climate

MDPI

Article

Analysis of Climate Variability and Its Implications on Rangelands in the Limpopo Province

Phumzile Maluleke [1,2,*], Mokhele E. Moeletsi [2,3] and Mitsuru Tsubo [4]

1 Department of Agriculture and Animal Health, College of Agriculture and Environmental Sciences, University of South Africa, Private Bag X6, Florida 1710, South Africa
2 Agricultural Research Council-Natural Resources and Engineering, Private Bag X79, Pretoria 0001, South Africa; moletsim@arc.agric.za
3 Risks and Vulnerability Assessment Centre, University of Limpopo, Private Bag X1106, Sovenga 0727, South Africa
4 Arid Land Research Center, Tottori University, 1390 Hamasaka, Tottori 680-0001, Japan; tsubo@tottori-u.ac.jp
* Correspondence: malulekep@arc.agric.za or phumzimaluleke@gmail.com

Abstract: In recent decades, southern Africa has experienced a shift towards hotter and drier climate conditions, affecting vital sectors like agriculture, health, water, and energy. Scientific research has shown that the combination of high temperatures and unreliable rainfall can have detrimental effects on agricultural production. Thus, this study focused on assessing climate variability, with implications on rangelands in the Limpopo Province of South Africa over 38 years. Historical climate data from 15 stations, including rainfall and minimum and maximum temperatures from 1980 to 2018, were analysed. To achieve the main objective, various statistics including mean, standard deviation, and coefficient of variation (CV) were computed for all variables across four seasons. The results highlighted significant variability in rainfall, with Musina (71.2%) and Tshiombo (88.3%) stations displaying the highest variability during the September-to-April season. Both minimum and maximum temperatures displayed low variability. The Mann–Kendall test revealed both increasing and decreasing trends in minimum temperatures and rainfall across different stations. Notably, there was a significant increase in maximum temperatures. This study provides valuable climate information for decision makers, aiding in the planning and management of agricultural activities, particularly in understanding how climate variations affect forage availability in rangelands.

Keywords: rainfall analysis; temperature analysis; climate change; coefficient of variation; trend analysis; Mann–Kendall test

check for updates

Citation: Maluleke, P.; Moeletsi, M.E.; Tsubo, M. Analysis of Climate Variability and Its Implications on Rangelands in the Limpopo Province. *Climate* **2024**, *12*, 2. https://doi.org/10.3390/cli12010002

Academic Editor: Nir Y. Krakauer

Received: 25 October 2023
Revised: 12 December 2023
Accepted: 22 December 2023
Published: 24 December 2023

1. Introduction

Climate variability and change, along with their interaction with anthropogenic activities, present significant challenges that have global repercussions on food production [1–8]. The complex mechanisms driving climate variability are influenced by various factors [9,10]. Variations in rainfall and temperature have been linked to various drivers such as El Niño Southern Oscillation (ENSO) across the globe [11–13]. Projections indicate that Africa will experience increased temperatures and unreliable rainfall during the 21st century [11,14–17].

Climate variability will affect various sectors such as agriculture, health, water, and energy [18]. Impacts resulting from climate variability and change range from sea level rise to increasing heat waves as well as variability in rainfall patterns [7,19–23]. These temperature and rainfall variations can have adverse effects, exacerbating existing challenges, including recurring droughts, floods, heatwaves, widespread poverty, and limited adaptive capacity in some regions [22]. For instance, a decline in grazing capacity has been noted globally, posing challenges for farmers and pastoralists who struggle to find sufficient grazing resources for both small and large livestock [4,6,20,24,25]. In most climatic regions, agricultural disruptions resulting from climate anomalies have led to substantial economic losses [1]. Moreover, tropical and subtropical areas, such as southern Africa, have primarily experienced adverse effects that have contributed to food insecurity and livelihood challenges [26–29]. The region has further witnessed increased maximum temperatures, marked by heatwaves [30], as well as unreliable rainfall patterns [31].

Agricultural production plays a critical role in South Africa's economy, influencing food security, employment, and overall economic growth [7,8,32]. Many small-scale farmers in the Limpopo Province primarily rely on rain-fed farming for their livelihoods [31,33]. This makes them particularly vulnerable to climate variability, resulting in livestock losses due to extreme weather events such as heatwaves, dry spells, and heat-related diseases [7,8,31,33–38]. Additional impacts on livestock, especially in arid and semi-arid regions, include reduced carrying capacity (pasture, water quality, and quantity) which will affect stocking rates [25]. However, if the adaptation of farmers to climate variability can be enhanced, they will become less vulnerable to the aforementioned impacts [39].

Therefore, a comprehensive analysis of regional spatial and temporal rainfall and temperature variations is crucial to provide evidence of climate variability, enhancing local understanding and interpretation. The dissemination of this analysis is crucial to ensure that pertinent stakeholders, including farmers, extension services, and land managers, are well informed for making on-farm decisions. This encompasses tasks such as scheduling grazing periods, adjusting livestock numbers, conducting controlled burning of the veld, administering vaccinations, and procuring livestock feed and protein supplements [38,40]. The communication of this information must be pertinent [41], taking into consideration language, regional specificity, and temporal scales [20,42,43].

Numerous studies in the Limpopo Province have focused on climate mitigation and adaptation [31,39,44–46] and climatic trends [27,47–50], but few have concentrated on the implications of climate variability on rangeland productivity. Subsequently, this study employs a statistical analysis to examine climate variability and its implications for rangeland productivity. The main objective of the study is to assess spatial and temporal changes in seasonal rainfall and temperature trends over the study period, investigating the hypothesis that the Limpopo Province has undergone climate variability during this time. The second objective is to provide implications for rangeland productivity based on the results. The findings are anticipated to contribute to predicting future trends in these climate variables and quantifying extreme events, encompassing exceptionally hot or cold temperatures, as well as exceedingly wet or dry conditions.

2. Materials and Methods

2.1. Site Description

The Limpopo Province is situated in the northeastern part of South Africa, spanning the geographic coordinates of 22° to 25° S latitude and 26° to 32° E longitude (Figure 1). This region is a significant component of the semi-arid savanna biome, comprising the bushveld, dry woodlands, and grasslands [51,52]. The topography of Limpopo Province varies from mountainous terrain (escarpment) to flatlands (Lowveld), with elevations ranging from below 400 m to over 1500 m above sea level. The diverse topography significantly influences the distribution of vegetation in this area [53]. The local economy is bolstered by mining, tourism, and agriculture as key sectors [54]; however, a high unemployment rate (49%) persists, particularly in rural areas [55].

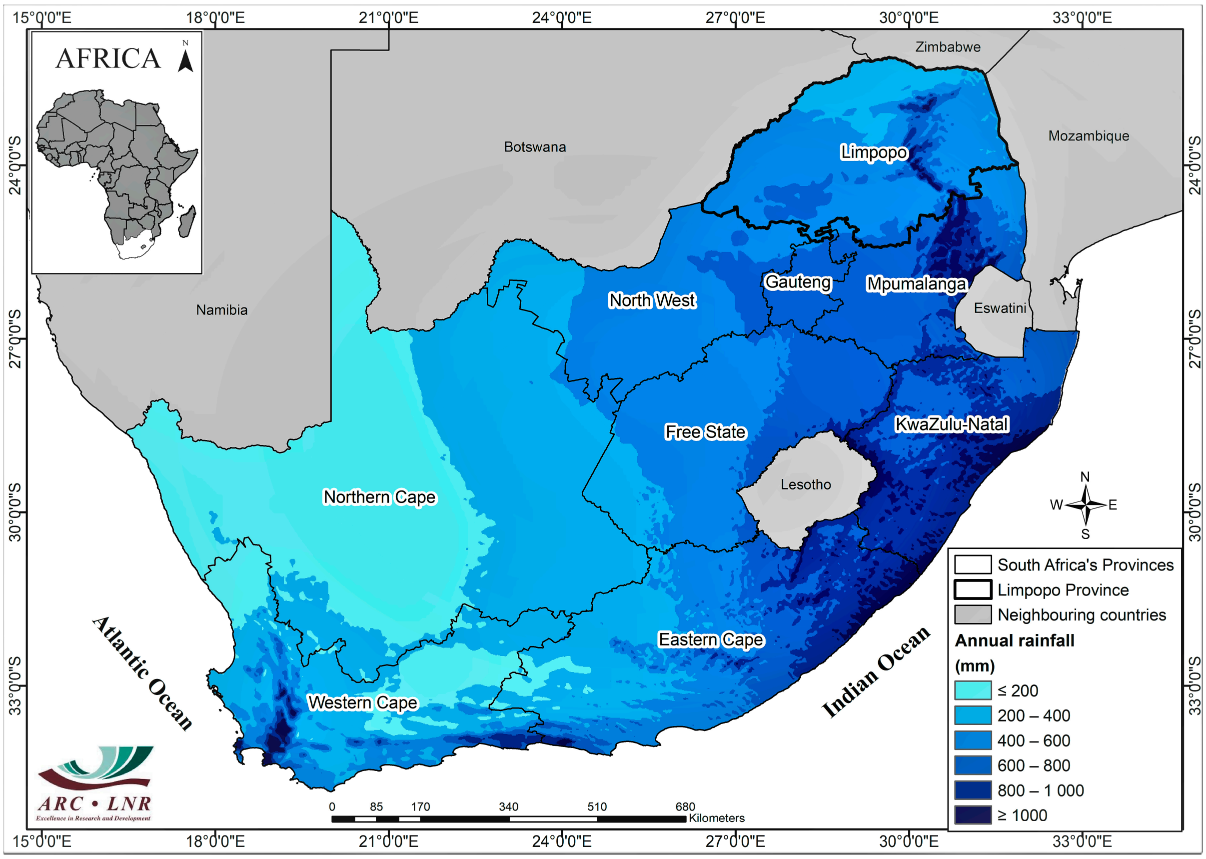

Figure 1. A map showing annual rainfall in South Africa, with the research area situated in the northeastern region.

2.2. Climate and Agricultural Activities

The climate in the Limpopo Province is characterized by a transition from warm desert (BWh) to warm semi-arid (BSh) and humid subtropical (Cwa) conditions based on the Köppen climate classification. Summers (December through February; DJF) are characterized by hot days and nights, with mean maximum temperatures reaching approximately 28 °C [48]. In contrast, winters (June through August; JJA) experience milder conditions with mean minimum temperatures of approximately 18 °C [48,56]. Rainfall patterns vary annually, resulting in a diverse range of vegetation across the province. Rainfall primarily occurs from October to April, with annual mean precipitation levels ranging from less than 350 mm in low-lying areas to over 1000 mm in mountainous regions. The primary source of rainfall in this region is convective systems [57]. However, recent decades have witnessed increased climate variability, leading to unreliable rainfall and recurrent droughts that have had severe impacts on agriculture and water resources [10]. Overpopulation, overgrazing, and rainfall variability have resulted in extensive land degradation in the northeastern parts of the province [31,58,59].

Agriculture plays a crucial role in the regional economy, with extensive livestock activities and ranching operations contributing significantly [60]. Approximately 75% of the natural vegetation is attributed to grazing lands, with the remaining 25% designated for various land uses, primarily commercial and small-scale farming activities [61]. Rain-fed subsistence farming is widely practiced by rural households, making them more prone to climate variability and change [23]. Commercial agriculture is mainly centralized in the southern and western regions of the province. The main soil types found in the region include sandy, loamy, and clay soils [62,63]. Key crops cultivated in Limpopo include tropical fruits, cereals, and vegetables, while livestock farming predominantly involves cattle, goats, and chickens [44].

3. Data and Methods

3.1. Data and Quality Control

The climate data utilized in this study were acquired from the Agricultural Research Council climate databank [64]. The dataset encompassed a 30-year span (1979/80–2017/18) of daily temperature and rainfall records. Rainfall and temperature are important parameters for determining climate variability in agricultural production systems [65]. A total of 15 stations, situated in different agroecological zones such as arid, semi-arid, and sub-humid, were chosen to provide comprehensive climate information, including minimum and maximum temperature as well as rainfall (Table 1). The selection of these stations followed the standards set by the World Meteorological Organization (WMO), which mandates a minimum data duration of 30 years and relatively complete data for climatological studies. A rigorous examination of the data was undertaken to identify inconsistencies and errors, leading to the removal of faulty values. Any gaps in the data were addressed using the ARC Stand-Alone Data Patch function, which utilizes the Inverse Distance Weighting method with neighbouring stations [64,66]. The weather station data were quantified through comparison with hourly field ERA5-Land climate reanalysis data [67]. This comparison not only enhances the scientific robustness of the dataset but also facilitates a comprehensive evaluation of its accuracy and reliability.

Table 1. Characteristics of selected weather stations in the Limpopo Province.

Station	Years of Available Data	Latitude (° S)	Longitude (° E)	Altitude (m)
Thabazimbi	83	−24.6	27.4	1164
Roedtan	66	−24.6	29.1	973
Fleur-de-lys	108	−24.5	31.0	622
Sentrum-ysterpan	33	−24.3	27.4	1005
Modjadji	32	−23.6	30.4	977
Phalaborwa	51	−23.9	31.2	433
Marnitz	58	−23.2	28.2	932
Shingwedzi	61	−23.1	31.4	215
Punda maria	94	−22.7	31.0	462
Musina	42	−22.2	29.9	505
Tshiombo	35	−22.8	30.5	650
Settlers	39	−24.9	28.6	1050
Zebediela	44	−24.3	29.3	1250
Bavaria fruit estates	74	−24.4	30.9	550
Lephalale	33	−23.8	27.7	826

3.2. Data Analysis

Climate data were collected and averaged annually and seasonally to determine minimum and maximum temperatures across the four seasons. Rainfall data were similarly compiled into annual and seasonal totals for the four seasons: summer (DJF), autumn (March through May; MAM), winter (JJA), and spring (September through November; SON). Linear regression was employed to illustrate inter-annual variability, focusing on the monthly, seasonal, and annual trends. The resulting time-series graphs were examined to evaluate climate variability. Various tests were employed to analyse climate parameters over the study period. To address the primary objective, statistical measures such as mean, standard deviation, and coefficient of variation [7,8,68,69] were calculated to assess both the annual and seasonal variability of rainfall, as well as minimum and maximum temperatures, spatially and temporally.

3.2.1. Coefficient of Variation (CV)

The coefficient of variation (CV) was employed to evaluate the extent of seasonal and annual variability during the observation period. This study utilized the following categories outlined by [70] for the coefficient of variation: (1) high variability (CV > 30), (2) moderate (20 < CV < 30), and (3) low (CV < 20) (Tables 2–5). A higher CV value indicates greater climatic variability within the study area, while a lower value signifies reduced variability. The CV is computed using the following equation:

$$CV = \sigma/\mu \times 100 \tag{1}$$

where CV represents the coefficient of variation, σ is the standard deviation, and μ is the mean recorded.

Table 2. The coefficient of variation results for selected weather stations in the Limpopo Province for rainfall, minimum and maximum temperatures (1980–2018).

Station Name	Rainfall		Minimum Temperature		Maximum Temperature	
	CV (%)	CV Category	CV (%)	CV Category	CV (%)	CV Category
Thabazimbi	27.0	Moderate	6.1	Low	4.8	Low
Roedtan	29.4	Moderate	5.6	Low	4.2	Low
Fleur-de-lys	29.2	Moderate	4.8	Low	2.9	Low
Sentrum-ysterpan	25.9	Moderate	7.4	Low	4.5	Low
Modjadji	35.7	High	7.3	Low	6.6	Low
Phalaborwa	38.4	High	3.1	Low	3.3	Low
Marnitz	32.3	High	6.4	Low	6.1	Low
Shingwedzi	42.4	High	3.8	Low	4.7	Low
Punda maria	59.4	High	5.6	Low	4.8	Low
Musina	41.5	High	3.9	Low	4.3	Low
Tshiombo	62.8	High	2.6	Low	2.6	Low
Settlers	20.9	Moderate	6.4	Low	4.2	Low
Zebediela	22.6	Moderate	6.1	Low	3.6	Low
Bavaria	29.5	Moderate	4.7	Low	2.8	Low
Lephalale	40.7	High	9.1	Low	3.5	Low

Table 3. The coefficient of variation results for total seasonal rainfall for the December–January–February (DJF), March–April–May (MAM), June–July–August (JJA), and September–October–November (SON) seasons in the selected stations in the Limpopo Province (1980–2018).

Station Name	DJF		MAM		JJA		SON	
	CV (%)	CV Category	CV (%)	CV Category	CV (%)	CV Category	CV (%)	CV Category
Thabazimbi	65.5	High	43.7	High	118.8	High	43.4	High
Roedtan	42.2	High	64.1	High	297.3	High	53.2	High
Fleur-de-lys	42.7	High	42.0	High	105.4	High	42.2	High
Sentrum-ysterpan	67.9	High	46.4	High	131.8	High	35.3	High
Modjadji	58.2	High	55.0	High	86.2	High	41.1	High
Phalaborwa	52.0	High	49.7	High	108.4	High	52.7	High
Marnitz	45.2	High	55.6	High	122.9	High	54.9	High
Shingwedzi	63.7	High	70.4	High	84.1	High	52.7	High
Punda maria	69.5	High	77.2	High	366.1	High	59.5	High
Musina	71.2	High	83.5	High	161.7	High	56.3	High
Tshiombo	57.3	High	77.3	High	316.1	High	88.2	High
Settlers	35.0	High	62.8	High	112.8	High	39.2	High
Zebediela	32.7	High	56.6	High	130.7	High	44.9	High
Bavaria	42.4	High	43.0	High	111.8	High	48.7	High
Lephalale	56.3	High	67.3	High	239.8	High	62.2	High

Table 4. The coefficient of variation results for mean minimum temperature for the December–January–February (DJF), March–April–May (MAM), June–July–August (JJA), and September–October–November (SON) seasons in the selected stations in the Limpopo Province (1980–2018).

Station Name	DJF		MAM		JJA		SON	
	CV (%)	CV Category	CV (%)	CV Category	CV (%)	CV Category	CV (%)	CV Category
Thabazimbi	4.5	Low	9.1	Low	28.9	Moderate	7.8	Low
Roedtan	4.2	Low	8.0	Low	32.5	High	7.4	Low
Fleur-de-lys	5.3	Low	6.1	Low	10.2	Low	5.2	Low
Sentrum-ysterpan	4.5	Low	12.6	Low	24.0	Moderate	9.2	Low
Modjadji	11.2	Low	10.3	Low	14.7	Low	10.2	Low
Phalaborwa	3.4	Low	5.0	Low	9.2	Low	3.7	Low
Marnitz	5.3	Low	8.8	Low	16.4	Low	8.2	Low
Shingwedzi	5.3	Low	7.0	Low	9.8	Low	6.6	Low
Punda maria	3.9	Low	8.0	Low	15.3	Low	5.3	Low
Musina	3.8	Low	6.5	Low	11.3	Low	4.1	Low
Tshiombo	2.6	Low	5.2	Low	7.0	Low	3.8	Low
Settlers	3.6	Low	7.5	Low	28.6	Moderate	7.8	Low
Zebediela	3.3	Low	8.4	Low	23.0	Moderate	6.0	Low
Bavaria	5.2	Low	6.6	Low	13.1	Low	5.1	Low
Lephalale	8.0	Low	10.9	Low	20.8	Low	11.8	Low

Table 5. The coefficient of variation results for mean maximum temperature for the December–January–February (DJF), March–April–May (MAM), June–July–August (JJA), and September–October–November (SON) seasons in the selected stations in the Limpopo Province (1980–2018).

Station Name	DJF		MAM		JJA		SON	
	CV (%)	CV Category	CV (%)	CV Category	CV (%)	CV Category	CV (%)	CV Category
Thabazimbi	5.7	Low	7.4	Low	5.8	Low	4.5	Low
Roedtan	4.6	Low	4.8	Low	5.5	Low	5.2	Low
Fleur-de-lys	3.3	Low	3.7	Low	3.4	Low	3.9	Low
Sentrum-ysterpan	5.0	Low	5.3	Low	5.0	Low	5.2	Low
Modjadji	7.0	Low	7.7	Low	7.8	Low	7.5	Low
Phalaborwa	3.5	Low	4.7	Low	4.3	Low	3.8	Low
Marnitz	6.8	Low	6.9	Low	6.7	Low	6.0	Low
Shingwedzi	6.1	Low	6.3	Low	4.7	Low	5.5	Low
Punda maria	9.0	Low	8.6	Low	4.4	Low	5.2	Low
Musina	5.9	Low	5.3	Low	4.6	Low	4.3	Low
Tshiombo	4.4	Low	4.4	Low	3.3	Low	3.5	Low
Settlers	5.2	Low	5.4	Low	5.1	Low	4.9	Low
Zebediela	4.3	Low	4.0	Low	4.8	Low	4.1	Low
Bavaria	3.8	Low	3.5	Low	3.6	Low	3.4	Low
Lephalale	4.4	Low	4.9	Low	4.5	Low	4.2	Low

3.2.2. Trend Detection

Trend detection was performed through a time-series analysis and the Mann–Kendall test. The time series encompassed total seasonal rainfall and mean seasonal minimum and maximum temperatures (Figures 2–4). To identify climatic trends in the time-series data, the Mann–Kendall test [1,7,8,65,71–73] was utilized at a significance level of $p < 0.01$, <0.05, and <0.10 (Tables 6–8). The process included detecting increasing and decreasing slopes of trends in rainfall and temperature data. To ensure accurate trend analysis, the data records spanned approximately 38 years, adhering to [74] guidelines that stipulate a minimum of 30 years' worth of data for precise climatic trend assessments.

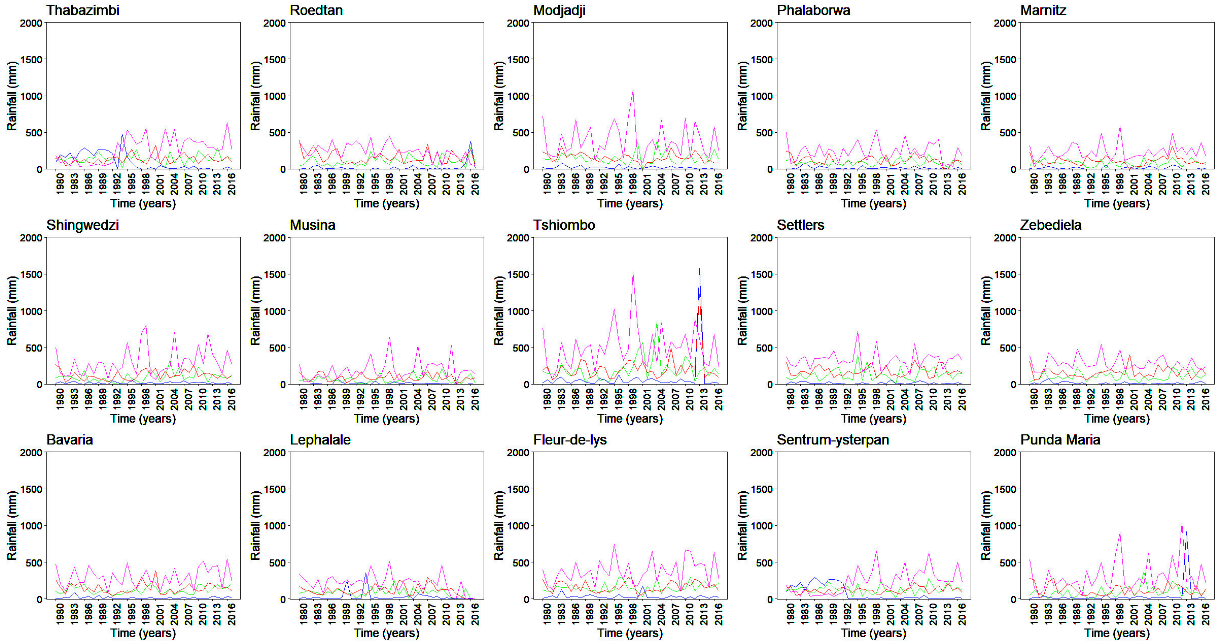

Figure 2. Inter-annual variation in total seasonal rainfall in the seasons December–January–February (DJF) (magenta line), March–April–May (MAM) (green line), June–July–August (JJA) (blue line), and September–October–November (SON) (red line) in the period 1980–2018.

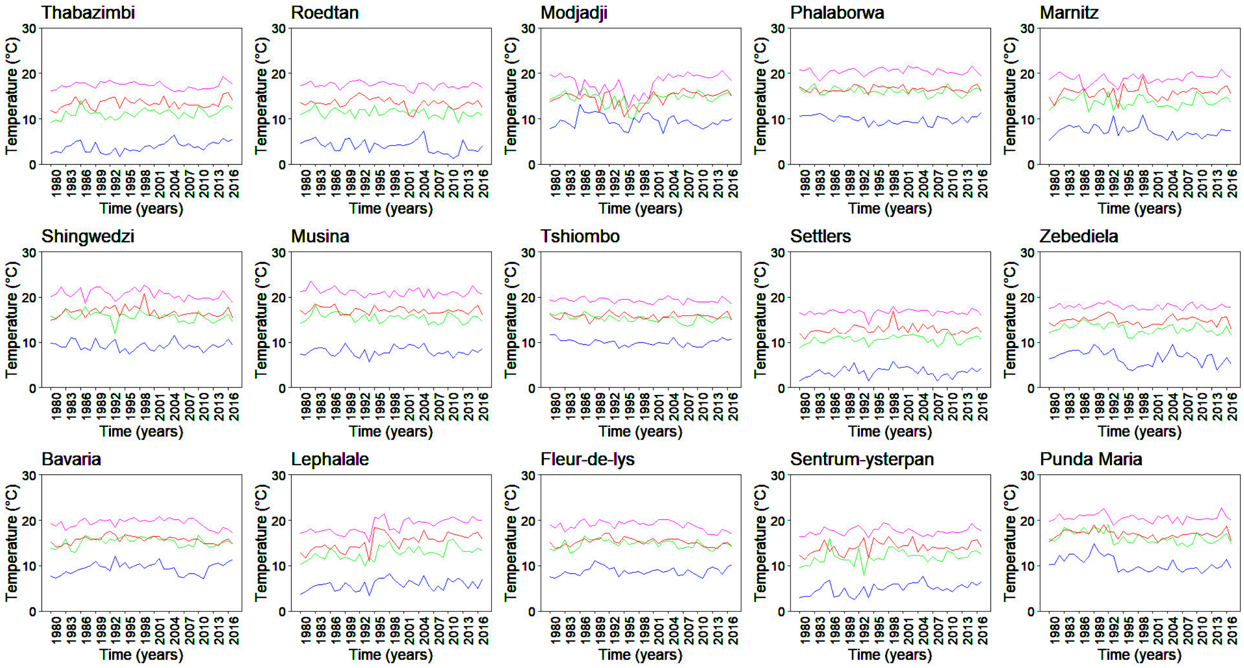

Figure 3. Inter-annual variation in mean minimum temperatures in the seasons December–January–February (DJF) (magenta line), March–April–May (MAM) (green line), June–July–August (JJA) (blue line), and September–October–November (SON) (red line) in the period 1980–2018.

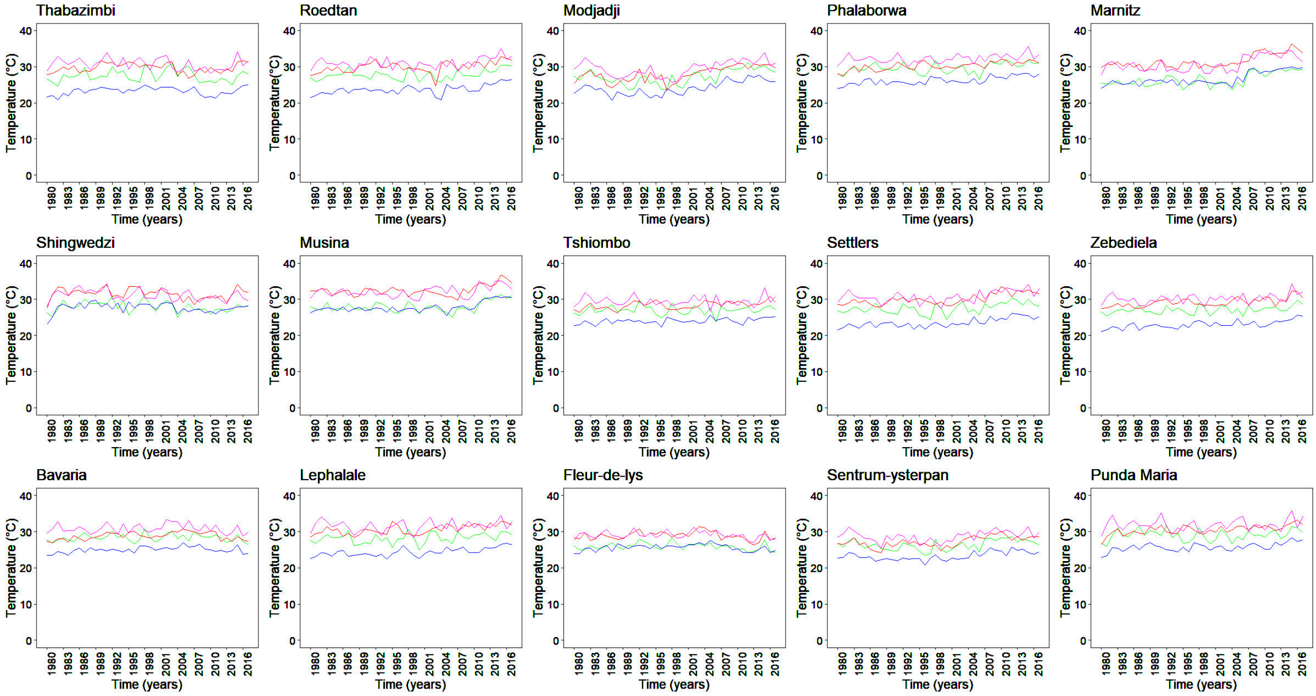

Figure 4. Inter-annual variation in mean maximum temperatures in the seasons December–January–February (DJF) (magenta line), March–April–May (MAM) (green line), June–July–August (JJA) (blue line), and September–October–November (SON) (red line) in the period 1980–2018.

Table 6. Mann–Kendall test results, showing the *p*-Value and z-statistic, for total seasonal rainfall for the December–January–February (DJF), March–April–May (MAM), June–July–August (JJA), and September–October–November (SON) seasons in the selected stations in the Limpopo Province (1980–2018).

Station	DJF		MAM		JJA		SON	
	p-Value	z	*p*-Value	z	*p*-Value	z	*p*-Value	z
Thabazimbi	0.00039 ***	3.545	0.632	0.477	0.00006 ***	−3.986	0.191	1.307
Roedtan	0.00567 ***	−2.765	0.279	1.081	0.1275	1.5239	0.257	−1.131
Fleur-de-lys	0.1379	1.483	0.320	0.993	0.4736	−0.716	0.546	0.603
Sentrum-ysterpan	0.00016 ***	3.771	0.939	0.075	0.0036 ***	−2.910	0.268	1.106
Modjadji	0.9599	−0.050	0.821	−0.226	0.1103	−1.596	0.041 **	−2.037
Phalaborwa	0.99	−0.012	0.979	0.025	0.1021	−1.634	0.489	−0.691
Marnitz	0.2373	1.181	0.850	−0.188	0.9097	0.1134	0.7154	0.364
Shingwedzi	0.0498 **	1.961	0.2179	1.232	0.9199	0.1005	0.2226	1.219
Punda maria	0.1251	1.533	0.0528 *	1.936	0.2474	1.1568	0.743	−0.326
Musina	0.0627 *	1.860	0.8014	0.251	0.8496	−0.189	0.7061	−0.377
Tshiombo	0.2909	1.056	0.2373	1.181	0.5546	−0.590	0.939	0.075
Settlers	0.8406	0.201	0.2579	1.131	0.5883	−0.541	0.919	0.100
Zebediela	0.5631	−0.578	0.4067	0.829	0.6778	−0.415	0.435	0.779
Bavaria	0.3788	0.880	0.3457	0.942	0.6328	−0.477	0.8801	0.150
Lephalale	0.0122 *	−2.503	0.1346	−1.496	0.9197	−0.100	0.296	−1.043

*** Trends statistically significant at $p < 0.01$; ** trends statistically significant at $p < 0.05$; * trends statistically significant at $p < 0.10$.

Table 7. Mann–Kendall test results, showing the p-Value and z-statistic, for mean minimum temperature for the December–January–February (DJF), March–April–May (MAM), June–July–August (JJA), and September–October–November (SON) seasons in the selected stations in the Limpopo Province (1980–2018).

Station	DJF		MAM		JJA		SON	
	***p*-Value**	**z**	***p*-Value**	**z**	***p*-Value**	**z**	***p*-Value**	**z**
Thabazimbi	0.419	−0.806	0.0276 **	2.2026	0.00023 ***	3.673	0.473	0.717
Roedtan	0.0962 *	−1.663	0.1618	−1.399	0.00885 ***	−2.617	0.101	−1.636
Fleur-de-lys	0.0440 **	−2.013	0.3194	−0.9956	0.2035	1.271	0.173	−1.360
Sentrum-ysterpan	0.357	0.919	0.0219 **	2.2912	0.00262 ***	3.008	0.0623 *	1.863
Modjadji	0.147	1.446	0.488	0.6925	0.3583	−0.918	0.0402 **	2.051
Phalaborwa	0.909	−0.113	0.161	−1.3988	0.0585 *	−1.891	0.742	0.327
Marnitz	0.118	1.562	0.99	0.0125	0.0590 *	−1.888	0.398	0.844
Shingwedzi	0.017 **	−2.367	0.0135 **	−2.4701	0.8799	−0.151	0.351	−0.931
Punda maria	0.419	0.808	0.005 ***	−2.7964	0.0184 **	−2.356	0.118	−1.562
Musina	0.0797 *	−1.752	0.0779 *	−1.7629	0.9397	0.075	0.246	−1.159
Tshiombo	0.0984 *	−1.652	0.0019 ***	−3.1032	0.3318	−0.970	0.969	−0.037
Settlers	0.742	0.328	0.1096	1.5999	0.2413	1.171	0.398	0.844
Zebediela	0.512	−0.655	0.0571 *	−1.9021	0.0367 **	−2.088	0.919	0.100
Bavaria	0.545	−0.604	0.6963	−0.390	0.1188	1.560	0.398	−0.843
Lephalale	0.000 ***	4.066	0.0007 ***	3.3848	0.0322 **	2.140	0.000 ***	4.190

*** Trends statistically significant at $p < 0.01$; ** trends statistically significant at $p < 0.05$; * trends statistically significant at $p < 0.10$.

Table 8. Mann–Kendall test results showing the p-Value and z-statistic, for mean maximum temperature for the December–January–February (DJF), March–April–May (MAM), June–July–August (JJA), and September–October–November (SON) seasons in the selected stations in the Limpopo Province (1980–2018).

Station	DJF		MAM		JJA		SON	
	***p*-Value**	**z**	***p*-Value**	**z**	***p*-Value**	**z**	***p*-Value**	**z**
Thabazimbi	0.2175	−1.233	0.899	−0.1258	0.3581	0.9189	0.571	0.5665
Roedtan	0.057 *	1.9005	0.0524 *	1.9394	0.0000 ***	3.9278	0.0004 ***	3.516
Fleur-de-lys	0.3987	−0.843	0.2897	−1.0588	0.7241	0.3530	0.8998	−0.125
Sentrum-ysterpan	0.064 *	1.8501	0.0993 *	1.6482	0.0028 ***	2.9864	0.0005 ***	3.4606
Modjadji	0.007 ***	2.666	0.0041 ***	2.8688	0.0000 ***	3.9752	0.0000 ***	4.7796
Phalaborwa	0.025 **	2.241	0.0073 ***	2.6814	0.0000 ***	4.4326	0.0000 ***	4.5083
Marnitz	0.003 ***	2.932	0.0001 ***	3.7272	0.0000 ***	4.4187	0.0000 ***	4.1934
Shingwedzi	0.019 **	−2.328	0.1659	−1.3854	0.1987	−1.285	0.1587	−1.409
Punda maria	0.781	0.276	0.5883	0.5412	0.0012 ***	3.237	0.0002 ***	3.7051
Musina	0.273	1.095	0.0314 **	2.1514	0.0000 ***	4.3348	0.0013 ***	3.1958
Tshiombo	0.919	0.100	0.4577	0.7425	0.0032 ***	2.9465	0.0017 ***	3.1218
Settlers	0.008 ***	2.643	0.006 ***	2.7065	0.0000 ***	4.3958	0.0000 ***	4.2781
Zebediela	0.069 *	1.815	0.0212 **	2.3044	0.0000 ***	4.5321	0.0001 ***	3.7397
Bavaria	0.762	−0.302	0.8012	0.2518	0.0991 *	1.649	0.04517 **	2.0031
Lephalale	0.488	0.692	0.0717 *	1.8006	0.0000 ***	4.5079	0.0002 ***	3.6749

*** Trends statistically significant at $p < 0.01$; ** trends statistically significant at $p < 0.05$; * trends statistically significant at $p < 0.10.5$.

The Mann–Kendall test, a non-parametric method for identifying trends in data, was adopted to evaluate trends and their significance in this study. The World Meteorological Organization has endorsed this test as suitable for assessing trends in environmental-data time series [75], as it does not necessitate a normal distribution of data [76]. The test involves comparing each value of the time series with the others in sequence. The sum of these comparisons is represented by the S statistic:

$$S = \sum_{i=2}^{n} \sum_{j=1}^{i-1} sign(x_i - x_j), \tag{2}$$

where $sign(x_i - x_j)$ is

$$-1\ for\ x_i - x_j < 0,$$
$$0\ for\ x_i - x_j = 0,$$
$$1\ for\ x_i - x_j > 0,$$

For large n, the S statistic tends to normality, with definitions for mean and variance shown below:

$$E(S) = 0 \tag{3}$$

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)\right], \tag{4}$$

where the time-series length is shown by n, the pth value's number of ties is shown by tp, and the number of tied values is shown by q. Subsequently, an adjustment of tied data is given by the second term. The Z statistic is given by:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if\ S > 0, \\ 0 & if\ S = 0, \\ \frac{S-1}{\sqrt{Var(S)}} & if\ S < 0. \end{cases} \tag{5}$$

The presence of a statistically significant trend is determined using the Z value. The null hypothesis is evaluated by the Z statistic in a case where there is no trend. A positive (negative) value shows an increasing (decreasing) trend in the time series. To test whether a monotonic trend is increasing or decreasing at a p-significance level, the null hypothesis is rejected at an absolute value of z greater than Z1 p = 2. This study considered a p-value of 0.01, 0.05, and 0.10.

$$\beta = \text{Median}\left[\frac{\left(X_{j\_}\ X_i\right.}{(j-i)}\right] \text{ for all } i < j \tag{6}$$

where j and i are measured by the slope between data points Xj and Xi, respectively.

4. Results

4.1. Inter-Annual Variability of Climatic Variables

Table 2 presents the coefficient of variation results for total rainfall, as well as minimum and maximum temperatures in the selected stations in the Limpopo Province spanning from 1980 to 2018. The mean and standard deviation (SD) results are available in Appendix A (Table A1).

Throughout the study period, rainfall displayed a combination of moderate (46.6% of the stations) and high (53.3% of the stations) CVs. The Tshiombo station displayed the highest CV at 62.8%, with an average of 1003.0 mm and an SD of 630.5 mm.

Minimum temperatures consistently displayed low CVs across all stations during the study period. The lowest CV of 2.6% was observed at the Tshiombo station, with an average temperature of 15.1 °C and an SD of 0.4 °C.

Similarly, all stations exhibited low CVs for maximum temperatures. The Tshiombo station recorded the lowest CV of 2.6%, with an average temperature of 27.3 °C and an SD of 0.7 °C.

4.2. Inter-Annual Variability of Seasonal Rainfall

Figure 2 illustrates the inter-annual variability observed in the total seasonal rainfall across all four seasons, while Table 3 presents the coefficient of variation with its category for total seasonal rainfall for the four seasons during the period from 1980 to 2018. The mean (mm) and standard deviation (SD) can be viewed in Appendix A (Table A2).

During the DJF season, all stations exhibited a notably high CV, with the Musina station recording the highest CV at 71.2%. The mean rainfall for this season at Musina was 193.9 mm, with a standard deviation of 138.0 mm. Similarly, during the MAM season, high CV values were observed at all stations, with the Musina station again recording the highest CV at 83.5%. The mean rainfall for the MAM season at Musina was 65.6 mm, with a standard deviation of 54.8 mm.

The JJA season also witnessed a high CV at all stations, with the Punda Maria station registering the highest CV at 366%. For this season, the mean rainfall at Punda Maria was 39.4 mm, with a standard deviation of 144.1 mm. Lastly, during the SON season, all stations exhibited a high CV. The Tshiombo station had the highest CV at 88.3%, with a mean rainfall of 216.1 mm and a standard deviation of 190.7 mm.

4.3. Inter-Annual Variability of Minimum Temperatures

Figure 3 illustrates the inter-annual variability observed in the analysis of mean minimum temperatures across all four seasons. Table 4 provides the coefficient of variation with its category for mean minimum temperatures during the four seasons during the period from 1980 to 2018. The mean (°C) and standard deviation (SD) can be viewed from Appendix A (Table A3).

During the DJF season, all the stations exhibited low CV values, with the lowest CV recorded at 2.6% in the Tshiombo station. At Tshiombo, the mean minimum temperature during DJF was 19.3 °C, with a standard deviation of 0.5 °C. Similarly, during the MAM season, low CV values were observed across all stations, with the lowest CV of 5.0% documented at the Phalaborwa station (mean temperature of 16.1 °C and a standard deviation of 0.8 °C).

In the JJA season, 10 stations displayed low CV values, with the Tshiombo station recording the lowest CV at 7.0%. The mean minimum temperature at Tshiombo during JJA was 10.0 °C, with a standard deviation of 0.7 °C. However, moderate CV values were observed in four stations: Thabazimbi, Sentrum-ysterpan, Settlers, and Zebediela, with CVs of 28.9%, 24.0%, 28.6%, and 23.0%, respectively. A higher CV of 32.5% was noted at the Roedtan station, where the mean minimum temperature was 4.0 °C, and the standard deviation was 1.3 °C.

Finally, during the SON season, all stations exhibited low CV values, with the lowest CV at 3.7% observed at the Phalaborwa station. At Phalaborwa, the mean minimum temperature during SON was 16.6 °C, with a standard deviation of 0.6 °C.

4.4. Inter-Annual Variability of Maximum Temperatures

Figure 4 presents the inter-annual variability observed in the analysis of mean maximum temperatures across all four seasons. Table 5 provides the coefficient of variation with its category for mean maximum temperatures for the four seasons during the period spanning from 1980 to 2018. The mean (°C) and standard deviation (SD) can be viewed from Appendix A (Table A4).

Throughout the DJF season, all the stations exhibited notably low CV values, with the lowest CV recorded at 3.3% in the Fleur-de-lys station. This particular station had a mean maximum temperature of 29 °C, with a standard deviation of 1.0 °C. Similarly, during the MAM season, low CV values were consistently observed across all stations, with the Bavaria station recording the lowest CV at 3.5%. At Bavaria, the mean maximum temperature for the MAM season was 28.3 °C, and the standard deviation was 1.0 °C.

In the JJA season, all the stations displayed low CV values as well, with the Tshiombo station recording the lowest CV at 3.3%. The mean maximum temperature at Tshiombo during the JJA season was 24.0 °C, and the standard deviation was 0.8 °C. Finally, during the SON season, all stations exhibited low CV values, with the Bavaria station again recording the lowest CV at 3.4%. At Bavaria, the mean maximum temperature for the SON season was 28.8 °C, with a standard deviation of 1.0 °C.

4.5. Trend Analysis for Total Seasonal Rainfall

Table 6 shows the total seasonal rainfall data for the four distinct seasons. Within the DJF season, ten stations experienced an increasing trend, while five stations experienced a decreasing trend. The increasing trend is statistically significant for only four stations, specifically Thabazimbi, Sentrum-ysterpan, Shingwedzi, and Musina. However, the decreasing trend is significant for only two stations, specifically Roedtan and Lephalale. The rest of the results are available in Appendix B (Table A5).

In the MAM season, 12 stations indicate an increasing trend, but statistical significance is only observed for the Punda Maria station. Conversely, a decreasing trend is noted in three stations.

During the JJA season, four stations experienced an increasing trend, while eleven stations exhibited a declining trend. Among these, statistical significance is found in two stations, namely Thabazimbi and Sentrum-ysterpan.

In the SON season, eight stations experienced an increasing trend, while seven stations experienced a decreasing trend. The decreasing trend is statistically significant solely for the Modjadji station.

4.6. Trend Analysis for Mean Minimum Temperature

Table 7 presents data indicating an increasing trend during the DJF season at five stations. However, this trend is statistically significant for only one station, Lephalale. Conversely, a declining trend is observed at ten stations, with statistical significance identified in five of them: Roedtan, Fleur-de-lys, Shingwedzi, Musina, and Tshiombo. The rest of the results are available in Appendix B (Table A6).

In the MAM season, an increasing trend is noticed at six stations, out of which only three (Thabazimbi, Sentrum-ysterpan, and Lephalale) demonstrate statistical significance. Conversely, a decreasing trend is observed at nine stations, with five of them demonstrating statistical significance: Shingwedzi, Punda Maria, Musina, Tshiombo, and Zebediela.

During the JJA season, an increasing trend is noted at seven stations. Statistical significance is found for the Thabazimbi, Sentrum-ysterpan, and Lephalale stations. Conversely, a decreasing trend is observed at eight stations, with only five of them displaying statistical significance: Roedtan, Phalaborwa, Marnitz, Punda Maria, and Zebediela.

Finally, during the SON season, an upward trend is observed in eight stations, with three of them (Sentrum-ysterpan, Modjadji, and Lephalale) being statistically significant. Conversely, a declining trend is observed at seven stations.

4.7. Trend Analysis for Mean Maximum Temperature

Table 8 shows an increasing trend in mean maximum temperatures during the DJF season at eleven stations, while a decreasing trend is noted at four stations. Statistically significant trends are observed in seven stations, specifically Roedtan, Sentrum-ysterpan, Modjadji, Phalaborwa, Marnitz, Settlers, and Zebediela. Additionally, Shingwedzi exhibits a statistically significant decreasing trend. The rest of the results are available in Appendix B (Table A7).

In the MAM season, an increasing trend is evident at 12 stations. Statistically significant trends are observed in nine stations, namely Roedtan, Sentrum-ysterpan, Modjadji, Phalaborwa, Marnitz, Musina, Settlers, Zebediela, and Lephalale. Conversely, a decreasing trend is observed at three stations.

In the JJA season, an increasing trend is observed in 14 stations. Statistically significant trends are observed in 12 stations, namely Roedtan, Sentrum-ysterpan, Modjadji, Phalaborwa, Marnitz, Punda Maria, Musina, Tshiombo, Settlers, Zebediela, Bavaria, and Lephalale. Conversely, a decreasing trend is observed at one station.

Finally, an increasing trend is observed in mean maximum temperatures for 13 stations during the SON season, with statistically significant trends in 12 stations, specifically Roedtan, Sentrum-ysterpan, Modjadji, Phalaborwa, Marnitz, Punda Maria, Musina, Tshiombo, Settlers, Zebediela, Bavaria, and Lephalale. Conversely, a decreasing trend is observed at two stations.

5. Discussion

The primary objective of this study was to investigate climate variability in the Limpopo Province by employing various statistical methods. The statistical analyses included calculating the mean, standard deviation, and coefficient of variation, and conducting the Mann–Kendall test with significance levels of $p < 0.01$, $p < 0.05$, or $p < 0.10$.

The findings of the time-series analysis for the long-term mean for rainfall throughout the study period indicate a combination of moderate and high CVs in rainfall over the study period. Notably, the Tshiombo station exhibited the highest CV of 62.8%, suggesting a degree of unpredictability in rainfall patterns in the Limpopo Province, specifically in the Tshiombo region.

On the other hand, the long-term mean for minimum temperatures displayed consistently low variability, particularly at the Tshiombo station with the lowest CV of 2.6%. This implies a higher level of predictability in minimum temperatures, specifically in the Tshiombo region.

Similarly, the long-term mean for maximum temperatures exhibited low variability across all stations, with the Tshiombo station again recording the lowest CV (2.6%). This reinforces the notion of relatively predictable maximum temperatures in the Tshiombo region.

The results of the time-series analysis revealed a consistently high coefficient of variation (CV) for seasonal rainfall across all stations and seasons. These findings highlight the highly variable and unreliable nature of rainfall in the region [31,77]. Notably, the DJF and SON seasons receive the highest rainfall in the Limpopo Province as the region receives spring and summer rainfall due to convective systems [58]. This rainfall variability significantly impacts livestock production and vegetation growth [31] in the area, which can affect the carrying capacity of rangelands. High-rainfall years enhance rangeland quality and water availability, positively affecting livestock production [31]. Conversely, low-rainfall years lead to a scarcity of quality forage and water, resulting in poor livestock production and increased mortality rates [31,38].

Mean minimum temperatures displayed a low CV during the DJF season for all stations. In contrast, during the JJA season, 66.7% of stations recorded a low CV, 26.7% of stations showed a moderate CV, and 6.6% of stations recorded a high CV. For the SON season, all stations displayed a low CV. The results concerning minimum and maximum temperatures indicate that these parameters are relatively less variable, compared to rainfall, across the four seasons.

Maximum temperatures displayed a low CV during all the seasons considered in all the stations. The highest mean maximum temperatures are observed in the DJF season [30]. Furthermore, mean maximum temperatures are generally increasing in the Limpopo Province, although variations exist among different areas. These findings are corroborated by previous studies [30,50,78]. The temperature variations can be attributed to factors such as elevation, as mountainous regions experience lower temperatures compared to other areas in the Lowveld.

The Mann–Kendall trend analysis exhibited both increasing and decreasing patterns in mean minimum temperatures, with some statistically significant trends observed (at $p < 0.01$, $p < 0.05$, or $p < 0.10$). Furthermore, both increasing and decreasing trends in minimum temperatures were observed across various stations in the province and different seasons, making the trends inconclusive. These results align with a study that also reported inconclusive findings for minimum temperatures in the region [48]. Recent findings from southern African countries indicated a rise in both minimum and maximum temperatures, but minimum temperatures exhibited greater variability [79].

Regarding mean maximum temperatures, there were notable increasing trends across all seasons, with statistical significance. Specifically, during the DJF season, 46.67% of stations exhibited increasing trends, while during the MAM season, this figure was 60%. Both the JJA and SON seasons saw 80% of stations with increasing trends. Therefore, the highest increase in temperatures was observed in winter and spring. These findings are consistent with results from another study that showed a significant increase in maximum temperatures [46,48,80]. Additional research conducted in Punjab, Pakistan, also identified rising trends in both minimum and maximum temperatures, though minimum trends displayed greater variation than maximum temperatures [62].

In terms of total seasonal rainfall, no significant trend was observed. This finding corresponds with earlier studies that also reported high variations in rainfall over the Limpopo Province [27,49,50,81,82]. Similar variability in inter-annual rainfall was noted in studies conducted in Ethiopia and India [8,69]. In contrast, a study found a decreasing trend in rainfall in the Olifants catchment of South Africa [46]. Prior research has illustrated the detrimental impacts of high temperatures combined with unreliable rainfall on agricultural production [22,25,31,46,62]. For instance, extreme temperatures and unreliable rainfall can negatively affect vegetation growth, thereby influencing livestock production [4,6,38,80,83–85].

6. Implications for Rangelands

6.1. Varying Rainfall

Findings in this study show fluctuations across different stations and seasons in rainfall, with some stations showing increasing trends while others show a decreasing trend. Rainfall patterns play a crucial role in determining the quality and quantity of forage available in rangelands [59,82,85]. Therefore, this implies that fluctuations in rainfall can have a profound impact on forage resources, especially for rain-fed rangelands in the Limpopo Province, and this is corroborated by other studies [80,86].

Periods of low rainfall mean that vegetation growth will decline, leading to a reduction in the carrying capacity of rangelands for grazing livestock. During periods of low rainfall coupled with high temperatures, high evapotranspiration rates in the Limpopo Province will have negative impacts on soil moisture, pasture growth, and livestock as drinking water will also be reduced [86,87].

Decisions that will have to be made include regulating grazing routines and monitoring stocking rates to prevent overgrazing and mortality of livestock. Common practices such as storing hay for feed and buying supplements will be enforced.

In the semi-arid rangelands of southern Africa, reduced production is typically attributed to unreliable rainfall [31,83,88,89] and diminished soil moisture levels [90]. Moreover, reduced vegetation cover due to insufficient rainfall can make rangelands susceptible to wind and soil erosion, potentially leading to long-term decreases in soil fertility and overall soil degradation [83,91–94]. Thus, land degradation in many regions of the Limpopo Province can be seen as a result of unreliable rainfall and anthropogenic causes.

Conversely, high levels of rainfall have been observed to result in abundant grass biomass in the rangelands of the Limpopo Province [40]. This implies that there will be ample pasture for grazing, and livestock will obtain ample pasture and drinking water. However, high rainfalls also imply that decision-makers will need to plan for the coming seasons by conserving feed and water through traditional methods such as storing hay for feed and in-field rainwater harvesting, both to conserve soil moisture for grass and drinking water.

6.2. Varying Minimum Temperatures

The findings for minimum temperatures show both increasing and decreasing trends across different stations and seasons. A rise in minimum temperatures can disrupt plant growth by interfering with the length of growing period, development stages, and their timing [79,95]. This implies that there will be food shortages caused by the low yields of grass biomass. Warmer temperatures observed in some stations will shorten the dormancy period, which can have repercussions on the availability and quality of forage resources in the rangelands [84]. This implies that both the quantity and quality of forage available in the rangelands of the Limpopo Province for livestock grazing may decrease. This will, therefore, affect the decisions taken regarding grazing, and practices such as rotational grazing may be employed to ensure that livestock obtain pasture.

Variations in minimum temperatures can also influence the distribution of plant species, potentially altering their palatability, and this will indirectly impact livestock [25]. This implies that certain parts of the rangelands may be grazed more than others due to palatability. However, it is important to note that pasture availability experiences seasonal fluctuations and is influenced by multiple factors, including grazing intensity, grassland management, precipitation, temperature conditions, and the prevailing species of pasture [79,96]. Hot (cold) temperatures during summer (winter) seasons can result in livestock pests and diseases and mortality for livestock [38]. During these extreme seasons, decisions to control potential pest outbreaks and impacts will be taken.

6.3. Increasing Maximum Temperatures

High maximum temperatures, particularly during the SON and DJF seasons, as observed in the findings, can lead to reduced forage and water availability in the rangelands due to heat stress [79]. This shows that heat stress can adversely affect the palatability and nutritional value of available forage for livestock [86]. Additionally, livestock grazing patterns may be altered by high temperatures, as livestock may prefer to graze in shaded areas rather than open pastures [97]. This implies that potential overgrazing in certain areas may result, while others may be underutilized, affecting livestock's ability to find sufficient grazing resources, which is prevalent in the northeastern rangelands of the Limpopo Province.

Other implications of high temperatures coupled with low rainfall include the flammability of vegetation, which may result from high fire frequency [28]. This will result in changes in species composition. Decisions that regulate wildfires and the construction of firebreaks will have to be enforced.

High temperatures, as observed in the findings, particularly in the SON and DJF seasons, can induce heat stress in cattle, goats, and sheep, impacting their productivity [79,86]. This implies that various physiological processes, including milk production in dairy cows, dry matter and water intake, and mating, can be affected by heat stress [38,84]. Moreover, this may have potential impacts on the prevalence of pests and diseases, significantly affecting livestock and, in some instances, resulting in illness and mortality [38,84]. Livestock illness and mortality will have a significant impact on the local economy, as some farmers will face a loss of income due to the mortality of their livestock. Consequently, there is a need for policies addressing pest and disease regulation, along with initiatives targeting livestock infestations, to mitigate these challenges and provide relief for affected farmers.

7. Conclusions

The study conducted a comprehensive analysis of long-term climate variability within the Limpopo Province over 38 years, focusing on rainfall and temperature data across different seasons. The main objective was to analyse climate variability (spatial and temporal), considering rainfall and minimum and maximum temperatures. The findings informed implications for rangeland productivity. The results highlighted significant fluctuations in rainfall across all stations, with the highest variability observed in the Punda Maria station during the June–July–August (JJA; 366%) season. Moreover, during the rainfall season, September–October–November (SON) and December–January–February (DJF), the highest variability was observed in Musina (71.2%) and Tshiombo (88.3%). Minimum temperatures showed relatively low variability, with the lowest variability observed during the DJF season in the Tshiombo station (2.6%), while maximum temperatures exhibited consistently low variability, with the lowest variability of 3.4% observed during the DJF and JJA seasons in Fleur-de-lys and Tshiombo. This indicates that there is more significant variability in rainfall when contrasted with temperature, and the observed variability varies seasonally.

Trends in minimum temperatures and rainfall were inconclusive, with both increasing and decreasing patterns observed. Conversely, there was a statistically significant increase in mean maximum temperatures across all seasons. However, the highest increase in maximum temperatures was observed in the JJA and SON seasons, with 80% of stations experiencing increasing trends. This emphasizes that Limpopo Province has experienced climate variability during the study period.

Climate variability findings for a rain-fed region can be used to guide on-farm decisions that can improve productivity in rangelands. Additionally, these findings caninform policy and prompt a reevaluation of existing policies in light of the new information. The findings are further expected to aid in forecasting future patterns of these climate variables and assessing extreme events in the region. It is advised that local farmers, extension officers, meteorologists and researchers work closely to monitor temperature and rainfall forecasting for future years.

Overall, this study effectively examined climate variability in the Limpopo Province and outlined the implications for rangelands. Moreover, further research is needed to explore the underlying mechanisms driving climate variability and to quantify the intricate interplay between climate variability and livestock herd dynamics, considering short- and long-term impacts.

Author Contributions: P.M. was responsible for the conceptualization, methodology, and formal analysis. P.M. also drafted the manuscript. M.E.M. and M.T. contributed to the restructuring, editing, and revising of the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Water Research Commission: project no. K5/2968//4.

Data Availability Statement: The climate data used in this study were acquired from the Agricultural Research Council, and the availability is subject to specific data policies. Interested parties can access this data by making a direct request to the Agricultural Research Council.

Acknowledgments: This study is based upon work fully supported financially by the Water Research Commission: project no. K5/2968//4—Development of an agricultural drought management framework for South African croplands and grasslands. The authors express their gratitude to Thomas Fyfield (ARC-NRE) for his editorial assistance in refining and enhancing the readability of the manuscript. The authors also acknowledge the reviewers whose feedback played a crucial role in clarifying and enhancing the quality of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Summary of statistics for climatic variables for selected weather stations in the Limpopo Province (1980–2018).

Station Name	Rainfall				Minimum Temperature				Maximum Temperature			
	Mean (mm)	SD (mm)	CV (%)	CV Category	Mean (°C)	SD (°C)	CV (%)	CV Category	Mean (°C)	SD (°C)	CV (%)	CV Category
Thabazimbi	630.3	170.1	27.0	Moderate	11.5	0.7	6.1	Low	27.7	1.3	4.8	Low
Roedtan	530.6	156.2	29.4	Moderate	11.6	0.6	5.6	Low	28.2	1.2	4.2	Low
Fleur-de-lys	722.2	210.8	29.2	Moderate	14.4	0.7	4.8	Low	27.6	0.8	2.9	Low
Sentrum-ysterpan	561.7	145.5	25.9	Moderate	12.1	0.9	7.4	Low	26.4	1.2	4.5	Low
Modjadji	718.4	256.2	35.7	High	14.2	1.0	7.3	Low	27.2	1.8	6.6	Low
Phalaborwa	461.5	177.0	38.4	High	15.8	0.5	3.1	Low	29.6	1.0	3.3	Low
Marnitz	445.4	143.9	32.3	High	13.9	0.9	6.4	Low	29.2	1.8	6.1	Low
Shingwedzi	532.6	225.9	42.4	High	15.6	0.6	3.8	Low	29.7	1.4	4.7	Low
Punda maria	565.9	336.1	59.4	High	16.0	0.9	5.6	Low	29.1	1.4	4.8	Low
Musina	358.0	148.7	41.5	High	15.4	0.6	3.9	Low	30.4	1.3	4.3	Low
Tshiombo	1003.0	630.5	62.8	High	15.1	0.4	2.6	Low	27.3	0.7	2.6	Low
Settlers	648.3	135.3	20.9	Moderate	10.9	0.7	6.4	Low	28.0	1.2	4.2	Low
Zebediela	560.5	123.7	22.6	Moderate	13.1	0.8	6.1	Low	27.4	1.0	3.6	Low
Bavaria	576.7	169.9	29.5	Moderate	15.0	0.7	4.7	Low	28.2	0.8	2.8	Low
Lephalale	445.8	181.6	40.7	High	13.1	1.2	9.1	Low	28.7	1.0	3.5	Low

Table A2. Statistical results for total seasonal rainfall for the December–January–February (DJF), March–April–May (MAM), June–July–August (JJA), and September–October–November (SON) seasons in the selected stations in the Limpopo Province (1980–2018).

Station Name	DJF				MAM				JJA				SON			
	Mean (mm)	SD (mm)	CV (%)	CV Category	Mean (mm)	SD (mm)	CV (%)	CV Category	Mean (mm)	SD (mm)	CV (%)	CV Category	Mean (mm)	SD (mm)	CV (%)	CV Category
Thabazimbi	260.0	170.3	65.5	High	141.6	61.9	43.7	High	98.1	116.5	118.8	High	134.1	58.1	43.4	High
Roedtan	241.7	102.0	42.2	High	103.6	66.4	64.1	High	20.8	61.8	297.3	High	160.6	85.4	53.2	High
Fleur-de-lys	374.7	159.8	42.7	High	152.8	64.2	42.0	High	30.9	32.5	105.4	High	162.3	68.6	42.2	High
Sentrum-ysterpan	237.0	160.9	67.9	High	131.0	60.7	46.4	High	77.0	101.5	131.8	High	119.8	42.3	35.3	High
Modjadji	387.6	225.4	58.2	High	147.6	81.1	55.0	High	21.0	18.1	86.2	High	151.6	62.3	41.1	High
Phalaborwa	238.7	124.2	52.0	High	90.7	45.1	49.7	High	15.4	16.7	108.4	High	114.5	60.4	52.7	High
Marnitz	238.4	107.8	45.2	High	80.8	44.9	55.6	High	12.1	14.8	122.9	High	107.9	59.3	54.9	High
Shingwedzi	299.5	190.7	63.7	High	97.5	68.6	70.4	High	16.4	13.8	84.1	High	121.2	63.9	52.7	High
Punda maria	308.0	214.1	69.5	High	93.9	72.5	77.2	High	39.4	144.1	366.1	High	124.2	73.9	59.5	High
Musina	193.9	138.0	71.2	High	65.6	54.8	83.5	High	9.4	15.2	161.7	High	88.8	50.0	56.3	High
Tshiombo	505.9	290.1	57.3	High	199.4	154.1	77.3	High	78.5	248.1	316.1	High	216.1	190.7	88.2	High
Settlers	328.9	115.0	35.0	High	128.0	80.4	62.8	High	13.2	14.9	112.8	High	177.2	69.4	39.2	High
Zebediela	280.4	91.6	32.7	High	102.3	57.9	56.6	High	11.7	15.3	130.7	High	157.4	70.7	44.9	High
Bavaria	295.8	125.4	42.4	High	119.3	51.2	43.0	High	15.2	17.0	111.8	High	145.3	70.8	48.7	High
Lephalale	211.3	119.1	56.3	High	86.4	58.1	67.3	High	28.2	67.6	239.8	High	111.7	69.5	62.2	High

Table A3. Statistical results for mean minimum temperature for the December–January–February (DJF), March–April–May (MAM), June–July–August (JJA), and September–October–November (SON) seasons in the selected stations in the Limpopo Province (1980–2018).

Station Name	DJF				MAM				JJA				SON			
	Mean (°C)	SD (°C)	CV (%)	CV Category	Mean (°C)	SD (°C)	CV (%)	CV Category	Mean (°C)	SD (°C)	CV (%)	CV Category	Mean (°C)	SD (°C)	CV (%)	CV Category
Thabazimbi	17.4	0.8	4.5	Low	11.2	1.0	9.1	Low	3.9	1.1	28.9	Moderate	13.4	1.0	7.8	Low
Roedtan	17.4	0.7	4.2	Low	11.4	0.9	8.0	Low	4.0	1.3	32.5	High	13.5	1.0	7.4	Low
Fleur-de-lys	18.9	1.0	5.3	Low	14.7	0.9	6.1	Low	8.8	0.9	10.2	Low	15.2	0.8	5.2	Low
Sentrum-ysterpan	17.6	0.8	4.5	Low	11.9	1.5	12.6	Low	5.0	1.2	24.0	Moderate	14.0	1.3	9.2	Low
Modjadji	18.0	2.0	11.2	Low	14.5	1.5	10.3	Low	9.5	1.4	14.7	Low	14.6	1.5	10.2	Low
Phalaborwa	20.5	0.7	3.4	Low	16.1	0.8	5.0	Low	9.8	0.9	9.2	Low	16.6	0.6	3.7	Low
Marnitz	18.9	1.0	5.3	Low	13.7	1.2	8.8	Low	7.3	1.2	16.4	Low	15.8	1.3	8.2	Low
Shingwedzi	20.6	1.1	5.3	Low	15.7	1.1	7.0	Low	9.2	0.9	9.8	Low	16.7	1.1	6.6	Low
Punda maria	20.5	0.8	3.9	Low	16.2	1.3	8.0	Low	10.4	1.6	15.3	Low	16.9	0.9	5.3	Low
Musina	21.1	0.8	3.8	Low	15.5	1.0	6.5	Low	8.0	0.9	11.3	Low	17.1	0.7	4.1	Low
Tshiombo	19.3	0.5	2.6	Low	15.3	0.8	5.2	Low	10.0	0.7	7.0	Low	15.8	0.6	3.8	Low
Settlers	16.7	0.6	3.6	Low	10.6	0.8	7.5	Low	3.5	1.0	28.6	Moderate	12.8	1.0	7.8	Low
Zebediela	18.0	0.6	3.3	Low	13.1	1.1	8.4	Low	6.6	1.5	23.0	Moderate	14.8	0.9	6.0	Low
Bavaria	19.4	1.0	5.2	Low	15.2	1.0	6.6	Low	9.4	1.2	13.1	Low	15.7	0.8	5.1	Low
Lephalale	18.7	1.5	8.0	Low	12.8	1.4	10.9	Low	5.8	1.2	20.8	Low	15.2	1.8	11.8	Low

Table A4. Statistical results for mean maximum temperature for the December–January–February (DJF), March–April–May (MAM), June–July–August (JJA), and September–October–November (SON) seasons in the selected stations in the Limpopo Province (1980–2018).

Station Name	DJF				MAM				JJA				SON			
	Mean (°C)	SD (°C)	CV (%)	CV Category	Mean (°C)	SD (°C)	CV (%)	CV Category	Mean (°C)	SD (°C)	CV (%)	CV Category	Mean (°C)	SD (°C)	CV (%)	CV Category
Thabazimbi	30.7	1.7	5.7	Low	27.2	2.0	7.4	Low	23.1	1.3	5.8	Low	29.7	1.3	4.5	Low
Roedtan	31.1	1.4	4.6	Low	27.8	1.3	4.8	Low	23.7	1.3	5.5	Low	29.9	1.5	5.2	Low
Fleur-de-lys	29.1	1.0	3.3	Low	25.9	1.0	3.7	Low	25.6	0.9	3.4	Low	28.9	1.1	3.9	Low
Sentrum-ysterpan	28.7	1.4	5.0	Low	26.3	1.4	5.3	Low	23.3	1.2	5.0	Low	27.2	1.4	5.2	Low
Modjadji	29.6	2.1	7.0	Low	27.2	2.1	7.7	Low	24.1	1.9	7.8	Low	27.9	2.1	7.5	Low
Phalaborwa	32.3	1.1	3.5	Low	29.6	1.4	4.7	Low	26.2	1.1	4.3	Low	30.2	1.2	3.8	Low
Marnitz	30.8	2.1	6.8	Low	26.5	1.8	6.9	Low	26.7	1.8	6.7	Low	31.5	1.9	6.0	Low
Shingwedzi	30.9	1.9	6.1	Low	27.8	1.7	6.3	Low	27.7	1.3	4.7	Low	31.5	1.7	5.5	Low
Punda maria	31.4	2.8	9.0	Low	28.8	2.5	8.6	Low	25.7	1.1	4.4	Low	30.2	1.6	5.2	Low
Musina	31.7	1.9	5.9	Low	28.0	1.5	5.3	Low	27.9	1.3	4.6	Low	32.7	1.4	4.3	Low
Tshiombo	29.5	1.3	4.4	Low	27.0	1.2	4.4	Low	24.0	0.8	3.3	Low	28.4	1.0	3.5	Low
Settlers	30.8	1.6	5.2	Low	27.5	1.5	5.4	Low	23.5	1.2	5.1	Low	30.1	1.5	4.9	Low
Zebediela	30.2	1.3	4.3	Low	27.1	1.1	4.0	Low	23.0	1.1	4.8	Low	29.2	1.2	4.1	Low
Bavaria	30.9	1.2	3.8	Low	28.3	1.0	3.5	Low	25.0	0.9	3.6	Low	28.8	1.0	3.4	Low
Lephalale	31.6	1.4	4.4	Low	28.2	1.4	4.9	Low	24.4	1.1	4.5	Low	30.6	1.3	4.2	Low

Appendix B

Table A5. Mann–Kendall test results for total seasonal rainfall for the December–January–February (DJF), March–April–May (MAM), June–July–August (JJA), and September–October–November (SON) seasons in the selected stations in the Limpopo Province (1980–2018).

Station	DJF					MAM					JJA					SON				
	S	Var(S)	*p*-Value	z		S	Var(S)	*p*-Value	z		S	Var(S)	*p*-Value	z		S	Var(S)	*p*-Value	z	
Thabazimbi	283.000	6327.0	0.000392 ***	3.545	I	39.000	6327.0	0.6328	0.4777	I	−318.0	6324.0	0.000067 ***	−3.986	D	105.0	6327.0	0.1911	1.3075	I
Roedtan	−221.000	6327.0	0.005678 ***	−2.7658	D	87.000	6327.0	0.2796	1.0812	I	121.0	6201.0	0.1275	1.5239	I	−91.00	6327.0	0.2579	−1.131	D
Fleur-de-lys	119.0000	6327.0	0.1379	1.4835	I	80.00000	6326.0	0.3206	0.9932	I	−58.00	6326.0	0.4736	−0.7166	D	49.00	6327.0	0.5462	0.6034	I
Sentrum-ysterpan	301.0000	6327.0	0.000162 ***	3.7716	I	7.000000	6327.0	0.9399	0.0754	I	−232.0	6298.6	0.0036 ***	−2.9106	D	89.00	6327.0	0.2686	1.1063	I
Modjadji	−5.0000	6327.0	0.9599	−0.0502	D	−19.000	6327.0	0.821	−0.2262	D	−128.0	6326.0	0.1103	−1.5968	D	−163.0	6325.0	0.0416 **	−2.037	D
Phalaborwa	−2.00000	6326.0	0.99	−0.0125	D	3.0000	6327.0	0.9799	0.0251	I	−131.0	6325.0	0.1021	−1.6346	D	−56.00	6326.00	0.4892	−0.6915	D
Marnitz	95.00000	6327.0	0.2373	1.1818	I	−16.0000	6326.0	0.8504	−0.1885	D	10.00	6294.0	0.9097	0.1134	I	30.00	6326.0	0.7154	0.364	I
Shingwedzi	157.0000	6327.0	0.04985 **	1.9612	I	99.00000	6327.0	0.2179	1.232	I	9.000	6325.0	0.9199	0.1005	I	98.00	6326.0	0.2226	1.2196	I
Punda maria	123.0000	6327.0	0.1251	1.5338	I	155.0000	6327.0	0.05286 *	1.9361	I	93.00	6325.0	0.2474	1.1568	I	−27.00	6327.0	0.7438	−0.3268	D
Musina	149.0000	6327.0	0.06279 *	1.8606	I	21.00000	6325.0	0.8014	0.2514	I	−16.00	6258.6	0.8496	−0.1896	D	−31.00	6327.0	0.7061	−0.3771	D
Tshiombo	85.00000	6327.0	0.2909	1.056	I	95.00000	6327.0	0.2373	1.1818	I	−48.00	6326.0	0.5546	−0.5909	D	7.000	6327.0	0.9399	0.0754	I
Settlers	17.00000	6327.0	0.8406	0.2011	I	91.00000	6327.0	0.2579	1.1315	I	−44.00	6309.3	0.5883	−0.5413	D	9.000	6327.0	0.9199	0.1005	I
Zebediela	−47.0000	6327.0	0.5631	−0.5783	D	67.00000	6327.0	0.4067	0.8297	I	−34.00	6309.3	0.6778	−0.4154	D	63.00	6327.0	0.4357	0.7794	I
Bavaria	71.0000	6327.0	0.3788	0.8800	I	76.0000	6326.0	0.3457	0.9429	I	−39.00	6325.0	0.6328	−0.4778	D	13.00	6327.0	0.8801	0.1508	D
Lephalale	−200.000	6317.3	0.01229 *	−2.5037	D	−120.000	6326.0	0.1346	−1.4962	D	−9.000	6295.6	0.9197	−0.1008	D	−84.00	6323.3	0.2966	−1.0438	D

*** Trends statistically significant at $p < 0.01$; ** trends statistically significant at $p < 0.05$; * trends statistically significant at $p < 0.10$. I—increasing trend; D—decreasing trend.

Table A6. Mann–Kendall test results for mean minimum temperature for the December–January–February (DJF), March–April–May (MAM), June–July–August (JJA), and September–October–November (SON) seasons in the selected stations in the Limpopo Province (1980–2018).

Station	**DJF**					**MAM**					**JJA**					**SON**				
	S	**Var(S)**	***p*-Value**	**z**		**S**	**Var(S)**	***p*-Value**	**z**		**S**	**Var(S)**	***p*-Value**	**z**		**S**	**Var(S)**	***p*-Value**	**z**	
Thabazimbi	−65.0000	6294.3	0.4198	−0.8066	D	176.0000	6312.6	0.02762 **	2.2026	I	293.0	6319.0	0.000239 ***	3.6733	I	58.00	6315.3	0.4732	0.7172	I
Roedtan	−133.000	6297.0	0.09622 *	−1.6634	D	−112.000	6295.3	0.1618	−1.399	D	−209.0	6314.3	0.008856 ***	−2.6176	D	−131.0	6307.6	0.1017	−1.6369	D
Fleur-de-lys	−161.000	6311.6	0.04402 **	−2.0139	D	−80.0000	6296.0	0.3194	−0.9956	D	102.0	6308.0	0.2035	1.2717	I	−109.0	6300.3	0.1736	−1.3606	D
Sentrum-ysterpan	74.000	6298.6	0.3577	0.9198	I	183.0000	6309.6	0.02195 **	2.2912	I	240.0	6312.0	0.002628 ***	3.0083	I	149.0	6306.3	0.06237 *	1.8637	I
Modjadji	116.0000	6317.3	0.1479	1.4469	I	56.00000	6307.3	0.4886	0.6925	I	−74.00	6315.3	0.3583	−0.9186	D	164.0	6314.6	0.04025 **	2.0512	I
Phalaborwa	−10.0000	6299.3	0.9097	−0.1134	D	−112.000	6297.3	0.1619	−1.3988	D	−151.0	6289.6	0.05857 *	−1.8914	D	27.00	6283.6	0.7429	0.3279	I
Marnitz	125.0000	6299.0	0.1182	1.5624	I	2.000000	6312.6	0.99	0.0125	I	−151.0	6312.3	0.05903 *	−1.888	D	68.00	6296.0	0.3985	0.8443	I
Shingwedzi	−189.000	6305.0	0.0179 **	−2.3676	D	−197.000	6296.3	0.01351 **	−2.4701	D	−13.00	6303.0	0.8799	−0.1511	D	−75.00	6305.0	0.3514	−0.9319	D
Punda maria	−65.0000	6271.6	0.419	0.8081	D	−223.000	6302.3	0.0051 ***	−2.7964	D	−188.0	6298.0	0.01846 **	−2.3564	D	−125.0	6299.0	0.1182	−1.5624	D
Musina	−140.000	6294.6	0.07978 *	−1.752	D	−141.000	6306.3	0.07791 *	−1.7629	D	7.000	6297.6	0.9397	0.0756	I	−93.00	6297.6	0.2463	−1.1593	D
Tshiombo	−132.000	6284.0	0.09842 *	−1.6525	D	−247.000	6284.3	0.0019 ***	−3.1032	D	−78.00	6295.3	0.3318	−0.9704	D	−4.000	6261.3	0.9698	−0.0379	D
Settlers	27.00000	6279.0	0.7428	0.3281	I	128.0000	6301.3	0.1096	1.5999	I	94.00	6298.6	0.2413	1.1718	I	68.00	6292.0	0.3983	0.8446	I
Zebediela	−53.0000	6291.6	0.5121	−0.6555	D	−152.000	6302.0	0.05716 *	−1.9021	D	−167.0	6315.6	0.03673 **	−2.0888	D	9.000	6303.6	0.9197	0.1007	I
Bavaria	−49.0000	6309.0	0.5456	−0.6043	D	−32.0000	6310.0	0.6963	−0.390	D	125.0	6318.3	0.1188	1.56	I	−68.00	6304.0	0.3988	−0.8438	D
Lephalale	324.0000	6309.3	0.0000 ***	4.0664	I	270.0000	6316.0	0.0007 ***	3.3848	I	171.0	6305.0	0.03228 **	2.1409	I	334.0	6314.6	0.0000 ***	4.1905	I

*** Trends statistically significant at $p < 0.01$; ** trends statistically significant at $p < 0.05$; * trends statistically significant at $p < 0.10$. I—increasing trend; D—decreasing trend.

Table A7. Mann–Kendall test results for mean maximum temperature for the December–January–February (DJF), March–April–May (MAM), June–July–August (JJA), and September–October–November (SON) seasons in the selected stations in the Limpopo Province (1980–2018).

Station	**DJF**					**MAM**					**JJA**					**SON**				
	S	**Var(S)**	***p*-Value**	**z**		**S**	**Var(S)**	***p*-Value**	**z**		**S**	**Var(S)**	***p*-Value**	**Z**		**S**	**Var(S)**	***p*-Value**	**z**	
Thabazimbi	−99.0000	6314.3	0.2175	−1.2333	D	−11.0000	6319.0	0.8999	−0.1258	D	74.00	6310.0	0.3581	0.9189	I	46.00	6308.6	0.571	0.5665	I
Roedtan	152.0000	6312.6	0.05737 *	1.9005	I	155.0000	6305.0	0.05245 *	1.9394	I	313.0	6309.6	0.0000 ***	3.9278	I	280.0	6296.6	0.0004 ***	3.516	I
Fleur-de-lys	−68.0000	6302.0	0.3987	−0.8439	D	−85.0000	6293.6	0.2897	−1.0588	D	29.00	6290.3	0.7241	0.3530	I	−11.00	6308.3	0.8998	−0.1259	D
Sentrum-ysterpan	148.0000	6313.3	0.0643 *	1.8501	I	132.0000	6317.3	0.09932 *	1.6482	I	238.0	6298.0	0.0028 ***	2.9864	I	276.0	6314.6	0.0005 ***	3.4606	I
Modjadji	213.0000	6323.0	0.0076 ***	2.6661	I	229.0000	6316.3	0.0041 ***	2.8688	I	317.0	6319.0	0.0000 ***	3.9752	I	381.0	6321.0	0.0000 ***	4.7796	I
Phalaborwa	179.0000	6308.3	0.02502 **	2.2411	I	214.0000	6310.0	0.0073 ***	2.6814	I	353.0	6306.3	0.0000 ***	4.4326	I	359.0	6305.6	0.0000 ***	4.5083	I
Marnitz	234.0000	6314.6	0.0033 ***	2.9321	I	297.000	6307.0	0.0001 ***	3.7272	I	352.0	6310.0	0.0000 ***	4.4187	I	334.0	6306.0	0.0000 ***	4.1934	I
Shingwedzi	−186.000	6310.6	0.01987 **	−2.3288	D	−111.000	6304.3	0.1659	−1.3854	D	−103.0	6298.3	0.1987	−1.2852	D	−113.0	6313.6	0.1587	−1.4095	D
Punda maria	23.00000	6309.6	0.7818	0.2769	I	44.00000	6312.0	0.5883	0.5412	I	258.0	6303.3	0.0012 ***	3.237	I	295.0	6296.3	0.0002 ***	3.7051	I
Musina	88.00000	6308.6	0.2734	1.0953	I	172.0000	6317.3	0.03144 **	2.1514	I	345.0	6297.6	0.0000 ***	4.3348	I	255.0	6317.0	0.0013 ***	3.1958	I
Tshiombo	9.00000	6308.3	0.9198	0.1007	I	60.00000	6312.6	0.4577	0.7425	I	235.0	6307.0	0.0032 ***	2.9465	I	249.0	6311.0	0.0017 ***	3.1218	I
Settlers	211.0000	6309.6	0.0082 ***	2.6437	I	216.0000	6310.6	0.0068 ***	2.7065	I	350.0	6303.3	0.0000 ***	4.3958	I	341.0	6316.3	0.0000 ***	4.2781	I
Zebediela	145.0000	6292.3	0.06947 *	1.8153	I	184.0000	6306.6	0.0212 **	2.3044	I	361.0	6309.6	0.0000 ***	4.5321	I	298.0	6307.3	0.0001 ***	3.7397	I
Bavaria	−25.0000	6304.3	0.7624	−0.3022	D	21.00000	6309.0	0.8012	0.2518	I	132.0	6310.6	0.09914 *	1.649	I	160.0	6300.6	0.04517 **	2.0031	I
Lephalale	56.00000	6305.3	0.4885	0.6926	I	144.0000	6307.3	0.07177 *	1.8006	I	359.0	6307.0	0.0000 ***	4.5079	I	293.0	6313.6	0.0002 ***	3.6749	I

*** Trends statistically significant at $p < 0.01$; ** trends statistically significant at $p < 0.05$; * trends statistically significant at $p < 0.10$. I—increasing trend; D—decreasing trend.

References

1. Li, Y.; Conway, D.; Xiong, W.; Gao, Q.; Wu, Y.; Wan, Y.; Li, Y.; Zhang, S. Effects of climate variability and change on Chinese agriculture: A review. *Clim. Res.* **2011**, *50*, 83–102. [CrossRef]
2. Vermeulen, S.J.; Aggarwal, P.K.; Ainslie, A.; Angelone, C.; Campbell, B.M.; Challinor, A.J.; Hansen, J.W.; Ingram, J.S.; Jarvis, A.; Kristjanson, P.; et al. Options for support to agriculture and food security under climate change. *Environ. Sci. Policy* **2012**, *15*, 136–144. [CrossRef]
3. Marshall, N.A.; Smajgl, A. Understanding variability in adaptive capacity on rangelands. *Rangel. Ecol. Manag.* **2013**, *66*, 88–94. [CrossRef]
4. Anderson, K.E.; Glenn, N.F.; Spaete, L.P.; Shinneman, D.J.; Pilliod, D.S.; Arkle, R.S.; McIlroy, S.K.; Derryberry, D.R. Estimating vegetation biomass and cover across large plots in shrub and grass dominated drylands using terrestrial lidar and machine learning. *Ecol. Indic.* **2018**, *84*, 793–802. [CrossRef]
5. Vogel, E.; Donat, M.G.; Alexander, L.V.; Meinshausen, M.; Ray, D.K.; Karoly, D.; Meinshausen, N.; Frieler, K. The effects of climate extremes on global agricultural yields. *Environ. Res. Lett.* **2019**, *14*, 054010. [CrossRef]
6. Dingaan, M.N.; Tsubo, M. Improved assessment of pasture availability in semi-arid grassland of South Africa. *Environ. Monit. Assess.* **2019**, *191*, 1–12. [CrossRef]
7. Asare-Nuamah, P.; Botchway, E. Understanding climate variability and change: Analysis of temperature and rainfall across agroecological zones in Ghana. *Heliyon* **2019**, *5*, e02654. [CrossRef]
8. Belay, A.; Demissie, T.; Recha, J.W.; Oludhe, C.; Osano, P.M.; Olaka, L.A.; Solomon, D.; Berhane, Z. Analysis of climate variability and trends in Southern Ethiopia. *Climate* **2021**, *9*, 96. [CrossRef]
9. Eden, C.; Willebrand, J. Mechanism of interannual to decadal variability of the North Atlantic circulation. *J. Clim.* **2001**, *14*, 2266–2280. [CrossRef]
10. Malherbe, J.; Dieppois, B.; Maluleke, P.; Van Staden, M.; Pillay, D.L. South African droughts and decadal variability. *Nat. Hazards* **2016**, *80*, 657–681. [CrossRef]
11. Zhao, Y.; Wang, C.; Wang, S.; Tibig, L.V. Impacts of present and future climate variability on agriculture and forestry in the humid and sub-humid tropics. *Clim. Chang.* **2005**, *70*, 73–116. [CrossRef]
12. Homar, V.; Ramis, C.; Romero, R.; Alonso, S. Recent trends in temperature and precipitation over the Balearic Islands (Spain). *Clim. Chang.* **2010**, *98*, 199–211. [CrossRef]
13. L'Heureux, M.L.; Takahashi, K.; Watkins, A.B.; Barnston, A.G.; Becker, E.J.; Di Liberto, T.E.; Gamble, F.; Gottschalck, J.; Halpert, M.S.; Huang, B.; et al. Observing and predicting the 2015/16 El Niño. *Bull. Am. Meteorol. Soc.* **2017**, *98*, 1363–1382. [CrossRef]
14. Cayan, D.R. Interannual climate variability and snowpack in the western United States. *J. Clim.* **1996**, *9*, 928–948. [CrossRef]
15. Usman, M.T.; Reason, C.J.C. Dry spell frequencies and their variability over southern Africa. *Clim. Res.* **2004**, *26*, 199–211. [CrossRef]
16. Roudier, P.; Sultan, B.; Quirion, P.; Berg, A. The impact of future climate change on West African crop yields: What does the recent literature say? *Glob. Environ. Change* **2011**, *21*, 1073–1083. [CrossRef]
17. Engelbrecht, F.; Adegoke, J.; Bopape, M.J.; Naidoo, M.; Garland, R.; Thatcher, M.; McGregor, J.; Katzfey, J.; Werner, M.; Ichoku, C.; et al. Projections of rapidly rising surface temperatures over Africa under low mitigation. *Environ. Res. Lett.* **2015**, *10*, 085004. [CrossRef]
18. Intergovernmental Panel for Climate Change. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK, 2007.
19. Salinger, M.J. Climate variability and change: Past, present and future—An overview. *Clim. Chang.* **2005**, *70*, 9–29. [CrossRef]
20. Ziervogel, G.; Bharwani, S.; Downing, T.E. Adapting to climate variability: Pumpkins, people and policy. In *Natural Resources Forum*; Blackwell Publishing Ltd.: Oxford, UK, 2006; Volume 30, pp. 294–305.
21. Chambers, J.C.; Pellant, M. Climate change impacts on northwestern and intermountain United States rangelands. *Rangelands* **2008**, *30*, 29–33. [CrossRef]
22. Aggarwal, P.K.; Baethegan, W.E.; Cooper, P.; Gommes, R.; Lee, B.; Meinke, H.; Rathore, L.S.; Sivakumar, M.V. Managing climatic risks to combat land degradation and enhance food security: Key information needs. *Procedia Environ. Sci.* **2010**, *1*, 305–312. [CrossRef]
23. Mpandeli, N.S.; Maponya, P.I. Coping with climate variability in Limpopo province, South Africa. *Peak J. Agric. Sci.* **2013**, *1*, 54–64.
24. Boansi, D.; Tambo, J.A.; Müller, M. Analysis of farmers' adaptation to weather extremes in West African Sudan Savanna. *Weather. Clim. Extrem.* **2017**, *16*, 1–13. [CrossRef]
25. Godde, C.; Dizyee, K.; Ash, A.; Thornton, P.; Sloat, L.; Roura, E.; Henderson, B.; Herrero, M. Climate change and variability impacts on grazing herds: Insights from a system dynamics approach for semi-arid Australian rangelands. *Glob. Chang. Biol.* **2019**, *25*, 3091–3109. [CrossRef] [PubMed]
26. Vogel, C. "Seven fat years and seven lean years"? Climate change and agriculture in Africa. *IDS Bull.* **2005**, *36*, 30–35. [CrossRef]
27. Thomas, D.S.; Twyman, C.; Osbahr, H.; Hewitson, B. Adaptation to climate change and variability: Farmer responses to intra-seasonal precipitation trends in South Africa. *Clim. Chang.* **2007**, *83*, 301–322. [CrossRef]
28. Hoffman, T.; Vogel, C. Climate change impacts on African rangelands. *Rangelands* **2008**, *30*, 12–17. [CrossRef]

29. Funk, C.; Hoell, A.; Shukla, S.; Blade, I.; Liebmann, B.; Roberts, J.B.; Robertson, F.R.; Husak, G. Predicting East African spring droughts using Pacific and Indian Ocean sea surface temperature indices. *Hydrol. Earth Syst. Sci.* **2014**, *18*, 4965–4978. [CrossRef]
30. Mbokodo, I.L.; Bopape, M.J.M.; Ndarana, T.; Mbatha, S.M.; Muofhe, T.P.; Singo, M.V.; Xulu, N.G.; Mohomi, T.; Ayisi, K.K.; Chikoore, H. Heatwave Variability and Structure in South Africa during Summer Drought. *Climate* **2023**, *11*, 38. [CrossRef]
31. Mpandeli, S.; Nesamvuni, E.; Maponya, P. Adapting to the impacts of drought by smallholder farmers in Sekhukhune District in Limpopo Province, South Africa. *J. Agric. Sci.* **2015**, *7*, 115. [CrossRef]
32. Conway, D.; Van Garderen, E.A.; Deryng, D.; Dorling, S.; Krueger, T.; Landman, W.; Lankford, B.; Lebek, K.; Osborn, T.; Ringler, C.; et al. Climate and southern Africa's water–energy–food nexus. *Nat. Clim. Chang.* **2015**, *5*, 837–846. [CrossRef]
33. Maponya, P.; Mpandeli, S. The role of extension services in climate change adaptation in Limpopo province, South Africa. *J. Agric. Ext. Rural. Dev.* **2013**, *5*, 137–142.
34. McGeehin, M.A.; Mirabelli, M. The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States. *Environ. Health Perspect.* **2001**, *109* (Suppl. S2), 185–189. [PubMed]
35. West, J.W. Effects of heat-stress on production in dairy cattle. *J. Dairy Sci.* **2003**, *86*, 2131–2144. [CrossRef] [PubMed]
36. Moeletsi, M.E.; Walker, S. Rainy season characteristics of the Free State Province of South Africa with reference to rain-fed maize production. *Water SA* **2012**, *38*, 775–782. [CrossRef]
37. Mazibuko, S.M.; Mukwada, G.; Moeletsi, M.E. Assessing the frequency of drought/flood severity in the Luvuvhu River catchment, Limpopo Province, South Africa. *Water SA* **2021**, *47*, 172–184. [CrossRef]
38. Archer, E.R.M.; Landman, W.A.; Malherbe, J.; Maluleke, P.; Weepener, H. Managing climate risk in livestock production in South Africa: How might improved tailored forecasting contribute? *Clim. Risk Manag.* **2021**, *32*, 100312. [CrossRef]
39. Gbetibouo, G.A. *Understanding Farmers' Perceptions and Adaptations to Climate Change and Variability*; The Case of the Limpopo Basin, South Africa: IFPRI Discussion Paper 00849; IFPRI: Washington, DC, USA, 2009; Available online: http://www.ifpri.org/publication/understanding-farmers-perceptions-and-adaptationsclimate-change-and-variability (accessed on 20 October 2023).
40. Maluleke, P.; Landman, W.A.; Malherbe, J.; Archer, E. Seasonal forecasts for the Limpopo Province in estimating deviations from grazing capacity. *Theor. Appl. Climatol.* **2019**, *137*, 1693–1702. [CrossRef]
41. Masupha, T.E.; Moeletsi, M.E.; Tsubo, M. Prospects of an agricultural drought early warning system in South Africa. *Int. J. Disaster Risk Reduct.* **2021**, *66*, 102615. [CrossRef]
42. Moeletsi, M.E.; Mellaart, E.A.R.; Mpandeli, N.S.; Hamandawana, H. The use of rainfall forecasts as a decision guide for small-scale farming in Limpopo Province, South Africa. *J. Agric. Educ. Ext.* **2013**, *19*, 133–145. [CrossRef]
43. Archer, E.; Landman, W.; Malherbe, J.; Tadross, M.; Pretorius, S. South Africa's winter rainfall region drought: A region in transition? *Clim. Risk Manag.* **2019**, *25*, 100188. [CrossRef]
44. Maponya, P.; Mpandeli, S. Climate change and agricultural production in South Africa: Impacts and adaptation options. *J. Agric. Sci.* **2012**, *4*, 48. [CrossRef]
45. Hoffmann, M.P.; Odhiambo, J.J.; Koch, M.; Ayisi, K.K.; Zhao, G.; Soler, A.S.; Rötter, R.P. Exploring adaptations of groundnut cropping to prevailing climate variability and extremes in Limpopo Province, South Africa. *Field Crops Res.* **2018**, *219*, 1–13. [CrossRef]
46. Olabanji, M.F.; Ndarana, T.; Davis, N. Impact of climate change on crop production and potential adaptive measures in the olifants catchment, South Africa. *Climate* **2021**, *9*, 6. [CrossRef]
47. Tshiala, M.F.; Olwoch, J.M. Impact of climate variability on tomato production in Limpopo Province, South Africa. *Afr. J. Agric. Res.* **2010**, *5*, 2945–2951.
48. Tshiala, F.M.; Mukarugwiza Olwoch, J.; Alwyn Engelbrecht, F. Analysis of temperature trends over Limpopo province, South Africa. *J. Geogr. Geol.* **2011**, *3*, 13–21. [CrossRef]
49. Nenwiini, S.; Kabanda, T.A. Trends and variability assessment of rainfall in Vhembe South Africa. *J. Hum. Ecol.* **2013**, *42*, 171–176. [CrossRef]
50. MacKellar, N.; New, M.; Jack, C. Observed and modelled trends in rainfall and temperature for South Africa: 1960–2010. *S. Afr. J. Sci.* **2014**, *110*, 1–13. [CrossRef]
51. Archer, E.R. Beyond the "climate versus grazing" impasse: Using remote sensing to investigate the effects of grazing system choice on vegetation cover in the eastern Karoo. *J. Arid. Environ.* **2004**, *57*, 381–408. [CrossRef]
52. Mucina, L.; Rutherford, M.C. *The Vegetation of South Africa, Lesotho and Swaziland in Strelitzia 19*; South African National Biodiversity Institute: Pretoria, South Africa, 2006.
53. Hoffman, M.T.; Todd, S. A national review of land degradation in South Africa: The influence of biophysical and socio-economic factors. *J. South. Afr. Stud.* **2000**, *26*, 743–758. [CrossRef]
54. Leonard, L.; Lebogang, T. Exploring the impacts of mining on tourism growth and local sustainability: The case of Mapungubwe Heritage Site, Limpopo, South Africa. *Sustain. Dev.* **2018**, *26*, 206–216. [CrossRef]
55. Phooko-Rabodiba, D.A.; Tambe, B.A.; Nesamvuni, C.N.; Mbhenyane, X.G. Socioeconomic determinants influencing nutritional status of children in sekhukhune district of Limpopo province in South Africa. *J. Nutr. Health* **2019**, *5*, 7.
56. Schulze, B.R. *Climate of South Africa. Part 8, General Survey*; Government Printer & Weather Bureau: Pretoria, South Africa, 1965.
57. Rapolaki, R.S.; Reason, C.J. Tropical storm Chedza and associated floods over south-eastern Africa. *Nat. Hazards* **2018**, *93*, 189–217. [CrossRef]

58. Wessels, K.J.; Prince, S.D.; Malherbe, J.; Small, J.; Frost, P.E.; VanZyl, D. Can human-induced land degradation be distinguished from the effects of rainfall variability? A case study in South Africa. *J. Arid. Environ.* **2007**, *68*, 271–297. [CrossRef]
59. Palmer, A.R.; Bennett, J.E. Degradation of communal rangelands in South Africa: Towards an improved understanding to inform policy. *Afr. J. Range Forage Sci.* **2013**, *30*, 57–63. [CrossRef]
60. Cobon, D.H.; Baethgen, W.E.; Landman, W.; Williams, A.; van Garderen, E.A.; Johnston, P.; Malherbe, J.; Maluleke, P.; Kgakatsi, I.B.; Davis, P. Agroclimatology in grasslands. *Agroclimatol. Link. Agric. Clim.* **2020**, *60*, 369–423.
61. Gibson, D.J. Land Degradation in the Limpopo Province, South Africa. Ph.D. Thesis, University of the Witwatersrand, Johannesburg, South Africa, 2006.
62. Odhiambo, J.J.; Magandini, V.N. An assessment of the use of mineral and organic fertilizers by smallholder farmers in Vhembe district, Limpopo province, South Africa. *Afr. J. Agric. Res.* **2008**, *3*, 357–362.
63. Phethi, M.D.; Gumbo, J.R. Assessment of impact of land use change on the wetland in Makhitha village, Limpopo province, South Africa. *Jàmbá J. Disaster Risk Stud.* **2019**, *11*, 1–6. [CrossRef]
64. Moeletsi, M.E.; Myeni, L.; Kaempffer, L.C.; Vermaak, D.; de Nysschen, G.; Henningse, C.; Nel, I.; Rowswell, D. Climate Dataset for South Africa by the Agricultural Research Council. *Data* **2022**, *7*, 117. [CrossRef]
65. Abbas, S.; Dastgeer, G. November. Analysing the impacts of climate variability on the yield of Kharif rice over Punjab, Pakistan. In *Natural Resources Forum*; Blackwell Publishing Ltd.: Oxford, UK, 2021; Volume 45, pp. 329–349.
66. Shabalala, Z.P.; Moeletsi, M.E.; Tongwane, M.I.; Mazibuko, S.M. Evaluation of infilling methods for time series of daily temperature data: Case study of Limpopo Province, South Africa. *Climate* **2019**, *7*, 86. [CrossRef]
67. Mistry, M.N.; Schneider, R.; Masselot, P.; Royé, D.; Armstrong, B.; Kyselý, J. Comparison of weather station and climate reanalysis data for modelling temperature-related mortality. *Sci. Rep.* **2022**, *12*, 5178. [CrossRef]
68. Kisaka, M.O.; Mucheru-Muna, M.; Ngetich, F.K.; Mugwe, J.N.; Mugendi, D.; Mairura, F. Rainfall variability, drought characterization, and efficacy of rainfall data reconstruction: Case of Eastern Kenya. *Adv. Meteorol.* **2015**, *2015*, 380404. [CrossRef]
69. Vrsalović, A.; Andrić, I.; Bonacci, O.; Kovčić, O. Climate Variability and Trends in Imotski, Croatia: An Analysis of Temperature and Precipitation. *Atmosphere* **2023**, *14*, 861. [CrossRef]
70. Hare, W. Assessment of knowledge on impacts of climate change-contribution. *Arctic* **2003**, *100*, 2–106.
71. Silva, V.D.P.R. On climate variability in Northeast of Brazil. *J. Arid. Environ.* **2004**, *58*, 575–596. [CrossRef]
72. Olefs, M.; Koch, R.; Schöner, W.; Marke, T. Changes in snow depth, snow cover duration, and potential snowmaking conditions in Austria, 1961–2020—A model based approach. *Atmosphere* **2020**, *11*, 1330. [CrossRef]
73. Rehman, S.; Sajjad, H.; Masroor, M.; Rahaman, M.H.; Roshani Ahmed, R.; Sahana, M. Assessment of evidence-based climate variability in Bhagirathi sub-basin of India: A geostatistical analysis. *Acta Geophys.* **2022**, *70*, 445–463. [CrossRef]
74. Stewart, J.I. *Response Farming in Rainfed Agriculture*; Foundation for World Hunger: Davis, CA, USA, 1988.
75. Yu, P.S.; Yang, T.C.; Wu, C.K. Impact of climate change on water resources in southern Taiwan. *J. Hydrol.* **2002**, *260*, 161–175. [CrossRef]
76. Kendall, M.G. *Rank Correlation Methods*; Griffin: London, UK, 1948.
77. Matimolane, S.; Chikoore, H.; Mathivha, F.I.; Kori, E. Maize producers' vulnerability to climate change: Evidence from Makhuduthamaga Local Municipality, South Africa. *Jàmbá J. Disaster Risk Stud.* **2022**, *14*, 1–10. [CrossRef]
78. Kruger, A.C.; Shongwe, S. Temperature trends in South Africa: 1960–2003. *Int. J. Climatol. A J. R. Meteorol. Soc.* **2004**, *24*, 1929–1945. [CrossRef]
79. Mupangwa, W.; Chipindu, L.; Ncube, B.; Mkuhlani, S.; Nhantumbo, N.; Masvaya, E.; Ngwira, A.; Moeletsi, M.; Nyagumbo, I.; Liben, F. Temporal changes in minimum and maximum temperatures at selected locations of southern Africa. *Climate* **2023**, *11*, 84. [CrossRef]
80. van der Walt, A.J.; Fitchett, J.M. Exploring extreme warm temperature trends in South Africa: 1960–2016. *Theor. Appl. Climatol.* **2021**, *143*, 1341–1360. [CrossRef]
81. van Wilgen, N.J.; Goodall, V.; Holness, S.; Chown, S.L.; McGeoch, M.A. Rising temperatures and changing rainfall patterns in South Africa's national parks. *Int. J. Climatol.* **2016**, *36*, 706–721. [CrossRef]
82. Sa'adi, Z.; Shahid, S.; Ismail, T.; Chung, E.S.; Wang, X.J. Trends analysis of rainfall and rainfall extremes in Sarawak, Malaysia using modified Mann–Kendall test. *Meteorol. Atmos. Phys.* **2019**, *131*, 263–277. [CrossRef]
83. Rufino, M.C.; Dury, J.; Tittonell, P.; Van Wijk, M.T.; Herrero, M.; Zingore, S.; Mapfumo, P.; Giller, K.E. Competing use of organic resources, village-level interactions between farm types and climate variability in a communal area of NE Zimbabwe. *Agric. Syst.* **2011**, *104*, 175–190. [CrossRef]
84. Lamega, S.A.; Komainda, M.; Hoffmann, M.P.; Ayisi, K.K.; Odhiambo, J.J.O.; Isselstein, J. It depends on the rain: Smallholder farmers' perceptions on the seasonality of feed gaps and how it affects livestock in semi-arid and arid regions in Southern Africa. *Clim. Risk Manag.* **2021**, *34*, 100362. [CrossRef]
85. Anyamba, A.; Tucker, C.J.; Eastman, J.R. NDVI anomaly patterns over Africa during the 1997/98 ENSO warm event. *Int. J. Remote Sens.* **2001**, *22*, 1847–1860.
86. Davis, C.L.; Vincent, K. *Climate Risk and Vulnerability: A Handbook for Southern Africa*, 2nd ed.; CSIR: Pretoria, South Africa, 2017.
87. Hatfield, J.L.; Prueger, J.H. Temperature extremes: Effect on plant growth and development. *Weather Clim. Extrem.* **2015**, *10*, 4–10. [CrossRef]

88. Evans, J.; Geerken, R. Discrimination between climate and human-induced dryland degradation. *J. Arid. Environ.* **2004**, *57*, 535–554. [CrossRef]
89. Pachavo, G.; Murwira, A. Land-use and land tenure explain spatial and temporal patterns in terrestrial net primary productivity (NPP) in Southern Africa. *Geocarto Int.* **2014**, *29*, 671–687. [CrossRef]
90. Mbatha, K.R.; Ward, D. The effects of grazing, fire, nitrogen and water availability on nutritional quality of grass in semi-arid savanna, South Africa. *J. Arid. Environ.* **2010**, *74*, 1294–1301. [CrossRef]
91. De Leeuw, P.N.; Tothill, J.C. *The Concept of Rangeland Carrying Capacity in Sub-Saharan Africa: Myth or Reality*; Overseas Development Institute, Pastoral Development Network: London, UK, 1990.
92. Pickup, G.; Bastin, G.N.; Chewings, V.H. Remote-sensing-based condition assessment for nonequilibrium rangelands under large-scale commercial grazing. *Ecol. Appl.* **1994**, *4*, 497–517. [CrossRef]
93. Calvao, T.; Palmeirim, J.M. Mapping Mediterranean scrub with satellite imagery: Biomass estimation and spectral behaviour. *Int. J. Remote Sens.* **2004**, *25*, 3113–3126. [CrossRef]
94. Kurtz, D.B.; Schellberg, J.; Braun, M. Ground and satellite based assessment of rangeland management in sub-tropical Argentina. *Appl. Geogr.* **2010**, *30*, 210–220. [CrossRef]
95. Hatfield, J.L.; Boote, K.J.; Kimball, B.A.; Ziska, L.H.; Izaurralde, R.C.; Ort, D.; Thomson, A.M.; Wolfe, D. Climate impacts on agriculture: Implications for crop production. *Agron. J.* **2011**, *103*, 351–370. [CrossRef]
96. Schulze, R.E.; Taylor, M.A. Planted Pastures in South Africa and Climate Change: Kikuyu, Eragrostis curvula and Coastcross II. In *Handbook for Farmers, Officials and Other Stakeholders on Adaptation to Climate Change in the Agriculture Sector within South Africa. Section D: Natural Grasslands and Pastures in South Africa and Climate Change, Chapter D2*; Schulze, R.E., Ed.; Department of Agriculture, Forestry and Fisheries: Pretoria, South Africa, 2016.
97. Phillips, C. *Cattle Behaviour and Welfare*; John Wiley & Sons: Hoboken, NJ, USA, 2008.