보건학석사 학위논문

설사와 온도 및 강수량의 연관성. 사하라 사막 이남의 아프리카 10개 국가들을 대상으로.

ASSOCIATION BETWEEN TEMPERATURE AND RAINFALL ON ALL-CAUSE DIARRHEA ACROSS SUB-SAHARAN AFRICA

2020년 6월

서울대학교 보건대학원

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이 논문을 보건학 석사학위논문으로 제출함

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Kristi Prifti의 석사학위논문을 인준함

2020년 6월

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Abstract

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“본 논문작성자는한국정부초청장학금(Global Korea Scholarship)을 지원받은장학생임”

Background: Climate change affects not only the economy and ecosystem but also health and its social and environmental determinants. Lower- and middle-income countries, which comprise most of the African continent, are more vulnerable to climatic changes and its effects. Various diseases, particularly water and vector-borne, have already started to see an increase in prevalence (i.e cholera) as well as a geographical displacement (i.e malaria). Comprised of a wide variety of climatic zones and already suffering from malnutrition and a variety of infectious diseases, the African continent sees major shifts under a climate change scenario. Particularly, diarrheal diseases, which are a major leading cause of morbidity and mortality, especially in children under five years of age. This study aimed to evaluate the association between temperature and precipitation on all- cause diarrhea for ten different countries in Sub-Saharan Africa.

Method: To analyze the association between the climatic drivers and diarrhea; firstly non-linear exposure-response functions using a natural cubic spline with 2 degrees of freedom were modeled, followed by three different quasi-Poisson generalized linear models for each country and all countries combined; 1- average temperature-diarrhea cases, 2-precipitation-diarrhea cases (controlled for temperature), 3- interaction term of temperature and precipitation - diarrhea cases. Seasonality was controlled for in all models, using a natural cubic spline of time (month of the study period) with 2 df per year. Secondly, group analysis based on geographical location and annual average temperature were conducted for both temperature-diarrhea and precipitation-diarrhea associations. Finally, subgroup analysis was conducted for age and gender.

Results: Three countries showed statistically significant association between temperature and diarrhea cases (Burkina Faso, Ethiopia, Sudan). Burkina Faso showed a protective effect for temperature (12% reduction of diarrhea cases per unit increase of average temperature), whereas Ethiopia and Sudan showed an increased risk (53 and 19 percent increase in diarrhea cases per unit increase of temperature). The precipitation-diarrhea model generally showed positive associations, with statistically significant estimates for Ethiopia and Kenya and for the pooled estimate for all countries (six percent increase in diarrhea for both Ethiopia and Kenya and three percent increase for all countries, per unit increase of precipitation). All age groups showed statistically significant increased (Ethiopia) or reduced risk (Burkina Faso) of diarrhea for average temperature-diarrhea models whereas only the under-five age group showed statistically significant increased risk of diarrhea per unit change of precipitation (Senegal, Kenya, Ethiopia).

Conclusion: The results are consistent with other publications investigating such associations and expand to new study sites previously not investigated. The importance of such results is highlighted when making informed decisions in resource management and allocation, policy, and education programs.

Keywords: temperature, precipitation, climate change, diarrhea disease, Africa, GLM, relative risk

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1. Introduction

Climate change is defined as fluctuations in global or regional temperatures, precipitation, wind patterns and other measures of climate over long periods (seasons, years, or decades). These changes can result in increased occurrences of extreme weather events such as droughts, floods, and storms. According to the World Health Organization (WHO) globally, the number of reported weather-related natural disasters has more than tripled since the 1960s.

Climate change affects the economy, ecosystem, and human health together with its social and environmental determinants, namely, clean air, safe water, sufficient food sources and secure shelter. (Thomas & Nigam, 2018)

Rising temperatures and increasingly variable precipitation affect the availability and variability of food sources in countries highly dependent on agriculture. Natural disasters can destroy crops and human settlements. Shifting weather patterns also affect fresh water sources and sanitation over time, with a lack of safe water compromising hygiene measures and increasing the risk of food and water-borne diseases, such as diarrheal disease, that every year takes the lives of over 500 000 children under the age of five. (WHO, 2018)

Advances in medicine and public health that had been constantly reducing the prevalence of many diseases, have recently, not only seen a rise but also geographical displacements. Especially water-borne diseases and those transmitted through insects (malaria, dengue fever etc.), and various cold-blooded animals, whose distribution and infectiousness is susceptible to changes in climatic conditions. (Wu X, 2016; Khan MD,2019; Ghazani M, 2018)

Though a global phenomenon, certain regions, mainly low and middle-income countries, which comprise most of the African continent, are disproportionately affected. The continent's susceptibility comes as a result of limited financial and human resources, economic dependence on agriculture, limited adaptation options, large population, lacking infrastructure, and other environmental changes that place stress on the health and functioning of the ecosystem (Busby et al. 2014; Fields 2005; Niang et al. 2014, (EEA), n.d.)).

Africa is home to a wide variety of climate zones, consisting of the Sahara Desert and Sahel in the North, Namib-Kalahari Desert – South, tropical rain forest in the Equatorial zone, and grasslands and savannas in between (Hulme et al. 2001).

Various climate change scenario models suggest that sub-Saharan

Africa, already exhibiting significant changes, will follow trends similar to those observed globally. Climatic zones that already get a lot of rainfall, such as the equatorial and subpolar rain belts, are expected to receive even more, and areas that get little precipitation, such as the subtropical dry zones, will receive even less. (Burden CC,2005) Under these models, the already high rates of malnutrition and infectious diseases are expected to further increase. (Serdeczny, Adams, 2017)

Diarrheal diseases, sensitive to weather and climate changes, are of significant concern for the region as they are leading causes for morbidity and mortality. However, the evidence on climate drivers of diarrheal diseases and their associations in sub-Saharan Africa is low. (WHO, 2018; Fields 2005)

Hence, this study aimed to investigate the association of temperature and precipitation on all-cause diarrhea across ten climatically different countries in Sub-Saharan Africa.

2. Methods

2. 1 Datasets & Descriptive statistics

Health indicators were extracted from The Typhoid Fever Surveillance in Africa Program (TSAP) dataset from the International Vaccine Institute (IVI) .The TSAP was established in 2009 as a consortium committed to introducing standardized multi-country surveillance for typhoid and invasive non-typhoidal salmonella disease in sub-Saharan Africa. Passive surveillance of invasive bacterial diseases was initiated in 13 sites across ten countries in select public healthcare facilities that provided general medical care and served patients of all ages. (Table 1) (Von Kalckreuth,2016).

Weather variables (temperature and rainfall) were extracted from the National Oceanic and Atmospheric Administration (NOAA) ; an American scientific agency within the United States Department of Commerce that focuses on the conditions of the oceans, major waterways, and the atmosphere (Commerce, 2020). Table 2 provides a look into the data coverage of the NOAA dataset per station from 2009-2015, one year before the first TSAP study year (2010) and one year after (2014).

Comprehensive information on the climate characteristics of the 10 sub-Saharan countries in the study, can be found in the appendix (Table A-2 & A-3). The list of countries, study sites, study periods and all-cause diarrhea case counts per country are provided in Table 1.

Table 1. List of TSAP study sites, study period and number of diarrhea cases

Country	Sites	Period (year-month)	Diarrhea Cases
Senegal	Pikine (Dakar)	2011-11 ~ 2013-05	409
Guinea-Bissau	Bandim (Bissau)	2011-10 ~ 2013-04	290
Burkina Faso	Ouagadougou	2012-01 ~ 2013-09	307
Ghana	Asante Akim North	2010-01 ~ 2012-05	1021
Sudan	East Wad Madani	2012-05 ~ 2013-07	100
Ethiopia	Butajira	2012-03 ~ 2014-01	138
Kenya	Kibera (Nairobi)	2012-01 ~ 2013-12	302
Tanzania	Moshi	2011-10 ~ 2013-05	136
Madagascar	Antananarivo	2011-09 ~ 2013-06	1173
South Africa	Pietermaritzburg	2012-02 ~ 2014-01	231

Table 2. NOAA Climate indicator coverage for 2009-2015.

Country	Station	Prcp (%)	Tavg (%)	Tmax (%)	Tmin (%)
Senegal	Dakar Yoff	15.3	100	65.6	45.5
Guinea-Bissau	Bissau Oswaldo Vieira Itl	0.5	100	56.9	0.7

Burkina Faso	Ouagadougou	25.1	100	84.9	46.5
Ghana	Kumasi	33.2	100	50.4	57.4
Sudan	Sennar	6.2	100	74.2	54.6
Ethiopia	Addis Ababa Bole	33.4	100	50.2	62.2
Kenya	Jomo Kenyatta Itl	32.6	100	66.6	67.8
	Nairobi Dagoretti	12.3		25.6	13
Tanzania	Jomo Kenyatta Itl	32.6	100	66.6	69.8
(Moshi)	Nairobi Dagoretti	12.3		25.6	24.5
Madagascar	Antananarivo Ivato	31.1	100	38.3	42
	Antananarivo Ville	34		96.4	92.1
South Africa	Cedara	54	100	96.2	100

The TSAP variables of interest (study id, sex, age, clinic visit date, site, diarrhea case-binary) were combined with NOAA variables (average temperature, min temperature, max temperature, precipitation, date) based on location (country) and time. The dependent variable was diarrhea of any cause, self-reported by the TSAP study participant upon presentation in the health clinic of their region. The independent variables were average temperature (degrees Celsius) and precipitation (mm).

The data was subset per country and aggregated into monthly count data for diarrhea and monthly average for average temperature and precipitation. Countries with weather data coverage below 10% were excluded from any analysis investigating the association of precipitation and diarrhea.

2. 2 Statistical analysis

Summary tables (Table 3 & A-1) and graphical representations (maps and time plots- Fig.A-1 appendix) were created to investigate the distribution, variations and trends of temperature, precipitation, and diarrhea cases per country.

Each diarrhea's case map scale (Fig 1 a-e) is presented differently according to the maximum number of cases for the year.

For the temperature maps (Fig 2, a-c), since annual average temperatures did not differ significantly (until the 100th decimal) across the years, the average of the 2009-2015 period was used.

In the precipitation map (Fig 2 d), being as precipitation coverage was not optimal (with many missing values) the average of the 7 years was used to just highlight any differences or patterns and aid when grouping the countries.

All-cause diarrhea case counts were also stratified by age group (< 5yrs, 5-15 yrs., 15-30yrs, 30-60 yrs. and over 60 yrs.) and sex (male & female) per country (Table 3).

The association between climatic drivers and all- cause diarrhea was investigated by firstly modeling and plotting non-linear exposure-response functions (Fig 3 & 4) using a natural cubic spline with 2 degrees of freedom for temperature and precipitation (adjusted for average temperature) per country and all countries combined. Based on the curves of the non-linear exposure-response plots, it was decided to use linear functions to best find the numerical evidence of the associations (Table 4-6). Hence, three different quasi-Poisson generalized linear models for; 1- average temperature (Table 4), 2- precipitation (adjusted for average temperature) (Table 5), 3- interaction term between temperature and precipitation (Table 6), were run for each country and for all countries combined. Seasonality was controlled for in all models using a natural cubic spline of time (month of the study period) with 2 df per year. Additionally, group analysis based on geographical location and annual average temperature (using descriptive maps Fig 1 & 2) were conducted for both temperature-diarrhea and precipitation-diarrhea associations (Tables A-3,4,5 in Appendix). The countries were grouped geographically into West (Senegal, Guinea-Bissau, Burkina Faso, Ghana) and East (Sudan, Ethiopia, Kenya, Tanzania, Madagascar, South Africa) and as 1-High (Senegal, Burkina Faso, Guinea-Bissau, Ghana, Sudan) and 2- Low (Ethiopia, Kenya, Tanzania, Madagascar, South Africa) based on annual average temperature. Finally, subgroup analysis was conducted per age group (< 5yrs and over 5 years old) and sex (Male & Female) (Table A – 7~10). Statistically significant estimates were determined based on Confidence Intervals in which 1 is not included.

All maps, tables and statistical analysis were conducted using RStudio software (Ver. 1.2.5033).

3. Results

3. 1 Descriptive results

The TSAP passive surveillance was conducted for about two years in each country, with Ghana being the first site to start the study in 2010, and the rest joining in 2011 (Senegal, Guinea-Bissau, Tanzania, Madagascar) and 2012 (Burkina Faso, Sudan, Ethiopia, Kenya, South Africa).

The number of diarrhea cases in 2010 were recorded only in Ghana, in 2011 in Ghana, Senegal, Guinea-Bissau, Tanzania, and Madagascar, in all ten countries simultaneously in 2012. In 2013, the study no longer had recordings of cases in Ghana and in 2014 only South Africa and Ethiopia reported few cases. For a graphical representation and a more refined look at the number of cases for each country per study year, please refer to Fig 1. A-e and Table A-1 in the appendix.

The total number of self-reported all-cause diarrhea for all study sites was 4107, with Madagascar recording the majority of cases (n= 1173), followed by Ghana (n=1021). Sudan had the least number of observations at 100 cases, and the rest fluctuated at less than 500 cases. For all countries, the majority of diarrhea cases were in participants under the age of 5 (n=1958) and females (n=2330). For each individual country, the same rings true, besides Senegal where most of the diarrhea cases were found in participants belonging to the 15 to 30-year-old age group (n=159) and in males (n=247). Burkina Faso and Guinea-Bissau also had slightly more cases in males (n=159 and n=157, respectively) as compared to females (n=148 and n=133, respectively) (Table 3).

Table 3. Diarrhea cases per country by age and gender

	Age					Gender	
	Under 5 yrs (n=1958)	5 to 15 yrs (n=534)	15 to 30 yrs (n=759)	30 to 60 yrs (n=722)	Over 60 yrs (n=134)	Male (n=1777)	Female (n=2330)
COUNTRY							
Burkina Faso	211 (10.8%)	39 (7.3%)	35 (4.6%)	18 (2.5%)	4 (3.0%)	159 (8.9%)	148 (6.4%)
Ethiopia	58 (3.0%)	32 (6.0%)	27 (3.6%)	19 (2.6%)	2 (1.5%)	57 (3.2%)	81 (3.5%)
Ghana	613 (31.3%)	98 (18.4%)	111 (14.6%)	146 (20.2%)	53 (39.6%)	282 (15.9%)	739 (31.7%)
Guinea-Bissau	239 (12.2%)	33 (6.2%)	8 (1.1%)	10 (1.4%)	0 (0%)	157 (8.8%)	133 (5.7%)
Kenya	210 (10.7%)	46 (8.6%)	23 (3.0%)	23 (3.2%)	0 (0%)	142 (8.0%)	160 (6.9%)
Madagascar	335 (17.1%)	167 (31.3%)	318 (41.9%)	312 (43.2%)	41 (30.6%)	529 (29.8%)	644 (27.6%)
Senegal	80 (4.1%)	71 (13.3%)	159 (20.9%)	79 (10.9%)	20 (14.9%)	247 (13.9%)	162 (7.0%)
South Africa	126 (6.4%)	6 (1.1%)	38 (5.0%)	58 (8.0%)	3 (2.2%)	105 (5.9%)	126 (5.4%)
Sudan	9 (0.5%)	32 (6.0%)	22 (2.9%)	30 (4.2%)	7 (5.2%)	40 (2.3%)	60 (2.6%)
Tanzania	77 (3.9%)	10 (1.9%)	18 (2.4%)	27 (3.7%)	4 (3.0%)	59 (3.3%)	77 (3.3%)

Figure 1.Map of Africa, highlighting study sites and the yearly diarrhea cases per each study year

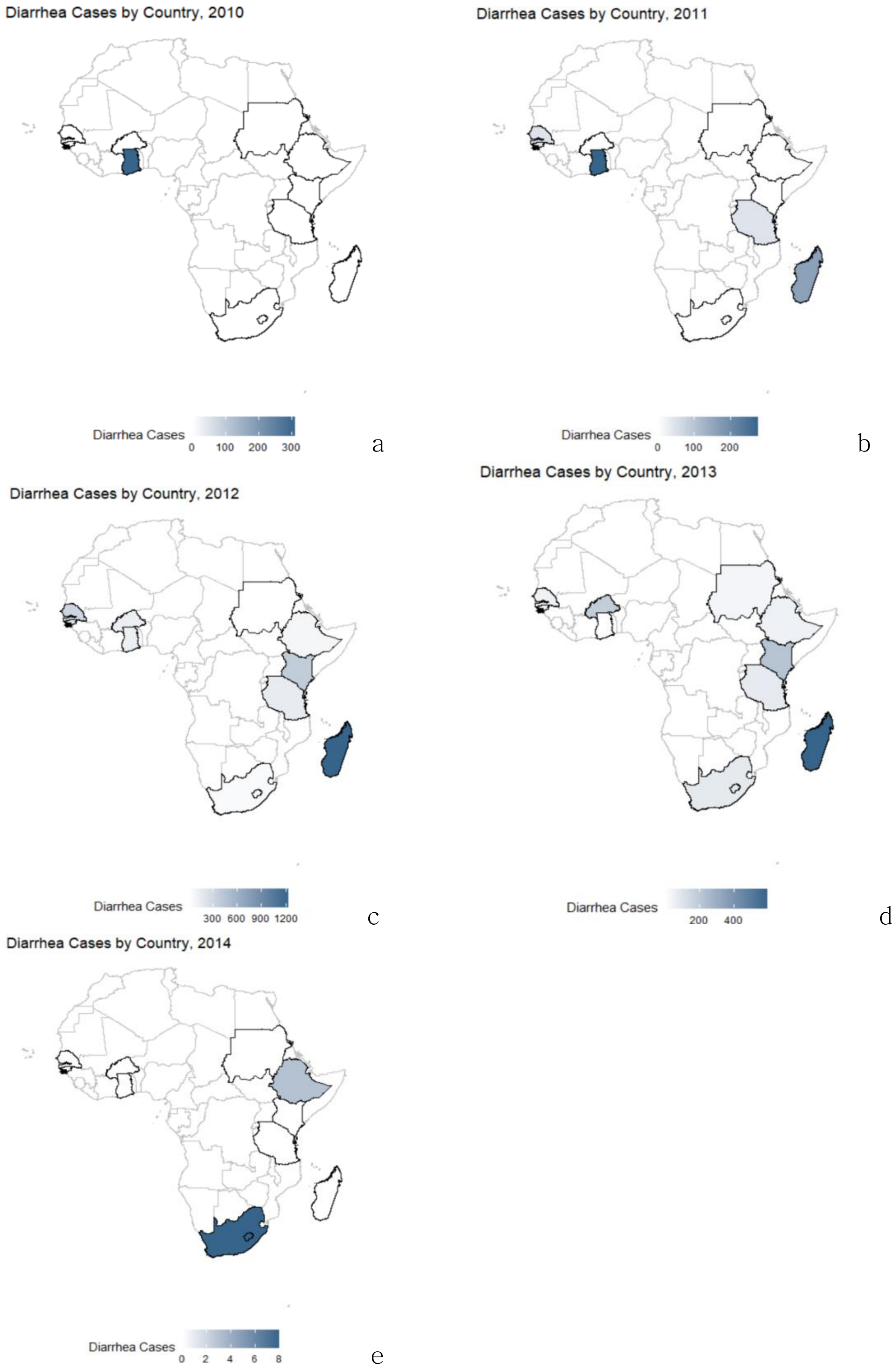
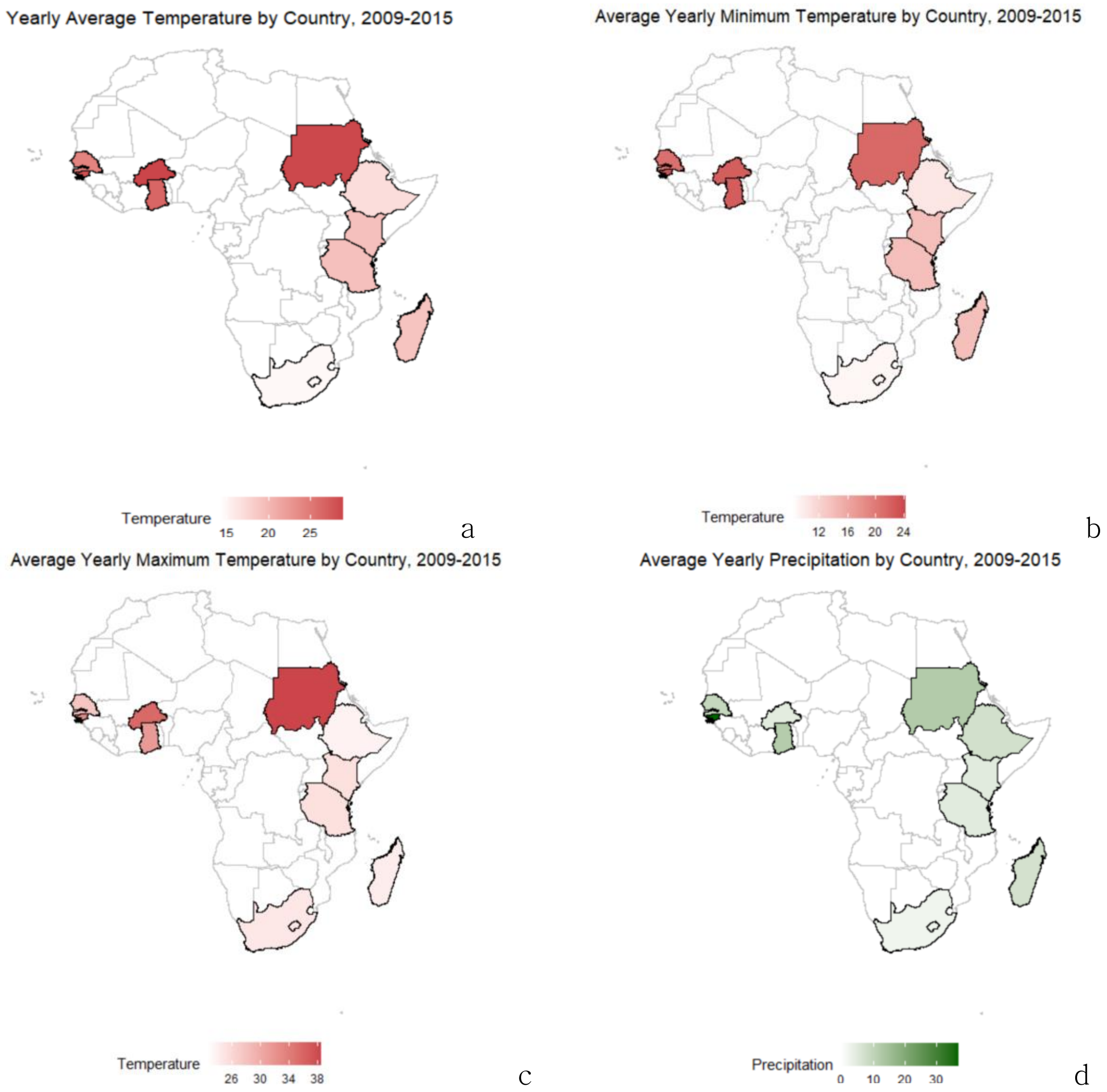


Figure 2. Map of the Africa, highlighting the study sites and 7-year averages of climate drivers



The maps showing the distribution of temperature (maximum, average, minimum) and precipitation for each country for the period of 2009-2015 graphically highlight the differences between the countries. (Fig 2 a-c) However, the pattern of each annual average maximum, minimum and average temperature were similar across the countries. The four countries in West Africa (Senegal, Guinea-Bissau, Ghana, Burkina Faso) and Sudan had the highest average temperatures for all- maximum, minimum, and average temperature ranging around 40, 25 and 30 degrees Celsius, respectively.

The monthly time plots of average temperature, precipitation and diarrhea gave an overview of the seasonality and trends for each country and highlighted the gaps in precipitation data and fluctuations of diarrhea cases during the study periods of each country. (Fig A-1 in Appendix)

3. 2 Statistical analysis results

The non-linear temperature- relative risk of diarrhea plot curves (Fig 3) for Senegal, Sudan, Ethiopia, Kenya, Madagascar, and the pooled estimate showed a positive trend, meaning an increase of unit temperature (degree Celsius) increased the relative risk of diarrhea. The estimates of the quasi-Poisson generalized linear model for temperature were statistically significant only for Sudan and Ethiopia, where an increase per unit temperature, increased the risk of diarrhea by 19 and 53 percent, respectively.

On the other hand, Guinea- Bissau, Burkina Faso, Tanzania, and South Africa showed a negative trend, meaning that an increase in unit temperature decreased the relative risk of diarrhea. Among these countries only Burkina Faso had a statistically significant estimate, where an increase in temperature lowered diarrheal contraction risk by 12 percent (Table 4). Unlike the aforementioned countries, Ghana's plot showed a distinct U-shaped curve.

Figure 3. Non-linear exposure-response plots of temperature and relative risk of diarrhea

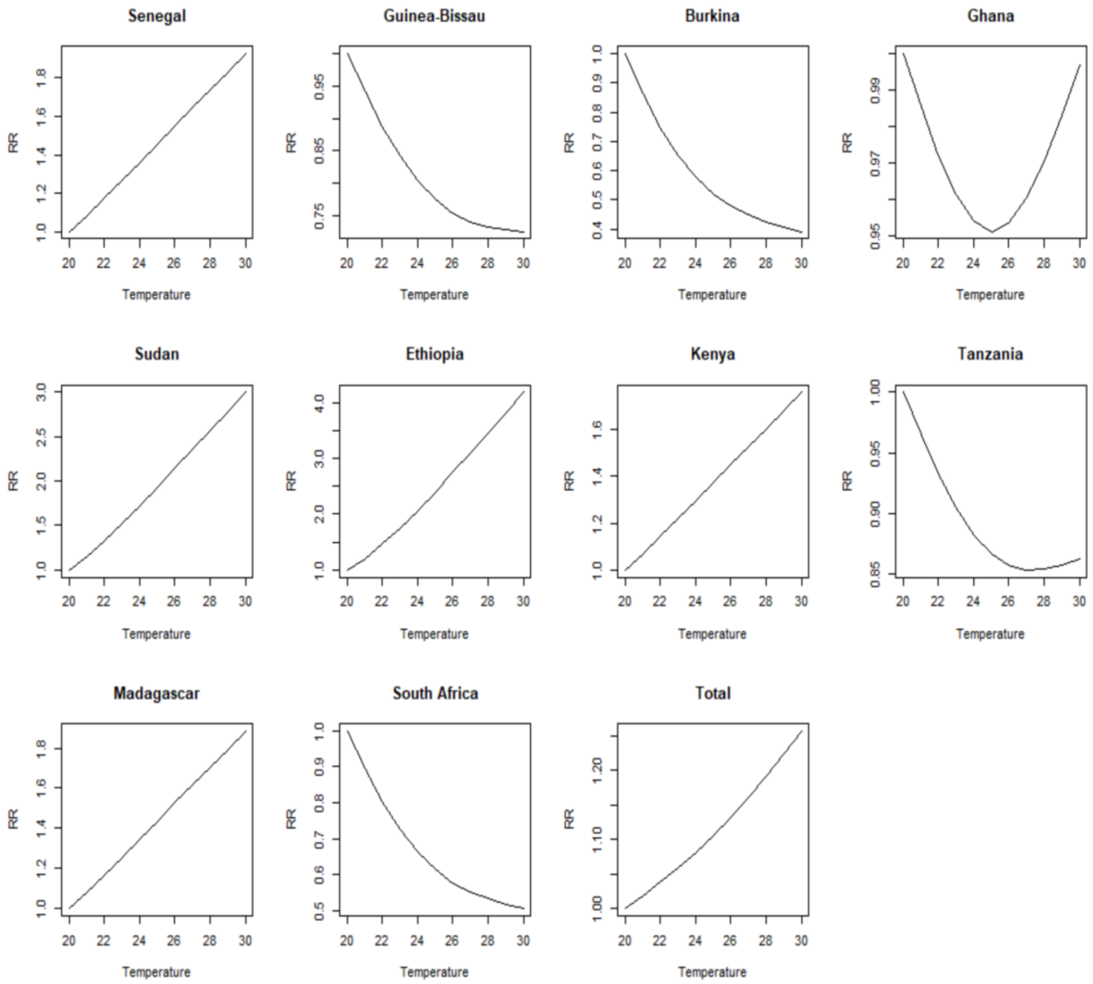


Table 4.Relative Risk of diarrhea per unit increase of temperature

Country	RR (CI)
Senegal	1.09 (0.97 to 1.22)
Guinea-Bissau	0.87 (0.66 to 1.16)
Burkina Faso	**0.88 (0.8 to 0.96) ***

Ghana	1 (0.83 to 1.2)
Sudan	**1.19 (1.01 to 1.4) ***
Ethiopia	**1.53 (1.2 to 1.95) ***
Kenya	1.17 (0.92 to 1.49)
Tanzania	0.94 (0.72 to 1.23)
Madagascar	1.21 (0.87 to 1.69)
South Africa	0.86 (0.73 to 1)
Total	1.04 (0.93 to 1.17)

*- statistical significance

The non-linear precipitation- risk ratio plot curves (Fig 4) for eight countries, excluding Guinea-Bissau and Sudan, and the pooled estimate generally showed a positive linear trend, meaning a unit increase in rainfall increased the risk of diarrhea. Any fluctuation of the curve seemed to take place after around 20mm of precipitation, where in Ghana and Madagascar the slope turned negative and in Senegal positive.

The estimates of the quasi-Poisson generalized linear model for precipitation (adjusted for temperature), were also generally positive, besides Burkina Faso, Madagascar, and South Africa, that showed a non-statistically significant negative association. However, Ethiopia's, Kenya's and the total pooled estimate showed statistically significant positive associations, with the risk of diarrhea increasing by six percent for both Ethiopia and Kenya and by three percent for all countries (Table 5) per unit increase of rainfall.

Figure 4. Non-linear exposure-response plots of precipitation and relative risk of diarrhea

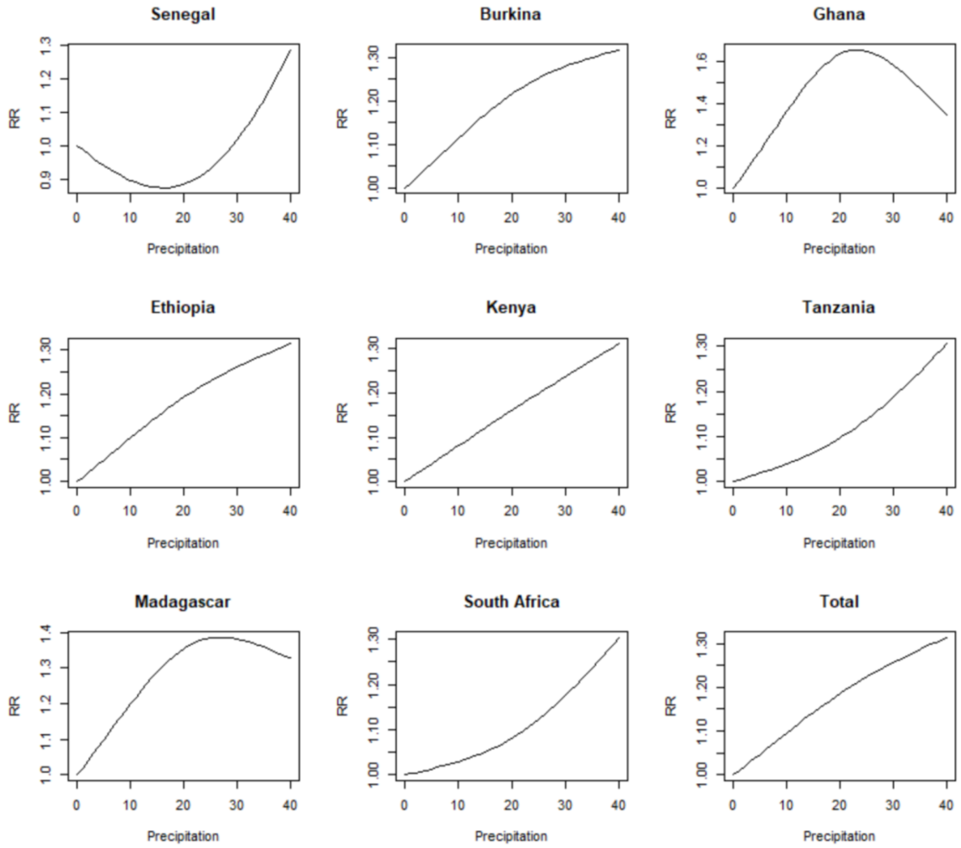


Table 5.Relative risk of diarrhea per unit increase of precipitation

Country	RR (CI)
Senegal	1.02 (0.98 to 1.06)
Burkina Faso	0.98 (0.91 to 1.06)
Ghana	1.07 (0.92 to 1.24)
Ethiopia	**1.06 (1.01 to 1.1) ***
Kenya	**1.06 (1 to 1.11) ***
Tanzania	1.01 (0.94 to 1.09)
Madagascar	0.96 (0.84 to 1.1)
South Africa	0.97 (0.87 to 1.08)
Total	**1.03 (1.01 to 1.05) ***

(The analysis was adjusted for temperature and Guinea-Bissau & Sudan were excluded from the model)

*- statistical significance

The analysis of the interaction between precipitation and temp on the risk of diarrhea showed no statistically significant interaction. (Table 6)

Table 6. Results of risk ratio for diarrhea by interactions between precipitation and temperature

Country	RR (CI)	PI (CI)
Senegal	1 (0.8 to 1.24)	-0.45 (-20.23 to 24.24)
Burkina Faso	0.98 (0.96 to 1.01)	-1.83 (-4.2 to 0.6)
Ghana	1.01 (0.94 to 1.09)	1.23 (-6.29 to 9.34)
Ethiopia	1.03 (0.97 to 1.1)	3.04 (-3.16 to 9.64)
Kenya	0.97 (0.89 to 1.06)	-2.84 (-11.09 to 6.17)
Tanzania	0.93 (0.83 to 1.04)	-7.31 (-17.27 to 3.84)
Madagascar	0.98 (0.92 to 1.04)	-1.9 (-7.88 to 4.46)
South Africa	1.02 (0.97 to 1.07)	1.6 (-3.2 to 6.64)
Total	0.99 (0.97 to 1.01)	-0.95 (-2.74 to 0.87)

(Guinea-Bissau & Sudan were excluded from the model)

The group analysis results for relative risk of diarrhea for average temperature were not statistically significant but showed a negative association for countries to the West and positive association for those to the East of the continent. (Table A-4 in Appendix).

The geographically grouped analysis for relative risk of diarrhea for precipitation showed a statistically significant four percent increase risk of diarrhea contraction per increase of rainfall for countries located to the East (Ethiopia, Kenya, Tanzania, Madagascar, and South Africa). (Table A-5 in Appendix)

The subgroup analysis results for the association of all-cause diarrhea with average temperature and precipitation by age group showed;
For average temperature-diarrhea association in the under five years of age group, most countries showed a positive association, besides Burkina Faso, Guinea-Bissau, Tanzania, and South Africa (statistically not significant). Two countries had statistically significant estimates, with Burkina Faso showing a 16% reduced risk and Ethiopia a 66% increased risk of diarrhea per degree Celsius increase of average temperature for individuals under the age of five years old.
Similarly, in the above five age group, a positive association was seen in most countries, besides Burkina Faso, Guinea-Bissau, and Ghana (statistically not significant). Ethiopia had the only statistically significant estimate of a 45% increased risk of diarrhea per degree Celsius increase of average temperature. (Fig A-2 &3; Table A-7 in Appendix)

For the precipitation-diarrhea association in the under-five age group, a statistically not significant association was found in most countries besides Burkina Faso and South Africa. Senegal, Kenya, and Ethiopia had statistically significant estimates of 8% for Senegal and Kenya, and 7% for Ethiopia increased risk of diarrhea per unit increase of rainfall. In the above five age group, similar trends were observed with negative associations for Burkina Faso and Madagascar (all estimates were statistically not significant). (Fig A-6 & 7; Table A-8 in Appendix)

The subgroup analysis results for the association of all-cause diarrhea with average temperature and precipitation by gender showed;
The average temperature-diarrhea non-linear plots for males, for most countries followed a generally positive linear trend, besides Guinea-Bissau and Burkina Faso. (Fig A-4 in Appendix) The generalized linear model estimates followed the same trend with Sudan and Ethiopia having have statistically significant values of 50% and 61% increase risk of diarrhea per degree Celsius increase in temperature. On the other hand, in the non-linear plots for females, only half the countries showed a positive trend and the total pooled estimate a negative one.(Fig A-5) The results of the generalized linear model were statistically significant only for Ethiopia with a 50% increased risk of diarrhea per unit increase in temperature for females. (Table A-9 in Appendix)

The precipitation-diarrhea non-linear plots for males had a generally positive trend with Ghana and Madagascar having a bell-shaped curve peaking at about 20mm of precipitation. (Fig A-8 in Appendix) The generalized linear model results were generally positive but not statistically significant. However, the estimate for the Ethiopian site for females was statistically significant with a 11% increased risk of diarrhea per unit increase of precipitation. (Table A-10 in Appendix)

The non-linear plots for females (Fig A-9 in Appendix) had a generally positive linear trend, besides Senegal and South Africa showing a U-shaped curve with lowest RR for diarrhea at 20mm precipitation and Ghana showed a slight bell-shaped curve peaking at 20mm rainfall.

4. Discussion

This study identified significant weather-diarrhea relationships likely to be influenced by forecasted climate changes in the region. The statistical models run for each country, highlighted the importance of weather and its influence on diarrhea by providing numerical evidence of the relationship for each country individually and for the region.

According to previous studies, increased temperature has been associated with increased diarrheal disease, as warmer temperatures can cause an increase of pathogen proliferation in food and water sources. Such an association was found in a study examining the correlation between temperature and childhood diarrhea in 14 sub-Saharan African countries, where a one-degree Celsius increase in the average maximum temperature increased diarrhea prevalence by one percent

(Bandyopadhyay, S.; Kanji, S. 2012).

In our study we also found positive associations for five of the ten study sites (two of which statistically significant – Sudan and Ethiopia) and for all the sites combined, showing a (statistically not significant) four percent increase risk of diarrhea per one-degree temperature increase in the region for all age groups.

However, in our study previously unobserved results of negative associations between temperature and risk of diarrhea were found. Four countries (Guinea-Bissau, Tanzania, Burkina Faso, South Africa), showed a clear negative trend, with Burkina Faso having a statistically significant estimate for all age groups.

Probable factors affecting such trend could, among others, be the sites; sanitary infrastructure and water management, access, and use, its' natural environment, climatic pattern, urbanization, and behavior of the population.

If the site has a better sanitation infrastructure and water management, increased temperatures could lower soil moisture, drying contaminated regions with fecal matter, and lowering spread and consequent ingestion of pathogens through contaminated food or water. (Mertens et al 2019)

Results of the Ghana site for the whole population are difficult to interpret, especially from the exposure-response plots' U-shaped curve. This could have come as a result of inconsistent data, strange climatic patterns or events, or differences in the population. The results of the subgroup analysis suggest the U-curve could be related to the gender composition of the population. With the right arm of the curve following the same negative slope as that seen in the exposure-response plot for females. This trend goes till 26 degrees Celsius, after which the slope turns positive. The majority of enrolled subjects in the Ghana study site were female, consequently possibly influencing the trend seen in the results for the whole population.

The increased risk of diarrhea in males and decreased risk in females per unit change of temperature, could come mostly as a result of differences in behavior and exposure. Females' decreased risk could be a result of higher hygiene practice awareness as they are usually the ones to prepare meals and clean the households, whereas males could be more at risk as they might work and eat outside in unhygienic conditions. This trend and reasoning could be expanded to sites other than Ghana, as well as the whole region, as seen from both the exposure-response plots and the generalized linear model estimates.

The higher prevalence of diarrhea cases in the under-five population could be related to the ingestion of pathogens through contaminated hands because of their hand-to-mouth behavior. (Mertens et al 2019)

Rainfall is a more complex meteorological variable as a significant increase can lead to flooding that in weak infrastructural settings, may contaminate fresh water with sewage matter, or reductions in rainfall can result in water shortages that may require unhealthy water consumption, decreasing hygiene practices and increasing risk of contracting diarrheal disease. (Horn, L. M., Hajat, A. 2018)

A study conducted in Botswana concluded that forecasted climate change increases in temperature and decreases in precipitation with hot, dry conditions starting earlier and lasting longer, increased the incidence of dry seasonal diarrheal disease. (Alexander K., Carzolio M, 2013) In contrast, a study in Mozambique found increased cases of diarrheal disease in the weeks following a precipitation event or temperature increase. (Horn, L. M., Hajat, A. 2018)

In our study, precipitation- diarrhea association results were generally positive when observing the exposure-response plots. Lack of data coverage made it impossible to include all countries in the model, hence the results estimate only eight countries (Senegal, Burkina Faso, Ghana, Ethiopia, Kenya, Tanzania, Madagascar, and South Africa). (Dinku T, 2019) Caution must be practiced when trying to interpret such results, considering the lack of data, seasonality, and short-term fluctuations of precipitation. Additional analysis and precipitation data imputation should be conducted to try to provide a more comprehensive understanding of the precipitation- diarrhea relationship.

Generally, our results were consistent with those of other studies, with differences in estimation or trends possibly stemming from differences in study periods, data quality, chosen statistical models and additional variables unadjusted for in the models of our study (socioeconomic, behavioral variables etc.). (Alexander K et al, 2013), (Horn, L et al, A. 2018) (Bandyopadhyay, et al. 2012).

Country and regional differences of the associations, in our study, might not only come because of the environmental and climatic differences within and between the countries and regions but also from demographic, socioeconomic and behavioral differences of the peoples.

According to previous studies, such factors including sanitation and hygiene practices, water source usage and management, strongly influence diarrheal diseases. Additionally, nutritional status especially, among children, can also generally influence disease susceptibility and particularly diarrheal disease (Alexander K., Carzolio M, 2013).

This study investigated self-reported all-cause diarrhea cases, and as it can be caused by various pathogens, patterns could also emerge as a result

of transmission dynamics influenced by pathogen-host characteristics and interactions. Transmission can occur due to numerous interdependent pathways, as direct transmission between hosts, or indirectly through vectors or environmental contaminations. Environments with numerous kinds of diarrhea causing pathogens might mask its' detailed interactions with meteorological factors. (Alexander K., Carzolio M, 2013)
Some studies have suggested higher temperature to be associated with increased diarrhea cases of a bacterial nature (D'Souza,2004; Zhang,2008) whereas lower temperature to increase viral diarrhea. (D'Souza ,2008; Konno,1983) In our study, Burkina Faso's protective effect of higher average temperatures on diarrhea could be suggestive of a viral infection, possibly rotavirus. The latter, a common viral diarrhea pathogen, was found to decrease in higher temperatures in a meta-analysis of influential factors of infection. (Levy et al. 2016)
Additionally, considering that different pathogens have different incubation periods, a lag effect might be important to analyze when investigating the interactions of a weather event and health response. (Health Protection Surveillance Centre,2012). Considering the use of passive fever surveillance data, recording self-reported all-cause diarrhea, not confirmed in a laboratory, our study was restricted by sample size to use monthly count data making it difficult to implement a lag effect.

Limitations

Though this study has the potential to fill in gaps of the available literature for the African continent, it comes with its own set of limitations.

The health outcome (all-cause diarrhea) was self-reported by the participants of the TSAP study, which itself was not designed to capture such cases, as it was a passive fever surveillance study. This could have led to low recording and missed cases of diarrhea.

This small sample size made it difficult to use finer time scales than monthly count data. In addition, the short time frame of the TSAP study conduct, brought difficulties in finding a more appropriate statistical model for the association of diarrhea to weather indicators and makes it difficult to make any conclusions regarding climate change in the countries individually and the continent as a whole.

The available weather variables were few, mainly average temperature and precipitation and data coverage for the latter was low, making it difficult to infer appropriate results. TSAP was conducted in specific study sites, where nearby weather stations were not always located, hence the closest possible station was used (the weather data for the Tanzania study site was the same as the one for Kenya). The study results could therefore be influenced by differences in the distance, elevation, and overall surrounding environment of the weather station to that of the health clinic of the site. Such differences are important to consider, especially for precipitation, as it is not only dependent on temperature but also among others, on atmospheric pressure, humidity, wind direction and velocity. There could also be differences between weather stations in terms of record keeping and the quality of recording instruments, as might be inferred by the noted differences in data coverage and availability. The uncertainty of the exact weather at each site could have led to exposure misclassification, and the low temporal resolution of both the exposures and outcomes may have led to bias. (Mertens et al 2019)

Demographic, socioeconomic, and behavioral factors are important when studying health outcomes as they greatly affect an individual's risk of contracting a disease and/or developing a morbidity. Unfortunately, this information was not included in the TSAP dataset and therefore, it was not accounted for in the models. Additionally, there was no information about the study sites, the sanitary infrastructure, the availability of water and its management and usage by the population. It should be noted the inclusion of such variables be accounted for in future analysis.

The aforementioned limitations are not unique to this study and can be found in similar studies investigating associations of weather variables and diarrhea. (Mertens et al 2019) (Dinku T, 2019) (Horn, L. M., Hajat, A. 2018)

Strengths

Even though there is available literature investigating climate and infectious diseases, there are few that focus on multi-country or regional analysis of diarrhea for the African continent. (Dinku T, 2019). This study would be one of the few to make use of available geographically representative data for a multi-site study covering multiple countries and important climatic regions of the continent.

Conclusion

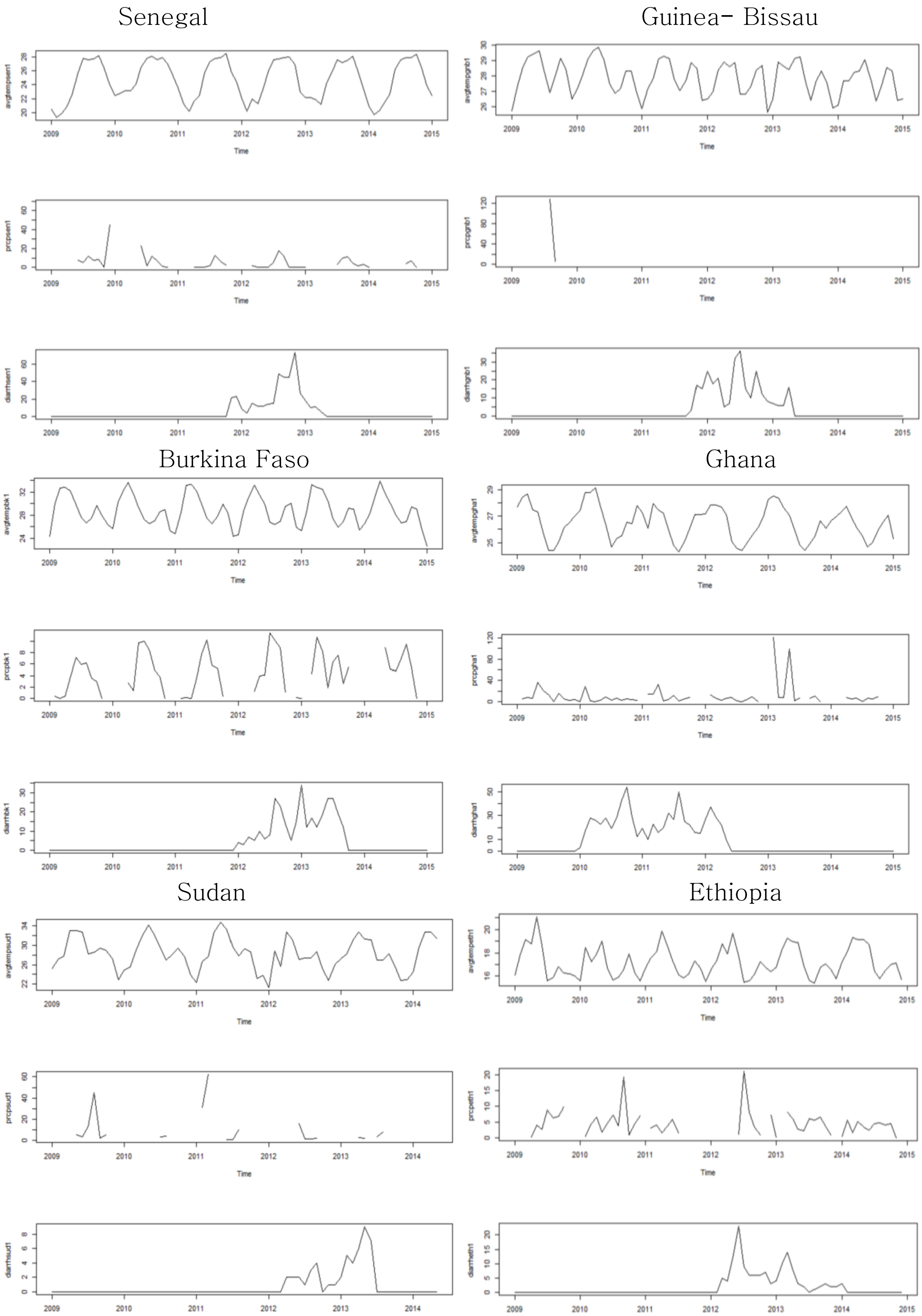
This study identifies strong meteorological signature of diarrhea case prevalence in sub-Saharan Africa and highlights the potential vulnerability of the region to further increase under climatic changes. Diarrhea as a major public health problem, poses a threat to a big proportion of populations in low and middle- income countries. This study may not have exactly indicated the occurrence of diarrheal cases due to climate change but has potentially been successful in accounting for sites previously not studied for and in conducting a climatically diverse multi-site study for a big region of the African continent. It is recommended further studies be carried out including primary data for water use and management, sanitation and disease control programs as well socio-cultural factors and other factors related to health system.

5. Appendix

Table A- 1. Distribution of diarrhea cases for each country by study year

	2010 (n=378)	2011 (n=684)	2012 (n=2096)	2013 (n=938)	2014 (n=11)	Total (n=4107)
COUNTRY						
Ghana	378 (100%)	494 (72.2%)	149 (7.1%)	0 (0%)	0 (0%)	1021 (24.9%)
Guinea-Bissau	0 (0%)	35 (5.1%)	218 (10.4%)	37 (3.9%)	0 (0%)	290 (7.1%)
Madagascar	0 (0%)	89 (13.0%)	749 (35.7%)	335 (35.7%)	0 (0%)	1173 (28.6%)
Senegal	0 (0%)	44 (6.4%)	320 (15.3%)	45 (4.8%)	0 (0%)	409 (10.0%)
Tanzania	0 (0%)	22 (3.2%)	78 (3.7%)	36 (3.8%)	0 (0%)	136 (3.3%)
Burkina Faso	0 (0%)	0 (0%)	127 (6.1%)	180 (19.2%)	0 (0%)	307 (7.5%)
Ethiopia	0 (0%)	0 (0%)	82 (3.9%)	53 (5.7%)	3 (27.3%)	138 (3.4%)
Kenya	0 (0%)	0 (0%)	194 (9.3%)	108 (11.5%)	0 (0%)	302 (7.4%)
South Africa	0 (0%)	0 (0%)	128 (6.1%)	95 (10.1%)	8 (72.7%)	231 (5.6%)
Sudan	0 (0%)	0 (0%)	51 (2.4%)	49 (5.2%)	0 (0%)	100 (2.4%)

Fig A- 1. Time -Series plots of average temperature, precipitation, and diarrhea cases per country



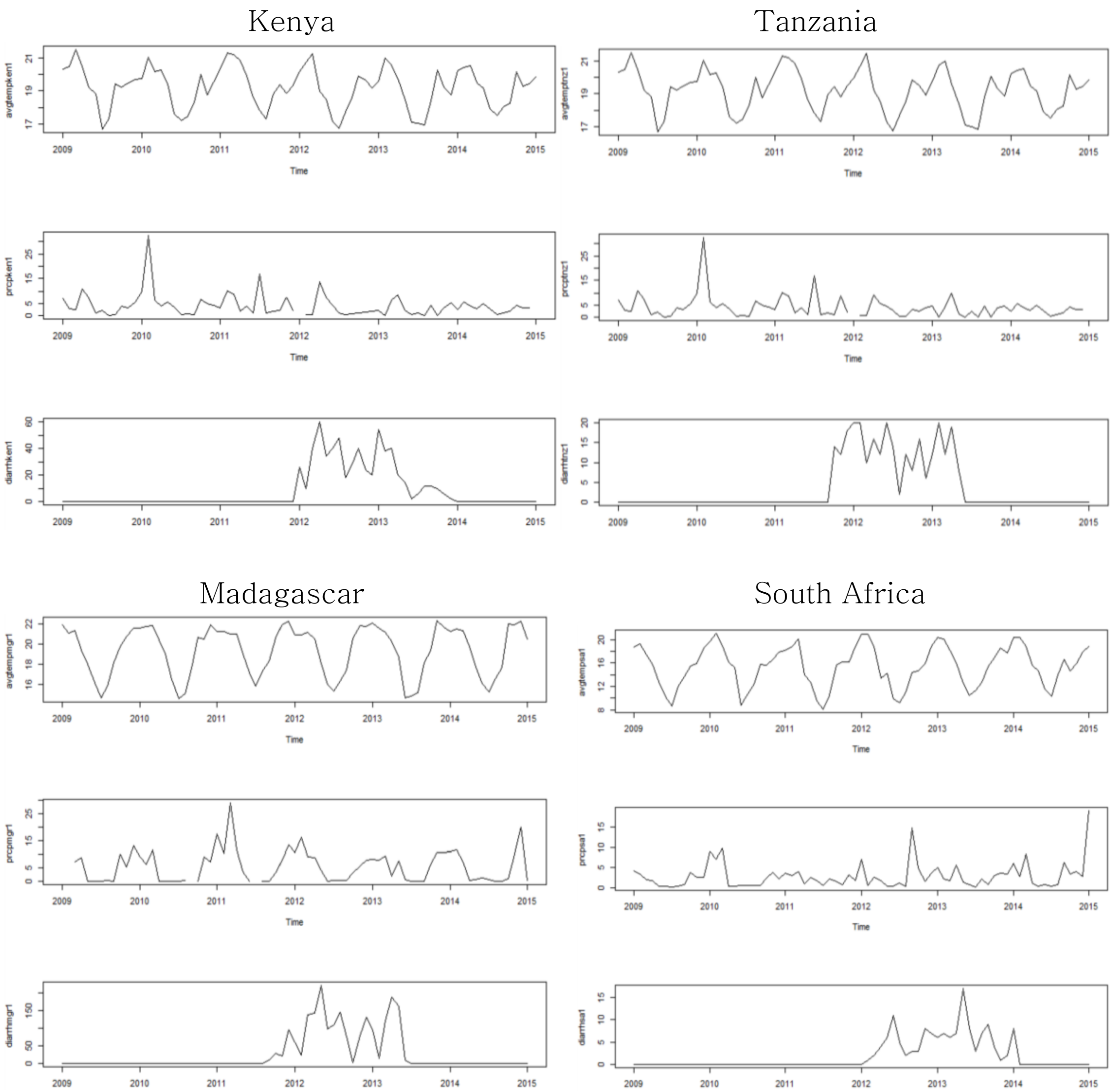


Table A- 2. Climate characteristics & seasons by country

Country	Climate	Rainy Season	Dry Season
Senegal	Tropical	June – October	December – April
Guinea-Bissau	Tropical	June – November	December – May
Ghana	Tropical	May – October	November – March
Burkina Faso	Tropical	May/June-September	November – March
Sudan	Equatorial/Tropical climate	April – November	December -April/ November -May
Ethiopia	Tropical	June – September	October – February
Kenya	Tropical (coast) Temperate (inland)	March/April – May/June	October – November/December
Tanzania	Tropical	Uni-modal (October-April)	January & February
		Bi-modal (October-	June to mid-

		December & March-May)	October
Madagascar	Tropical (coast)/Temperate (inland)/Arid (south)	November to April	August to December
South Africa	Temperate	November -March	June to October

Table A- 3.Seasonal temperature characteristic by country

Country	Hot period	Cool Period
Senegal	July - November	February
Guinea-Bissau	March & April	December & January
Ghana	November - May	July - September
Burkina Faso	April	August
Sudan	January - April	June - September
Ethiopia	April-June	November & December
Kenya	February-March	July to mid-August
Tanzania	November - February	May - August
Madagascar	November to April	July
South Africa	November to March	May-August

Table A- 4. Risk ratio of diarrhea for average temperature for grouped countries

a. Grouped based on geolocation

Geo Grouped	RR (CI)
West	0.96 (0.86 to 1.09)
East	1.12 (0.94 to 1.33)

b. Grouped based on annual average temperature

Temperature Group	RR (CI)
1	1 (0.89 to 1.13)
2	1.11 (0.89 to 1.37)

c. Grouped based on the expose-response plots

Temperature Group	RR (CI)
1	1 (0.89 to 1.13)
2	1.11 (0.89 to 1.37)

1-Countries showing a positive trend
2-Countries showing a negative trend

Table A- 5. Risk ratio of diarrhea for precipitation for geographically grouped countries

Geo Grouped	RR (CI)
West	1.01 (0.98 to 1.05)
East	**1.04 (1.01 to 1.07) ***

(In the analysis Guinea-Bissau & Sudan were excluded)
*- statistically significant

Table A- 6. Risk ratio of diarrhea for interaction of temperature and precipitation

Geo Grouped	RR (CI)
West	0.98 (0.96 to 1.01)
East	1 (0.97 to 1.03)

(In the analysis Guinea-Bissau & Sudan were excluded)

Table A- 7. Risk ratio of diarrhea for average temperature per age group

Country	RR (CI) under 5 yrs	RR (CI) over 5 yrs
Senegal	1.1 (0.79 to 1.55)	1.07 (0.95 to 1.2)
Guinea-Bissau	0.86 (0.64 to 1.16)	0.92 (0.63 to 1.34)
Burkina Faso	**0.85 (0.76 to 0.94) ***	0.93 (0.78 to 1.1)
Ghana	1.06 (0.86 to 1.32)	0.95 (0.77 to 1.16)
Sudan	1.3 (0.38 to 4.54)	1.18 (0.91 to 1.53)
Ethiopia	**1.66 (1.18 to 2.33) ***	**1.45 (1.07 to 1.96) ***
Kenya	1.23 (0.89 to 1.71)	1.04 (0.77 to 1.41)
Tanzania	0.81 (0.52 to 1.26)	1.01 (0.76 to 1.36)
Madagascar	1.42 (0.96 to 2.11)	1.17 (0.81 to 1.7)
South Africa	0.91 (0.75 to 1.12)	1.04 (0.87 to 1.23)
Total	1.05 (0.9 to 1.22)	1.04 (0.98 to 1.12)

Table A- 8.Risk ratio of diarrhea for precipitation per age group

Country	RR (CI) under 5 yrs	RR (CI) over 5 yrs
Senegal	**1.08 (1.03 to 1.13) ***	1 (0.95 to 1.05)
Burkina Faso	0.99 (0.91 to 1.06)	0.98 (0.83 to 1.17)
Ghana	1.08 (0.92 to 1.27)	1.05 (0.9 to 1.23)

Ethiopia	**1.07 (1 to 1.15) ***	1.06 (0.98 to 1.13)
Kenya	**1.08 (1 to 1.16) ***	1.01 (0.93 to 1.08)
Tanzania	1.04 (0.93 to 1.16)	1 (0.92 to 1.09)
Madagascar	1 (0.86 to 1.18)	0.95 (0.82 to 1.11)
South Africa	0.85 (0.69 to 1.05)	1.04 (0.95 to 1.14)
Total	1.05 (1.02 to 1.08)	1.01 (0.98 to 1.04)

(In the analysis Guinea-Bissau & Sudan were excluded)

*- statistically significant

Table A- 9.Risk ratio of diarrhea for temperature per gender

Country	RR (CI) - Male	RR (CI) - Female
Senegal	1.13 (0.96 to 1.33)	1.04 (0.93 to 1.15)
Guinea-Bissau	0.85 (0.64 to 1.14)	0.9 (0.66 to 1.23)
Burkina Faso	0.86 (0.77 to 0.96)	0.89 (0.79 to 1.01)
Ghana	1.19 (0.87 to 1.63)	0.95 (0.79 to 1.14)
Sudan	**1.5 (1.14 to 1.97) ***	1.04 (0.83 to 1.31)
Ethiopia	**1.61 (1.23 to 2.09) ***	**1.5 (1.06 to 2.12) ***
Kenya	1.21 (0.92 to 1.59)	1.14 (0.84 to 1.55)
Tanzania	0.97 (0.66 to 1.45)	0.82 (0.59 to 1.14)
Madagascar	1.26 (0.9 to 1.76)	1.18 (0.83 to 1.66)
South Africa	0.96 (0.83 to 1.12)	0.98 (0.83 to 1.16)
Total	1.11 (0.97 to 1.28)	1 (0.93 to 1.07)

Table A- 10. Risk ratio of diarrhea for precipitation per gender

Country	RR (CI) - Male	RR (CI) - Female
Senegal	1.03 (0.98 to 1.08)	1.01 (0.97 to 1.05)
Burkina Faso	0.98 (0.89 to 1.08)	0.98 (0.89 to 1.08)
Ghana	1.05 (0.9 to 1.24)	1.07 (0.92 to 1.25)
Ethiopia	0.98 (0.91 to 1.05)	**1.11 (1.04 to 1.19) ***
Kenya	1.05 (0.98 to 1.12)	1.07 (1 to 1.13)
Tanzania	1.05 (0.94 to 1.16)	0.99 (0.91 to 1.08)
Madagascar	0.98 (0.85 to 1.13)	0.94 (0.82 to 1.09)
South Africa	1.01 (0.9 to 1.13)	0.9 (0.79 to 1.04)
Total	1.02 (0.99 to 1.05)	1.02 (0.98 to 1.07)

Fig A-2. Non-linear exposure-response plots of temperature and relative risk of diarrhea for under 5 years old age group

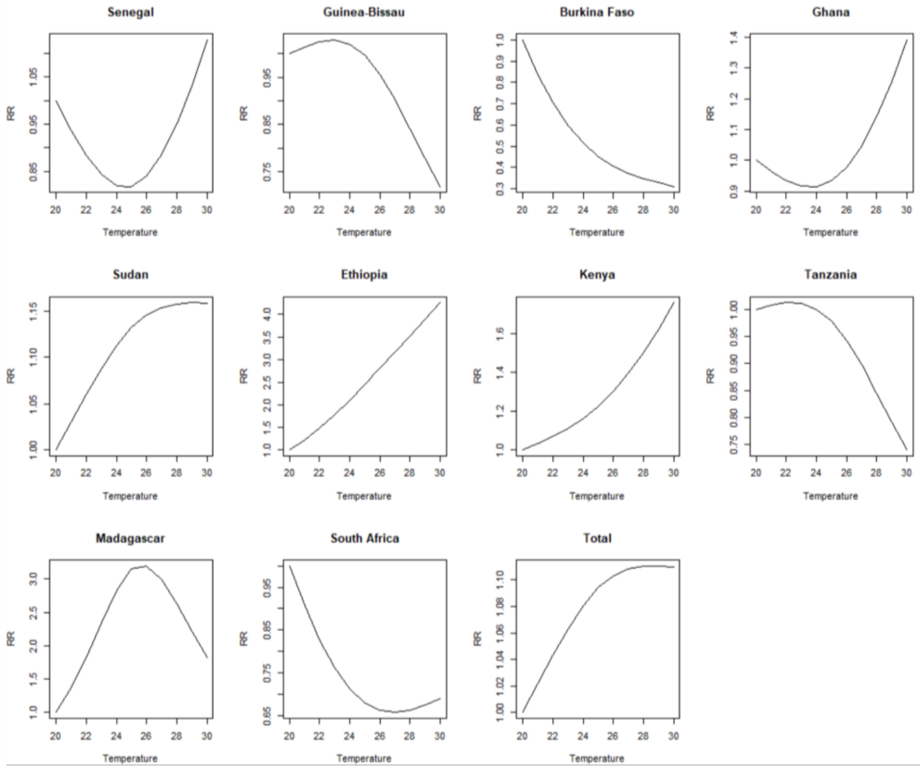


Fig A- 3.Non-linear exposure-response plots of temperature and relative risk of diarrhea for over 5 years old age group

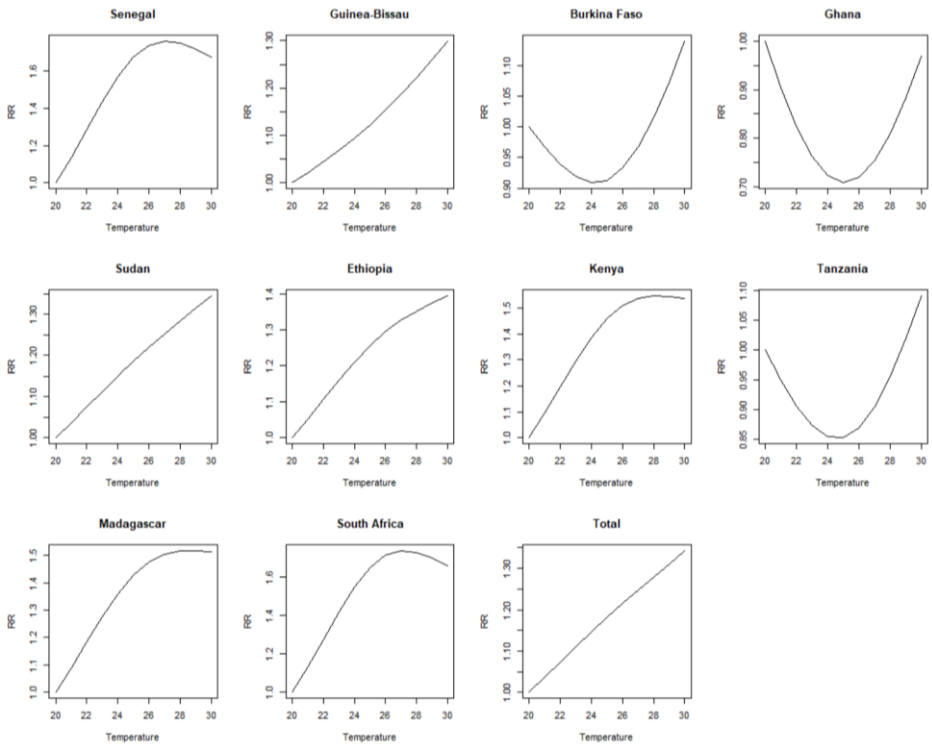


Fig A- 4. Non-linear exposure-response plots of temperature and relative risk of diarrhea for males

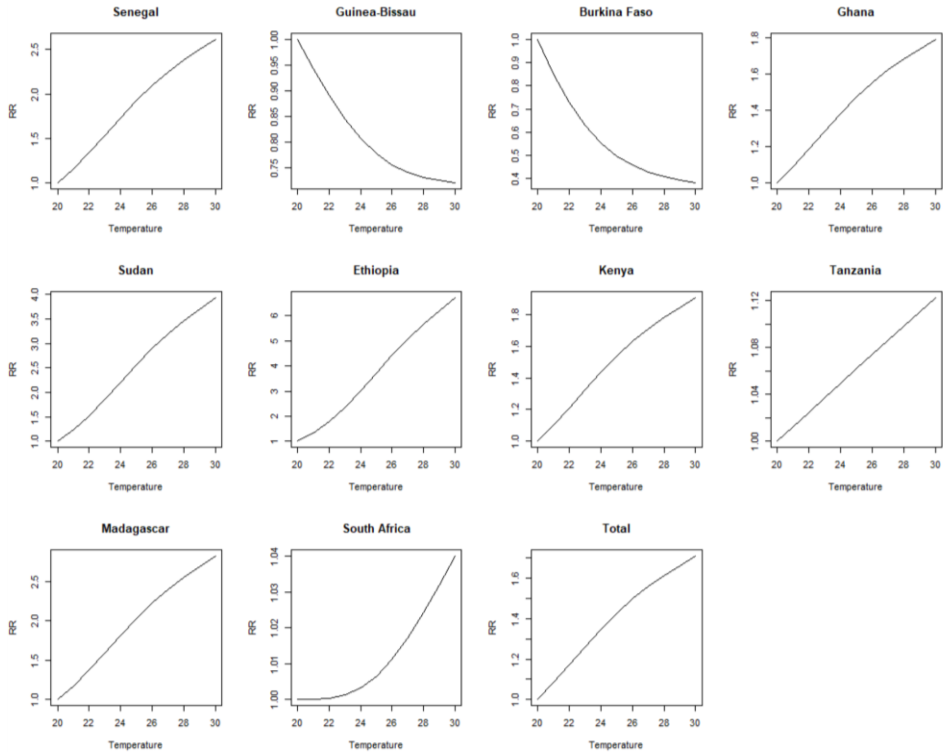


Fig A- 5.Non-linear exposure-response plots of temperature and relative risk of diarrhea for females

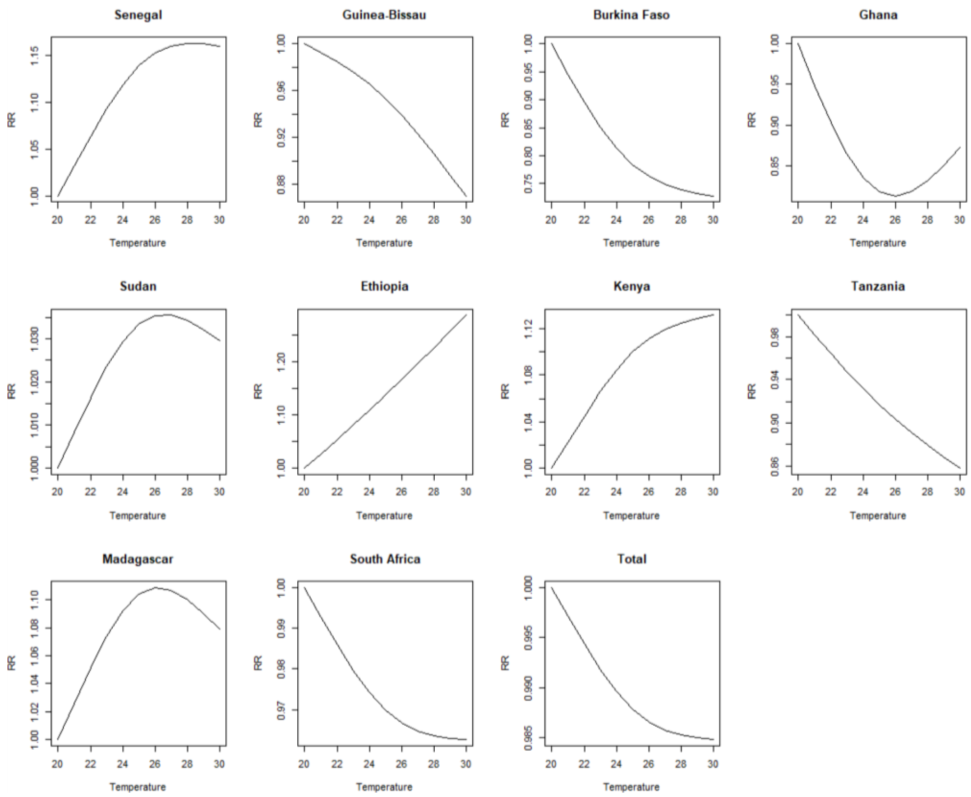


Fig A- 6. Non-linear exposure-response plots of precipitation and relative risk of diarrhea for under 5 years old

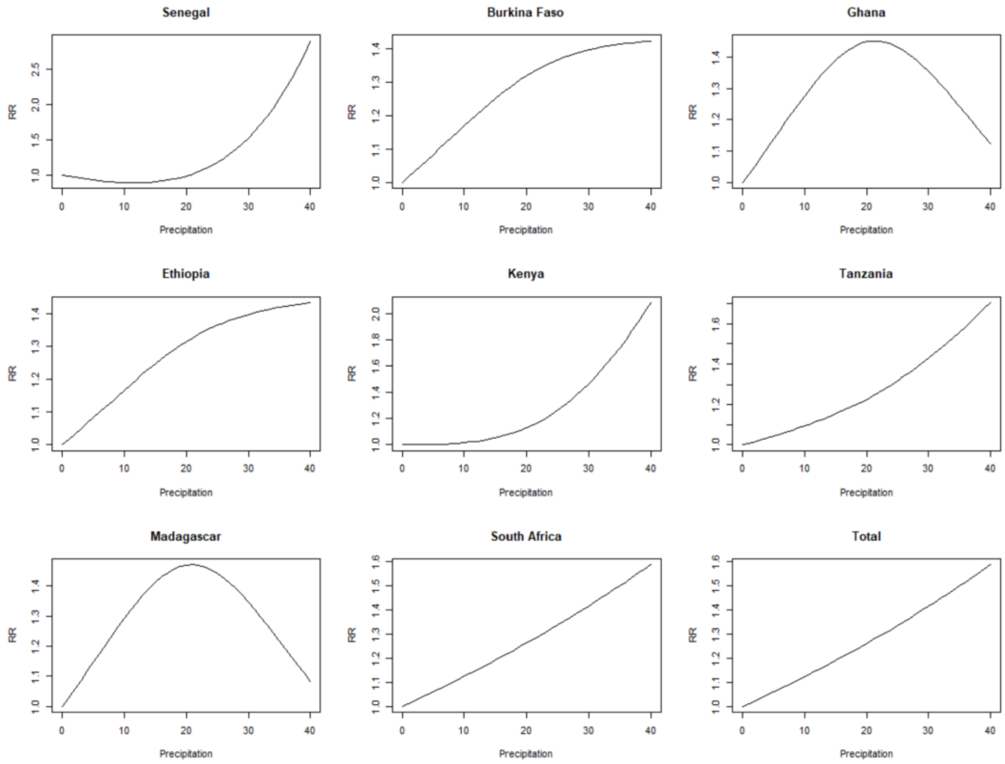


Fig A- 7. Non-linear exposure-response plots of precipitation and relative risk of diarrhea for over 5 years age group

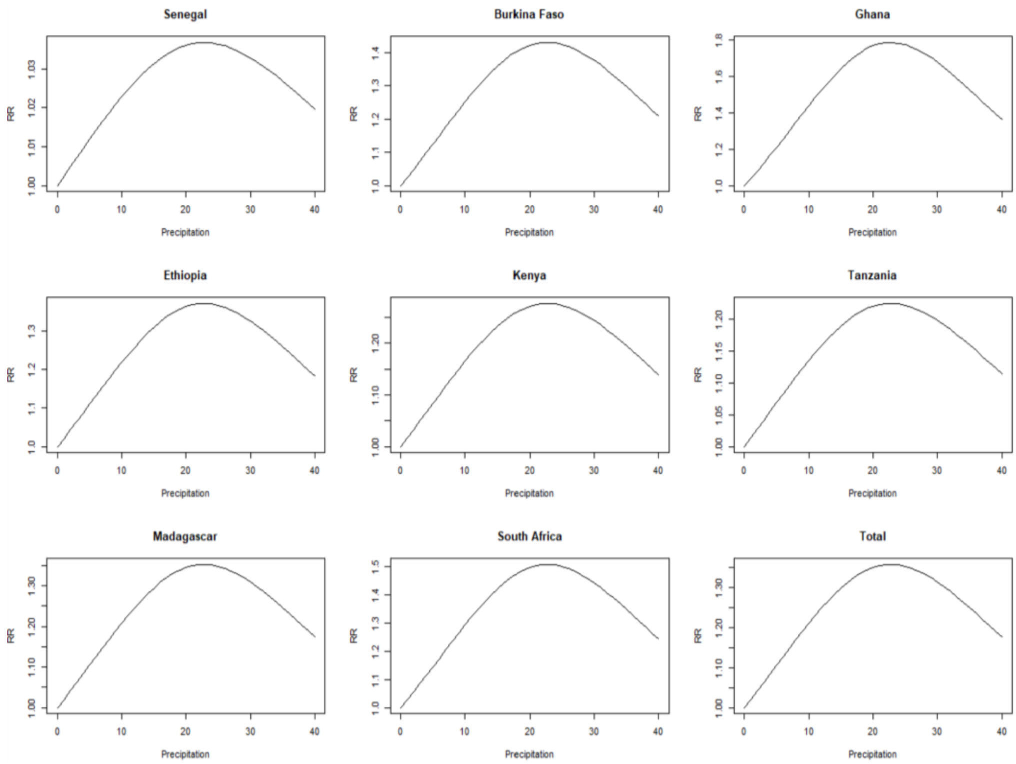


Fig A- 8. Non-linear exposure-response plots of precipitation and relative risk of diarrhea for males

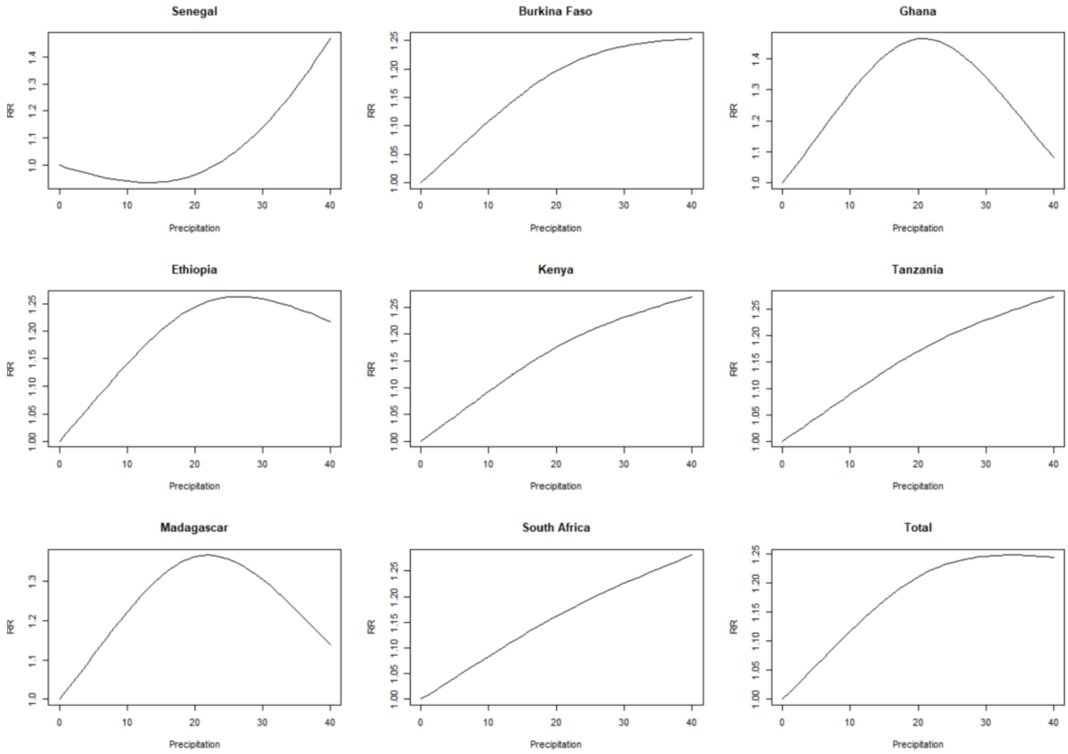
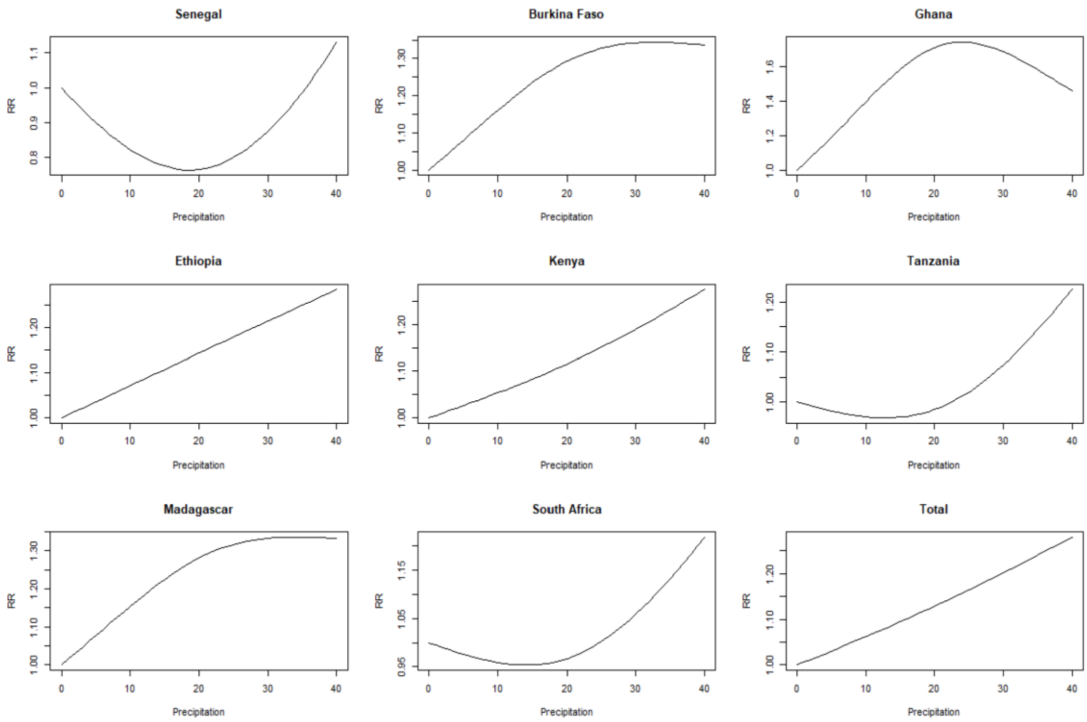


Fig A- 9. Non-linear exposure-response plots of precipitation and relative risk of diarrhea for females



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국문 초록

설사와 온도 및 강수량의 연관성. 사하라 사막 이남의 아프리카 10개 국가들을 대상으로.

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보건학과 보건통계학전공

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본 논문작성자는한국정부초청장학금(Global Korea Scholarship)을 지원받은장학생임

배경: 기후 변화는 경제와 생태계뿐만 아니라, 건강 및 건강의 사회적, 환경적 결정요인에도 영향을 미친다. 아프리카 대륙의 대부분을 차지하는 중하위권 국가들은 기후 변화와 그 영향에 더 취약한 것으로 알려져 있다. 각종 질병, 특히 물과 벡터 매개 질병은 이미 유병률 (즉 콜레라)뿐만 아니라 지리적 변위(즉 말라리아)도 증가하기 시작했다. 다양한 기후 지역으로 구성되어 있고 이미 영양실조와 다양한 전염병으로 고통 받고 있는 아프리카 대륙은 기후 변화 시나리오 하에서 주요한 변화를 겪고 있다. 특히, 5세 미만 아동에게 질병과 사망의 주요 원인으로는 설사 질환이 제시되고 있다.

본 연구는 사하라 이남 아프리카 10개국의 설사에 대한 온도와 강수량 사이의 연관성을 평가하는 것을 목표로 했다.

방법: 기후 요인와 설사 사이의 연관성 분석; 먼저 자유도가 2도인 natural cubic spline을 이용한 비선형 노출-반응 함수를 준-포아송 일반화 선형 모형을 사용하여 모델링 한 다음, 각 나라 및 모든 국가를 합친 결과를 제시한다; 1-평균 온도-설사 사례, 2-강수량과 설사 사례(온도가 제어된), 3-온도 및 강수량의 설사 사례에 대한 교호작용. 계절성은 연간 2df의 natural cubic spline(연구 기간의 월)을 사용하여 모든 모델에서 고려되었다. 둘째, 지리적 위치와 연평균 온도에 기초한 group별 분석은 온도-지질 및 강수-지질 연관성 모두에 대해 실시되었다. 마지막으로 연령과 성별에 대한 Sub-group 분석을 실시했다.

결과: 3개국은 기온과 설사 환자 사이에 통계적으로 유의미한 연관성을 보였다(부르키나파소, 에티오피아, 수단). 부르키나파소는 기온에 대한 protective한 관계(온도 상승당 12%의 설사환자 감소)를 보인 반면 에티오피아와 수단은 위험성이 증가(온도 상승당 설사환자 각 53%, 19% 증가)했다. 강수-지질 모형은 일반적으로 양의 연관성을 보여주었는데, 통계적으로 유의한 추정치는 에티오피아와 케냐와 모든 국가에 대한 합동 추정치였다(강수량 단위 증가 당 이티오피아와 케냐의 경우 설사가 6% 증가, 모든 국가의 경우 3% 증가).

결론: 본 연구의 결과는 온도- 및 강수량과 설사 사례의 연관성을

조사하는 다른 기존 연구들과 일치하며, 이전에 조사되지 않았던 새로운 연구 지역을 포함하여 확장되어 수행되었다. 본 연구 결과는 자원 관리와 할당, 정책 및 교육 프로그램에서 정보에 입각한 의사결정을 내릴 때 중요하게 사용될 수 있다.

키워드: 기온, 강수량, 기후변화, 설사병, 아프리카, GLM, 상대위험도

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