RELATIONSHIP BETWEEN CLIMATE CHANGE AND OCCURRENCE OF INFECTIOUS DISEASES (DIARRHEA, PNEUMONIA AND MALARIA) IN TANGA, TANZANIA

A Thesis Submitted to the
Department of Public Health
School of Health Sciences

University of Eastern Africa, Baraton

In Partial Fulfilment of the Requirements
For the Degree of
Master of Science in Global Health Care

Samweli Faraja Miyayo

December, 2020

APPROVAL SHEET

This thesis/dissertation entitled **Relationship between Climate Change and Occurrence of Infectious Diseases (Diarrhea, Pneumonia and Malaria) in Tanga, Tanzania**

Written and submitted by **Samweli Faraja Miyayo** in partial fulfillment of the requirements for the degree of

Master of Science in Global Health Care

is hereby accepted and approved.

Dr. Patrick O. Owili, PhD, PhD
Supervisor

24/06/2021
Date

Dr. Miriam A. Muga, PhD
Supervisor

24/06/2021
Date

Accepted in partial fulfilment of the requirements for the degree of

Master of Science in Global Health Care

Mr. Khol Helmut, MPH
Department Chair

Date

Prof. Jackie Obey, PhD
School Dean

Date

Dr. Moses Kibirango, PhD
Director of Graduate Studies and Research

Date

DECLARATION

DECLARATION BY THE CANDIDATE

I declare that this thesis is my original work and to the best of my knowledge this work has not been published and/or presented to any University for an award of a degree.

____________________________ 23/06/2021
Samweli Faraja Miyayo, BSc Date

DECLARATION BY SUPERVISORS

This thesis has been submitted for examination with our approval as supervisors at the University of Eastern Africa, Baraton.

____________________________ 24/06/2021
Dr. Patrick O. Owili, PhD, PhD Date

____________________________ 24/06/2021
Dr. Miriam A. Muga, PhD Date

ABSTRACT

Climate change extremes are now a contemporary issue. The Intergovernmental Panel on Climate Change acknowledges that evidence on trends in public health threats, including infectious diseases resulting from climate change, exists. The groups most affected by climate change are those with less ability to adapt to changes, and thus causing concern for their health. There are also several studies in Sub-Saharan Africa that are aimed at understanding the morbidity and mortality of diarrhea, pneumonia and malaria. Nevertheless, literature on the understanding of the relationship between climate change and the occurrence of diarrhea, pneumonia and malaria are limited. This study therefore sought to bridge this gap by exploring the relationship between climate change and the occurrence of infectious diseases (i.e., diarrhea, pneumonia and malaria) in Tanga, Tanzania.

The study adopted a longitudinal study design using the Health Management Information System (HMIS) data in Tanga and Handeni districts, Tanzania, for the period between January 2016 and December 2018. While, the monthly climate change data (i.e., precipitation, humidity and temperature) for the same period were retrieved from the Tanzania Meteorological Authority (TMA). The data were analyzed using Multilevel Mixed-Effects Negative Binomial Regression (MMENBR) to assess the association between climate change indicators and the infectious diseases as well regional differences (i.e., Tanga and Handeni districts) using STATA version 13.

The analysis showed a significant relationship between climate change and the occurrence of infectious diseases. There were mean differences in the climate indicators and in the occurrence of infectious diseases between Tanga and Handeni districts among all the age groups except for the newborns (i.e., < 1 month*)* in different years. The trend differences, between the two district, in the occurrence of infectious diseases and climate indicators were also statistically significant. There was an association between precipitation and an increased rate of diarrhea without dehydration (Adjusted incidence rate ratio, IRR = 1.01; 95% Confidence interval, CI: 1.00 – 1.01; $p \leq 0.10$) and diarrhea with dehydration (Adjusted IRR = 1.01; 95% CI: 1.01 – 1.02; $p \leq 0.01$), and a reduced rate of malarial infections (Adjusted IRR = 0.99; 95% CI: 0.99 – 0.99; $p \leq 0.001$). The relationship between humidity levels and the occurrence of diarrhea without dehydration (Adjusted IRR = 0.98; 95% CI: 0.97 – 0.99; $p \leq 0.05$), severe diarrhea (Adjusted IRR = 1.03; 95% CI: 1.01 – 1.06; $p \leq 0.05$), non-severe pneumonia (Adjusted IRR = 1.01; 95% CI: 1.01 – 1.02; $p \leq 0.05$) and severe pneumonia (Adjusted IRR = 1.02; 95% CI: 1.01 – 1.03; $p \leq 0.05$) were statistically significant.

On the other hand, an increase in the maximum temperature was associate with an increased incidence of diarrhea with severe dehydration (Adjusted IRR = 1.13; 95% CI: 1.01 – 1.27; $p \leq 0.05$) and malaria as diagnosed using blood smear technique (Adjusted IRR = 1.18; 95% CI: 1.03 – 1.35; $p \leq 0.05$). Furthermore, the minimum temperature was associated with increased rates of malaria as diagnosed using rapid diagnostic test (Adjusted IRR = 1.23; 95% CI: 1.09 – 1.39; $p \leq 0.001$). The rates of malaria were in the opposing directions when using blood smear and rapid diagnostic test for the different temperature indicators (i.e., maximum and minimum temperature).

In conclusion, there was an association between climate change and the rates of infectious diseases in Tanga and Handeni districts, Tanzania. The results of this study have critical policy implications for health intervention programs and resource allocation during the different seasons. The health facilities should be well equipped while at the same time health professionals should be prepared to handle the major infectious diseases in the different seasons of the year.

Keywords: Climate change, temperature, humidity, precipitation, infectious disease, Tanga

ACKNOWLEDGEMENT

Am grateful to God for the opportunity to pursue my Masters studies, for the good health, wisdom and courage, and for seeing me through the course.

I am very thankful to my supervisors, Dr. Patrick Owili and Dr. Miriam Muga who gave me enormous support and guidance while developing my thesis. Am also grateful to the department Chairperson Mr. Khol Helmut, Mr. Omambia Benard, Dr. Joyce Owino and Prof. Jackie Obey and the entire team in the department of Public health for giving me the necessary support and advice.

I wish to express my gratitude to my colleagues in Tanga City for encouraging me to complete my studies. Special thanks to the Tanzania Meteorological Authority and the office of the Regional Medical Officer who gave freely of their time and provided the information that enabled me to conduct the study.

I further thank my parents, sister and friends for the support and encouragement they gave me throughout my study.

DEDICATION

This thesis is dedicated to my beloved parents Lameck Miyayo and Yunia Miyayo and my lovely twin sister Raheli Miyayo for instilling in me the desire to learn and for their encouragement, love and support during the entire time of my studies.

TABLE OF CONTENTS

APPROVAL SHEET i

DECLARATION ii

DECLARATION BY SUPERVISORS ii

ABSTRACT iii

ACKNOWLEDGEMENT v

DEDICATION vi

TABLE OF CONTENTS vii

LIST OF TABLES xi

LIST OF FIGURES xii

LIST OF ACRONYMS xiii

CHAPTER ONE INTRODUCTION 1

1.1 Background of the Study 1

1.2 Statement of the Problem 5

1.3 Research Objectives 6

1.3.1 Main objective 6

1.3.2 Specific objectives 6

1.4 Significance of the Study 7

1.5 Justification of the Study 8

1.6 Conceptual Framework 8

1.7 Scope of the Study 11

1.8 Operational Definition of Terms 12

CHAPTER TWO 14

REVIEW OF RELATED LITERATURE AND STUDIES 14

2.1 Introduction 14

2.2 Infectious Disease Epidemiology 14

2.2.1 Diarrhea 14

2.2.2 Pneumonia 15

2.2.3 Malaria 17

2.3 Climate Change 17

2.3.1 Climate Change and Diarrheal Diseases 20

2.3.2 Climate Change and Pneumonia 22

2.3.3 Climate Change and Malaria 24

2.4 Climate Change Adaptation and Approaches 26

CHAPTER THREE RESEARCH METHODS 27

3.1 Introduction 27

3.2 Research Design 27

3.3 Data Acquisition 27

3.4 Outcome Variables 28

3.5 Exposure Variables 28

3.6 Other Variables ... 29
3.7 Study Site ... 31
3.8 Statistical Treatment of Data ... 32
3.9 Ethical Considerations ... 33
CHAPTER FOUR ... 34
PRESENTATION OF FINDINGS, ANALYSIS ANDINTERPRETATION ... 34
4.0 Introduction ... 34
4.1 Descriptive Statistics(Objective 1) ... 34
4.1.1 Occurrence of Diarrhea ... 34
4.1.2 Occurrence of Pneumonia ... 40
4.1.3 Occurrence of Malaria ... 40
4.1.4 Climate Change ... 41
4.2 Infectious Diseases and Climate Change Trends(Objective 2) ... 41
4.2.1 Trends in the Occurrence of Diarrheal Infection ... 41
4.2.2 Trends in the Occurrence of Pneumococcal Infection ... 46
4.2.3 Trends in the Occurrence of Malarial Infection ... 49
4.2.4 Trends in the Climate Indicators ... 52
4.3 Association between Climate Change and Infectious Diseases(Objective 3) ... 53
4.3.1 Climate Change and Diarrheal Infections ... 53
4.3.2 Climate Change and Pneumococcal Infections ... 56
4.3.3 Climate Change and Malarial Infections ... 60

4.4 Discussions of the Findings 63

CHAPTER FIVE 70

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS 70

5.0 Introduction 70

5.1 Summary 70

5.2 Conclusions 71

5.3 Recommendations 72

5.3.1 Limitations of the study 72

5.3.2 Areas for Further Research 73

REFERENCES 74

APPENDICES 95

Appendix 1: Checklist of Data Retrieved 95

Appendix 2: Schedule of Activities 97

Appendix 3: Budget for Research 98

Appendix 4: Ethical Clearance 100

Appendix 7: Map of Tanga Region 102

Appendix 8: Curriculum Vitae 103

LIST OF TABLES

Table 1 Distribution of Health Facilities by District/Town/City Councils 43

Table 2: Descriptive statistics of the annual mean of diarrhea, pneumonia and malaria infections in Tanga and Handeni districts by years 49

Table 3: Crude and adjusted incidence rate ratio (IRR) and 95% confidence interval (CI) of the association between climate change and diarrheal infection in Tanga, Tanzania. 67

Table 4: Crude and adjusted incidence rate ratio (IRR) and 95% confidence interval (CI) of the association between climate change and pneumococcal infection in Tanga, Tanzania. 71

Table 5: Crude and adjusted incidence rate ratio (IRR) and 95% confidence interval (CI) of the association between climate change and malaria infection in Tanga, Tanzania. 74

LIST OF FIGURES

Figure 1. Conceptual framework of the relationship between climate change and infectious diseases..22

Figure 2: Monthly diarrheal infections without dehydration (A, C and E) and with some dehydration (B, D and F) of the under 5 children across 2016 to 2018 in Tanga, Tanzania. 56

Figure 3: Monthly diarrheal infections without dehydration (A and C) and with some dehydration (B and D) of the age groups above 5 years across 2016 to 2018 in Tanga, Tanzania. 57

Figure 4: Monthly diarrheal infections with severe dehydration (A – E) of all the age groups across 2016 to 2018 in Tanga, Tanzania. 58

Figure 5: Monthly non-severe (A, C and E) and severe (B, D and F) pneumococcal infections of the under 5 children across 2016 to 2018 in Tanga, Tanzania. 60

Figure 6: Monthly non-severe (A and C) and severe (B and D) pneumococcal infections of the age groups above 5 years across 2016 to 2018 in Tanga, Tanzania. 61

Figure 7: Monthly malarial infection diagnosed using rapid diagnostic test (A, C and E) and blood smear (B, D and F) of the under 5 children across 2016 to 2018 in Tanga, Tanzania. 63

Figure 8: Monthly malarial infection diagnosed using rapid diagnostic test (A and C) and blood smear (B and D) of the age groups above 5 years across 2016 to 2018 in Tanga, Tanzania. 64

Figure 9: Monthly rainfall (A), humidity (B), maximum temperature (C) and minimum temperature (D) from 2016 to 2018 in Tanga, Tanzania. 65

LIST OF ACRONYMS

BS	-	Blood Slide
CAP	-	Community Acquired Pneumonia
CI	-	Confidence Intervals
CLTS	-	Community-Led Total Sanitation
DALYs	-	Disability Adjusted Life Years
ECDC	-	European Center for Disease Prevention and Control
GHG	-	Greenhouse gas emission
HMIS	-	Health Management Information System
IPCC	-	Intergovernmental Panel on Climate Change
LMICs	-	Low and Middle Income Countries
MoHCDGEC	-	Ministry of Health Community Development, Gender, Elderly and Children
NASA	-	National Aeronautics and Space Administration
RDT	-	Rapid Diagnostic Test
TMA	-	Tanzania Meteorological Authority
UNICEF	-	United Nation Children's Fund
WHO	-	World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Globally, there have been some major impacts of climate variation on human health and well-being (Bandyopadhyay et al., 2012). It is also evident that the effect of climate change is predominant now than it was before. In 2018, the National Aeronautics and Space Administration reported a rise in the sea level and that the oceans had warmed by 0.17 °C since 1960's. Moreover, the Greenland and Antarctic ice sheets were seen to be shrinking at a rate more than 150 km^3/year and, at the same time, there was an increase in the extreme weather events including high temperature and intense rainfalls (National Aeronautics and Space Administration, 2019). The current global warming trend is of specific importance since most of it is particularly a result of human action.

Different continents and countries contribute substantially to the overall climate change. Globally, the impact and burden of climate change attributable disability adjusted life years (DALYs) is over 30%.

In Sub-Saharan Africa (SSA), the populace is vulnerable to climate change, in addition to other health factor, in spite of the awareness of its health effects. Moreover, research on the effect of climate change on human health in SSA is limited (Kula et al., 2013). With the already existing other health problems such as weak health care systems, communicable diseases, undernutrition and increased rates of non-communicable diseases, the health effect of climate change is anticipated to increase (Serdeczny et al., 2017).

Tanzania, among other African countries, has been experiencing extreme weather conditions as a result of climate change such as prolonged droughts, sporadic precipitation and increased temperatures. These weather conditions have a significant effect on the health of the population and livelihood. It is still expected that the situation will intensify (Division of Environment, United Republic of Tanzania, 2014; Kabir & Serrao-Neumann, 2020). The dangers of climate change are evident in other Tanzania regions including a submerged island off the coast of Indian ocean in Pangani district (i.e., Maziwe Island) and the experience in the coastal town (i.e., Bagamoyo town) where there is intrusion of sea water into the fresh water wells (Mboera et al., 2011). Furthermore, the Tanzania's annual mean temperature is also expected to rise by 1.0 to 2.7 °C by the 2060s. While the future projections of mean precipitation are generally steady, there are increases in yearly precipitation (Irish Aid, 2018). These climate changes will most certainly affect human health in general.

The World Health Organization (WHO) has identified diarrheal diseases, respiratory diseases and malaria as among the top ten causes of deaths related to the environmental factors (World Health Organization, 2009, 2018). The global burden of diarrhea has been cited as the main reason of mortality and morbidity among under-five children in low- and middle-income countries (LMICs) with almost 1.7 billion diarrheal disease cases occurring each year (World Health Organization, 2017). Azage and colleagues (2015) examined the seasonal trends of childhood diarrhea in Ethiopia and found that diarrhea does not randomly occur, ant that there was a spatiotemporal variation. Some of the meteorological parameters such as precipitation and temperature anomalies have been found to influence diarrheal morbidity in Mozambique (Bandyopadhyay et al., 2012). In another study, the authors also found a direct correlation between diarrhea and humidity (Phung et al., 2015). Furthermore, the seasonal variability has been found to have a greater influence on childhood diarrheal morbidity (Anyorikeya et al., 2016). However, most of these studies have found that diarrhea epidemics were common in tropical areas with high temperature in other regions (Xu et al., 2015; Zhou et al., 2013).

The WHO and the Intergovernmental Panel on Climate Change (IPCC) (Paynter, Ware, Weinstein, Williams, & Sly , 2010) identified vector borne diseases, diarrhea and undernutrition as some of the major health effect of climate changes. Even though these health issues are important public health problems, pneumonia is cited as the leading cause of death and morbidity among adults and children, globally (Caggiano et al., 2017). However, pneumonia is hardly cited in the context of climate change (Paynter et al., 2010). In 2010, it was estimated that pneumonia among the under-five children accounted for 120 million cases globally (Fischer Walker et al., 2013). Since most of these disease are preventable, it is essential to explore several factors that contribute to their occurrence including climate indicators. Recently, there has been a research attention on the relationship between climate indicators and pneumonia transmission, with some authors reporting an association between maximum and minimum temperature and the incidence of pneumonia (Xu, Hu, et al., 2014).

According to Guzman Herrador and colleagues (2015) various international health organizations including the European Centre for Disease Prevention and Control (ECDC) and the WHO have noticed the changing pattern of diseases with the change in climate, and hence have called for strengthening of the climate drivers-health partnerships. Enhanced disease surveillance and weather measurement can therefore improve the understanding of diseases in different seasons to enable effective decision making with regards to resource allocation among different health departments (Beyene et al., 2018).

The change in climate comes with the extreme weather patterns that can lead to an increase in the incidence of infectious disease including both the new and re-emerging diseases. Hence, this study was aimed to explore the association between climate indicators (i.e., precipitation, humidity and temperature) and the occurrence of several climate-sensitive diseases (i.e., diarrhea, pneumonia and malaria) in Tanga, Tanzania.

1.2 Statement of the Problem

Globally, and in Tanzania, global warming has caused changes in the weather patterns leading to an intense environmental and health issues (Horn et al., 2018). There is indisputable evidence on the warming of the climate system and its effects. The Intergovernmental Panel on Climate change (IPCC) estimated that the global temperatures is expected to rise by 2 °C and may upsurge to 4.8 °C by 2100 resulting in increased temperatures and rainfall in many areas in the globe (Intergovernmental Panel on Climate Change, 2014). Observational evidence from the local communities in Tanzania indicated increased climate variability and change such as increased temperature, late rainfall onset, decreasing rainfall amounts, and shift in rainfall pattern. This also brings new challenges in the management of infectious diseases and threatens to worsen today's health issues. For instance, the increase in temperature, rainfall or humidity due to climate variability may have significant impact on health and an increase in infectious disease outbreaks such as cholera and dengue among others (WHO, 2009)

In Tanzania, there has been an upsurge in the occurrence of some infectious diseases such as chikungunya (i.e., in Tanga region), dengue fever, malaria and cholera among others (Kinimi et al., 2018). It is not clear whether the global climate change could be a contributing factor for this occurrence and reemergence of infectious diseases in Africa, and most significantly in Tanzania.

Moreover, there is limited evidence on the relationship between climate variability and infectious disease in Tanzania, and particularly in Tanga region. This study, therefore, was aimed to explore the relationship between climate change and occurrence of infectious diseases in Tanga region, Tanzania. This is important towards the development of appropriate policies for prevention, resource allocation and coping mechanism that are capable of increasing adaptability to the effects of short and long lag climate changes. It is also important in the understanding of negative impacts of climate change and how to overcome.

1.3 Research Objectives

1.3.1 Main objective

To explore the association between climate change and occurrence of infectious diseases in Tanga, Tanzania.

1.3.2 Specific objectives

1. To determine the occurrence of infectious diseases (diarrhea, pneumonia and malaria) among different age groups from the year 2016 to 2018 in Tanga,Tanzania.
2. To assess the trend in the occurrence of infectious diseases and climate indicators (precipitation, humidity and temperature) from the year 2016 to 2018 in Tanga, Tanzania.
3. To explore the association between precipitation, humidity and temperature and the occurrence of diarrhea, pneumonia and malaria in Tanga, Tanzania.

1.4 Significance of the Study

The findings of this study will motivate public health consultants and policy makers to search for better ways to fight infectious diseases resulting from climate change. The results of this study will lead to the development of an early warning system for taking precautions and facilitating steps towards reducing the number of people affected by climate sensitive infectious diseases.

The Ministry of Health, Community Development, Gender, Elderly and Children (MoHCDGEC) of Tanzania can benefit from the results of this study towards the development of adaptation methods that can minimize the risk of infectious disease associated with the change of climate as well as planning of the health care resource allocation and management of its effects.

The study is significant to the populace of Tanga region who will be enlightened on the climate-sensitive infectious diseases and precautionary measures to combat the diseases taken. Moreover, it brings out the importance of surveillance of diseases—especially, diarrhea, pneumonia and malaria epidemics—and the observation of early warnings and dissemination of information on time to prevent the changing health risks.

The study will contribute to a better understanding of the association between climate change and the occurrence of infectious diseases. Climate change is a global issue of concern, Tanzania included. Thus, this study adds to the body of literature on this area. It is also forms a useful foundation on which other researchers can undertake further studies on the health effects of climate change.

1.5 Justification of the Study

The study is necessary because the climate change issue transcends the geopolitical regions and health impacts. The effects of climate change on health is already experienced in Tanzania. These effects are likely to increase in the future, and with water-related and vector-borne diseases being among key adaptation priorities for the country, this study is necessary. A review by other researchers from Texas State University in USA and Tsinghua University in China acknowledged that change in climate and extreme weather events have a direct impact on infectious diseases. The review recommended that more scientific studies are still necessary to understand the causes and effect climate change on health. They also indicated that the predictions on how the change in climate leads to the spread of disease across space and time are necessary (X. Wu et al., 2016). Infectious diseases are a major cause of death, disability and social disruption for millions of people. Water- and vector-borne diseases have increasingly affected the population, and as the climate change advances, the burden of these diseases is expected to increase (Nava et al., 2017) For this reason, it is essential to conduct a study on climate change and the occurrence of infectious disease and its implications on health.

1.6 Conceptual Framework

The conceptual framework in this study examines and explains the relationship between climate change and the occurrence of climate-sensitive infectious diseases (Figure 1). In the conceptual model, the main independent variable is climate change which include three indicators as temperature, precipitation and humidity; while the dependent variable indicators of infectious diseases including malaria, diarrheal disease and pneumonia.

The framework incorporates moderating factors that affects the magnitude of the effects. Some factors that affects human health, including social and environmental factors, may influence the spreading and magnitude of the infectious diseases.

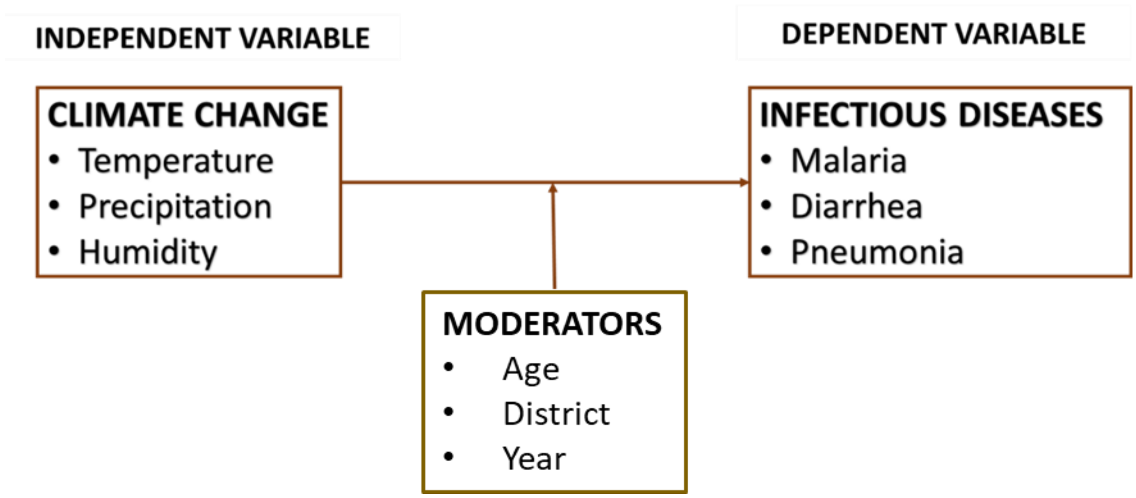


Figure 1. Conceptual framework of the relationship between climate change and infectious diseases

Infectious diseases are caused by the pathogenic microorganisms such as parasites, fungi, viruses or bacteria. These diseases always spread directly or indirectly from one individual to another, and climate conditions contributes to this spread through several ways such as: increase in the vector population like mosquitoes and ticks; survival of pathogens outside of the host; contamination of the environment and hence exposing individuals to water-borne infections; weakening of the host immunity; and malnutrition due to droughts or floods. As a result, changes in climate may affect the present and the future burden of infectious diseases (Metcalf et al., 2017).

The pathogens are directly impacted by climate change leading to change in the distribution and survival outside the host. As observed by (Morand et al., 2013) the effect of climate change can also be realized indirectly through several factors that can affect transmission of disease. For example, change in social behavior such as social gatherings during favorable climatic conditions. The vectors, pathogens and hosts need favorable weather and climatic conditions in order to survive, reproduce, spread and infect. As the changes in climate and weather conditions affects the living environment of vectors, pathogens and host, it affects the rate of infectious disease transmission (X. X. Wu et al., 2014). Several authors have also associated long-term climate warming with the geographic expansion of several infectious disease (Ostfeld & Brunner, 2015; Rodó et al., 2013).

The life cycle of pathogens may also be impacted by temperature. For example, the temperatures above 16 °C in tropical regions is favorable for anopheles mosquitoes to complete the life cycle. Some authors also indicate that malaria epidemic is prevalent during rainy seasons in tropical regions because mosquitoes tend to lay their eggs in stagnant waters (Shuman, 2010). Temperatures affect the spatial-temporal distribution of disease vectors. For instance, an increase in the temperature may lead to vector migration to high altitude and mid or high latitude regions from the low latitude areas, and hence causing a shift in the disease distribution (Nava et al., 2017).

Precipitation may also be affected by climate change, which in turn contributes to the rate of water-borne pathogens transmission. Rainfall can influence the transport and dissemination of these infectious agents. The fecal pathogens is always linked to rainy season since heavy rains may stir up water sediments an thus resulting in poor water quality and sanitation (Bhavnani et al., 2014). This sometimes happens after a long drought where precipitation may lead to pathogens increase resulting into an outbreak of a disease. Moreover, the breeding sites for some vectors such as mosquitos is influenced by the precipitation amount and season (Abiodun et al., 2016).

Furthermore, the survival and activity of mosquitoes is affected by relative humidity. For instance, it takes about 8 to 10 days for mosquitoes to transmit malaria, and they mainly become more active when humidity rises (Ferrão et al., 2017).

Nevertheless, in this study, the moderating factors such as age, district and year have been included. These factors are non-climatic factors that affect the magnitude of the effect of climate on the related health outcomes. For instance, the climate change may have different effect between different age groups in the occurrence infectious disease. A stronger associations with infectious diseases has been found among the age group 0-4years in both short and long terms and the 10 mm rise in rainfall (Mrema et al., 2012).

1.7 Scope of the Study

The study focused on the association between climate change and occurrence of infectious diseases (diarrhea, pneumonia and malaria) in Tanga, Tanzania. The study obtained data for the selected region between 2016 and 2018 from the Tanzania Meteorological Authority and Health Management Information System (HMIS). The independent variables included climate change indicators such as temperature, precipitation and humidity, while the dependent variable included three infectious diseases (diarrhea, pneumonia and malaria).

1.8 Operational Definition of Terms

1. **Infectious disease:** "This is the presence and activity of a pathogenic microbial agent (bacteria, fungus, virus or parasite) that can spread from an infected inanimate reservoir, an animal, or a person to a susceptible host either directly or indirectly through an intermediate host." In this study, the count data of the total monthly occurrences of infectious diseases were used. The following infectious diseases and standard case definitions—based on the Tanzania National Guideline for Integrated Disease Surveillance and Response (The United Republic of Tanzania, 2011)—were used in this study:
   a. **Diarrhea with no dehydration:** Diarrhea without enough signs to classify as dehydration.
   b. **Diarrhea with some dehydration:** Diarrhea with 2 or more of the following signs: skin pinch goes back slowly, drinks eagerly, sunken eyes, restless/irritable.
   c. **Diarrhea with severe dehydration:** Diarrhea with 2 or more of the following signs: skin pinch goes back very slowly, unable to drink, sunken eyes, unconscious.
   d. **Pneumonia**: The existence of a cough or difficulty in breathing and tachypnea with one or more of the general danger signs: lethargy or

unconsciousness, convulsions, vomiting, unable to drink/breastfeed, but not lower chest in-drawing among the under-five children.

e. **Malaria:** The presence of malaria and related symptoms (high fever, temperature above 37.5 °C, vomiting, headache, severe malaise or chills) in an individual. Tested using the rapid diagnostic test and the blood smear test.

2. **Climate change:** This is change in climate over time, due to human activity or naturally, that continues for a prolonged period. The average monthly data of the following three indicators of climate were used in this study:

    a. **Precipitation**: This is rainfall. It was measured in millimeter per hour (mm/h).

    b. **Humidity**: This is the moisture amount in the air expressed as percentage. It was measured using relative humidity (i.e., actual vapor pressure divided by saturation vapor pressure)—expressed as pressure or density—multiplied by 100 to give a percentage (%).

    c. **Temperature**: A measure of hotness and coldness measured on a definite scale. It was measured in terms of degree Celsius (°C). Both the estimated maximum and minimum temperature were used.

3. **Age:** The length of time someone has been alive (Cambridge Dictionary , n.d.)

4. **District:** Sub-divisions of a regions of the study as Tanga and Handeni districts.

5. **Year:** The period used in this study were starting from January to December of the years 2016, 2017 and 2018.

CHAPTER TWO

REVIEW OF RELATED LITERATURE AND STUDIES

2.1 Introduction

A review of relevant literature is presented in this chapter. It looks at infectious disease epidemiology, climate change and infectious diseases occurrence, and climate change adaptations.

2.2 Infectious Disease Epidemiology

2.2.1 Diarrhea

The WHO defines diarrhea as "the passage of three or more loose or watery stools in a 24-hour period" (Farthing et al., 2013). It is a global challenge and one of the chief cause of morbidity and death among children, especially in countries with limited resource and robust infrastructure to manage the burden (Kotloff et al., 2013). It is estimated that diarrhea incidence is about 1.3 million occurrences while the under-five diarrhea attributable deaths is about 4 million deaths. Nearly 80% of diarrheal-related deaths is common among children who are below two years of age. The route of infectious agent that causes diarrhea is by fecal-oral (Bbaale, 2011). Even though the diarrheal-related deaths is lower among the adults than the under-five children (Walker & Black, 2010), the burden is equally high among the elderly in a number of high-income countries with these deaths being five times more than that among children in some circumstances (Ben et al., 2011). However, the prevalence of diarrhea ranges between 6% to 33% Tanzania as reported by some community based studies, and this is somewhat similar to the population based survey in Tanzania of 2015/16 which found a diarrheal prevalence of 12% (Edwin & Azage, 2019).

In most cases, there is a distinct seasonal patterns of diarrhea in several regions. The diarrheal bacterial tends to be frequently in the warm seasons, while viral diarrhea peaks during the winter. Rotavirus tend to occur throughout the year in tropical areas (Chao et al., 2019).

2.2.2 Pneumonia

The WHO (2019) identified that pneumonia as the leading cause of mortality among the under-five children worldwide. In 2017, pneumonia alone accounted for 15% of all deaths of the under-five children (i.e., over 800, 000 deaths). It is however prevalent in Sub-Saharan Africa and Southern Asia (WHO, 2019b). Furthermore, it remains the foremost common reason for adult hospitalization in Sub-Saharan Africa (Ruuskanen et al., 2011; Scott et al., 2012). Pneumonia spreads in a number of ways, either through blood shortly after a child is born or through the air from droplets of sneezing or coughing. Most of the pneumonia cases are experienced in the winter months than in other seasons. It has also been found that pneumonia is more prevalent among males than females (Ota et al., 2019). In a study by Sharma and Singh (2018), the risk of severe pneumonia, empyema and septicemia is linked to comorbidities such as diabetes and alcoholism that are related to a more severe pneumonia—which is associated with septicemia and mortality. Seasons may have significant influence in the occurrence of a particular pathogen. In a study by Chen and colleagues (2015) that used Pneumoslide IgM test in children to explore Mycoplasma pneumoniae, parainfluenza viruses and respiratory syncytial, virus were found to be associated with seasonality. The Mycoplasma pneumoniae was found to be higher in autumn while the Legionella pneumophila was found to be prevalent in August and September. On the other hand, the adenovirus and the influenza B virus were found to be in the months of June and March, respectively.

In the years between 2000 and 2015, the global incidence of pneumonia among children and clinical pneumonia episodes were found to have decreased by 30% and 22%, respectively. Some of the risk factors that are associated with developing pneumonia among children included under nutrition, suboptimal breastfeeding, low birth weight, charcoal use, crowding, low maternal education, limited access to healthcare, passive care seeking behavior and zinc deficiency (Dherani et al., 2008; Lamberti et al., 2013; Smith et al., 2011).

2.2.3 Malaria

Malaria remains one of the most important public health issue in terms of mortality and morbidity. In 2017, the WHO (2018) estimated over 219 million malaria cases and about 435,000 deaths—with Africa contributing significantly to the global burden of malaria. The female Anopheles *spp.* mosquito is well known to transmit malaria parasite via a bite occurring majorly at dawn and during the sunset (Cox, 2010). The other rare methods of transmitting malaria include blood transfusion and congenitally acquired disease (G. Singh & Sehgal, 2010). The spread of malaria is greater in places where the mosquitos live for a longer period of time and bites human beings rather than animals. Climatic conditions such as rainfall patterns, temperature and humidity—which have an effect on the quantity and survival of mosquitoes—is important towards the spread of malaria (WHO, 2019a).

2.3 Climate Change

Human activities, which leads to an increase in the amount of atmospheric carbon dioxide, greenhouse gases and anthropogenic activities, are continuing to cause ongoing climate changes that has a substantial impact on physical, biological and human managed systems. It is estimated that by the year 2100 there will be an increase in the extremes of sea level in some regions. The sea level changes is becoming a measure of climate change and it is likely to occur in spatial and temporal scales (Church et al., 2010).

A report by the IPCC analyzed the effect of an increase in global temperature by 1.5 °C, which is higher than the pre-industrial levels, and noted that human activities are responsible for approximately 1°C and 0.5°C increase in global warming and greenhouse gas emissions, respectively. However, using the current rate of global warming, it is estimated that the global temperature shall increase by 1.5°C from the year 2030 to the year 2052. Some suggestions towards the reduction of global warming include transition in industrial, infrastructures, urban, land and energy systems (Masson-Delmotte, V. et al., 2018).

From 1951 to 2010, there is growing evidence of an increase in the greenhouse gas emissions as a result of the anthropogenic pollutants emanating from human activities, which in turn has influenced the climatic system. The global warming as well as several observed changes as a result of climate system's changes is undeniable since the 1950s (Intergovernmental Panel on Climate Change, 2014). However, the WHO noted that there is a knowledge gap on the effect of a 1.5 °C temperature increase, especially with regards to infectious diseases, air quality and occupational health. This knowledge gap is highlighted since there are limited quantitative studies that assesses the impact of 1.5 °C or 2 °C global temperature increase on the human health and the sea levels. This knowledge gap extends also to the trade-offs and co-benefits of reducing the climate change drivers (Masson-Delmotte et al., 2018).

There is however an increased evidence on the future projections of the relationship between climate change, morbidity and mortality in several regions. Regions with the temperature latitudes that are estimated to warm up disproportionately are especially vulnerable (Patz et al., 2005). The impact of adverse environmental exposure and climate change on children, especially in low-resourced settings, is expected to be greater than on adults since they bear close to 90% of the global burden of disease (Philipsborn & Chan, 2018).

The changes in climate is negatively affecting human health as indicated in some studies conducted in Canada and Northern Europe. In Canada, the effect of heatwaves and Lyme disease was highlighted. The geographical distribution and rates of the diseases as a result of weather pattern changes were observed (Ebi et al., 2017). Similarly, the relationship between the temperature and annual vibriosis cases was explored in another study (Ebi et al., 2017).

Nevertheless, the estimates for Tanzania shows that there will be an increase in both the minimum and maximum temperatures with a range of 1.7 to 2.4 °C and 2 to 4 °C by the end of the 21st century, respectively. In other words, the country is expected to be warmer than the months between October and April or May which are warmer. This may be as a result of greenhouse gas emissions in the country. It is also expected that with this increase in temperature, there will be an eruption of pests and diseases (Luhunga et al., 2018).

Authors have also shown the effect of weather and climatic factors on infectious diseases, cardiovascular diseases and mortality. These factors affects health either directly or indirectly through various ways including the intermediate factors (e.g., crop yields that affects nutritional status), infectious agents and disease transmission, and physiological effects to heat or cold (Schumann et al., 2013). Since the global disease pattern is affected by the climate change and variability, integration of the climate information and the changing risks into the health promotion and prevention methods is important towards promoting the health and wellbeing of individuals in low-resource settings and vulnerable communities (Coughlan de Perez et al., 2015).

2.3.1 Climate Change and Diarrheal Diseases

Diarrheal diseases are caused by several pathogens including protozoa, viruses and bacteria. It is a sign of gastrointestinal infections. There is a lot of complexity in the association between climate and diarrheal diseases because of several transmission routes and potential confounders that influences the disease occurrence (Thiam et al., 2017). Horn and colleagues (2018) explored the relationship between precipitation and diarrheal disease in Mozambique, and found a positive relationship which was in support of the another finding in Botswana (Alexander et al., 2013). The study in Mozambique reported an increased diarrheal disease with increase in temperature and precipitation event. Although, the study noted that the majority of the population practices open defecation. Nevertheless, the 42% of urban dwellers, who have access to adequate sanitation, are still at risk since the drinking water can still be contaminated during heavy rain seasons as a result of the overflowing sewer systems (World Health Organization, 2015). Similarly, in an explorative study conducted in China the childhood diarrheal cases increased in spite of improvements in vaccination coverage, water and sanitation hygiene (Xu et al., 2015).

Several studies have explored the effect of shifts in temperature on diarrhea. In exploring the effect of temperature on the outcome, some authors have employed the minimum, maximum and average temperatures over several resolutions such as annual, monthly, biweekly, weekly and daily exposures, as well as several temporal time lags (Bandyopadhyay et al., 2012; Carlton et al., 2016; Chowdhury et al., 2018; Mertens et al., 2019; Xu, Liu, et al., 2014). These studies have revealed a significant positive effect of temperature on diarrhea. Some authors, however, have found a negative association between temperature and rotavirus (Levy et al., 2016).

On climate variability, it has been found that an increase in temperature is associated with high morbidity of diarrheal disease in a subtropical Taiwan (Chou et al., 2010). The study used Poisson regression technique to estimate the diarrhea associated morbidity dynamics and found that extreme precipitation and maximum temperature were strongly related to diarrhea-associated morbidity, mainly, among middle-aged and elderly adults and children aged 40-64 years and 0-14 years, respectively, and minimal effect on individuals aged 15-39 years.

Alexander and colleagues (2013) used 30-year period monthly diarrheal disease data from Botswana's health facilities to explore the relationship with climate variables, using autoregressive covariance structure, and found a relationship between climate indicators and incidence of diarrhea.

A study by Wang and colleagues in China also explored the association between some meteorological indicators and incidence of diarrhea, and found that precipitation, atmospheric pressure, relative humidity, higher diurnal temperature range and low mean temperature were associated with an increased risk for infectious diarrhea (Wang et al., 2019). Similarly, other authors found a positive relationship between higher humidity levels and higher incidence of diarrhea and malaria cases in Bangladesh (Chowdhury et al., 2018).

A study in Mozambique conducted by Horn and colleagues (2018) also observed a relationship between increased precipitation and diarrheal diseases, though, the disease burden was lower in the coastal regions. It was also found that an increase in the temperature by 1 °C increased the diarrheal diseases by 6%. The study explained this relationship could have been as a result of causative pathogens being more sensitive to temperature, in terms of the transmission cycle and the replication rate along the coastal region. The results of a study in Sub-Saharan Africa also indicated that rainfall shortage in the dry seasons increased the incidence of diarrhea (Bandyopadhyay et al., 2012).

There is, however, some complexity in the transmission pathways of climate indicators and the incidence of infectious diseases. The transmission pathways are related with some other environmental the living conditions of a particular population. Nevertheless, the relationship between climate variables and diarrheal diseases is clear in literature.

2.3.2 Climate Change and Pneumonia

One of the acute respiratory infection that seriously affects the lungs is pneumonia. The disease can be transmitted from one person to another and its development is is closely associated with climate. The occurrence of pneumonia is highly associated with seasons, that is, it is relatively higher during the rainy seasons in tropical regions and during the winter seasons in low temperate regions. However, other factors such as behavioral changes, decreased immunity of the host, pneumococci stability in the air, divergence of survival and increased contact with persons infected also cause the occurrence of the disease (Kim, et al., 2016).

Globally, pneumonia is one of the health concerns among the elderly adults aged 65 years and the under-five children, because of the high mortality rates associated with it in these age groups. The United Nations Children's Fund (UNICEF) reported that over 1,400,000 deaths of children were diarrhea- and pneumonia-attributable, annually, and that both the diseases were the main causes of child deaths globally as a result of climate change (Amouzou et al., 2016). Little however is known on the mechanisms by which the environmental indicators affect the infectious diseases associated with the respiratory system, yet the association with several illnesses such as asthma, chronic obstructive pulmonary disease (COPD) and cardiovascular diseases is well established (Kayembe & Kayembe, 2017).

Paynter and colleagues (2010) noted that childhood pneumonia is sensitive to climate and is one of the most significant infectious diseases that cannot be ignored. The article suggested that studies on the impact of climate change should endeavor to quantify its effect on childhood pneumonia, especially in tropical settings. Even though the precise cause of seasonal pneumonia is not clear, several other factors are likely to contribute such as low ultraviolet radiation, indoor air pollution other seasonal pathogens affecting the respiratory system, immune system variation in different seasons, low relative humidity and indoor crowding (Mirsaeidi et al., 2016; Weinberger et al., 2014).

Host related factors (i.e., aging, comorbidities, immunity) or hematogenous spread of pathogens (i.e., survival, concentration, virulence) or aerosols inhaled also responsible for the severity and incidence of pneumonia. The seasonality of streptococcal pneumonia and influenza during the winter months has been observed in low temperate climate (Ben-Shimol et al., 2015). A study in Nairobi urban informal settlement revealed that deaths related to pneumonia among the under-five children are more common between the rainy season and at the beginning of the cold seasons, that is, from April to June (Ye et al., 2009).

In a prospective longitudinal study conducted by Herrera-Lara and colleagues (2013), the incidence of community acquired pneumonia (CAP) was high during winter among the patients who had been admitted January 2006 through to December 2009. The results show the highest incidence of CAP was in the winter. The main causative agent was streptococcus pneumonia in all the seasons, except summer which had legionella pneumophila. In exploring the effect of environmental humidity, there was no etiological differences in the occurrence of pneumonia by season.

2.3.3 Climate Change and Malaria

In the association between climate change and infectious disease, malaria is one of the most important research concerns (Onyango et al., 2016). In the estimation of the disease burden, malaria moved from 217 million cases to 219 million cases from the year 2016 to the year 2017, respectively, while the deaths associated with it stood at over 430 thousand in the year 2017. The African countries bears the greatest burden of global malaria (WHO, 2018).

The change in climate affects both the distribution of malaria mosquito and parasite. In many areas, mosquito breeding pattern is favored by the change in climate such as rainfall patterns and rising temperatures (Onyango et al., 2016). In 1980s, an increase in the mean monthly rainfall and maximum temperatureprecipitation led to a series of malaria epidemics in the Easten Africa highlands. Intensified agricultural activities led to land use changes that enhance vector production in the highlands (Omumbo et al., 2011). The results of a study conducted by Caminade and colleagues (2014) point out that, in the tropical highland regions, the climate might become favourale for the transmission of malaria in the future. Though, several other socioeconomic factors such as economic development, changes in migration, urbanization, population growth and change in the land use will also contribute (Wandiga et al., 2010).

Both the rainy seasons and the warm temperatures are associated with the risk of malaria epidemic. In fact, the rate of development of mosquito parasite and larval is controlled by temperature, with the development time being shortened by high temperatures (Karungu et al., 2019; Parham & Michael, 2010). On the other hand, precipitation provides favorable environment for mosquitos to breed, and hence an increase in the mosquito population (Parham & Michael, 2010; Wandiga et al., 2010). However, studies exploring the relationship between the variations in temperature and the occurrence of malaria have been conducted and debated in Africa, a continent that has been experiencing changes in the malaria distribution (Alonso et al., 2011; Omumbo et al., 2011).

Moreover, a study in rural Tanzania employed time series Poisson regression technique to assess the influence of monthly rainfall and temperature on mortality among different age groups and found a stronger positive association among the under-five years in both the long and short time lag (Mrema et al., 2012). A 10 mm increase in precipitation increased the risk of mortality by 1.4%. There was a highly significant relationship between monthly temperatures and mortality among all the age groups. The decrease in the monthly temperatures led to a decreased mortality (Mrema et al., 2012). Similarly, a study conducted in Bangladesh found that most of the cases of malaria, diarrhea and pneumonia were prevalent during the rainy season (Chowdhury et al., 2018).

2.4 Climate Change Adaptation and Approaches

The African governments resolved to prioritize climate change, and hence an action plan was developed which included the following: “baseline risk and capacity assessments; capacity building; integrated environment and health surveillance; awareness raising and social mobilization; public health oriented environmental management; scaling up of existing public health interventions; strengthening of partnerships and promotion of research” (United Nations Environment Programme, 2011). Among the key recommendations emerging from a review of adaptation measures for climate change is that all the countries in African should be dedicated towards the implementation of mitigation measures in order to address the effects climate change on health (Kula et al., 2013).

Moreover, some countries like Nigeria have invested in the improvement of how the most current and relevant information on weather forecast is provided (Federal Republic of Nigeria, 2014). A country like Egypt is also mounting warning systems that would provide both the seasonal and the weather forecast in order to raise public awareness and conduct educational programs towards abating disasters (Egyptian Environmental Affairs Agency, 2016).

CHAPTER THREE

RESEARCH METHODS

3.1 Introduction

This chapter focuses on the overall research plan and procedures used for this study. It describes the research design, population and sampling techniques, reliability and validity of the research instrument, data acquisition process, statistical treatment of data and ethical consideration.

3.2 Research Design

This study adopted a longitudinal study design to explore the association between climate change and occurrence of infectious diseases (i.e., diarrhea, pneumonia and malaria). The study analyzed, described and documented various aspects of the climate change (i.e., rainfall, humidity and temperature) and occurrence of infectious diseases in Tanga, Tanzania.

3.3 Data Acquisition

The meteorological and health data was obtained from the Tanzania Meteorological Authority (TMA) and Health Management Information System (HMIS), respectively, after various approvals (see Appendices 4 to 6). The secondary data from January 2016 to December 2018 was used in this study. Application and approval to use the data was obtained from TMA and HMIS. The TMA is responsible for daily forecasting, climate services. weather forecasting, meteorological services and warnings for each region in Tanzania. The TMA data on temperature, precipitation and humidity usually collected daily, was transformed into monthly average to be used in this study. While, the HMIS data on infectious diseases is collected monthly, the data are usually collected daily by the personnel health facilities who in turn compile the monthly report and then submit it to the district HMIS coordinator for data entry. The HMIS data is used to assess the distribution of diseases within the region. In this study, data on malaria, diarrhea, and pneumonia was used (see Appendix 1 for the data checklist retrieved).

3.4 Outcome Variables

There were three outcome variables, that is, diarrhea, pneumonia and malaria. Data on these variables was from different districts. The total number of cases from Tanga and Handeni districts were the monthly outcome from the year 2016 to 2018.

3.5 Exposure Variables

Three indicators for climate change were included in this study, that is, precipitation, humidity and temperature. The daily average data on temperature, precipitation and humidity were converted into monthly average for Tanga region from the year 2016 to 2018. Temperature data was measured in degree Celsius (°C), data on precipitation was collected using rain gauge measured in (mm) and data on humidity was collected using the digital hygrometer measured in percentage.

3.6 Other Variables

The other variables used in this study include district, age and months of the year. Tanga and Handeni districts were selected in the region as indicated in Table 1. Data on age, district and months of the year were retrieved as per the HMIS data. The age data was grouped as under 1 month, 1 month -1 year, 1-5 years, 5-60 years, and 60 years and above.

Table 1 Distribution of Health Facilities by District/Town/City Councils

No.	District	Total (2018)
1	Bumbuli District Council	24
2	Handeni Town Council	7
3	**Handeni District Council**	**43**
4	Korogwe Town Council	15
5	Korogwe District Council	51
6	Kilindi District Council	37
7	Lushoto District Council	43
8	Mkinga District Council	30
9	Muheza District Council	47
10	Pangani District Council	21
11	**Tanga City Council**	**55**
	Total	**373**

3.7 Study Site

The study was conducted in two districts (Tanga and Handeni) in Tanga region which is located in the far North-east corner of Tanzania. It is bordered by Indian Ocean to the east, Pwani and Morogoro regions to the south, Manyara region to the West, and Kilimanjaro region and Kenya to the North.

Tanga region is administratively divided into 11 councils namely, Handeni, Korogwe, Lushoto, Muheza, Mkinga, Bumbuli, Kilindi, and Pangani district councils; Handeni and Korogwe town councils; and Tanga city council. The Tanga region is in the land area of 27,348 sq kms, and yet about 17,000 sq kms is arable land with a total population of about 1,280,262 individuals.

The climatic condition of Tanga region is predominantly warm and wet both inland and in the coastal areas. However, Handeni district in the western plateau of the Usambara Mountains has generally a hot and dry climate. The average temperature is about 26 °C to 29 °C and 30 °C to 32 °C in the hot months between December and March during the night and day, respectively. While, the average temperature in cool months between May and October is about 20 °C to 24 °C and 23 °C to 28 °C during the night and day, respectively. In Tanga, the atmospheric humidity is relatively high with a minimum of 65% and a maximum of 100%. With regards to precipitation, the region experiences average of 750 mm of rainfall, annually. The coastal region of Tanga has an annual average of about 1,100 to 1,400 mm of rainfall.

3.8 Statistical Treatment of Data

The data collected were analyzed in two phases using both the descriptive statistics and inferential statistics. The first phase used monthly frequencies, tables, graphs and figures of the distribution of infectious diseases and the meteorological information. Line graphs of the monthly and seasonal trends were also used in the study. Two-sample *t*-test with equal variances estimation technique was used to test the mean differences between Tanga and Handeni districts to answer Objective 1. The study tested for equality of variances between districts. The consistency of different procedures to unequal variance may vary greatly, hence the need to do a test for equal variances. While, the Multilevel Mixed-Effects Poisson regression with the unstructured covariance structure—level 1 and 2 being month and year, respectively—was used to test the trend differences between Tanga and Handeni districts in the Figures in order to answer Objective 2.

However, the second phase of the analysis used Generalized negative binomial regression techniques was employed to explore the associations between climate indicators and infectious diseases (Objective 3). The study analyzed two models. In the first model, the analysis was crude; while in the second model, the analysis was adjusted for all the variables which included different climate indicators, age, district and year. Analysis for each infectious disease was performed and the moderating effect of the other variables were explored. STATA version 13.1 was used to analyze data (StataCorp, 2013).

3.9 Ethical Considerations

In considering the ethical and scientific soundness, approvals were sought and obtained from the research ethics committee of the University of Eastern Africa, Baraton (Kenya) and the National Research Ethics Committee (Tanzania). The Regional Medical Officer for Tanga and the Tanzania Meteorological Authority also gave permission to conduct the study in Tanga.

CHAPTER FOUR

PRESENTATION OF FINDINGS, ANALYSIS AND INTERPRETATION

4.0 Introduction

This chapter presents the findings, analysis and interpretation of data gathered to explore the relationship between climate change and occurrence of infectious diseases in Tanga, Tanzania. This section begins by presenting the descriptive statistics of all the variables. Finally, the two Poisson regression model for trend differences and exploring the associations between climate indicators and infectious disease are presented succeeded by a discussion and interpretation of the results.

4.1 Descriptive Statistics

(Objective 1)

4.1.1 Occurrence of Diarrhea

The results presented in

Table 2 show the annual mean differences of infectious disease cases and climate indicators in Tanga district and Handeni district from year 2016 to year 2018. Almost all the mean differences for diarrheal cases in different age groups in the two districts were statistically significant, except for the mean differences among the newborns (i.e., less than 1 month old) who had diarrhea. Some of the newborns had diarrhea without dehydration (p = 0.596, 0.751 and 0.609 for the year 2016, 2017 and 2018, respectively); some with some dehydration (p = 0.413, 0.466 and 0.324 for the year 2016, 2017 and 2018, respectively); and some with severe dehydration (p = 0.534, 0.178 and 0.291 for the year 2016, 2017 and 2018, respectively).

Moreover, the mean difference of the diarrheal infection with severe dehydration among the infants (i.e., between 1 month and 1-year-old) in Tanga and Handeni in the year 2016 was also not statistically significant at p = 0.418 (

Table 2). Likewise, the diarrheal infection with severe dehydration among the elderly aged 61 and above was not statistically different in the years 2017 and 2018 at p-value of 0.071 and 0.158, respectively. However, the results showed that the mean diarrheal infections were higher in Tanga district than Handeni district across the years for all age groups in all the three diarrhea indicators.

Table 2: Descriptive statistics of the annual mean of diarrhea, pneumonia and malaria infections in Tanga and Handeni districts by years

	2016, Annual μ (*SD*)[a]			**2017, Annual μ (*SD*)[a]**			**2018, Annual μ (*SD*)[a]**		
	Tanga	**Handeni**	***p*-value**	**Tanga**	**Handeni**	***p*-value**	**Tanga**	**Handeni**	***p*-value**
Diarrhea (no dehydration)									
< 1 month	6.7 (6.5)	5.5 (3.8)	0.596	10.6 (8.4)	9.6 (6.8)	0.751	10.3 (11.7)	8.4 (5.2)	0.609
1 month – < 1 year	472.6 (96.7)	164.9 (27.2)	< 0.001	380.6 (69.7)	211.4 (56.0)	< 0.001	386.3 (86.3)	189.6 (48.5)	< 0.001
1 – < 5 year	705.3 (124.1)	256.7 (54.7)	< 0.001	647.2 (142.2)	302.5 (100.1)	< 0.001	619.4 (76.3)	276.4 (95.0)	< 0.001
5 – 60 year	720.7 (137.7)	141.3 (31.4)	< 0.001	788.4 (148.3)	145.3 (36.1)	< 0.001	756.9 (105.5)	134.2 (62.2)	< 0.001
≥ 61 years	215.1 (81.9)	46.5 (15.7)	< 0.001	199.2 (38.5)	44.1 (20.8)	< 0.001	193.3 (51.6)	41.6 (25.0)	< 0.001
Diarrhea (some dehydration)									
< 1 month	8.1 (22.7)	2.5 (4.4)	0.413	1.1 (1.6)	0.7 (1.1)	0.466	2.2 (3.9)	0.9 (1.7)	0.324
1 month – < 1 year	108.7 (28.1)	38.5 (12.9)	< 0.001	132.8 (29.5)	56.3 (16.9)	< 0.001	102.4 (11.7)	75.6 (28.2)	< 0.001
1 – < 5 year	228.5 (40.7)	71.7 (14.0)	< 0.001	249.9 (53.7)	92.3 (28.8)	< 0.001	191.5 (30.1)	101.6 (51.2)	< 0.001
5 – 60 year	227.6 (61.2)	40.3 (11.9)	< 0.001	247.8 (54.5)	42.4 (15.8)	< 0.001	199.0 (46.8)	31.3 (20.9)	< 0.001
≥ 61 years	68.8 (47.2)	13.3 (5.3)	< 0.001	66.2 (17.5)	14.1 (6.9)	< 0.001	68.0 (26.4)	13.8 (12.5)	< 0.001

	2016, Annual μ (*SD*)[a]			2017, Annual μ (*SD*)[a]			2018, Annual μ (*SD*)[a]		
	Tanga	**Handeni**	***p*-value**	**Tanga**	**Handeni**	***p*-value**	**Tanga**	**Handeni**	***p*-value**
Diarrhea (severe dehydration)									
< 1 month	0.1 (0.3)	0.3 (0.9)	0.534	0.5 (1.2)	0.0 (0.0)	0.178	1.2 (3.7)	0.0 (0.0)	0.291
1 month – < 1 year	2.3 (2.6)	3.5 (4.1)	0.418	11.4 (9.1)	2.4 (3.3)	0.004	4.4 (4.2)	0.3 (0.5)	0.003
1 – < 5 year	12.5 (8.8)	6.5 (4.3)	0.044	25.8 (12.2)	9.2 (5.9)	< 0.001	11.3 (11.6)	0.3 (0.9)	0.004
5 – 60 year	21.3 (8.8)	9.3 (17.7)	0.047	24.6 (12.2)	5.3 (5.4)	< 0.001	10.8 (10.0)	1.1 (1.3)	0.003
≥ 61 years	5.9 (4.4)	1.3 (3.4)	0.009	6.2 (6.8)	2.3 (1.7)	0.071	1.8 (1.9)	0.8 (1.0)	0.158
Non-severe pneumonia									
< 1 month	18.1 (13.5)	31.6 (14.5)	0.027	25.1 (16.3)	32.1 (14.7)	0.281	30.1 (25.9)	18.6 (10.4)	0.168
1 month – < 1 year	389.8 (81.6)	203.9 (25.8)	< 0.001	431.8 (89.7)	227.7 (55.6)	< 0.001	438.8 (92.5)	185.0 (57.1)	< 0.001
1 – < 5 year	668.4 (108.8)	308.2 (59.1)	< 0.001	655.3 (154.1)	334.1 (101.3)	< 0.001	655.0 (116.9)	244.5 (79.5)	< 0.001
5 – 60 year	638.2 (139.2)	239.9 (62.1)	< 0.001	763.8(158.0)	219.7 (73.9)	< 0.001	775.8 (306.7)	283.3 (145.7)	< 0.001
≥ 61 years	176.2 (69.4)	81.7 (25.1)	< 0.001	172.1 (65.2)	77.8 (31.3)	< 0.001	182.8 (76.3)	70.0 (27.7)	< 0.001

	2016, Annual μ (*SD*)[a]			2017, Annual μ (*SD*)[a]			2018, Annual μ (*SD*)[a]		
	Tanga	**Handeni**	***p*-value**	**Tanga**	**Handeni**	***p*-value**	**Tanga**	**Handeni**	***p*-value**
Severe pneumonia									
< 1 month	8.8 (6.1)	5.3 (3.0)	0.090	7.8 (6.8)	6.4 (3.8)	0.536	8.1 (4.1)	7.9 (7.7)	0.948
1 month – < 1 year	92.2 (34.9)	48.4 (22.1)	0.001	107.5 (52.3)	54.1 (32.2)	0.006	93.3 (33.6)	35.3 (17.7)	< 0.001
1 – < 5 year	156.3 (65.5)	61.9 (20.0)	< 0.001	137.8 (46.9)	101.8 (134.2)	0.390	101.8 (51.6)	49.0 (34.0)	0.007
5 – 60 year	88.8 (48.4)	32.8 (16.6)	0.001	119.0 (87.8)	85.9 (208.0)	0.617	104.3 (79.7)	29.0 (23.1)	0.005
≥ 61 years	18.4 (14.8)	13.9 (9.2)	0.382	31.3 (49.0)	10.0 (6.9)	0.151	34.2 (29.2)	9.8 (8.4)	0.011
Malaria, RDT									
< 1 month	13.5 (36.3)	1.3 (1.9)	0.258	4.0 (6.1)	14.3 (15.4)	0.043	2.6 (5.1)	25.5 (30.9)	0.019
1 month – < 1 year	44.6 (113.9)	326.1 (152.1)	< 0.001	42.3 (40.6)	693.2 (369.3)	< 0.001	109.5 (63.1)	1195.1 (327.7)	< 0.001
1 – < 5 year	460.5 (237.3)	1883.2 (965.6)	< 0.001	386.0 (152.3)	2719.2 (1479.3)	< 0.001	722.6 (393.3)	4282.9 (1675.9)	< 0.001
5 – 60 year	1488.8 (1041.3)	2200.9 (1122.2)	0.121	1391.7 (723.8)	3354.1 (1888.1)	0.003	3136.5 (1472.4)	5032.0 (2523.0)	0.035
≥ 61 years	260.8 (124.3)	554.6 (249.4)	0.001	155.9 (70.8)	567.3 (336.6)	< 0.001	269.9 (114.7)	1087.5 (1052.1)	0.014

	2016, Annual μ (*SD*)[a]			2017, Annual μ (*SD*)[a]			2018, Annual μ (*SD*)[a]		
	Tanga	**Handeni**	***p*-value**	**Tanga**	**Handeni**	***p*-value**	**Tanga**	**Handeni**	***p*-value**
Malaria, BS									
< 1 month	0.1 (0.3)	0.1 (0.3)	1.000	0.0 (0.0)	0.8 (2.6)	0.277	0.3 (1.2)	0.4 (0.9)	0.846
1 month – < 1 year	3.9 (8.3)	11.3 (14.6)	0.145	2.6 (3.3)	22.7 (24.2)	0.009	1.6 (3.1)	6.3 (7.6)	0.057
1 – < 5 year	49.0 (30.4)	142.7 (165.8)	0.067	25.0 (14.4)	80.4 (73.0)	0.017	21.2 (10.3)	29.1 (33.2)	0.439
5 – 60 year	147.1 (68.8)	224.6 (222.1)	0.261	93.5 (74.6)	163.8 (132.8)	0.124	60.1 (45.2)	83.9 (64.0)	0.304
≥ 61 years	32.2 (24.1)	76.3 (83.4)	0.092	9.7 (11.2)	28.8 (54.4)	0.245	7.8 (6.0)	53.6 (76.7)	0.051
Climate indicators									
Rainfall, $_{mm}$	83.6 (101.2)	53.1 (73.5)	0.406	136.6 (180.7)	78.8 (80.1)	0.322	111.2 (85.1)	66.9 (80.4)	0.204
Humidity, $_{\%}$	75.6 (4.3)	82.3 (5.2)	0.002	78.3 (6.2)	72.8 (7.4)	0.058	80.2 (4.5)	82.3 (9.8)	0.493
Temperature, $_{Max\ °C}$	31.3 (1.7)	29.1 (2.7)	0.024	31.2 (1.5)	28.7 (2.8)	0.012	30.9 (1.4)	28.6 (2.7)	0.020
Temperature, $_{Min\ °C}$	23.5 (1.7)	19.4 (1.7)	< 0.001	23.5 (1.5)	19.2 (1.3)	< 0.001	23.2 (1.5)	18.9 (1.3)	< 0.001

[a], The mean differences between the districts were analyzed using the two-sample *t*-test technique with equal variances.

4.1.2 Occurrence of Pneumonia

For pneumococcal infections presented in Table *2*, the non-statistical mean differences were presented among the newborns (i.e., less than 1 month old) who had non-severe pneumonia (p-value of 0.281 and 0.168 for the year 2017 and 2018, respectively) and severe pneumonia (p-value of 0.090, 0.536 and 0.948 for years 2016, 2017 and 2018, respectively). However, in the year 2017, the mean differences of the occurrence of severe pneumonia in Tanga and Handeni among all age groups were not statistically significant, except for the infants (i.e., between 1 month and 1-year-old) that was significantly different at $p = 0.006$. Among the elderly aged 61 years and above who had severe pneumonia, the mean difference was only statistically significant in the year 2018 at $p = 0.011$. The results showed that the mean pneumococcal infections were higher in Tanga district than Handeni district across the years for almost all age groups.

4.1.3 Occurrence of Malaria

Malaria was tested using two approaches (Table *2*), that is – rapid diagnostic test (RDT) and thick blood smear (BS). The RDT results indicated a non-statistically significant difference in the occurrence of malaria in Tanga and Handeni only in 2016 among the infants ($p = 0.258$) and children and adults aged from 5 to 60 years ($p = 0.121$). Nevertheless, there were no differences in malarial infection in the two districts and across the years using the BS diagnostic technique at $p < 0.05$, except for the infants (i.e., between 1 month and 1-year-old) and toddlers (i.e., 1 year to less than 5 years) in 2017 at p-value of 0.009 and 0.017, respectively. However, the mean malarial infections were higher in Handeni district than in Tanga district across the years for almost all age groups.

4.1.4 Climate Change

Table *2* also presents the differences in climate indicators in the two districts (i.e., Tanga and Handeni). There were statistically different maximum and minimum temperature in the two districts across all the years, with the temperature in Handeni district being much lower than that of Tanga district. Using the mean differences, humidity levels were relatively different in the two districts in the year 2016 and 2017, but not for the rainfall levels across all the years.

4.2 Infectious Diseases and Climate Change Trends (Objective 2)

4.2.1 Trends in the Occurrence of Diarrheal Infection

Figure 2 and Figure 3 show the monthly trend of diarrheal infections without dehydration and with some dehydration for under 5 children (Figure 2) and for children and adults aged 5 years and above (Figure 3), from January 2016 to December 2018. The results of Multilevel Mixed-Effects Negative Binomial Regression (MMENBR), when assessing the trend differences of Tanga and Handeni districts, revealed that there were statistically significant trend differences in diarrhea without dehydration and diarrhea with some dehydration for all age groups.

In all age groups, diarrheal infections were significantly higher in Tanga district than in Handeni district. The number of diarrheal infections rose in different months across different years.

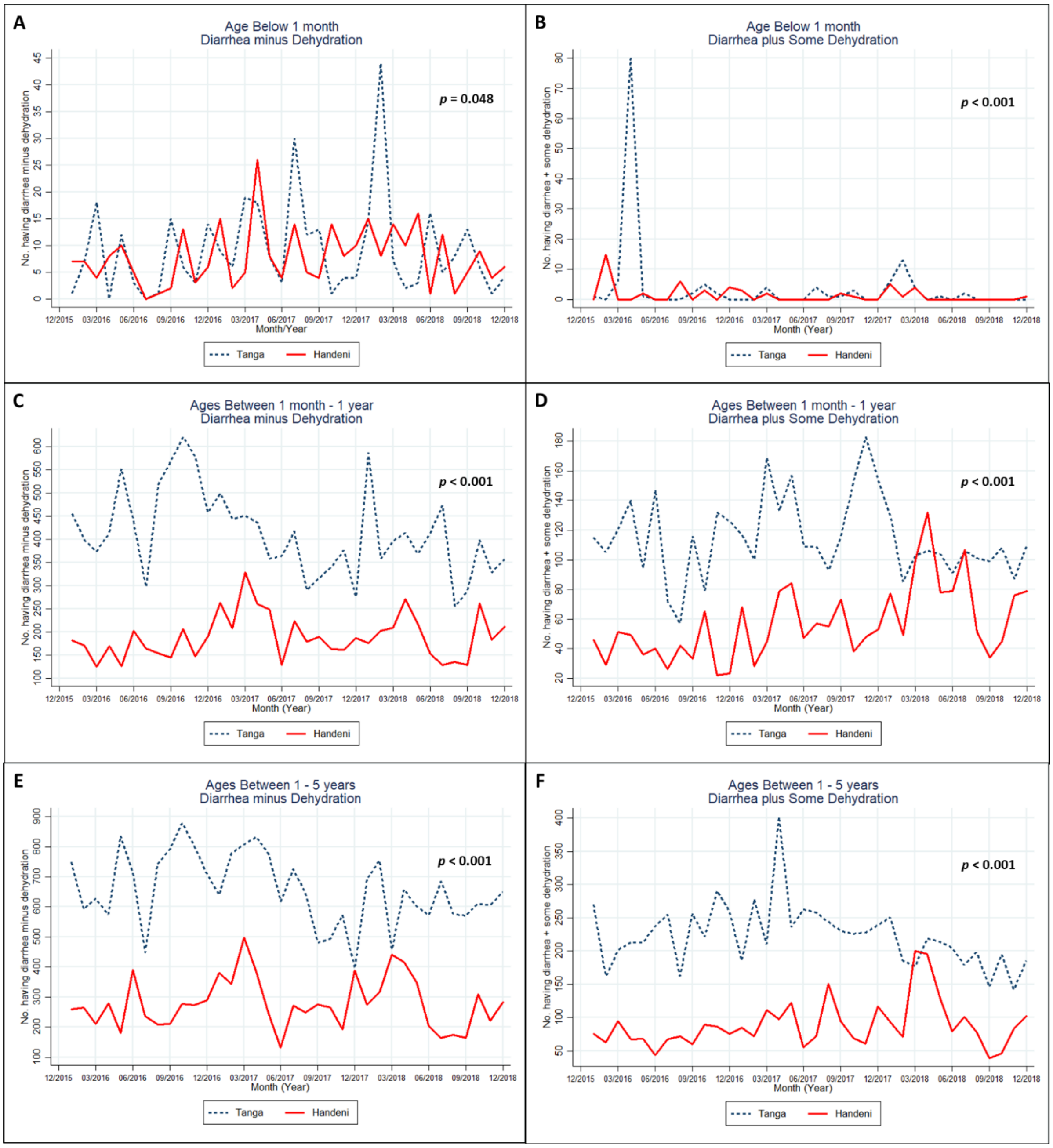


Figure 2: Monthly diarrheal infections without dehydration (A, C and E) and with some dehydration (B, D and F) of the under 5 children across 2016 to 2018 in Tanga, Tanzania.

Note: The Multilevel Mixed-Effects Poisson regression—with level 1 and 2 being month and year, respectively—was used to test the trend differences.

Figure 3: Monthly diarrheal infections without dehydration (A and C) and with some dehydration (B and D) of the age groups above 5 years across 2016 to 2018 in Tanga, Tanzania.

Note: The Multilevel Mixed-Effects Poisson regression—with level 1 and 2 being month and year, respectively—was used to test the trend differences.

Also, Figure 4 presents the results of MMENBR for the trend differences of diarrheal infections with severe dehydration which were statistically different, except for that of the infants (Figure 4A) which was not statistically significant ($p = 0.159$).

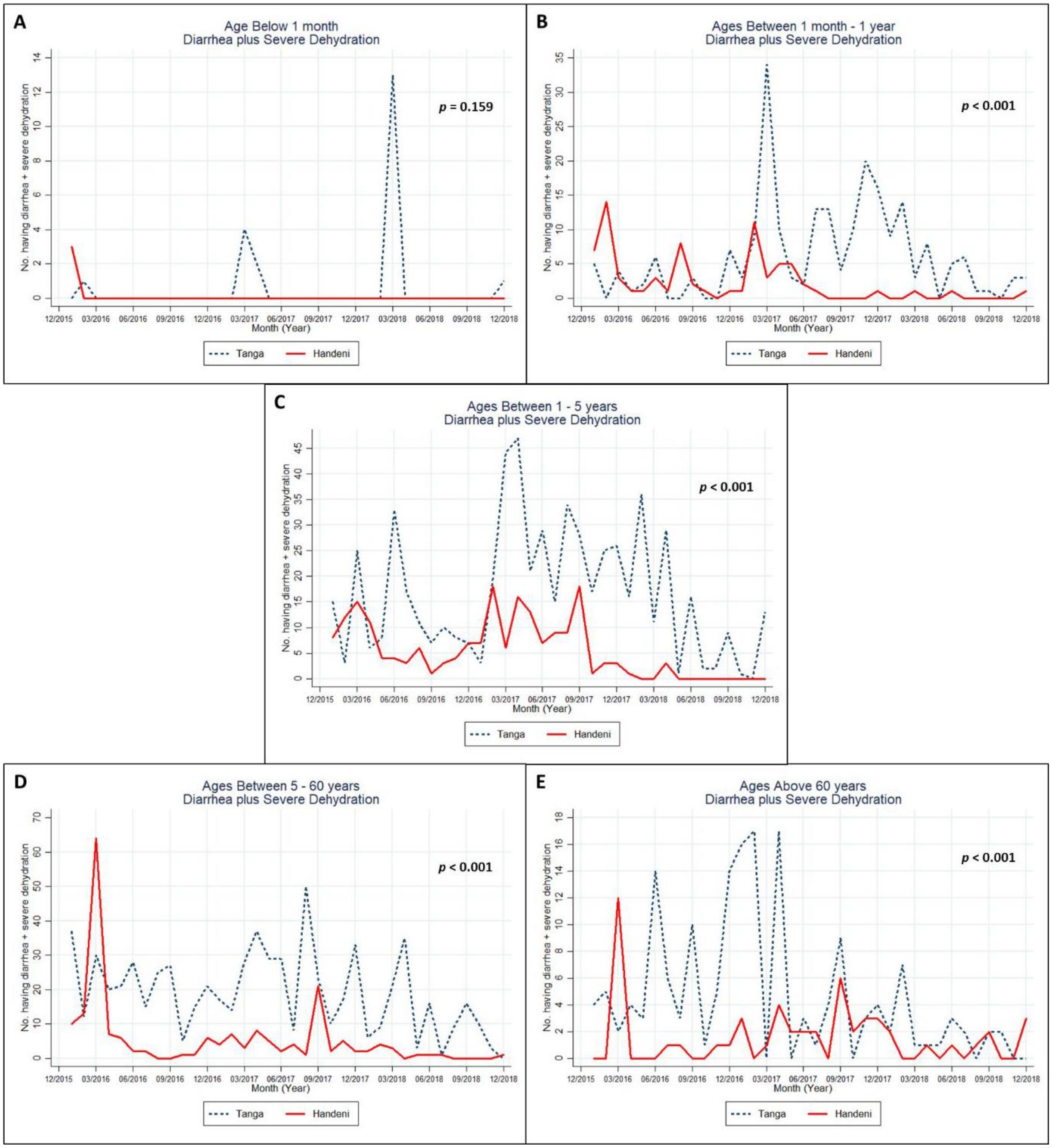


Figure 4: Monthly diarrheal infections with severe dehydration (A – E) of all the age groups across 2016 to 2018 in Tanga, Tanzania.

Note: The Multilevel Mixed-Effects Poisson regression—with level 1 and 2 being month and year, respectively—was used to test the trend differences.

4.2.2 Trends in the Occurrence of Pneumococcal Infection

The monthly trend of the non-severe and severe pneumonia for the under 5 children (Figure 5) and for the children and adults aged 5 years and above (Figure 6) indicated statistically significant differences in the trend of infection in Tanga and Handeni districts in all the age groups. Pneumonia infections were higher in Tanga, with Handeni district only exhibiting a much higher numbers of severe infections than Tanga in the month of June 2017 among toddlers (1 – 5 years, Figure 5F) and among children and adults aged 5 – 60 years (Figure 6B).

Moreover, the non-severe pneumonia infections were relatively higher among infants in Handeni district than those in Tanga district (Figure 5A).

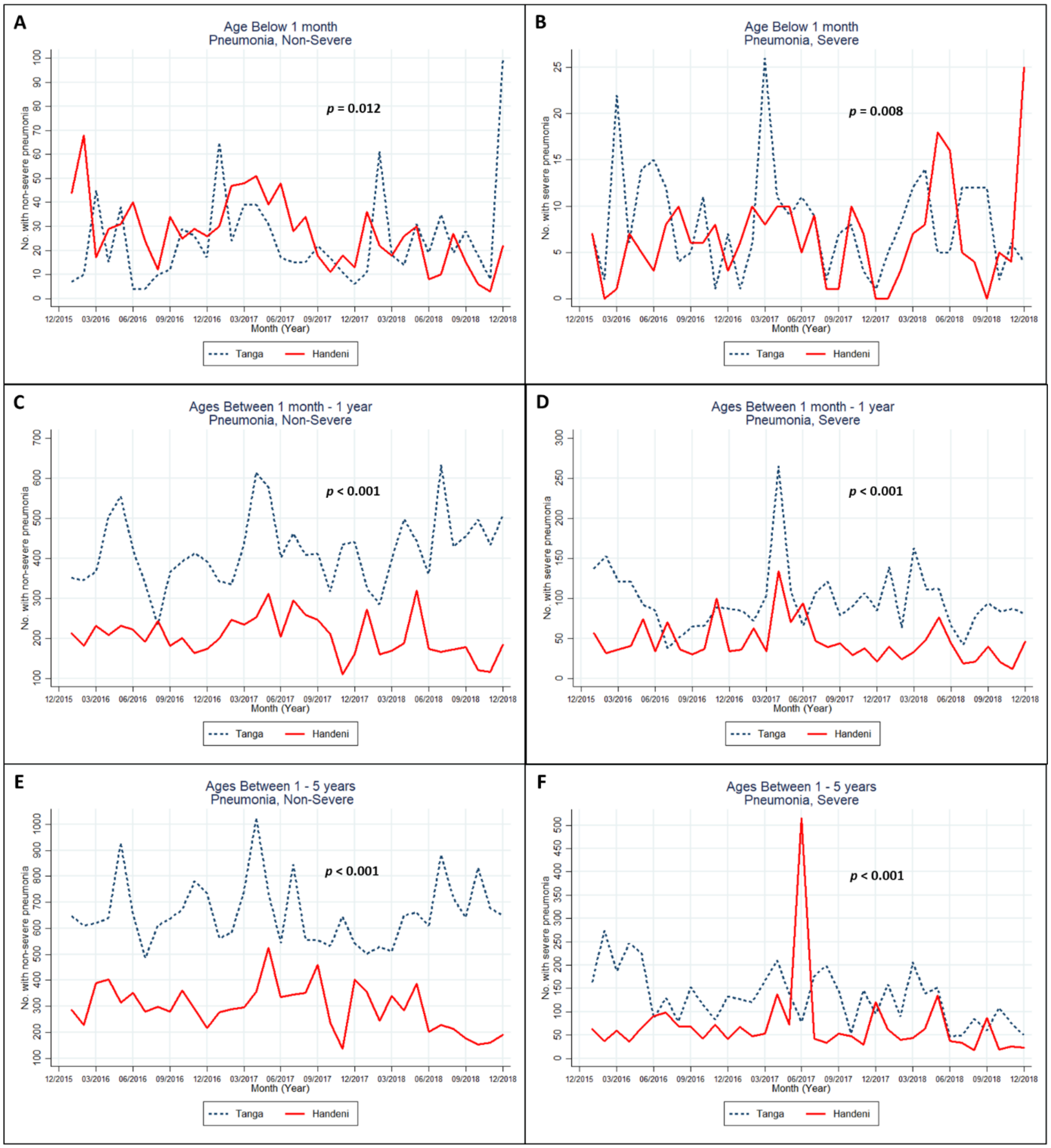


Figure 5: Monthly non-severe (A, C and E) and severe (B, D and F) pneumococcal infections of the under 5 children across 2016 to 2018 in Tanga, Tanzania.

Note: The Multilevel Mixed-Effects Poisson regression—with level 1 and 2 being month and year, respectively—was used to test the trend differences.

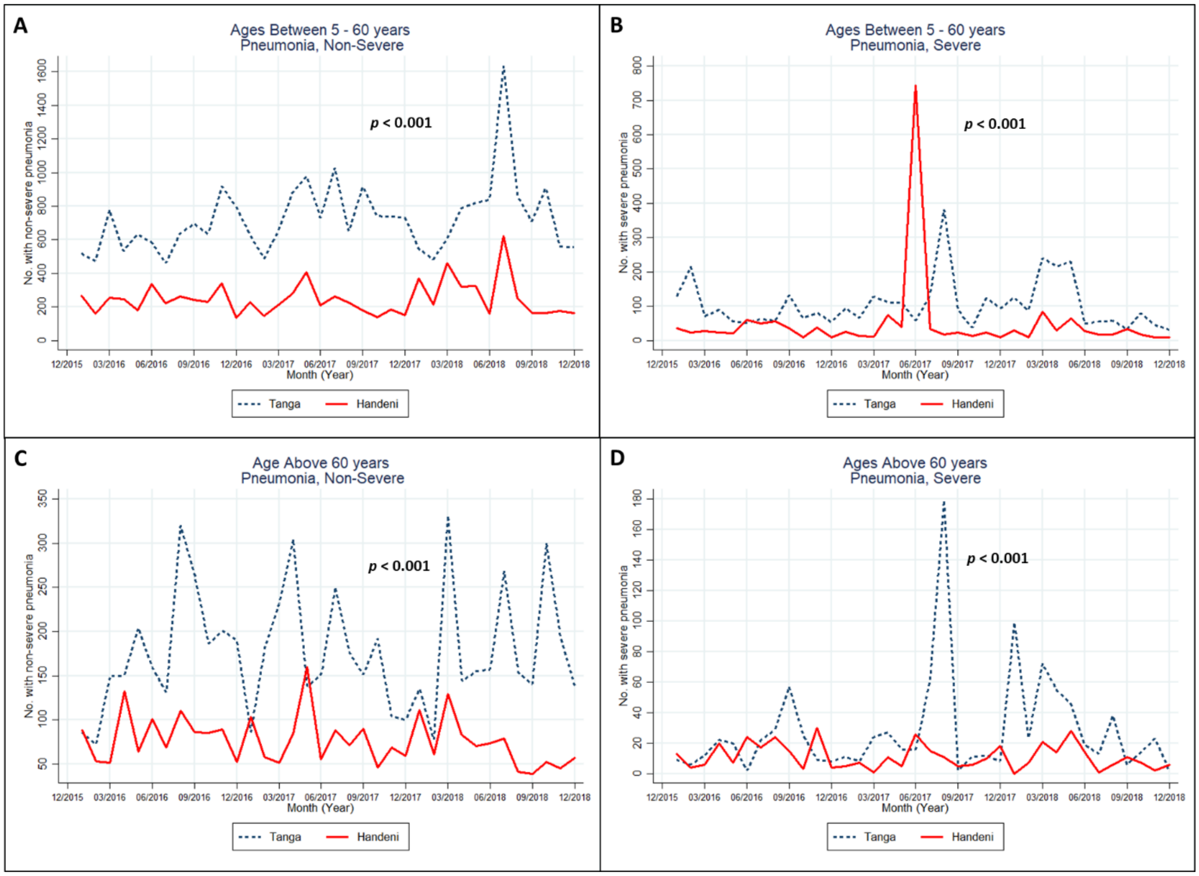


Figure 6: Monthly non-severe (A and C) and severe (B and D) pneumococcal infections of the age groups above 5 years across 2016 to 2018 in Tanga, Tanzania.

Note: The Multilevel Mixed-Effects Poisson regression—with level 1 and 2 being month and year, respectively—was used to test the trend differences.

4.2.3 Trends in the Occurrence of Malarial Infection

The monthly trend of malarial infections for the under 5 children (Figure 7) and for the children and adults aged 5 years and above (Figure 8) also shows statistically significant differences in the trend of infection in Tanga and Handeni districts in all the age groups. However, using RDT and BS diagnostic techniques, the infections were higher in Handeni than in Tanga.

There were months that had higher rates of infection than others throughout the three-year period. Basing on RDT technique, the numbers of malaria infection in Tanga were only high in February 2016 among the infants below 1 month of age (Figure 7A).

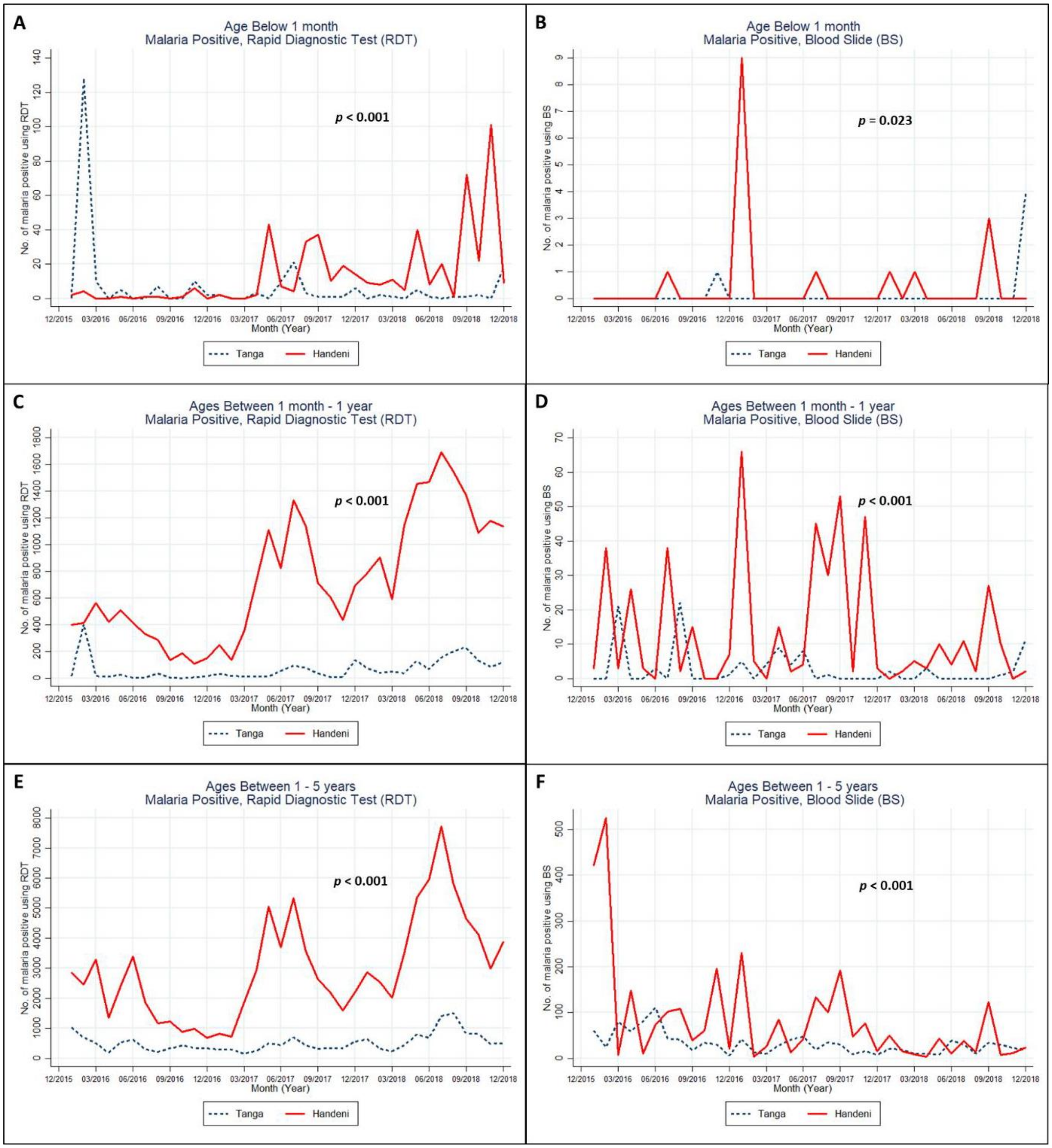


Figure 7: Monthly malarial infection diagnosed using rapid diagnostic test (A, C and E) and blood smear (B, D and F) of the under 5 children across 2016 to 2018 in Tanga, Tanzania.

Note: The Multilevel Mixed-Effects Poisson regression—with level 1 and 2 being month and year, respectively—was used to test the trend differences.

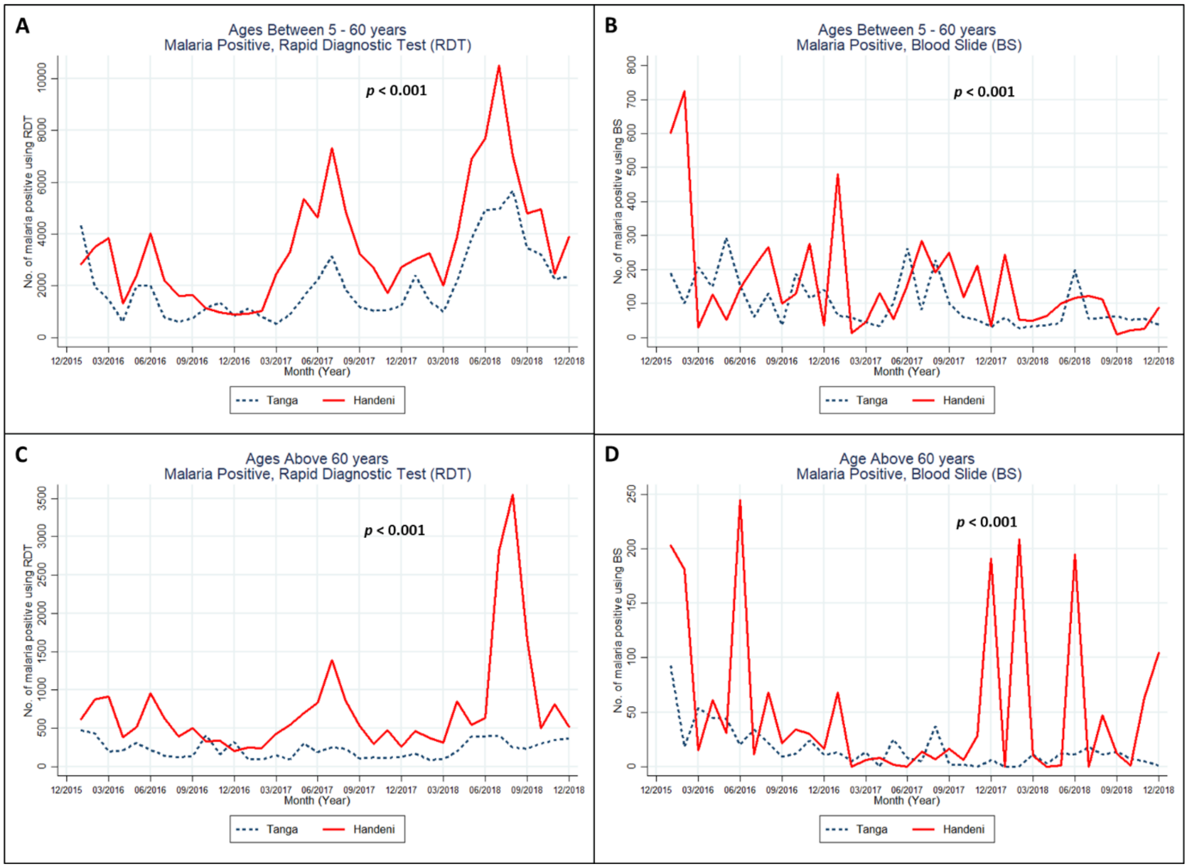


Figure 8: Monthly malarial infection diagnosed using rapid diagnostic test (A and C) and blood smear (B and D) of the age groups above 5 years across 2016 to 2018 in Tanga, Tanzania.

Note: The Multilevel Mixed-Effects Poisson regression—with level 1 and 2 being month and year, respectively—was used to test the trend differences.

4.2.4 Trends in the Climate Indicators

Only the trends in the monthly rainfall (Figure 9A) and monthly minimum temperature (Figure 9D) were statistically different in Tanga district and Handeni district, with the minimum temperature being extremely lower in Handeni than in Tanga. The difference in the maximum temperature was marginally significant (p = 0.072). All the graphs of the two districts exhibited, somewhat, a similar pattern in the trends of each indicator.

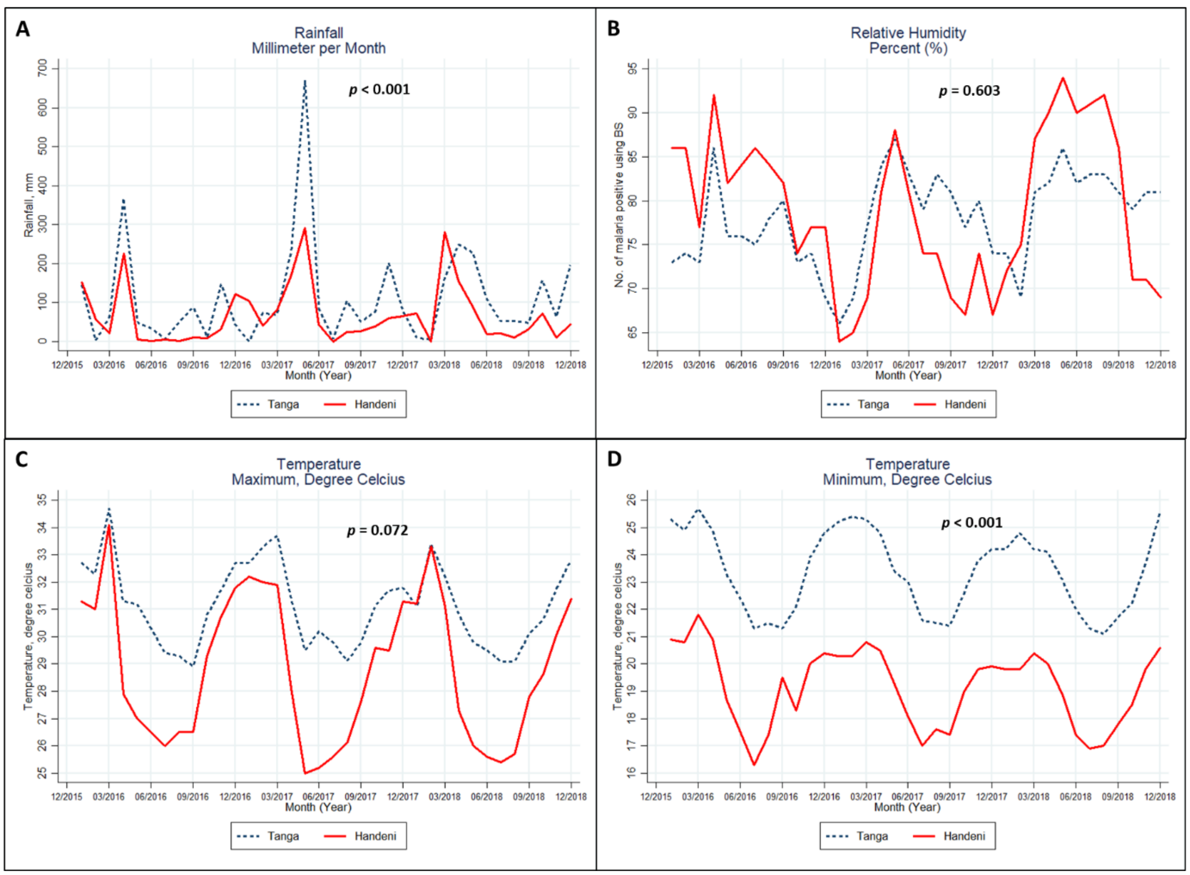


Figure 9: Monthly rainfall (A), humidity (B), maximum temperature (C) and minimum temperature (D) from 2016 to 2018 in Tanga, Tanzania.

Note: The Multilevel Mixed-Effects Poisson regression—with level 1 and 2 being month and year, respectively—was used to test the trend differences.

4.3 Association between Climate Change and Infectious Diseases (Objective 3)

4.3.1 Climate Change and Diarrheal Infections

Table 3 presents the results of the unadjusted and adjusted negative binomial regression models of the relationship between climate indicators and diarrheal infection in Tanga. As the amount of rainfall increased by one unit, the incidence rate of diarrhea without dehydration (Incidence rate ratio, IRR = 1.01; 95% Confidence interval, CI: 1.00 – 1.01; $p \leq 0.10$) and with some dehydration (IRR = 1.01; 95% CI: 1.00 – 1.01; $p \leq 0.01$) increased by the same percentage after adjusting for all the variables.

However, an increase in the humidity levels by one unit reduced the incidence rate of diarrhea without dehydration (IRR = 0.98; 95% CI: 0.97 – 0.99; $p \leq 0.05$) and increased the rates of diarrhea with severe dehydration by 3% after adjusting for all the variables.

After adjusting for all the variables, there was no association between the change in temperature and diarrheal infection without and with some dehydration. Yet the relationship between the change in maximum temperature and diarrhea with severe dehydration was statistically significant with an increased rate (IRR = 1.13; 95% CI: 1.01 – 1.27; $p \leq 0.05$).

Table 3: Crude and adjusted incidence rate ratio (IRR) and 95% confidence interval (CI) of the association between climate change and diarrheal infection in Tanga, Tanzania.

Infectious disease	**Crude IRR (95% CI)**	**Adjusted IRR (95% CI)**
Diarrhea (no dehydration)		
Rainfall, mm	1.01 (1.00, 1.02)*	1.01 (1.00, 1.01)*
Humidity, %	0.98 (0.97, 1.01)	0.98 (0.97, 0.99)**
Temperature, Max °C	1.16 (1.10, 1.22)****	1.00 (0.95, 1.04)
Temperature, Min °C	1.22 (1.16, 1.28)****	1.03 (0.97, 1.08)
Age group (ref: > 60 years)		
< 1 month	0.07 (0.05, 0.09)****	0.09 (0.07, 0.10)****
1 month – 1 year	2.44 (1.96, 3.04)****	2.88 (2.53, 3.29)****
1 – < 5 years	3.80 (3.05, 4.72)****	4.40 (3.86, 5.01)****
5 – 60 years	3.63 (2.92, 4.52)****	3.51 (3.08, 3.99)****
District (ref: Tanga)		
Handeni	0.32 (0.26, 0.41)****	0.39 (0.32, 0.46)****
Year (ref: 2016)		
2017	1.00 (0.74, 1.36)	1.03 (0.92, 1.15)
2018	0.96 (0.71, 1.30)	1.04 (0.94, 1.16)
Diarrhea (some dehydration)		
Rainfall, mm	1.02 (1.01, 1.03)**	1.01 (1.01, 1.02)***
Humidity, %	0.99 (0.97, 1.02)	1.00 (0.99, 1.02)
Temperature, Max °C	1.15 (1.08, 1.22)****	1.01 (0.95, 1.07)
Temperature, Min °C	1.22 (1.16, 1.29)****	1.04 (0.96, 1.12)

Infectious disease	**Crude IRR (95% CI)**	**Adjusted IRR (95% CI)**
Age group (ref: > 60 years)		
< 1 month	0.06 (0.05, 0.09)****	0.06 (0.05, 0.08)****
1 month – 1 year	2.11 (1.60, 2.78)****	2.63 (2.20, 3.15)****
1 – < 5 years	3.83 (2.91, 5.05)****	4.49 (3.76, 5.36)****
5 – 60 years	3.23 (2.45, 4.25)****	3.06 (2.56, 3.65)****
District (ref: Tanga)		
Handeni	0.31 (0.24, 0.41)****	0.37 (0.29, 0.48)****
Year (ref: 2016)		
2017	1.12 (0.79, 1.58)	0.95 (0.82, 1.12)
2018	0.97 (0.69, 1.37)	0.94 (0.81, 1.09)
Diarrhea (severe dehydration)		
Rainfall, mm	1.01 (0.99, 1.03)*	1.00 (1.00, 1.00)
Humidity, %	0.98 (0.95, 1.01)	1.03 (1.01, 1.06)**
Temperature, Max °C	1.23 (1.15, 1.32)****	1.13 (1.01, 1.27)**
Temperature, Min °C	1.30 (1.21, 1.39)****	1.12 (0.96, 1.31)
Age group (ref: > 60 years)		
< 1 month	0.11 (0.06, 0.20)****	0.10 (0.06, 0.18)****
1 month – 1 year	1.33 (0.85, 2.07)	1.27 (0.88, 1.83)
1 – < 5 years	3.58 (2.32, 5.52)****	3.54 (2.49, 5.02)****
5 – 60 years	3.95 (2.56, 6.09)****	3.70 (2.60, 5.25)****
District (ref: Tanga)		
Handeni	0.30 (0.22, 0.42)****	0.51 (0.31, 0.83)***

Infectious disease	**Crude IRR (95% CI)**	**Adjusted IRR (95% CI)**
Year (ref: 2016)		
2017	1.39 (0.92, 2.10)	1.62 (1.19, 2.22)***
2018	0.51 (0.33, 0.76)****	0.48 (0.35, 0.65)****

IRR, Incidence rate ratio; CI, Confidence interval

* $p \leq 0.10$; ** $p \leq 0.05$; *** $p \leq 0.01$; **** $p \leq 0.001$

Only the infants (i.e., below 1 month) had a lower incidence rate than the elderly aged 61 and above. The other age groups had a higher incidence rate of diarrheal infections in all the three indicators after adjustment. The Handeni district had a lower incidence of diarrheal infections than Tanga district in all the three indicators. Nonetheless, there was a 62% increased rates and a 52% reduced rates of diarrhea with severe dehydration in 2017 and 2018, respectively.

4.3.2 Climate Change and Pneumococcal Infections

The crude and adjusted negative binomial regression results of the relationship between climate indicators and pneumonia infection is presented in Table 4. The only climate indicator that was positively associated with non-severe pneumonia was humidity with an increased rate of non-severe pneumonia infections (IRR = 1.01; 95% CI: 1.01 – 1.02; $p \leq 0.05$) after adjusting for all the variables.

However, after adjustment, an increase in the levels of humidity and minimum temperature increased the rates of severe pneumonia at IRR = 1.02 (95% CI: 1.01 – 1.03; $p \leq 0.05$) and IRR = 1.21 (95% CI: 1.11 – 1.33; $p \leq 0.001$), while an increase in the maximum temperature reduced the rate of pneumonia infections by 14%.

As in the case of diarrheal infection, only the infants (i.e., below 1 month) had a lower incidence rate of both non-severe and severe pneumonia than the elderly aged 61 and above. The other age groups had a higher incidence rate of non-severe and severe infections respectively before and after adjustment.

After adjustment, the district of Handeni had also a much lower incidence rate of non-severe (IRR = 0.51; 95% CI: 0.43 – 0.60; $p \leq 0.001$) and severe (IRR = 0.73; 95% CI: 0.54 – 0.98; $p \leq 0.05$) pneumonia infections than Tanga district. However, there was an increased incidence rates of severe pneumonia in the year 2017 than 2016 by 1.26 times (95% CI: 1.05 – 1.52; $p \leq 0.05$).

Table 4: Crude and adjusted incidence rate ratio (IRR) and 95% confidence interval (CI) of the association between climate change and pneumococcal infection in Tanga, Tanzania.

Infectious disease	**Crude IRR (95% CI)**	**Adjusted IRR (95% CI)**
Non-severe pneumonia		
Rainfall, $_{mm}$	1.01 (1.01, 1.02)***	1.00 (1.00, 1.00)
Humidity, $_{\%}$	1.01 (0.99, 1.02)	1.01 (1.01, 1.02)**
Temperature, $_{Max\ °C}$	1.07 (1.02, 1.12)***	1.00 (0.96, 1.04)
Temperature, $_{Min\ °C}$	1.13 (1.10, 1.18)****	1.01 (0.96, 1.06)
Age group (ref: > 60 years)		
< 1 month	0.20 (0.17, 0.24)****	0.23 (0.20, 0.27)****
1 month – 1 year	2.47 (2.08, 2.93)****	2.52 (2.22, 2.85)****
1 – < 5 years	3.77 (3.17, 4.47)****	3.80 (3.35, 4.30)****
5 – 60 years	3.84 (3.23, 4.56)****	3.69 (3.26, 4.18)****
District (ref: Tanga)		
Handeni	0.42 (0.35, 0.51)****	0.51 (0.43, 0.60)****
Year (ref: 2016)		
2017	1.07 (0.83, 1.37)	1.07 (0.96, 1.20)
2018	1.05 (0.81, 1.34)	0.95 (0.86, 1.05)

Infectious disease	**Crude IRR (95% CI)**	**Adjusted IRR (95% CI)**
Severe pneumonia		
Rainfall, $_{mm}$	1.01 (1.01, 1.02)**	1.00 (1.00, 1.00)
Humidity, $_{\%}$	1.02 (0.99, 1.03)*	1.02 (1.01, 1.03)**
Temperature, $_{Max\ °C}$	1.02 (0.97, 1.07)	0.86 (0.80, 0.92)****
Temperature, $_{Min\ °C}$	1.11 (1.07, 1.16)****	1.21 (1.11, 1.33)****
Age group (ref: > 60 years)		
< 1 month	0.38 (0.29, 0.49)****	0.43 (0.34, 0.54)****
1 month – 1 year	3.67 (2.84, 4.73)****	3.80 (3.06, 4.72)****
1 – < 5 years	5.18 (4.02, 6.68)****	5.37 (4.33, 6.67)****
5 – 60 years	3.91 (3.03, 5.05)****	3.71 (2.99, 4.60)****
District (ref: Tanga)		
Handeni	0.50 (0.40, 0.62)****	0.73 (0.54, 0.98)**
Year (ref: 2016)		
2017	1.26 (0.95, 1.66)	1.26 (1.05, 1.52)**
2018	0.90 (0.68, 1.18)	0.94 (0.79, 1.11)

IRR, Incidence rate ratio; CI, Confidence interval

* $p \leq 0.10$; ** $p \leq 0.05$; *** $p \leq 0.01$; **** $p \leq 0.001$

4.3.3 Climate Change and Malarial Infections

Table 5 presents the crude and adjusted negative binomial regression results of the relationship between climate indicators and malarial infection using the RDT and BS techniques. The results of the RDT technique revealed that the incidence rate of malarial infections reduced by 1% and 18% with an increase in one unit of rainfall and maximum temperature levels, respectively. They increased by 1.23 times (95% CI: 1.09 – 1.39; $p \leq 0.001$) with a one-unit increase in the minimum temperature after adjustment.

On the other hand, the BS diagnostic technique revealed that an increase in the maximum temperature by one unit increased the incidence rate of malaria (IRR = 1.18; 95% CI: 1.03 – 1.35; $p \leq 0.05$), and reduced with a one-unit increase in the minimum temperature (IRR = 0.82; 95% CI: 0.69 – 0.98; $p \leq 0.05$) after adjusting for all the variables.

After adjusting for all the indicators, the incidence rate of malarial infections was lower among less than 1-year-old children than the elderly aged 61 and above, while it was higher among toddlers and children and adults up to the age of 60 years in both the RDT and BS diagnostic techniques.

However, after adjustment, malaria incidence rate was higher in Handeni district than in Tanga district at 4.92 times (95% CI: 3.29 – 7.36; $p \leq 0.001$) and 1.85 times (95% CI: 1.05 – 3.25; $p \leq 0.05$) using RDT and BS technique respectively. There was also an increased rate of malaria incidence in the year 2018 (IRR = 1.81; 95% CI: 1.42 – 2.30; $p \leq 0.001$) than 2016 when using RDT technique, but a reduced rate of malaria incidence in 2017 and 2018 lower than in 2016 when using BS technique.

Table 5: Crude and adjusted incidence rate ratio (IRR) and 95% confidence interval (CI) of the association between climate change and malaria infection in Tanga, Tanzania.

Infectious disease	**Crude IRR (95% CI)**	**Adjusted IRR (95% CI)**
Malaria, RDT		
Rainfall, mm	0.99 (0.99, 0.99)**	0.99 (0.99, 0.99)****
Humidity, %	1.04 (1.01, 1.06)****	1.00 (0.98, 1.02)
Temperature, Max °C	0.84 (0.79, 0.89)****	0.82 (0.75, 0.89)****
Temperature, Min °C	0.81 (0.76, 0.86)****	1.23 (1.09, 1.39)****
Age group (ref: > 60 years)		
< 1 month	0.02 (0.01, 0.03)****	0.02 (0.02, 0.03)****
1 month – 1 year	0.83 (0.58, 1.19)	0.58 (0.43, 0.77)****
1 – < 5 years	3.61 (2.53, 5.16)****	3.03 (2.30, 4.00)****
5 – 60 years	5.73 (4.01, 8.20)****	6.62 (5.02, 8.74)****
District (ref: Tanga)		
Handeni	2.82 (2.03, 3.92)****	4.92 (3.29, 7.36)****
Year (ref: 2016)		
2017	1.29 (0.85, 1.95)	1.01 (0.77, 1.31)
2018	2.19 (1.45, 3.32)****	1.81 (1.42, 2.30)****

Infectious disease	**Crude IRR (95% CI)**	**Adjusted IRR (95% CI)**
Malaria, BS		
Rainfall, $_{mm}$	0.99 (0.99, 1.00)	1.00 (1.00, 1.00)
Humidity, $_{\%}$	1.01 (0.98, 1.04)	1.01 (0.98, 1.04)
Temperature, $_{Max\ °C}$	0.97 (0.89, 1.06)	1.18 (1.03, 1.35)**
Temperature, $_{Min\ °C}$	0.90 (0.83, 0.97)**	0.82 (0.69, 0.98)**
Age group (ref: > 60 years)		
< 1 month	0.01 (0.01, 0.02)****	0.01 (0.01, 0.02)****
1 month – 1 year	0.23 (0.15, 0.35)****	0.23 (0.16, 0.34)****
1 – < 5 years	1.67 (1.10, 2.52)**	1.72 (1.19, 2.48)***
5 – 60 years	3.71 (2.46, 5.61)****	4.53 (3.13, 6.54)****
District (ref: Tanga)		
Handeni	2.04 (1.37, 3.01)****	1.85 (1.05, 3.25)**
Year (ref: 2016)		
2017	0.62 (0.38, 1.00)*	0.71 (0.50, 1.03)*
2018	0.38 (0.24, 0.62)****	0.43 (0.31, 0.60)****

IRR, Incidence rate ratio; CI, Confidence interval

* $p \leq 0.10$; ** $p \leq 0.05$; *** $p \leq 0.01$; **** $p \leq 0.001$

4.4 Discussions of the Findings

The study determined the occurrence of infectious diseases (i.e., diarrhea, pneumonia and malaria) among different age groups, and then assessed the trend in the occurrence of both the infectious diseases and climate indicators (i.e., precipitation, humidity and temperature) before exploring the associations between climate indicators and infectious diseases in Tanga region of Tanzania. Also, the analyses revealed the mean differences in the trend of the climate indicators and the occurrence of infectious diseases between Tanga and Handeni. The findings on the mean difference and the trend supports the findings of other studies on age and regional differences and seasonal variability of infectious diseases (Amouzou et al., 2016; Caminade et al., 2014; Chou et al., 2010; Edwin & Azage, 2019; Herrera-Lara et al., 2013; Parham & Michael, 2010).

On the association between climate indicators and the infectious diseases used in this study, this study found a positive association also supporting the findings of other studies (Caminade et al., 2014; Herrera-Lara et al., 2013; Kayembe & Kayembe, 2017; Mertens et al., 2019; Parham & Michael, 2010; Wang et al., 2019). The existence of differences in the occurrence of diarrhea among different age groups in different regions is also in agreement with a survey which reported that the overall prevalence of childhood diarrhea in Tanzania was 7.35 times higher among children who were aged between 6 to11 months as compared to children with 48-59 months of age. This study found that rainfall, humidity and temperature were associated with diarrheal diseases.

Though, several other factors are also known to be contributing to incidences of diarrhea among different age groups. These factors include improper waste disposal practices, lack of handwashing facilities, mother's poor hand washing practices, forms of water storage equipment, methods of complementary feeding, behavioral factors, latrine use and socioeconomic position (Anteneh et al., 2017). Other authors also found an increased odds of diarrhea among children aged between 12 and 23 months (Gupta et al., 2015). The reason for the occurrence of diarrhea among children may also be related, but not limited, to the low antibodies levels acquired from the mother that act as the primary source of antigen-specific immunity. At younger ages, most children are crawling and can easily be exposed to contaminated objects (Melese et al., 2019).

However, the mean difference of diarrheal infection with severe dehydration among the infants and elderly were not statistically significant. This is in line with a study done in Bangladesh on determinant of severe dehydration from diarrheal disease which demonstrated that people have different health seeking behavior based on age and gender (Andrews et al., 2017). The findings of this study, nevertheless, are in disagreement with the results of a study in Nigeria which found diarrhea to be commonly experienced among the infants (Dairo et al., 2017). Severe diarrheal diseases were also common among the older population in Tanga region than among the newborns. Though, the role of other factors such as behavioral, environmental and socioeconomic factors should not be overlooked.

The results of this study also found that humidity and minimum temperature were positively associated with pneumonia, which is in agreement with the findings of other authors (Onozuka et al., 2010). Nevertheless, one study found a that a decrease in absolute humidity levels increased the risk of pneumonia unlike the findings of this study which found a positive association (Mäkinen et al., 2009). However, this study did not find any association between rainfall and pneumonia as is the case of another study which alluded to the occurrence of pneumonia during rainy seasons (Mirsaeidi et al., 2016).

Though, this study document interesting differences in occurrence of pneumococcal infection across different age groups with only non-statistical differences presented majorly among the newborn less than 1 month between Tanga and Handeni districts. Age has a strong influence on the general incidence of invasive infections most frequent in the first years of life and persons older than 65years who remain vulnerable to morbidity and mortality caused by pneumococcal disease (Inostroza et al., 2001). The findings herein, though, indicate that severe pneumonia was common among the children between the age of 1 and 5 years than those who were older than 60 years, and the differences between the districts were statistically significant. The reasons as to why there is a decrease in the invasive pneumococcal disease among the infants (less than 1 year) could be the introduction of pneumococcal conjugate vaccine. However, the effect of pneumococcal vaccine on infants, less than 1 year old, needs to be explored further since its effect on them may be a challenge because the infection can be transmitted through vertical or horizontal means, and yet they are still too young to be protected directly by vaccine (Saso & Kampmann, 2017).

The occurrence of severe pneumonia was also higher in the year 2017 than 2016 after adjustment. However, pneumonia case in the year 2018 was lower than those in 2016 but it was not statistically significant. This may probably be due to high rates of home remedy particularly with antibiotics. Consequently, efforts are needed to look into antimicrobial resistance. There is need to improve case management of pneumonia in children in order to define local methods to pneumonia management as a strategy to reduce morbidity and mortality.

The diagnostic technique for malaria presented different information. In using malaria rapid diagnostic tests, the minimum temperature was positively associated with the occurrence of malaria; while for malaria blood smear test, the maximum temperature was positively related with the incidence of malaria. Though, the positive association between temperature and malaria was also found by other authors (Alonso et al., 2011). It is however important to explore this area further because other authors also found a negative association between temperature and incidence of malaria (Arab et al., 2014). Nevertheless, precipitation was negatively associated with malaria incidence in Tanga region as found by Arab and colleagues (2014). The findings on malaria may be attributed to different diagnostic techniques and use of mean temperature in this study. However, other studies may also be getting conflicting results because most epidemiological studies that are exploring the effect temperature on malaria are constructed solely on the mean temperatures (Arab et al., 2014; Ferrão et al., 2017; Xiang et al., 2018). On one hand, the rainfall provided a favorable environment for breeding and fertilization, on the other, temperature has an effect on the life cycle of mosquitoes and parasite (Mohammadkhani et al., 2016).

The occurrence of malaria was higher in Handeni than in Tanga. This might be due to the fact that the recent decline of malaria burden in the Tanga district has been attributed to an enhancement of intervention such as use of treated bed net, vector control, and use of SP in management of uncomplicated malaria (Mmbando et al., 2010). Moreover, there could be mosquito migration from the coastal region of Tanga to the highlands of Handeni district. The changing epidemiology of infection and disease cannot be easily explained by the changing coverage of intervention such as vector control and treated bed nets. It is therefore important to establish the contribution of these and other factors to the decline in malaria in one region and not the other (Mmbando et al., 2010). The high mean malarial infections in Handeni across the years is in line with a previous study conducted on the influence of the meteorological indicators on malaria cases patterns in the North-Eastern part of Tanzania which indicate that malaria among under five and above five years was significantly higher (Kajeguka, 2018). However, this study found that malaria was common among the children and adults aged between 1 to 60 years than the elderly aged above 60 years. Malaria is still a major public health problem.

In this study, there were significant trend differences in diarrhea without dehydration and in diarrhea with some dehydration for all age groups, with the differences being higher in Tanga than in Handeni in different months across different years. Diarrheal infections were higher in Tanga district than in Handeni district. This could be due to seasonal patterns that follow higher temperatures and which may end up with beyond expected diarrhea incidences. Results of the study indicated that an increase in rainfall days was strongly associated with diarrhea with some dehydration and with diarrhea without dehydration. However, increase in humidity levels by one unit reduced the incidence rate of diarrhea and increased the rate of diarrhea with severe dehydration by 3%. The finding on the effect of humidity on diarrheal disease in this study differ with the findings of Aik and colleagues (2020) which found a non-relationship between relative humidity and the incidence of diarrheal disease. However, the positive association on diarrhea with severe dehydration is in agreement with other authors (Onozuka et al., 2010; Phung et al., 2015). Some of the reasons for the variations in studies could be that some diarrhea causative agents may be active on object at room temperature and at low relative humidity for 10 days or more (Azage et al., 2017). Thus, more research on humidity may be necessary to assess the relationship with diarrhea.

Infants below 1 month had a lower incidence rate than the elderly aged 61years. The incidence rate was higher in other age groups in all three indicators. This study differs with a study conducted in Taiwan which examined the effect of climate variations on morbidity associated with diarrhea in the sub-tropical region where the effect of maximum temperature was found to be u-shaped on the morbidity associated with diarrhea (Chou et al., 2010).

The findings of this study found an association between rainfall and diarrheal infections. The findings are in agreement with a study in Mozambique where precipitation had an effect on diarrheal diseases (Horn et al., 2018). The lack of association between the change in temperature and diarrhea without dehydration are in disagreement with other studies (Bandyopadhyay et al., 2012; D'Souza et al., 2004; R. B. K. Singh et al., 2001) where an increase in temperature was associated with diarrheal increase because warm temperature causes proliferation of pathogen in food and water. However, maximum temperature and diarrhea with severe dehydration was statistically significant.

The forthcoming trends in the occurrence will depend on climate and weather changes in the districts. Access to improved sanitation and effective adaptation techniques is therefore necessary. It is worth noting that significant reduction in diarrhea with severe dehydration was observed between 2017 and 2018. This could probably be due to the National Sanitation Campaigns through a Community-Led Total Sanitation (CLTS) that were initiated in the country since 2012 aimed at improving the hygiene and sanitation.

In this study, a positive relationship between humidity and non-severe pneumonia was found. This is in line with a study by (Liu et al., 2009) who reported that temperature and humidity changes had an effect on pneumonia, and that precipitation influenced viral activity and transmission (Mirsaeidi et al., 2016). The study also revealed that increase in humidity and minimum temperature increased the rates of severe pneumonia. This supports the previous findings on the relationship between meteorological indicators (precipitation, humidity, temperature) and pneumonia among patients. Several studies have also found that the incidence of respiratory infection increased with the decrease in air temperature (Lin et al., 2013; Qui et al., 2016). Also, a study in two subtropical Chinese cities slightly differ from these results where exposure to high and low temperature caused an acute and chronic health effects, respectively (Lin et al., 2013). Increasing humidity could also create a favorable environment for microorganisms. High occurrence of pneumonia in Tanga district suggests that people should be careful about infection during hot and humid days.

The results of the binomial regression indicate that malaria increased by 1.23 times in one-unit increase in minimum temperature levels. The temperature, rainfall and malaria relationships is documented (Mbouna et al., 2019; Mordecai et al., 2013; Onyango et al., 2016; Paaijmans et al., 2010). Favorable temperature could influence the amount of vectors by providing a favorable environment for the life cycle of the parasite to be complete. Moderate rainfall, on the other hand, is appropriate for the aquatic development stage of mosquitoes to mature into adults. Extreme rainfall could however lead to larvae flush out from habitats as a result of flooding, and hence a decrease in the density of mosquitoes. Omumbo and colleagues (2011) found that rainfall is inversely associated with maximum and minimum temperature. Likewise, a study in Rufiji, Tanzania, highlighted that there was an increased risk under-five mortality as a result of rainfall in both long and short lag time (Mrema et al., 2012). Climate should therefore be regarded as a possible determination of detected surges in malaria.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This chapter presents the summary of the study, conclusions drawn and recommendations based on the findings of the study. It also outlines the study's limitation and areas for further research.

5.1 Summary

The study sought to explore the relationship between climate change and occurrence of infectious diseases in Tanga, Tanzania. This was a longitudinal study design where meteorological and health data were obtained from the Tanzania Meteorological Authority and Health Management Information System respectively. The health outcomes in this study were diarrhea, pneumonia and malaria. The data was analyzed using Multilevel Mixed-Effects Negative Binomial Regression to assess the trend differences in occurrence of infectious diseases of Tanga and Handeni districts. A Poisson regression model was employed because the dependent variable was count.

From the results, climate indicators that were statistically significant and directly or indirectly affected occurrence of diarrhea, pneumonia and malaria were maximum temperature and increased amount of rainfall increased the incidence rate of diarrhea. While increase in levels of humidity reduced the incidence rate of diarrhea without dehydration. This is to mean that, the occurrence of these extremes was found to have influenced the occurrence of diarrheal infections. Additionally, from the findings there was variance in age groups affected with pneumonia, diarrhea and malaria in both districts over the years. As for pneumonia, humidity was found to significantly affect non-severe pneumonia. Climate indicators (i.e. temperature and rainfall) also plays the most important role in influencing malaria epidemic both directly and indirectly. Directly it leads to breeding grounds and sites for mosquitoes.

5.2 Conclusions

In conclusion, the study looked at the association between climate change and occurrence of infectious disease in Tanga, Tanzania over a three-year period. The major conclusions arising from the study are discussed below with respect to the research objectives.

As for diarrhea and pneumonia an increase in climate indicators were found to be associated with the outcome of disease. Since climate change will continue to occur in future. The government through the MoHCDGEC should factor in climate indicators while planning interventions that reduce the burden of diarrhea and pneumonia morbidity in the Country. Equally for malaria morbidity, increase in rainfall and maximum temperature was associated with occurrence of malaria. Consequently, the government through the malaria control programme should monitor these climate variables during the surveillance and implement programs to prevent problems due to climate change.

The findings of the study highlight the need of changing our understanding of climatic and non-climatic drivers of infectious disease occurrence in order to manage current and possible future climate change effects. The findings also indicate the strong need for districts health systems resilience including close monitoring of health facilities in reporting health outcomes to ensure there are no outbreaks of diseases due to these climate indicators. Lastly, this study could be used by policy makers to enable them allocate budgets that could help toward mitigating the effects of climate factors on health.

5.3 Recommendations

Considering the findings and conclusions, this study makes the following recommendation with respect to Climate Change and occurrence of infectious diseases:

1. Since climate change continues to change over time, it is important that the MoHCDGEC capitalize in disease surveillance and preventive measures to ensure there are no outbreaks of the disease that could be as a result of climate change.
2. The districts should ensure that health promotion messages reach all age groups by increasing the frequency of health promotion on the effects of climate change.
3. The disease surveillance division should monitor disease pattern in relation to climatic conditions to understand the pattern of diseases, in order to lay down appropriate preventive measures.

5.3.1 Limitations of the study

1. Data obtained from the surveillance systems (HMIS) may not be clear on important confounding factors such as behavioral and cultural practices, economic status, sanitation and hygiene practices, nutritional status among children and health seeking behavior. Hence, the illness of the present patients could not be classified by cause.

5.3.2 Areas for Further Research

The following are areas suggested for further study:

1. This study only explored association between climate change and infectious disease occurrence in Tanga, Tanzania. This cannot provide a full picture of how infectious disease are influenced by climate change, the researcher recommends future studies focusing on the wide array of infectious diseases in Tanzania in different geographical contexts to find out on climatic and non-climatic drivers that influence the occurrence of infectious disease.
2. From the findings of this study, it is recommended that factors associated with the occurrence of diarrheal disease among different age groups should be looked at in further studies.

REFERENCES

Abiodun, G. J., Maharaj, R., Witbooi, P., & Okosun, K. O. (2016). Modelling the influence of temperature and rainfall on the population dynamics of Anopheles arabiensis. *Malaria Journal*, *15*(1), 364. https://doi.org/10.1186/s12936-016-1411-6

Aik, J., Ong, J., & Ng, L. C. (2020). The effects of climate variability and seasonal influence on diarrhoeal disease in the tropical city-state of Singapore – A time-series analysis. *International Journal of Hygiene and Environmental Health*, *227*, 113517. https://doi.org/10.1016/j.ijheh.2020.113517

Alexander, K. A., Carzolio, M., Goodin, D., & Vance, E. (2013). Climate change is likely to worsen the public health threat of diarrheal disease in Botswana. *International Journal of Environmental Research and Public Health*, *10*(4), 1202–1230. https://doi.org/10.3390/ijerph10041202

Alonso, D., Bouma, M. J., & Pascual, M. (2011). Epidemic malaria and warmer temperatures in recent decades in an East African highland. *Proceedings of the Royal Society B: Biological Sciences*, *278*(1712), 1661–1669. https://doi.org/10.1098/rspb.2010.2020

Amouzou, A., Velez, L. C., Tarekegn, H., & Young, M. (2016). One is too many: Ending child deaths from pneumonia and diarrhoea. *UNICEF. New York, NY*, 1–74.

Andrews, J. R., Leung, D. T., Ahmed, S., Malek, M. A., Ahmed, D., Begum, Y., Qadri, F., Ahmed, T., Faruque, A. S. G., & Nelson, E. J. (2017). Determinants of severe dehydration from diarrheal disease at hospital presentation: Evidence from 22 years of admissions in Bangladesh. *PLoS Neglected Tropical Diseases*, *11*(4). https://doi.org/10.1371/journal.pntd.0005512

Anteneh, Z. A., Andargie, K., & Tarekegn, M. (2017). Prevalence and determinants of acute diarrhea among children younger than five years old in Jabithennan District, Northwest Ethiopia, 2014. *BMC Public Health*, *17*(1), 1–8. https://doi.org/10.1186/s12889-017-4021-5

Anyorikeya, M., Ameme, D. K., Nyarko, K. M., Sackey, S. O., & Afari, E. (2016). Trends of diarrhoeal diseases in children under five years in the War Memorial Hospital-Navrongo, Ghana: 2010-2013. *The Pan African Medical Journal*, *25*(Suppl 1). https://doi.org/10.11604/pamj.supp.2016.25.1.6173

Arab, A., Jackson, M. C., & Kongoli, C. (2014). Modelling the effects of weather and climate on malaria distributions in West Africa. *Malaria Journal*, *13*(1), 126. https://doi.org/10.1186/1475-2875-13-126

Azage, M., Kumie, A., Worku, A., & Bagtzoglou, A. C. (2015). Childhood Diarrhea Exhibits Spatiotemporal Variation in Northwest Ethiopia: A SaTScan Spatial Statistical Analysis. *PLOS ONE*, *10*(12), e0144690. https://doi.org/10.1371/journal.pone.0144690

Azage, M., Kumie, A., Worku, A., Bagtzoglou, A. C., & Anagnostou, E. (2017). Effect of climatic variability on childhood diarrhea and its high risk periods in northwestern parts of Ethiopia. *PLoS ONE*, *12*(10). https://doi.org/10.1371/journal.pone.0186933

Bandyopadhyay, S., Kanji, S., & Wang, L. (2012). The impact of rainfall and temperature variation on diarrheal prevalence in Sub-Saharan Africa. *Applied Geography*. https://doi.org/10.1016/j.apgeog.2011.07.017

Bbaale, E. (2011). Determinants of diarrhoea and acute respiratory infection among under-fives in uganda. *Australasian Medical Journal*, *4*(7), 400–409. https://doi.org/10.4066/AMJ.2011.723

Ben, L. A., Aron, H. J., Aaron, C. T., & Umesh, P. D. (2011). Increasing Rates of Gastroenteritis Hospital Discharges in US Adults and the Contribution of Norovirus, 1996-2007—PubMed. *Clinical Infectious Diseases*, *52*(4), 466–474.

Ben-Shimol, S., Greenberg, D., Hazan, G., Shemer-Avni, Y., Givon-Lavi, N., & Dagan, R. (2015). Seasonality of Both Bacteremic and Nonbacteremic Pneumonia Coincides With Viral Lower Respiratory Tract Infections in Early Childhood, in Contrast to Nonpneumonia Invasive Pneumococcal Disease, in the Pre-Pneumococcal Conjugate Vaccine Era. *Clinical Infectious Diseases*, *60*(9), 1384–1387. https://doi.org/10.1093/cid/civ023

Beyene, H., Deressa, W., Kumie, A., & Grace, D. (2018). Spatial, temporal, and spatiotemporal analysis of under-five diarrhea in Southern Ethiopia. *Tropical Medicine and Health*, *46*, 18. https://doi.org/10.1186/s41182-018-0101-1

Bhavnani, D., Goldstick, J. E., Cevallos, W., Trueba, G., & Eisenberg, J. N. S. (2014). Impact of rainfall on diarrheal disease risk associated with unimproved water and sanitation. *American Journal of Tropical Medicine and Hygiene*, *90*(4), 705–711. https://doi.org/10.4269/ajtmh.13-0371

Caggiano, S., Ullmann, N., de Vitis, E., Trivelli, M., Mariani, C., Podagrosi, M., Ursitti, F., Bertolaso, C., Putotto, C., Unolt, M., Pietravalle, A., Pansa, P., Mphayokulela, K., Lemmo, M. I., Mkwambe, M., Kazaura, J., Duse, M., Nieddu, F., Azzari, C., & Cutrera, R. (2017). Factors that negatively affect the prognosis of pediatric community-acquired pneumonia in district hospital in Tanzania. *International Journal of Molecular Sciences*, *18*(3), 623. https://doi.org/10.3390/ijms18030623

Caminade, C., Kovats, S., Rocklov, J., Tompkins, A. M., Morse, A. P., Colón-González, F. J., Stenlund, H., Martens, P., & Lloyd, S. J. (2014). Impact of climate change on global malaria distribution. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(9), 3286–3291. https://doi.org/10.1073/pnas.1302089111

Carlton, E. J., Woster, A. P., DeWitt, P., Goldstein, R. S., & Levy, K. (2016). A systematic review and meta-analysis of ambient temperature and diarrhoeal diseases. *International Journal of Epidemiology*, *45*(1), 117–130. https://doi.org/10.1093/ije/dyv296

Chao, D. L., Roose, A., Roh, M., Kotloff, K. L., & Proctor, J. L. (2019). The seasonality of diarrheal pathogens: A retrospective study of seven sites over three years. *PLOS Neglected Tropical Diseases*, *13*(8), e0007211. https://doi.org/10.1371/journal.pntd.0007211

Chen, K., Jia, R., Li, L., Yang, C., & Shi, Y. (2015). The aetiology of community associated pneumonia in children in Nanjing, China and aetiological patterns associated with age and season. *BMC Public Health*, *15*(1). https://doi.org/10.1186/s12889-015-1422-1

Chou, W. C., Wu, J. L., Wang, Y. C., Huang, H., Sung, F. C., & Chuang, C. Y. (2010). Modeling the impact of climate variability on diarrhea-associated diseases in Taiwan (1996-2007). *Science of the Total Environment*, *409*(1), 43–51. https://doi.org/10.1016/j.scitotenv.2010.09.001

Chowdhury, F. R., Ibrahim, Q. S. U., Shafiqul Bari, M., Jahangir Alam, M. M., Dunachie, S. J., Rodriguez-Morales, A. J., & Ismail Patwary, M. (2018). The association between temperature, rainfall and humidity with common climate-sensitive infectious diseases in Bangladesh. *PLoS ONE*, *13*(6). https://doi.org/10.1371/journal.pone.0199579

Church, J. A., Aarup, T., Woodworth, P. L., Wilson, W. S., Nicholls, R. J., Rayner, R., Lambeck, K., Mitchum, G. T., Steffen, K., Cazenave, A., Blewitt, G., Mitrovica, J. X., & Lowe, J. A. (2010). Sea-Level Rise and Variability: Synthesis and Outlook for the Future. *Understanding Sea-Level Rise and Variability*, 402–419. https://doi.org/10.1002/9781444323276.ch13

Coughlan de Perez, E., Nerlander, L., Monasso, F., van Aalst, M., Mantilla, G., Muli, E., Nguyen, T., Rose, G., & Rumbaitis Del Rio, C. (2015). Managing health risks in a changing climate: Red Cross operations in East Africa and Southeast Asia. *Climate and Development*, *7*(3), 197–207. https://doi.org/10.1080/17565529.2014.951012

Cox, F. E. (2010). History of the discovery of the malaria parasites and their vectors. In *Parasites and Vectors* (Vol. 3, Issue 1, p. 5). BioMed Central. https://doi.org/10.1186/1756-3305-3-5

Dairo, M. D., Ibrahim, T. F., & Salawu, A. T. (2017). Prevalence and determinants of diarrhoea among infants in selected primary health centres in kaduna north local government area, nigeria. *Pan African Medical Journal*, *28*. https://doi.org/10.11604/pamj.2017.28.109.8152

Dherani, M., Pope, D., Mascarenhas, M., Smith, K. R., Weber, M., & Bruce, N. (2008). Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: A systematic review and meta-analysis. *Bulletin of the World Health Organization*, *86*(5), 390–394. https://doi.org/10.2471/BLT.07.044529

Division of Environment, United Republic of Tanzania. (2014). *Second National Communication of Tanzania submitted to the United Nations Framework Convention on Climate Change (UNFCCC)*. Division of Environment, Vice President's Office, URT. https://unfccc.int/sites/default/files/resource/tzanc2.pdf

D'Souza, R. M., Becker, N. G., Hall, G., & Moodie, K. B. A. (2004). Does ambient temperature affect foodborne disease? *Epidemiology*, *15*(1), 86–92. https://doi.org/10.1097/01.ede.0000101021.03453.3e

Ebi, K. L., Ogden, N. H., Semenza, J. C., & Woodward, A. (2017). Detecting and attributing health burdens to climate change. *Environmental Health Perspectives*, *125*(8). https://doi.org/10.1289/EHP1509

Edwin, P., & Azage, M. (2019). Geographical Variations and Factors Associated with Childhood Diarrhea in Tanzania: A National Population Based Survey 2015-16. *Ethiopian Journal of Health Sciences*, *29*(4), 513–524. https://doi.org/10.4314/ejhs.v29i4.13

Egyptian Environmental Affairs Agency. (2016). *Egypt Third National Communications submitted to the United Nations Framework Convention on Climate Change*. Egyptian Environmental Affairs Agency, Government Printers. https://unfccc.int/sites/default/files/resource/TNC%20report.pdf

Farthing, M., Salam, M. A., Lindberg, G., Dite, P., Khalif, I., Salazar-Lindo, E., Ramakrishna, B. S., Goh, K. L., Thomson, A., Khan, A. G., Krabshuis, J., & Lemair, A. (2013). Acute diarrhea in adults and children: A global perspective. In *Journal of Clinical Gastroenterology* (Vol. 47, Issue 1, pp. 12–20). J Clin Gastroenterol. https://doi.org/10.1097/MCG.0b013e31826df662

Federal Republic of Nigeria. (2014). *Second National Communication of Nigeria submitted to the United Nations Framework Convention on Climate Change (UNFCCC)*. Federal Ministry of Environment, Government Printers. https://unfccc.int/resource/docs/natc/bwanc2.pdf

Ferrão, J. L., Mendes, J. M., & Painho, M. (2017). Modelling the influence of climate on malaria occurrence in Chimoio Municipality, Mozambique. *Parasites and Vectors*, *10*(1), 1–12. https://doi.org/10.1186/s13071-017-2205-6

Fischer Walker, C. L., Rudan, I., Liu, L., Nair, H., Theodoratou, E., Bhutta, Z. A., O'Brien, K. L., Campbell, H., & Black, R. E. (2013). Global burden of childhood pneumonia and diarrhea: Department of International Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, USA. *The Lancet*, *381*(9875), 1405–1416. https://doi.org/10.1016/S0140-6736(13)60222-6

Gupta, A., Sarker, G., Rout, A. J., Mondal, T., & Pal, R. (2015). Risk correlates of diarrhea in children under 5 years of age in slums of Bankura, West Bengal.

Journal of Global Infectious Diseases, *7*(1), 23–29. https://doi.org/10.4103/0974-777X.150887

Guzman Herrador, B. R., De Blasio, B. F., MacDonald, E., Nichols, G., Sudre, B., Vold, L., Semenza, J. C., & Nygård, K. (2015). Analytical studies assessing the association between extreme precipitation or temperature and drinking water-related waterborne infections: A review. *Environmental Health: A Global Access Science Source*, *14*(1). https://doi.org/10.1186/s12940-015-0014-y

Herrera-Lara, S., Fernández-Fabrellas, E., Cervera-Juan, Á., & Blanquer-Olivas, R. (2013). Do seasonal changes and climate influence the etiology of community acquired pneumonia? *Archivos de Bronconeumologia*, *49*(4), 140–145. https://doi.org/10.1016/j.arbres.2012.11.001

Horn, L. M., Hajat, A., Sheppard, L., Quinn, C., Colborn, J., Zermoglio, M. F., Gudo, E. S., Marrufo, T., & Ebi, K. L. (2018). Association between precipitation and diarrheal disease in mozambique. *International Journal of Environmental Research and Public Health*, *15*(4). https://doi.org/10.3390/ijerph15040709

Inostroza, J., Vinet, A. M., Retamal, G., Lorca, P., Ossa, G., Facklam, R. R., & Sorensen, R. U. (2001). Influence of patient age on Streptococcus pneumoniae serotypes causing invasive disease. *Clinical and Diagnostic Laboratory Immunology*, *8*(3), 556–559. https://doi.org/10.1128/CDLI.8.3.556-559.2001

Intergovernmental Panel on Climate Change. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]*. IPCC. https://www.ipcc.ch/report/ar5/syr/

Kabir, M. E., & Serrao-Neumann, S. (2020). Climate Change Effects on People's Livelihood. In W. Leal Filho, A. M. Azul, L. Brandli, P. G. Özuyar, & T. Wall (Eds.), *Climate Action* (pp. 167–179). Springer International Publishing. https://doi.org/10.1007/978-3-319-95885-9_7

Kajeguka, C. (2018). *Meteorological Influence in Pattern of Malaria Cases in North-Eastern Tanzania: Five Years Analysis of Malaria Incidence and Climate Condition*. Journal of Pathology and Microbiology. https://www.researchgate.net/publication/320010918_Meteorological_Influence_in_Pattern_of_Malaria_Cases_in_North-Eastern_Tanzania_Five_Years_Analysis_of_Malaria_Incidence_and_Climate_Condition

Karungu, S., Atoni, E., Ogalo, J., Mwaliko, C., Agwanda, B., Yuan, Z., & Hu, X. (2019). Mosquitoes of Etiological Concern in Kenya and Possible Control Strategies. *Insects*, *10*(6). https://doi.org/10.3390/insects10060173

Kayembe, J.-M. N., & Kayembe, H.-C. N. (2017). Pneumonia: A Challenging Health Concern with the Climate Change. In *Contemporary Topics of Pneumonia*. InTech. https://doi.org/10.5772/intechopen.71609

Kinimi, E., Shayo, M. J., Patrick, B. N., Angwenyi, S. O., Kasanga, C. J., Weyer, J., Jansen van Vuren, P., Paweska, J. T., Mboera, L. E. G., & Misinzo, G. (2018). Evidence of chikungunya virus infection among febrile patients seeking healthcare in selected districts of Tanzania. *Infection Ecology and Epidemiology*, *8*(1). https://doi.org/10.1080/20008686.2018.1553460

Kotloff, K. L., Nataro, J. P., Blackwelder, W. C., Nasrin, D., Farag, T. H., Panchalingam, S., Wu, Y., Sow, S. O., Sur, D., Breiman, R. F., Faruque, A. S. G., Zaidi, A. K. M., Saha, D., Alonso, P. L., Tamboura, B., Sanogo, D., Onwuchekwa, U., Manna, B., Ramamurthy, T., … Levine, M. M. (2013). Burden and aetiology of diarrhoeal disease in infants and young children in developing countries (the Global Enteric Multicenter Study, GEMS): A prospective, case-control study. *The Lancet*, *382*(9888), 209–222. https://doi.org/10.1016/S0140-6736(13)60844-2

Kula, N., Haines, A., & Fryatt, R. (2013). Reducing Vulnerability to Climate Change in Sub-Saharan Africa: The Need for Better Evidence. *PLoS Medicine*, *10*(1). https://doi.org/10.1371/journal.pmed.1001374

Lamberti, L. M., Zakarija-Grković, I., Fischer Walker, C. L., Theodoratou, E., Nair, H., Campbell, H., & Black, R. E. (2013). Breastfeeding for reducing the risk of pneumonia morbidity and mortality in children under two: A systematic literature review and meta-analysis. In *BMC Public Health* (Vol. 13, Issue SUPPL.3). BMC Public Health. https://doi.org/10.1186/1471-2458-13-S3-S18

Levy, K., Woster, A. P., Goldstein, R. S., & Carlton, E. J. (2016). Untangling the Impacts of Climate Change on Waterborne Diseases: A Systematic Review of Relationships between Diarrheal Diseases and Temperature, Rainfall, Flooding, and Drought. In *Environmental Science and Technology* (Vol. 50, Issue 10, pp. 4905–4922). American Chemical Society. https://doi.org/10.1021/acs.est.5b06186

Lin, H., Zhang, Y., Xu, Y., Xu, X., Liu, T., Luo, Y., Xiao, J., Wu, W., & Ma, W. (2013). Temperature Changes between Neighboring Days and Mortality in Summer: A

Distributed Lag Non-Linear Time Series Analysis. *PLoS ONE, 8*(6), e66403. https://doi.org/10.1371/journal.pone.0066403

Liu, L., Poon, R., Chen, L., Frescura, A.-M., Montuschi, P., Ciabattoni, G., Wheeler, A., & Dales, R. (2009). Acute Effects of Air Pollution on Pulmonary Function, Airway Inflammation, and Oxidative Stress in Asthmatic Children. *Environmental Health Perspectives*, *117*(4), 668–674. https://doi.org/10.1289/ehp11813

Luhunga, P. M., Kijazi, A. L., Chang'a, L., Kondowe, A., Ng'ongolo, H., & Mtongori, H. (2018). Climate change projections for Tanzania Based on high-resolution regional climate models from the Coordinated Regional Climate Downscaling Experiment (CORDEX)-Africa. *Frontiers in Environmental Science*, *6*(OCT). https://doi.org/10.3389/fenvs.2018.00122

Mäkinen, T. M., Juvonen, R., Jokelainen, J., Harju, T. H., Peitso, A., Bloigu, A., Silvennoinen-Kassinen, S., Leinonen, M., & Hassi, J. (2009). Cold temperature and low humidity are associated with increased occurrence of respiratory tract infections. *Respiratory Medicine*, *103*(3), 456–462. https://doi.org/10.1016/j.rmed.2008.09.011

Masson-Delmotte, V., P. Z., H.-O. Pörtner, D., Roberts, J., Skea, P. R., Shukla, A., Pirani, W., Moufouma-Okia, C., Péan, R., Pidcock, S., Connors, J. B. R., Matthews, Y., Chen, X., Zhou, M. I., Gomis, E., Lonnoy, T., Maycock, M., Tignor, & Waterfield, T. (2018). *Summary for Policymakers In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of*

1.5°Cabove pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to t.

Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P. R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J. B. R., Chen, Y., Zhou, X., Gomis, M. I., Lonnoy, E., Maycock, T., Tignor, M., & Waterfield, T. (2018). *Global warming of 1.5°C An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, .*

Mboera, L. E. G., Mayala, B. K., Kweka, E. J., & Mazigo, H. D. (2011). Impact of climate change on human health and health systems in Tanzania: A review. *Tanzania Journal of Health Research*, *13*(5 SUPPL.ISS), 1–23. https://doi.org/10.4314/thrb.v13i1.10

Mbouna, A. D., Tompkins, A. M., Lenouo, A., Asare, E. O., Yamba, E. I., & Tchawoua, C. (2019). Modelled and observed mean and seasonal relationships between climate, population density and malaria indicators in Cameroon. *Malaria Journal*, *18*(1), 1–14. https://doi.org/10.1186/s12936-019-2991-8

Melese, B., Paulos, W., Astawesegn, F. H., & Gelgelu, T. B. (2019). Prevalence of diarrheal diseases and associated factors among under-five children in Dale District, Sidama zone, Southern Ethiopia: A cross-sectional study. *BMC Public Health*, *19*(1), 1235. https://doi.org/10.1186/s12889-019-7579-2

Mertens, A., Balakrishnan, K., Ramaswamy, P., Rajkumar, P., Ramaprabha, P., Durairaj, N., Hubbard, A. E., Khush, R., Colford, J. M., & Arnold, B. F. (2019).

Associations between High Temperature, Heavy Rainfall, and Diarrhea among Young Children in Rural Tamil Nadu, India: A Prospective Cohort Study. *Environmental Health Perspectives*, *127*(4). https://doi.org/10.1289/EHP3711

Metcalf, C. J. E., Walter, K. S., Wesolowski, A., Buckee, C. O., Shevliakova, E., Tatem, A. J., Boos, W. R., Weinberger, D. M., & Pitzer, V. E. (2017). Identifying climate drivers of infectious disease dynamics: Recent advances and challenges ahead. In *Proceedings of the Royal Society B: Biological Sciences* (Vol. 284, Issue 1860). Royal Society Publishing. https://doi.org/10.1098/rspb.2017.0901

Mirsaeidi, M., Motahari, H., Khamesi, M. T., Sharifi, A., Campos, M., & Schraufnagel, D. E. (2016). Climate change and respiratory infections. In *Annals of the American Thoracic Society* (Vol. 13, Issue 8, pp. 1223–1230). American Thoracic Society. https://doi.org/10.1513/AnnalsATS.201511-729PS

Mmbando, B. P., Vestergaard, L. S., Kitua, A. Y., Lemnge, M. M., Theander, T. G., & Lusingu, J. P. A. (2010). A progressive declining in the burden of malaria in north-eastern Tanzania. *Malaria Journal*, *9*(1), 216. https://doi.org/10.1186/1475-2875-9-216

Mohammadkhani, M., Khanjani, N., Bakhtiari, B., & Sheikhzadeh, K. (2016). The relation between climatic factors and malaria incidence in Kerman, South East of Iran. *Parasite Epidemiology and Control*, *1*(3), 205–210. https://doi.org/10.1016/j.parepi.2016.06.001

Morand, S., Owers, K. A., Waret-Szkuta, A., McIntyre, K. M., & Baylis, M. (2013). Climate variability and outbreaks of infectious diseases in Europe. *Scientific Reports*, *3*. https://doi.org/10.1038/srep01774

Mordecai, E. A., Paaijmans, K. P., Johnson, L. R., Balzer, C., Ben-Horin, T., de Moor, E., Mcnally, A., Pawar, S., Ryan, S. J., Smith, T. C., & Lafferty, K. D. (2013). Optimal temperature for malaria transmission is dramatically lower than previously predicted. *Ecology Letters*, *16*(1), 22–30. https://doi.org/10.1111/ele.12015

Mrema, S., Shamte, A., Selemani, M., & Masanja, H. (2012). The influence of weather on mortality in rural Tanzania: A time-series analysis 1999–2010. *Global Health Action*, *5*(1), 19068. https://doi.org/10.3402/gha.v5i0.19068

National Aeronautics and Space Administration. (2019). *Climate Change: Vital Signs of the Planet*. Climate Change: Vital Signs of the Planet. https://climate.nasa.gov/

Nava, A., Shimabukuro, J. S., Chmura, A. A., & Luz, S. L. B. (2017). The impact of global environmental changes on infectious disease emergence with a focus on risks for Brazil. *ILAR Journal*, *58*(3), 393–400. https://doi.org/10.1093/ilar/ilx034

Omumbo, J. A., Lyon, B., Waweru, S. M., Connor, S. J., & Thomson, M. C. (2011). Raised temperatures over the Kericho tea estates: Revisiting the climate in the East African highlands malaria debate. *Malaria Journal*, *10*. https://doi.org/10.1186/1475-2875-10-12

Onozuka, D., Hashizume, M., & Hagihara, A. (2010). Effects of weather variability on infectious gastroenteritis. *Epidemiology and Infection*, *138*(2), 236–243. https://doi.org/10.1017/S0950268809990574

Onyango, E. A., Sahin, O., Awiti, A., Chu, C., & Mackey, B. (2016). An integrated risk and vulnerability assessment framework for climate change and malaria transmission in East Africa. *Malaria Journal*, *15*(1), 1–12. https://doi.org/10.1186/s12936-016-1600-3

Ostfeld, R. S., & Brunner, J. L. (2015). Climate change and Ixodes tick-borne diseases of humans. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*(1665), 1–11. https://doi.org/10.1098/rstb.2014.0051

Ota, K., Sasabuchi, Y., Matsui, H., Jo, T., Fushimi, K., & Yasunaga, H. (2019). Age distribution and seasonality in acute eosinophilic pneumonia: Analysis using a national inpatient database. *BMC Pulmonary Medicine*, *19*(1), 38. https://doi.org/10.1186/s12890-019-0800-3

Paaijmans, K. P., Blanford, S., Bell, A. S., Blanford, J. I., Read, A. F., & Thomas, M. B. (2010). Influence of climate on malaria transmission depends on daily temperature variation. *Proceedings of the National Academy of Sciences of the United States of America*, *107*(34), 15135–15139. https://doi.org/10.1073/pnas.1006422107

Parham, P. E., & Michael, E. (2010). Modelling climate change and malaria transmission. *Advances in Experimental Medicine and Biology*, *673*, 184–199. https://doi.org/10.1007/978-1-4419-6064-1_13

Patz, J. A., Campbell-Lendrum, D., Holloway, T., & Foley, J. A. (2005). Impact of regional climate change on human health. In *Nature* (Vol. 438, Issue 7066, pp. 310–317). Nature Publishing Group. https://doi.org/10.1038/nature04188

Paynter, S., Ware, R. S., Weinstein, P., Williams, G., & Sly, P. D. (2010). Childhood pneumonia: A neglected, climate-sensitive disease? *Lancet (London, England)*, *376*(9755), 1804–1805. https://doi.org/10.1016/S0140-6736(10)62141-1

Philipsborn, R. P., & Chan, K. (2018). Climate change and global child health. *Pediatrics*, *141*(6). https://doi.org/10.1542/peds.2017-3774

Phung, D., Huang, C., Rutherford, S., Chu, C., Wang, X., Nguyen, M., Nguyen, N. H., Do, C. M., & Nguyen, T. H. (2015). Temporal and spatial patterns of diarrhoea in the Mekong Delta area, Vietnam. *Epidemiology and Infection*, *143*(16), 3488–3497. https://doi.org/10.1017/S0950268815000709

Qui, H., Sun, S., Tang, R., Chan, K.-P., & Tian, L. (2016). Pneumonia Hospitalization Risk in the Elderly Attributable to Cold and Hot Temperatures in Hong Kong, China. *American Journal of Epidemiology, 184*(8), 570–578.

Rodó, X., Pascual, M., Doblas-Reyes, F. J., Gershunov, A., Stone, D. A., Giorgi, F., Hudson, P. J., Kinter, J., Rodríguez-Arias, M. À., Stenseth, N. C., Alonso, D., García-Serrano, J., & Dobson, A. P. (2013). Climate change and infectious diseases: Can we meet the needs for better prediction? *Climatic Change*, *118*(3–4), 625–640. https://doi.org/10.1007/s10584-013-0744-1

Ruuskanen, O., Lahti, E., Jennings, L. C., & Murdoch, D. R. (2011). Viral pneumonia. In *The Lancet* (Vol. 377, Issue 9773, pp. 1264–1275). Lancet Publishing Group. https://doi.org/10.1016/S0140-6736(10)61459-6

Saso, A., & Kampmann, B. (2017). Vaccine responses in newborns. In *Seminars in Immunopathology* (Vol. 39, Issue 6, pp. 627–642). Springer Verlag. https://doi.org/10.1007/s00281-017-0654-9

Schumann, B., Edvinsson, S., Evengård, B., & Rocklöv, J. (2013). The influence of seasonal climate variability on mortality in pre-industrial Sweden. *Global Health Action*, *6*(1). https://doi.org/10.3402/gha.v6i0.20153

Scott, J., Adegbola, R., & Gordon, S. (2012). Pneumonia in adults. In *Principles of Medicine in Africa*, (pp. 264–276).

Serdeczny, O., Adams, S., Baarsch, F., Coumou, D., Robinson, A., Hare, W., Schaeffer, M., Perrette, M., & Reinhardt, J. (2017). Climate change impacts in Sub-Saharan Africa: From physical changes to their social repercussions. *Regional Environmental Change*, *17*(6), 1585–1600. https://doi.org/10.1007/s10113-015-0910-2

Sharma, B. B., & Singh, V. (2018). Pneumonia bugs and determinants of their occurrence. In *Lung India* (Vol. 35, Issue 2, pp. 95–97). Medknow Publications. https://doi.org/10.4103/lungindia.lungindia_33_18

Shuman, E. K. (2010). Global Climate Change and Infectious Diseases. *New England Journal of Medicine*, *362*(12), 1061–1063. https://doi.org/10.1056/NEJMp0912931

Singh, G., & Sehgal, R. (2010). Transfusion-transmitted parasitic infections. In *Asian Journal of Transfusion Science* (Vol. 4, Issue 2, pp. 73–77). Wolters Kluwer -- Medknow Publications. https://doi.org/10.4103/0973-6247.67018

Singh, R. B. K., Hales, S., De Wet, N., Raj, R., Hearnden, M., & Weinstein, P. (2001). The influence of climate variation and change on diarrheal disease in the Pacific Islands. *Environmental Health Perspectives*, *109*(2), 155–159. https://doi.org/10.1289/ehp.01109155

Smith, K. R., McCracken, J. P., Weber, M. W., Hubbard, A., Jenny, A., Thompson, L. M., Balmes, J., Diaz, A., Arana, B., & Bruce, N. (2011). Effect of reduction in household air pollution on childhood pneumonia in Guatemala (RESPIRE): A randomised controlled trial. *The Lancet*, *378*(9804), 1717–1726. https://doi.org/10.1016/S0140-6736(11)60921-5

StataCorp. (2013). *Stata Statistical Software: Release 13*. StataCorp LP.

Thiam, S., Diène, A. N., Sy, I., Winkler, M. S., Schindler, C., Ndione, J. A., Faye, O., Vounatsou, P., Utzinger, J., & Cissé, G. (2017). Association between childhood diarrhoeal incidence and climatic factors in urban and rural settings in the health district of Mbour, Senegal. *International Journal of Environmental Research and Public Health*. https://doi.org/10.3390/ijerph14091049

United Nations Environment Programme, W. H. O. (2011). Adaptation to climate change in Africa, plan of action for the health sector 2012–2016. *Geneva: World Health Organization*.

Walker, C. L. F., & Black, R. E. (2010). Diarrhoea morbidity and mortality in older children, adolescents, and adults. In *Epidemiology and Infection* (Vol. 138, Issue 9, pp. 1215–1226). https://doi.org/10.1017/S0950268810000592

Wandiga, S. O., Opondo, M., Olago, D., Githeko, A., Githui, F., Marshall, M., Downs, T., Opere, A., Oludhe, C., Ouma, G. O., Yanda, P. Z., Kangalawe, R., Kabumbuli, R., Kathuri, J., Apindi, E., Olaka, L., Ogallo, L., Mugambi, P., Sigalla, R., … Achola, P. (2010). Vulnerability to epidemic malaria in the highlands of Lake Victoria basin: The role of climate change/variability, hydrology and socio-economic factors. *Climatic Change*, *99*(3), 473–497. https://doi.org/10.1007/s10584-009-9670-7

Wang, H., Di, B., Zhang, T. J., Lu, Y., Chen, C., Wang, D., Li, T., Zhang, Z., & Yang, Z. (2019). Association of meteorological factors with infectious diarrhea incidence in Guangzhou, southern China: A time-series study (2006–2017). *Science of the Total Environment*, *672*, 7–15. https://doi.org/10.1016/j.scitotenv.2019.03.330

Weinberger, D. M., Harboe, Z. B., Viboud, C., Krause, T. G., Miller, M., Mølbak, K., & Konradsen, H. B. (2014). Pneumococcal disease seasonality: Incidence, severity and the role of influenza activity. *European Respiratory Journal*, *43*(3), 833–841. https://doi.org/10.1183/09031936.00056813

WHO. (2009). WHO | Climate change and human health—Risks and responses. Summary. *World Health Organization*.

WHO. (2018). *World Malaria report 2018*.

WHO. (2019a). *Guidelines for Malaria Vector Control—Malaria and related entamological and vector control concepts.* World Health Organization. https://www.ncbi.nlm.nih.gov/books/NBK538113/

WHO. (2019b). *Pneumonia*. World Health Organization. https://www.who.int/news-room/fact-sheets/detail/pneumonia

World Health Organization. (2009). *Global health risks: Mortality and burden of disease attributable to selected major risks*. World Health Organization.

World Health Organization. (2017). *Diarrhoeal disease*. https://www.who.int/news-room/fact-sheets/detail/diarrhoeal-disease

World Health Organization. (2018). *Climate change and health*. https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health

Wu, X., Lu, Y., Zhou, S., Chen, L., & Xu, B. (2016). Impact of climate change on human infectious diseases: Empirical evidence and human adaptation. In *Environment*

International (Vol. 86, pp. 14–23). Elsevier Ltd. https://doi.org/10.1016/j.envint.2015.09.007

Wu, X. X., Tian, H. Y., Zhou, S., Chen, L. F., & Xu, B. (2014). Impact of global change on transmission of human infectious diseases. *Science China Earth Sciences*, *57*(2), 189–203. https://doi.org/10.1007/s11430-013-4635-0

Xiang, J., Hansen, A., Liu, Q., Tong, M. X., Liu, X., Sun, Y., Cameron, S., Hanson-Easey, S., Han, G. S., Williams, C., Weinstein, P., & Bi, P. (2018). Association between malaria incidence and meteorological factors: A multi-location study in China, 2005–2012. *Epidemiology & Infection*, *146*(1), 89–99. https://doi.org/10.1017/S0950268817002254

Xu, Z., Hu, W., & Tong, S. (2014). Temperature variability and childhood pneumonia: An ecological study. *Environmental Health: A Global Access Science Source*, *13*(1). https://doi.org/10.1186/1476-069X-13-51

Xu, Z., Hu, W., Zhang, Y., Wang, X., Zhou, M., Su, H., Huang, C., Tong, S., & Guo, Q. (2015). Exploration of diarrhoea seasonality and its drivers in China. *Scientific Reports*, *5*(Class C), 1–9. https://doi.org/10.1038/srep08241

Xu, Z., Liu, Y., Ma, Z., (Sam) Toloo, G., Hu, W., & Tong, S. (2014). Assessment of the temperature effect on childhood diarrhea using satellite imagery. *Scientific Reports*, *4*(1), 5389. https://doi.org/10.1038/srep05389

Ye, Y., Zulu, E., Mutisya, M., Orindi, B., Emina, J., & Kyobutungi, C. (2009). Seasonal pattern of pneumonia mortality among under-five children in Nairobi's informal settlements. *The American Journal of Tropical Medicine and Hygiene*, *81*(5), 770–775. https://doi.org/10.4269/ajtmh.2009.09-0070

Zhou, X., Zhou, Y., Chen, R., Ma, W., Deng, H., & Kan, H. (2013). High Temperature as a Risk Factor for Infectious Diarrhea in Shanghai, China. *Journal of Epidemiology*, *23*(6), 418–423. https://doi.org/10.2188/jea.JE20130012

APPENDICES

Appendix 1: Checklist of Data Retrieved

No.	Variable	Coding
1. Month	Months of the year	☐1: January ☐2: February ☐3: March ☐4: April ☐5: May ☐6: June ☐7: July ☐8: August ☐9: September ☐10: October ☐10: November ☐10: December
2. Year	The years of data collection	☐1: 2016 ☐2: 2017 ☐3: 2018
3. Region	This is the district	☐1: Tanga ☐2: Handeni
4. Age	Age group of the patients	☐1: < 1 month ☐2: 1 month to 1 year ☐3: 1 year to < 5 years ☐4: 5 years to 60 years
INFECTIOUS DISEASE		

5. Diarrhoeal Disease	The number of patients diagnosed with **Diarrhea (no dehydration)**	__ __ __ __
	The number of patients diagnosed with **Diarrhea (some dehydration)**	__ __ __ __
	The number of patients diagnosed with **Diarrhea (severe dehydration)**	__ __ __ __
6. Pneumococcal Disease	The number of patients diagnosed with **Pneumonia (non-severe)**	__ __ __ __
	The number of patients diagnosed with **Pneumonia (severe)**	__ __ __ __
7. Malarial Disease	The number of patients diagnosed with **Malaria (rapid-diagnostic test)**	__ __ __ __
	The number of patients diagnosed with **Malaria (blood smears)**	__ __ __ __
CLIMATE INDICATORS		
8. Precipitation	This is rainfall amount	______mm/hour

9. Humidity	The amount of moisture in the air expressed as percentage.	______%
10. Temperature		☐ Maximum: ______°C ☐ Minimum: ______°C

Appendix 2: Schedule of Activities

Activity	**Aug (2019)**	**Sept (2019)**	**Oct (2019)**	**Nov (2019)**	**Dec (2019)**	**Jan (2020)**	**Feb (2020)**	**March (2020)**	**Apr (2020)**	**May (2020)**
Title defense										
Proposal writing and presentation										
Data collection and entry										
Data analysis										
Thesis writing										
Presentation/Thesis defense										
Dissemination of findings										
Publication										

Appendix 3: Budget for Research

No.	Budget Item	Total (Tshs)
1	Printing, Photocopying and Binding	400,000/=
2	Transport and Communication	500,000/=
3	Examiners fee	200,000/=
4	Approval and Clearance fee	630,000/=
5	Miscellaneous	300,000/=
	Total	**2,030,000/=**

Appendix 4: Ethical Clearance

OFFICE OF THE DIRECTOR OF GRADUATE STUDIES AND RESEARCH
UNIVERSITY OF EASTERN AFRICA, BARATON
P.O. BOX 2500-30100, Eldoret, Kenya, East Africa

B1214102019 — October 14, 2019

TO: Samweli Faraja Miyayo
Global Health Program, Department of Public Health
University of Eastern Africa, Baraton

Dear Samweli,

RE: Relationship Between Climate Change and Occurance of Infectious Diseases (Malaria, Diarrhea and Pneumonia) in Tanga, Tanzania

This is to inform you that the Research Ethics Committee (REC) of the University of Eastern Africa Baraton has reviewed and approved your above research proposal. Your application approval number is UEAB/REC/12/10/2019. The approval period is 14th October, 2019- 13th October, 2020.

This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, MTA) will be used.
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by the Research Ethics Committee (REC) of the University of Eastern Africa Baraton.
iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to the Research Ethics Committee (REC) of the University of Eastern Africa Baraton within 72 hours of notification.
iv. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to the Research Ethics Committee (REC) of the University of Eastern Africa Baraton within 72 hours.
v. Clearance for export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to the Research Ethics Committee (REC) of the University of Eastern Africa Baraton.

Prior to commencing your study, you will be expected to obtain a research license from the research authorities in Tanzania and also obtain other clearances needed.

Sincerely yours,

Jackie K. Obey

Prof. Jackie K. Obey, PhD
Chairperson, Research Ethics Committee

University of Eastern Africa, Baraton
14 OCT 2019
Research Ethics Committee

A SEVENTH-DAY ADVENTIST INSTITUTION OF HIGHER LEARNING
CHARTERED 1991

Ethical Clearance (TMA)

Form No.72

Data Delivery Report

In reply please quote:
Ref. No. TMA/ 1422

12th December 2019

Request No. (*yymmno*)	: 2019121201
Customer Name	: Samwel F. Miyayo
Customer Address	: P.O.Box 178 TANGA
Phone number	: 0783764410
Email Address	: sammiyayo@yahoo.com

Description for data provided

Parameter(s) provided: - Monthly Rainfall, Temperature and Relative Humidity

Station (s) provided: Handeni: Latitude:- **5°26'** Longitude:- **38°2'** Elevation:- **756m**

Tanga: Latitude:- **5°5'** Longitude:- **39°4'** Elevation:- **49m**

Duration (Year/ Month): 2016 - 2019

Data given as: - Hard copy and Soft copy

Data Gaps: - No Gaps

Attended by:- Jafari Chobo, Meteorologist — Signature — Date: 12/12/2019

Verified by:- Dr. Hashim Ng'ongolo, MCC — Signature — Date: 12/12/2019

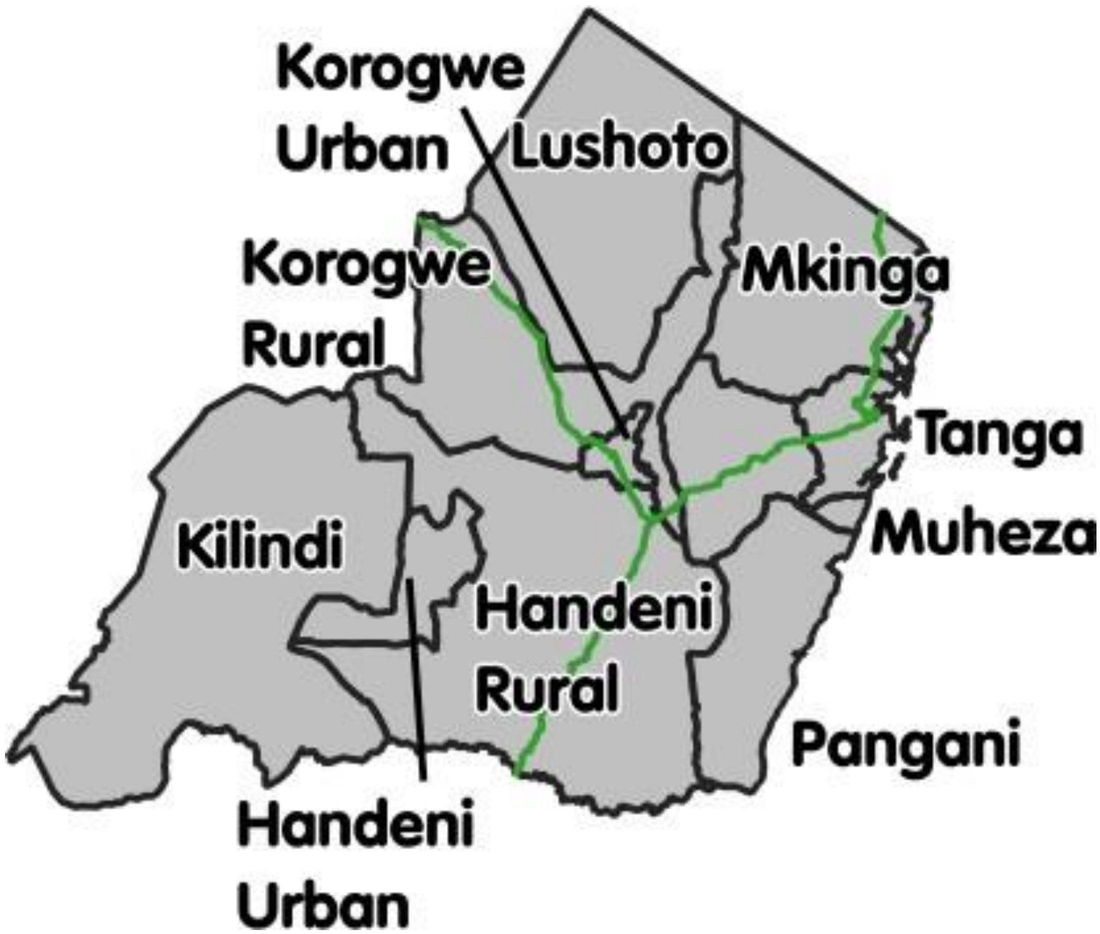
Ag. DIRECTOR GENERAL
MINISTRY OF TRANSPORT
TANZANIA METEOROLOGICAL AGENCY
P. O. Box 3056
DAR ES SALAAM

Customer's signature: ……………………………

All correspondences should be directed to:
Director General, Tanzania Meteorological Authority, Ubungo Plaza, 3rd Floor, 388 Morogoro Rd
P.O. Box 3056, 16102 Dar es Salaam, Tanzania. Fax: +255 22 2460735, Tel: +255 22 2460706-8
Email: met@meteo.go.tz, Website: www.meteo.go.tz

tive Date: October 31, 2019 Revis

Appendix 7: Map of Tanga Region



Appendix 8: Curriculum Vitae

CONTACT INFORMATION

Name:	Samweli Faraja Miyayo
Address:	P. O. Box 1121
	Arusha,Tanzania
Mobile:	+254 726647398 or +255 783764410
Email:	sammiyayo@yahoo.com
	faraja088@gmail.com

BIO DATA

Place of birth: Moshi, Tanzania

Citizenship: Tanzania

Sex: Male

Languages Spoken: English, Kiswahili among other African dialects

PERSONAL PROFILE

A competent self-motivated and hardworking public health practitioner with a friendly personality who is able to communicate clearly and respectfully. Holder of BSc. Public health (Environmental Health Option), with keen interest in research. My personal career target is to see a transformed universal healthcare system.

CAREER OBJECTIVE

My Goal is to be a transformational health practitioner in my area of specialization and to utilize my skills and abilities that offer opportunity for personal growth.

EDUCATION AND QUALIFICATIONS

University of Eastern Africa, Baraton **August 2021**
MSc. Global Health Care

University of Eastern Africa, Baraton **August 2014**
BSc. Public Health (Environmental Health Option)

Bugema Adventist Secondary School **November 2008**
Certificate of Secondary Education

CERTIFICATION AND LICENSURE

- Registered and Licensed Environmental Health Practitioner in Tanzania

PROFESSIONAL SKILLS

- Communication: Increased knowledge in writing and speaking English fluently when interacting with people from different nationalities and in my professional area.
- Interpersonal relationship: Advanced in getting along well with others, team player, tactful in dealing with coworkers, students, peers and supervisors as well as able to solve conflicts that may arise among communities.
- Confidentiality: Ability to keep information and any other personal issues that someone can confidently trust me and share with me his/her private issues.

WORK EXPERIENCE

- **Environmental health officer (EHO)** in Tanga City Council, November 2017-present
- **Cholera outbreak:** Assisted in combating cholera outbreak in Arusha region, 2016
- **Internship:** Professional practice in Arusha Region, May 2015- March 2016
- **Tutorial Assistant**: Ngudu School of Environmental Health, February 2015-April 2015
- **Laboratory Assistant:** Developing students with day to day GIS analysis and Cartography needs, University of Eastern Africa Baraton, 2009-2011
- **Seminars Attended/Conducted**
  - Attended dengue case management guideline orientation in Morogoro, June 2019
  - Facilitated in a seminar for Social Mobilization for combating cholera in Arusha City, December 2016
  - Community lead total sanitation training (CLTS) in Arusha, 2015

- Attended different seminars in my career and others depending on my interest and accessibility of the seminar to up-date my knowledge and skills.

AWARDS

- Certificate of Appreciation for combating the spread of Cholera in Arusha City, February 2016.
- Certificate of Participation for Training of Trainers in Hand washing, October 2010
- Certificate of training on disease surveillance and infection prevention and control, March 2013
- Certificate of training on HIV and Nutrition care NASCOP curriculum, March 2013
- Certificate of community bases rehabilitation (CBR) in disability Management, October 2012

PUBLICATION AND PRESENTATION

Miyayo SF, Anjenjo D (2014). Men's involvement in family planning: Factors associated with Men's involvement in family planning among married men living in Baraton Sub-location, Kenya. Lambert Academic Publishing. ISBN 13: 9783659623400

AREAS OF EXPERTISE

- Administration
- Academic Research
- Instructing students

PERSONAL SKILLS AND ATTRIBUTES

- Active listening
- Attention to detail
- Communication skills
- Problem sensitivity
- Good in planning, organizing and problem solving
- Ability to work effectively under pressure
- Computer literate and other health support systems
- Possess strong leadership skills
- Effective time management and able to prioritize

HOBBIES & INTEREST

- Reading and Research
- Physical Exercise

REFEREES

Khol Helmut
Chairperson Department of Public Health
University of Eastern Africa, Baraton
Box 2500
Eldoret, Kenya
Mobile No: +254723509098

John N Sagaika
City Health Officer
P.O. Box 178
Tanga, Tanzania
Mobile No: +255713485120