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TENDÊNCIA DA PRECIPITAÇÃO PLUVIOMÉTRICA NA REGIÃO CENTRAL DE MOÇAMBIQUE

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1 RESUMO

As emissões de gases de efeito estufa têm contribuído com mudanças climáticas, ocasionando ocorrências de eventos extremos, influenciando a variabilidade do regime de chuvas nas regiões. Mudanças substanciais na precipitação trazem grandes consequências a países focados na agricultura familiar devido a sua dependência das precipitações para o alcance de altas produtividades. Desse modo, o objetivo do trabalho foi verificar a tendência da precipitação pluviométrica na região central de Moçambique. Os dados foram classificados com variabilidade moderada, com o coeficiente de variação 20 a 30, verificando-se tendência não significativa pelo teste de Mann Kendall. O índice de anomalia padronizada indicou a presença de secas em baixa porcentagem que variam de moderadamente seco (MS) a extremamente seco (ES) nas cidades de Chimoio, Beira e Tete. Já o comportamento quase normal (QN) foi maior com ocorrência em 69,23% dos dados. A cidade de Quelimane apresentou um comportamento diferente, com mais de 97,4% dos dados classificados como extremamente úmido (EU) e menos de 2,56% como quase normal (QN).

Palavras chaves: regimes de Chuvas, variabilidade de precipitação, secas.

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2 ABSTRACT

The emission of greenhouse gases has contributed to climate change, causing the occurrence of extreme events and influencing rainfall variability. Substantial changes in precipitation have

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major consequences for countries focused on family farming because of their dependence on rainfall to achieve high yields. Therefore, the objective of this work was to verify the rainfall trend in the central region of Mozambique. The data were classified as having moderate variability, with the coefficient of variation in the range of 20--30, with a nonsignificant trend according to the Mann–Kendall test. The standardized anomaly index indicated the presence of droughts in low percentages, ranging from moderately dry (MD) to extremely dry (ED) in the cities of Chimoio, Beira, and Tete. The behavior almost normal (AN) was observed in 69.23% of the data. The city of Quelimane behaved differently, with more than 97.4% of the data classified as extremely humid (EH) and less than 2.56% as almost normal (AN).

Keywords: rainfall regimes, precipitation variability, droughts.

3 INTRODUÇÃO

Greenhouse gas (GHG) emissions contribute to increased climate change and global warming. The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) noted that climate change is the main environmental challenge of the 21st century due to the occurrence of extreme weather events around the world, such as the increase in the global average temperature, the variability of the rainfall regime, the incidence of droughts and even the occurrence of cyclones (EICKEMEIER *et al* ., 2014; RODRIGUES, 2023; SUMILA; FERRAZ; DURIGON, 2023) . These changes are often caused by variations in the precipitation regime and directly affect agricultural activities (Silva *et al.* , 2022) .

Precipitation is crucial for the management of irrigated crops, as is the availability of water resources in the areas of interest, as it allows the classification of regions, offering data for the viability of activities such as hydroelectric energy production, planning of agricultural activities, and tourism, among other activities (MENEZES; FERNANDES, 2016; LOPES *et al.* , 2022; BRAIMAH *et al.* , 2022; SILVA *et al* ., 2022) .

In Mozambique, agriculture is the main basis of the economy, with relevance for family production, depending on the availability of rainfall throughout the phenomenological phases of the crops to achieve high productivity. In general, production systems are susceptible to the impacts of climate change, and research is needed to guide government policies in the decision-making process in the agricultural sector., baseadas em atualizações do zoneamento agroclimático (CASSAMO *et al.*, 2023; FERREIRA *et al.,* 2021; UELE; LYRA; OLIVEIRA JÚNIOR, 2017).

The central region al of Mozambique has been the epicenter of the effects of climate change, which estão associadas, mainly results from variability in volume da precipitation, alterações de temperature and sea level, bem como modificações quanto aos episódios de droughts andinundações, além de outras ocorrências como a observação de ciclones tropicais durante o ano todo.

Therefore, it is extremely important to develop studies that aim to demonstrate climate variability and trends over the years. For this purpose, statistical modeling is an essential tool since it is capable of revealing the relationships among variables through models that allow the visualization of predictions regarding changes in climate dynamics (BAIG *et al*., 2021).

The coefficient of variation and the standardized anomaly index are instruments for analyzing precipitation variability. High values of coefficients of variation represent regions prone to drought, whereas low values indicate flood risks (ALEMU;

BAWOKE, 2020; KANELLOPOULOU, 2002; KISAKA *et al* ., 2015) .

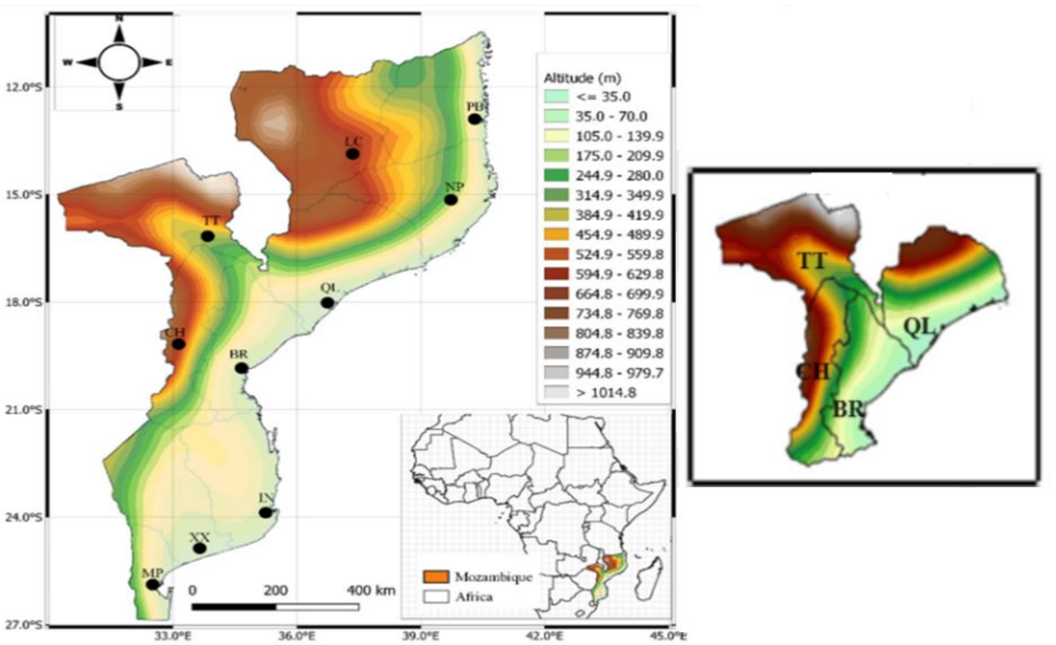
Em virtude das possíveis mudanças climáticas e da possibilidade de ocorrência de eventos extremos de precipitação, este artigo teve como aim de to analyze the spatial and temporal trends of rainfall in the central region of Mozambique via a historical series of data from 1982--2020.

4 MATERIALS AND METHODS

The research was carried out via a historical series (1982--2020) of precipitation data from cities located in the central region of Mozambique, where more than 90% of economic activities are based on agriculture.

Figure 1 shows the geographical location and topography of Mozambique (with a section of the area under study).

Figure 1. Topography and location of the study area (Central Mozambique) in Africa



Source: Sumila; Ferraz; Durigon (2023)

The colors on the graph represent topographic altitudes, which range from values less than 14 to greater than 1000 meters above sea level.

The region has four main cities: , a saber: Quelimane, Beira Chimoio and Tete (Tabela 1), which have favorable climates for agricultural production, with temperatures ranging from 10°C to 45.4°C, relative air humidity between 11 and 100% and average annual rainfall between 300 and 1800 mm, with the mais rainy season occurring between November and March. . The factors of latitude and the warm current that descends the Mozambique Channel are those that most influence the climate in this region (INE, 2021).

Table 1. Geographical location of cities located in the central region of Mozambique

City	Latitude (°)	Longitude (°)	Altitude (m)	Climatic Class
Quelimane	- 17°52'42"S	36°53'17"L	9	Aw
Beira	- 19°49'53.74"S	34°50'13.27"L	6	Aw
Tete	- 16° 7'58.12"S	33°36'22.99"L	150	BSh
Chimoio	- 19° 6'19.76"S	33°27'38.79"L	709	Cwa

Climatic Class – climate classification;*Aw* – clima tropical de savana (chuva no verão); *BSh* – clima seco, semiárido quente; *Cwa* – clima subtropical, invernos secos e verão quente;
Source: Authors (2023)

The data used were obtained from the *Langley Research Center* (https://power.larc.nasa.gov/data-acess-viewer) , que apresenta dados para variaveis meteorológicas and solar data. A 38-year historical precipitation series was used, covering the period from January 1, 1982, to December 31, 2020, from the cities of Quelimane, Tete, Beira and Chimoio. The data were grouped into 30-day periods.

Descriptive statistics were calculated to verify the distribution of the data over the years. The Mann–Kendall statistical test was used to determine the temporal trend, and the standardized anomaly index was used to measure the susceptibility to dry and rainy years (occurrence of drought severity) in a historical data series (FERNANDES *et al* ., 2022) .

4.1 Statistical analysis

The mean, median, standard deviation, standard error, maximum, minimum, coefficient of variation (CV) and 95% confidence level were calculated. To assess data variability, the CV was used, which was categorized as low ($CV < 20$), moderate ($20 < CV < 30$), high ($CV > 30$) or very high ($CV > 40$) (ASFAW *et al*., 2018; GETAHUN; LI; PUN, 2021).

4.2 Standardized Anomaly Index (SAI)

The standardized anomaly index (SAI) is an excellent instrument for determining the nature of trends and seasonality in the temporal and spatial distributions of precipitation (HARKA; JILO; BEHULU, 2021; MOHAMED; EL-AFANDI; EL-MAHDY, 2022; TAYE *et al.* , 2021) . The mathematical formula for calculating this index is presented in Equation (1):

$$Z = \frac{(x-\mu)}{\sigma} \quad (1)$$

where x = annual precipitation (mm/year), σ = standard deviation and μ = mean of the time series. Note: A negative IAP value indicates drought, whereas a positive value suggests humidity.

Table 2 presents the classification of the standardized anomaly index.

Table 2. IAP classification for the central region of Mozambique from 1982--2020.

Condition	**IAP (Z)**
Extremely Dry (ES)	Z < - 2
Severely Dry (SS)	-1,99 < Z < -1,5
Moderately Dry (MS)	-1,49 < Z < -1
Almost Normal (QN)	-0,99 < Z < 0,99
Moderately Humid (MODU)	1 < Z < 1,49
Very Wet (MMU)	1,5 < Z < 1,9
Extremely Humid (EU)	Z > 2

Source: Adapted from Rodrigues (2023)

4.3 Mann–Kendall test

The test statistic proposed by Kendall (Equation 2), according to Forthofer; Lehnen (1981) , is given by:

$$S=\sum_{i=n}^{n-1}\sum_{j=i+1}^{n}\operatorname{sign}\left(x_j-x_i\right) \quad (2)$$

where S is the test statistic S, n is the number of observed data points, x_i and x_j are the time series values i and j (j > i) and sign $\left(x_j-x_f\right)$ are calculated according to Equation 3:

$$\operatorname{sign}\left(x_j-x_i\right)=\begin{cases}+1, \text{ se } x_j-x_i>0\\ 0, \text{ se } x_j-x_i=0\\ -1, \text{ se } x_j-x_i<0\end{cases} \quad (3)$$

If there are a greater number of observations (n), the data tend to have a normal probability distribution (S), with a mean of zero and a variance (Var) calculated according to Equation (4):

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

where Tp is the number of data points with equal values in a certain group and eq is the number of groups containing equal values in the data series in a group p.

Note: The Mann–Kendall test statistic is based on the value of the ZMK variable, which is calculated according to Equation 5:

$$Z_{MK}=\begin{cases}\frac{S-1}{\sqrt{\operatorname{Var}(S)}}, \text{ se } S>0\\ 0, \text{ se } S=0\\ \frac{S+1}{\sqrt{\operatorname{Var}(S)}}, \text{ se } S<0\end{cases} \quad (5)$$

Positive values Z_{MK} indicate an increasing trend, whereas negative values indicate a decreasing trend. The hypothesis that there is no trend is rejected when the *p value* is below the significance level. The Mann–Kendall test was performed at the 5% significance level.

5 RESULTS AND DISCUSSION

5.1 Descriptive statistics, variability and trend of precipitation

In the analysis of data from the historical precipitation series (1982--2020), a higher incidence of rainfall was observed in Chimoio, followed by the city of Quelimane, accounting for 29.25% and 27.76%, respectively, of the total rainfall in the region studied. The cities of Beira and Tete accounted for 21.92% and 21.06%, respectively, of the total average annual rainfall. In the central region of Mozambique, the rainy season runs from November to April, and the dry season runs from May to October. The rainiest month is January, with 24.41% of the total average annual rainfall, followed by February and December, which constitute 19.21% and 18.56%, respectively, of the average annual rainfall. The driest month is August, which corresponds to only 0.67% of the total average annual rainfall. The cities of Chimoio, Quelimane, Beira and Tete presented average annual precipitation values of 1,106.61, 1,050.49, 829.55 and 796.96 mm/year, respectively (Table 3).

Table 3. Precipitation Data

Descriptive Statistics	**Chimoio**	**Tete**	**Quelimane**	**Beira**
	Precipitation (mm)			
Average	1,106.61	796.96	1,050.49	829.55
Standard error	46.53	35.94	39.52	32.65
Median	1,123.23	785.74	980.86	849.02
Standard deviation	290.56	224.46	246.79	203.94
CV (%)	26	28	23	24
Minimum	595.90	337.50	580.07	411.32
Maximum	1,850.97	1,302.54	1,829.88	1281.46
Confidence level (5%)	94.18	72.76	80.00	66.11

Source: Authors (2023)

For the data under analysis, the coefficient of variation was classified as moderate since the variability of the data was concentrated in the interval between 20 < CV < 30 (Table 3). The highest CV, equal to 28%, was obtained for the data from the city of Tete, whereas the lowest CV, equal to 23%, was observed in the data from the city of Quelimane.

5.2 Mann–Kendall test

For the nonparametric Mann–Kendall test, the following hypotheses were defined: H_0: there is no trend in the series; H_1: there is a positive trend in the series.

Table 4 presents the results obtained for the Mann–Kendall test regarding the trend analysis of the time series.

Table 4. Results obtained via the Mann–Kendall test with data from the annual precipitation series (1982--2020)

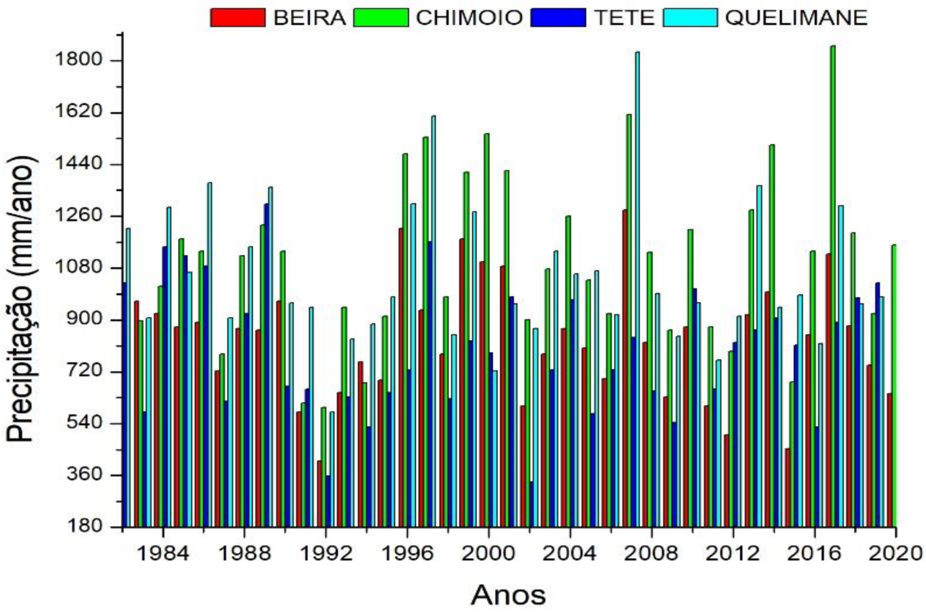
Cities	**Results**	
	s	p value
Beira	- 66	0.432
Chimoio	84	0.315
Tete	34	0.689
Quelimane	- 19	0.828

Source: Authors (2023)

To perform the Mann–Kendall test, a 95% confidence level was used, and Table 5 shows that the *p value* is greater than the alpha value (0.05) in all cities, that is, greater than the statistical significance level of 5%; therefore, there is not enough evidence to reject the H0 hypothesis of equality of means in the time series; therefore, the series studied did not present a significant trend (positive or negative).

The annual distribution of rainfall in the region during the period evaluated is presented in Figure 1.

Figure 1. Annual accumulated precipitation in the central region of Mozambique from 1982--2020



Source: Authors (2023)

Figure 1 shows that over the years, there was variability in the amount of rainfall in the cities of Chimoio, Tete, Quelimane and Beira. There was also variability in rainfall between the cities in the region under study, which may have been caused by topography or relief, as well as as a consequence of the orographic effect, or even by the movement of cold air masses coming from the Mozambique Channel or by the effect of continentality. The highest annual rainfall in the data series evaluated, equal to 1,850.97 mm/year, occurred in 2017 in the city of Chimoio. The lowest value, equal to 358.59 mm/year, observed in 1992, occurred in the city of Tete. In the cities of Beira and Quelimane, where the principle of maritime nature occurs, rainfall tended to be higher throughout the series because of high humidity.

Some researchers correlate the presence of lower and higher rainfall with the occurrence of El Niño and La Niña phenomena, which alter the position of the Intertropical Convergence Zone (LUCIANA *et al* ., 2017; ROCHA; SIMMONDS, 1997; SUMILA; FERRAZ; DURIGON, 2023 ; MACHAIEIE *et al.* 2020) identified the years 1982--1983, 1988--1989, 1991--1992, 1994--1995, 1999--2000 and 2015--2016 as the years in which El Niño and La Niña phenomena occurred in Quelimane. Figure 1 unequivocally shows a significant decrease in the rainfall regime in the central region of Mozambique, indicating that ENSO influenced the variability in accumulated annual precipitation in this region during this period, which is corroborated by the study by Alahacoon *et al.* (2021) , who reported the occurrence of El Niño and La Niña events.

5.3 Standardized Anomaly Index

The standardized anomaly index has been used in forecasting floods and droughts (ARYAL *et al.* , 2022; KOUDAHE *et al* ., 2017; NKIAKA; NAWAZ; LOVETT, 2017; WMO, 2011) . Table 5 shows the results of the standardized anomaly index for the cities under analysis from 1982--2020.

Table 5. Standardized anomaly index for the central region of Mozambique from 1982--2002

Year	Z Beira	Condition	Z Chimoio	Condition
1982	-0.085	QN	-0.033	QN
1983	0.664	QN	-0.723	QN
1984	0.457	QN	-0.306	QN
1985	0.225	QN	0.257	QN
1986	0.302	QN	0.112	QN
1987	-0.525	QN	-1.122	MS
1988	0.199	QN	0.057	QN
1989	0.173	QN	0.42	QN
1990	0.664	QN	0.112	QN
1991	-1.223	MS	-1.703	SS
1992	-2.051	ES	-1.758	SS
1993	-0.887	QN	-0.56	QN
1994	-0.37	QN	-1.467	MS
1995	-0.68	QN	-0.669	QN
1996	1.905	MMU	1,273	WAY
1997	0.509	QN	1,473	WAY
1998	-0.241	QN	-0.433	QN
1999	1,725	MMU	1,055	MMU
2000	1,337	WAY	1,509	WAY
2001	1,259	WAY	1,074	QN
2002	-1.12	MS	-0.705	QN

QN: near normal; MS: moderately dry; SS: severely dry; ES: extremely dry; MODU: moderately moist; MMU: very moist; EU: extremely moist,
Source: Authors (2023)

Table 6. Standardized anomaly index for the central region of Mozambique from 2003--2020

Year	Z Beira	Condition	Z Chimoio	Condition
2003	-0.241	QN	-0.106	QN
2004	0.199	QN	0.529	QN
2005	-0.137	QN	-0.233	QN
2006	-0.654	QN	-0.632	MMU
2007	2.216	EU	1.745	QN
2008	-0.034	QN	0.094	QN
2009	-0.965	QN	-0.832	QN
2010	0.225	QN	0.366	QN
2011	-1.12	MS	-0.796	MS
2012	-1.611	SS	-1.086	QN
2013	0.432	QN	0.602	MODU
2014	0.819	QN	1.382	MS
2015	-1.844	SS	-1.449	QN
2016	0.095	QN	0.112	EU
2017	1.466	MODU	2.562	QN
2018	0.251	QN	0.329	QN
2019	-0.422	QN	-0.632	QN
2020	-0.913	QN	0.184	MMU

QN: near normal; MS: moderately dry; SS: severely dry; ES: extremely dry; MODU: moderately moist; MMU: very moist; EU: extremely moist,
Source: Authors (2023)

Table 7. Standardized anomaly index for the central region of Mozambique from 1982--1986

Year	Z Tete	Condition	Z Quelimane	Condition
1982	1.0307	MODU	0.6794	QN
1983	-0.9662	QN	2.6753	I
1984	1.5945	MMU	5.2351	I
1985	1.4536	MODU	4.3162	I
1986	1.2891	MODU	5.5771	I

QN: near normal; MS: moderately dry; SS: severely dry; ES: extremely dry; MODU: moderately moist; MMU: very moist; EU: extremely moist,
Source: Authors (2023)

Table 8. Standardized anomaly index for the central region of Mozambique from 1987--2013

Year	Z Tete	Condition	Z Quelimane	Condition
1987	-0.8018	QN	3.6752	I
1988	0.5608	QN	4.6796	I
1989	2.2524	I	5.5130	I
1990	-0.5668	QN	3.8890	I
1991	-0.6138	QN	3.8249	I
1992	-1.9530	SS	2.3504	I
1993	-0.7313	QN	3.3762	I
1994	-1.2012	MS	3.5899	I
1995	-0.6608	QN	3.9744	I
1996	-0.3084	QN	5.2779	I
1997	1.6650	MMU	6.5172	I
1998	-0.7548	QN	3.4402	I
1999	0.1380	QN	5.1710	I
2000	-0.0500	QN	2.9274	I
2001	0.8193	QN	3.8676	I
2002	-2.0470	EN	3.5257	I
2003	-0.3084	QN	4.6155	I
2004	0.7723	QN	4.2949	I
2005	-0.9898	QN	4.3377	I
2006	-0.3084	QN	3.7180	I
2007	0.1850	QN	7.4147	I
2008	-0.6373	QN	4.0172	I
2009	-1.1307	MS	3.4188	I
2010	0.9368	QN	3.8890	I
2011	-0.6138	QN	3.0769	I
2012	0.1145	QN	3.6966	I
2013	0.3024	QN	5.5343	I

QN: near normal; MS: moderately dry; SS: severely dry; ES: extremely dry; MODU: moderately moist; MMU: very moist; EU: extremely moist,
Source: Authors (2023)

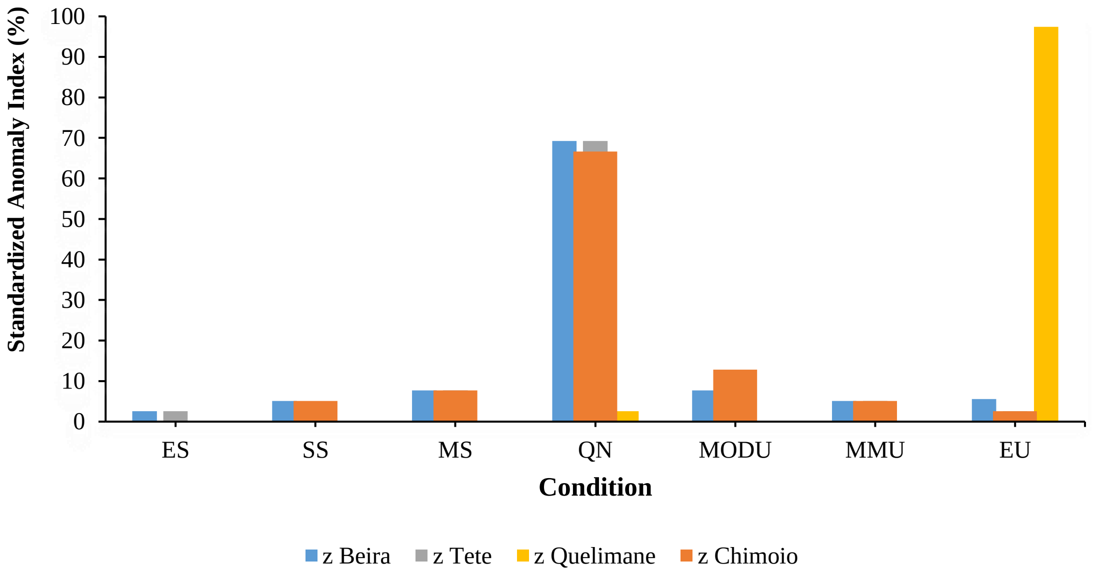
Table 9. Standardized anomaly index for the central region of Mozambique from 2014--2020

Year	Z Tete	Condition	Z Quelimane	Condition
2014	0.4904	QN	3.8248	I
2015	0.0675	QN	3.9958	I
2016	-1.2012	MS	3.312	I
2017	0.4199	QN	5.2565	I
2018	0.7958	QN	3.8675	I
2019	1.0307	MODU	3.9745	I
2020	-0.0735	QN	4.4231	I

QN: near normal; MS: moderately dry; SS: severely dry; ES: extremely dry; MODU: moderately moist; MMU: very moist; EU: extremely moist,
Source: Authors (2023)

Among the standardized anomaly indices of the city of Beira, 69.23% presented almost normal behavior (QN), followed by moderately dry (MS) and moderately humid (MODU) behaviors, each representing 7.69% of the data. The extremely dry (SS) and very humid (MMU) behaviors represented 5.13% of the data, whereas the extremely dry (ES) and extremely humid (EU) behaviors represented 2.56% of the data. In the city of Chimoio, 64.10% of the indices presented QN behavior, 12.82% MODU, 10.26% MS, 5.13% SS, 2.56% MMU and 2.56% EU (Table 5, Figure 2).

Figure 2. Standardized anomaly index percentages for the central region of Mozambique



QN: Near normal; MS: Moderately dry; SS: Severely dry; ES: Extremely dry; MODU: Moderately moist; MMU: Very moist; EU: Extremely moist.
Source: Authors (2023)

As shown in Figure 2, 69.23% of the indices of the city in Tete were classified as almost normal, 10.26% as moderately humid, 7.69% as moderately dry, 5.13% as very humid, 2.56% as severely dry, 2.56% as extremely humid and 2.56% as extremely dry. The city of Quelimane presented 97.4%

of the indices in the extremely humid classification and 2.56% as almost normal.

Droughts occurred in 6 (six) years: 1987, 1991, 1992, 1994, 2012 and 2015 in the city of Chimoio. The city of Beira also recorded the same number of droughts, which occurred in 1991, 1992, 2002, 2011, 2012 and 2015.

In the city of Tete, droughts occurred in the years 1992, 1994, 2002 and 2009. Moreover, the city of Quelimane did not record any drought periods in the years evaluated. The total drought recorded in the region was 13.90% (Table 4). Studies carried out in the central region of Mozambique confirm the presence of droughts in the aforementioned years (ARANEDA-CABRERA; BERMUDEZ; PUERTAS, 2021a; ARANEDA-CABRERA; BERMUDEZ; PUERTAS, 2021b; USMAN; REASON, 2004) .

The wettest years varied from city to city, with Quelimane being the wettest, presenting a humidity value greater than 2 in all years from 1983--2020 and a humidity less than 2 in 1982. Notably, the city of Beira had higher humidity in 1996, 1999 and 2007, while the city of Chimoio had high humidity in 1997, 2000 and 2017, and the city of Tete presented high humidity in 1984, 1989 and 1997 (Table 4).

Figure 2 visually presents the behavior pattern of the standardized anomaly index for the central region of Mozambique. During the period under study, three types of anomalies related to precipitation regimes were recorded in the cities of Beira, Tete and Chimoio: extremely dry, severely dry and moderately dry (Figure 2).

It is clear that Mozambique has experienced significant changes in precipitation patterns in recent years, which have resulted in several major floods, including those recorded in 1977, 1981, 1988, 1996, 2000, 2007/2008, 2013, 2019, 2022 and 2023. In addition, major cyclones have been reported to cause numerous destructions, although on a smaller scale (MILLER, 2002; INGC, 2009; MANANE; VAZ; VIVEROS, 2019; NDAPASSOA; MATOS, 2020; CARDOSO, 2023).

Uamusse, Tussopova and Persson (2020) reported a decreasing trend in Mozambique's annual precipitation regime, with an average decrease of 2.5 mm per month (3.1% per decade) between 1960 and 2006.

To address recurring droughts, in 2013, the Ministry of Agriculture launched a national irrigation strategy that aims to increase agricultural productivity and production with the goal of ensuring food security and sustainable management of water resources (MICOA, 2005; Ministry of Agriculture, 2013) .

6 CONCLUSION

There was no significant variability in the data, and the standardized anomaly index was predominantly found to be almost normal, which was observed in the cities of Beira, Chimoio and Tete, whose participation values varied between 66.6% and 69.23%; in contrast, the city of Quelimane presented predominantly extremely humid behavior, with 97.4% participation. Droughts were a recurring phenomenon in all cities except Quelimane, with anomalies that varied from extremely dry to moderately dry, with participation values equal to 2.56% and 7.69%, respectively. The years that presented drought patterns were 1991, 1992, 2002, 2011, 2012 and 2015 in the cities of Beira, Chimoio and Tete, respectively.

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