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Examining the effect of precipitation on diarrheal mortality outcomes in The City of Tshwane, South Africa

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Examining the effect of precipitation on diarrheal mortality in The City of Tshwane, South Africa

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An abstract of
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Master of Public Health
in Global Environmental Health

2021

Abstract

Examining the effects of precipitation on diarrheal mortality in The City of Tshwane, South Africa

By: Asmita Talukdar

Background: South Africa is anticipated to experience higher levels of climate change compared to many other parts of the world. This includes changes to rainfall, which has been associated with diarrheal disease in other parts of the world. Here we explore the relationship between rainfall and diarrheal mortality in the City of Tshwane, South Africa.

Objectives: In a time-series study consisting of the whole of the population of the City of Tshwane from the years 1997-2013, I examined whether heavy rainfall, and other key factors like temperature, time, and age, was associated with increased diarrheal mortality.

Methods: Binary exposure variables along with the rainfall count variables were compared against overall diarrheal mortality and that of children <5. Seven day and fourteen day lagged rain variables were also calculated and factored into the continuous and binary models. With these, I estimated associations between both rainfall exposure variables, temperature, and time using poisson regression models, then subsequently, confidence interval plots.

Results: There was no risk of mortality from neither heavy rainfall events, nor continuous rainfall in the final interval plots with 95% CI. In subsequent sensitivity analyses, neither heavy rainfall exposure nor continuous rainfall was associated with changes to several spline functions nor when the thresholds for heavy rainfall were changed.

Conclusions: The results suggest that, in the City of Tshwane, over the past 17 years, neither continuous rainfall nor heavy rainfall, coupled with temperature, resulted in significant risk of mortality for the population. General rainfall trends over 17-years indicated that temperature and time are major factors in diarrheal mortality overall, especially among children; this was not the case for the overall population though. The findings of this study warrant future studies focusing specifically on the seasonality of rainfall trends relating to diarrheal mortality to establish the environmental pathway of diarrheal disease in this part of South Africa.

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1. Introduction:

Diarrheal disease adversely affects childhood mortality, as well as adult health outcomes in regions around the world [2]. Drinking water is a major source of microbial pathogens in developing regions, though inadequate sanitation and food supply are an integral part of enteric pathogen exposure to populations [2]. Often as a result of common enteric pathogens like rotavirus, *Campylobacter*, or giardia, this disease is endemic in nearly all regions of the world, with the most vulnerable communities being those living in poverty and having the lowest capacity to adapt [6:10]. Even with global vaccination campaigns, diarrhea remains the primary cause of early childhood mortality and cases, with an estimated 2.5 billion cases occurring per year among children under 5, more than half of which occur in Africa and South Asia [25]. With climate change poised to alter infectious disease transmission, it is critical to understand the potential impacts it may have on diarrheal disease.

Progressively rising global temperatures due largely in part to anthropogenic emissions, have caused noticeable changes in global climatic patterns, sea level rise and disease transmission routes, among other detrimental effects. Future climate change effects on human health are projected to be dramatic, especially if some tropical diseases expand into formerly temperate areas [11]. Climate change directly affects the water cycle in its evaporation phase; increasing rates of evaporation, and consequently precipitation, have led to, and will likely continue to result in the intensification of hydrological extremes [20] globally. Sub-Saharan Africa is a particularly vulnerable region as it has the highest burden of infectious disease and is projected to be among the most affected by climate change [1,10]. Two decades ago, climate change accounted for about 2.4% of diarrheal cases worldwide [7], but now, that statistic is likely to be higher given that the past 18 years have been the warmest temperature-wise, on record. Limited access to clean water, sanitation/hygiene facilities, coupled with a heavy dependence on agriculture and a limited capacity to adapt, make numerous African countries vulnerable to the effects of climate change [7].

Rainfall patterns have been linked to diarrheal disease in previous studies [25], but due to limited long-term time-series studies in the region focusing on rainfall and diarrhea [17], it is difficult to gauge the depth of the association. As alluded to earlier, poor water and sanitation infrastructure are thriving environments for enteric pathogens, and a setting inclusive of all these elements increases the likelihood of community exposure [7,24]. The impact of precipitation patterns is worsened by such conditions, as rainfall pulses can flush fecal matter into waterways, and drought conditions concentrate microorganisms into water sources [7].

Infectious disease burden in the African continent, particularly in the Sub-Saharan countries, is high. Poor water, sanitation, and hygiene and healthcare infrastructure and its climatic conditions are primarily to blame for the high prevalence of infectious disease in Africa. The reason for this is because approximately half of the African population have little to no access to safe water, and roughly two-thirds of the population has little to no access to hygienic sanitation [6]. Contamination of water supplies ensues, leading to growth of enteric pathogens like *E. coli*, giardia, shigella and cryptosporidium [24]. For this reason and the adequate climatic conditions, such diseases like diarrhea, malaria, and a slew of other waterborne, vector-borne, and disease-carrying pathogens thrive in the continent, especially in the Sub-Saharan region [10, 24].

This study focuses on The City of Tshwane, South Africa, a large urban center located in the Sub-Saharan nation located at the very tip of the African continent, with a myriad of climatic conditions spanning across its borders. Diarrhea accounts for nearly 20% of deaths in all of South Africa, and 46% throughout the continent [3] .The most common culprits of diarrhea in South Africa include: bacterial or viral pathogens; since South Africa also has a high prevalence of HIV/AIDS, those infected will likely experience diarrhea caused by protozoan pathogens [3]. With climate change, the southern region of Africa is projected to become hotter and drier [10], which will lead to limited water availability in that area.

Therefore, it is critical to clarify the relationship between heavy rainfall events and waterborne diarrheal mortality to not only inform communities how to better prepare, but also to further elaborate upon the environmental pathway of diarrheal disease as it relates back to rainfall exposure. In an era where climate change threatens to upend livelihoods and health outcomes, this knowledge is vital. Using a seventeen-year precipitation and diarrheal disease dataset (1997-2013), I hope to provide a preliminary time-series analysis of diarrheal disease mortality and its relationship with heavy precipitation.

2. Methods:

In this study I conducted an analysis on the City of Tshwane on the association between rainfall and mortality using a time-series regression. I hypothesized that higher rainfall would be associated with increased mortality.

2.1 Study Site: The City of Tshwane district municipality, formerly known as Pretoria, is the administrative capital of South Africa located in the northeastern part of the country. The City of

Tshwane is a large urban center in South Africa, with nearly 1,200 people per square mile [8] (Figure 1).

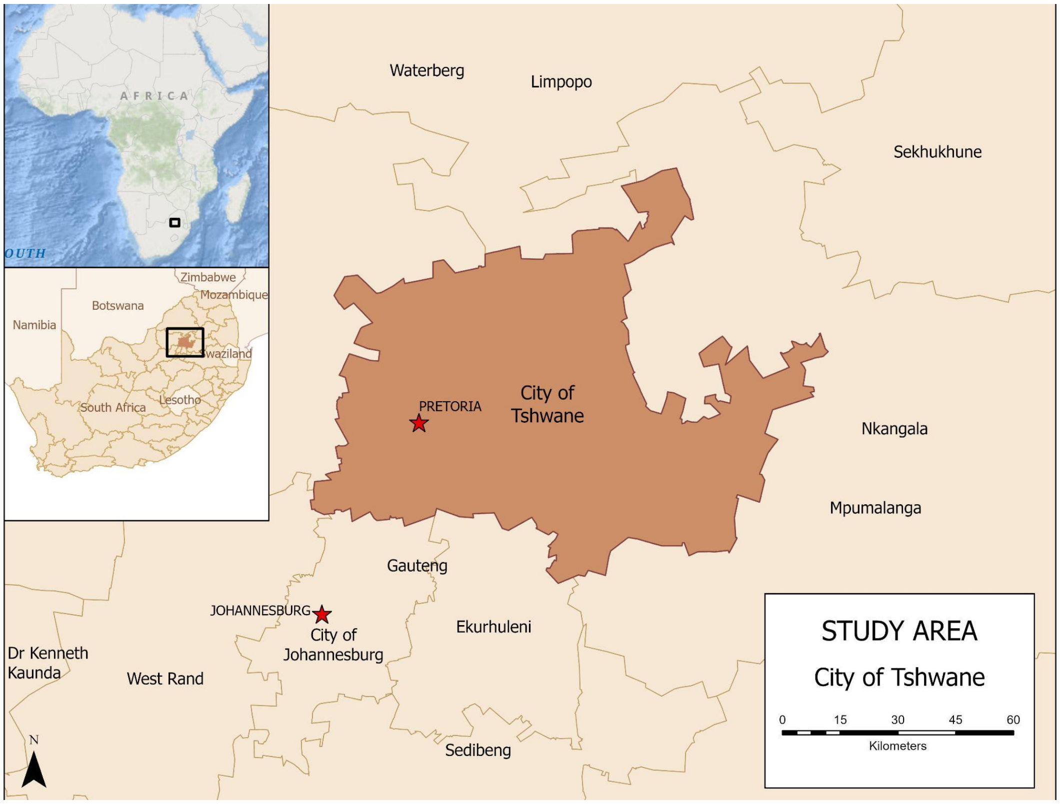


Figure 1: Location of City of Tshwane (Pretoria)

2.2 *Diarrheal Mortality Dataset*

The mortality data in this dataset comes from the country's civil registration system and was provided by Statistics South Africa, who had no role in the design or analysis in this study. This data includes information from 1997-2013 on daily counts of diarrheal deaths in the City of Tshwane, inclusive of all ages and children <5. Because infectious diarrhea-causing pathogens following rainfall events have a 1-week incubation period, and a 2-week transmission period [7], I aggregated the daily counts into weekly counts.

2.3 Exposure Dataset

The precipitation data came from records of daily measurements (in millimeters) from a single monitoring station in the City of Tshwane. The data was provided by the Agricultural Research Council of South Africa. To align with the diarrheal mortality data, I aggregated the daily precipitation measurements into weekly counts. To control for the potential association between temperature and mortality, I also included temperature data from the same monitoring station. Pre-aggregation, there were a total of 252 missing rainfall data points, but post-aggregation, there were only a total of 56 missing rainfall data points in the dataset.

2.4 Statistical Analysis

I conducted the analyses using poisson regression on the association between weekly rainfall and weekly diarrheal mortality. To control for time varying trends, I used a cubic spline with 6 degrees of freedom per year. I also controlled for temperature using a temperature decile variable. We looked at the linear association between mortality and rainfall in the week prior and two weeks prior. Additionally, I created a binary exposure for heavy rainfall, for which the threshold was estimated at the 90th percentile value of the weekly rainfall variable; this value was calculated based on previous literature [12]. In sensitivity analyses, I altered the heavy rainfall threshold and decreased the degrees of freedom in the cubic spline by 1 per year.
All statistical analyses were conducted using RStudio.

*3. **Results***

Descriptive Analysis

Over the 17-year study period, there were a total of 13,066 deaths from diarrhea, including 4,277 deaths in children; this equates to approximately 15 and 5 deaths per week respectively (Table 1). Table 1 also shows that the average weekly rainfall over 17-years was 1.33 cm, the majority of which occurred in the summer months. **Figure 2** shows weekly rainfall over time, but it fails to show seasonal patterns, even though total summer rainfall, as indicated in **Table 1,** accounted for nearly 45% of all the rainfall that occurred over the duration of the study. **Figure 3** shows the diarrheal mortality trend over time, with noticeable peaks between the years 2005-2010 evident in both Plot A and Plot B. These peaks can be attributed to the HIV/AIDS epidemic, and since afflicted populations are immunocompromised, they are highly susceptible to diarrheal morbidity and mortality caused by protozoan pathogens.

Table 1: Mean & Standard Deviations of Weekly Rainfall, Seasonal Rainfall, All Age Diarrheal Mortality, and Diarrheal Mortality in Children <5

	Total	**Mean**	**Standard Deviation**
Weekly Rainfall (cm)	1105.80	1.33	2.33
Summer Weekly Rainfall (cm)	492.80	2.48	2.72
Winter Weekly	20.8	0.10	0.40

Rainfall (cm)			
Weekly All age mortality	13,066	14.73	9.36
Weekly mortality in children <5 yrs	4,227	4.82	5.26

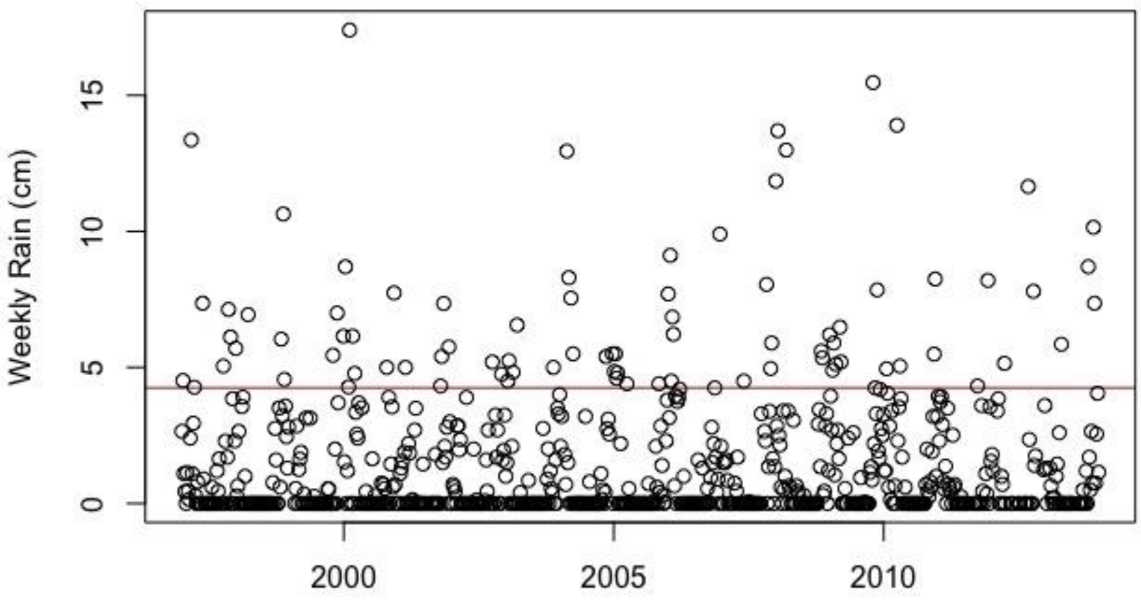
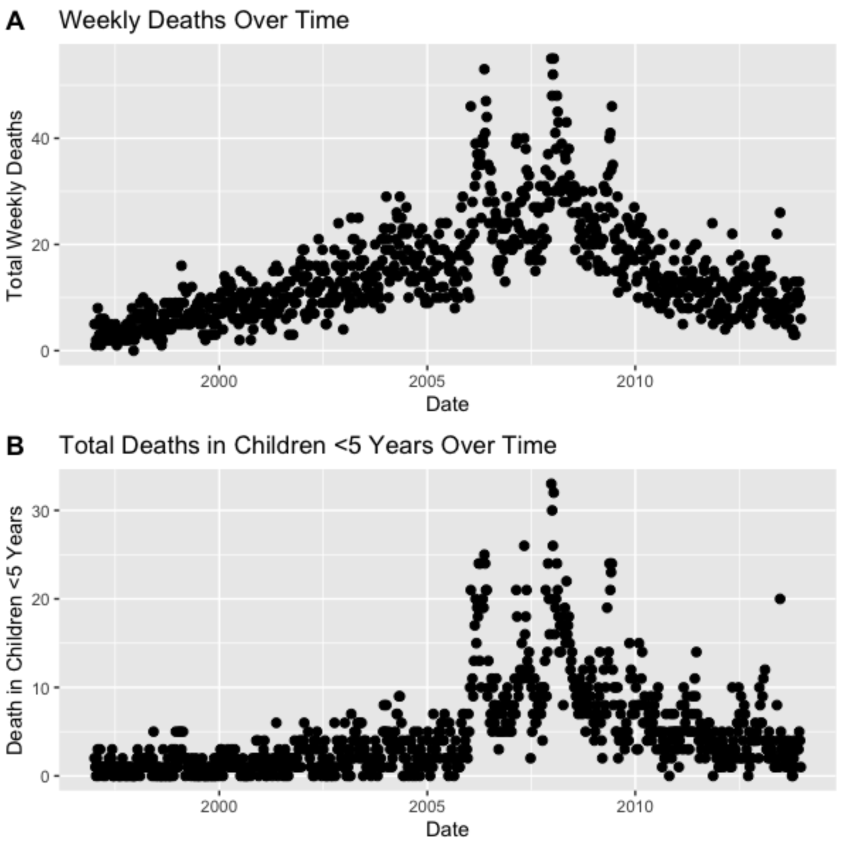


Figure 2: Scatterplot of weekly rainfall over time. The red line indicates the heavy rainfall threshold of 4.25 cm as decided by the 90th percentile of rainfall in the weekly rainfall variable.


A Weekly Deaths Over Time

B Total Deaths in Children <5 Years Over Time

Figure 3: Comparison of overall deaths vs. deaths in children <5 over time. Plot A shows the deaths over time, plot B shows the deaths in children <5 over time.

Outcome & Exposure Measurements

Figure 4 shows significant overlap in all the plots, which indicates that continuous rainfall does not have a significant association with neither diarrheal mortality in children <5, nor among all ages in the City of Tshwane. The central estimates in the plots are higher among all ages than in children, albeit with highly overlapping confidence intervals.

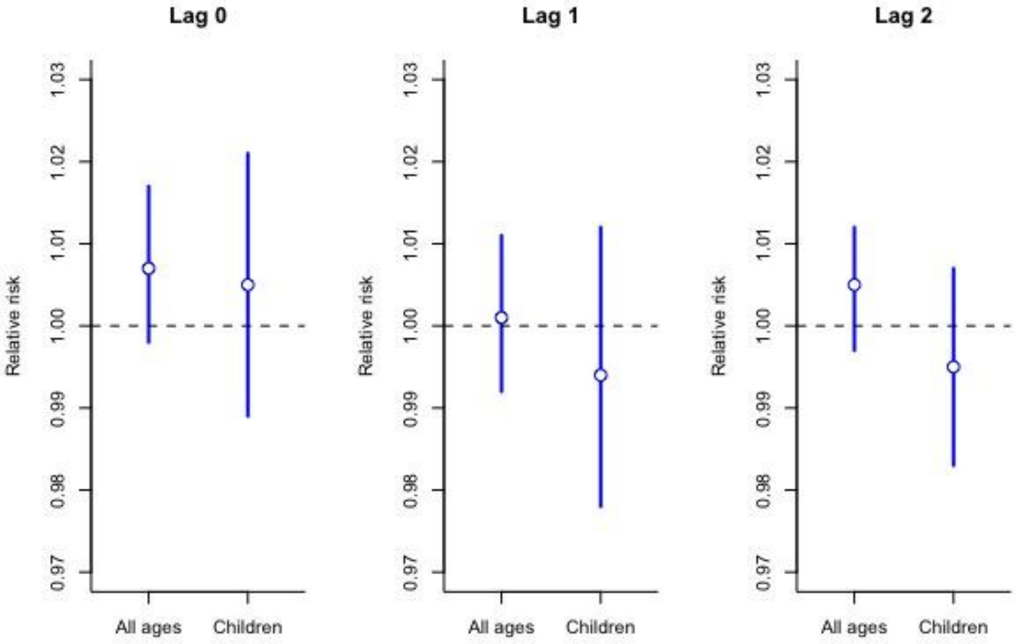


Figure 4: 95% CI Plot of continuous rainfall vs. relative risk of diarrheal mortality in all ages and in children <5

Figure 5 also shows that I observed no association between diarrheal mortality and heavy rainfall events

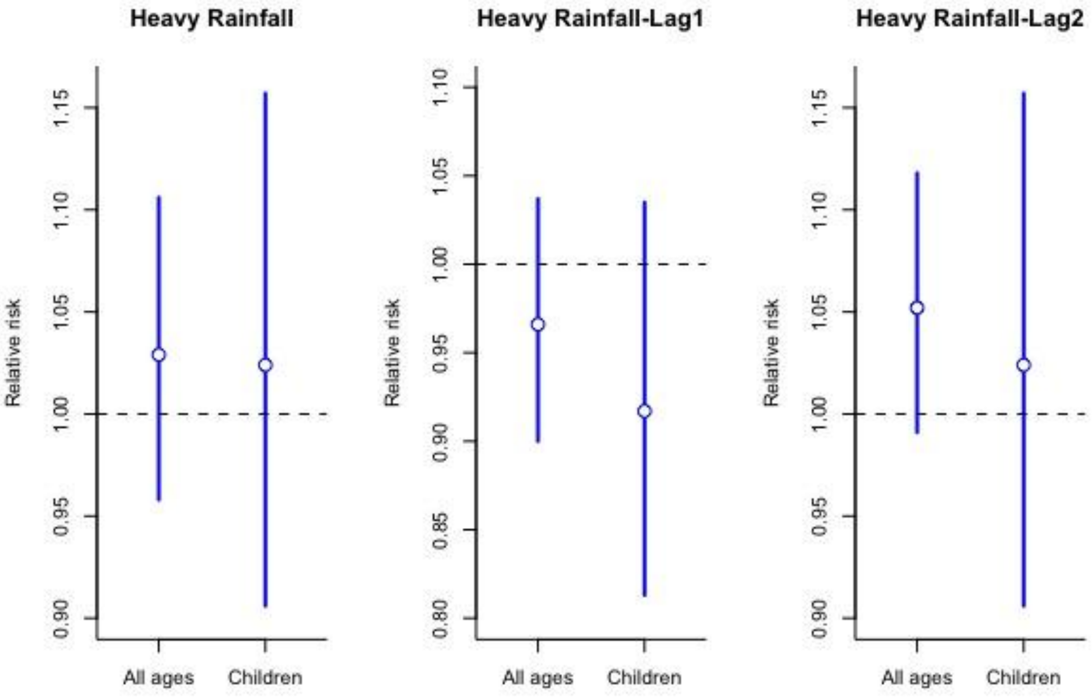


Figure 5: 95% CI Plot of binary rainfall vs. relative risk of diarrheal mortality in all ages and in children <5

Sensitivity Analyses:

In sensitivity analyses, I ran additional models that decreased degrees of freedom in the cubic splines per year and varied the heavy rainfall threshold (Table 3), none of which yielded any significant associations. omission of the temperature variable yielded no association.

Table 2: Sensitivity Analysis for Continuous Rainfall

	Lag 0	**Lag 1**	**Lag 2**
Main Model (dF = 6/year, controlled for temperature)	RR = 1.007 Lower CI: 0.998 Upper CI: 1.017	RR = 1.001 Lower CI: 0.992 Higher CI: 1.011	RR = 1.005 Lower CI: 0.997 Higher CI: 1.012
dF = 5/year	RR = 1.009 Lower CI = 0.999 Upper CI = 1.018	RR = 1.001 Lower CI = 0.991 Upper CI = 1.011	RR = 1.004 Lower CI = 0.997 Upper CI = 1.012
dF = 7/year	RR = 1.007 Lower CI = 0.997 Upper CI = 1.017	RR = RR = 1.001 Lower CI = 0.991 Upper CI = 1.011	RR = 1.004 Lower CI = 0.997 Upper CI = 1.011
No control for temperature	RR = 1.003 Lower CI = 0.994 Upper CI = 1.013	RR = 0.999 Lower CI = 0.990 Upper CI = 1.009	RR = 1.003 Lower CI = 0.996 Upper CI = 1.011

Table 3: Sensitivity Analysis for Binary Rainfall

	Lag 0	**Lag 1**	**Lag 2**
Main Model (dF = 6/year, controlled for temperature, threshold = 4.25 cm)	RR = 1.066 Lower CI = 0.983 Upper CI = 1.156	RR = 0.966 Lower CI = 0.900 Upper CI = 1.037	RR = 1.053 Lower CI = 0.991 Upper CI = 1.118
dF = 5/year	RR = 1.061 Lower CI = 0.977 Upper CI = 1.152	RR = 0.960 Lower CI = 0.893 Upper CI = 1.031	RR = 1.040 Lower CI = 0.980 Upper CI = 1.104
dF = 7/year	RR = 1.062 Lower CI = 0.977 Upper CI = 1.154	RR = 0.963 Lower CI = 0.896 Upper CI = 1.035	RR = 1.057 Lower CI = 0.992 Upper CI = 1.125
No control for temperature	RR = 1.041 Lower CI = 0.962 Upper CI = 1.127	RR = 0.970 Lower CI = 0.906 Upper CI = 1.040	RR = 1.054 Lower CI = 0.994 Upper CI = 1.118
Threshold = 3.65 cm	RR = 0.998 Lower CI = 0.933 Upper CI = 1.068	RR = 0.982 Lower CI = 0.919 Upper CI = 1.048	RR = 1.047 Lower CI = 0.985 Upper CI = 1.112

Threshold = 4.05 cm	RR = 1.014 Lower CI = 0.945 Upper CI = 1.087	RR = 0.971 Lower CI = 0.907 Upper CI = 1.039	RR = 1.058 Lower CI = 0.998 Upper CI = 1.123
Threshold = 4.55 cm	RR = 1.057 Lower CI = 0.980 Upper CI = 1.141	RR = 0.946 Lower CI = 0.878 Upper CI = 1.020	RR = 1.039 Lower CI = 0.976 Upper CI = 1.106
Threshold = 5.05 cm	RR = 1.067 Lower CI = 0.983 Upper CI = 1.156	RR = 0.970 Lower CI = 0.895 Upper CI = 1.052	RR = 1.038 Lower CI = 0.974 Upper CI = 1.105
Threshold = 5.15*	RR = 1.083 Lower CI = 0.998 Upper CI = 1.176	RR = 0.985 Lower CI = 0.907 Upper CI = 1.068	RR = 1.037 Lower CI = 0.974 Upper CI = 1.105

*= 99th percentile for heavy rainfall is 11.35 cm, highest decided threshold + 1

4. Discussion

This is the first long-term city-wide study of precipitation-diarrheal mortality associations in the Gauteng Province in South Africa. Findings from this preliminary study indicated that there were no associations found in continuous rainfall nor binary rainfall with neither diarrheal mortality or diarrheal mortality in children <5 across the whole population for the duration of the study. Subsequent sensitivity analyses did not yield any significant associations with diarrheal mortality.

Lagged rainfall trends can have a noticeable impact on diarrheal outcomes among afflicted populations. 1 & 2-week lagged continuous and heavy rainfall trends compared to diarrheal mortality among all ages and in children under 5 yielded no significant association in this study. Conversely, Ikeda, et.al [17] and Horn, et. al [16], the former having conducted a study in the Limpopo Province of South Africa, and the latter in Mozambique, used a range of lagged rainfall from 0-8 weeks and four weeks respectively, before a diarrheal episode, and discovered significant associations with diarrheal morbidity outcomes in children under 5 and in young adults. Though no association was found in my study, heavy rainfall events, as noted in previous studies [12,23], can lead to an increase in diarrheal prevalence and morbidity, especially among children under 5.

Investigating the effects of precipitation on diarrheal mortality outcomes over a long period of time was a notable strength of this study, but there were also some limitations. Statistics South Africa estimates that up to 11% of deaths may not have been recorded by the national registry early in the study period, declining to about 6% in the end [26, 27, 28]. They do not report the completeness of child mortality records. If these missing mortality records are random, it will have little impact on the calculated relative risk estimates, but if these omissions were related to precipitation, they could be meaningful [26].

The precipitation data in and of itself is a limitation of this study because in a large urban setting such as the City of Tshwane, rainfall measurements were taken from a single monitoring station and generalized to the entire city's population, which does not necessarily account for the local weather conditions; this can lead to exposure misclassification.

Future research should focus on diarrheal disease trends that occur following heavy rainfall events with dry antecedent conditions, akin to Deshpande et.al [12], in South Africa and other Sub-Saharan African countries. This would be especially critical for South Africa and its neighboring countries like Botswana and Lesotho because their relatively low rainfall index [13] can increase dry season diarrheal disease incidence with hot, dry conditions starting earlier and lasting longer [1]. Not only would these findings help establish the urban-rural differential in terms of diarrheal susceptibility following heavy rainfall events in the region, it would also help build upon a framework of existing interventions.

In Bandyopadhay et.al [5], the researchers were able to gather DHS data from 14 Sub-Saharan African nations, and in concurrence with previous studies [1,12,4] surmise that a shortage of rainfall in the dry season increases the prevalence of diarrhea across the region. As 90% of global diarrheal deaths occur in Africa, the Eastern Mediterranean Region and Southeast Asia [29], conducting a similar study on a larger scale, would conclusively determine if prior drought conditions increase the risk of overall diarrheal disease, and can inform crucial policy decisions and public health measures going forward.

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