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| **Study title** | Impact of Cyclones and Extreme Weather on Vaccine Coverage in Mozambique |
| **Country** | Mozambique: Cabo Delgado Province, Gaza Province, Inhambane Province, Manica Province, Maputo City, Maputo Province, Nampula Province, Niassa Province, Sofala Province, Tete Province, Zambezia Province |
| **Study period** | November 2023 – August 2024 |
| **Background** | Mozambique is one of the world's most vulnerable countries to climate change and is frequently affected by extreme weather events (EWEs), including cyclones, floods, heatwaves, and droughts. These weather phenomena pose significant challenges to the country's public health infrastructure and the well-being of its population, and as a consequence of a globally warming climate, these events are increasing in severity and frequency (1). Among the most common extreme weather events in Mozambique are tropical cyclones, which cause the most damage along the country's extensive coastline. Cyclones Idai and Kenneth, which struck Mozambique in March and April 2019 respectively, had a devastating impact on both public health and health infrastructure. Cyclone Idai resulted in over 1,000 fatalities, displaced 1.85 million people, and caused extensive damage to infrastructure and farmland. Cyclone Kenneth affected over 370,000 people and inflicted significant damage to homes, schools, and health facilities in northern Mozambique (2, 3). While Cyclone Kenneth resulted in fewer casualties compared to Idai, the impact of both storms underscores the urgent need for an enhanced understanding of the full impact of EWE on health, in order to inform disaster preparedness, resilience-building efforts, and long-term sustainable development initiatives in Mozambique.  In addition to cyclones, floods and droughts also affect the region, exacerbating existing vulnerabilities and posing significant challenges to the population. Nampula and Zambezia, followed by Inhambane, Cabo Delgado and Sofala, are the provinces most affected by cyclones, while floods are mainly reported in Sofala, Zambezia and Nampula (Figure 1).  A map of different countries/regions  Description automatically generated with medium confidence  Figure 1: Map of Mozambique showing province-level data of the at-risk population to (a) floods, and (b) cyclones; (c) the affected population by (d) landslides and (e) droughts, as illustrated by annual agricultural income loss (4).  It has been demonstrated that EWEs disrupt healthcare systems of LMICs, including Mozambique, via the disruption of delivery and access to healthcare services (2, 5, 6). EWEs have also been demonstrated to directly trigger disease outbreaks (7, 8), lead to higher rates of lifetime hospitalization (9), and negatively impact the mental health of affected populations (10). The impact of EWEs on national Expanded Programs on Immunization (EPI) has not been well explored, though one study in Puerto Rico demonstrated that Hurricane Maria led to a significant decrease in vaccination coverage (11). Extreme weather events can disrupt vaccine transportation, damage healthcare facilities, and cause population displacement, all of which can have far-reaching consequences on the accessibility and coverage of vaccinations.  To date, there is a dearth of quantitative data exploring the effects of EWEs and interruptions in healthcare systems to the subsequent health impact on affected populations. There is limited comprehensive analysis that systematically investigates how EWEs affect EPI vaccination coverage across Mozambique. This research seeks to bridge this knowledge gap by examining data across all provinces, including those affected and unaffected by EWEs. It aims to identify risk factors associated with increased burden of diarrhoeal disease and explore potential correlation with meteorological and demographic data.  Building resilience and informing preparedness strategies to manage extreme weather events is a critical aspect of minimizing their deleterious effects. Identifying and implementing effective strategies that can protect communities and healthcare facilities from the impacts of these events is vital. Through this data analysis and modelling, this research aims to assess various preparedness strategies and determine which ones are most effective in safeguarding populations and healthcare services from the adverse effects of EWEs, thus contributing to public health knowledge and informing decision-making of future public health interventions, primarily vaccination in extreme weather climates. |
| **Objectives and** o**utcomes** | |  |  | | --- | --- | | **Primary Objective** | **Outcomes** | | * Understand and quantify the impact of extreme weather events (EWEs) on average EPI vaccination coverage between 2017 and 2022, across all provinces in Mozambique, i.e. those affected and unaffected by those events. | * Determination of the magnitude of the impact of EWEs on EPI vaccination coverage in Mozambique. * Identification of any trends in vaccination coverage data between 2017 and 2022, particularly in relation to predicting the impact of future EWEs. | | **Secondary Objectives** | **Outcomes** | | * Assess the impact of EWEs in Mozambique over the past decade on cases of diarrhoeal disease, frequency of communicable disease outbreaks and morbidity and mortality due to extreme weather at the healthcare facility level. | * Determination of the magnitude of the impact of EWEs on diarrhoeal disease burden in Mozambique. * Determination of the magnitude of the impact of EWEs on weather-related morbidity and mortality in Mozambique. * Identification of any trends in diarrhoeal disease outbreaks and associated morbidity and mortality data, particularly in relation to predicting the impact of future EWEs. | | * Assess the impact of EWEs in Mozambique over the past decade on health infrastructure through quantifying HCFs, equipment and stocks destroyed. | * Determination of the magnitude of the impact of EWEs on healthcare infrastructure in Mozambique. * Inform the design of questionnaires for HCWs and head of HCFs concerning understanding the impact of EWEs. | | * Explore which preparedness strategies may best protect vulnerable areas from the deleterious impacts of EWEs through the review of existing literature, consultation with experts, and above analysis, with an aim to determine effectiveness of preparedness strategies. | * Identification of optimal preparedness strategies for future occurrences of EVEs in liaison with local government officials. | |
| **Study design** | * This will be a quantitative study in which we will collect various province-level data from Mozambique. Data from 2017-2022 will be collected including, but not limited to, the following variables: EPI administrative vaccination coverage, meteorological information (rainfall, wind speed, temperature etc.), cyclone/flood/drought severity (GDACS score), mortality due to EWE, sociodemographic information/WASH), diarrhoeal disease burden (full details in Table 1). * After the compilation of these data we plan to perform interrupted time series analysis and investigate the impact of other confounding variables through regression analysis or modelling, with an aim to inform preparedness strategies and better understand the deleterious effects of climate change on health. |
| **Sources of data (full details in Table 1)** | * EPI administrative vaccine coverage:   + Number of doses given for BCG, IPV, PCV 1st dose, PCV 3rd dose, Penta 1st dose, Penta 3rd dose, Polio 1st dose, Polio 3rd dose, Rota 1st dose, Rota 2nd dose, MR. * Occurrence of (diarrhoeal) disease * Occurrence of malaria * Number of homes destroyed by cyclones and extreme weather * Mortality due to extreme weather * Meteorological data (e.g. temperature, rainfall, humidity, max. wind speed, instances of lightning) * Number and magnitude of storm surges * Sociodemographic and WASH information |
| **Study analysis plan** | As EWE represent relatively short and unplanned occurrences, sudden reductions in vaccination coverage soon after an EWE are quite likely to be associated with disturbances in health services affiliated with the EWE. In this study, we will use the interrupted time series (ITS), or weighted ITS, analytic framework to investigate this relationship (12-14). The ITS formalizes models changes in the values of a quantitative variable pre-versus-post EWE. This approach to modelling a time series allows for a potential EWE-effect over-and-above both long and/or short-term secular trends in vaccination coverage.  Potential predictors and confounding factors of an EWE's postulated effect on vaccination coverage will be adjusted for in secondary models – including meteorological data: rainfall, humidity, temperature etc. Allowing for additional lag time, the same ITS approach will be employed to investigate the impact of EWE on diarrhoeal disease outbreaks (14). Since the impact of EWE on diarrhoeal disease outbreaks could in part operate via any earlier effect of the same EWE on coverage for vaccines designed to prevent diarrhoea, the ITS models will be used to explore how much of any association between EWE and diarrhoeal disease outbreaks can be explained by any intermediate drop in vaccination coverage.  Provinces unaffected by a particular EWE will be used as control time series, and if sufficient information is available to characterize a time series for a health service indicator that would not be expected to be impacted by an EWE, then these types of time series can be used as negative controls. |
| **Benefits of the study** | * Findings from this study will contribute to public health knowledge and decision-making vis-à-vis the potential impact of cyclones on routine vaccination rates, an area previously not well-investigated against rising cyclone severity and frequency caused by climate change. * Direct future public health benefits may include the opportunity to design a strategic approach to increase and diversify means of public health interventions, primarily vaccination in extreme weather climates. |

Table 1: Data sources to investigate the impact of extreme weather events on health and health systems in Mozambique.

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| **Database** | **Data to be included in analysis** | **Geographic unit** | **Time unit** | **Areas covered** | **Data period covered** | **Data source** |
| EPI administrative vaccine coverage | Projected estimates of the number of vaccine eligible children (aged 0-11 months); number of doses given for BCG, IPV, PCV 1st dose, PCV 3rd dose, Penta 1st dose, Penta 3rd dose, Polio 1st dose, Polio 3rd dose, Rota 1st dose, Rota 2nd dose, MR. | District, province | Month | All provinces of Mozambique | 2017-2022 | Mozambique EPI |
| Occurrence of (diarrheal) disease | Number of cases of diarrheal diseases (by all causes) in different age groups: children under 5 years and pop. above 5 years | District, province | Week | All provinces of Mozambique | 2017-2022 | SIS-MA (DHIS2) |
| Occurrence of malaria | Number of cases of malaria in different age groups: children under 5 years and population above 5 years | District, province | Week | All provinces of Mozambique | 2017-2022 | SIS-MA (DHIS2) |
| Number of homes destroyed by cyclones and extreme weather | Number of houses partially and completely destroyed collected by INGD during and after the extreme weather events | District, province | Month | All provinces of Mozambique | 2017-2022 | INGD database |
| Number of lightning registered between 2017 - 2022 | Minimum, mean and maximum of meteorological data registered by National Institute of Meteorology/Satellite data (ERA5) during the extreme weather events | District, province | Week | All provinces of Mozambique | 2017-2022 | INGD,INAM&INE |
| Number of Storm surge and their magnitude | Number of Lightning registered by National Institute of Meteorology/Satellite data (ERA5) during the extreme weather events | District, province | year | All provinces of Mozambique | 2017-2023 | INAM |
| WASH | Access to water supply and access to sanitation at HCF and households, including Proportion of population using improved drinking water sources; proportion of population using improved sanitation and Percentage of people in the population who practice open defecation | District, province | Week | All provinces of Mozambique | 2017-2022 | **MIS 2018, IDS 2022** MISAU&MOPHRH |
| Sociodemographic information | Proportion of population by age group; percentage of rural and urban population by province; level of education; family income; and level of migration | District, province | Month | All provinces of Mozambique | 2017-2022 | INE (Census 2017 and projections) |
| Mortality due to extreme weather | Number of deaths registered during/after and due to extreme weather event, collected by the INGD | District, province | Month | All provinces of Mozambique | 2017-2023 | INGD |

Works Cited

1. Bhatia KT, Vecchi GA, Knutson TR, Murakami H, Kossin J, Dixon KW, et al. Recent increases in tropical cyclone intensification rates. Nat Commun. 2019;10(1):635.

2. Mugabe VA, Gudo ES, Inlamea OF, Kitron U, Ribeiro GS. Natural disasters, population displacement and health emergencies: multiple public health threats in Mozambique. BMJ Glob Health. 2021;6(9).

3. IFRC. Mozambique | Tropical Cyclones Idai and Kenneth. 2022.

4. Kellett J, Caravani A. Financing disaster risk reduction: a 20 year story of international aid: Overseas Development Institute and the Global Facility for Disaster …; 2013.

5. Petricola S, Reinmuth M, Lautenbach S, Hatfield C, Zipf A. Assessing road criticality and loss of healthcare accessibility during floods: the case of Cyclone Idai, Mozambique 2019. Int J Health Geogr. 2022;21(1):14.

6. Fernandes Q, Augusto O, Chicumbe S, Anselmi L, Wagenaar BH, Marlene R, et al. Maternal and Child Health Care Service Disruptions and Recovery in Mozambique After Cyclone Idai: An Uncontrolled Interrupted Time Series Analysis. Glob Health Sci Pract. 2022;10(Suppl 1).

7. Li C, Zhao Q, Zhao Z, Liu Q, Ma W. The association between tropical cyclones and dengue fever in the Pearl River Delta, China during 2013-2018: A time-stratified case-crossover study. PLoS Negl Trop Dis. 2021;15(9):e0009776.

8. Focus Adriano L, Nazir A, Uwishema O. The devastating effect of cyclone Freddy amidst the deadliest cholera outbreak in Malawi: a double burden for an already weak healthcare system-short communication. Ann Med Surg (Lond). 2023;85(7):3761-3.

9. Parks RM, Anderson GB, Nethery RC, Navas-Acien A, Dominici F, Kioumourtzoglou MA. Tropical cyclone exposure is associated with increased hospitalization rates in older adults. Nat Commun. 2021;12(1):1545.

10. Tasdik Hasan M, Adhikary G, Mahmood S, Papri N, Shihab HM, Kasujja R, et al. Exploring mental health needs and services among affected population in a cyclone affected area in costal Bangladesh: a qualitative case study. Int J Ment Health Syst. 2020;14:12.

11. Colón-López V, Díaz-Miranda OL, Medina-Laabes DT, Soto-Abreu R, Vega-Jimenez I, Ortiz AP, et al. Effect of Hurricane Maria on HPV, Tdap, and meningococcal conjugate vaccination rates in Puerto Rico, 2015–2019. Human Vaccines & Immunotherapeutics. 2021;17(12):5623-7.

12. Bonakdari H, Pelletier JP, Martel-Pelletier J. Viewpoint on Time Series and Interrupted Time Series Optimum Modeling for Predicting Arthritic Disease Outcomes. Curr Rheumatol Rep. 2020;22(7):27.

13. Ewusie J, Beyene J, Thabane L, Straus SE, Hamid JS. An improved method for analysis of interrupted time series (ITS) data: accounting for patient heterogeneity using weighted analysis. Int J Biostat. 2022;18(2):521-35.

14. Cruz M, Bender M, Ombao H. A robust interrupted time series model for analyzing complex health care intervention data. Stat Med. 2017;36(29):4660-76.