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Original Article

Assessing the Impacts of Climate Change on Human Health: A Study of the Climate-Health Nexus in Nampula City, Mozambique

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Abstract

Background: Variations in temperature and precipitation can cause an increase in vector-borne and water-borne diseases. Situated in a vulnerable geographic area, Mozambique is particularly susceptible to such climate-related incidents, leading to floods and the spread of diseases. In this study, we investigated the changes in temperature and precipitation patterns and their impact on the occurrence of vector-borne and water-borne diseases in Nampula, Mozambique.

Methods: We used both intra-annual and inter-annual analysis techniques to identify monthly and yearly trends. Linear regression and ANOVA models were applied to assess the relationship between temperature, precipitation, and the selected vector and water-borne diseases (malaria, diarrhea, and dysentery).

Results: The analysis of temperature and precipitation data from 2000 to 2019 revealed an overall positive trend and delayed onset and earlier end of the rainy season, implying changes in the timing and duration of rainfall. The analysis of temperature data over the last 10 years revealed an increase in mean minimum temperature. These findings suggest a changing climate pattern characterized by consistent warming trends. Statistically significant results were obtained for the mean minimum temperature from 2010 to 2019 and the mean precipitation from 2000 to 2009 in relation to diarrhea and dysentery, respectively ($P<0.05$; $r=0.70$ and 0.64).

Conclusion: This study demonstrates a positive correlation between climate variables and malaria, diarrhea, and dysentery.

Keywords: Temperature, Precipitation, Vector-Borne, Water-Borne, Diseases

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Introduction

Recent global natural events indicate an increase in the frequency and intensity of extreme weather conditions, which can be attributed to factors such as human activities and fossil fuel consumption.[1] The Intergovernmental Panel on Climate Change (IPCC)[2] reports that the global average temperature has risen by 1.5-5.8 °C in the 21st century, leading to more frequent and severe weather events. The World Health Organization (WHO)[3] has recognized the link between climate change and extreme floods and precipitation, as well as the potential risks to human health due to temperature fluctuations.[4]

Climate variability and changes directly affect human health and well-being.[4-6] These changes manifest as extreme weather events such as floods and droughts, increasing the risk of infectious and vector-borne diseases.[6] Variations in temperature and precipitation contribute to the spread of vector-borne diseases like malaria and water-borne diseases such as diarrhea and dysentery.[7,8] Short-term weather changes, including temperature increases and rainfall patterns, have no correlation with the incidence of multiple diseases, as observed in Singapore.[9] The instability of weather conditions can result in an upsurge of infectious diseases like cholera, which are triggered by higher temperatures and floods.[4,10] Furthermore, the prevalence of these diseases often correlates with wet and dry seasons.

Previous studies have emphasized the vulnerability of African countries to climate-related diseases.[11] Developing nations with inadequate sanitation systems are particularly susceptible to the consequences of climate events.[12] Therefore, it is imperative to do research on assessing the impact of climate change on affected populations, especially in some regions such as Mozambique. Mozambique has experienced numerous climate events, including tropical cyclones leading to floods and the spread of vector and water-borne diseases. For instance, cyclone 'Idai' on March 14th, 2019, caused intense rainfall and flooding in central Mozambique, increasing diarrheal diseases and cholera.[13] Similarly, on March 11th, 2023, the coastal province of Zambezia was struck by tropical cyclone 'Freddy', causing significant disruption to essential services.[14] Preceding studies have already established a correlation between climate change and the prevalence of vector-borne and water-borne diseases in Mozambique.[15-18] The IPCC[2] indicates that climate change may contribute to the rise of malaria epidemics, particularly in East Africa's highland regions. Given the aforementioned context and the geographical location of our study area, the present study aims to achieve the following objectives: (1) to assess the changes in temperature and precipitation patterns; (2) to summarize the incidence of clinical illnesses; (3) to investigate the connection between the variability of these two weather elements (temperature and precipitation) and the occurrence of malaria, diarrhea, and dysentery in Nampula city. By examining the climate-health nexus in this region, we aim to provide valuable insights into the impacts of climate change on human health.

Materials and Methods

Study Area

Mozambique is situated in the southeastern region of Africa between 18˚15'S and 35˚00'E, with the Indian Ocean to its east. Its borders are with Tanzania in the north, Malawi in the northwest, Zambia and Zimbabwe in the west, and Eswatini and South Africa in the south. It has a total land area of 823 588.75 km^2 and a coastline of 2470 km. Mozambique exhibits diverse latitudinal extents and landforms, resulting in a range of tropical to subtropical climates. Within this context, the city of Nampula, located in the northern province of the same name, is mostly surrounded by hills and mountains with an elevation of 360 m. Nampula is the third most populous city in the country, with 663 212 inhabitants according to the latest population census,[19] accounting for 20.6% of the total population. Figure 1 represents the geographical location of the study area in Mozambique.

Weather Data

The weather data for this research was supplied by the Nampula branch of the National Institute of Meteorology in Mozambique.[20] The averages of dry air temperature, maximum and minimum temperature, and precipitation were collected from the weather station near the Nampula International Airport at 15°06'00''S, 39°16'60''E. The data was initially given in a monthly format covering the period from 2000 to 2019, and then analyzed through two different approaches: intra-annual and inter-annual analysis.

Health Data

This research utilized health data obtained from the Mozambican Ministry of Health[21] through the District Directorate of Nampula City and primarily focused on vector and water-borne diseases, namely malaria, diarrhea, and dysentery. These diseases were selected for analysis due to their high prevalence in the country and their known association with temperature and precipitation.[16,17,22] The data used in this study was initially reported in the weekly epidemiological bulletin, subsequently compiled into

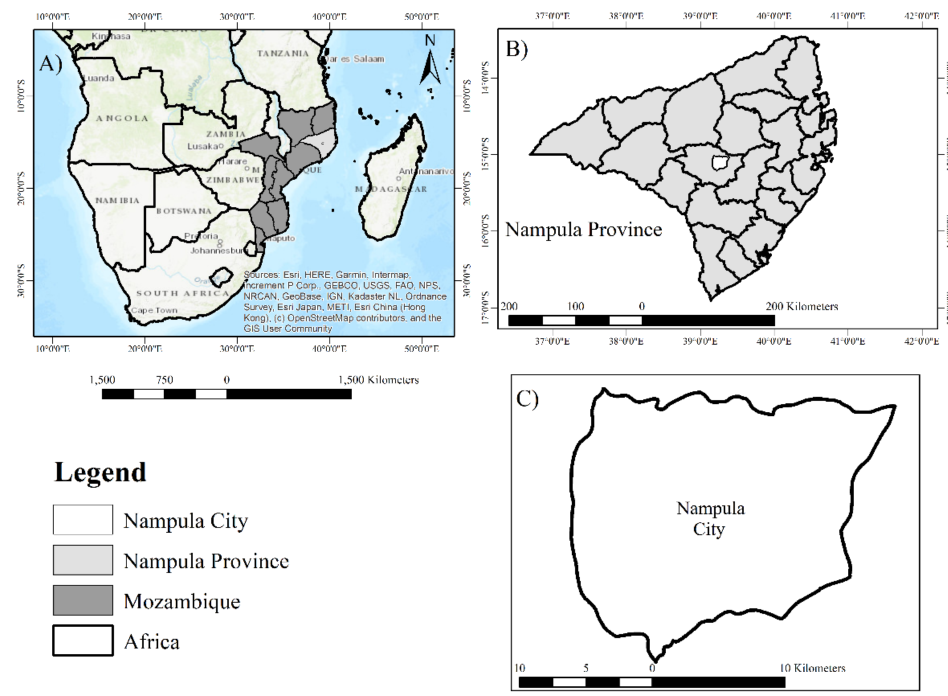

Figure 1. Geographical Location of the Study Area; A: the location of Mozambique in the continent of Africa, B: the Nampula Province including all its districts, C: the city of Nampula.

monthly and annual reports.

Statistical Methods

In this study, we utilized both intra and inter-annual analyses to investigate changes in temperature and precipitation patterns. According to the study by Gasparrini and Armstrong,[23] time series data exhibits a unique temporal structure, with observations collected at regularly spaced time points. For the intra-annual evaluation of temperature and precipitation, we employed a seasonal decomposition technique to identify monthly trends and seasonal patterns within the study period. On the other hand, the inter-annual analysis focused on examining the data across multiple years. To accomplish this, trend analysis was employed. Trend analysis look at changes in data over a period of time in order to identify patterns and determine the direction of movement, and uncertainties during various points in time.[24] This approach helped identify temporal dynamics of temperature and precipitation patterns, including monthly trends and seasonal patterns within the study period.

Regression models were specifically used to assess the impact of temperature and precipitation on the occurrence of the selected vector and water-borne diseases. Moreover, we calculated the correlation coefficient (*r*), *P* value, mean, and slope to assess the correlation between weather and health data. The correlation coefficient measures the strength and direction of the linear relationship between the two variables, while the p-value indicates the statistical significance of the correlation.[25,26] By incorporating these analyses, we were able to determine the influence of weather on the incidence of vector and water-borne diseases within our study area.

Results and Discussion

Mozambique has a hot and wet summer from November to April or October to March and a cooler dry period from May to September or October.[27] Analysis of the mean temperature and precipitation data revealed specific periods within the year that corresponded to different climatic conditions. The period from October to March was identified as the hottest season (referred to as the 'Hot season'), while the period from April to September was designated as the cooler season (the 'Cool season'). Furthermore, the rainy season occurred from November to April (the 'Wet season'), while the dry season spanned from May to October (the 'Dry season'). These results suggest a delayed start and an earlier end of the rainy season, as initially reported by a study.[22] Figure 2 provides a detailed diagram illustrating the climate patterns and corresponding data.

The mean temperature in July 2000 and December 2017 was between 20.3 °C to 31.6 °C. The average temperature over this period was 25.2 °C, with a standard deviation of 0.4 °C. Notably, the highest mean temperatures were observed in November (40%), followed by December (45%), January (10%), and February (5%). The lowest mean temperatures were recorded in June (25%) and July (75%). In terms of rainfall, the years 2000-2003, 2007, 2009-2012, and 2015-2017 exhibited notably low levels, registering values consistently below 1 millimeter (mm) during September. In contrast, the highest recorded rainfall of 826.6 mm occurred in January 2003. The annual evaluation of rainfall indicated an average of 101.4 mm, with a standard deviation of 17.9 mm. In the intra-annual evaluation, January demonstrated the highest monthly mean precipitation (65%), followed by February (20%), March (5%), and December (10%). Conversely, the lowest average precipitation was observed in June, July, and October (each 5%), May (10%), August (20%), and September (55%). For the inter-annual evaluation, the standard deviation for the maximum and minimum precipitation values was determined as 137.2 mm and 1.4 mm, respectively. We identified patterns corresponding to hot and cool seasons, as well as wet and dry seasons through analyzing the frequency of mean temperature and precipitation.

Annual Aggregate Disease Cases, 2000-2019

An examination of long-term changes in yearly disease incidence showed some patterns. The highest number of malaria cases was recorded in 2018, while the peak incidences of diarrhea and dysentery occurred in 2015. The lowest values of the three diseases were found in 2009, 2005, and 2011, respectively. Over the 2000-2019, there was a general increase in reported cases of malaria, diarrhea, and dysentery. When analyzing the data in two distinct decades, it was noted that the first decade displayed a downward trend in dysentery and malaria cases, while the second decade experienced an upward trend. In contrast, diarrhea demonstrated a consistent growth pattern across both decades.

Despite the decline in dysentery and malaria cases during the first decade, the magnitude of this decrease did not significantly alter the overall trend. Regardless of the overall positive trend, year-by-year comparisons of the health data revealed some fluctuations. Table 1 provides a more detailed representation and understanding of the observed trends and changes in disease incidence.

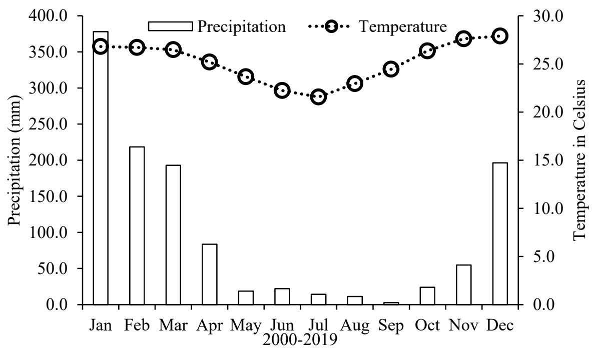

Figure 2. Intra-annual Evaluation of the Mean Monthly Records of Temperature and Precipitation.

Temperature and Precipitation Data Analysis, 2000-2019

The time series analysis revealed a clear upward trend in mean temperature over time. Similarly, when evaluating the hot and cold seasons, we observed a noticeable trend, albeit relatively minor, in the cold season. Detailed information and graphical representation is found in Figure 3 a-d. Figure 3a provides insights into the impact of the hot season on the mean temperature values. Additionally, we conducted similar analyses for mean precipitation (Figure 3b) as well as mean minimum and maximum temperatures (Figure 3c and 3d, respectively).

To ensure consistency in our analysis, we divided the climate data into two decades. The analysis of the decadal and seasonal evaluation of temperature and precipitation data indicated a predominantly positive trend observed during the period from 2000 to 2019. When considering separate time intervals, distinct patterns emerged. During the 2000-2009 period, there was an increasing trend in the mean temperature and precipitation, particularly in Season I. However, in Season II, a decrease in the mean temperature was observed. From 2010 to 2019, a contrasting pattern emerged. The mean maximum temperature showed a decrease across both seasons. In contrast, the mean minimum temperature and mean precipitation displayed an increasing trend during the same period, spanning both Season I and Season II. Table 2 provides a detailed representation of the results.

The analysis of temperature and precipitation data over 10 years revealed an increase in mean minimum temperature. These findings suggest a changing climate pattern characterized by overall warming trends.

Evaluation of the Relationship Between the Weather and Health Data

When comparing the decadal data of temperature and precipitation with the health data, statistically significant results were obtained for the mean minimum temperature from 2010 to 2019 and mean precipitation from 2000 to 2009 in relation to diarrhea and dysentery, respectively, with a P value less than 0.05. Although the remaining pairs did not display a P value less than 0.05, there was still a positive correlation. It was found that in 2019, the wet and hot season was associated with higher levels of malaria, diarrhea, and dysentery. Additional studies such as those conducted by Bandyopadhyay et al[28] and Alexander and Blackburn[29] have also reported that both the dry and wet seasons can be linked to disease peaks. A comprehensive overview of the information has been provided in Table 3. The results of our analysis demonstrated a positive correlation between the climate variables and the disease. Taking into account an incubation period of two weeks or more following the precipitation events, it is plausible to consider the occurrence of diarrhea cases. In line with previous studies by Tornheim et al,[30] an increase in diarrheal cases was observed one to two months following substantial rainfall. A recent example of this is the tropical cyclone named ‘Freddy’.[14] The results suggest a complex

Table 1. Health data of the study over 2000-2019

	Malaria	Diarrhea	Dysentery
Mean	285468	22464	557
SD	127888	7610	547
Total	5709352	449281	11137
Maximum	488975	36024	2504
Year	2018	2015	2015
Minimum	122874	11880	127
Year	2009	2005	2011

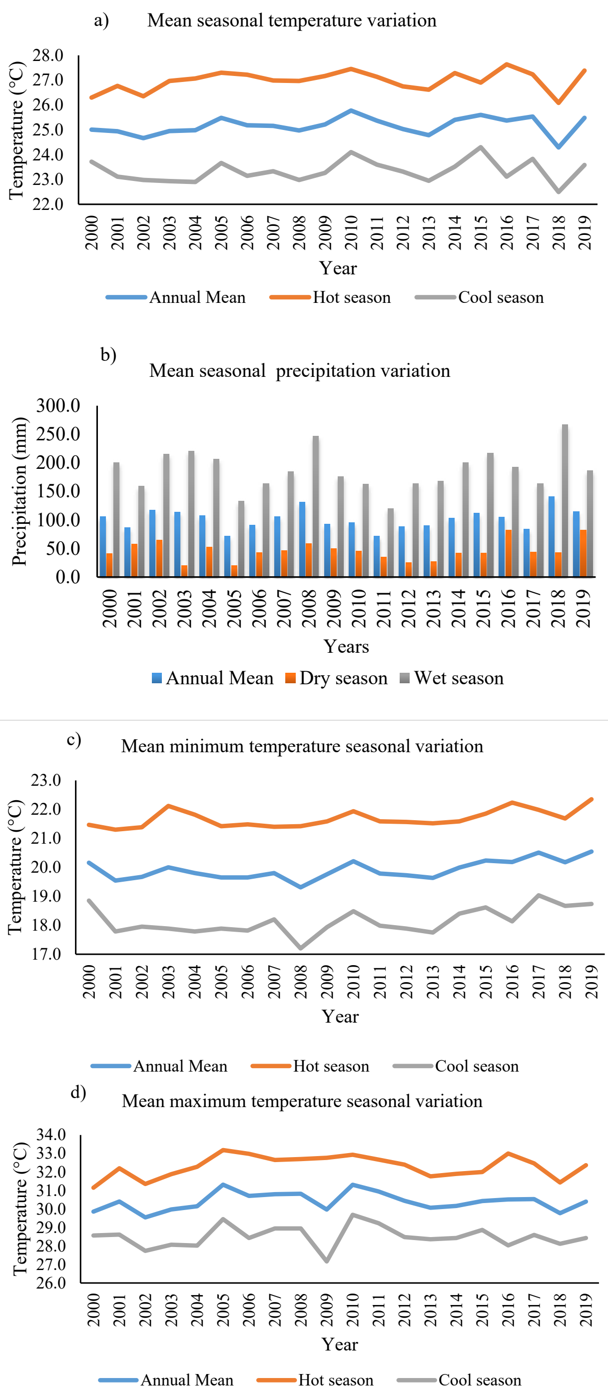

Figure 3a-d. Time Series Analysis of Temperature and Precipitation Data

Table 2. Seasonal evaluation of the weather data (Season-I = hot and wet seasons; Season-II = cool and dry seasons)

Decades	Temperature						Precipitation	
	Mean (ºC)	Slop	Mean Max (ºC)	Slop	Mean Min (ºC)	Slop	Mean (mm)	Slop
2000-2019	25.2	0.015	30.4	0.012	19.9	0.031	101.4	0.397
Season-I	27.0	0.018	32.3	0.001	21.7	0.028	187.4	0.491
Season-II	23.3	0.013	28.5	0.001	18.1	0.035	15.5	0.302
2000-2009	25.1	0.034	30.4	0.082	19.7	-0.034	102.4	0.179
Season-I	27.0	0.080	32.3	0.174	21.5	0.002	190.7	-0.013
Season-II	23.2	-0.011	28.4	-0.01	17.9	0.067	14.0	0.371
2010-2019	25.3	-0.034	30.5	-0.086	20.1	0.07	100.5	4.178
Season-I	27.0	-0.017	32.3	-0.058	21.8	0.054	184.0	8.059
Season-II	23.5	-0.051	28.6	-0.115	18.4	0.085	16.9	0.297

Table 3. Correlation Between Weather and Health Data

Weather Data	Decades	*r*			*P* Value		
		Malaria	Diarrhea	Dysentery	Malaria	Diarrhea	Dysentery
Mean temperature	2000-2009	0.36	0.17	0.32	0.30	0.64	0.37
	2010-2019	0.54	0.24	0.24	0.11	0.50	0.51
Mean Max Temperature	2000-2009	0.22	0.12	0.51	0.54	0.75	0.13
	2010-2019	0.19	0.14	0.16	0.60	0.71	0.65
Mean Min temperature	2000-2009	0.11	0.18	0.38	0.77	0.61	0.27
	2010-2019	0.02	0.70	0.04	0.96	0.02	0.90
Mean precipitation	2000-2009	0.09	0.40	0.64	0.81	0.25	0.04
	2010-2019	0.14	0.47	0.16	0.70	0.17	0.65

relationship between climate factors and disease incidence, with potential temporal delays in the manifestation of certain health outcomes.

Conclusion

Mozambique urgently needs to address the health implications of climate change, as climate-related diseases pose a significant threat to public health. Informed forecasts of these diseases can help identify priorities and allocate resources effectively. Understanding the relationship between climate change and diseases enables evidence-based decision-making and proactive tactics to manage outbreaks. City-level understanding is crucial for targeted interventions, considering regional variations in climate patterns and disease burdens. Collecting and analyzing data on disease prevalence, climate patterns, and environmental factors can improve evidence-based policymaking and overall healthcare system preparedness. The analysis of temperature and precipitation data from 2000 to 2019 in Nampula city, revealed shifts in seasonal patterns, indicating potential climate change effects. Rising mean minimum temperature and precipitation further suggested climate change impacts. Positive correlations were found between temperature, precipitation, and disease incidence, emphasizing the influence of climate variables on disease incidence. These findings show the need for comprehensive strategies to mitigate climate change's adverse health effects, particularly in vulnerable regions like Mozambique. The study contributes to the growing body of evidence on climate change's influence on diseases, calling for further research to enhance preparedness and response measures in the face of changing climatic conditions.

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Author Contribution

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Data curation: Augusto Vundo, Estrela Muchiguere, Almaz Akhmetov..
Formal analysis: Augusto Vundo, Estrela Muchiguere, Almaz Akhmetov.
Funding acquisition: Augusto Vundo, Estrela Muchiguere, Almaz Akhmetov.
Investigation: Augusto Vundo, Estrela Muchiguere, Almaz Akhmetov.
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Writing–review & editing: Augusto Vundo, Estrela Muchiguere, Almaz Akhmetov.

Competing Interests

The authors report no actual or potential conflicts of interest.

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