Assessing the spatio-temporal distribution of extreme heat events in Mozambique using the CHIRTS temperature dataset for 1983-2016

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Summary

The frequency, duration, and intensity of extreme heat events are increasing worldwide, posing a significant threat to public health. However, these events have been largely under-reported and understudied across the African continent. Consequently, the nature of extreme heat hazards and the impacts of such events across Africa remain largely unknown. This research aims to address this research gap by characterising extreme heat events and their trends for Mozambique using the high-resolution remotely sensed CHIRTS-daily temperature data for 1983-2016. The results can be used for heat impact assessments and development of heat early warning system for Mozambique and other data-scarce regions.

KEYWORDS: heatwaves; excess heat factor; CHIRTS-daily; Mozambique; early warning system

1. Introduction

1.1. Background

As global mean temperatures continue to rise due to climate change, extreme heat events are increasingly being observed worldwide (Coughlan de Perez et al., 2018). Various studies have shown that the frequency, duration, and intensity of heatwaves are increasing, and are projected to increase in the future (Perkins et al. 2012). Extreme heat events impact many areas of society and pose a serious threat to human health and well-being, observed through excess mortality and morbidity rates (Watts et al. 2021).

1.2. Research gap

To date much of the research on extreme heat has been focused on mid-latitude and high-income countries, and most predominantly lacking across Africa (Campbell et al. 2018). Several recent studies provided evidence for heatwaves across Africa and highlight the urgent need for assessing heatwave risks and impacts (Harrington and Otto 2020; van der Walt and Fitchett 2021; Scott et al. 2017; Pasquini et al. 2020). Furthermore, as extreme heat events are largely under-reported and understudied in Africa, the impacts are simply unknown. Recent developments in remote sensing technology and methods can advance such research, including the development of the CHIRTS-daily product which presents a high-

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resolution global temperature dataset which will be routinely updated in real time (Verdin et al. 2020). This study aims at filling the gap in understanding heat waves in Mozambique, a data-scarce country highly vulnerable to climate hazards (USAID 2017).

The objectives of this study are to examine (i) the spatio-temporal characteristics of extreme heat events in Mozambique with regards to heatwave number, frequency, duration, magnitude, and amplitude, and (ii) the trends with regards to each heatwave characteristic.

2. Methods and data

The CHIRTS-daily is a global remotely sensed high-resolution (5 km) daily temperature dataset developed by the Climate Hazards Center (CHC), currently available for 1983-2016 (see Verdin et al. (2020) for details on the development and validation of the dataset). This data is the first of its kind and has proved highly accurate for measuring extreme temperatures, also for data-scarce regions (Reda et al. 2021; Tuholske et al. 2021).

In order to move towards a general framework to measure heatwaves, the WMO's ET-SCI has adopted three heatwave definitions due to their advantages compared to other definitions (based off Perkins and Alexander, 2013). Using internationally agreed indices to measure extreme weather events is important to quantitatively compare heatwaves events and trends across regions. For the purpose of this study, the third definition of the Excess Heat Factor (EHF) was used which classifies heatwaves when excess heat conditions are experienced for at least three consecutive days, using both maximum and minimum temperatures. This definition considers both heatwave intensity (based on the 90th percentile calculated per grid cell), as well as acclimatization to heat (for details on the calculation, see Alexander and Herold 2016). This definition is appealing from a climatological perspective and has shown to be a useful indicator of impacts on human health (Nairn et al. 2018).

Five heatwave characteristics were calculated for each heatwave season (November – March), including heatwave number, frequency, duration, magnitude, and amplitude for the period of 1983-2016 (**Table 1**). The climatologies were obtained by averaging the characteristics per grid cell. Furthermore, annual trends were calculated using the non-parametric Mann Kendall test and Sen's slope estimator with significance computed at the 5% level (Perkins and Alexander 2013). Lastly, summaries for the four cities across Mozambique (Maputo City, Beira, Nampula, and Tete) were calculated by taking the average of the grid cells overlapping the administrative boundaries of each city. These were chosen based on their large population size as well as geographic locations, to compare heatwaves across the varying climates in Mozambique. Calculations were done using Climpact, R Software, and visualized using ArcGIS Software.

Table 1 Heatwave characteristics (Perkins and Alexander, 2013)

Index (short)	**Index (long)**	**Description**	**Units**
HWN	Number of heatwaves	The number of individual heatwaves per year	Number of events
HWF	Heatwave frequency	Total number of days that contribute to heatwaves per year	Days
HWD	Heatwave duration	Length of the longest yearly heatwave	Days
HWM	Heatwave magnitude	Average temperature across all heatwaves identified by HWN *(for EHF definition: average excess heat felt across all heatwave events)*	°C *(°C^2 for EHF definition)*
HWA	Heatwave amplitude	Hottest day of the hottest yearly heatwave *(for EHF definition: excess heat felt on the hottest day of the hottest yearly heatwave)*	°C *(°C^2 for EHF definition)*

3. Results

Heatwaves varied across the country. Since 1983, 1-3 annual heatwaves have been recorded (HWN), with a higher number of heatwaves occurring in the North and along the coast (**Figure 1a**). More days on average contributed to heatwave events (HWF) in the North compared to the South (18.5 vs 4.8 days) (**Figure 1b**). Furthermore, the longest heatwaves (HWD) were observed in the North and alongside the coastline, compared to the South (12 vs 4 days, **Figure 1c**). In contrast, the average excess heat felt across heatwave events (HWM) was highest in the South and Central Mozambique compared to the North (5 vs 0.3 $°C^2$), as well as for the average peak excess heat felt during the hottest heatwave (HWA) (0.8 vs 11.7 $°C^2$) (**Figure 1d,e**).

The trends for HWN, HWF show significant increases across most part of the country, with increases up to 0.17 heatwaves year^{-1} (HWN), 1 number of days contributing to heatwaves year^{-1} (HWF), and 0.8 days year^{-1} for the duration of the longest heatwave (HWD). The trends for HWM and HWA are not significant for the time period analyzed in this study (**Figure 4i,j**).

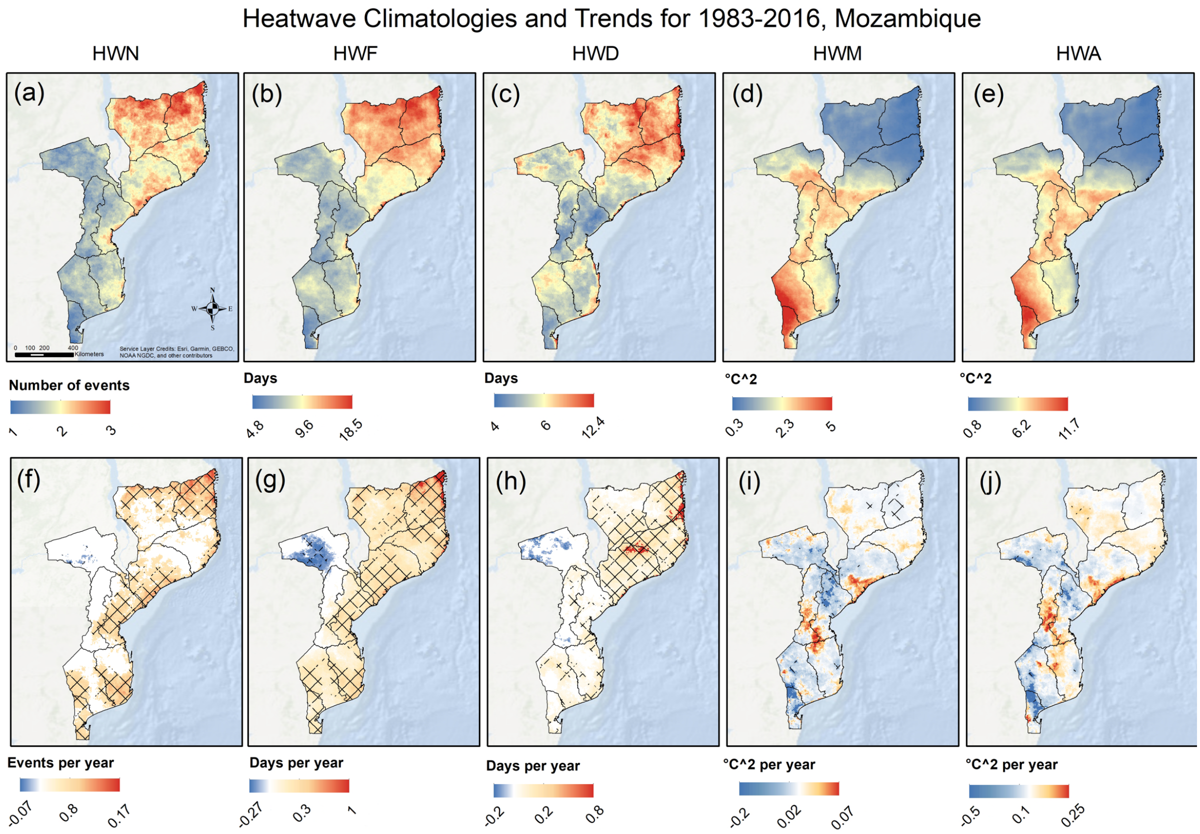

Figure 1 Climatologies and trends for Mozambique 1983-2016. The climatologies are shown using the EHF definition for (a) HWN, (b) HWF, (c) HWD, (d) HWM and (e) HWA, and respectively; (f)-(i) the corresponding trends (hatching indicates trends that are statistically significant at the 5% level)

Since 1983, all cities have experienced more than 50 heatwaves (**Table 2**). Tete has the highest 90th percentile values, meaning its heatwaves are based on higher absolute temperatures. Years with a high number of heatwave events include the summer of 1997/1998 for Nampula, 2006/2007 for Maputo City, and 2015/2016 for all cities (**Figure 2**). The average number of days contributing to heatwaves was highest in Nampula (10.6 days year^{-1}) as well as the length of the longest heatwave (5.45 days year^{-1}). Yet, Tete contained the highest maximum values for those characteristics (50.9 and 16 days year^{-1} respectively). For the HWM and HWA, highest average values were observed in Tete (7.2 °C^{2} year^{-1}).

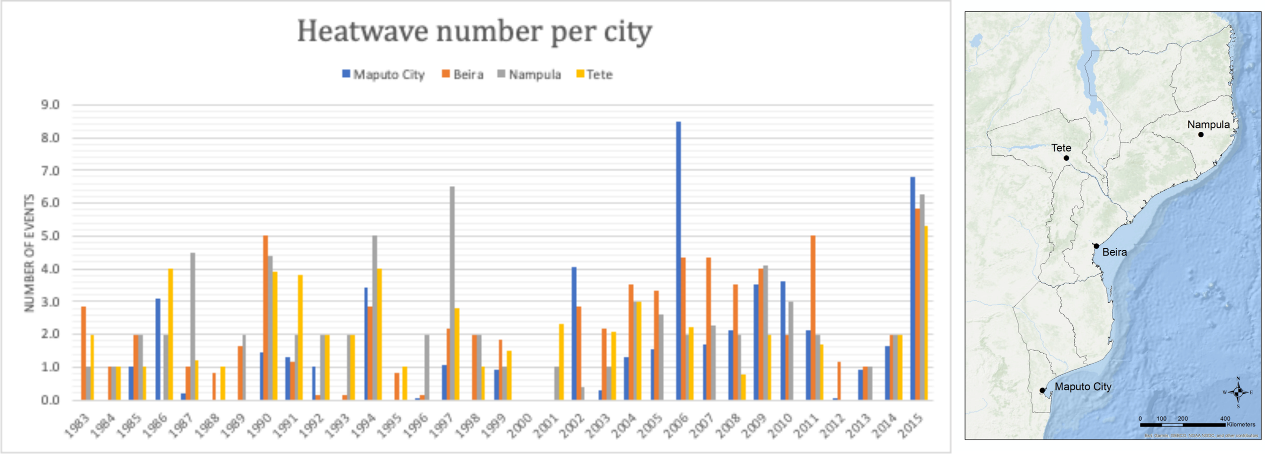

Figure 2 Annual heatwave events for different cities in Mozambique for 1983-2016 (left) and map with the locations (right)

Table 2 Summary of heatwave characteristics for different cities in Mozambique for 1983-2016

City*	**90th percentile (°C)[1]**		**Number of heatwave events (HWN)**	**Number of days contributing to heatwave events (HWF)**	**Length of longest heatwave event (HWD)**	**Average excess heat felt across all heatwave events (HWM)**	**Excess heat felt during hottest day of hottest yearly heatwave (HWA)**
	Tmax	*Tmin*	*Total (events) (min-max)*	*Average (days year^{-1}) (min-max)*	*Average (days) (min-max)*	*Average (°C^{2} year^{-1}) (min-max)*	*Average (°C^{2} year^{-1}) (min-max)*
Maputo	35	27.5	51.8 (0-**8.5**)	7.7 (0-39.2)	5.4 (3-10.6)	2.3 (0.15-5.7)	6.3 (0.3-14.7)
Beira	35.7	26.9	70.7 (0-5.8)	8.6 (0-28)	4.6 (3-10.33)	2.2 (0.4-5)	6.4 (0.9-**21.6**)
Nampula	34.4	24.7	**72** (0-6.5)	**10.6** (0-47.8)	**6.1** (3-14)	0.7 (0.06-1.8)	1.9 (0.1-5.8)
Tete	**39.4***	**28.8**	53.6 (0-5.3)	7.6 (0-**50.9**)	5.2 (3-**16**)	**3** (0.8-**8.7**)	**7.2** (2.1-17.3)

[1] The 90th percentile was calculated by taking the average of the calculated 90th percentile over each calendar day, over the extended austral summer period (November – March)

* Numbers in **bold** indicate the highest value across the cities

4. Conclusion

The findings from this study clearly highlight the variations in heatwaves characteristics and show significant increases across a large part of the country for the number, frequency, and duration of heatwave events using the CHIRTS-daily dataset. At present, this study is the first to assess historical heatwave events and their spatio-temporal characteristics for Mozambique. Combining the outputs presented here with impact data such as mortality rates can provide evidence for the magnitude of the impact and inform temperature thresholds for early warning systems. Future research will examine intra-urban variabilities of heat, such that strategies can be developed at a city level to reduce heat risk. The data and methodology used in this study can be applied to other data-scarce countries, where research on extreme heat is highly needed.

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Biographies

Carolina Pereira Marghidan is a graduate student at the Faculty of Geo-Information Science and Earth Observation, University of Twente, the Netherlands. She has a large interest in global, interdisciplinary issues related to climate adaptation, disaster risk management, and urban development, and hopes to address these using spatial analysis and GIS.

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