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Climate variability, drought, and vegetation - a comparison of three district municipalities in Northern KwaZulu-Natal, South Africa

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Abstract

A study was conducted to compare climate variability, drought, and their effects on vegetation in northern KwaZulu-Natal. The assessment was done by examining the weather elements (rainfall, humidity, and temperature) over six years (2017-2022) in the three district municipalities of northern KwaZulu-Natal. The three district municipalities investigated were Zululand, King Cetshwayo, and uMkhanyakude. The spectral/drought (Rainfall Anomaly Index) and the vegetation indices [Modified Water Difference Index (MWDI) and Normalized Difference Vegetation Index (NDVI)] were also investigated. The results showed significant differences in humidity, temperature, and rainfall between the three district municipalities. There were indications that drought occurred at different times of the year in the studied municipalities. The intensity and duration of the drought also varied. Other findings include a correlation between rainfall and the vegetation indices. On average, King Cetshwayo received more rainfall than both uMkhanyakude and Zululand District Municipalities. uMkhanyakude had the least rainfall and was the most drought-prone, especially between May and September. The outcome of this study will undoubtedly contribute to how farmers in the three district municipalities decide when, what, and where to plant their crops to avoid or reduce the negative impact of climatic changes on crop growth and, consequently, on the yields of their crops.

Keywords: Climate, Drought, Humidity, Rainfall, Temperature, Vegetation, Weather.

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Transparency: The author confirms that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.
Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (Higher degrees committee of the University of Zululand, KwaDlangezwa 3886, South Africa). Project registration number: S615-17, Ethical clearance number: UZREC 171110-030 PGD 2017/175 entitled "Sweet Potato (Ipomoea batatas L) Response to Different Agro Ecologies and Soil Amendments in Northern Kwazulu-Natal".
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1. Introduction

Agricultural drought is a condition whereby crops do not have access to adequate water needed for optimal growth leading to reduced yield [1-3]. It is a period of no, or insufficient rainfall, and it is one of the greatest threats to agricultural production [2]. Drought is a global phenomenon and South Africa like most parts of the world experiences drought in almost all its provinces [1-3]. For example, droughts were reported in the 1960s, 1980s, 1990s, 2002, 2003, 2005, 2015 and with the worst occurring between 2018 and 2021 [1, 4-8]. Implicated in the recurrent drought are El Niño which is the natural warming of the sea, and climate change which affects the equatorial Pacific region [4, 6]. Unfortunately, it has been projected that drought will continue and may be more severe in the future [3, 9].

Considering the entire summer rainfall pattern, drought, and other weather conditions are not uniform throughout the country. Also, the intensity and duration of drought differ among the nine provinces of the country [1, 9]. Besides rainfall, other factors responsible for agricultural drought include high temperature, [6, 10]. The combination of both rainfall and temperature affects evapotranspiration and consequently humidity [6, 10]. Whatever may be responsible for drought in a particular place, one of the major adverse effects is on agriculture. For instance, due to the severity of the impact of the 2015 drought, five of the nine provinces in South Africa were declared as 'drought disaster areas' for agriculture [11, 12]. KwaZulu-Natal (and by extension, northern KwaZulu-Natal) was one of the provinces so declared. Other provinces included in the declaration were the Free State, Limpopo, Northwest Province, and Mpumalanga.

There is a direct correlation between rainfall and crop yield, especially in rain-fed crop production [2]. At the national level, there is a correlation between rainfall and the country's gross domestic product (GDP) growth in many countries such as Ghana, Nigeria, and South Africa, because the agricultural sector accounts for a large share of the national income [13]. One of the consequences of crop failure due to drought is population drift from rural areas into urban centers. Others include veld fires, farm closures, and subsequently the layoff of farm and allied business employees [14].

During drought, the only viable option to ensure that agricultural productivity continues unaffected is the irrigation of farmlands. Unfortunately, the cost of installing and maintaining irrigation equipment is high and unaffordable to small-scale farmers [6, 15]. Besides the cost, other challenges associated with irrigation include expertise in the maintenance of irrigation systems, availability and power supply [16]. All these are not within the reach of small-scale farmers. Hence, the effect of drought is more severe on small-scale farming [6, 15]. Due to a lack of resources for irrigation, many small-scale farmers may experience reduced farm yields/income and in more severe cases many of the small-scale farmers may go out of farming business [11, 12].

A range of challenges such as low rainfall, poor vegetation conditions, and high temperatures is elevated during drought [6, 10]. Agriculture is very sensitive to these constraints. Hence, the effects of the variability in weather and climate (especially rainfall and temperature) at a range of time and spatial scales can be observed in crops, and the general vegetation of the area [10, 15, 17]. Hence, vegetation indices such as the Normalized Difference Vegetation Index (NDVI), the Enhanced Vegetation Index (EVI), and the Normalized Difference Water Index (NDWI), have been successfully used to study drought and vegetation pattern [18].

Due to the non-uniformity in weather patterns in northern KwaZulu-Natal, the choice of farm site is very important. Also, the responses of plants to droughty weather differ. While some plants such as sweet potato are drought tolerant due to their phenotypic plasticity, some plants such as chicory and alfalfa can survive a drought if they are already established before the onset of drought. For instance, chicory and alfalfa have deeper roots than most other perennials like clover. Hence, they become dormant during a drought, but they will spring up when the weather becomes conducive (cooler temperatures and some moisture) [19]. Therefore, it is not all gloom for rain-fed agriculture, but farmers will have to work around the dry weather or the prevailing weather in their areas and make informed choices to mitigate the effect of drought. Such choices include, when and where to grow which crop. However, there is a paucity of information (if any) on the vegetation and drought indices in uMkhanyakude, King Cetshwayo, and Zululand district municipalities of KwaZulu-Natal province. Hence, this study was aimed at comparing the climate variability, drought, and their effects on the vegetation in northern KwaZulu-Natal.

2. Materials and Methods

2.1. Study Areas and Humidity, Rainfall and Temperature Data Collection

The study was done in uMkhanyakude, King Cetshwayo and Zululand district municipalities. The weather elements data (humidity, temperature and rainfall were taken via remote sensing by the South African Weather Service at Makhathini Research Station (Climate Number: 0411323 2, Latitude: -27.3940, Longitude: 32.1760, Height: 63 m) for uMkhanyakude district municipalities. For King Cetshwayo district municipality the data was taken at Richards Bay Airport weather station (Climate Number: 0305134 6, Latitude: -28.7370, Longitude: 32.0930, Height: 36 m). In the case of Zululand district municipality, the data was taken at Vryheid weather station (Climate Number: 0372527 1, Latitude: -27.7770, Longitude: 30.7960, Height:1163 m), and Ulundi weather station (Climate Number:0372527 1, Latitude: -27.7770, Longitude:30.7960, Height:1163 m). The data for humidity, rainfall and temperature were logged hourly from January 2019 to December 2021. The hourly data collected were added to make up for the daily values, and subsequently the monthly values were generated. The average monthly temperature was calculated and reported in this study. The standard deviations calculated were not reported in the Tables because the RAI has effectively served same purpose.

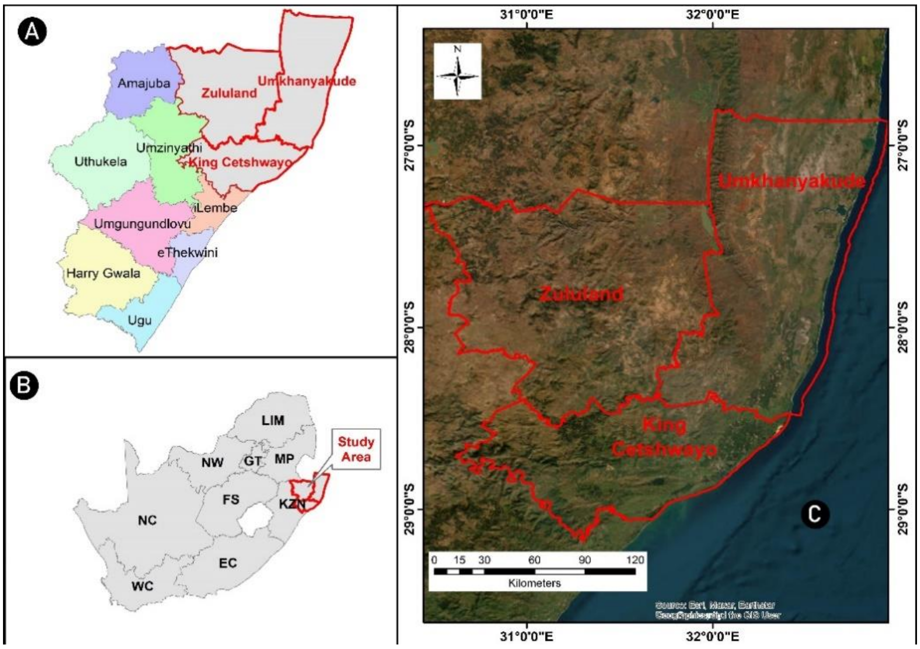

Figure 1.
Maps of KwaZulu-Natal province (A), South Africa (B) and the satellite imagery of the study area.
Note: All the images/graphs in the (Figure 1) are original. The right to use it for educational, research and developmental purposes are granted, but must the referenced and or acknowledge appropriately.

The study area are the following district municipalities: uMkhanyakude, King Cetshwayo and Zululand district municipalities.

2.2. Spectral Indices Data Collection and Analyses

High-resolution Sentinel-2 satellite imagery was obtained for the study area from the periods: Autumn/Summer: 1st December – 31st May (2017-2021) and Winter/Spring: 1st June – 20th November (2017-2021). Data were acquired at specific wavelengths to capture detailed information about the land surface, including Band 2 (Blue): 490 nm, Band 3 (Green): 560 nm, Band 4 (Red): 665 nm, Band 8 (NIR): 842 nm, and Band 11 (SWIR 1): 1610 nm. Google Earth Engine (GEE) was utilized as a powerful cloud computing platform to process and analyze the large volume of Sentinel-2 imagery. The platform's capabilities were harnessed for efficient data filtering, pre-processing, and computation of various spectral indices.

i. Spectral Indices Computation was done as follows:

NDVI was calculated using the following formula:

$NDVI=(B8+B4)/(B8-B4)$ [20] where $B8$ represents the Near-Infrared band (842 nm) and $B4$ represents the red band (665 nm) of the Sentinel-2 multispectral imagery.

MDWI (Modified Water Difference Index): MDWI was computed using the formula $MDWI=(B3+B11)/(B3-B11)$ (Du et al., 2016), where $B3$ represents the green band (560 nm) and $B11$ represents the Short-Wave Infrared band (1610 nm) of the Sentinel-2 multispectral imagery.

ii. Rainfall Anomaly Index (RAI)

Monthly precipitation data was collected from the PERSIANN-Cloud Classification System for the study area. The data spans the period from 2000 to 2022. The spatial resolution of the data is (4x4 km), providing detailed information on precipitation patterns. The Rainfall Anomaly Index (RAI) for each month using the formula [21]:

- $\text{RAI} = \pm 3(\frac{Pi-P}{E-P})$

In this equation, Pi is the sequence of measured precipitation at the time I, P is average precipitation, E is average of 10 extrema and ± 3 is the prefix used to determine the limits of the lower and upper bounds of the anomalies.

Rainfall anomaly was calculated thus Rainfall anomaly = Total rainfall each year – Average rainfall over a long period of time.

Note: All figures presented in this study were prepared using ArcMap 10.2.

3. Results and Discussions

The weather elements (rainfall, temperature, and humidity) varied across the three district municipalities of uMkhanyakude, King Cetshwayo, and Zululand. The weather conditions in the two weather stations of Zululand (Vryheid and Ulundi) were closely related when compared to those of uMkhanyakude and King Cetshwayo. The result of the study indicated that drought occurred more in the uMkhanyakude district municipality than in any of the other district municipalities studied both in terms of the frequency and duration of drought. The images of vegetation indices explored in this study corroborated the weather elements data obtained in this study.

3.1. Rainfall (Drought) in Northern KwaZulu-Natal

Although the global annual rainfall is 786 mm (average: 65.5mm monthly), in South Africa, it is 464 mm [22]. Hence, South Africa is very prone to drought. If distributed evenly, the average monthly rainfall would be 38.6 mm. However, rainfall varies widely between the 12 months of the year, and between various locations within the Republic. For instance, in 2017, while the average annual rainfall was 441.6 mm in Makhathini, the station received a total of 102.2 mm in December, 1.6 mm in July and no rain at all in June (Table 1). Also, in 2022, Vryheid received a total rainfall of 1138.0 mm which is above the global average, in July of the same year, it only received 1.0 mm rainfall (Table 1).

A critical point to note is the deviation of average rainfall from the national average (rainfall anomaly). The greatest deviation occurred in King Cetshwayo district municipality (Figure 2). Deviation from the average over a long period can affect planning related to rainfall expectations on the farms. Generally, South Africa's climate is characterized by periods of wet and dry spells [23]. During the wet spells, the country receives rainfall more than the normal or average rainfall (known as La Niña), and during the dry spells, the country receives rainfall that is below normal rainfall (El Niño). In other words, a positive precipitation anomaly occurs in a La Niña year while a negative rainfall anomaly occurs in an El Niño year. In this study, Makhathini experienced a lack of rain more than the other 3 locations studied. Based on the global average monthly rainfall of 65.5 mm [22] Makhathini experienced negative rainfall anomaly in 4 of the years studied, while in Richards Bay negative rainfall anomaly only occurred in one year (Year 2020) (Table 1). Generally, more rainfall is received in the summer/autumn seasons resulting in greener vegetation compared to the spring/winter seasons (Figure 3).

The drought in South Africa has been widely attributed to El Niño [1, 6], but this may not be true for Richards Bay. While the drought in Makhathini may be largely attributed to El Niño, the drought in Richards Bay, Vryheid, and Ulundi may be linked to daily and monthly rainfall distribution patterns. The lack of rain is closely related to lower temperatures. It has been reported that as temperature increases by 1 °C, the intensity of rainfall increases by 7% [24].

3.2. Temperature Changes in Orthern KwaZulu-Natal

Generally, the temperature was higher in Richards Bay and Makhathini when compared to the data obtained in Vryheid and Ulundi (Table 2). While the average monthly temperature over the 6 years studied was 23°C and 22.2°C in Makhathini and Richards Bay respectively, the average temperature was 20.5°C and 18.5°C at Ulundi and Vryheid respectively (Table 2). Hence, Vryheid had the mean temperature which is closest to the national average of 17.5°C [22]. Zululand (average of Vryheid and Ulundi) enjoys lower temperatures when compared to uMkhanyakude, and King Cetshwayo district municipalities.

The hottest district municipality was Makhathini which had an average temperature of 23°C for the 6 six years of the study. This was closely followed by King Cetshwayo at 22.4 °C, while Zululand had an average of 19.5 °C. The hottest months of the year were January, February, March, and December in all the district municipalities studied (Table 2). Generally, in South Africa, temperatures vary according to the season, and sometimes within the same district municipality [22]. In this study, although both Ulundi and Vryheid municipalities are within the same Zululand municipality, the average temperature in Ulundi was 2°C higher than that of Vryheid.

3.3. Humidity Changes in Northern KwaZulu-Natal

Current climate models indicate that as temperatures increase, evaporation will also increase, resulting in drying over some land areas and thereby increasing the likelihood of drought [25]. The water vapor that escapes into the atmosphere increases its humidity [25]. Based on the data from this study, Richards Bay, which is in the King Cetshwayo District Municipality, was the most humid and may be considered to be extremely humid [26, 27]. In some of the years studied (Table 4), the highest average monthly humidity in Richards Bay occurred in April (78.4%) and May (78.4%) (Table 3). Unlike other study sites, a consistent increase in yearly humidity occurred from 2017 to 2021, with 2021 and 2022 having similar humidity (79.7%), which was the highest yearly humidity obtained in the entire six years studied (Table 3). The higher humidity in Richards Bay may be associated with its proximity to the Indian Ocean [28, 29].

The Normalized Difference Water Index (of NDWI- In satellite imaging, open waters are highlighted with NDWI) to make them distinct from the vegetation and soil at the location) uMkhanyakude, King Cetshwayo, and Zululand district municipalities of KwaZulu-Natal province in the winter/spring and autumn/ summer of 2017 and 2021 are presented in Figure 4. Although the average humidity in Makhathini was lower than that of Richards Bay, the highest humidity occurred in April (75.7%) and May (75.5%). However, in Vryheid and Ulundi, the most humid months were February (76.7%) and December (76.5%). Hence, Zululand is the least humid. Over the entire period studied, the least humid month was July 2019 in all the study sites (Table 3).

Table 1.
Rainfall in King Cetshwayo (Richard’s Bay Airport weather station), uMkhanyakude (Makhathini research station) and Zululand (Vryheid and Ulundi weather stations) district municipalities of the KwaZulu-Natal province of South Africa from January to December (2017 – 2022).

	Richard's bay airport								**Makhathini research station**					
	2017	**2018**	**2019**	**2020**	**2021**	**2022**	**Average**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Average**
January	189.8	61.4	115.4	57.0	248.8	63.0	122.6	51.6	115.0	39.6	17.6	175.0	53.0	75.3
February	269.4	141.0	179.8	173.6	198.4	127.6	181.6	79.8	253.8	95.2	64.2	228.5	16.4	123.0
March	81.4	90.4	131.6	34.0	3.0	138.2	79.8	47.6	156.4	123.2	10.4	55.6	69.4	77.1
April	14.2	163.6	149.2	78.4	121.0	485.0	168.6	11.2	16.2	28.8	87.0	27.0	44.2	35.7
May	375.8	228.8	8.0	29.8	145.0	143.2	155.1	16.0	37.2	0.0	13.2	6.2	41.6	19.0
June	46.0	66.4	0.0	62.2	90.2	44.6	51.6	0.0	3.4	0.0	30.6	8.8	4.4	7.9
July	20.0	13.8	10.0	26.7	45.4	16.6	22.1	1.6	1.2	0.2	8.6	1.8	0.6	2.3
August	34.2	65.4	67.4	52.4	48.0	48.0	52.6	13.2	24.8	5.6	4.6	4.4	4.6	9.5
September	15.2	55.8	51.8	79.8	178.0	62.8	73.9	36.8	60.6	0.8	17.4	16.4	19.8	25.3
October	100.0	154.0	142.4	86.2	138.6	58.2	113.2	36.2	38.4	36.2	30.8	68.0	20.8	38.4
November	89.2	90.6	165.6	19.6	37.4	120.2	87.1	45.4	30.6	92.8	36.8	42.0	63.6	51.9
December	130.0	88.4	197.2	65.8	235.2	202.4	153.2	102.2	51.8	63.0	107.8	159.8	98.8	97.2
Total	1365.2	1219.6	1218.4	765.5	1489	1509.8	1261.3	441.6	789.4	485.4	429	793.5	437.2	562.7
Average	113.8	101.6	101.5	63.8	124.1	125.8	105.1	36.8	65.8	40.5	35.8	66.1	36.4	46.9
		Vryheid								Ulundi				
January	216.0	93.0	109.0	82.8	256.2	165.2	153.7	99.2	87.6	71.8	85.4	134.6	96.2	95.8
February	129.2	83.6	190.0	113.6	108.4	56.8	113.6	82.0	72.6	58.6	78.0	136.0	15.8	73.8
March	47.0	128.4	150.6	33.4	58.8	184.2	100.4	37.6	121.0	47.2	60.0	65.2	71.8	67.1
April	42.6	48.6	119.4	134.0	19.2	176.2	90.0	46.0	20.2	42.8	57.6	26.6	160.8	59.0
May	59.6	63.6	0.6	3.6	9.6	32.2	28.2	48.4	121.6	0.2	0.6	14.0	56.0	40.1
June	0.0	0.0	0.0	42.6	19.6	13.2	12.6	0.0	4.0	5.2	36.6	4.0	14.6	10.7
July	0.2	3.2	1.4	0.2	0.0	1.0	1.0	0.4	2.0	0.0	2.0	0.0	0.0	0.7
August	3.8	53.2	1.8	1.2	25.6	13.2	16.5	3.8	35.8	9.2	2.8	24.2	2.8	13.1
September	10.8	64.2	23.4	14.0	48.0	32.4	32.1	18.2	45.8	10.0	24.0	62.2	25.2	30.9
October	88.0	113.8	46.6	53.8	50.4	70.4	70.5	64.4	49.0	45.6	30.0	36.6	23.4	41.5
November	87.2	89.8	104.6	71.4	78.0	208.2	106.5	78.4	41.4	145.2	92.2	50.4	101.0	84.8
December	201.8	251.0	109.4	205.8	303.2	185.0	209.4	108.1	81.6	112.6	134.4	153.0	140.6	121.7
Total	886.2	992.4	856.8	756.4	977.0	1138.0	934.5	586.5	682.6	548.4	603.6	706.8	708.2	639.4
Average	73.9	82.7	71.4	63.0	81.4	94.8	77.9	48.9	56.9	45.7	50.3	58.9	59.0	53.3

The more intense the red is, the greater the severity of the lack of rain. The deeper the blue color, the higher the rainfall exceeds the average rainfall in the study area.

Table 2.
The temperature in King Cetshwayo (Richard's Bay Airport weather station), uMkhanyakude (Makhathini research station) and Zululand (Vryheid and Ulundi weather stations) district municipalities of the KwaZulu-Natal province of South Africa from January to December (2017 – 2022).

Month	**Richard's Bay Airport**							**Makhathini research station**						
	2017	**2018**	**2019**	**2020**	**2021**	**2022**	**Average**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Average**
January	25.4	25.4	24.9	26.4	25.6	25.6	25.6	26.6	26.5	26.4	28.8	*	25.9	26.8
February	26.3	24.9	25.6	25.9	25	25.9	25.6	27.4	25.9	26.8	27.6	*	26.8	26.9
March	25.9	24.9	25.9	24.6	24.4	25.1	25.1	26.3	25.4	26.9	26.9	26.6	25.3	26.2
April	23.4	23.6	23	21.9	22.6	21.9	22.7	24.4	24	24.1	23.8	22.8	22.6	23.6
May	25.4	20.7	21.8	20.1	19.9	20.8	21.5	21.5	21.2	21.9	20.7	21.8	20.4	21.3
June	19.2	18.8	19.4	18.4	18.2	17.5	18.6	19.4	18.7	19.3	18.3	18.6	16.6	18.5
July	19.3	18.4	19.1	17.7	17	19.3	18.5	19.6	17.9	18.9	17.4	20.9	18	18.8
August	19.6	19.2	20.2	18.4	18.4	19.4	19.2	20.1	20.1	21.8	19.6	18.9	19.3	20.0
September	21.8	21.3	20.1	20.2	20.1	21.9	20.9	22.6	22.4	22.1	21.3	20.9	22.6	22.0
October	20.9	20.8	22.3	21.9	20.3	24.1	21.7	23.1	21.4	24.4	23.8	21.4	25.4	23.3
November	22.8	22.4	23.3	23.6	22.3	23.1	22.9	24.1	23.6	25.8	26.1	23.4	24	24.5
December	23.4	25.5	23.4	25.7	24.1	24.1	24.4	25.3	26.8	26.3	27.5	25.4	26.3	26.3
Average	22.8	22.2	22.4	22.1	21.5	22.4	22.2	23.4	22.8	23.7	23.5	22.1	22.8	23.0
	Vryheid							Ulundi						
	2017	2018	2019	2020	2021	2022	Average	2017	2018	2019	2020	2021	2022	Average
January	21	21.1	22.1	22.6	22.1	21.6	21.8	24	23.3	23.8	25.2	24.8	23.7	24.1
February	21.4	21.3	22.1	22.1	21.1	22.7	21.8	24.6	22.7	24.6	24.8	23.4	24.3	24.1
March	20.9	21.1	22.5	20.7	21.1	20.9	21.2	23.9	22.5	24.4	23.6	23.3	23.1	23.5
April	18.5	19.6	19.8	17.8	19.1	16.9	18.6	21.4	21.1	21.9	20.6	21.6	19.8	21.1
May	15.3	16.6	17.1	15.2	16.1	15.5	16.0	18.9	17.6	19.8	17.8	18.6	17.8	18.4
June	14.4	15.1	13.8	12.4	13.4	12.6	13.6	17.4	15.3	16.3	15.6	16.4	14.8	16.0
July	14.7	13.3	15.7	12.7	12.6	14.1	13.9	16.9	14.2	17.4	15.8	14.8	16.4	15.9
August	15.4	16.8	17.9	15.3	15.1	15.3	16.0	17.9	17.3	19.2	17.3	17.3	17.1	17.7
September	19.1	19.1	18.1	17.1	17.5	19.2	18.4	20.9	19.8	19.2	19.4	19.2	20.8	19.9
October	18.2	16.9	20.6	19.7	17.9	19.8	18.9	20.7	19.2	22.1	21.4	19.6	22.6	20.9
November	19	19.7	21.4	21.3	19.3	19.9	20.1	20.4	21.1	22.9	22.9	21.9	21.6	21.8
December	20.1	23.2	21	22.6	20.7	20.6	21.4	21.3	24.4	22.4	24.4	22.9	22.4	23.0
Average	18.2	18.7	19.3	18.3	18.0	18.3	18.5	20.7	19.9	21.2	20.7	20.3	20.4	20.5

Note: *Data unavailable. The more intense the red colour is, the more the temperature exceeds the average temperature in the study areas.

Table 3.
The humidity in King Cetshwayo (Richard's Bay Airport weather station), uMkhanyakude (Makhathini research station) and Zululand (Vryheid and Ulundi weather stations) district municipalities of the KwaZulu-Natal province of South Africa from January to December (2017 – 2022). The darker the blue colour the more humid the area was. *Data unavailable.

Month	**Richards Bay Airport**							**Makhathini Research Station**						
	2017	**2018**	**2019**	**2020**	**2021**	**2022**	**Average**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Average**
January	70	72	76	76	80	79	74.8	72	67	72	65	*	78	70.8
February	73	77	79	79	84	79	78.4	73	78	74	70	*	74	73.8
March	70	76	78	77	81	79	76.4	72	76	76	66	82	76	74.7
April	69	77	81	83	82	85	78.4	69	76	77	76	77	79	75.7
May	76	79	78	79	80	82	78.4	74	76	72	72	78	81	75.5
June	75	78	76	76	80	78	77.0	69	74	71	71	79	79	73.8
July	77	75	68	74	75	79	73.8	70	71	64	69	72	78	70.7
August	73	73	79	74	79	76	75.6	66	71	70	66	70	71	69.0
September	73	75	76	78	78	79	76.0	69	70	64	69	70	72	69.0
October	75	73	78	80	78	79	76.8	67	69	67	71	73	70	69.5
November	73	72	81	78	78	80	76.4	66	67	73	68	74	76	70.7
December	76	76	80	78	81	81	78.2	72	73	71	72	77	77	73.7
Average	73.3	75.3	77.5	77.7	79.7	79.7	76.7	69.9	72.3	70.9	69.6	75.2	75.9	72.2
	Vryheid							Ulundi						
January	76	71	74	74	78	78	75.2	72	66	72	74	77	79	73.3
February	77	78	77	74	82	74	77.0	72	76	72	77	84	77	76.3
March	73	75	78	74	73	78	75.2	70	73	74	74	78	77	74.3
April	73	76	77	77	70	79	75.3	71	73	75	78	74	82	75.5
May	67	72	64	63	65	71	67.0	67	72	66	68	72	77	70.3
June	58	57	56	63	61	66	60.2	60	67	60	64	63	70	64.0
July	58	61	42	52	51	64	54.7	62	66	46	59	58	64	59.2
August	56	58	54	53	60	61	57.0	60	65	62	60	65	66	63.0
September	60	54	53	67	63	62	59.8	62	65	61	69	66	68	65.2
October	69	67	58	70	68	72	67.3	67	66	63	72	72	71	68.5
November	70	66	72	70	75	77	71.7	67	66	72	75	74	81	72.5
December	78	73	72	73	78	80	75.7	74	72	76	78	77	86	77.2
Average	67.9	67.3	64.8	67.5	68.7	71.8	68	67	68.9	66.6	70.7	71.7	74.8	69.9

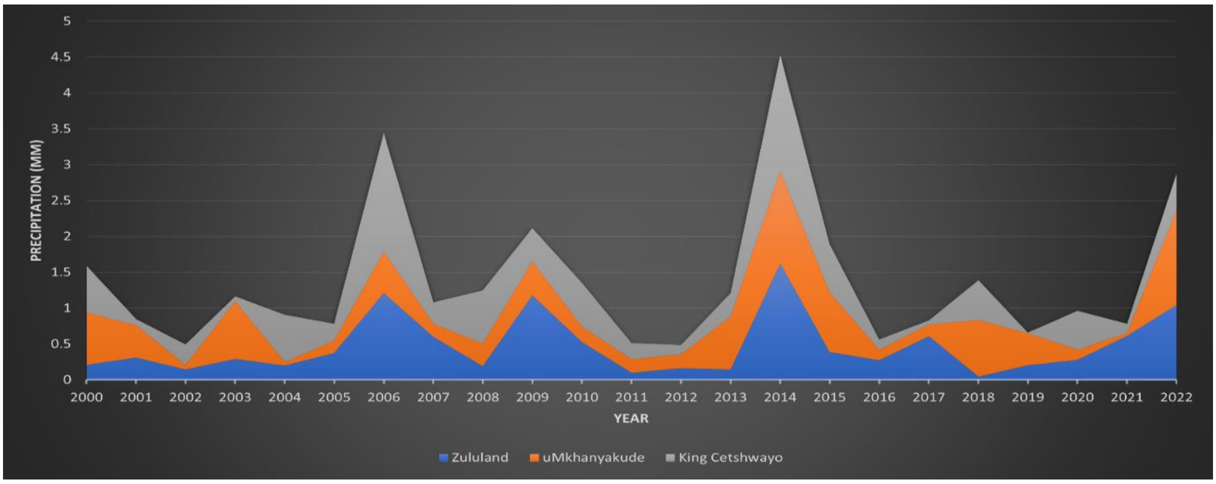

Figure 2.
A 22-year (2000-2022) Rainfall anomaly index of King Cetshwayo, uMkhanyakude, and Zululand District.

Municipalities of Northern KwaZulu-Natal from 2000 to 2022 as captured by Geographic Information System Mapping of the areas.

Figure 2 is original. The right to use it for educational, research and developmental purposes are granted, but must the referenced and or acknowledge appropriately.

Table 4.
Classification of rainfall anomaly index (RAI).

	RAI Range	Classification
Rainfall anomaly index (RAI)	Above 4	Extremely humid
	2-4	Very humid
	0-2	Humid
	-2 to 0	Dry
	-4 to -2	Very dry
	Below -4	Extremely dry

Source: De Sousa Freitas [27] and Costa and Rodrigues [26].

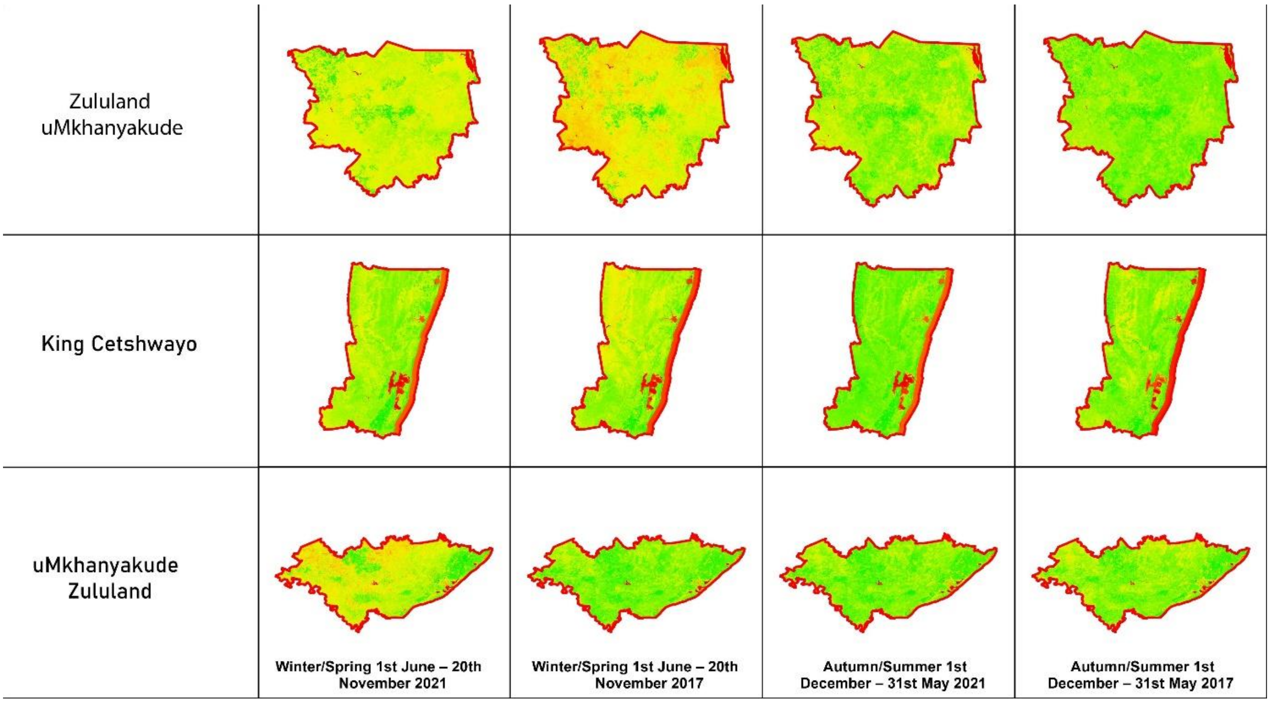

Figure 3.
The Normalized Difference Vegetation Index of uMkhanyakude, King Cetshwayo and Zululand district municipalities of KwaZulu-Natal province in the winter/spring and Autumn/Summer of 2017 and 2021.

The (Figure 3) is original. The right to use it for educational, research and developmental purposes are granted, but must the referenced and or acknowledge appropriately.

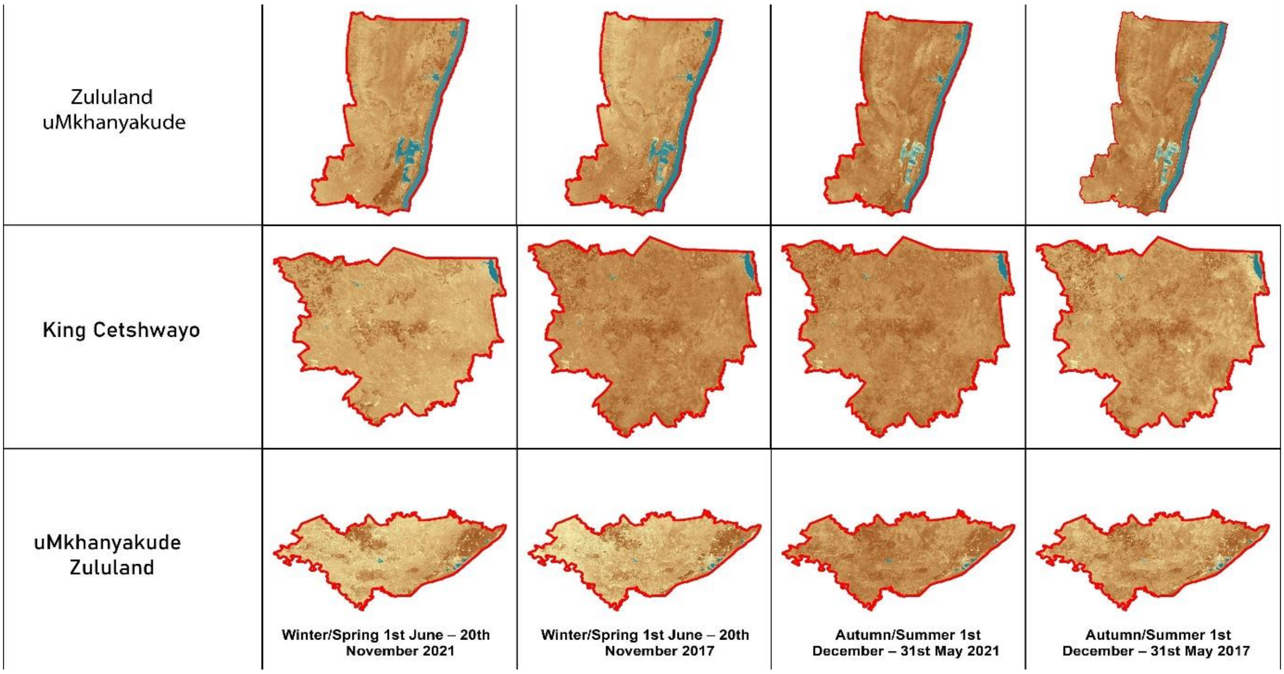

Figure 4.
The Normalized Difference Water Index (NDWI) of uMkhanyakude, King Cetshwayo and Zululand district municipalities of KwaZulu-Natal province in the winter/spring and autumn/ summer of 2017 and 2021.

This figure is original. The right to use it for educational, research and developmental purposes are granted, but must the referenced and or acknowledge appropriately.

4. Conclusion and Recommendations

Drought is a natural hazard with severe consequences on the agricultural sector which is one of the most important sectors in South Africa [30]. The socioeconomic impact of drought may include a lack of employment and danger to food security [30, 31]. Also, the lack of rain is accompanied by soaring daily temperatures (data not shown). However, as the average daily temperatures at the earth's surface rise, evaporation increases, which eventually increases overall precipitation [22]. It has been reported that under ideal conditions and on average worldwide, rain intensity increases by seven percent for every degree Celsius of rise in temperature [24].

Rainfall, temperature, and humidity varied across the three district municipalities of uMkhanyakude, King Cetshwayo, and Zululand. The weather conditions in the two weather stations of Zululand (Vryheid and Ulundi) were closely related when compared to those of uMkhanyakude and King Cetshwayo. The results of the study indicated that drought occurred more frequently in the uMkhanyakude district municipality than in either of the other two district municipalities studied, both in terms of the frequency and duration of drought. The images of vegetation indices explored in this study corroborated the data obtained from the weather elements (humidity, temperature, and rainfall).

This study thoroughly examined the weather elements in the three district municipalities studied. It answered the question of the likely weather conditions to expect in the study area. The area that is prone to drought and the likely duration of such drought were also identified. The issues of deviation from the expected weather conditions were also covered in this study. These findings are a tool that could be used to decide on what to plant, when to plant, and where to plant a particular crop in the three district municipalities.

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