry/wet seasons across clusters of the Free State Province between 1960 and 2013 during the OND sub-season

Dry seasons					Wet seasons			
Cluster	Total number of drought seasons (SPI ≤ − 1.282)	Years	SPI value	Drought description	Total number of wet seasons SPI ≥ 1.282	Years	SPI value	Wetness description
1	4	1997/1998	− 2.16281	Extremely dry	5	1988/1989	1.295963	Severely wet
		1994/1995	− 1.99891	Extremely dry		1993/1994	1.373079	Severely wet
		1972/1973	− 1.7166	Extremely dry		1991/1992	1.400916	Severely wet
		1990/1991	− 1.41388	Severely dry		2001/2002	1.431789	Severely wet
						1985/1986	1.777238	Extremely wet
2	5	1994/1995	− 2.66479	Extremely dry	4	1988/1989	1.296026	Severely wet
		1972/1973	− 1.60519	Severely dry		1975/1976	1.297385	Severely wet
		1997/1998	− 1.59277	Severely dry		1996/1997	1.469364	Severely wet
		1990/1991	− 1.5794	Severely dry		2001/2002	1.50466	Severely wet
		1965/1966	− 1.37782	Severely dry				
3	5	1990/1991	− 1.94591	Extremely dry	3	1995/1996	1.283789	Severely wet
		1994/1995	− 1.8689	Extremely dry		2009/2010	1.44685	Severely wet
		1965/1966	− 1.5985	Severely dry		2001/2002	1.753815	Extremely wet
		1972/1973	− 1.50548	Severely dry				
		1997/1998	− 1.46052	Severely dry				
4	4	1990/1991	− 2.15643	Extremely dry	3	2009/2010	1.334237	Severely wet
		1965/1966	− 2.07882	Extremely dry		2001/2002	1.528796	Severely wet
		2003/2004	− 1.69667	Extremely dry		1995/1996	1.671978	Extremely wet
		1994/1995	− 1.59741	Severely dry				
5	4	2003/2004	− 1.77732	Extremely dry	3	1983/1984	1.298381	Severely wet
		1994/1995	− 1.66441	Extremely dry		2001/2002	1.519329	Severely wet
		1990/1991	− 1.37618	Severely dry		1995/1996	1.626414	Severely wet
		1972/1973	− 1.32358	Severely dry				

national level, there has been a decline in the area planted (Goldblatt and von Bormann 2010) which may be due to the increase in intensity and spatial extent of dry conditions during the growing season. Establishing if there is a link between SPI and crop production in the province is beyond the scope of this work.

Tables 2, 3 and 4 show that there are variations in the years identified as dry (SPI ≤ − 1.282) or wet (SPI ≥ 1.282) in each cluster. The SPI_6 ONDJFM identifies eight seasons with at least ≤ − 1.282 (severe drought) from different clusters while the SPI_3 JFM identifies 11 years. SPI_3 OND identifies six seasons of at least a severe drought magnitude. There are more seasons in common identified at SPI_3 JFM with those identified at SPI_6 ONDJFM. SPI_3 OND identifies only 1965/1966 season as a common drought season with SPI_6 ONDJFM. The spatial coverage of these drought and wet years is best expressed as percentage area coverage. Yu et al. (2014) recommended at least 40% area coverage for a year to be defined as dry or wet. In this study, severe/extreme dry (wet) years with at least 40% area coverage by drought SPI ≤ − 1.282 or wet conditions SPI ≥ 1.282 were considered. Figure 7 shows the temporal variations of percentage area coverage by at least severe drought/severe wet conditions in the province for the ONDJFM season.

The distribution of SPI_6 ONDJFM droughts shows that cluster 5, in the extreme eastern part of the province, has the

Table 4 Distribution of severe and extreme dry/wet seasons across clusters of the Free State Province between 1960 and 2013 during the JFM sub-season

Dry seasons					Wet seasons			
Cluster	Total number of drought seasons (SPI ≤ − 1.282)	Years	SPI value	Drought description	Total number of wet seasons SPI ≥ 1.282	Years	SPI value	Wetness description
1	4	1998/1999	− 1.95104	Extremely dry	4	2010/2011	1.41028	Severely wet
		1963/1964	− 1.47298	Severely dry		1987/1988	1.427595	Severely wet
		1982/1983	− 1.39106	Severely dry		1975/1976	2.201378	Extremely wet
		1983/1984	− 1.38975	Severely dry		1973/1974	2.694811	Extremely wet
2	6	1991/1992	− 1.80711	Extremely dry	5	2010/2011	1.420564	Severely wet
		1982/1983	− 1.57348	Severely dry		1990/1991	1.43955	Severely wet
		1969/1970	− 1.45516	Severely dry		1987/1988	1.835171	Extremely wet
		1963/1964	− 1.41997	Severely dry		1975/1976	2.09646	Extremely wet
		1967/1968	− 1.29489	Severely dry		1973/1974	2.379977	Extremely wet
		2006/2007	− 1.28659	Severely dry				
3	3	1991/1992	− 2.25945	Extremely dry	4	1971/1972	1.452383	Severely wet
		2006/2007	− 1.81325	Extremely dry		1987/1988	1.495905	Severely wet
		1982/1983	− 1.48794	Severely dry		1973/1974	1.601053	Severely wet
						1975/1976	1.94454	Extremely wet
4	4	1991/1992	− 2.35691	Extremely dry	2	1990/1991	1.593596	Severely wet
		2006/2007	− 1.89984	Extremely dry		1966/1967	1.737079	Extremely wet
		1982/1983	− 1.76166	Extremely dry				
		2012/2013	− 1.30377	Severely dry				
5	3	2006/2007	− 1.55708	Severely dry	2	1966/1967	1.510002	Severely wet
		1981/1982	− 1.43879	Severely dry		1995/1996	1.727613	Extremely wet
		1978/1979	− 1.37838	Severely dry				

highest occurrence of droughts (five) in the severe and extreme categories and the lowest count of wet years in the severe wet and extreme wet categories. A unique aspect of cluster 5 is that while all the other clusters experienced breaks in extreme drought conditions, this cluster had two consecutive seasons of at least severe drought, 1981/1982–1982/1983.

The eastern parts of the province experienced severe-extremely dry seasons in the later decades compared to the western areas. Both clusters 4 and 5 experienced the 2011/2012 severe drought, while cluster 2 last experienced a drought of the same magnitude during the 1969/1970 season (Fig. 8). SPI_3 OND results show that the extreme west and central parts of the province, making up clusters 1, 2 and 3 had their last recorded severe drought in the 1997/1998 season. The eastern parts experienced extreme drought during the 2003/2004 season. This observation suggests that the eastern parts of the province are getting drier. This shift towards more severe drought conditions in areas that have a low historical record of severe droughts can be linked to an observed increase in the frequency of the negative southern oscillation phase (Wolter and Hastenrath 1989).

Regarding wet conditions (characterised by SPI ≥ 1.282 for the ONDJFM season), cluster 5 experienced its wettest season during the 1999/2000 season, while the rest of the clusters had at least a wet season after 2009. It is interesting to note that for the OND sub-season, before the 2001/2002 widespread wet

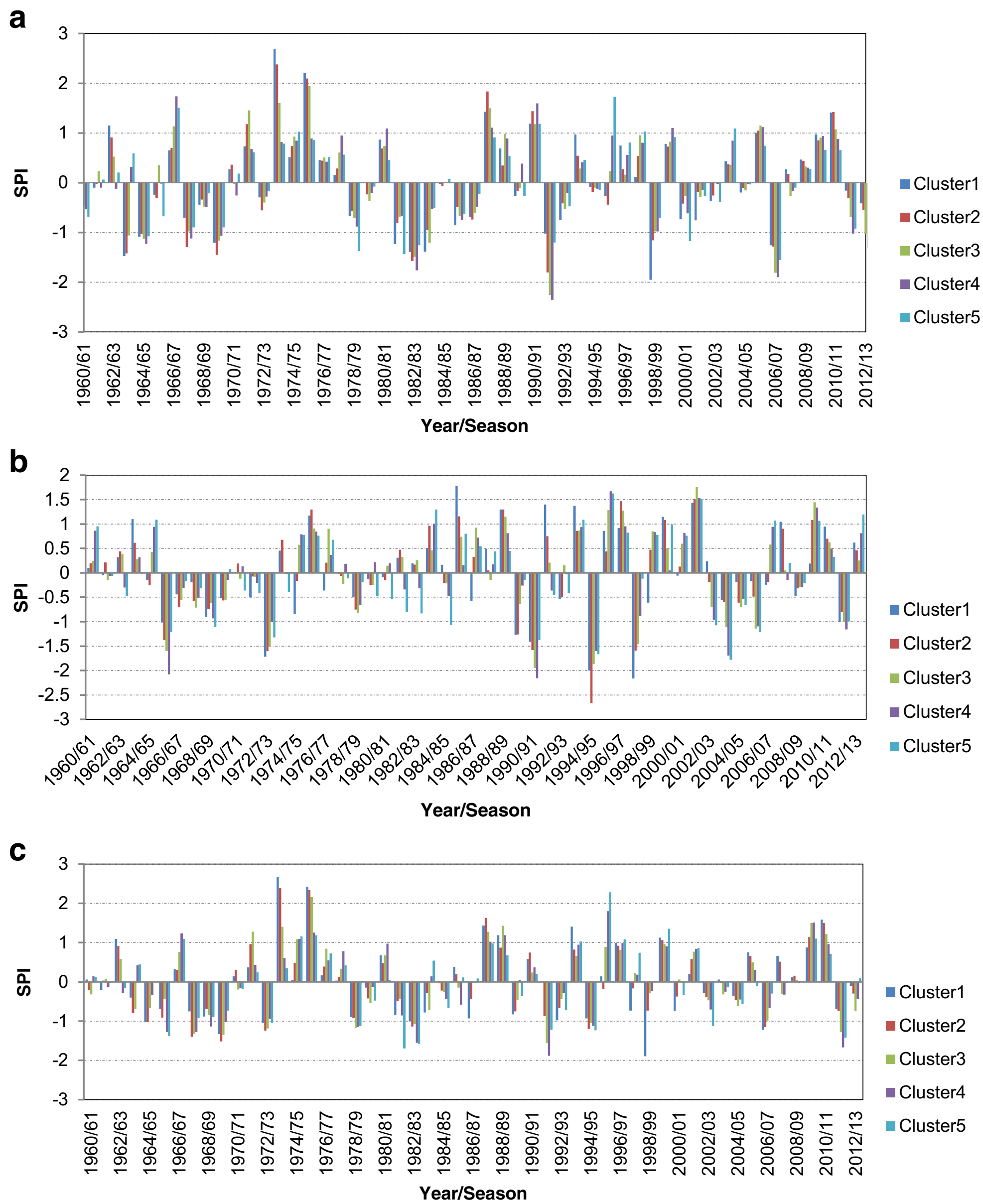


Fig. 6 Temporal annual variation of SPI at 3- and 6-month scale in the five clusters of the Free State for **a** JFM ((SPI_3), **b** OND (SPI_3) and **c** ONDJFM (SPI_6). Data is for 1960–2013

season, the last wet season had been experienced in the 1990s. Before 1983, save for cluster 2 during the 1975/1976 season, the rest of the province did not have any wet season with SPI ≥ 1.282 during the OND period (Fig. 6b). This suggests

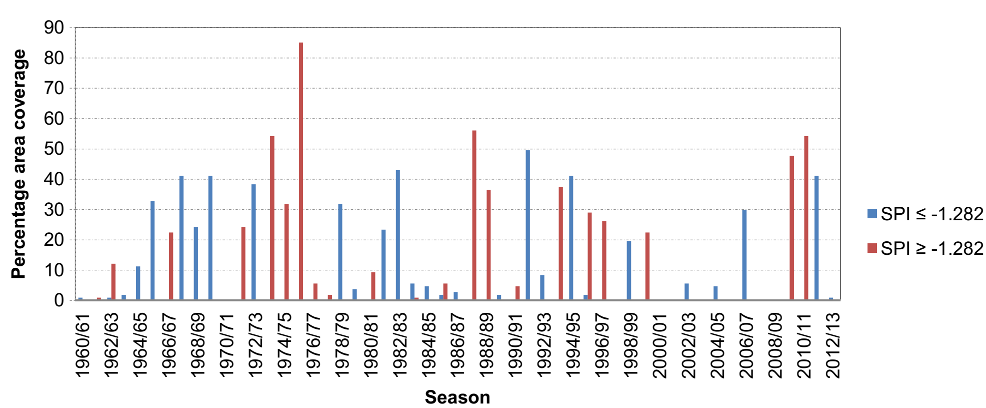


Fig. 7 Temporal variation of total percentage area covered by drought/ wet conditions in the Free State Province (SPI ≤ −1.282 and SPI ≥1.282) for ONDJFM season

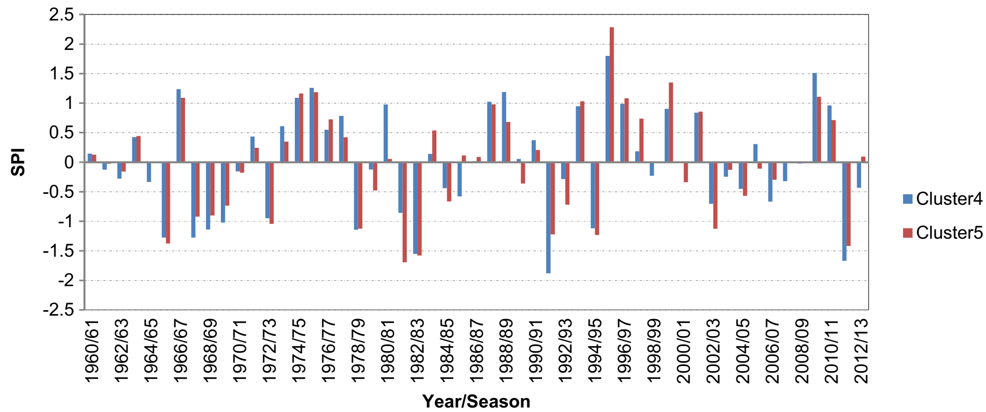


Fig. 8 Temporal annual variation of SPI_6 in the eastern parts of Free State Province (clusters 4 and 5) over the study period 1960–2013

that the OND sub-season has become wet recently compared to the past.

With respect to the JFM sub-season, cluster 2 recorded the highest incidences of both dry ($SPI \leq -1.282$) and wet ($SPI \geq 1.282$) seasons. However, a downward trend can be observed in the number of wet and dry seasons, from the western to the eastern parts of the province. This illustrates that during the JFM sub-season, the western parts of the region are usually drier than the eastern parts. The same pattern was observed for the wet conditions during the same period in the region. The western extreme and central parts of the province have more wet occurrences in the JFM sub-season than the eastern areas. This is despite the fact that on average, the east receives far more seasonal precipitation than the extreme west (Moeletsi and Walker 2012). This means that the JFM precipitation varies more, in terms of deviation from the mean in the west than in the east.

To test for any significant differences in drought intensity between clusters, One-way analysis of variance was performed using SPSS for the period 1960 to 2013 for each of the sub-seasons. This included a multiple comparison procedure to identify the exact clusters with significant differences. Table 5 shows the results for SPI_6 multi-cluster comparison.

Table 5 SPI_6 multiple cluster comparison ANOVA results

Cluster (I)	Cluster (J)	Mean difference (I–J)	Std. Error	Sig.
1	2	− 0.00082	0.00217	0.707
	3	− 0.00139	0.00196	0.481
	4	0.00611*	0.00253	0.017
	5	0.01086*	0.00217	0.000
2	3	− 0.00057	0.00190	0.765
	4	0.00692*	0.00248	0.006
	5	0.01168*	0.00211	0.000
3	4	0.00749*	0.00230	0.002
	5	0.01225*	0.00190	0.000
4	5	0.00476	0.00248	0.058

*Statistically significant differences ($p < 0.05$)

The results show that for the SPI_6, there is a clear division between the east and the west. Clusters 1, 2 and 3 are not significantly different from each other which is the same for clusters 4 and 5. Thus, there are three main groups which are significantly different, the east, the central and the west. However, during the OND period, average SPIs show that cluster 1 is significantly different from clusters 2 and 3 but there is no significant difference between clusters 2 and 3. This implies that cluster 1 is unique within the western region during the OND sub-season. To the eastern part of the province, the significant differences also exist between neighbouring clusters 4 and 5. Thus, there are more significant differences in the OND period than there are for the whole season. It is intriguing to note that the JFM period has an almost homogenous pattern in as far as drought intensity is concerned. Significant differences are only noted between cluster 2 and cluster 3 and between clusters 2 and 5. During the JFM period, the neighbouring clusters, 2 and 3, show significant difference while clusters 1 and 2 and clusters 4 and 5 show significant differences during the OND sub-season. This suggests that there is a unique climatic forcing that makes cluster 2 significantly different from others and this deserves further investigation. These results agree with variations of drought/wet occurrences (Tables 2, 3 and 4) observed over the province.

3.3 Drought/wet percentage area coverage

The spatiotemporal characteristics of droughts ($SPI \leq -1.282$) and wet years ($SPI \geq 1.282$) in the Free State Province were analysed. The 40% area coverage threshold for a drought or wet year was adopted (Yu et al. 2014). Using this threshold, it can be argued that three seasons experienced at least severe drought conditions in the Free State Province during the JFM sub-season (Fig. 9a): 1982/1983 (75%), 1991/1992 (67%) and the 2006/2007 (65%). These correspond with the provincial, that is the Free State averaged, JFM droughts in terms of intensity, although 1991/1992 was the worst in terms of drought

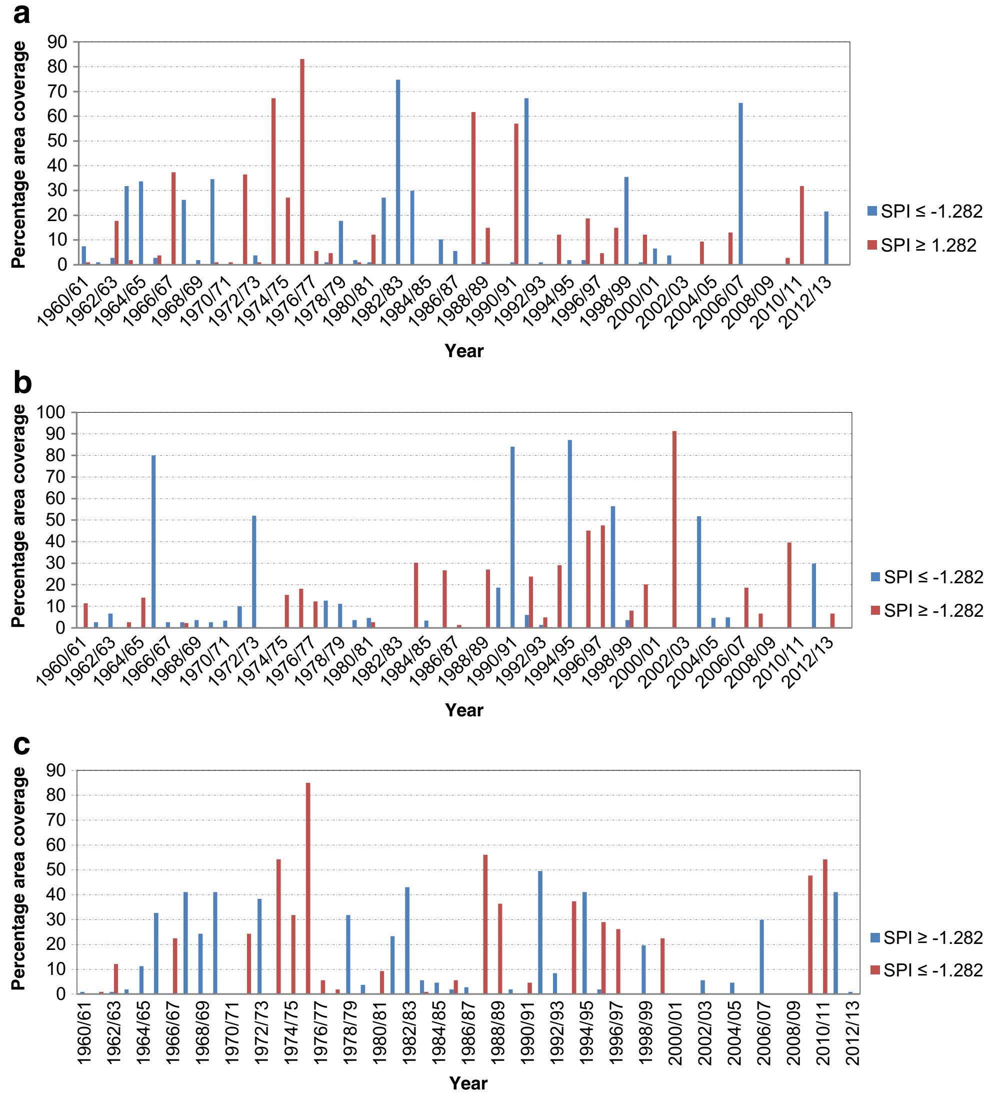


Fig. 9 Annual variability of total percentage area covered by severe drought and severe wet conditions as denoted by SPI values over Free State Province at SPI_3 (**a**) JFM, (**b**) OND and SPI_6 (c) ONDJFM time scale between the period 1960–2013

severity. Thus, 1991/1992 JFM sub-season was extremely dry and was the second leading in terms of area coverage after the 1982/1983 drought. These results concur with observations by (Unganai and Kogan 1998) although 2006/2007 falls outside their study period.

For the OND sub-season (Fig. 9b), there were six drought years covering at least 40% of the province. These seasons match the years on the severity scale, with the 1994/1995 OND sub-season as extremely dry. Consequently, the 1994 drought was both the worst intense in terms of severity and covered the largest area in the history of droughts during this sub-season. In the wet category, 2001/2002 OND sub-season had the highest percentage coverage of 83%. For the 6-month scale (Fig. 9c), there were no years with severe or extreme drought conditions covering at least 40% of the province. The driest years in the province were only moderately dry. Of these moderately dry years, the highest percentage coverage was 50% during the 1991/1992 season and 1982/1983 (43%). However, spatial distribution of SPIs for the whole season (Fig. 10a) shows that the extreme south-western areas had severe drought, which is an indication that using large area average may be misleading. The moderately dry years fall within the dry periods of 1964 to 1970 and 1991 to 1995 and again from 2002 to 2005 identified by (South African Weather Services 2017). By 1987, the 1983/1984 was reported as the worst drought in central and southern Africa (Downing 1987). However, this was only a continuation of the drought that had started in 1982 (Unganai and Kogan 1998), which had 43% area coverage in the Free State province. It would be misleading to conclude that the whole of southern Africa had a drought of the same severity. Rather, some areas were more affected by drought conditions than others. Thus, using the average index for the large area may be misleading in describing the dryness/

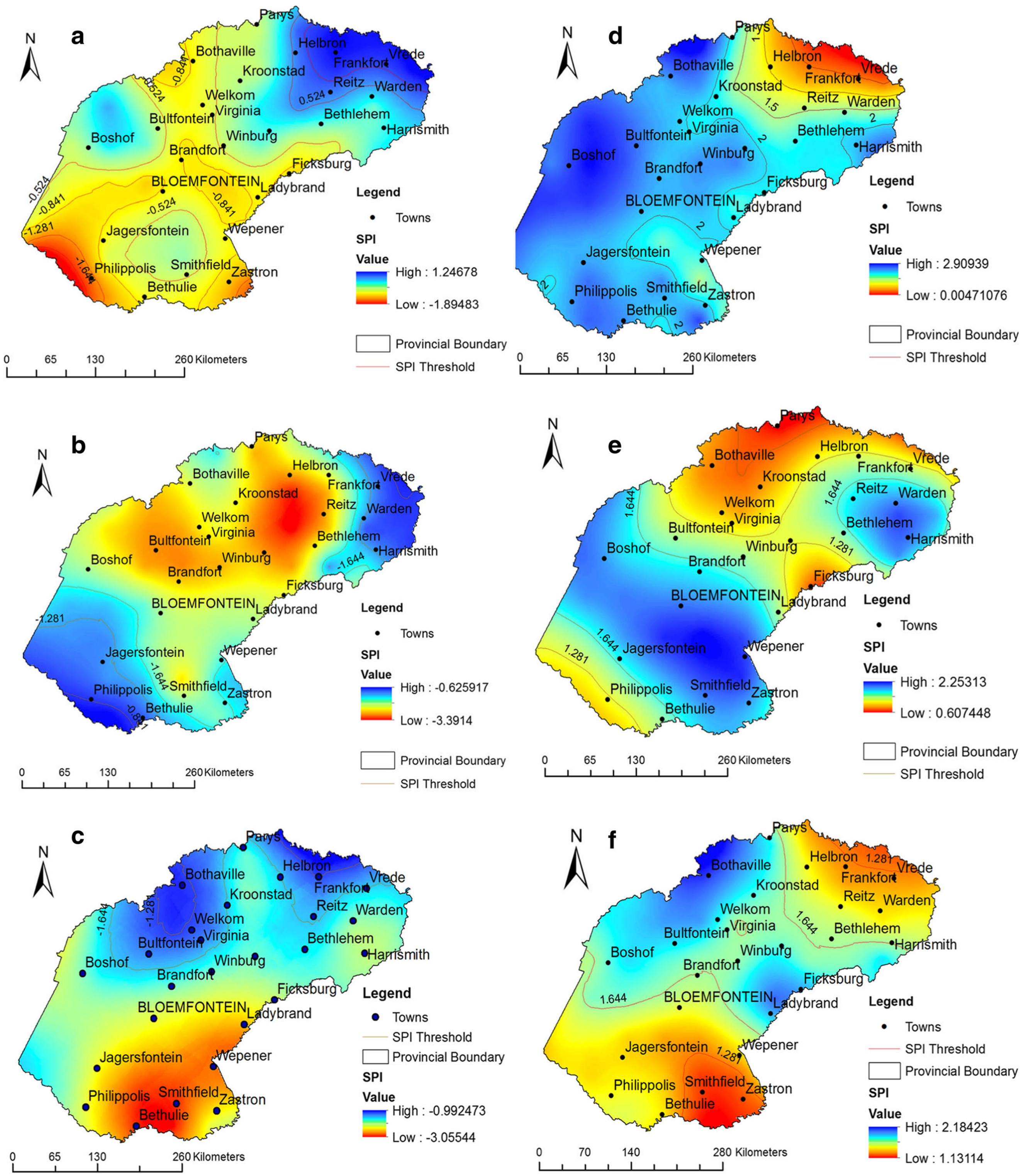


Fig. 10 Spatial distribution of drought (**a**) 1983/1984 SPI_6 (**b**) 1992 SPI_3(JFM) (**c**) 1994 SPI_3 (OND) and wet (**d**) 1975/1976 SPI_6 (**e**) 1988 SPI_3(JFM) (**f**) 2001 SPI_3 (OND) conditions over Free State Province. Only the driest and wettest years are shown for each time scale

wetness of the area because it eliminates extreme cases. These variations are illustrated on the maps showing the distribution of drought and wet conditions in the Free State for selected years with outstanding provincial area average SPI values (Fig. 10a–f).

3.4 Variations in drought duration

Since the Free State Province has heterogeneous seasonal climate characteristics, drought duration was analysed per cluster within each sub-season. Drought duration was also analysed at provincial scale. Results show that duration of drought varies across clusters and with seasonality. We developed a program within Microsoft Excel developer to analyse drought duration. Drought duration was calculated from the time the SPI value dropped to − 1, as the start to the time when the SPI value returned to + 1 (Yu et al. 2014). For the OND sub-season for the whole province, a wet sub-season came after 23 years, after a drought which had started in 1965. By cluster analysis, the drought that started in 1965 lasted the longest in cluster 3 (23 years) while in clusters 1 and 2, the drought ended in the 10th year. A comparison of drought duration between the two sub-seasons shows that JFM droughts have a much shorter duration than OND droughts. For the JFM sub-season, a wet season came after 14 years, drought having started during the 1991/1992 season; thus, it ended in 2006. The year 2006 coincides with the SAWS' end-of-drought year for the 2000–2005 drought period. Areas to the west of the province experienced this long drought spell but reduced in duration in the eastern parts of the province (clusters 4 and 5 with each lasting 8 and 4 years, respectively). JFM droughts increased in duration in the 1980s, while OND droughts show a decrease between the 1960s and 1995. For the entire growing season (SPI_6), the longest drought lasted for 9 years, 1964/1965–1973/1974 in cluster1 and 2; 1978/1979–1987/1988 in clusters 3 and 4. The 1991/1992 drought lasted the longest in cluster 3, that is the central part of the province, for 8 years. The ONDJFM season droughts lasted between 6 and 9 years making the season with the smallest range, followed by JFM with 12 and OND with the highest, 22 years. It is important to note however that for OND sub-season, the 23 years between 1965 and 1988 influenced the range, at provincial level. At provincial level, the longest drought lag for JFM sub-season was 14 years (1991/1992–2005/2006), 23 years for OND (1965/1966–1988/89) and 9 years (1978/1979–1987/1988) for the SPI_6. This points to the idea that the OND sub-season has more consecutive droughts than the JFM sub-season. This calls for government and stakeholder intervention to improve awareness among farmers and educating them on drought management strategies in order to reduce their vulnerability to drought. This may include the adoption of policy instruments such as, but not limited to, extension agrometeorology through which farmers' preparedness and decision-making skills can be improved (Stigter et al. 2013).

3.5 Conclusion

The results of this study show that droughts within the province are unevenly distributed, with different areas experiencing either drought or wet conditions during the same seasons annually. The eastern parts of the Free State Province experience the shortest drought duration periods, regardless of the sub-season and yet these areas experience drought in different years from the rest of the province. This suggests that there is need to assess the performance of the season at a much smaller spatial scale since a season may be 'good' nationally but 'very bad' in some local areas. While the eastern part of the Free State Province generally receives more precipitation than the rest of the region, it has the highest frequency of drought years, followed by the central region of the province. However, there could be other factors other than altitude influencing precipitation variability differences between the western and the eastern parts of the province. Regardless of the situation of the cluster within the province, the JFM sub-season's performance largely controls the general outlook and behaviour of the total growing season. This means that what happens in the early summer season has little influence on whether the season can be regarded as dry or wet although this does not make this sub-season unimportant. While previous studies have focused on southern African region as a whole, what happens on small scale has remained unexplored, leaving the societies vulnerable to climate variability impacts. Notably, in the Free State Province, there are more significant differences between clusters during the early summer period than in the late summer period. There is thus a need to pay attention in monitoring the climatic variations and changes taking place in the Free State Province to ensure that its status as the country's breadbasket is not compromised.

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