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Analysis of Dry-Spells in the Western Maize-Growing Areas of South Africa

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Abstract: Crop yield in rainfed agriculture is directly influenced by rainfall patterns, which vary from one growing season to another. The failure or success of such crops can depend on the amount and distribution of the rainfall and, particularly, on the occurrence of dry- and wet-spells during the growing season. The aim of this study was to investigate the initial and conditional probabilities of dry-spell pentads using the Markov chain model in the western maize-growing region of South Africa, as well as to determine the direction and magnitude of dry-spell trends using the Mann–Kendal monotonic trend test and Sen's slope estimator. The results revealed that all the rainfall districts are affected by dry-spells during the mid-January-to-end-of-February period. This finding is significant because maize is usually planted during late November to late December in this region, and dry-spells may coincide with the flowering stage of the maize crop. When dry-spells occur during the flowering stage of maize, they significantly affect yield. The Mann–Kendal analysis revealed that most of the districts (7 out of 11 districts) have a decreasing trend in dry-spell occurrences except for districts 86, 87, 91 and 93. However, the decreasing trend is statistically insignificant in all the rainfall districts, and, thus, this reveals that there is no change or there is a minor change in dry-spell occurrence across all the districts. Furthermore, Sen's slope estimator signalled a decrease in dry-spell magnitude or occurrence over the study period. Information from this study will inform farmers of the various districts regarding changes in their particular risk profile for dry-spells.

Keywords: dry-spell; wet-spells; maize; crop yield; Markov chain model; pentad rainfall; rainfed

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1. Introduction

Maize is one of the most important summer staple grain crops produced in South Africa for both human and animal consumption [1]. The crop is produced throughout the country, with Free State, Mpumalanga and North-West provinces being the major producers and accounting for over 85% of the national output [2]. Most of the production is commercialised in these provinces, and small-scale farming is predominant in the rural provinces of Limpopo, KwaZulu-Natal and the Eastern Cape. Around 90% of the production of maize in the country is under dryland production [3]. Maize needs around 400 mm to 600 mm over the growing season for optimal production, and with South Africa being a semi-arid region, maize is generally exposed to water stress and drought conditions [4]. One of the major limiting factors in dryland production is, therefore, water stress, the consequences being delayed maturity and low crop yield [5,6]. This is especially important during the flowering stage when maize is most sensitive to water stress conditions [4].

In addition to the semi-arid rainfall pattern, southern Africa has a high rainfall unpredictability at various temporal and spatial scales and experiences extreme droughts and floods [7]. Drought is a natural phenomenon that occurs when there is below average rainfall over a period [8]. The lack of rainfall can cause reduced groundwater levels, soil moisture and stream levels. South Africa is a semi-arid country with rainfall averages of less than 500 mm [5,9]. Much of the country receives summer rainfall, which starts from October, and cessation occurs in April [5]. The south-western parts of the country receive winter rainfall, and the southern coast receives rainfall throughout the year [5,10]. Rainfall is the most important factor affecting crop production, especially in dry land farming [11]. In semi-arid regions, the yield parameters depend on the amount and temporal distribution of rainfall [12]. Maize requires a minimum of 300 mm per annum to grow and yield [13]; however, for optimal yields, 400 to 700 mm of rainfall is required annually [14,15]. As South Africa is relatively dry, monitoring of drought, dry-spells as well as wet-spells is vital for agricultural planning. For crop production, the timing of rainfall is more vital than the amount received. Thus, crops tend to do well when precipitation is spread uniformly over a growing season rather than with a few occasions of heavy rains intercepted by dry conditions [16]. The study area is regarded as a warm western production region subjected to persistent dry-spells and drought conditions, hence the desire to investigate the trend in dry-spells in this production area.

A dry-spell is a period where dry conditions persist for days to weeks but are shorter and less severe than drought conditions [17]. As dry-spells do not occur at the same time each year, it is important to understand the trend in these phenomena. Dry-spells are characterised by a reduced flow of moist warm air from the south-western Indian Ocean over South Africa with a dominant high-pressure system over the interior [18] and inflow of some moisture from the South Atlantic Ocean, which is less moist and cooler than that from the Indian Ocean [18]. Wet-spell conditions dominate when there is a ridging high-pressure system along the coast and an easterly low over the northern interior [7]. Wet-spells are defined as a continuous period of daily rainfall equating to, or greater than, the daily mean rainfall of a particular area [8]. Consecutive wet-spells signal excessive surface run-off, which has benefits for water harvesting but requires mitigation measures to avoid soil erosion and potential flood damage. Farmers can ease runoff by applying mulch or organic manure on their fields.

The Markov chain model has been extensively used to study spell distribution and other properties of rainfall occurrence and long-term frequency behaviour of wet- and dry-spells [19]. The use of the Markov chain probability model in the analysis of wet-spells and dry-spells was first introduced by Gabriel and Neumann (1957), using 27 years (1923–1950) of rainfall data with a threshold of 0.1 mm from November to April in Tel Aviv, Israel [20]. The Markov chain probability model was introduced in transitional probability where conditions change between two states [19,21]. The Markov chain model is widely used to determine the relative chance of occurrence of a given rainfall, to characterize a rainfall period as a dry- or wet-spell [19]. This model is also useful in assessing the onset and cessation of the wet season, which largely determines the success of rainfed agriculture [19]. In the past decades, several studies used the Markov chain probability model to fit statistical distributions to meteorological observations [16].

Climatologically, the western maize production region has a drier climate than the other maize production regions in South Africa [5]. This region experiences late onset of the rainfall season, which leads to late planting of summer crops such as maize and sorghum. Mengistu et al. [5] performed a dry-spell frequency analysis on the three maize production regions of South Africa, namely: cool eastern region, temperate eastern region, and parts of the warm western growing region during the conventional mid-summer period (mid-December to mid-January). A dry pentad was considered as a pentad with less than 15 mm of rainfall and a pentad with 15 mm or more rainfall as a wet pentad [22]. The investigation succeeded in detecting the occurrence of dry-spells in the cool and temperate growing regions and, to some extent, in parts of the western growing region during the mid-summer period. However, the study highlighted that the western growing region experiences late onset of rainfall, and maize is planted much later than in the other two growing regions. Therefore, the need to perform dry-spell analysis during the mid-January-to-end-of-February period was vital.

This study follows the investigation carried out by Mengistu et al. [5], which focused on the spatial and temporal analysis of dry-spells during the mid-summer period (mid-December to mid-January) for parts of the western maize-growing region. However, for the western maize-growing areas, due to the late planting, the flowering stage, which is sensitive to water stress, occurs during January and February and not necessarily during the specified mid-summer period used in the study of Mengistu et al. [5]. Consequently, this necessitated that this study be carried out to investigate the occurrence of dry-spell frequency in the western maize-growing region during the mid-January-to-end-of-February period. Therefore, the aim of this study was to

1. Investigate the initial and conditional probabilities of dry- and wet-spell pentads using the Markov chain model in the western maize-growing region from mid-January to end of February;
2. Determine direction and magnitude of trends of dry-spells using the Mann–Kendal monotonic trend test and the Sen slope estimator.

2. Materials and Methods

2.1. Study Area

The study area, known as the western maize-growing region (Figures 1 and 2), produces significant outputs of maize under rainfed conditions. The area is a major maize production region in the eastern parts, while the rest of the region is a minor production area (Figure 2). This region is essential to the production of summer grains (maize, sorghum, soybeans, sunflower and groundnuts) under rainfed conditions with only small areas under irrigation.

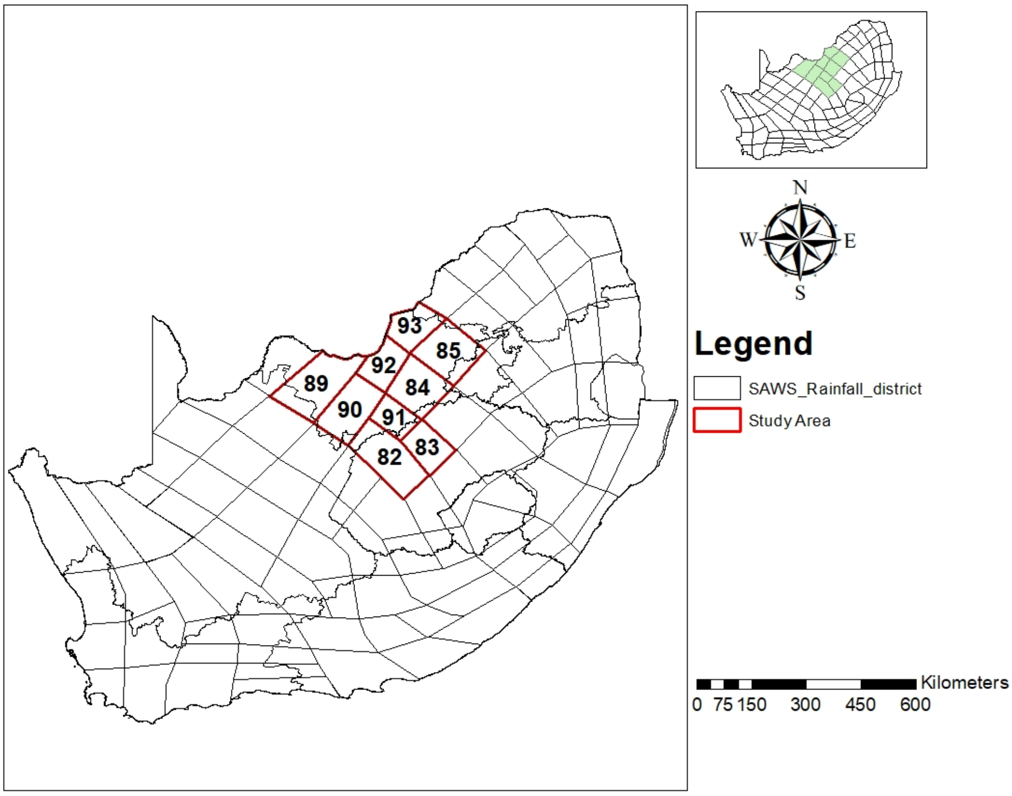

Figure 1. Study area showing rainfall districts for South Africa with provincial borders [23], showing the selected districts with red polygons.

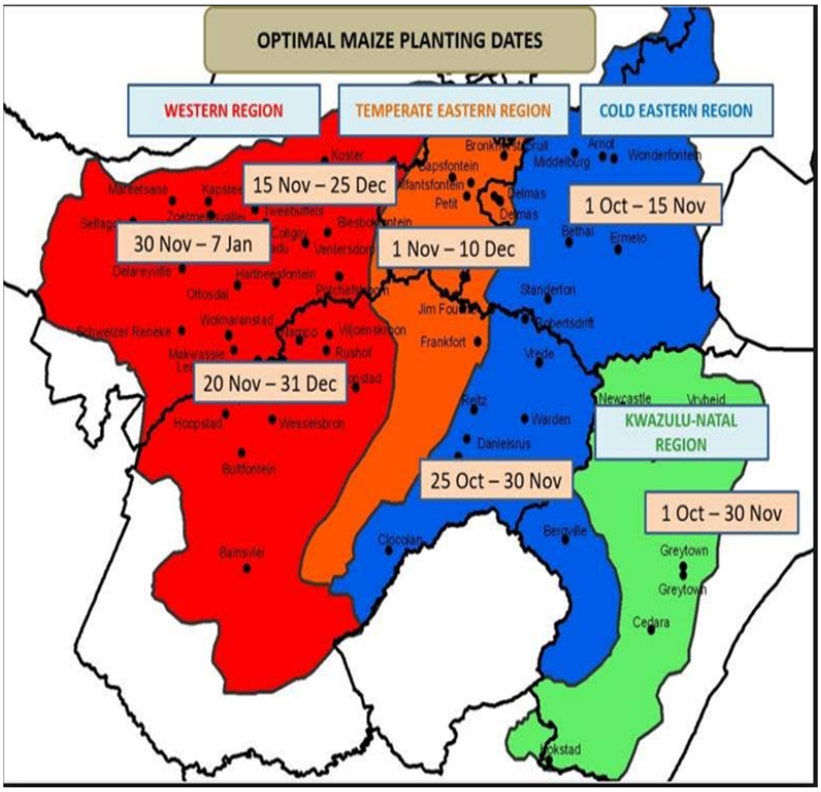

Figure 2. Maize growing regions and optimal maize planting dates [24].

The South African Weather Service (SAWS) rainfall districts 82, 83, 84, 85, 89, 90, 91, 92 and 93 (Figure 1) were selected for this study [23]. These districts are most relevant to this study, as they fall under the dryland western maize production region [24]. The study area falls under the dry Highveld climate region (Table 1) of South Africa. The boundaries of the climatic regions were determined by investigating the type of natural vegetation found in each region. The climatic conditions that are generally observed in these climatic regions are summarised in the table below.

Table 1. Summary of climate properties of dry Highveld [25].

Climate Region	Climatic Properties	Vegetation	Agricultural Use
Dry Highveld	Temperatures often exceed 30 °C in summer months and cool during winter months, with cold nights (<5 °C) observed. Over the high-lying areas, snow does occur in winter. Precipitation ranges from about 450 to 700 mm. The rainy season reaches its peak during mid-summer in the north and late summer in the south and west. Winds tend to be from the north to north–easterly direction.	Vegetation consists of grassland with some trees along streams.	Maize production, cattle and sheep

2.2. Dataset

The daily district rainfall dataset was obtained from the South African Weather Service (SAWS) rainfall database for a period of 30 years (1985–2015) [26]. The data for the summer rainy season (October to April) were assessed [26]. Pentad (defined as a period of five days) total rainfall values were used to investigate the wet- and dry-spells by using the

Markov chain probability model. A threshold of 3 mm rainfall depth per day (15 mm per pentad) was used in this study, which is the minimum threshold value for crops to satisfy their water requirements during a growing season [21]. A dry pentad is considered to be a pentad with less than 15 mm of rainfall and a pentad with 15 mm or more rainfall to be a wet pentad.

2.3. Data Analysis

2.3.1. Calculation of the Wet- and Dry-Spells Using the Markov Chain

Each year was divided up into consecutive pentads, with the first pentad being 1st to 5th of July and the 73rd pentad from 26th to 30th of June. This captures the whole summer rainfall season that commences in October and ends in April as a single period. The period of interest was mid-January to end of February, which is represented by pentads 40 to 48. This period is critical in the western growing region, as dry-spells tend to dominate in this period, and the crops planted in this region are usually in the water-stress-sensitive flowering stage [2].

In this study, a Markov chain probability model was used for analysing the wet- and dry-spells. The probability of rainfall received during a pentad ($P_{\mathrm{W}}/P_{\mathrm{D}}$) was known as the "initial probability", and the probability of receiving rain in the following pentad ($P_{\mathrm{WW}}/P_{\mathrm{DD}}$) was termed "conditional probabilities". In the first order probability, the Markov chain assumes that the probability of an incident occurring in the pentad depends on the previous pentad only; thus, it is independent of the events beyond the previous pentad [4]. Dry- and wet-spells for each pentad are calculated independently in the initial probability model. In the conditional probability model, dry-spells or wet-spells that are followed by a dry/wet-spell and vice versa were considered. The model probabilities are calculated in the following manner:

Initial Probability Percentage:

Initial probability of receiving less or more than 15 mm of rainfall

$$P_{\mathrm{D}} = F_{\mathrm{D}}/N \tag{1}$$

$$P_{\mathrm{W}} = F_{\mathrm{W}}/N \tag{2}$$

Conditional Probability Percentage:

$$P_{\mathrm{DD}} = F_{\mathrm{DD}}/F_{\mathrm{D}} \tag{3}$$

$$P_{\mathrm{WW}} = F_{\mathrm{WW}}/F_{\mathrm{W}} \tag{4}$$

$$P_{\mathrm{DW}} = 1 - P_{\mathrm{WW}} \tag{5}$$

Consecutive dry and wet week probabilities:

$$2D = P_{\mathrm{Dp1}} P_{\mathrm{DDp2}} \tag{6}$$

$$2W = P_{\mathrm{Wp1}} P_{\mathrm{WWp2}} \tag{7}$$

$$3D = P_{\mathrm{Dp1}} P_{\mathrm{DDp2}} P_{\mathrm{DDp3}} \tag{8}$$

$$3W = P_{\mathrm{Wp1}} P_{\mathrm{WWp2}} P_{\mathrm{WWp3}} \tag{9}$$

where P_{D} is the probability of the pentad being dry; P_{W} is the probability of the pentad being wet; N is the number of years of data; F_{D} is the number of dry pentads; F_{W} is the number of wet pentads; P_{DD} is the probability of a dry pentad being preceded by a dry pentad; P_{WW} is the probability of a wet pentad being preceded by a wet pentad; P_{DW} is the probability of a dry pentad being preceded by a wet pentad; F_{DD} is the number of dry pentads preceded by another dry pentad; F_{WW} is the number of wet pentads preceded by another wet pentad; *2D* is the probability of 2 consecutive dry pentads starting with a particular pentad; *2W* is the probability of 2 consecutive wet pentads starting with the particular pentad; *3D* is the probability of 3 consecutive dry pentads starting with the pentad; *3W* is the probability of 3 consecutive wet pentads starting with the pentad; P_{Dp1} is the probability of the pentad being dry (first pentad); P_{DDp2} is the probability of the second pentad being dry, given that the preceding pentad was dry; P_{DDp3} is the probability of the third pentad being dry, given that the preceding pentad was dry; P_{Wp1} is the probability of the pentad being wet (first pentad); P_{WWp2} is the probability of the second pentad being wet, given that the preceding pentad was wet; and P_{WWp3} is the probability of the third pentad being wet, given that the preceding pentad was wet.

2.3.2. Trend Detection Using the Mann–Kendall Test

The non-parametric Mann–Kendall (MK) monotonic trend test is commonly used to detect increasing or decreasing trends in time series climate data or hydrological data [26]. In this study, the MK test was used to detect the increasing or decreasing number of dry-spells per year. The number of dry-spells and the maximum length of a consecutive dry-spell for the time series data were assessed using Mann–Kendall trend test statistics and Sen's slope test (Q2) at a 95% confidence level (11).

The MK test is given by

$$S = \sum_{k-1}^{n-1} \sum_{j-k+1}^{n} \mathrm{sgn}\left(x_j - x_k\right) \tag{10}$$

where x_j and x_k represent a rainfall variable, and k is the total number of data points available in the time series for analysis.

The standard normal statistical test (p-value) helps determine the significance of results in relation to the null hypothesis. The null hypothesis states that there is no relationship between the two variables being investigated and that the results are due to chance and are not significant in terms of supporting the idea being investigated. Thus, the null hypothesis (H_0) assumes that that there is no trend existing in your time series. The alternative hypothesis (H_1) assumes existence of a trend in the time series. The level of statistical significance is a p-value between zero and one with a p-value of less than 0.05 being statistically significant and a p-value of greater than 0.05 not being statistically significant.

2.3.3. Sen's Slope Estimator

While the MK-test gives the trend, the direction, and the p-value statistic, it does not give the frequency of change. Sen's slope estimator was used to calculate the magnitude of change, providing a more robust estimation of the trend, especially when the trend cannot be estimated by other statistical approaches like the MK test. Sen's slope was estimated using the following:

$$Q = \frac{Yi - Yj}{Ni - i} \tag{11}$$

where Q is the slope estimate; Yi and Yj are the values at times i and j, where i is greater than j; N' is all data pairs for which i is greater than j.

Positive results for Sen's slope in several dry-spells indicates an increasing trend, and a negative result indicates a decreasing trend over a given time.

2.3.4. Spatial Analysis Interpolation

The spatial distribution of rainfall is often analysed using rain gauges, and they are typically the most reliable point data [27]. However, the network is sparsely distributed, and it is impossible to attain a compact data analysis using only the rain gauges that can be used to generate adequate spatial maps [27]. Therefore, to generate quality spatial maps, spatial interpolation was used. Several interpolation methods, deterministic and geostatistical, are available to analyse rainfall data. In this study, the geostatistical method was favoured over deterministic methods, and Kriging was favoured [28]. Kriging is a geostatistical method based on statistical models that have the capability of surface prediction and have been found to provide some measure of accuracy of prediction [28].

Kriging has several advantages over traditional interpolation techniques such as inverse distance weighting or nearest neighbour:

- It provides a measure of uncertainty attached to the results (i.e., Kriging variance).
- It accounts for direction-dependent relationships (i.e., spatial anisotropy).
- Weights are assigned to observations based on the spatial correlation of data instead of assumptions made by the analyst for IDW.
- Kriging predictions are not constrained to the range of observations used for interpolation.
- Data measured over different spatial supports can be combined, and change in support, such as downscaling or upscaling, can be conducted.

Kriging can use a limited set of data points to estimate the variable over a continuous spatial field [29]. Kriging assumes that the interpolation is stationary (joint probability is the same across the study area) and isotropic (uniform in all directions) [30].

3. Results

3.1. Total Annual Rainfall

South Africa is a semi-arid region, and its average rainfall is less than 500 mm. This shows that some regions may not meet the minimum water requirement for growing maize, which is 300 mm (Figure 3). During a LA Niña period such as 1988 and 2000, all the districts received over 500 mm of rainfall; however, during normal years such as 2003 and 2012, most rainfall districts received less than 500 mm. Some rainfall districts have received less than 300 mm of rainfall during drought years such as 1992 and 2015. Figure 3 indicates that the western production region is at risk due to more years of less or just-enough rain to meet the water requirement of maize. Moreover, this annual precipitation may not be evenly distributed during the planting season, which has an impact on maize yield. Extreme rainfall, such as intense rainfall or lack of rainfall, has a negative impact on maize yield.

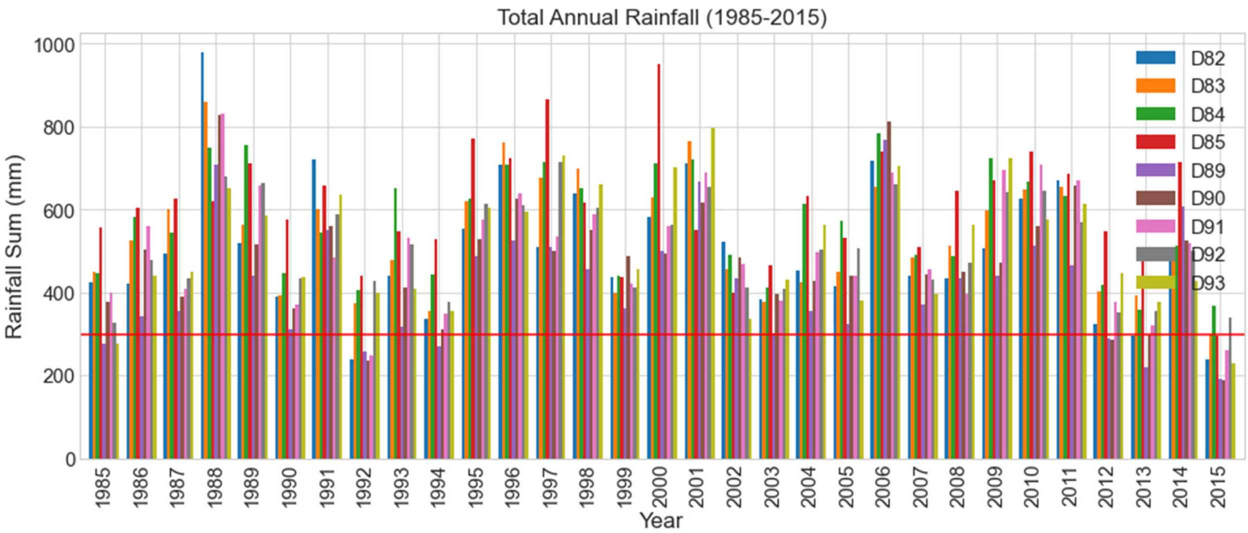

Figure 3. Total Annual Rainfall for rainfall districts (82,83,84,85,89,90,91,92,93) from 1985 to 2015.

3.2. Dry-Spell Occurrence

Analysis of rainfall for 30 years showed that for all rainfall districts, pentads 40 to 48 (mid-January to the end of February) were affected by dry-spells (Table 2). Rainfall district 84 had the lowest average initial dry-spell frequency over the period, with rainfall district 93 having the highest initial dry-spell probability during the same period. Pentad 41 (18–22 January) had the lowest average percentage of initial dry-spell probability across all districts, whereas pentad 48 (22–26 February) had the highest percentage. The conditional dry-spell probability results indicate that the district with the lowest probability was rainfall district 84, while district 89 was the highest.

Table 2. Initial dry-spell probability (%) of SAWS rainfall districts during the mid-January-to-end-of-February period (pentads 40 to 48) from 1985 to 2015.

District	40	41	42	43	44	45	46	47	48
82	64.5	58.1	71.0	80.7	71.0	54.8	51.6	64.5	77.4
83	67.7	54.8	54.8	83.9	67.7	61.3	61.3	64.5	80.7
84	48.4	41.9	58.1	77.4	64.5	61.3	61.3	48.4	71.0
85	41.9	38.7	64.5	67.7	77.4	64.5	71.0	58.1	80.7
89	77.4	67.7	77.4	77.4	77.4	71.0	74.2	64.5	87.1
90	71.0	51.6	64.5	74.2	67.7	67.7	58.1	67.7	83.9
91	67.7	48.4	71.0	74.2	71.0	64.5	67.7	58.1	77.4
92	54.8	41.9	64.5	74.2	61.3	61.3	64.5	61.3	83.9
93	51.6	61.3	74.2	74.2	67.7	64.5	71.0	74.2	74.2

The pentad with the highest conditional dry-spell probability was pentad 44 (2–6 February), and the lowest was pentad 41 (18–22 January) as illustrated in Table 3. Figures 4 and 5 are schematic results of the initial and two consecutive dry-spell probabilities. The probability of having a dry-spell is at its lowest during pentad 41 (orange colour) for most districts, with the highest probability of occurrence being in pentad 48 (black colour) (Figures 4 and 5).

Table 3. Conditional dry-spell probability table (%) of SAWS rainfall districts during the mid-January-to-end-of-February period (pentads 40 to 48) from 1985 to 2015.

District	40	41	42	43	44	45	46	47	48
82	38.7	41.9	54.8	54.8	64.5	48.4	25.8	38.7	51.6
83	48.4	45.2	38.7	45.2	61.3	41.9	41.9	41.9	54.8
84	35.5	25.8	29.0	45.2	51.6	41.9	41.9	32.3	38.7
85	25.8	19.4	25.8	51.6	58.1	51.6	41.9	41.9	45.2
89	58.1	58.1	54.8	67.7	67.7	58.1	54.8	54.8	58.1
90	58.1	45.2	35.5	48.4	61.3	48.4	35.5	45.2	61.3
91	54.8	35.5	38.7	61.3	54.8	54.8	41.9	41.9	48.4
92	29.0	25.8	25.8	48.4	45.2	38.7	38.7	45.2	51.6
93	25.8	41.9	45.2	54.8	54.8	48.4	45.2	61.3	58.1

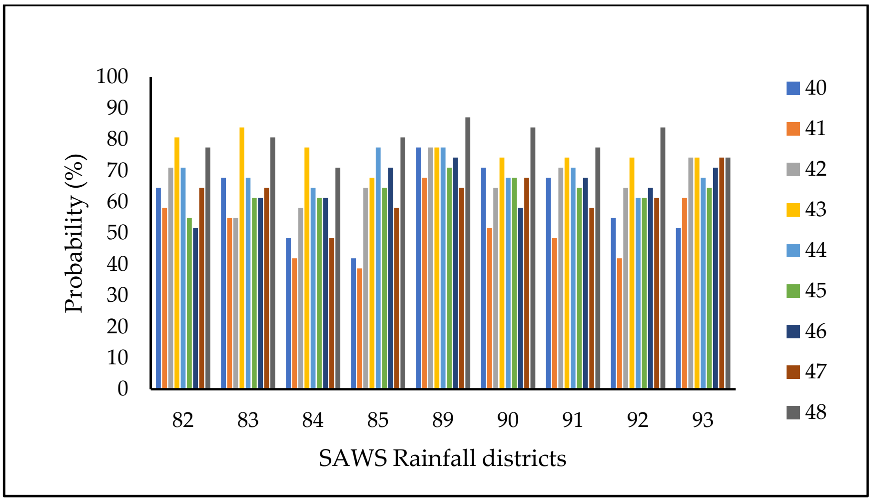

Figure 4. Initial dry-spell probability for selected SAWS rainfall districts from 1985 to 2015 during pentad 40 to 48.

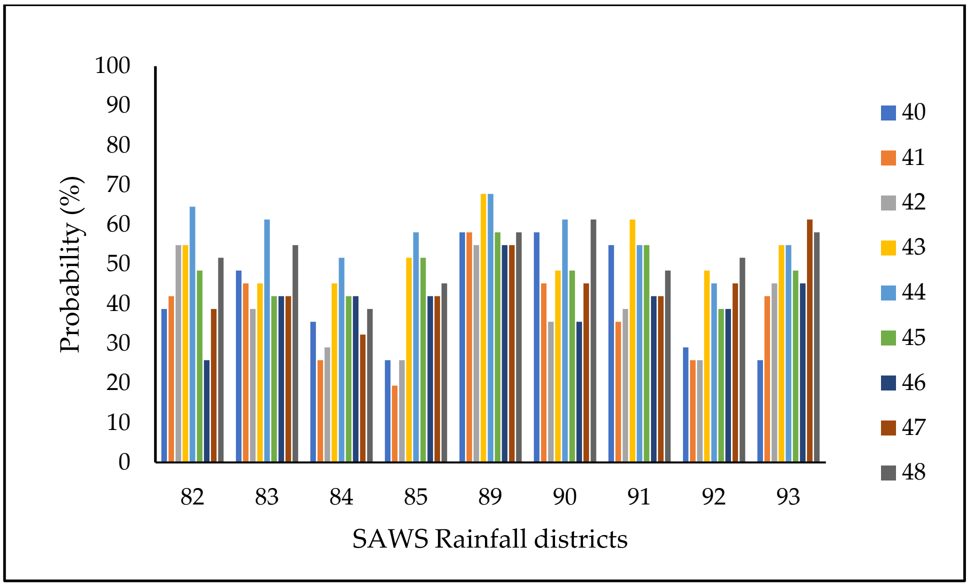

Figure 5. Probability of experiencing two consecutive dry-spells for selected SAWS rainfall districts from 1985 to 2015 during pentads 40 to 48.

Pentads 40 to 48 showed the highest probabilities of dry-spell occurrence during the study period. The occurrence of two consecutive dry pentads was low to moderately high, as shown in Figure 5. However, there is an increased risk that the study area will experience two consecutive dry-spells due to the continued lack of rainfall. The increased risk of two consecutive dry pentads will likely lead to water stress that could negatively affect the yield of summer grain crops.

The spatial analysis in Figures 6 and 7 shows that the dry-spell and wet-spell occurrences within the study area are erratic. In Figure 6, the spatial analysis of initial dry-spell probability is shown for pentads 40, 44, 46 and 48. These pentads were selected because the 40th pentad is the first pentad of the analysis period, the 44th pentad has the highest probability, while the 46th pentad generally has an average probability, and, lastly, the 48th pentad is the end of the analysis period. For pentad 40, the highest initial dry-spell probabilities were observed for the west and south-western parts. High initial dry-spell probabilities were also noticed in the north-eastern part for pentad 44, in the western, north, and north-eastern parts for pentad 46, and only the western area for pentad 48. For example, for pentad 44, the highest probability is 77% for districts 89 and 85, while districts 84 and 92 have the lowest probability of 61%. This indicates that all districts experienced dry-spells. For pentad 46 (12–16 February), the highest probability of initial dry-spell was 77%, and the lowest was 51%, with districts 85, 89 and 93 showing the highest initial probability and district 82 the lowest. For pentad 48 (22–26 February), the highest initial dry-spell probability was 87%, and the lowest was 70%, with districts 89, 90 and 92 showing the highest risk of dry-spell occurrences and district 84 the lowest. These spatial initial dry-spell probability results, presented in Figure 6, show that the probabilities are high and that the whole study area is affected by dry-spells.

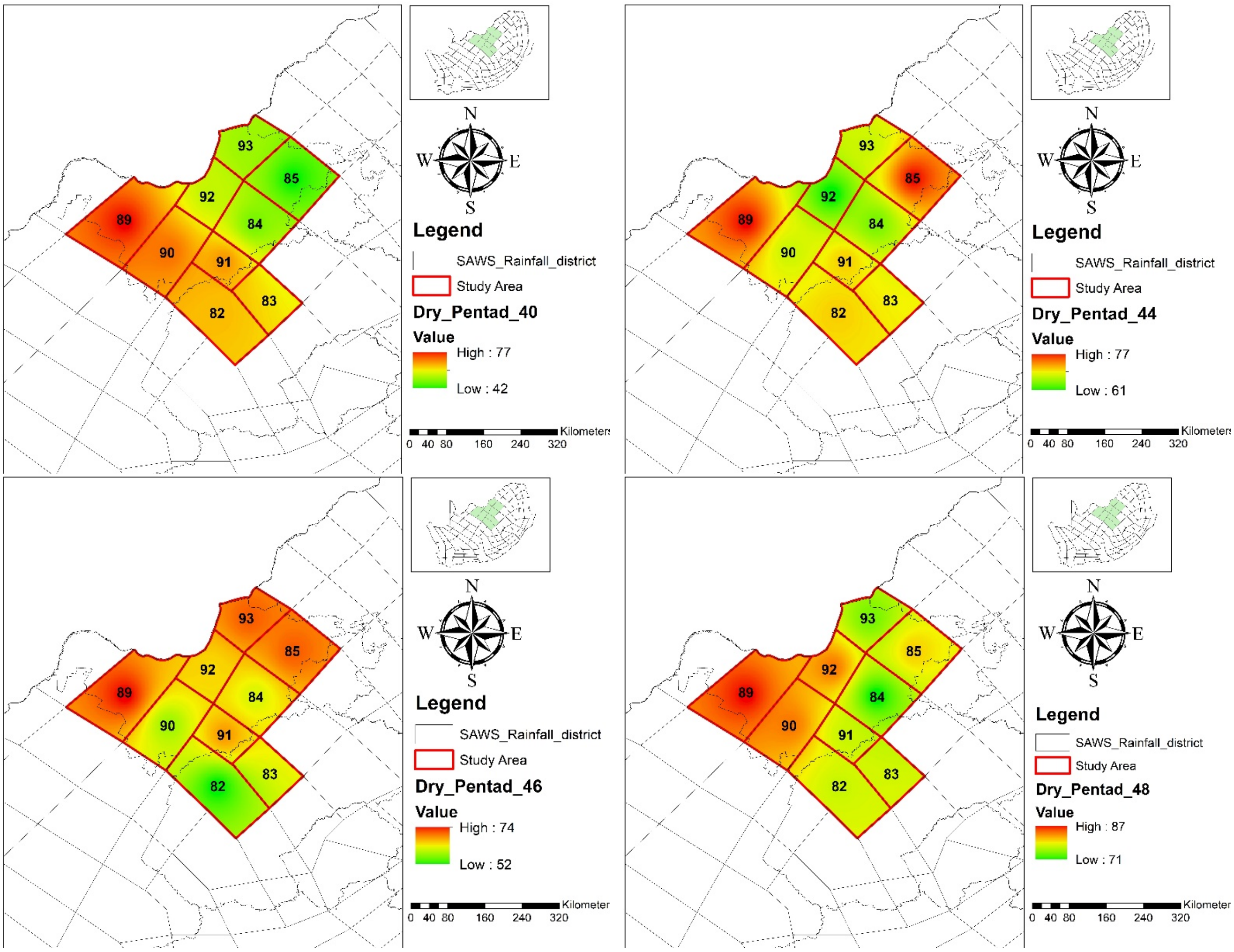

Figure 6. Spatial analysis of initial dry-spell probability (*Pd*) for pentad 40, 44, 46 and 48.

The wet-pentad probabilities are low, as expected, due to the high dry-spell probabilities, as shown in Figure 7. For pentad 40 (13–17 January), rainfall districts 84 and 85 had the highest initial wet-spell probability (58%) and the lowest probability of 22% for rainfall district 89. For pentad 44 (2–6 February), district 92 had the highest chance of 37%, and districts 85 and 89 had the lowest chance (22%) of initial wet-spell probability. In pentad 46 (12–16 February), the highest chance of a wet-spell was 48% for district 82, and the lowest probability of 25% was for districts 85, 89 and 93. The highest probability of 29% was observed in district 84 and the lowest in district 89 (12%) for pentad 48 (22–26 February). It is worth noting that district 89 had the lowest probabilities of wet-spells for the study period. These results further highlight that this period is dominated by dry-spells.

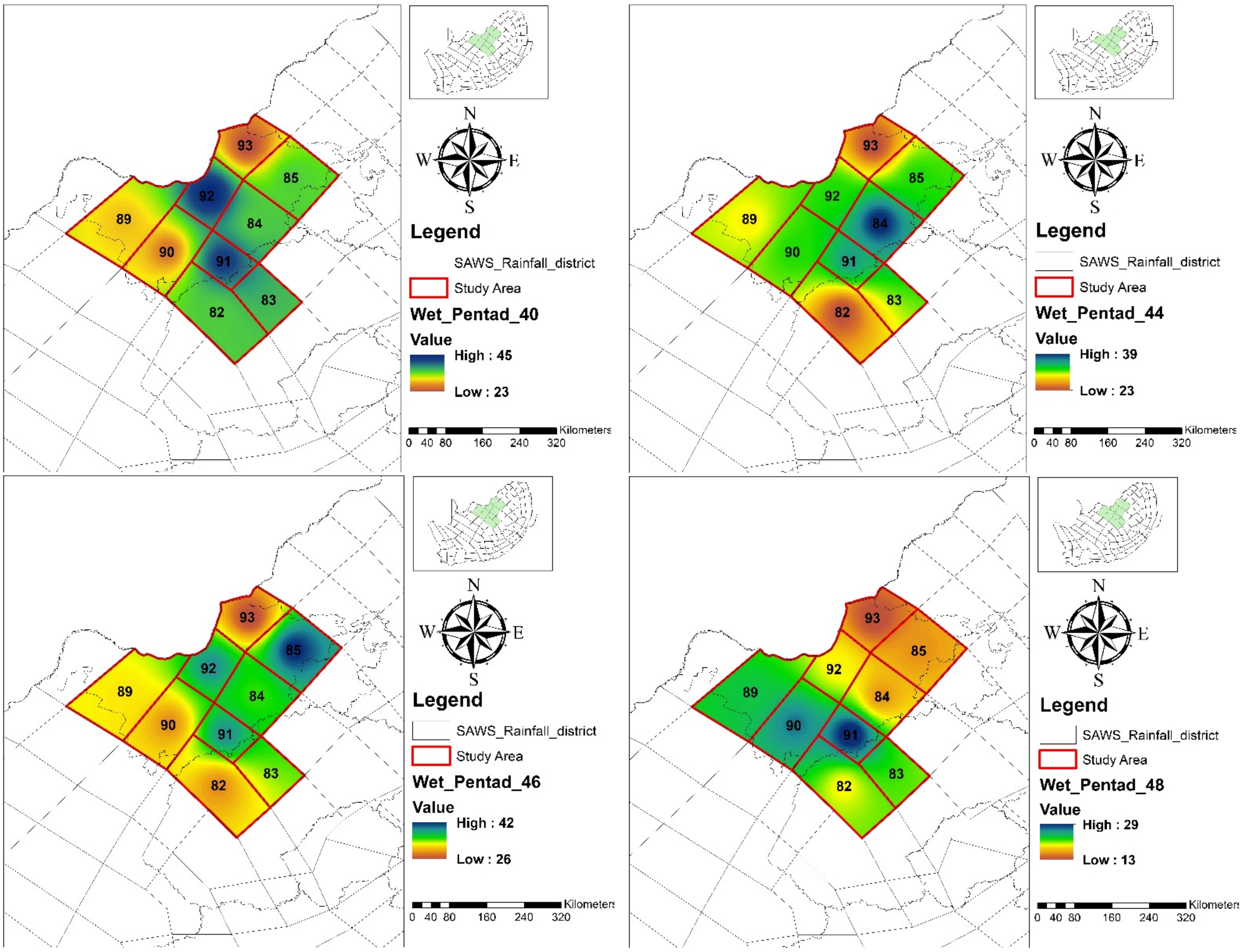

Figure 7. Spatial analysis of initial wet-spell probability (*Pw*) for pentad 40, 44, 46, 48.

3.3. Trend Analysis of Dry-Spells

The results of the MK and Sen's slope trend analysis at a 95% confidence interval for SAWS rainfall districts in the study area for pentads 40 to 48 (Table 4) indicate that there was no statistically significant trend detected in any of the rainfall districts (Table 4). A detectable change in the trend was noticed for district 92, with a magnitude of −0.03 per year, indicating a decrease in the occurrence of dry-spells over the 30-year study period (1985 to 2015). The other rainfall districts showed no significant detectable magnitude of change in the trend. The magnitude of the trend (Sen's slope) was provided and showed that there is no change in the dry-spell magnitude over the years. Rainfall districts 83 and 84 show a stable trend (in dry-spell < 15 mm), with the MK statistics at −0.12 and −0.04, respectively. The *p*-values of 0.91 for district 83 and 0.97 for district 84 reveal that the trend is not statistically significant, and, thus, the trend is inconsistent.

Districts 86 and 91 show an upward trend in the number of observed dry-spells (<15 mm dry-spell) over the 30-year period. District 86 has an MK statistic value of 0.38, with a *p*-value of 0.71. This indicates that there is an increasing trend in the number of dry-spells occurring over the years; however, the trend is not significant, and the Sen slope is at 0.00. An MK value of 0.75 and *p*-value of 0.45 were found for district 91. Although there is no significant trend, the upward trend may be of concern, as the region is already dry, and this will further aggravate the conditions faced by dryland producers. Rainfall districts 89 and 92 had the highest MK values, and they are −0.99 and −1.42, respectively. This is evident in the charts in Figure 8, where the trend line clearly shows a decreasing trend in dry-spells for both districts. Furthermore, district 92 has a Sen slope magnitude of −0.03; this further suggests that there is a decreasing trend in this district during the study period.

Table 4. Mann–Kendal and Sen's slope analysis at 95% confidence interval for SAWS rainfall districts during pentads 40 to 48 (1985 to 2015).

District	Dry-Spell < 15 mm		
	MK Stat	*p*-Value	Sen's Slope
82	−0.37	0.71	0
83	−0.12	0.91	0
84	−0.04	0.97	0
85	−0.14	0.89	0
86	0.38	0.71	0
87	0.27	0.78	0
89	−0.99	0.32	0
90	−0.54	0.59	0
91	0.75	0.45	0
92	−1.42	0.16	−0.03
93	0.62	0.53	0
95% Confidence level—Pentads 40 to 48 (Mid-January-End of February)			

The lack of significance in the direction of the trends for the individual rainfall districts within the study area indicates that the occurrence of dry-spells is normal during the study period in this study area.

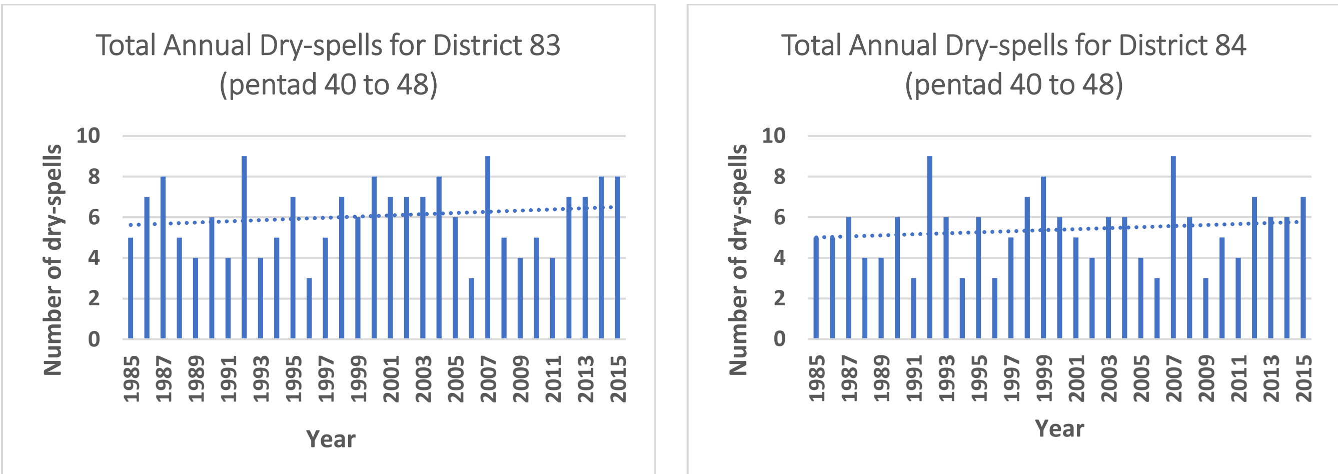

Figure 8. *Cont.*

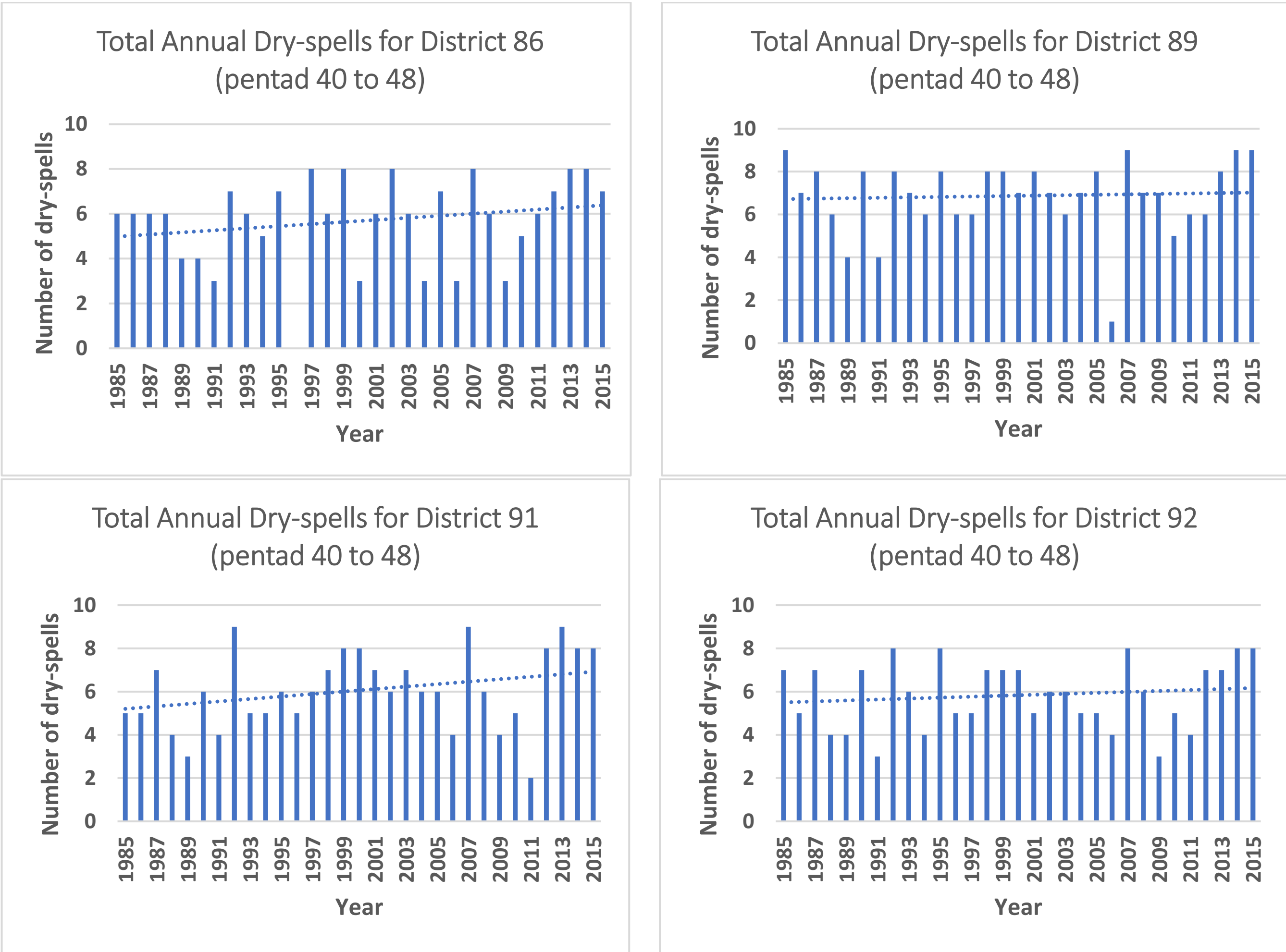

Figure 8. Trend analysis of the number of dry-spells per year in SAWS rainfall district 83, 84, 86, 89, 91 and 92 during pentad 40 to 48.

4. Discussion

The occurrence of wet- and dry-spells is an important phenomenon for summer crops, as it may signal a "good or a bad" season, depending on when they occur. Grobler [31] illustrated that, during the mid-summer period, dry-spells tend to dominate in the major maize production areas. In the study carried out by Mengistu et al. [5], it was discovered that dry-spells occur at different frequencies and magnitudes during mid-summer in the major maize production areas of South Africa. The western maize-growing region experiences late onset of the rainfall season, which leads to late planting of summer crops. However, for the western maize-growing areas, due to the late planting, the flowering stage, which is sensitive to water stress, usually occurs during the end of January to February and not necessarily during the specified mid-summer period used in the study of Mengistu et al. [5]. Findings from this study revealed that dry-spells still occur at a relatively frequent rate during the mid-January-to-end-of-February period, and their occurrence might have an adverse effect on the summer grains if the flowering stage coincides with the dry-spells.

This is not favourable for dryland farming, which only relies on rainfall for crop production. A season with poor rains and a higher-than-normal dry-spell frequency will lead to crops being water-stressed and result in lower crop yields. Most of the rainfall districts have a neutral trend in dry-spell frequency; the unpredictable nature of the occurrence of these dry-spells has a negative impact on the annual planning of crop production.

Information on dry-spell characteristics such as frequency, duration, and intensity with respect to maize crop phenology is particularly important for dryland maize production. Therefore, planting dates should be chosen to ensure that the flowering stage coincides with normally favourable growing conditions and does not coincide with mid-summer dry-spell periods [2]. Knowledge on the length of dry-spells can be used for selecting drought-tolerant varieties and can be used in irrigation planning during the critical dry period. Thus, the investigation of dry-spells is critical in this region, as the impacts of water stress have dire consequences on grain crop production, especially those produced under dryland conditions.

The results of this study reveal that the occurrence, as well as the intensity, of dry- (wet-) spells is variable. This poses a serious risk to farmers that rely on rainfed agriculture, especially in the western region where these dry-spells occurred more often during the study period. The neutral trend in dry-spell frequency in much of the study area is a sign that dry-spells have been occurring continuously during the study period. It is worth noting that the occurrence of dry-spells in the western part are attributed to the characteristics of the dry climate of the region. As dry-spells have an impact in reducing maize crop yield if they coincide with the flowering stage, it is therefore vital that more research is carried out on introducing strategies to minimise risk and avoid production losses.

The knowledge of dry- and wet-spell probability prepares agricultural advisors with a tool to equip the farmers in gaining knowledge, understanding the risks, and potentially improving production. Critically analysing spells and planting dates in a district can assist farmers with deciding when to plant and avoid the dry-spell period by predicting when it is likely to occur. Knowledge of dry- and wet-spells can also assist researchers in breeding new crop varieties that mature at different stages, when they know the general occurrence of the dry-spells. Monitoring dry- and wet-spells coupled with the onset and cessation of the rainy season is vital information, as it equips role-players with the knowledge of what to generally expect in each region or rainfall district.

Furthermore, the findings from this study show that dry-spells occur frequently during the study period, and this has adverse effects on crop production. As most districts in the study area illustrate, no changes were observed in the trends of dry-spell frequencies, except for one (district 92), which showed a decreasing trend in dry-spell occurrence. However, this observed decreasing trend in dry-spell frequency for district 92 was not statistically significant.

5. Conclusions

Rainfall patterns directly affect the crop yield in rainfed agriculture; hence, it is significant to monitor the probability of wet- and dry-spells. The success and failure of crops in a planting season is directly influenced by the occurrence of wet- and dry-spells. Dry conditions are beneficial during the ripening stage of crops. The rainfall districts that were analysed in this study reveal that the occurrence of dry-spells is a major threat to crops, where most summer crops in this region are at the flowering stage as they are planted later than in the eastern regions. The Markov chain model proved to be the most accurate method of analysing the dry-spell occurrence.

It is evident from the results that all rainfall districts in the study area are subjected to dry-spells. It is therefore crucial that future research focus more on the effects of dry-spells on different varieties of maize. This will allow farmers to select cultivars that can withstand these dry conditions.

The recommendations from this study are as follows:

1. An investigation into optimum planting dates by using crop models to avoid the occurrence of dry-spells should be conducted, which is crucial to assist farmers and decision makers in preventing production losses and other adverse effects of dry-spells.
2. The impact of climate change on future projections of dry-spells should be investigated.

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