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Population Density and Spatial Distribution of Neglected Tropical Diseases in Sierra Leone

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Abou Funna

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Walden University
2020

Abstract

Population Density and Spatial Distribution of Neglected

Tropical Diseases in Sierra Leone

by

Abou Funna

MPH, Walden University

BSc, N'jala University, University of Sierra Leone

Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Philosophy

Epidemiology

Walden University

February 2020

Abstract

Neglected tropical diseases (NTDs) are the most common health conditions affecting the poorest residents of sub-Saharan Africa (SSA). These infections affect an estimated 2 billion people worldwide, including 500 million people living in SSA. About 85% of NTD infections are a result of helminth infections; hookworm is also a common occurrence among SSA's poorest people, especially children. Schistosomiasis is the 2nd most prevalent NTD after hookworm. This quantitative correlational study investigated population distribution and the spread of NTDs in Sierra Leone. The focus was on 5 major NTDs: ascariasis, hookworm, schistosomiasis, soil-transmitted helminthiasis, and trichuris. Data were obtained from the Sierra Leone Ministry of Health and Sanitation and the World Health Organization (N=1,537). Due to data availability, correlation analysis was limited to climate pattern (temperature and precipitation change), population density, and prevalence of NTDs. Logistic regression analysis was also used to test the research hypotheses. Population density was taken as the dependent variable, and temperature and precipitation were taken as the independent variables. The results of this study did not show a relationship between climate patterns, as measured by temperature and precipitation trend, and population density in Sierra Leone. Furthermore, this study did not indicate any association between population density and the prevalence of NTDs in Sierra Leone. In future studies on similar topics, it is recommended that researchers collect pretreatment and posttreatment data on the same populations. Thorough and complete data sets should be collected for population movement and density as well as disease prevalence. More should be done to improve public health infrastructure and funding to prevent the transmission of neglected tropical diseases.

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Dedication

This PhD dissertation is dedicated in loving memory of my parents, Mr. Amadu Funna and Mrs. Isatu Funna, and my elder brothers, Dr. Jim Funna and Dr. Soule Funna, whose hard work and commitment to my success have enabled me to accomplish many things in life, including my educational goals. I am honored to have been blessed with an enormous amount of support from both relatives and friends, whom I will acknowledge in the acknowledgments section. My parents' counsel and nurturing and my brothers have always been "The Wind Beneath My Wings." The early education they provided me about life has been my pillar of success. Their love of God and enduring faith, human decency, and abundant love for family and human dignity are just some of their qualities that I strive to emulate. I feel extremely lucky to have them as my parents and brothers. I want to thank my late sister, Mammy Fatu Funna, whose love and belief in me contributed to the success of my journey. Although you are gone, you left fingerprints of grace on my life. In addition, this dissertation is in loving memory of my late Funna family members. I pray that their souls rest in perfect peace. The fact that they are no longer with me here in this world does not diminish the role they continue to play in my endeavors on earth. A wise person once said that "those who leave everything in God's Hand will see God's Hand in everything." This PhD is for all of you, Pa Amadu, Mammy Iye, Mammy Fatu, Dr. Jim Funna, and Dr. Soule Funna. Love you forever.

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Chapter 1: Introduction to the Study

The suffering of people affected by neglected tropical diseases (NTDs) has long been overlooked by various stakeholders, including researchers and the pharmaceutical industry. In contrast, malaria, tuberculosis (TB), and HIV/AIDS, known as the "big three" infectious diseases, have received attention from various stakeholders for decades. According to the World Health Organization (WHO, 2017), the NTD portfolio consists of the following: Buruli ulcer, Chagas disease; dengue and chikungunya; dracunculiasis (guinea-worm disease); echinococcosis; foodborne tematodiases; human African trypanosomiasis (HAT; sleeping sickness); leishmaniasis; leprosy (Hansen's disease); lymphatic filariasis; mycetoma, chromoblastomycosis and other deep mycoses; onchocerciasis (river blindness); rabies; scabies and other ectoparasites; schsitosomiasis; soil-transmitted helminthiasis; snakebite envenoming; taeniasis/cysticercosis; and trachoma and yaws (endemic treponematoses). Snakebite was only recently added to the portfolio after the 10^{th} meeting of the Strategic and Technical Advisory Group for NTDs received proposals to add diseases (WHO, 2017). The Strategic and advisory group implemented the normal procedures for such proposals by performing chromoblastomycosis and other deep mycoses, scabies and other ectoparasites and snake envenoming for inclusion in the NTD portfolio (WHO, 2017).

NTDs affect mostly poor and underserved populations, whose needs tend to be neglected in society. However, recent decades have seen marked improvement in efforts to address NTDs. There are new initiatives and sources of funding to address these diseases, as indicated by Spiegel et al. (2014). WHO (2014) reported that it is important to monitor NTD financing because it can also be helpful when it comes to monitoring equity in financing for sustainable development goals (SDGs) and official development assistance, including domestic government financing for infectious diseases. However, it is evident that the worldwide disease burden remains at a level that requires more attention.

Africa is a continent whose residents have suffered greatly from infectious diseases. NTDs are a group of infectious diseases that are known to contribute immensely to poverty in this part of the world. Poverty is reported to be associated with NTDs. Zhang, Baker, MacArthur, and Mubila (2019) argued that NTDs are poverty-driven as well as poverty-promoting diseases. Zhang et.al. (2010) contended that NTDs and poverty constitute a vicious circle, such that NTD infections can be seen as being responsible for poverty at the same time that they are a result of poverty.

The conditions in which people live have been reported by Zhang et.al. (2010) to contribute to these infections. NTDs thrive in impoverished environments where sanitation is poor and safe, clean drinking water is scarce. Furthermore, overcrowding contributes to the spread of infections. Unsanitary living conditions and poor toilet facilities are among the most important factors that experts have reported to contribute to the disease burden.

Coendemicity is a condition that has also been highlighted. The WHO (2019b) indicated that coendemicity varies by region; in the African region, coendemicity of multiple helminthiasis within countries makes it an important candidate for the integration of several disease programs, which is in fact, most justifiable.

Socioeconomic status can influence the health outcomes of people with regard to NTDs. Studies conducted by Houweling et al. (2016) have shown that improvement of the socioeconomic status of people can reduce the burden of NTD infections, and this may occur in the presence of various conditions, such as access to safe, clean drinking water and proper housing facilities. When such conditions are combined with proper hygiene practices, most infections can be avoided.

My focus in this study was investigating the possible effects of climate change and population density on the spread and control of NTDs in sub-Saharan Africa (SSA). There is ample evidence, as explained by Errecaborde, Stauffer, and Cetron (2015), that populations that are displaced due to conflict are usually disenfranchised, resulting in a high prevalence of NTDs. These are susceptible populations, and their members tend to be more vulnerable when forced out of their communities as internally displaced people (IDPs), refugees, or forced migrants. Marginalized populations whose members flee conflict or environmental catastrophe are often burdened with insidious NTD infections, which may range from asymptomatic to overt and may be debilitating (Erreccaborde et al., 2015). Errecaborde et al. (2015) noted that Aagaard-Hansen, Nombela, and Alvar (2010) eloquently argued that population movement has many causes, including seasonal weather changes, drought, and decreasing water availability.

Climate change and its consequences for population dynamics constitute a major factor that contributes immensely to population density in SSA countries. This is evident in high exposure to negative climate change which has an impact on population increase on lands with a decrease in rainfall (Lopez-Carr et al., 2014). This was seen in the recent Ebola outbreak in Sierra Leone, West Africa, in which population density was a factor and movements of people had to be restricted (Peak et al., 2018). Ebola is a rare and deadly disease caused by infection with a strain of the Ebola virus (Centers for Disease

Control and Prevention [CDC], 2014). The disease can be spread through direct contact with blood and bodily fluids of an individual already showing symptoms of Ebola infection (CDC, 2014). Ebola is not a disease that is spread through air, water, food, or mosquitoes (CDC, 2014). Restricting people's movements is one way to inhibit the spread of the disease. Densely populated areas also need constant surveillance to reduce the spread of infection. Severely affected countries such as Guinea, Liberia, and Sierra Leone enforced a lockdown system in which individuals were not allowed to leave their homes, in order to prevent them from coming into contact with infected persons or, if they were already infected, to prevent them from transmitting the disease to uninfected individuals.

Additionally, civil conflicts play a major role in the migration patterns seen in SSA. Population density may increase in certain areas that receive individuals fleeing conflict zones, as seen in the case of Sierra Leone when individuals fled to Freetown for their safety.

The United Nations met in Katowice, Poland to advance the climate agenda at the 24th Conference of Parties (COP24) in 2018. The issue of environmental or "climate" refugees was addressed at the World Climate Conference in Poland, where participants considered the devastating effects of climate change on populations (International Fund for Agriculture [IFAD], 2018).

I applied ecological principles in this study to examine the relationship between population density and the distribution of NTDs. The ecology of the host–parasite relationship and the interactions among parasite, hosts, and environmental conditions may clarify the variables and the factors contributing to the spread of the infections.

Onoma (2017) indicated that experts such as Aagaard-Hansen, Nombela, and Alvar (2010) argued that infectious diseases can be transmitted through various migration patterns. Furthermore, Onoma (2017) reported that Aagaard-Hansen et al. (2010) described the complex ways in which population movements are linked to the distribution and control of NTDs. A study conducted by Murto et al. (2014) indicated that leprosy in Brazil is known to be concentrated in high-risk clusters. Internal migration is a common phenomenon in Brazil and can potentially influence leprosy transmission and hinder epidemiological controls by the authorities.

With infectious diseases, the relationships that exist among vector, host, and pathogen are quite complex and dynamic. Reidpath, Allotey, and Pokhrel (as cited in Braks, Giglio, Tomassone, Sprong, & Leslie, 2019) reported that this complex relationship usually evolves in a social and cultural setting that includes physical and biological elements. Addressing NTDs requires sophisticated funders who are also priority setters and are not thwarted by the traditional neglect of NTD research by the drug industry. The social and physical environment is a core influence on an individual's health and behavior (Queensland Government, 2016).

Statement of Purpose

NTDs have been overlooked for many years by various stakeholders, such as governments, nongovernmental organizations (NGOs), the pharmaceutical industry, and researchers. An important reason for this neglect is that NTDs typically affect the disadvantaged and the poorest of the poor. NTDs flourish in poor and unsanitary living conditions, which may include poor toilet facilities.

NTDs are responsible for chronic and debilitating diseases in some parts of the world. SSA seems to bear the brunt of these debilitating infections. NTDs are known to have severe socioeconomic consequences, in that those who suffer from these infections may experience long-term poor health, disfigurement, social stigma and marginalization, and decreased productivity (Zhang et al., 2019). Errecaborde (2015) noted that Aagaard-Hansen et.al. (2010) reported in their study that population movements have quite often been linked to the spread and control of NTD infections and tend to be exacerbated by the lack of or insufficient healthcare services and poor sanitary infrastructure. Zhang et al. (2019) reported that 90% of NTD infections occur in SSA countries, stating that migration is quite common in this region of Africa as well.

People migrate in response to various factors, such as civil conflict, family needs, economic conditions, and natural disasters such as droughts, floods, and cyclones. Experts on population movements include climate change in their discussions of migration. Recently, climate change has been reported to contribute to migration, especially for populations in the Sahel region, which continues to experience significant climate variations (European Council on Foreign Relations [ECFR], 2017).

According to the ECFR (2017), The Europeans seem to underestimate the primary reasons for migration from SSA. Climate change and environmental changes appear to have particularly pronounced impact on migration from Africa. There are several critical reasons that this is the case. The first reason is the continent's high level of dependence on natural resources and agriculture, which are the first assets that climate change can undermine (ECFR, 2017). Second, the continent has poor infrastructure; for instance, flood defenses are often inadequate (ECFR, 2017). Additionally, the continent's states are characterized by weak institutions that are less capable of adapting to climate change (ECFR, 2017). Finally, high poverty rates usually undermine local populations' resilience to climate shocks (ECFR, 2017).

The Sahel belt is at the center of EU efforts to curb illegal migration in Africa (ECFR, 2017). The Sahel has experienced both environmental and demographic changes with devastating effects (ECFR, 2017). Unfortunately, with a rise in greenhouse emissions, temperatures have been increasing; as a result, there has been a dramatic increase in the intensity and frequency of catastrophic events in this region (ECFR, 2017). Countries such as Chad, Niger, Mali and Nigeria have been most affected, according to ECFR (2017). It was also reported by ECFR that in 2012 alone, approximately 6 million people in the North East (NE) region of Nigeria were forcibly displaced as a result of floods, while 500,000 people were displaced in Chad. Further, Lake Chad (bordering Chad, Niger, Nigeria, and Cameroon) has shrunk by 90% since 1960 (ECFR, 2017). About 12 million people in this region have always depended on the lake for their livelihoods in fisheries and agriculture, including livestock (ECFR, 2017). The dramatic decrease in the lake's water level means that almost 7 million people in this region are currently experiencing food insecurity, and thousands of fishermen and farmers have become unemployed in recent years (ECFR, 2017). These circumstances have clearly contributed to forced migration, with 2.5 million people already displaced from the region (ECFR, 2017).

Climate change has also been reported to affect stability and security (ECFR, 2017). A demonstration of the effect of climate change was seen in the severe droughts and desertification that affected eastern Syria in 2008, which contributed to civil unrest that eventually led to the war in Syria (ECFR, 2017). This is not meant to imply that climate change caused the Syrian war; however, it appears to have been a contributing factor (ECFR, 2017). Similar dynamics could be applicable to the Sahel, with migration-related population pressure increasing conflict over scarce resources. Climate change in these contexts could act as a threat multiplier; this is why the Sahel region has been reported to be particularly vulnerable (ECFR, 2017). Displacement does not lead to conflict when other contributing factors are not present; however, many parts of the Sahel are already extremely fragile (ECFR, 2017). The recent hurricane disaster (Hurricane Dorian) in the Bahamas caused huge destruction, leaving behind a massive impact, both in the human death toll and in infrastructure. Severe weather conditions may be observed in many parts of the world as a result of climate change.

The previously stated idea that NTD infections occur due to poverty has been refuted by some experts, and recent studies now indicate that these infections are, in fact, a significant cause of poverty that should be addressed in order to break the cycle of poverty, especially in SSA countries, where they are a menace (Houweling et al., 2016). In their study, Houweling et al. (2016) found that there was considerable evidence that there was a greater chance of NTD infections or disease among socioeconomically disadvantaged groups. In other words, the burden of NTD infection or disease was reported to be heavily concentrated in low and middle-income countries, and this applied between countries as well as within countries (Houweling et al., 2016). Zhang et al. (2019) explained that 198 million people who are infected with hookworm are in SSA countries, along with 192 million infected with schistosomiasis, 173 million with ascaris infections, 37 million infected with onchocerciasis, and 30 thousand suffering from leprosy. NTDs thrive in impoverished environments, where they cause debilitating health conditions.

The previous decade has seen marked improvement in funding activities for both the elimination and eradication of NTD infections among the world's poorest populations. Despite these efforts by the international community, the burden of disease is still high (Speigel et al., 2014). Some experts have argued that the reason for the continued prominence of these infections is the neglect of NTD research in important areas such as the social determinants of disease. The focus of this study was the effect that population density has on the spread and control of NTDs in the sub-Saharan African country of Sierra Leone, whose people have suffered immensely from these diseases. I investigated the possible effects of climate change and population density on the spread and control of NTDs in SSA.

Purpose of the Study

The purpose of this quantitative correlational study was to determine the relationship between climate change and population density, and the spatial distribution of NTDs in SSA. Patz et al. (as cited in WHO, 2019) indicated that health problems in SSA are usually either exacerbated or intensified by changing weather patterns, including other climatic conditions. Many people in SSA are unprepared or ill-prepared for these impacts on their health (Patz et al., as cited in WHO, 2019). Rising temperatures affect pathogens' life cycles and ranges (Patz et al., as cited in WHO, 2019). Experts indicate that current weather patterns affect rates of infection, especially for vector-borne diseases. However, a pathogen can only spread if it is able to mature and replicate. Patz et al. (as cited in WHO, 2019) indicated that conversely, temperature and moisture availability are usually influenced by climate change, which can also affect pathogen proliferation. Given the connection that communicable diseases have with water and other organisms, climate change is most likely to lead to an increase in the range and seasonal duration of suitable conditions for the survival of communicable pathogens (Patz et al., as cited in WHO, 2019).This trend is likely to result in an increase in the distribution of communicable diseases.

Research Questions and Hypotheses

The research questions and hypotheses were developed after a thorough review of the literature on population density and its epidemiological impact on NTDs in SSA. Research in this area of NTDs is scanty, and sample sizes are limited. As a result, the research questions were geared toward investigating whether there is a relationship between the independent variables and the dependent variables. The variables are defined in Chapters 2 and 3.

Research Question 1: Is there a relationship between climate factors, as indicated by change in temperature and precipitation over time, and population density in Sierra Leone?

Hypothesis 1: There is a relationship between climate factors and population density in Sierra Leone.

Null H_1: There is no relationship between climate change, such as change in temperature, temperature, and population density in Sierra Leone.

Research Question 2: What is the relationship between population density and the spread of neglected tropical diseases (NTDs) in Sierra Leone?

Hypothesis 2: There is a relationship between population density and the distribution of NTDs in Sierra Leone.

Null H_2: There is no relationship between population density and the distribution of NTDs in Sierra Leone.

Research Question 3: Is there a relationship between climate factors and the distribution of NTDs?

Hypothesis 3: There is a relationship between climate factors and the distribution of NTDs.

Null H_3: There is no relationship between climate factors and the distribution of NTDs.

Conceptual Framework

The ecological framework (ecological theory) encompasses the interaction and integration of biological, behavioral, environmental, and social determinants. The ecological framework also includes the influence of organizations such as workplaces and schools, individuals, family, friends, peers, and public policies, which together contribute to individuals' healthy choices (Queensland Government, 2016). Three dimensions are known for the ecological model: (a) the individual and their behavior, (b) the physical environment, and (c) the social environment. My study focused on the relationship between the physical (climatic) and biological (population density and prevalence) environment and the distribution of NTDs in Sierra Leone. A study conducted by Transer, Sharp and le Sueur (2003), in which they described Africa as a continent that has a physical and ecological structure that is as diverse as its social, political and demographic characteristics (as cited by Dallas and Rivers-Moore, 2014).

An earlier study conducted by Tanser et al. (as cited in Dallas & Rivers-Moore, 2014) explained a projected increase in malaria transmission as the result of an increase in distribution (particularly altitudinal). Africa's major biomes consist of tropical rainforest, moist and dry savanna, semi desert and desert, and temperate lands. Studies by Tanser and le Sueur (as cited in Dallas & Rivers-Moore, 2014) explained the diversity of Africa's ecological structure by using certain factors such as the political, environmental, poverty, and general low levels of well-being of the majority of the population, climatic conditions, vegetation and biography that cause the prevalence of organisms, such as bacteria, viruses, and worms that are disease causing agents in humans. Various researchers have used different theoretical models in their studies. Clements et al. (2015) used Bayesian geostatistical models in their research on the role of climate and the socioeconomic variables in the distribution of NTDs.

The geostatistical and the socioeconomic model is an inclusive framework that involves different aspects of the study area, such as economic status, social and the geospatial distribution of disease. These models were used to simultaneously predict the prevalence of infection. Experts on population density and its epidemiological impact on the distribution of NTDs had to think of new causes, such as migration patterns and environmental conditions. There has been an increase in the depth and complexity of existing knowledge of environmental determinants of health. This, in fact, places immense pressure on the various elements of conceptual frameworks of epidemiology, such as the way in which people think about the causes of disease. Transmission of infectious disease was examined within the ecological framework in this study. Infectious agents usually obtain their essential nutrients and energy through parasitic means, and as a result, they depend on higher organisms they parasitize for their survival (Patz et al., as cited in WHO, 2019). The majority of these infections are benign, and Patz et al. (as cited in WHO, 2019) reported that some of these infectious agents have a commensal relationship with the host. Only a minority of infections actually have an adverse effect on the host's biology, and these are typically referred to as *infectious diseases* (Patz et al., as cited in WHO, 2019).

Climate is critical to the parasite's survival in the environment. Patz et al. (as cited in WHO, 2019) reported the lack of thermostatic regulation due to the size of the infectious agent (protozoa, bacteria, viruses, etc.) and the associated vector organisms, such as mosquitoes, ticks, sandflies, etc., ectothermic temperature and fluid levels of these organisms are determined by the local climate. This is a situation that creates a limited range of climatic conditions, usually referred to as a *climate envelope*, which is the ideal temperature range for the survival and reproduction of both infective and vector species (Patz et al., as cited in WHO, 2019). More interesting is the issue of the incubation period of a vector-borne infective agent within its vector organism, which has been reported to be quite sensitive to temperatures because of the exponential relationship displayed by the organism (Patz et al., as cited in WHO, 2019). Additional factors, such as climatic sensitivity, precipitation, sea-level elevation, wind, and duration of sunlight, all play important roles for the agent, vector, and host. Hotez, Rubestein, and Sachs (2011) reported that in SSA, the incidences of hookworm and other NTDs do overlap intensely, sometimes with geography of falciparum malaria, particularly in the estimated 50 million hookworm-infected school-aged children. This estimate also includes approximately 7 million pregnant women infected with the disease. Public health practice in general requires timely information on the course of disease and other health events if appropriate actions are to be implemented.

Nature of the Study

This quantitative correlational study investigated the relationship between climate and population density and the prevalence and distribution of NTDs in SSA. Sierra Leone was the focus of this study. The choice of this investigation culminated from the endemicity of NTDs in this country as well as its high poverty rate. This quantitative study was based on ecological theory due to its broad inclusions of the various elements of society. The model encompasses the interaction and integration of environmental, behavioral, biological, as well as social determinants of health and disease. Other aspects of society are also addressed by the ecological framework, such as workplace, schools, individuals, family, friends, peers, and public policies.

The dependent variables were population density and prevalence of NTDs (as a measure of NTD distribution), and the independent variable was climate change with respect to change in temperature and precipitation. The interactions between population density and prevalence of NTDs were also examined. Secondary data were used in the study, and data were analyzed by using multiple linear regression.

Definitions

Africa: This is the second largest continent, after Asia, and is bounded by the Atlantic Ocean, the Mediterranean Sea, the Red Sea, and the Indian Ocean (National Geographic, 2019). Interestingly, Africa is sometimes nicknamed the “Mother Continent” as a result of it being the oldest inhabited continent on Earth, with humans and human ancestors having lived on the continent for over 5 million years (National Geographic, 2019). The Equator almost divides Africa in half, according to National Geographic (2019). National Geographic indicated that Africa has eight major physical regions: the Sahara, the Sahel, the Ethiopian Highlands, the Savanna, the Swahili Coast, the rainforest, the African Great Lakes, and Southern Africa. Not all of these regions have the same bands of the continent in terms of size; for example, the Sahara and Sahel cover large bands. Others are simply isolated areas, such as the Ethiopian Highlands and the Great Lakes. Further, each of these regions seems to have a unique animal and plant community (National Geographic, 2019). According to the National Geographic, the Sahara was reported as the world's largest hot desert, with a size of 8.5 million square kilometers (3.3 million square miles), which is approximately the size of Brazil in South America. In other words, the Sahara makes up 25% of the African continent, whereas the Sahel is simply a narrow band of semi-arid land that is a transition zone between the Sahara in the north and the savannas in the south (National Geographic, 2019). By the same token, the Swahili stretches approximately 1,610 kilometers (1,000 miles) along the Indian Ocean, from Somalia to Mozambique (National Geographic, 2019). National Geographic (2019) reported that Africa is home to diverse ecosystems, from sandy deserts to lush rain forests. Worldometers (2019) stated that Africa's population was equivalent to 16.72% of the total population of the world. Africa was ranked number two among the regions of the world, and the population density was reported to be 44 people per km^2 (114 people per ml^2) according to Worldometers.

Coendemicity: Refers to the clustering of certain NTDs (e.g., *Schistosoma mansoni* and *S. haematobium*) within specific foci. Sometimes *S. mansoni* and *S. haematobium* infection densities cluster in different sections of a community, and this may be a result related to heterogeneities in the use of various water contact sites (Meurs et al., 2013). Knowledge of such coendemicity can provide vital insights into the drivers of infection and disease and as a result may enable experts to better tailor schistosomiasis control and elimination efforts (Meurs et al., 2013).

Communicable diseases: These are spread from one person to another, or from an animal to a person. The CDC (2014) defined such diseases as illnesses caused by infectious agents or their toxins that occur either through direct or indirect transmission of the infectious agents or their products from an infected individual or via an animal, vector, or the inanimate environment to a susceptible animal or human host.

Climate change and climate factors: Climate change is now accepted as a result of an increase in the emissions of greenhouse gases, such as water vapor, carbon dioxide, methane, and nitrous oxide released due to human activity (WHO, 2018). It is estimated that by the end of the 21stcentury, the earth's temperature may rise above mid-1990 levels by 1.1^{o}C, a change that experts have predicted to result in additional heatwaves, floods, and droughts. In my study, I used the climate factors temperature and precipitation. Changes in these climate factors during the time frame of my study were used as a substitute for the much more difficult-to-assess climate change.

Disease elimination: This refers to the interruption of disease transmission. In other words, the process of disease elimination is the reduction to zero of the incidence of infection caused by a particular pathogen in a specific geographical area due to deliberate efforts, such as continued actions to prevent the re-establishment of transmission (WHO, 2019).

Disease eradication: This is the permanent reduction to zero of the global incidence of infection caused by a particular pathogen due to deliberate efforts, with no risk of reintroduction of the disease (WHO, 2019). In certain cases, the pathogen may become extinct. However, other pathogens may be present, but only in confined settings such as laboratories (WHO, 2019).

Endemic: The frequent occurrence of an infectious disease in a specific geographical locale. Such diseases tend to occur in cycles (e.g., influenza; WHO, 2019).

Endemic stability: This is said to occur when infection rates of all ages of animals are quite low, according to Hanzlicek (2017). In other words, when there is a high rate of infection, only those animals from birth to 1 year of age will most likely become infected, which could result in endemic stability (Hanzlicek, 2017). By the same token, Hanzlicek indicated that when infection rates are quite high, only those animals from birth to 1 year of age are most likely to become infected, which results in endemic stability. However, when the infection rate is moderate, animals in that category tend to be unstable (Hanzlicek, 2017). The persistence of disease is ensured by the fact that a majority of animals are infected and immune before they reach an age at which they are susceptible to clinical disease (Hanzlicek, 2017). This is a relationship between host, vector, and environment in which all coexist with the virtual absence of clinical disease, and this includes infectious agents that have low pathogenicity according to Hanzlicek The concept describes a dynamic epidemiological state in which clinical disease is rare in spite of a high incidence of infection within a population (Hanzlicek, 2017). In other words, this is a situation in which all factors influencing disease occurrence are relatively stable, resulting in little fluctuation in disease incidence over time.

Health outcomes: According to the Canadian Institute for Health Information (CIHI, 2019), health outcomes refer to changes in health that are a result of measures or specific health care investments or interventions. Health outcomes include situations such as the prevention of death after experiencing heart attack through in-hospital care (CIHI, 2019). A change in the health status of a person, group, or population that is attributable to a planned intervention or set of interventions, regardless of the intention of the intervention to change the health status, is a health outcome (WHO, 2014). In other words, this term refers to the impact that healthcare activities have on people, their symptoms, their ability to perform their functions, and ultimately whether they live or die. Further, health outcomes may also refer to medical conditions that directly affect the length and quality of a person's life. The WHO (2014) indicated that health inequalities can be defined as differences in health status or in the distribution of health determinants between different population groups.

Neglected tropical diseases (NTDs): These comprise a group of debilitating infections that affect more than 1 billion people worldwide, and they result from four different causative agents: (a) virus (dengue/severe dengue, rabies), (b) protozoa (Chagas disease, HAT, leishmaniasis), (3) helminth (onchocerciasis, dracunculiasis, lymphatic filariasis, schistosomiasis, soil-transmitted helminthiasis), and (d) bacteria (Buruli ulcer, leprosy, trachoma, and yaws; WHO, 2014). These are diseases that are especially endemic in low-income populations. NTDs thrive in impoverished environments with overcrowding that lack proper sanitation (Houweling et al., 2016).).

Population density: Population density as defined here refers to the number of individuals occupying an area in relation to the size of that area. Geographers usually focus on the spatial distribution of population density at various levels of scale, such as local, state or province, national, and global (National Geographic, 2016).

Population movement. A broad definition of this includes migration patterns. The European Environment and Information Network (EIONET, 2018) defined population movement as any shift or migration of a statistically significant number of persons inhabiting a country, district, or area. In this study, change in population density during the time frame considered in the study was used as a substitute for population movement (migration).

Social determinants of health: These are the conditions or circumstances in which people are born, grow up, live, work, and age, including the systems put in place to deal with diseases (CDC, 2014). These circumstances are, in turn, shaped by a wider set of forces, such as economics, social policies, and politics (CDC, 2014).

Sub-Saharan Africa (SSA): The area of Africa that lies south of the Sahara. There are 50 countries of SSA, and this area includes the Western Indian Ocean Islands but excludes the North African countries of Algeria, Egypt, Libya, Morocco, and Tunisia (Population Reference Bureau, 2019). This is in contrast with North Africa, which is considered to be part of the Arab world. The Sahel region is a transitional zone that lies between the Sahara and the tropical savanna (the Sudan region) as well as the forest savanna mosaic to the south. Although sub-Saharan African countries are rich and possess diversified resources, these countries remain the world's poorest and are ranked quite low in terms of human development and indicators (Adepoju, 2016).

Assumptions

The first assumption was that data obtained from Sierra Leone, WHO, HKI, and the UN databases were in fact entered accurately and in general were error free. The second assumption was that the measurements for incidence calculated by these organizations' databases were derived from the prevalence of NTD infections. It was also assumed that the variable measures supported by the literature were appropriate metrics.

The scope of this study was limited to the sub-Saharan West African country of Sierra Leone because of the availability of data. North Africa is considered to be closer to the Arab world (Middle East), and most migrant populations in this region of Africa usually emigrate to Europe, the Middle East, and the United States (Croll, 2017). Most migrant populations in SSA migrate within the African continent, unlike their northern neighbors (Croll, 2017).

Limitations

This research had several limitations. There were significant gaps that existed in the variables used in the study. Most African countries have either little data or inaccurate data on population densities, including migration patterns and the spread of infectious diseases. Population movements are not usually recorded by many governments in Africa. As a result, data on population movements are limited or not available. SSA has been plagued by civil conflicts, political instability, and environmental degradation for many years (Adepoju, 2016). Data on population movements and distribution of infectious diseases are not maintained on a regular basis and may potentially hinder effective and efficient reporting. As a result, it is not uncommon to find a significant number of gaps on data relating to limitations on reporting that are provided to the WHO.

In countries such as Sierra Leone and Liberia where there have been civil wars for many years, the lag in data collection may have contributed to reporting inconsistencies. Because migration data were not available, I used population density data in this study.

Ecological studies involve the unit of observation at the population or community level rather than the individual. As a result, individual-level data are missing on the joint distribution of variables within groups. Results of ecological analysis are designed to enable epidemiological inferences about effects on individual risks or ecological inferences about effects on group rates (Grant, 2013). Ecological studies are also prone to ecological fallacy, which occurs when an investigator infers that associations at the group or community level reflect those at the individual level. In an effort to avoid this fallacy, findings were limited to Sierra Leone in SSA and not generalized to the entire region of SSA.

Significance of the Study

A key factor in NTDs and their continued endemic patterns in many parts of the world has been neglect by organizations, including researchers and government bodies, for many years (Speigel et al., 2014). The poverty of the victims of NTDs has discouraged pharmaceutical companies from engaging in research that might go far toward reducing the disease burden within populations suffering from these infections. Leaders within the pharmaceutical industry perceive NTDs as diseases of the poor and therefore unprofitable. Because the vast majority of those most exposed to NTDs cannot afford drug treatments, pharmaceutical companies are not interested in developing them. As a result, those infected with these diseases often cannot find medications for treatment. Beyond the suffering and misery they cause, the debilitating effects of NTD infections negatively impact local economies; people cannot work due to their poor health. Onchocerciasis causes blindness; leishmaniasis, ascariasis, lymphatic filariasis, Chagas disease, and other NTDs cause serious health conditions in poor urban communities as well as rural areas. Population movements and their effects on epidemiological aspects of NTDs have been reported. Aagaard-Hansen et al. (as cited in Lopez-Carr et al., 2014) stated that population movements are linked to the spatial distribution and control of NTDs.

This study contributes to the awareness that environmental and social determinants of disease need to be addressed in order to prevent the spread of disease as well as reduce disease burden in SSA. In this study, I sought to explore the role that climate change and population density play in the distribution of NTD infections. This approach could help alleviate the burden of NTD infections. Treating NTD infections and alleviating the stigmatization that follows such disease may improve the social well-being of people in these communities.

Summary

Research on climate change, population density, and the epidemiological impact on the spatial distribution of NTDs is limited, and the social determinants of NTD infections have not been fully explored or researched. The ecological framework provided the theoretical foundation for this research. SSA continues to bear the brunt of NTDs. Although research on the social determinants of such diseases is limited, the continued endemicity of these infections indicates that more has to be done to address the problem. New approaches are necessary, and the reemergence of diseases such as leprosy, dengue fever, Chagas disease, malaria, trypanosomiasis, and schistosomiasis, coupled with surveillance systems that are absent or insufficient, indicates that the capacity to control disease epidemics in endemic areas requires collaboration by the global health community. Further research is needed to better understand the interaction of climate factors, population densities, and the spread of disease. Analysis of the relationships among climate factors, population density, and the spatial distribution of NTDs may provide a profound understanding of the effect of population density and the spread of disease in SSA.

Chapter 2 follows the introduction to the study and consists of a review of relevant literature on population density and its epidemiological impact on the spread and control of NTDs in SSA. This chapter focuses on research on the epidemiology of ascaris, hookworms, and schistosomiasis. Chapter 3 provides details on the research design as well as the statistical analysis of population distribution and measures on variables associated with the burden of disease. This includes the prevalence of these infections in SSA. Chapter 4 presents the results of the study; Chapter 5 contains my interpretation of the results and discussion of the conclusions drawn from the research questions presented in the previous chapters, including proposed social-change implications for future studies.

Chapter 2: Review of the Literature

The literature review contained within this chapter is based on the research problem, which was identified to be the epidemiological impact that population density has on the spread and control of NTDs. As a result, certain factors were taken into consideration, such as migration patterns, factors that influence population densities, and climate change with respect to temperature and precipitation and its influence on population movement and density. Researchers have also focused on factors such as socioeconomic status and climate change with regard to agriculture and water availability. Civil conflicts have also been studied by researchers, along with drought systems and floods. Urban development, which can attract individuals from rural communities to seek employment in big cities, has also been investigated by some researchers.

Literature Search Strategy

The quality of the sources of articles and other research materials used in this study was of great concern, and extreme effort was taken to achieve a successful review of the literature. Most of the literature search was conducted through Internet search engines, with the sources accessed including materials from the WHO, United Nations, and other organizations, and institutions' websites. Google Scholar and Mozilla Firefox were the most used search engines. Several databases were also used, including those of the CDC, the National Institutes of Health (NIH), Helen Keller International, the WHO), and the United Nations. The dominant keywords for relevant literature were *neglected tropical diseases in sub-Saharan Africa*, *epidemiology of infectious diseases*, *poverty and infectious diseases*, *climate change and infectious diseases*, *population density*, *population movements and the spread of infections*, and *NTD infections in SSA countries*. The selection of articles was limited to those published in the English language within the last 10 years.

NTDs have been largely overlooked until recently, when their epidemiological and socioeconomic impacts were brought to the world's attention by various stakeholders. As a result of this attention, there has been new focus and growing awareness toward developing intervention programs in the fight against NTDs. In reviewing the literature, it became apparent that there are several gaps in understanding the epidemiological impact of population densities in SSA. Reidpath et al. (as cited in Braks et al., 2019) described the dynamic relationship that exists in infectious diseases among the vector, the host, and the pathogen. This complex interaction generally evolves within a social and cultural setting that includes physical and biological elements. Reidpath et al. (2011) noted that it is vital to have sophisticated funders for efforts to address NTDs, including priority setters who are not thwarted by lack of attention to NTD research by the drug industry.

Speigel et al. (2014) and Hotez (2017) explained that the disease burden is still high globally, regardless of the fact that the past decades have seen considerable improvements in funding and new initiatives to address NTDs that affect the poorest people. Further, Hotez noted that with new leadership at the United Nations, WHO, World Bank, and governments of the United States and United Kingdom, it will be necessary to regroup, refocus, and increase global efforts toward the elimination of NTDs. It was also suggested that the current NTD situation must change to reflect a broader G20 remit through expansion of NTD support and activities initiated by new global leaders (Hotez, 2017).

In the case of other neglected as well as stigmatized diseases such as HIV, the benefits of human rights advocacy in terms of health care are quite clear. Sun and Amon (2018) indicated that human rights advocacy with regard to NTDs could bring needed attention to the debilitating aspects of NTDs, including the ongoing gap in resources for the prevention and treatment of these diseases.

Furthermore, the WHO (2019) indicated that differences exist in coendemicity based on region. The African region, which experiences a high level of coendemicity of multiple helminthiases in different countries, is the region where the use and integration of several disease intervention programs is most justified. Moreover, it is possible to achieve effective control when using selective public health approaches that are combined and delivered at a local level (WHO, 2019).

Poverty is known to be associated with NTDs, and Zhang et al. (2019) explained how NTDs are poverty-driven as well as poverty-promoting diseases. Because they are usually less overtly life threatening, are not overtly symptomatic in the early stages of infection, and usually affect the poorest populations, these diseases may be neglected by policy makers and donors. Zhang et al. noted that NTD infections present a serious health burden for vulnerable populations, especially children and expectant women. The rural and impoverished urban inhabitants who are most affected by these neglected infections are not knowledgeable about these diseases. The role of government in making a political commitment to NTDs can create greater visibility of the diseases for the general population. When the problem of NTDs is given priority at the national level, there may be an increase in resource mobilization, which can enable the development of vaccines and treatments including disease control programs (Sun & Amon, 2018).

The social and physical environment has a core influence on a person's health and behavior. This understanding is evident in the frequent use of the ecological approach in the implementation of health services, including health programs (Issel, 2009). The ecological model takes into consideration an intrapersonal, interpersonal, and community approach (McKenzie, Neiger, & Thackeray, 2009). Further, the ecological approach involves awareness of the influences that immediate social and physical environmental factors have on individuals.

This chapter consists of four parts. In the first part, I describe the phenomenon of population densities in SSA. This section addresses (a) population densities, migration patterns, and the various reasons that people migrate within this geographical area of Africa; (b) the theoretical model that describes the reasons for migration; and (c) the distinguishing factors of migrants in SSA. The second part of this chapter focuses on the new experience of migrants in relation to NTD infections. The third section addresses climate change and its impact on the spread of NTDs in SSA. The fourth section focuses on the epidemiological impact of population density on the spread and control of NTDs.

NTDs are responsible for various clinical conditions in many tropical areas of the world. Molyneux and Malecela (2011) reported that 17 conditions belong to a group of core organisms known as NTDs. However, there are 13 parasitic and bacterial infections that are collectively referred to as NTDs, which include soil-transmitted helminth infections, as well as ascariasis, hookworm, trichuriasis, lymphatic filariasis, onchocerciasis, schistosomiasis, Chagas disease, HAT, leishmaniasis, Buruli ulcer, leprosy, and trachoma (Hotez et al., 2012). Most researchers who have conducted studies on NTDs in SSA highlight the existence of NTDs in mostly impoverished areas. NTDs thrive in impoverished environments, where they cause severe health conditions (Houweling et al., as cited in Zhang et al., 2019).

It has long been argued by experts that infectious diseases can be transmitted through population movements. Aagaard-Hansen et al. (2010) explained the complex ways in which population movements are linked to the spread and control of NTDs. Migration, disasters, and conflicts are some of the factors in the spread of infectious diseases (Errecaborde et al., 2015). Sometimes, migration is temporary, such as in the cases of nomads, refugees, labor migrants, as well as people who are forced to resettle.

Population Densities and Migration Patterns

Brooker and Utzinger (as cited in Hotez et al., 2014) explained that for decades, individuals inhabiting low-income and middle-income countries have been exposed to endemic parasitic infections, which impose serious socioeconomic and health burdens on these communities. A report by Ramin (2009) indicated that SSA is known to be the least urbanized region of the world, with barely 39% of people living in cities. Despite this trend, studies show that the region's urban population is expected to double to over 760 million by 2030. It will be challenging to manage the health effects of increasing urbanization. The author of a recent report in the *New England Journal of Medicine* argued that urbanization should be considered a "health hazard for certain vulnerable populations," noting that "the demographic shift threatens to create a humanitarian disaster" (Ramin, 2009, p. 886). Several studies have shown a link between urbanization and poverty in Africa.

Estimates indicate that approximately 1 billion people inhabit slums, and this trend is projected to double to about 2 billion in 30 years. The United Nations Human Settlements Program (UNHABITA) has defined a *slum* as an urban area with a lack of basic services, such as sanitation, potable water, and electricity, whose residents may experience substandard housing, overcrowding, unhealthy and hazardous locations, insecure tenure, as well as social exclusion. It is estimated that 71.8% of urban dwellers in Africa inhabit slums, which appears to be the highest rate in the world (Ramin, 2009).

Alirol, Getaz, Stoll, Chappuis, and Loutan (2010) reported that NTDs that were once common chiefly in remote rural communities had become common in urban areas. Leishmaniasis is now considered an increasing health problem, and the fast growth in urbanization has contributed greatly to its spread (Alirol et al., 2010). Cases of cutaneous leishmaniasis have increased in areas such as Ouagadougou, Burkina Faso, where the incidence rose from 28 cases in 1995, to 2,375 cases in 2000 (Alirol et al., 2010). Studies have also shown that migrations are probable contributing factors to the increasing urban occurrence of visceral leishmaniasis. Aagaard-Hansen et al. (as cited in Onoma, 2017) reported the emergence of visceral leishmaniasis in Khartoum, Sudan, in 1988 as a result of an influx of migrants from western Upper Nile province in southern Sudan who had previously fled civil conflict. Unsanitary conditions, including changes in vector ecology, contributed immensely to the spread of visceral leishmaniasis. Additionally, high numbers of sandflies were recorded in various cities.

Population movements are relevant in several respects with regard to communicable diseases. Aagaard-Hansen et al. (as cited in Onoma, 2017) explained how migration patterns can lead to new exposure to disease agents. This may happen in several ways: Migrants may relocate to new areas and come into contact with infective populations or environments that are already infected with disease, or new migrants may carry disease and infect unexposed populations at the point of arrival. Several studies conducted on population movements in relation to NTDs have addressed water resource development schemes, which tend to cause planned and unplanned migration in SSA. The extensive research of Houweling et al. (2016) explained how nomadism relates to an increase in prevalence of trachoma (due to proximity to cattle) and dracunculiasis (due to unsafe drinking water). In contrast, soil-transmitted helminth infections were reported to be relatively rare, because nomads have a habit of leaving their waste behind, according to Onoma (2017). The literature also indicates that nomads avoid soil-transmitted helminth infections due to the different forms of exposure compared to resident populations. Aagaard-Hansen et al. (as cited in Onoma, 2017) explained that nomads are usually able to avoid potential health risks but noted that the irony is that they may also have the potential to transmit disease. Pilgrimages involving large crowds of people gathering in one particular location in unsanitary conditions can lead to the spread of infectious diseases.

Urbanization is also known to contribute to infectious disease transmission, as in the case of HAT, which was introduced to the suburban areas of Kinshasa, the Democratic Republic of Congo (DRC), by people who fled from conflict zones in areas that were endemic to HAT. Aagaard-Hansen et al. (as cited in Onoma, 2017) reported that this trend was ongoing, with more people affected daily by civil conflicts, noting that these migrants potentially faced public health risks. Migrating populations tend to be particularly vulnerable to disease agents that they are exposed to; this vulnerability may result from lack of immunity or, in certain cases (e.g., individuals fleeing from famine), it may result from malnutrition.

Bwire et al. (2018) reported that cholera is a major problem in the East African Great Lakes basin. They suggested two possible reasons for this phenomenon: The lakes may serve as reservoirs of toxigenic *Vibrio cholera* O1 and O139 bacteria, or cholera outbreaks may result from repetitive pathogen introduction from neighboring communities and countries, with the lakes servicing as facilitators for the introduction of the pathogen. Onoma (2017) elaborated on a study by Aagaard-Hansen et al. (2010) that offered a historical overview of how cholera is transmitted in Africa in relation to population movements and refugees. Errecaborde et al. (2015) discussed the problem of migration and disease transmission in Africa, especially the work of Aagaard-Hansen et al. (2010), which indicated that Saker et al. (2004) reported that 50,000 Rwandan refugees were known to have died in refugee camps in the DRC due to epidemics of cholera and dysentery.

In reviewing the literature, Aagaard-Hansen et al. revealed a case study by Suwanvanichkij (2008) that reported the migration of the Shan ethnic group as a result of civil conflict in Myanmar. Movements of the Shan ethnic group had implications for diseases such as HIV, TB, and lymphatic filariasis, according to Onoma (2017). The movements not only affected the Shan people themselves, but also impacted the control of these infections in the western parts of Thailand (Aagaard-Hansen et al., as cited in Onoma, 2017).

Onoma (2017) noted that Aagaard-Hansen et al. (2010) reported on an earlier study conducted in Nigeria by Watts (1987), which showed that population movements tend to complicate the control of dracunculiasis, while Picado and Ndung'u (2017) explained how both internal and regional conflicts caused dysfunction of health care systems, population movement, and subsequently the recurrence of HAT. This idea was buttressed by Maudlin (as cited in Aagaard-Hansen et al., 2010), who provided several examples, such as Angola, DRC, northwestern Uganda, and Sudan. Dodge (1990) noted the health implications of war in both Uganda and Sudan, while Molyneux and Davies (1997) and Molyneux and Malecela (2006) pointed out particular cases in which dracunculiasis, HAT, leishmaniasis, and onchocerciasis had all increased as a result of wars in African countries (Aagaard-Hansen et al., 2010), according to Onoma (2017).

Both natural disasters and violent human conflicts have been reported to be responsible for the death and displacement of millions of people in the world. Most of these people suffer from disease and starvation, as well as sexual and physical abuse (WHO, 2019). The WHO (2019) estimated that some 23 conflicts are known to have been waged or continue to be waged in sub-Saharan African countries where there is high prevalence of NTDs. Since 1998, for instance, 5.4 million people are known to have died in the DRC, while 1.5 million are reported to have become refugees or to have been displaced from their homes (WHO, 2019)

I retrieved literature on schistosomiasis and population movements using Google Scholar with a link to the WHO. Schistosomiasis, also known as bilharziasis, has been reported to be of public health importance second only to malaria. Estimates are that 200 million people in the world are infected with schistosomiasis, which is a snail-transmitted, waterborne parasitic helminth, and 20,000 deaths are known to be associated with these parasitic infections, as a result of bladder cancer or renal failure

(*Schistosomiasis haematobium*), liver fibrosis, as well as portal hypertension (*S. mansoni*; WHO, 2014). In a report on parasitic diseases by the WHO (2014), it was indicated that schistosomiasis constitutes a vital public health problem. For example, estimates show that in Sub-Saharan Africa, 70 million individuals out of 682 million had in fact, experienced hematuria, while 32 million suffered from dysuria associated with *S. haematobium* infection. Further, 18 million are estimated to have suffered from bladder wall pathology, while 10 million have suffered from hydronephrosis. *S. mansoni* was estimated to have been responsible for diarrhea in 0.78 million individuals, with blood in stool in 4.4 million and hepatomegaly in 8.5 million. Schistosomiasis is known to occur near bodies of freshwater. Whenever there are environmental changes in SSA as a result of water resource development, as well as population movements with an increase in population growth, there is tendency to spread schistosomiasis to areas that previously had low endemicity to non-endemicity of the disease (WHO, 2014). This was seen with the construction of the Diama dam on the Senegal River, which introduced intestinal schistosomiasis into Senegal and neighboring Mauritania (WHO, 2014).

The issue of population movements and the spread of schistosomiasis has also been seen in refugee movements and population displacements in the Horn of Africa. This phenomenon has given rise to intestinal schistosomiasis in Somalia and Djibouti. On the other hand, the disease has been brought under control in several countries in Asia, the Americas, North Africa, and the Middle East.

Mackey et al. (2014) reported that apart from actions by humans, weather extremes as well as natural disasters have been identified as influencers of vector-borne infectious disease spread, indicating that climate change plays a role in these events. A change in the environment such as the introduction of a new insect or plant vector into an area or population has been reported to lead to rapid transmission of diseases that had not been prevalent in the region, such as dengue and Rift Valley fever, including malaria (Mackey et al., 2014).

Another area of emergence is food-borne illnesses, considering outbreaks of *Salmonella, E. coli,* and bovine spongiform encephalitis, which all occur as a result of poor food processing practices (Mackey et al., 2014). Interestingly enough, more recent attention to Emerging Infectious Diseases (EIDs) and Re-emerging Infectious Diseases (ReIDs) is globalization, which is fueled by the rapid growth of worldwide travel as well as interdependent trade (Mackey et al., 2014). The increase in globalization was linked to the recent seminal infectious disease events and future concerns for global health which emanated from large-scale population movement and migration (Mackey et al., 2014). An example of such an event was the 2002 severe acute respiratory syndrome (SARS) outbreak as well as the 2009 H1N1 influenza pandemic were known to be directly related to globalization and international travel (Mackey et al., 2014). Furthermore, the Hajj in Saudi Arabia which involves a large-scale international gathering may serve as a newly recognized social mechanisms for spreading infectious diseases rapidly, such as the emergence of Middle Eastern respiratory syndrome (MERS), which was caused by the second novel corona virus that was identified in the past decade (Mackey et al., 2014). Mackey et al. (2014) reported on the Studies conducted by Aagaard-Hansen and Chaignat (2011) which indicated evidence of the spread of mosquitoes in used tires (Aedes albopictus) from northern Asia to North America. This has some implications with respect to the transmission of dengue fever as well as other arboviruses. The infectious agents are not only carried by people but sometimes transported by (traded) commodities or animals. In other words, trade and movement of goods can contribute to the spread of parasites and vectors. Studies conducted by Aagaard-Hansen and Chaignat (2011) indicated evidence of the spread of mosquitoes in used tires (Aedes albopictus) from northern Asia to North America. This has some implications with respect to the transmission of dengue fever as well as other arboviruses. The infectious agents are not only carried by people but sometimes transported by (traded) commodities or animals.

Aagaard-Hansen and Chaignat (2011) explained how refugees that flee to neighboring countries or to other parts within their country (known to be internally displaced, IDPs) are usually vulnerable especially the latter group which international humanitarian laws and organizations do not cover or protect. Migration has consequences, and population movements even within Sub-Saharan countries can influence exposure as well as vulnerability to some of the most chronic NTD infections. Schistosomiasis and leishmaniasis were chosen by Aagaard-Hansen et al. (2010) to exemplify some of the complex ways population movements may play in the spatial distribution of NTDs. The consequence is a reduced access to health care systems. Additionally, health services and intervention programs for migrant populations can be difficult for these populations to use. It can be a logistic problem and in many cases these services are almost non-existent for these populations (Houweling et al., 2016). This is seen in Sierra Leone, Liberia, Uganda and Sudan where negative implications of civil conflicts have contributed to the breakdown of health care systems. Sierra Leone's armed conflict between 1991-2001, left the country's health system in complete ruins, approximately 55% of the country's health care facilities were completely or partially destroyed (Koroma et. al., 2011, 2012, 2018).

Mackey et al. (2014) stated that in their study, Aagaard-Hansen & Chaignat (2011) indicated that cholera is a typical disease that is associated with migrant populations fleeing conflict zones and settling in new areas as refugees. In fact, cholera epidemics over the years have been experienced by refugees in conflict ravaged regions of SSA countries, such as Mozambique, Malawi, Rwanda and the Democratic Republic of the Congo.

Murto et al. (2014) reported that leprosy in Brazil is quite endemic and concentrated in high-risk clusters. Internal migration is a common phenomenon in Brazil and this has the potential to influence leprosy transmission and hinder epidemiological controls by the authorities. They emphasized that migration is one of the known social determinants that clearly influence transmission dynamics of NTDs. In their investigation of the rural migrant population in Brazil, Murto et al. (2014) reported that population movement can introduce new diseases by movements of infected migrant populations from endemic to nonendemic areas.

Epidemiologists argue that NTDs are responsible for poverty because of the debilitating health conditions they inflict on their victims, however recent studies have given reason to accept the idea that, poverty can also be the cause for NTD infections. It is important to recognize the cycle of poverty in this regard.

Several authors have discussed population movements, and many classifications have been suggested. The International Organization for Migration (IOM) (2018) estimated that there are 244 million international migrants globally, in other words 3.3%

of the world's population, and by the same token, there are more than 40 million internally displaced people which is aa record high (IOM, 2018). Further, the number of refugees has grown to over 22 million (IOM, 2018). In a more recent study, Murto et al. (2014) placed the internal migrant population at 740 million people, and internal migration is now considered a part of life for people who live in many low-and middle-income countries.

Onoma (2017) noted the work done by Aagaard-Hansen et al. (2010) on migration in SSA countries which takes different forms, such as labor migration, family re-unification, trade, income and employment disparities, including political instability and conflict, as well as environmental degradation, and are often the major reasons for an individual to leave home, while they also reported that Prothero (1963) went further by providing a nuanced form of population movement in the African continent; and the breadth of details provided by Prothero on labor migration involving pastoralism including voluntary rural movements of those engaged in land cultivation indicating how complex this issue has been. However, according to Aagaard-Hansen et al. (2010) and Kalipeni and Oppong (1998) had a completely different approach which is the political/ecology approach, proposing a conceptual framework that could be used to analyze the refugee situation in Africa (Onoma, 2017). Kalipeni and Oppong identified three important elements: (a) war/political instability/persecution, (b) ecological crisis/life threatening economic decline, (c) ethnic/religious conflicts (Aagaard-Hansen et al., 2010) according to Onoma (2017). Not ignoring the issue of climate change and water resources, Ouedraogo (1991) provided a vivid description of how these can affect population movements both planned and unplanned (Aagaard-Hansen et al., 2010, 2018) according to Errecaborde et al. (2015). Furthermore, Errecaborde et al. (2015) reported that Birley (1995) (as cited in WHO, 1999) chose to investigate rural/urban migration together with variations with regards to circulation, whether it is daily, periodic, or seasonal) as well as long-term, and their relationship to migration patterns, because these are important elements in health assessments with regards to water resources development projects.

Although SSA is a region that is rich in resources, it is also a region of contradictions, and remains the poorest of all regions (Adepoju, 2016). The rampant corruption practices, civil wars and frequent political destabilization at various levels have contributed greatly to the lack of development and progress in the post-independence years. With the current trend of globalization as well as economic restructuring, SSA countries are at great disadvantage. Instead of being a competitor in the global marketplace, SSA has had to grapple quickly with more fundamental issues, such as poverty, civil conflicts and the problem of HIV/AIDS pandemic, which impact heavily on migration dynamics (Onoma, 2017).

It has long been the prevailing view that African migrants relocate to European countries and North America. This long-held belief is a result of the one-sided media coverage. In fact, a study conducted by Croll (2017) indicated that the reality is quite contrary to this popular belief. Croll (2017) explained that only 1.5% of all sub-Saharan African migrants actually live in European Union countries, while two-thirds of sub-Saharan migrant populations usually migrate to other countries in the region (i.e., SSA countries). Furthermore, SSA is a region that has been reported to have high numbers of forced migrants, and this situation has resulted in having the world's highest concentration of internally displaced persons (IDPs), and SSA region is host to about 20% of the world's refugee population.

Shimeless (2018) reported that approximately 140 million people of African descent live outside of the African continent. Many of these people are not true emigrants but belong to families that have long lived in destination countries for many generations. Most of these people tend to maintain fewer ties with their countries of origin in Africa.

Unlike this group of people, African migrants that emigrated in recent decades are estimated to be over 30 million which is only a conservative estimate (Croll, 2017). These recent immigrants tend to maintain close contacts with relatives, and they also maintain economic, social, as well as political relationships with their countries of origin. This can be attributed mainly to the advent of electronic communications technology and globalization. By contrast, 90% of the immigrant populations in North Africa migrate to Europe, the Middle East, and North America (The World Bank, 2013, 2018).

A recent development is the substantial increase in emigration over the last decades. The World Bank's (2013, 2018) bilateral migration matrix data for 2010 indicates that approximately 30.6 million African immigrants (3% of the world's population) lived outside of their country of birth. However, the migration rate, which takes into account the ratio of emigrants to the total population of the country of origin, tends to be low on average, although this trend varies with the different countries in the continent. The actual number of people emigrating from Africa is expected to rise significantly. The first choice for emigrants from Africa is France at 9% of total emigrants, followed by Ivory Coast at 8%, while South Africa is at 6% and Saudi Arabia at 5% with United States and United Kingdom sharing at 4% (The World Bank, 2013, 2018).

It is quite often the case that data on migration in Africa are either missing or simply not available, and sometimes, outdated or inconsistent compared to definitions used by other countries. Moreover, intraregional migration tends to be informal and is not included in national statistics. Data collection on seasonal as well as transit migration is still a huge challenge. However, data that are collected by the United Nations High Commissioner for Refugees (UNHCR) are more accurate and timely. Forty-nine out of 54 countries in Africa actually provide national census data based on immigrants by source country, while data on intra-African migration show significant gaps. The World Bank (2013, 2018) reported that only 15 countries in Africa collected data after 2000, and only 24 countries possessed data for the 1990s but no later than that, and 10 countries are without data even for the 1990s. Data are available for the 1990s for the entire Southern African countries, including three-quarters of East and West African countries and half of Central and North African countries also possess data for that period (The World Bank, 2013, 2018). Central Africa has the weakest data, with no country collecting data after 2000 (The World Bank, 2013, 2018). Many countries in Africa report migrants entirely from the major source countries. The World Bank (2013, 2018) indicated that there should be a holistic approach on the migration data in Africa, particularly when it comes to intra-African migration, which actually requires a significant improvement in terms of availability, timeliness, quality, as well as cross-country comparability.

The World Bank (2013, 2018) indicated that many countries in Africa have realized some significant changes over the years in net migration rates (the difference between immigration and emigration as a share of origin country population) as far back as the late 1970s, and this is a reflection of the tumultuous history of the past decades. These widespread variations in net migration rates were partly a result of civil conflicts, both internal and external. Typical of these are the net migration rates that were so volatile in Eritrea, Liberia, Malawi, Mozambique, Rwanda, Sierra Leone, and Somalia. However, the net migration rates for Africa as a whole have been rather stable over time, ranging from -0.4% to -0.6%across five-year periods from 1975 to 2010 according to The World Bank (2013, 2018). The intra-Africa emigration rate is approximately 50 percent. This is comparable to intraregional rates for developing countries in both Europe and Central Asia at 59% as well as the Middle East at 45%. A large percentage of African migration occurs within the continent, with the cross-country average being close to zero.

Since 2006, migration patterns indicate a decline in the average net migration including its variability across countries (The World Bank, 2013, 2018). Emigration rates vary significantly across countries. For example, some of the smaller countries, like Cape Verde, Equatorial Guinea, Lesotho, Mali, Sao Tome and Principe, and Seychelles have been reported to have gross emigration rates that exceed 10% (The World Bank, 2013, 2018). This excessive emigration rate reflects limited livelihood opportunities, as well as a high variability of income due to the dependence on primary commodities (The World Bank, 2013, 2018). Some countries that suffer from civil conflicts have high emigration rates, and this is seen in the case of Eritrean emigration rate which is almost 20% of the entire population (The World Bank, 2013, 2018). There is a vast difference between SSA and North Africa in this regard. The World Bank (2013, 2018) reported that about 65% of the total emigrant population accounts for intraregional emigration in SSA, which seems to be the largest intra-continental or South-South migration patterns in the world. In addition, the bulk of intra-African emigration has actually taken place across neighboring countries. Seventy percent of emigration in West Africa took place within the same sub-region, while in Southern Africa 66% of emigration was in fact, intra-African, which is a reflection of positive attraction by South Africa (The World Bank, 2013, 2018). It is important to recognize the predominance of cross-border emigration which is taking place numerous times. This is seen in the migration patterns of large numbers of emigrants from Djibouti, Eritrea, Ethiopia, and Somalia which all exist in the same region due to strong ethnic, religious, as well as linguistic ties along vast international borders shared by these countries. Kenya is also a common destination for emigrants from Tanzania and Uganda. Sudan is the ultimate destination for emigrants from Chad, Eritrea, and Ethiopia, while emigrants from Burundi and Rwanda quite often speak the same language or even have a shared history with natives of Tanzania and Uganda. The melting pot in West Africa is Ivory Coast for most of her neighbors as a result of easy communication as well as religious and historical connections. Emigrants from Benin, Ghana, and Niger all head to Nigeria for the same reasons. Southern Africa attracts migrants from Botswana, Lesotho, Mozambique, and Swaziland who can easily blend into communities in South Africa, which enables migrants to have easy mobility and settlement. There is also an inclination by intra-African migrant population to migrate to relatively prosperous countries such as South Africa. This is due to income differences which also affects migration flow. However, Tanzania is an exception in this regard, because although it is a common destination for emigrants from Burundi, the Democratic Republic of Congo, (DRC) and Zambia, the fact remains that the difference in per capita gross domestic product (GDP) is in fact, negligible or sometimes favors the source country (The World Bank, 2013, 2018).

The UNHCR (2010) reported that almost 2.2 million Africans who reside in other countries outside of their country of birth are known to be refugees, who have been displaced mostly by civil conflict or drought as well as other natural disasters (The World Bank, 2013, 2018). About half of these refugees live in Kenya, Chad, the Democratic Republic of Congo, and Sudan. However, the World Bank (2013, 2018) also indicated that the main sources of international migrants are people from Somalia, the Democratic Republic of Congo, Sudan, and Eritrea. Other groups of refugees numbered about 6.5 million are categorized as internally displaced persons (IDPs), who have been forced to migrate within other African countries (The World Bank, 2013, 2018).

Ecological Theory—Ecological Framework

The International Journal of Health Geographics (IJHG, 2014) reported a study conducted by Tanser and Sueur (2002) in which they indicated that Africa has a physical and ecological structure that is as varied as its social, political and demographic characteristics. In reviewing the literature, Dallas and Rivers-Moore (2014) reported on earlier studies conducted by Tanser, Sharp, and Le Sueur (2002) in which they explained the projected increase in malaria transmission as a result of an increase in distribution (particularly altitudinal). This report also included season length, in the Limpopo Province of South Africa, which has a substantial latitudinal extension (Dallas & Rivers-Moore, 2014). Africa’s major biomes include tropical rainforest, moist and dry savanna, semi-desert as well as desert and temperate lands. IJHG (2014) reported that Tanser and Sueur (2002) used certain factors, the political environment of Africa, poverty, general low levels of well-being of majority of the population, climatic conditions, vegetation and biogeography that affect the prevalence of organisms, for example bacteria, viruses and worms that cause disease in humans (Dallas & Rivers-Moore, 2014). Numerous experts have critiqued the notion of applications of geographical systems (GIS) to health which Tanser had used earlier in his studies. However, experts have now concluded that using the GIS system would contribute to the health sciences. There is less clarity on the application and sustainability of GIS technology in an African setting reported by Tanser & le Sueur (2002) according to IJHG (2015). According to IJHG (2015) the GIS system would be a vital tool of great inherent potential for health studies in Africa since health is generally determined by environmental factors as well as the sociocultural and physical environment, which usually vary in space. Moreover, the spatial modeling capacity provided by the GIS system has direct applicability to understanding the spatial variation of infection, including its relationship to environmental factors as well as the healthcare system (IJHG, 2015). Public health practice usually requires timely information on the course of disease including other health events if appropriate actions are to be implemented. The GIS system fulfills this role, even though the use of this tool has yet to be recognized by the various experts because it is usually misunderstood or unfamiliar.

Various researchers used different theoretical models in conducting their studies. The issue of population movement and its epidemiological impact lead to new causes, such as migration patterns and climatic conditions. There is an increase in the depth and complexity of our knowledge of environmental determinants of health that informs the conceptual frameworks of epidemiology, and the way we think about the causes of disease. This is seen in the approach taken by many researchers in their choice of theoretical models used in different studies.

It is important to recognize that transmission of infectious disease must be examined within the ecological framework. Infectious agents usually obtain their essential nutrients and energy through parasitic means. In other words, infectious agents depend on higher organisms they parasitize for their survival. However, the majority of these infections are benign, and it has been reported that some of the infectious agents have a commensal relationship with the host. According to the WHO (2019) Patz et. al. (2003, p. 001-017) indicated that only a minority of infections that adversely affect the host's biology are usually referred to as 'infectious diseases'. The effect of climate change on parasites is critical to their survival in the environment. There is a lack of thermostatic mechanisms as a result of the size of the infectious agent (protozoa, bacteria, viruses, etc.) and the associated vector organism, such as mosquitoes, ticks, sandflies, etc. (WHO, 2019). Hence, the temperature and fluid levels of these organisms are determined by the local climate (WHO, 2019). This situation creates a limited range of climatic conditions usually referred to as climate envelope, which is the ideal temperature range for the survival and the ability to reproduce of both infective and vector species as indicated by (Patz et al., 2003, p.001-017, according to the WHO, 2019). The incubation period of the pathogen within its vector is typically quite sensitive to temperature changes, and usually displays an exponential relationship Patz et al. (2003, p. 001-017) according to the WHO (2019). Additionally, other climatic sensitivity factors such as level of precipitation, sea level elevation, wind and duration of sunlight, all play a vital role for the agent, vector, as well as the host.

Clements et. al. (2010) used the Bayesian geostatistical models in their study on the role of climate including socioeconomic variables in the spread of NTDs. The Bayesian geostatistical models were used as a mechanism to interpolate the prevalence of NTD infections in the entire study area. The geostatistical and the socioeconomic model is an inclusive framework that takes various aspects of the study area, such as economic status, social and the geospatial distribution of disease into consideration. The models were used to simultaneously predict the prevalence of infection. Climate change has been reported to have an effect in the spread of infectious diseases. There is an apparent increase in several infectious diseases including HIV/AIDS, hantavirus, hepatitis C, and SARS. The WHO (2019) noted that Patz et al. (2003, p. 001-017) stated that this is a result of a combination of factors, such as the impacts of rapid demographic, environmental, social, technological changes in our ways-of-living. Moreover, the authors used theoretical models and statistical, process-based, as well as landscape-based models, in forecasting future climatic influences on infectious diseases. Researchers used statistical models which required an empirical relationship between the current geographical distribution of the infectious disease as well as the present location-specific climatic conditions (Patz et al., 2003, p.001-017) according to the WHO (2019). This model provided a vivid description of the climatic influence on the actual distribution of infectious diseases, taking into consideration the prevailing levels of human intervention, in terms of disease control and environmental management. The WHO (2019) stated that Patz et al. (2003, p. 1395-1405) reported on applying this statistical equation to forecast future climate situations, experts can determine the actual distribution of the disease being investigated with the assumption that levels of human intervention remain unchanged within a specific climate. Such models were applied to the impacts of climate change on some infectious diseases such as malaria, dengue fever, and encephalitis in the United States. Using these models indicated some net increases in the case of malaria in the next half century, while others showed little change if any. Other models such as process-based (mathematical) models had been used which indicate the relationship that exists between climatic variables and the biological parameters, such as vector breeding, survival, the biting rates, and the parasite incubation rates. By using a set of equations, these models expressed how a configuration of climate variables would affect vector and parasite biology, hence, disease transmission.

According to the WHO (2019) Patz et al. (2003, p.001-017) explained that these types of models address the question. “If climatic conditions alone change, how do these change the potential transmission of the disease?”

The conditioning effects of human interventions including the social contexts could be included by simply using more complex “horizontal integration”. When this modeling method was used specifically for malaria and dengue fever, the malaria modeling showed that small increases in temperature greatly affected the potential for disease transmission. Globally, temperature increases of 2-3^{o} C has the potential of increasing the number of people who (in climatic terms) are at risk of getting infected with the malaria parasite by approximately 3-5%, which is about several hundred million people Patz et al. (2003, p.001-017) according to the WHO (2019). Subsequently, such a situation would tend to increase the seasonal duration of malaria in what is now regarded as typically endemic areas.

Climatic activity can influence habitats. This necessitates the use of land-based models which consist of a combination of climate-based and the fast emerging "spatial analytical methods" to investigate climate and environmental factors. This particular modeling has been in use in an effort to estimate the effect of future climate-induced changes on ground cover and surface water in Africa that would potentially affect mosquitoes and tsetse flies, as well as malaria and African trypanosomiasis (African sleeping sickness). Clements et.al. 2010) reported that their models provided several insights into the epidemiology of helminthes. In addition, these models also indicate the associations between the relevant helminth infections and environmental variables. The variables included but were not limited to temperature, distance from water bodies and extent of urbanization. Hotez et al. (2011) noted that in SSA, the incidences of hookworm and other NTDs tend to overlap intensely with the geographic range of falciparum malaria particularly with the estimated 50 million hookworm-infected school-aged children. Hotez et al. (2012) indicated that 40 million African women of reproductive age are infected with hookworms, and 7 million of them are pregnant women infected with the disease. There are high rates of hookworm and malaria co-morbidities in these areas, and these infections are also reported to cause severe anemic conditions in children as well as expectant mothers.

Distinguishing Factors of Migrants in Sub-Saharan Africa

The literature pertaining to this area of migration in SSA was retrieved from a report by Adepoju (2016) on migration in SSA for the Swedish government including some of his recent studies. The author outlined the root causes of migration dynamics before attempting to clarify some of the issues peculiar to SSA. SSA is a region of fragile ecosystems with desertification, including deteriorating arable land, and these are some of the factors that have contributed immensely to the lack of land for many agricultural workers to farm. Pastoralists have also been driven by these harsh conditions to migrate to coastal regions, to towns and cities, including neighboring countries for their survival. Additionally, the outrageously low commodity prices, combined with unstable and low-paid jobs, provide reasons for the persistence of migration in Africa. Unfair trade regulations, particularly on corn subsidies by rich nations are an added burden. The seasonality and precariousness of the weather is reported to have influenced the local ecology. Over the past decades, desertification has added immensely to areas of aridity and this is affecting about 300 million people. The arid zones are reported to cover almost half of the African continent, and this environmental condition has in fact, created some 10 million environmental refugees in Africa by the late 1980s.

The Levin Institute (2014) reported that during 2012, about 32.4 million people were displaced by environmental disasters, and this includes those who were forced to relocate within their countries of origin as well as those who seek refuge through international migration. Another 135 million people are considered as environmental refugees in areas that are considered vulnerable to desertification and 80% of the entire pasture including range lands are being threatened by soil erosion (Adepoju, 2016). Further, 98% of this disruption was a result of climate-and weather-related disasters, such as flooding. Most poor people in Africa depend on rain-fed agriculture, as well as pastoralism for their livelihood. Unfortunately, the persistent drought has contributed greatly to crop failures, poor harvests including significant loss of livestock. As a result, this has caused many families in a complex situation of hunger, poverty, as well as perennial humanitarian problems. Further studies by Adepoju (2016) indicated that land productivity has declined by about 25% in sub Saharan Africa. Grote and Warner (2009) reported that land degradation, desertification and drought in the Sahel region has resulted to a significant proportion of environmental refugees in this part of the world. The Sahel region spans west to east across nine countries from Mauritania, Senegal and into Sudan according to Grote and Warner (2009). The United Nations reported that SSA countries are the only developing countries that continue to register a decline in per capita food production over the years (Adepoju, 2016).

SSA countries have problems of poverty and landlessness and these are a result of a host of interrelated factors, such as the sizes of farms which are usually small, marginal ecological conditions, soil depletion, low productivity, and the problem of intense population pressure. Adepoju (2016) also indicated the lack of access to credit, including institutional constraints. Regardless of the declining urban employment situation, migration to urban areas continues to be a serious issue. Grote and Warner (2009) reported on the environmental degradation, desertification, and deforestation combined with natural disasters such as floods or droughts, which all contribute to migration which serves as a coping mechanism of households. The report includes an explanation of environmental changes which are especially more pronounced in SSA.

The Sahel region is reported to experience vast climatic changes coupled with political tension, armed conflict, ethnic pressure, increasing poverty, deteriorating services including infrastructure, all of which are factors that accelerate the process that lead to migration, and eventually conflict (ECFR, 2017).Adepoju (2016) noted that Africa is currently experiencing migratory configurations, and this happens within as well as outside the continent. The most pronounced are labor, refugee migration and internal displacement. Migration to urban areas is always considered better because regardless of the inadequate job opportunities, there are still more jobs than in rural areas with more educational opportunities for children of migrants. Adepoju (2016) referred to population movements in SSA countries as a matter of migration or circulation. Adepoju (2016) was actually referring to Oucho's 1990 statement that migration in SSA is in fact, conceptualized as a process of circulation that continues starting with the origin-migrant-destination. The concept of "environmental refugees" is rapidly gaining importance, due to global climate change and desertification that continue to threaten the livelihoods of millions of people, resulting in many people leaving home in search of new opportunities (The Levin Institute, 2014).

The various concepts that have been applied to migration over the past several decades include, for example, circulation of labor, circular migration, labor migration, commercial migration, oscillatory migration, target migration and reciprocal migration have all been discussed in the literature, which is a reflection of the complexity of migration configurations discovered by researchers (Adepoju, 2016). The concept of 'circulation' seems to be the most accommodating because it encompasses the dynamics of migration in SSA countries-indicating non-permanent movements based in circuits within as well as across national boundaries which ultimately starts and has to end at 'home' (Adepoju, 2016). It is also the practice in some sub-regions to hire migrants with the understanding that they would have to go back to their country of origin at the end of their assignment. This was seen in the case of the mine workers during apartheid-era South Africa where migrant workers were recruited from neighboring countries for only a specific time and had to return after the contractual period, and this process was repeated many times. In West Africa, the seasonal, short-term and frontier workers view their own movements as just another extension of internal movements across national boundaries. In other words, they simply see these movements as rural-rural migration. This is the case in West Africa, where travelers who cross international borders along extensive frontiers that separate homogeneous groups of people, such as the Ewes between Ghana and Togo and the Yorubas between Benin and Nigeria. Migration in the Sahel region may be increasingly non-circular or non-cycling due to climate change. Although in the past, nomadic and semi-nomadic people migrated cyclically with the seasons from north to south and east to west, now these migrants are becoming increasingly one-way (north to south). Increasingly, drought and desertification are making traditional homeland areas uninhabitable with the result that people must leave permanently for other areas.

Table 1 Typology of population movements according to the characteristics of onset, cause, direction and motivation-partly based on previous work of Lechat (1976), Shears (1991) and others.

Population Movement and Neglected Tropical Diseases

Movement type	Examples	Onset	Cause	Direction	Motivation
Resettlement	Relocation because of water development schemes Urbanization	Slow	Human/political	Unidirectional	Voluntary
Labour migration	Permanent migration to other countries				
Family unification	Diaspora				
Pastoralism	Nomadism Transhumance			Circular	
Labour migration	Seasonal work in agriculture				
Trading	Selling rural products in towns				
Pilgrimage	Hajj				
Tourism	Charter Long-term backpacking				
Refuge	War	Rapid	Human/political	Both	Forced
Forced displacement	Forced resettlement	Slow			
Refuge	Earthquake	Rapid	Natural		
Refuge	Drought	Slow			

Note. Adapted from “Population Movement: A Key Factor in the Epidemiology of Neglected Tropical Diseases,” by J. Aagaard-Hansen, N. Nombela, and J. Alvar, 2010, *Tropical Medicine and International Health*, *15*(11), p. 1281-1288 Copyright 2010 by NCBI

Experience of Migrants in Relation to NTD Infections

Migrant populations seem common in developing countries. In a report on migration 2009, it was indicated that 80% of the estimated 16 million refugees including 26 million of those persons who were internally displaced worldwide were reported to live in developing countries (Gazzinelli et al., 2012). Recent estimates show that 100 million migrant workers sent over $US300 billion to their home countries, while many of these migrant workers live in congested, unsanitary conditions, where intestinal parasitosis as well as other infectious diseases are reported to be prevalent, especially during the drought period, food shortages and civil conflicts (Gazzinelli et al., 2012). Over the past decades, the migrant worker migration pattern has grown and has become more complex in a globalized world. Now, there are new trends of migrant worker migration, for example there is an increase in sponsorships of migrants by private organizations as well as intermediaries including an increase of female migration, which has resulted in more precarious working conditions, hence increasing possible health risks (Gazzinelli et al., 2012). As a result of mobility of migrants, most of them fail to receive the essential treatments of mass chemotherapy as well as outreach programs, and this particular issue needs further investigation. Failure of migrants to receive mass chemotherapy and outreach programs means that these migrants are not screened for helminth infections. Despite the existence of international conventions designed to ensure human rights and welfare of migrant populations, helminth infections still seem high in many migrant people (Gazzinelli et al., 2012).

Additionally, infected migrants might have the potential to increase disease transmission that already exists in an urban center. This is seen in Kinshasa, Democratic Republic of Congo, where the huge inflow of internally displaced persons from rural communities that are endemic to African trypanosomiasis has caused a vast increase of the disease ten times in the number of cases that were reported (Alirol et al., 2010). Rural migrants moving from non-endemic areas may also change the epidemiology of infectious diseases that already exist in the city. Many migrant populations such as refugees and other internally displaced persons, either as a result of environmental or political reasons, and migrant workers are known to be at a risk.

Climate Change and Its Impact on the Spread of NTDs

Climate change is increasingly becoming an area of interest that experts are investigating with respect to the endemicity of soil-transmitted helminths and schistosomiasis. The impact of climate change is reported to have resulted in an estimated 150,000 deaths and 5 million disability-adjusted life years (DALYs) worldwide over the past 30 years (Gazzinelli et al., 2012). It is also anticipated that the increase in temperatures as well as greater rainfall fluctuations, will trigger alterations in both physical and biological systems, including shifts in the spatial distribution of disease vectors as well as intermediate hosts (Gazzinelli et al., 2012). The exact impacts of climate change on vector competence, how long the extrinsic duration would last, vector survival, intermediate hosts, reservoirs as well as helminth transmission cycles in general all remain elusive and poorly investigated with minimal understanding particularly for helminthiases.

An ongoing postulation is that climate change is a more likely factor for the distribution of freshwater snails, such as *Biomphalaria*, which is in fact, an intermediate host of S. *mansoni.* China's current water resource project, referred to as the "south-to-north water transfer project", together with climate change, has more than likely facilitated the introduction of snail which serves as the intermediate host of S. *japonicum* (*Oncomelania hupensis*) to new environments in the northern parts of China (Gazzinelli et al., 2012). Climate change is postulated to result in a wider range of health risks due to ensuing social and demographic disruptions that have created a stream of environmental refugees (Gazzinelli et al., 2012). This trend would challenge the livelihood of poor people, with the ultimate emergence of new challenges for control and changes with regards to access in healthcare services. Not ignoring the issue of climate change and water resources, Ouedraogo (1991) provided a vivid description of how these can affect population movements both planned and unplanned (Aagaard-Hansen et al., 2010). On the other hand, Birley (1995, as cited in WHO, 1999) chose to investigate rural/urban migration together with variations with regards to circulation, whether it is daily, periodic, or seasonal) as well as long-term, and their relationship to migration patterns, because these are important elements in health assessments with regards to water resources development projects (Aagaard-Hansen et al., 2010).

So far, two core strategies have been employed in an effort to manage or reduce the risks of environmental change, which are: (1) mitigation and (2) adaptation. Mitigation reduces the existence and strength of anticipated risks especially when the risks are identified. This is achieved by encouraging and investing in preparedness. It is important to conduct further studies, such as large-scale, longitudinal interdisciplinary studies involving both social and biological sciences which would inform initiatives including programs that aim at ameliorating and adapting to the impacts of climate change. Gazzinelli et al. (2012). revealed the consequences of polyparasitism which is a result of commonalities in both ecological and environmental needs, infection routes, host exposures, including susceptibility and behavioral, sociological, as well as economic factors, that enable co-occurrence of multiplicity involving parasite-host systems considering time and space.

Disease transmission (helminth infections) can also be reduced by modifying the biophysical and domestic environments, such as economic development and urbanization or through a mechanism of focused activities according to Gazzinelli et al. (2012). The soil transmitted helminthes (STHs) are intestinal nematode infections considered to be some of the most common and persistent parasitic infections in the world. Recent estimates show that 1221-1472 million people are known to be infected with roundworm (*A. lumbricoides*), 795-1050 million with whipworm (*Trichuris*), and 740-1300 million with hookworm (*N. americanus, A. duodenale*), (Lustigman et al., 2012). Consequently, the disproportionate burden of helminthiasis is reported to occur in marginalized, low-income populations and resource-constrained areas of the world that experience extreme poverty. These populations live in areas of inadequate sanitation, which contributes to a vicious circle of infection, poverty, decreased productivity including inadequate socio-economic development (Lustigman et al., 2012). It is often the case that NTD control programs tend to rely heavily on antihelmintic treatment and sometimes depend only on one drug. This increases the risk of antihelminthic resistance and jeopardizes the effectiveness of the program.

Trachoma: is an eye infection caused by a bacterium known as *Chlamydia trachomatis.* This disease is a major cause of preventable blindness in the world. Trachoma as a chronic inflammation of the conjunctiva can lead to scarring of the conjunctiva including the cornea, and this condition can eventually result in blindness (NIAID, 2007). Children under 10 years old exhibit the greatest morbidity through repeat infections. There are about 11 million cases of infection and 8 million cases of blindness reported annually worldwide. Trachoma is known to be endemic in impoverished areas of Africa, Asia and the Middle East, as well as in other areas of South America and Australia.

Climate change is a major factor that should be observed closely in SSA. Ramin (2009) reported that the impact of climate change will be experienced in many parts of the African continent. Climate change is reported to have an impact on NTDs in SSA countries. Despite the current funding of NTDs, experts are concerned that changes in rainfall patterns may cause a loss of “endemic stability” for some of the diseases transmitted by mosquitoes, ticks, including other disease hosts (Irish News, 2015). Consequently, environmental conditions could become favorable for disease re-distribution as well as infections. A WHO senior scientist, Diamond Campbell-Lendrum, noted that climate change has to be in the discussion because nobody disputes the fact that climate sensitivity is quite evident now in some of these diseases, therefore it would not make sense to exclude it (Irin, 2015). Humans have always known that climatic conditions can affect epidemic infections before there was an understanding of infectious agents in the nineteenth century (Patz et. al., 2003, p.001-017) according to the WHO (2019). There will be an interaction between urbanization and climate change, and scientists are unsure of the results. In the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, it was emphasized that urbanization and climate change are critical in Africa particularly when it comes to vulnerable urban populations (Ramin, 2009). As a result, public health professionals should consider the role of climate change (i.e., climate change and urbanization) when planning health interventions in Africa. In fact, African slum dwellers are most susceptible in this situation (Ramin, 2009).

The Anopheles species as well as the Culex species are considered as the main vectors of Lymphatic Filariasis (LF) with Culex playing only a minor role in the transmission process. However, this is a disease that is predominantly rural; hence, the question is whether civil conflict-related migration of rural populations into urban centers would suffice for the parasite's active transmission. West Africa is host to the Culex mosquitoes which can be found in large cities including urban areas. In spite of the existence of *W. bancrofti* antigen positive individuals in numerous cities in West Africa, experts have not been able to demonstrate an on-going transmission of the parasite in these areas (de Souza et al., 2014). De Souza et al. (2014) postulated that LF is a predominantly rural disease which is transmitted by the *Anopheles gambiae* complex considered to be the major vectors. De Souza et al. (2014), working in Ghana, could not demonstrate any active transmission of LF in the Ghanaian capital, Accra. They were only able to report minor capability for LF transmission in those areas that were infested with Culex mosquitoes which were also the predominant human biting mosquitoes (de Souza et al., 2014). As a disease that is typical of rural areas in West Africa, there have been reports that micro-filaremic individuals are hardly found in big cities in this region of Africa. The question that most experts ask is whether large population movements from rural to urban centers would cause the parasite to be transmitted in these cities, particularly in post-conflict countries where massive population movements from rural to urban areas occurred as a result of people seeking safe havens during the civil conflict. LF is endemic in rural Sierra Leone, and the disease is known to exist in all twelve provincial districts (de Souza et al., 2014). Sierra Leone has a long history of LF since the 1900s when it was first reported by Ronald Ross.

Sierra Leone's civil conflict that began in 1991 triggered several events in the country. About 47% of the pre-war population found themselves displaced internally while some had to flee to neighboring countries such as Liberia and Guinea. The majority of the internally displaced persons (IDPs) had to stay in camps as well as in urban centers. During the civil conflict in Sierra Leone in 1997, the population of Freetown, (the capital city of Sierra Leone), was at 1.2-1.5 million people which was an increase from its pre-war population of about 750,000 (Souza et al., 2014). Studies conducted by de Souza et al., (2014) in seven IDP camps in Freetown in 1997 show the presence of a 14.5% antigen prevalence rate among internally displaced people (IDPs). de Souza and colleagues proceeded with another study in which they conducted an LF mapping process using Information and Communication Technology (ICT) in 2005 in an effort to determine LF prevalence in Sierra Leone. This process shows the prevalence of 23.3% in Sierra Leone and 11.7% in the capital, Freetown. However, there were no cases of individuals infected with microfilaria (MF) in Freetown. The World Health Organization (WHO) guidelines recommend treatment if antigen positive rate is over 1%. As a result, the Ministry of Health in Sierra Leone initiated a mass drug administration (MDA) campaign to treat an additional one million people residing in the Western Area of Freetown. This was not a decision that was evidence-based but rather a pre-emptive strategy to defend against the possibility of LF infections.

Liberia is a completely different situation because this is a country with a history of LF prevalence in the capital city, Monrovia. Poindexter conducted a study in which he reported several cases of LF infections in urban Monrovia (de Souza et al., 2014). Ironically, Monrovia was the only major city in the entire country with an operational organized mosquito eradication program (de Souza et al., 2014). Poindexter's findings also indicated that individuals with LF infections were transient persons that had migrated from rural communities into urban Monrovia. The Anopheles species *An*. *gambiae* and *An*. *melas* are the known primary vectors of LF in Liberia. The non-important LF transmission Culex and Aedes species are reported to be the abundant mosquitoes in urban Monrovia. In a national mapping project in 2010-2011, results indicated that LF disease exists in many counties, including the Monserrado County in which the capital city is located. Although MDA in Liberia was first implemented in counties outside Monserrado in 2012, experts question the wisdom of not including the national capital, Monrovia.

Estimates indicate that MDA for LF eradication is cost effective compared to many other public health intervention programs, for example, country specific financial costs usually range from $0.06 to $2.23 (de Souza et al., 2014). De Souza et al. (2014) conducted a study in which the aim was to determine whether there was an ongoing transmission of LF in major cities of Sierra Leone, such as Freetown, Bo, and Pujehun, and Liberia's capital Monrovia. The aim of the Sierra Leone study in 2010 was to determine whether there was the possibility for sustainable transmission of LF in the big cities, such as Freetown, Bo and Pujehun including Monrovia in Liberia. The researchers tested the hypothesis that a transient population that is a carrier of microfilaremia and settled in urban centers is not capable of initiating LF transmission involving an Anopheles transmission area. In poor neighborhoods located in urban centers, such as in Nigeria the problem of waste-water mismanagement, the absence of sewer systems, and the accumulation of waste actually promote the proliferation of *Wuchereria bancrofti* vectors, hence increase biting rates (Alirol et al., 2010). In a recent statement by the Programs Manager of Neglected Tropical Diseases in Ghana, Dr. Nana Kwadwo Biritwum stated that all of the districts in Ghana are being affected by debilitating and NTDs (Ghana Health News, 2014). Ghana is burdened with 10 out of the 17 identified NTDs that occur mainly in SSA which are generally caused by both parasitic as well as bacterial infections. This disclosure was made by Dr. Nana Kwadwo during the recent launch of the Mass Drug Administration and Neglected Tropical Diseases Master Plan that was put together in an effort to address the problem of NTDs.

Buruli ulcer is caused by bacterium, *Mycobacterium ulcerans*, which can develop into extensive skin ulcerations, typically found on an infected person’s arms and legs. For the disease to be prevented from developing into a condition that would lead to extensive skin and soft tissue destruction with the ultimate restriction of joint movement, treatment has to be provided early on, and in time, while sometimes the patient might require limb amputation. Studies show that *M. ulcerans* is in fact, not transmitted from individual to individual but known to be an environmental mycobacterium suspected to be transmitted to humans from aquatic environments, small aquatic animals and biofilms. This bacterium belongs to the same family of organisms responsible for leprosy and tuberculosis; however, it is a unique organism because it is capable of producing toxin, known as mycolactone, which can destroy tissue (WHO, 2014). The disease is usually characterized by big ulcers and can lead to disfiguration which sometimes can result to loss of limbs (Aagaard-Hansen, & Chaignat, 2010, 2018). Humans seem to have increased the risk of infection in areas of stagnant water or slow-moving water; however, the mode of transmission is still being investigated by researchers.

Dengue fever: this is a fast-emerging pandemic-prone viral infection which can be found in many parts of the world. The disease is known to flourish in poor urban areas, including suburbs as well as the countryside (WHO, 2014). It is also known to exist in affluent neighborhoods in both tropical and subtropical countries (WHO, 2014). The disease is caused by an arbovirus usually transmitted by mosquitoes (*Aedes aegypti*). The symptoms fever, headache, musculoskeletal pain and rash (Aagaard-Hansen & Chaignat, 2010, 2018). Reinfection of the disease can sometimes result in a potentially lethal complication referred to as severe dengue which was previously known as dengue hemorrhagic fever (WHO, 2014). The literature also indicates that dengue incidence has increased 30-fold in the last 50 years (Lugo, 2015).

Dracunculus medinensis (guinea-worm disease)**:** this disease is caused by a worm (*Dracunculus medinensis*). The larvae usually enter the human body through drinking water that contains tiny crustaceans that are carriers of the larvae (Aagaard-Hansen, & Chaignat, 2010, 2018). This is the largest worm that parasitizes human tissues (WHO, 2014). The adult female is reported to carry about 3 million embryos, and can measure 600 to 800 mm in length and 2mm in diameter (WHO, 2014). The WHO (2014) reported that the parasite migrates through a person's subcutaneous tissues, thereby causing severe pain which can be felt even more if the joints are involved. The worm usually emerges from the feet, and this causes an intense painful edema. Accompanying this condition is a blister and an ulcer with a fever, nausea and vomiting (WHO, 2014). The worm takes 10-14 months to emerge after infection, and there is no known vaccine or treatment for the disease (WHO, 2014). Prevention of the disease is quite simple, and through preventive strategies, the disease is on the verge of eradication (WHO, 2014). The literature indicates that since 2013, the annual incidence of the disease is reported to have decreased drastically by more than 99% compared to the previous years.

*Human African Trypanosomiasis (HAT-Sleeping Sickness):*This is a disease that is caused by various *Trypanosoma* spp. Tsetse flies (*Glosina* spp.) are the known vectors for the transmission of the disease, including other types of animals, such as pigs, cattle, and antelopes which are known to serve as reservoirs. The disease is reported to affect mostly poor populations inhabiting remote rural areas in Africa (WHO, 2014). If the disease remains untreated, it becomes fatal. Untreated disease usually progresses invariably to a condition that results to body wasting, somnolence, coma and death eventually (WHO, 2009, 2018). The central nervous system tends to be affected and it is difficult for treatment with drugs and quite expensive; while control is largely focused on vectors (Aagaard-Hansen & Chaignat, 2010). Travelers can also risk getting infected if they venture into areas where the insect (tsetse fly) is common (WHO, 2014). The disease does not exist in urban centers, however some cases of the disease have been found in suburban areas of large cities where endemicity of the disease in those countries has been reported (WHO, 2014).

Leishmaniases: these are diseases that are caused by protozoan parasites, and more than 20 of these species are known to exist. They are usually transmitted to humans when the female phlebotomine sandflies (both *phlebotomus* and *Lutzomyia* spp.) bite an individual. The WHO (2014) reported the three types of the disease: (1) cutaneous, (2) visceral, and (3) mucocutaneous. In other words, there is cutaneous leishmaniasis (most common), visceral leishmaniasis or kala-azar (most serious form of the disease), and mucocutaneous leishmaniasis. It is difficult to get treatment for the disease. The disease affects the poorest people in the world, and is generally associated with malnutrition, population displacement, poor housing facilities, a weak immune system of people living in these impoverished conditions, and above all, a lack of resources (WHO, 2014). The spatial distribution of leishmaniasis is linked to environmental changes, for example deforestation, construction of dams, irrigation schemes, and urbanization (Aagaard-Hansen et al., 2010). The WHO (2014) estimated 1.3 million new infections and approximately 20,000 to 30, 000 fatalities that occur each year.

Leprosy (Hansen's disease): This is a chronic disease that affects skin, nervous tissue, respiratory tract, and eyes which is caused by infection with *Mycobacterium leprae.* Treatment for leprosy is only successful in the early stages of the disease. Consequently, there is no treatment for leprosy once the nerves have been damaged (National Institute of Allergy and Infectious Diseases [NIAID], 2007, 2013, 2018). *M. leprae* has the potential to cause a vast range of clinical manifestations, such as peripheral neurological damage (nerve damage involving the arm and legs), and this condition results in sensory loss in the skin including muscle weakness. Studies indicate that people with long-term infection may end up losing the use of their hands or feet as a result of continuous traumatic injuries because of lack of sensation. However, the stigma that has always been associated with leprosy continues to exist in many parts of the world. There is also a biological consequence, such as the contribution of biological sex and age which has a significant effect on the outcomes of infections (WHO, 2013, 2018). An example of this is seen in the combined effects of puberty and first pregnancy in young mothers which has the potential to reactivate leprosy (WHO, 2013, 2018). Nerve damage from leprosy is reported to accelerate in expectant and lactating mothers, and 45% of the women develop silent neuritis, including those who are undergoing chemotherapy as well as those considered cured (WHO, 2013, 2018). The psychological and social stigma of leprosy seems more difficult to cope with than the disease itself. WHO (2014) reported a decline in Hanson's disease epidemiology in the actual number of disease cases. However, experts raise concerns and question the source of infection, transmission, and incubation period of *M. leprae* as a result of the number of new cases detected each year.

Lymphatic filariasis: this is an infection that is known to be endemic in 83 countries with an estimated 1.3 billion people at risk to develop the disease. According to the WHO (2015) 120 million people are also known to be infected. Over 40 million people are seriously incapacitated and also disfigured by the disease (Lustigman et al., 2012). WHO (2015) indicated that 90% of the victims are infected with *Wuchereria bancrofti;* the remaining victims are infected with *Brugia malayi* or *Brugia timori.* LF infection is usually acquired at quite an early stage in life (childhood), and this causes severe morbidity including social stigma as a result of the deformities people develop. Lymphatic filariasis is also reported to provoke acute dermatolymphangioadenitis (ADLA) as well as lymphoederma. If the disease becomes a major chronic manifestation, it would result in conditions, such as hydrocele and lymphedema of limbs, chyluria, and lymphedema of the scrotum, adenopathy, haematuria, and tropical pulmonary eosinophilia. LF can cause permanent and long-term disability, with the ultimate effect of damaging and deforming the limbs, breasts, and genitals, and this has the potential to result to severe psychosocial consequences. Five million DALYs (disability-adjusted life year) are known to be lost to LF annually worldwide. The region of Southeast Asia accounts for approximately 57% of the entire global burden of the disease while India is reported to experience economic losses estimated at US$ 1 billion annually as a result of LF.

Onchocerciasis: Commonly known as “river blindness”, is a parasitic disease that is caused by a filarial worm known as *Onchocerca volvulus*. The disease transmission in humans is usually through exposure caused by multiple bites of infected black flies. Infected individuals usually get symptoms, such as itching, disfigurement of the skin, visual impairment, and permanent blindness. The disease is spread when an infected blackfly bites an individual. When the black fly bites an infected person, the microscopic worm larvae (also known as microfilariae) found in the skin of the infected person enter the blackfly thereby infecting it. The larvae will then develop over two weeks inside the fly into a form that is infectious to humans. The infected fly will inject larvae in the process of biting a person. Once this has occurred the larvae will penetrate the skin and eventually infect the individual (Centers for Disease Control and Prevention, CDC, 2014). The worms can only reproduce in humans; however, they have to complete part of their development in the blackfly. The intensity of human infections is related to the number of infectious bites a person sustained (CDC, 2014). The World Health

Organization WHO (2014) indicated that 99% of people infected with the disease are in 31 African countries, although the disease is also known to exist in some foci in Yemen as well as in Latin America. The countries in which onchocerciasis is found in SSA include the following: Angola, Benin, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Republic of the Congo, Equatorial Guinea, Ethiopia, Gabon, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Malawi, Mozambique, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Sudan, Sudan, Togo, Uganda, and United Republic of Tanzania (WHO, 2014). The blackflies which breed in fast-flowing rivers and streams are found in mostly remote village communities usually near fertile land where the inhabitants depend on agriculture.

Schistosomiasis (bilharzia): This disease is commonly referred to as a disease of the impoverished that generally results to chronic poor health. People become infected from contact with freshwater that is contaminated with larval forms of parasitic fluke worms (cercariae) referred to as schistosomes (WHO, 2014). These are microscopic organisms that live in the veins that drain the urinary tract and intestines. Most of the eggs laid by these blood flukes are usually trapped in the tissues and reaction by the body to these invaders causes massive damage (WHO, 2014). According to the WHO (2014) almost 240 million people are afflicted by schistosomiasis globally, and approximately 700 million people are known to live in areas that are endemic to the disease. The eggs of blood fluke are spread by urine or feces, while the snail species serve as the intermediate hosts for the larvae, which have the potential to penetrate human skin in contact with infested water. There are several forms of the disease that cause urogenital schistosomiasis, and intestinal schistosomiasis, which can be caused by any of the following organisms: *S. guineensis, S. intercalatum, S. mansoni, S. japonicam,* and *S. mekongi* (WHO, 2014). According to the WHO (2015) control measures include inexpensive medications, sanitation and snail control as well as complete avoidance of contaminated water.

Soil-transmitted helminth infections: The human helminth parasitic worms belong to the phyla Nematode (roundworms) as well as the platyhelminthes (flatworms). These two parasitic worms are the most infectious agents affecting people in developing countries (Lustigman, 2012). These infections, which are caused by various species of parasitic worms, which include *ascariasis*, *trichuriasis*, and hookworms (*Nector americanus* and *Ancylostoma duodenale*) followed by schistosomiasis as well as lymphatic filariasis (LF). Lustigman (2012) reported that the collective burden of the common helminthiasis rivals that of high-mortality health conditions, for example HIV/AIDS or malaria. Eighty-five percent of NTD infections of the poorest 500 million people that live in SSA are due to helminth infections (Lustigman, 2012). Out of the 580 million people that live in Latin America and the Caribbean, 241 million of them are reported to live in areas where there is at least an endemicity of one of the NTDs. They are usually transmitted by eggs found in human feces, which contaminate the soil in areas of poor sanitary conditions; the eggs contaminate the soil and eventually get attached to vegetables and ingested especially when vegetables are not properly cooked, washed or peeled (WHO, 2014). The eggs of hookworms are also known to hatch in the soil, releasing larvae that can mature into a form which is capable of penetrating the skin easily. In fact, a person can become infected with hookworm by simply walking barefoot on contaminated soil (WHO, 2014). Further reports by the WHO (2014) revealed that about two billion people are infected with the disease worldwide. Soil-transmitted helminth infections happen to be among the most common NTD infections worldwide and affect the poorest and most disadvantaged communities. Babatunde, Adebayo, Ajiboye, Sunday, Ojo, and Ameen (2013, 2017) reported that STH are found in many tropical and sub-tropical areas of the world. Bethany (2006, 2018) explained how adequate moisture and warm temperature are important factors for larval development in the soil (Babatunde, 2017). Bethony (2006, 2015) also explained that a child who lives in poverty in a less developed country may possibly have his or her gastrointestinal tract parasitized by one or more of these soil-transmitted helminthes, and the result is impairment in physical, intellectual as well as cognitive development of the child (Babatunde, 2017). Alirol et al. (2010) revealed the establishment of schistosomiasis in urban areas and migration of people (infected migrants) is thought to have been the factor for this. The snail which is the intermediate host of the schistosoma spp. is known to be present in urban water bodies, and endemic foci have also been reported to occur in large cities, for example, Bamako, in Mali, Dar el Salam in Tanzania, and Kampala in Uganda.

Climate change is increasingly becoming an area of interest that experts are investigating with respect to the endemicity of soil-transmitted helminths and schistosomiasis. The impact of climate change is reported to have resulted in an estimated 150,000 deaths and 5 million disability-adjusted life years (DALYs) worldwide over the past 30 years (Gazzinelli et al. 2012). It is also anticipated that the increase in temperatures as well as greater rainfall fluctuations, will trigger alterations in both physical and biological systems, including shifts in the spatial distribution of disease vectors as well as intermediate hosts (Gazzinelli et al, 2012). The exact impacts of climate change on vector competence, how long the extrinsic duration would last, vector survival, intermediate hosts, reservoirs as well as helminth transmission cycles in general all remain elusive and poorly investigated with minimal understanding particularly for helminthiases.

Trachoma: this is an eye infection caused by a bacterium known as *Chlamydia trachomatis.* This disease is a major cause of preventable blindness in the world. Trachoma as a chronic inflammation of the conjunctiva can lead to scarring of the conjunctiva including the cornea, and this condition can eventually result in blindness (NIAID, 2007). Children under 10 years old exhibit the greatest morbidity through repeat infections. There are about 11 million cases of infection and 8 million cases of blindness reported annually worldwide. Trachoma is known to be endemic in impoverished areas of Africa, Asia and the Middle East, as well as in other areas of South America and Australia.

The Epidemiological Impact of Population Density

The world is becoming more urbanized on a daily basis, and this trend has been progressing since the industrial revolution in the 18th century (Neiderud, 2015). Based on the United Nations estimates, 3.9 billion people inhabit urban areas (Neiderud, 2015). The increase in urban populations has created major challenges for governments and health care systems to keep up to pace. This means that governments have to develop their social services including health care as these urban centers grow. The growth of new modern cities has the potential for risks and difficult challenges with respect to infectious diseases. Some of the risk factors can be poor housing facilities which can potentially lead to insect including other vectors and geohelminthiasis (Neiderud, 2015).

Unfortunately, the rapid migration of people to cities tends to create overcrowding. These eventually generate slums as well as shanty towns, and these are places that are characterized by poor housing, lack of clean fresh water and very poor sanitation facilities (Neiderud, 2015). These shortages are a threat to the inhabitants' health and also serve as a breeding ground for infectious diseases. Diarrhoeal diseases have been reported to be more wide spread in slums, and infections have been linked to slums found in Dar es Salaam, Tanzania (Neiderud, 2015). Infectious diseases spread more quickly among people who live in close proximity and overcrowded housing facilities are potentially at risk. The WHO (2019) reported that communities with inadequate shelter and overcrowding are at risk of disease transmission with epidemic potential, for example acute respiratory infections, meningitis, typhus, cholera, scabies, and many others. Furthermore, disease outbreaks are more frequent, as well as more severe in most cases when there is a high population density (WHO, 2019). In fact, public facilities, such as health care facilities do not only represent areas of high concentration of patients, but also a high concentration of germs (WHO, 2019). In the case of an emergency, the number of hospital-associated infections usually rise. NTDs thrive in impoverish environments with poor sanitation, overcrowding and lack of safe drinking water. Addressing these problems would help alleviate the disease burden of people living in these places. It is therefore, necessary to decrease overcrowding by providing more health care facilities as well as a proper organization of those sites or services (WHO, 2019). It is critical to have safe sanitation systems as the fundamentals in protecting public health. High population density areas are even more crucial for water safety and quality and proper hygiene in order to prevent disease epidemics in these environments. This should be a priority if the spread and control of infections is to be achieved by governments and health care professionals.

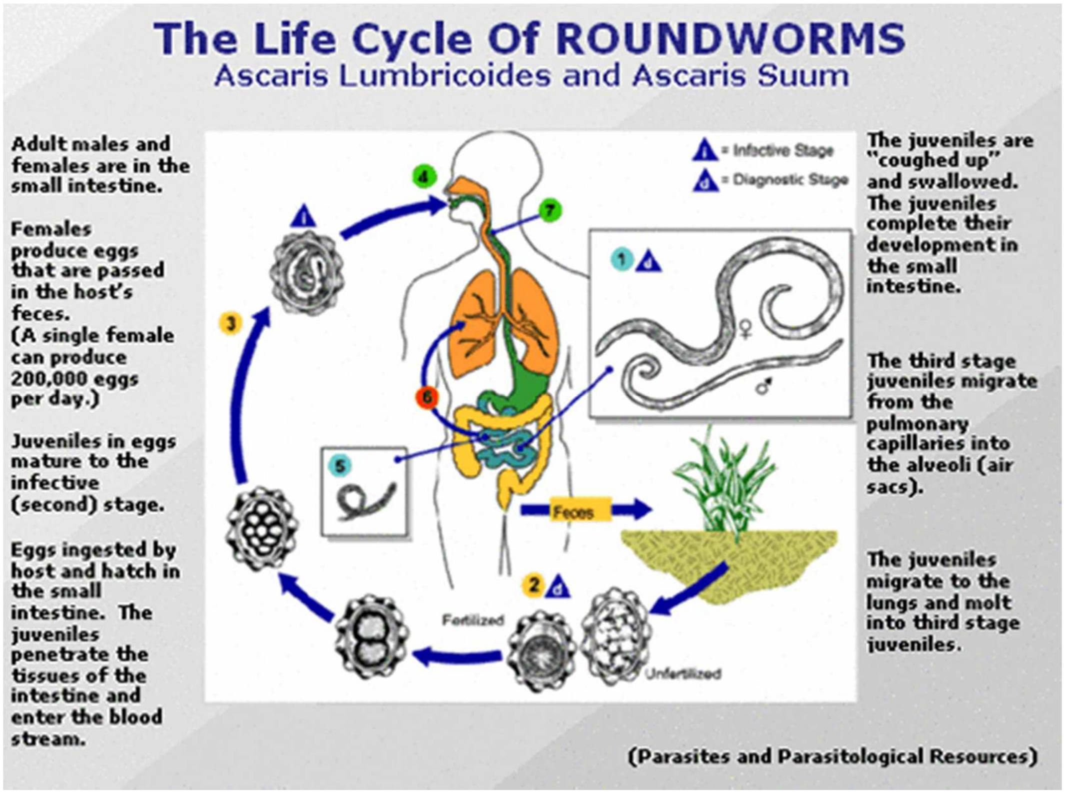

Figure 1. The life cycle of roundworms. From "Parasites," by Health News 1996-2014. (http://www.healthnews-nz.com/parasites.html

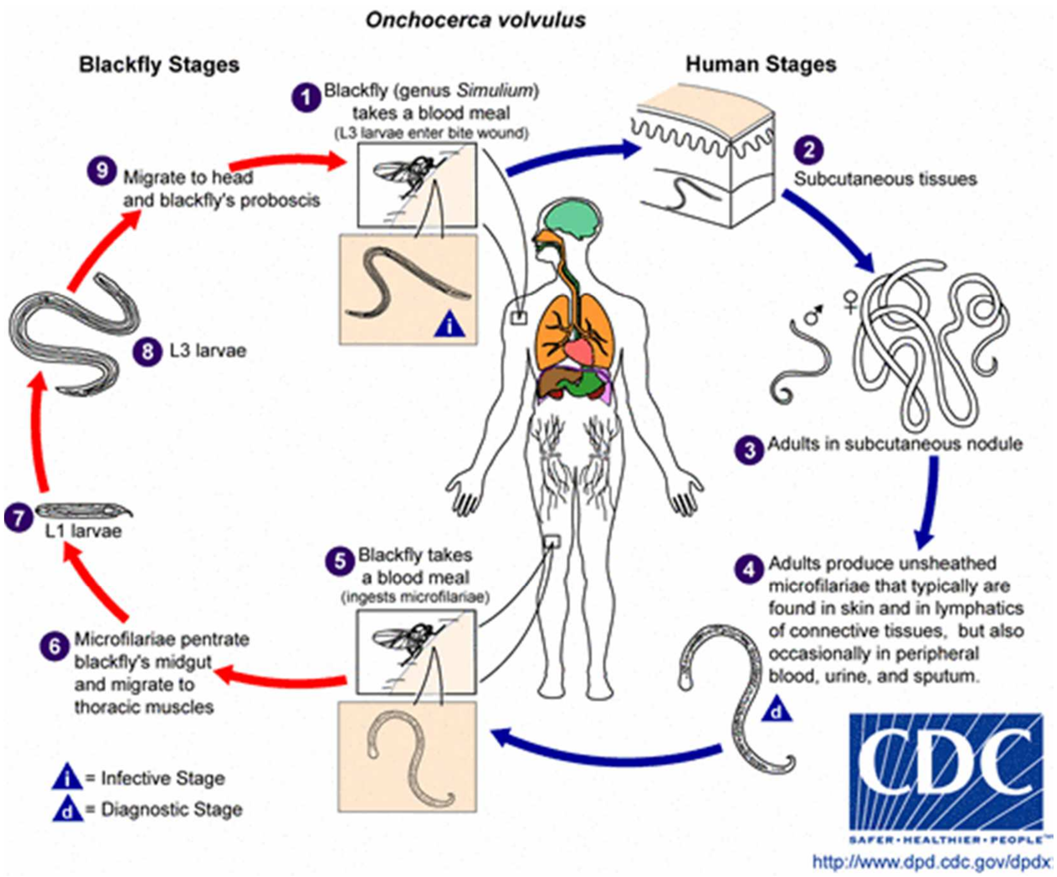

Figure 2. Life cycle of the blackfly. From "Onchocerciasis," by Centers for Disease Control and Prevention, 2014 (https://www.cdc.gov/dpdx/onchocerciasis/index.html). In the public domain.

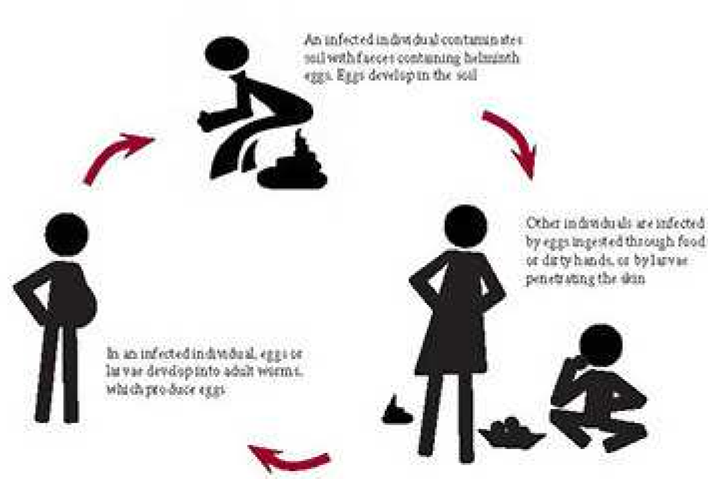

Figure 3. Infection through fecal matter. From "Intestinal Worms," by World Health Organization, 2014 (http://www.who.int/intestinal_worms/disease/en/.

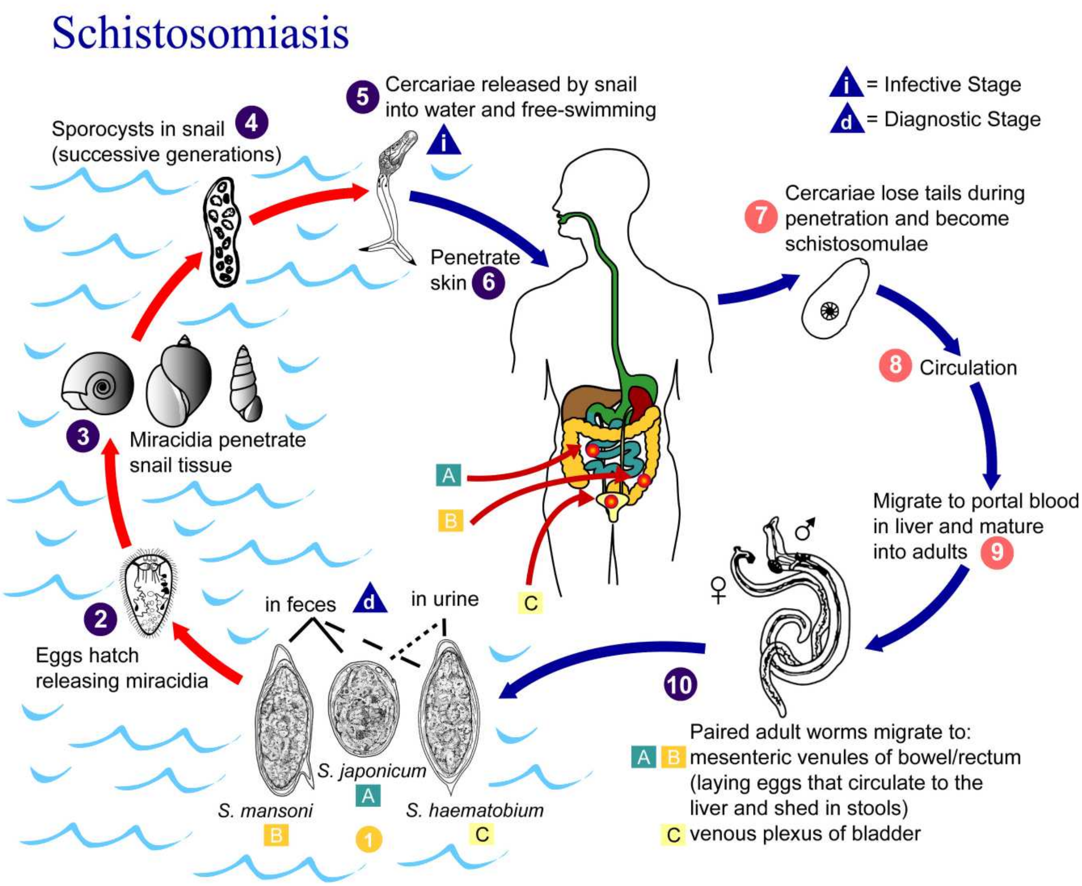

Figure 4. Life cycle of schistosomiasis. From "Parasites—Schistosomiasis," by Centers for Disease Control and Prevention, 2014 (https://www.cdc.gov/parasites/schistosomiasis /biology.html). In the public domain.

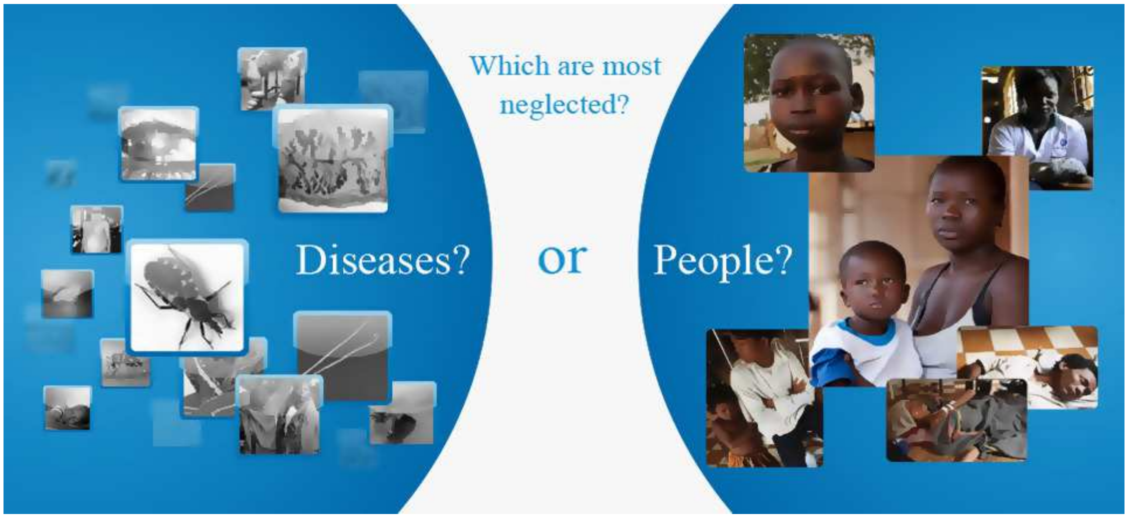

Figure 5. Diseases or people: Which are most neglected? "Global Health Progress" by Global Health Innovative Technology Fund, 2013-2017 (https://www.ghitfund.org).

Conclusion

This review discussed the literature that had been conducted on population movement and its epidemiological impact on the spread and control of NTDs in SSA. The most common of these infections include onchocerciasis, leishmaniasis, schistosomiasis, trachomiasis, lymphatic filariasis, helminthiasis, and leprosy. There were several significant gaps revealed by the review. This may have been the result of the serious neglect over the years by the various stakeholders including researchers. The neglect may have resulted from the lack of proper data collection with regards to migration patterns which can influence the spread and control of disease. The lack of interest in NTD research is a result of the fact that those infected with the disease are usually the poorest of the poor among us. Unfortunately, the pharmaceutical industry is not interested in research and development (R&D) of drugs that those infected with the disease cannot afford. The review also provided an overview of how complex migration is to the spread and control of NTDs (Aagaard-Hansen et al., 2010, 2018). Civil conflicts, natural disasters, socioeconomic factors, etc., have all contributed to the various forms of migration which in some cases are considered as forced migration. Climate change is no less of a factor with its influence on the spread of NTDs in SSA where the Sahel region continues to experience severe climatic events. In fact, temperature and precipitation constantly influence the epidemiology of NTDs in this region of Africa. For these reasons, some researchers and political entities have adopted a political/ecology approach as conceptual framework as a mechanism to analyze the refugee crisis in SSA. This study will attempt to provide the necessary information on migration patterns and their epidemiological impact on the spread and control of NTDs in SSA. Chapter three discusses the methodology, sample, instrumentation as well as the setting and analysis utilized in conducting the study.

Chapter 3: Research Methods

A fundamental objective of public health is to promote healthy communities as well as populations. This is usually achieved through prevention and control strategies designed to prohibit the spread of disease. The health of humans has become intertwined with environmental factors, and to adequately address this issue there should be some new approaches, especially when it comes to the spread and control of infectious diseases such as NTDs. The intent of this study was to determine the relationship between population density and the spatial distribution of NTDs in West Africa with a focus on Sierra Leone.

In my review of the literature, I found that several studies emphasized the need for more funding and research on the spatial distribution of NTDs in SSA. The literature indicates a need to understand the relationship between population density and its epidemiological impact on the spatial distribution of NTDs. The different forms of migration patterns and their relationships to NTD infections are also critical in the various interventions needed for the control and eradication or elimination of these infections. Furthermore, the literature indicates the different methodologies that various researchers have used in their studies.

In Chapter 3, I provide the purpose of the study, offer a description of the study design, and reiterate the research questions as well as the hypotheses. This chapter also contains a section in which I explain the variables used in this study, populations of interest, samples, and data sources. In this chapter, I emphasize techniques used to obtain data and the variables in the study.

Research Design and Rationale

This was a quantitative study, and the research design was an ecological, correlational study based on populations in the sub-Saharan African country of Sierra Leone that are affected by NTDs (i.e., ascariasis, hookworm, and schistosomiasis). Data on the spread and control of these infections were used to determine disease burden, incidence, distribution, control, and mortality in this country. Data on population density and climate change (i.e., temperature and precipitation) were used to compare the relationship between NTD infections in rural communities versus urban populations. This design was appropriate for this study because it focused on the relationships among population density, climate change, and the spread and control of NTDs in SSA. I examined the association between population distribution and the spread of disease at the rural and urban levels, which ultimately had an epidemiological and socioeconomic impact on these populations. Because individual-level data were not available for this country, an ecological study was most feasible.

There are some studies on population densities and the spread of infectious diseases, but not to the extent that one would expect. In other words, this area of research is still in its infancy. However, in this new age of globalization, there are new efforts being made on the world stage to study the spread and control of infectious diseases, especially in relation to the reemergence of some of these infections. Unfortunately, few studies have been conducted on NTD epidemiology.

Research Questions

The research questions were developed after a thorough review of the literature on population movement and its epidemiological impact on NTDs.

Research Question 1 (RQ 1): What is the relationship between climate factors, such as change in temperature and precipitation, and population density in Sierra Leone?

Research Question 2 (RQ 2): What is the relationship between population density and the prevalence of neglected tropical diseases (NTDs) in Sierra Leone?

Research Question 3 (RQ 3): What is the relationship between climate factors and the prevalence of NTDs in Sierra Leone?

Based on the above research questions, the following hypotheses were tested for the study.

Research Question 1 (RQ1): Is there a relationship between climate factors, such as change in temperature and precipitation, and population density in Sierra Leone?

Hypothesis 1_0: There is no relationship between climate factors, such as change in temperature and precipitation, and population density in Sierra Leone.

Hypothesis 1_A: There is a relationship between climate factors, such as change in temperature and precipitation, and population density in Sierra Leone.

Research Question 2 (RQ 2): Is there is a relationship between population density and the prevalence of NTDs in Sierra Leone?

Hypothesis 2_0: There is no relationship between population density and the prevalence of NTDs in Sierra Leone.

Hypothesis 2_A: There is a relationship between population density and the prevalence of NTDs in Sierra Leone.

Research Question 3 (RQ 3): What is the relationship between climate factors and prevalence of NTDs in Sierra Leone?

Hypothesis 3_0: There is no relationship between climate patterns, such as a change in temperature and precipitation, and prevalence of NTDs in Sierra Leone.

Hypothesis3_A: There is a relationship between climate patterns, such as a change in temperature and precipitation, and prevalence of NTDs in Sierra Leone.

Study Variables

The following variables were used in Research Question 1: temperature and precipitation as independent or predictor variables, and population density as the dependent variable. Climate change is known to affect weather patterns, and as a result, it affects temperatures, precipitation, and atmospheric changes. IRIN News (2012) reported that Mark Booth, deputy director of the Wolfson Research Institute for Health and wellbeing, indicated that "there is a great deal of uncertainty" concerning the impact of climate change on NTDs. In other words, experts are still not sure about the effect of climate change on disease transmission rates.

When it comes to climate change, opinions are divided. However, many researchers are quite concerned about changes in rainfall patterns, which may result in a loss of "endemic stability" for those diseases that are transmitted by mosquitoes, ticks, as well as other disease hosts (IRIN News, 2012). This may result in an environment that is favorable for disease transmission. IRIN News (2012) indicated that rising average annual temperatures are already blamed for an increase in numbers of malarial mosquitoes at higher altitudes in countries such as Tanzania and Kenya. Similar cases have also been reported in the highlands of Madagascar, Rwanda, and Ethiopia. Although malaria is not considered an NTD, experts fear similar patterns of disease expansion for other tropical infections transmitted by mosquitoes and other flies. Temperature and rainfall, including runoff, have the potential to affect the growth and spread of microbial infections (IRIN News, 2012). According to IRIN News (2012), climate change that is a result of humans releasing greenhouse gases into the atmosphere is considered a wide-ranging effect in relatively short form; however, other human factors are expected to contribute greatly to the spread of NTDs as well. Ahmad, Getso, Ahmad, and Abdullahi (2014) indicated that climatic factors variation effects in vector-borne-disease transmission include the following: (a) survival and reproduction rate of vector, (b) time of year and level of vector activity with respect to the biting rate, and (c) rate of development and reproduction of the pathogen within the vector. Studies indicate that vectors, pathogens, and hosts each survive and reproduce within certain optimal climate conditions. Hence, changes in these conditions have the potential to modify greatly the properties of infection transmission (Ahmad et al., 2014). According to Ahmad et al. the most important climatic variables for vector-borne diseases are temperature and precipitation; however, sea level elevation, wind, as well as daylight duration may contribute to this trend as well.

In research question 2, population density is the independent variable, and the spread of NTDs is the dependent variable. Hodges et al. (2011) indicated that prevalence of *S. mansoni* was definitely associated with population density, while hookworm prevalence had a negative association with population density.

Population Sample

The current population of Sierra Leone is 7,805,670 people, of which 3,184,256 (48.9%) are male and 3,330,498 (51%) are female (Countrymeters, 2015). In Sierra Leone, population density was 89.0 people per square mile as of December 2015. According to the UN Statistics Division, population density refers to the number of people who are permanently settled in a country or an area divided by the total area of the country (Countrymeters, 2015). The total area is usually the sum of the land and water areas within existing international boundaries and coastlines of a country. The UN Statistics Division estimated the total area of Sierra Leone at 71,740 km^2 (as cited in Countrymeters, 2015).

This study used archival data obtained from Sierra Leone. The population sample was based on some districts, chiefdoms, and towns in various areas of Sierra Leone. Data obtained from these areas indicated the geographical distribution of ascariasis, hookworm, and schistosomiasis and population density.

History and Demographics

Sierra Leone is a small country that is about half the size of Illinois in the United States. It is located on the Atlantic Ocean in West Africa. It is bordered by Guinea on the north and east, while Liberia borders it on the south. Sierra Leone has mangrove swamps in its coastal region with wooded hills. The interior of the country is made up of plateau with a mountainous eastern region.

Sierra Leone was first occupied by the Bulom people, who were followed by the Mende and Temne peoples as early as the 15th century (Sandbox Networks, 2017). The Fulani arrived there afterward. The Portuguese were the first Europeans to explore this country dating back to 1462, when Pedro da Centra, who sailed down the coast of West Africa, first came up with the name *Sierra Lyoa*, which means “the Lion Mountains.” Later, in the 16th century, English sailors called it *Sierra Leoa*, and in the 17th century, the name evolved to *Sierra Leone*, which was officially adopted by the British in 1787 (Visit Sierra Leone, 2015). During the same period, British philanthropists founded what was referred to as the “Province of Freedom,” which later became known as Freetown. This was a British crown colony and served as the principal base for the suppression of the slave trade (Visit Sierra Leone, 2015). The actual name for Freetown before the arrival of the Europeans was *Romarong*, which means “the place of the wailers,” a name that referred to the constant weeping and screaming of victims of storms and cross-current disasters at the mouth of the Sierra Leone River (Visit Sierra Leone, 2015).

Sierra Leone has 16 ethnic groups, with the Mendes being the largest of these, followed by the Temnes. The Mendes are found in the Southern and Eastern Provinces, and the Temnes are in the Northern Province. Several ethnic groups are also found in the Northern Province, including the Limba, which is the third largest group, followed by the Kono in the Eastern Province. Additional ethnic groups in the Northern Province include the Koranko, Yalunka, Loko, Soso, Madingo, and Fula. On the coast, north, and south are the Bullom and Sherbro, followed by smaller groups of Krim, Vai, and Gola, with the Kissi found further inland in the Eastern Province (Visit Sierra Leone, 2015). In the western area, including Freetown, the capital city, is quite a mixed population; however, this is the home of freed slaves known as the Krio.

Through the efforts of men such as William Wilberforce, Thomas Clarkson, and Granville Sharpe, Lord Mansfield formed an administration that became instrumental in the abolition of the Trans-Atlantic slave trade in 1807 by the British Empire. The British established a naval base in Freetown in an effort to stop illegal slave ships with fines amounting to $100 for every slave found on board a British ship (Visit Sierra Leone, 2015).

Figure 6. Map of Sierra Leone showing the districts. Google.com/search?q=map+of+sierra+leone+showing+the+districts

Sierra Leone officially became a crown colony in 1808, with the land possessions of Sierra Leone (formerly called *St. George's Bay Company*) made available to the crown. The dedication of the colony was a way to demonstrate the core principles of Christianity, "civilization," and commerce. The British Parliament passed the Emancipation Act in 1833 with the final abolition of slavery; in contrast, the United States only passed the 13th Amendment in 1865 to abolish slavery (Visit Sierra Leone, 2015). Over 50,000 freed slaves were settled in Freetown by 1855. These were known as the *Krios*. These repatriated settlers now live in a multiethnic nation. The Krio language is widely spoken in Sierra Leone, but the official language remains English. Muslim traders brought Islam to Sierra Leone. The Rokel estuary served as a source of fresh water for sea traders and explorers.

Sierra Leone became an independent nation on April 27, 1961, and by April 19, 1971, the country attained republic status. Many changes have taken place in the country since independence, both politically and economically. Successive civil disturbances were experienced in the 1990s, which culminated in a ghastly Revolutionary United Front (RUF) rebel war that caused the international community to intervene, led by the United Nations Mission in Sierra Leone (UNAMSIL, 2017). In 2002, various international organizations helped by providing an environment for fair and free elections for both president and parliament. The war officially ended in 2002, and the country has been in the process of rebuilding and re-establishing the nation's failed institutions since that time. Sierra Leone has been ruled by nine heads of state.

Figure 7. Physical map of Sierra Leone. From "Sierra Leone Map," by Ezilon.com, 2015 (https://www.ezilon.com/maps/africa/sierra-leone-physical-maps.html

Figure 8. Map of Sierra Leone showing districts and chiefdoms. Retrieved from google.com/search? q=maps+of+sierra+leone&sxsrf

The current population of Sierra Leone is 7,805, 670 according to Worldometers (2019). Previous census indicated population growth rate in Sierra Leone was 1.8% during 1984 to 2004 period which is a decline from 2.3% annual rate that was reported for 1974-1985 period (Ministry of Health and Sanitation, 2014). Sierra Leone is a country that is characterized by younger men and women, about 42% of the population are under 15 years old. Sierra Leone had a Demographic and Health Survey in 2013 (SLDHS) which was designed to provide data to monitor the population and health situation of the country. In fact, this was the second of such surveys after the 2008 SLDHS survey. The survey instruments for the 2013 SLDHS used three questionnaires for data collection: (a) Household Questionnaire, (b) a Woman's Questionnaire, and (c) a Man's Questionnaire. These questionnaires which are based on the models developed by the MEASURE DHS program, are modified to adapt them to the Sierra Leone's specific situations as well as the lexicon of the country. The objective of these surveys is to obtain up-to-date information on fundamental variables such as fertility levels, marriage, fertility preferences, knowledge of family planning and methods, child feeding practices, nutritional status of women and children, childhood mortality, awareness and attitudes with regards to HIV/AIDS, domestic violence, as well as the prevalence of HIV, malaria, and anemia (Ministry of Health and Sanitation, 2014). Policy makers and program managers can utilize this information to evaluate and design programs to improve health including family planning services in the country. The SLDHS results of 2013 indicate that 46% of the population is under 15 years old and approximately 90% of households in urban areas can access improved source of water, while only 10% of households have an improved, not shared sanitation facility (Ministry of Health and Sanitation, 2014).

The survey also indicates that 20% of urban households have access to improved sanitation facilities, unlike rural areas which are only 5% of improved sanitation facilities. Education is low among women and two in five men age 15-49 have no education, while 30% of women and 47% of men have some level of secondary school or higher levels of education (Ministry of Health and Sanitation, 2014). More than one-third (36%) of women and 54% of men are literate. Sierra Leone has a relatively low fertility rate compared to its neighbors. Fertility varies by residence and district, while women in urban areas have the lowest fertility rates, it is highest in rural communities. Fertility is also highest among women with less or no education in rural areas while it is lowest among educated women. Fertility also varies based on economic status. In other words, it increases as the wealth of the household decreases, and vice versa. The five-year period before the 2013 survey, infant and under-five mortality rates are 92 and 156 deaths per 1,000 live births, indicating that at these levels of mortality, 1 in every 11 children born in Sierra Leone would die before age 1. One in every 7 children would not make it to their fifth birthday. The government of Sierra Leone works in concert with various stakeholders in making efforts into implementing high-impact interventions. Both the African Health Observatory and the World Health Organization (2010) reported that various policies and reforms, such as the "Free Health Care Initiative" and the "Basic Package of Essential Health Services" have been created to improve the health status of both women and children (2010). Reviewing the progress of the Millennium Development Goals indicates that the health-related Millennium Development Goals 4 and 5 are possible to attain by 2015, with the sustained efforts. The introduction of the Free Health care initiative increased the health service coverage in 2010 with an increase in the number of children going to a health facility (WHO, 2010). However, the health system still has major challenges, such as the inadequate human resources, and the lack of adequate equipment and infrastructure. There is also progress in health care financing, as well as health management information system.

Data Sources

Secondary data obtained from the Ministry of Health in Sierra Leone. Data obtained from Sierra Leone were queried, and converted to comma-separated values and imported into Microsoft Excel. The following measures were obtained for the neglected tropical diseases distribution rates, and control measures. Data for ascariasis, hookworm, and schistosomiasis were obtained from Sierra Leone. The country's data queries are from 2002 to 2012.

Data Management

Data obtained from these sources were posted in Microsoft Excel in the form of a worksheet. This worksheet consists of data for DALY and disease mortality for ascariasis, hookworm and schistosomiasis. Data on prevalence of ascariasis, hookworm and schistosomiasis including new cases of these infections, household screening activities, and drugs used for the control of the infections are gathered from Sierra Leone statistics and Epidemiological Reports. Only the most robust data sets from 2002 to 2012 were used due to some inconsistencies with regards to data availability for some of the variables.

Data Analysis

This was a correlational study and nonparametric analysis was used to determine the relationships between the prevalence of NTDs and population density. Also, the study investigates the relationship between precipitation and temperature change. Nonparametric analysis is a more appropriate methodology for this study since this type of analysis does not require fitting a normal distribution. Data was entered into a database, such as Microsoft Excel 2003-2010, and eventually transferred into a statistical package for analysis (SPSS for Windows version 23.0). The use of this software enabled me to perform certain statistical tasks in SPSS producing graphs and results that can be interpreted based on the output of each question answered. This procedure was limited to a single criterion variable per analysis; hence regression analyses was performed based on the dependent variables in the categories of disease burden, mortality, prevention and control, and incidence. This process made it plausible to observe the potential influence of the predictors (temperature and precipitation changes, population density, and disease distribution) in each step of the way. Results obtained were utilized for the overall multiple correlation with the dependent variable when all independent variables are included in the regression model. Data were screened for potential outliers and missing data including any discrepancies to be accounted for prior to conducting analyses. The data was also examined regarding the assumptions underlying regression. Any observed violations were rectified and/or taken into account in the interpretation of the results.

Protection of Participants' Rights

This analysis used archival NTD data on Sierra Leone obtained from Department of Health and NTD Programs implemented in the country. This study did not use human participants. The NTD infection rates and incidence data from Sierra Leone have no identifiers and did not pose any risks to individuals. Walden University Institutional Review Board approval was obtained prior to conducting this study.

Summary

In Chapter 3, I described a quantitative ecological, correlational study as the research design. I also reiterated the study's purpose, research questions, including hypotheses. Secondary data was extracted for the sample from Sierra Leone in West Africa. The independent or predictor variables, climate change and the dependent variable population density together with the data sources were described and linked to the research questions. The final section of the chapter concludes with how the data was analyzed using multiple regression analysis.

Chapter 4: Findings

This study was originally focused on population movement and the spatial distribution of NTDs in SSA. However, it turned out that data on population movements in this part of the world were almost nonexistent, or were very scanty and not sufficient for the purpose of this study. As a result, population density was substituted for population movement, and its effect on the spatial distribution of NTDs such as ascaris, hookworm, and schistosoma in the sub-Saharan African country of Sierra Leone was investigated. The purpose of this correlational study was to investigate the interrelationships among population density, the spread and control of NTDs (e.g., ascaris, hookworm, and schistosoma), and climate factors (change in precipitation and temperature). A review of literature indicated the need for more research on the relationship between population density and the spread and control of NTDs in SSA.

I begin Chapter 4 with an introduction to the geography of Sierra Leone, and I address demographic aspects of the population such as age and sex. The justification for including this information here is that it is necessary for an understanding of the impact on the population concerning the spatial distribution and control of NTDs so that the right policies can be developed to address health conditions. The chapter continues with analysis and presentation of the data. Included in the chapter are descriptive statistics of samples. The final part of the chapter contains a summary of the results.

A report of the statistical analysis findings for the three research questions and hypotheses are included in Chapter 4. This includes statements and values as well as maps and tables to illustrate the results.

Issues and Difficulties in Data Agreement

In chapter 3, I described the study variables, as well as how they were obtained. Much effort was made to obtain data on population movements and the spatial distribution of NTDs in SSA. All attempts turned out to be futile, in spite of the fact that I was very explicit with my requests to several organizations, including the WHO, United Nations, Helen Keller International, Nigerian government, and Ghanaian government, all of which were unable to help. I wrote letters of request, sent emails, and made phone calls, but I could not obtain data on population movements and the spread of NTDs in SSA countries for my dissertation.

I was able to obtain data on population density, the prevalence of NTDs in the sub-Saharan country of Sierra Leone, and temperature and precipitation. The Sierra Leone Ministry of Health and Sanitation conducted several studies on NTDs in all of the districts in the country between 2008 and 2012. Considering the variables in the study as well as the social outcomes to be achieved, I conducted the research as a quantitative study, ensuring that the variables were clearly identified in an effort to find a correlation.

Results

A total of 1,537 students ages 8 to 16 years were examined for infections with soil-transmitted helminthes (STH). The data were organized in separate Microsoft Excel files. A total of 247 cases (*n* = 247, 35%) were examined in the Bo (Central) District, and six cases (*n* = 6, 2%) of *S. mansoni* (*S.M.*) were found, 22 cases (n=22, 9%) of *S. haematobium* (*S.H.*) were found, 55 cases of ascaris (ASC) n=0.0 were found, and 55 cases (n=55, 22%) of hookworm (HW) were found (see Table 1). In Bombali District (Northwest), 239 (n=239, 20%) children were examined. Among this group, there were

20 cases (n=20, 8%) of *S.M.*, 3 cases (n=3, 1%) of *S.H.*, 10 cases (n=10, 4%) of ASC, and 8 cases (n=8, 3%) of HW.

To examine the associations between climate factors and NTDs, Statistical Package for Social Sciences (SPSS) 23 was used. Regression analysis, analysis of variance (ANOVA), correlation, nonparametric tests, Friedman test, and chi-square were applied. A bivariate correlation was applied to examine zero-order correlation of each NTD with temperature and precipitation. The ordinal logic-based models were selected. The null and alternative hypotheses based on research questions were as follows:

H_0: There is no relationship between climate patterns, such as a change in temperature and precipitation, and population density in Sierra Leone.

H_1: There is a relationship between climate patterns, such as a change in temperature and precipitation, and population density in Sierra Leone.

RQ 1: What is the relationship between climate factors, such as change in temperature and precipitation, and population density in Sierra Leone?

RQ 2: What is the relationship between population density and the prevalence of neglected tropical diseases (NTDs) in Sierra Leone?

RQ 3: What is the relationship between climate factors and the distribution of NTDs in Sierra Leone?

Schistosomiasis in urinary and intestinal forms was reported to be prevalent in Sierra Leone (White, 1998), as were STHs (Gbakima & Sahr, 1995). The prevalence of NTDs was not a result of climatic factors such as temperature and precipitation, which are summarized in Tables 6 and 7, respectively. The data in the tables reveal that these NTDs, which included ascariasis, hookworm, and schistosomiasis, were spread as a result of an impoverished environment that lacked proper toilet facilities, clean drinking water, and other sanitary conditions. Hence, there was no effect of climate factors on the prevalence of NTDs. The NTDs were negatively associated with population density and climate factors such as temperature and precipitation.

A multiple regression analysis was conducted to test the hypothesis. The population density was taken as the dependent variable; temperature and precipitation were taken as independent variables. Table 2 provides r and r^2 values. Simple correlation is represented by r, which indicates positive correlation. The r^2 depicts the extent of variation in the dependent variable population density due to the independent variables precipitation and temperature, which was 10.6% or approximately 11%.

Table 2

Correlation Analysis

Model summary Model	*R*	*R* square	Adjusted *R* square	Std. error of the estimate
1	.32[a]	.10	.03	1.28

a. Predictors: (Constant), Precipitation, Temperature

There is an estimate for three parameters: intercept, temperature, and precipitation. Because *p* values are greater than 0.05, climate patterns, such as a change in temperature and precipitation, do not have a significant influence on human population density. There is no relationship between climate patterns, such as a change in temperature and precipitation, and population density in Sierra Leone.

Table 3

Regression Analysis

Model	Unstandardized coefficients *B*	Std. error	Standardized coefficients Beta	*T*	Sig.
(Constant)	1.368	.539		2.537	.017
Precipitation	.000	.001	.192	.278	.783
Temp	-.004	.087	-.029	-.042	.967

Note. Dependent variable: population density.

The null and alternative hypotheses based on second research question were as follows:

H_0: There is no relationship between population density and the prevalence of NTDs in Sierra Leone.

H_A: There is a relationship between population density and the prevalence of NTDs in Sierra Leone.

Table 4 provides *r* and r^2 values. Simple correlation is represented by *r*, which indicates positive correlation; r^2 depicts the extent of variation in the dependent variable population density due to the independent variables precipitation and temperature, which was approximately 1.3%.

Table 4

Model Summary

Model	*R*	*R* square	Adjusted *R* square	Std. error of the estimate
1	.114[a]	.013	-.019	4.4330

Estimate: Two parameters, intercept and population density, p values larger than 0.05. No significant impact on NTDs by population density.

There is an estimate for two parameters, intercept and population density. Because *p* values are larger than 0.05, population density does not have a significant impact on the prevalence of NTDs. There is no relationship between population density and the prevalence of NTDs in Sierra Leone.

Table 5

Regression Analysis

Model	Unstandardized coefficients		Standardized coefficients		
	B	Std. error	Beta	*t*	sig.
(Constant)	3.726	1.327		2.807	.009
Population density	-.387	.603	-.114	-.641	.526

RQ 3: What is the relationship between climate factors and the distribution of NTDs in Sierra Leone?

Hypothesis 3_0: There is no relationship between climate factors, such as a change in temperature and/or precipitation, and the distribution of NTDs in Sierra Leone.

Hypothesis3_A: There is a relationship between climate patterns, such as a change in temperature and/or precipitation, and the distribution of NTDs in Sierra Leone.

Focusing attention on the significance of controlling NTDs as a commitment to alleviate destitution in order to accomplish necessary improvement objectives, it is important to have scale-up projects to accomplish more extensive general healthcare utilization.

Poverty is a significant contributing factor with regard to the prevalence of NTDs in many subtropical and tropical regions.

Contaminated water plays a significant role in the transmission of NTDs (Ahorlu, Koka, Yeboah-Manu, Lamptey, & Ampadu, 2013). It has been determined that adult mosquitoes, biting arthropods, and aquatic insects are possible reservoir species that spread diseases.

This present research showed the result that there was no relationship between climate factors (i.e., temperature, precipitation) and the prevalence of NTDs. Table 6 addressed the hypothesis that there was no relationship between climate factors such as temperature and precipitation and the prevalence of NTDs. The results concerning temperature and the distribution of NTDs indicated that *Schistosoma mansoni* (temperature =.627, N=33, sig. [2-tailed] = .482), schistosoma (temperature = .756, N=33, Sig. [2-tailed] = .387), ascaris (temperature = .852, N=33, Sig. [2-tailed] = .157), hookworm (temperature = .717, N=33, Sig. [2-tailed] = .925), and trichuris (temperature = .622, N=33, sig. [2-tailed] = .904) showed insignificant determinant of temperature relationship with NTD distribution. In other words, temperature had no relationship with the distribution of NTDs. According to the research data, ascaris disease had a higher temperature (.825) compared to other diseases. A lower temperature was noted for trichuris disease (.622) relative to other diseases. Hookworm showed higher nonsignificant response, which was (.925) against the temperature compared to other NTDs. The nonsignificant response against the temperature by these NTDs increased in the following order: hookworm > trichuris > *Schistosoma mansoni* >schistosoma > ascaris. It was clear that the prevalence of NTDs in Sierra Leone was not affected by temperature.

The results in Table 7 showed that precipitation also had greater value of *p* than 0.05, which indicated that there was no significant relationship between precipitation and prevalence of NTDs. The climate factor, which included precipitation, showed these results: *Schistosoma mansoni* (precipitation = .530, N=33, sig. [2-tailed] = .462), schistosoma (precipitation = .614, N=33, sig. [2-tailed] = .160), ascaris (precipitation = .810, N=33, sig. [2-tailed] = .317), hookworm (precipitation = .710, N=33, sig. [2-tailed] = .262), trichuris (precipitation = .713, N=33, sig. [2-tailed] = .531). The results indicated a nonsignificant relationship of precipitation with NTD prevalence in Sierra Leone. The maximum value of nonsignificant effect was observed for trichuris (.531) relative to other NTDs. The nonsignificant response against precipitation by these NTDs increased in the following order: trichuris > *Schistosoma mansoni* > ascaris > hookworm > schistosoma. This means that precipitation, which was the climate factor, had no effect on the prevalence of NTDs in Sierra Leone.

As the data for NTDs were not normally distributed, nonparametric tests were applied to measure the differences among all NTDs as the dependent variable. Population density was in ordinal scale, and the nonparametric Friedman test was applied. Table 5 shows the mean ranks for each NTD. The table indicates that occurrence of each disease is different depending on the type of disease and area of data collection. Table 5 presents the actual result of the Friedman test. To test the hypothesis by determining whether the mean ranks of all five diseases are significantly different or not, the Friedman test was applied. The asymptotic significance was 9.58×10^{-13} and was less than 0.05, as shown in Table 5. Thus, the mean ranks of all NTDs were statistically significant.

Table 6

Ranks

NTD	Mean rank	*p*
Schistosoma mansoni	4.97	9.58×10^{-13}
Schistosoma haematobium	2.71	
Ascaris	2.97	
Hookworm	4.38	
Trichuris	2.00	

Correlation of each NTD with temperature was calculated. The results are displayed in Table 7. Because *p* values were larger than 0.05, all NTDs were not correlated with temperature.

Table 7

Correlations

	Schistosoma mansoni	*Schistosoma haematobium*	Ascaris	Hookworm	Trichuris
Temperature	.627	.756	.852	.717	.622
Sig. (2-tailed)	.482	.387	.157	.925	.904
N	33	33	33	33	33

Correlation of each NTD with precipitation was also calculated. The results are tabulated in Table 8. Because *p* values were larger than 0.05, all NTDs were not correlated with precipitation.

Table 8

Correlations

	Schistosoma mansoni	*Schistosoma haematobium*	Ascaris	Hookworm	Trichuris
Precipitation	.530	.614	.810	.710	.713
Sig. (2-tailed)	.462	.160	.317	.262	.531
N	33	33	33	33	33

Summary

Based on the available data, climate patterns as measured by temperature and precipitation changes were not correlated with human population density. Population density was not correlated with the distribution of NTDs in Sierra Leone. All NTDs were not correlated with precipitation and temperature. Nonparametric Friedman test depicted the significant difference in mean ranks of all five neglected tropical diseases, namely *Schistosoma mansoni*, schistosoma, ascaris, hookworm, and trichuris, in Sierra Leone. In Chapter 5, the findings are interpreted.

Chapter 5: Interpretation and Conclusions

Introduction

My original intention in this study was to examine population movement, climate patterns, and the spread of NTDs in SSA, specifically Ghana, Nigeria, and Sierra Leone. Unfortunately, data were not available to conduct the study as planned. As a result, the focus of the study was switched to the association between population density, temperature, and precipitation and the spatial distribution of NTDs.

The purpose of this quantitative correlational study was to determine the relationship between population density, temperature, and precipitation and the spatial distribution of neglected tropical diseases in the sub-Saharan African country of Sierra Leone. Data were analyzed using correlation and regression analyses. I conducted the study because I sought to examine the interrelationships among population density, climate factors (temperature and precipitation), and distribution of NTDs.

Climate patterns, as measured by temperature and precipitation changes, were not correlated with population density in Sierra Leone. There was no relationship between population density and the distribution of NTDs in Sierra Leone. Precipitation and temperature were not correlated with all NTDs. There were significant differences in mean ranks of all five neglected tropical diseases (i.e., *Schistosoma mansoni*, *Schistosoma haematobium*, ascaris, hookworm, and trichuris) in Sierra Leone. The mean ranks show the relationship between the values that were replaced by rank when the data were sorted. The use of these nonparametric statistics was necessary because the normality assumption was not met, and the scale of measurement in this case was ordinal.

Second, the sample size was small; therefore, using nonparametric statistics and ranking the data was ideal in this situation.

Interpretation of the Findings

The results of this study show that there was no relationship between climate patterns, as measured by temperature and precipitation changes, and population density in Sierra Leone. These findings were not in agreement with other similar studies.

In their study, Siraj et al. (2015) explained that in order to better understand the persistence of malaria in very high seasonal environments, such as highlands and desert outskirts, it is necessary to identify the essential factors that support the spatial reservoir of the pathogen during the low season. In such “unstable” malaria regions, the reservoirs play a crucial role by allowing persistence during the low transmission season and therefore between seasonal outbreaks as well (Siraj, 2015). Using a Bayesian approach to estimate parameters as well as a generalized linear mixed model that also included a spatially structured random effect, Siraj et al. were able to demonstrate that population density is vital to disease persistence during the low transmission season. Furthermore, Siraj et al. explained that while climate factors play quite an important role, it is a combination of their effect with population density that maintains a reservoir of disease transmission, which explains the spatial heterogeneity of persistence in the trough period between transmission seasons. Siraj et al. noted that it was population density that helped to define explicitly the spatial effects that were identified in the statistical models. There was a clear correlation between temperature and population density in this study.

Lord, Hargrove, Torr, and Vale (2018) quantified the effects of climate change on the entomological and epidemiological components of vector-borne diseases as an essential part of climate change study. However, evidence of these effects remained scanty, and predictions relied mainly on extrapolation of statistical correlations, according to Lord et al. The model that they developed incorporated the effects of temperature on mortality, larviposition, and emergence rates and was fitted to a 27-year time series of tsetse caught from cattle (Lord et al., 2018). Based on this model, it was suggested that an increase in temperature may explain the observed collapse in tsetse abundance; this finding provided a first step in linking temperature to trypanosomiasis risk. Furthermore, if the effect at Mana pools had extended across the entire Zambezi Valley, transmission of trypanosomes would have been reduced in this warm low-lying region. On the other hand, rising temperatures may have made some higher, cooler areas of Zimbabwe more ideal for tsetse and led to the emergence of new disease foci (Lord et al., 2018).

Data for these studies were properly collected and secured by the researchers, unlike the data from Sierra Leone, which were collected in a completely different situation. Lack of proper coordination of the treatments to prevent duplication and improve coverage by the various organizations contributed to the poor quality of that data that I obtained. As a result, my study did not find a significant correlation between temperature and population density.

Sirisena et al. (2017) examined the effects of climatic factors and population density on the distribution of dengue in Sri Lanka. Dengue is a major health problem that is responsible for high morbidity and mortality rates in Sri Lanka, which is an island nation. Sirisena et al. collected epidemiological, population, and meteorological data from an epidemiology unit, including data from the Department of Census and Statistics and the Department of Meteorology of Sri Lanka. Data analysis indicated that there was no positive correlation between dengue incidence and temperature. On the other hand, dengue incidence showed a significant positive correlation with rainfall (Sirisena et al., 2017). Furthermore, it was reported that there was a direct and indirect influence of climate on disease transmission, distribution, vector breeding, and establishment, according to Sirisena et al. Overall, the correlation between dengue incidence and climatic factors including temperature, rainfall, as well as humidity was determined using Spearman's correlation, which was considered significant at a level of 0.01. It was reported that an increase in the average rainfall had a positive correlation with dengue incidence, while on the contrary, there was no positive correlation indicated between dengue incidence and temperature as well as dengue incidence and humidity (Sirisena, 2017).

In an effort to identify serial correlations and trends in the data over time, as well as seasonal variations in the data over time, including the feasibility of forecasting future dengue outbreaks, a time series analysis was performed by Sirisena et al. (2017). This study by Sirisena et al. was designed to identify the risks of dengue associated with population density, land pattern, as well as climatic factors. The findings indicated that increased population density contributes to an increase in dengue incidence, as shown in several highly populated districts of Sri Lanka, such as Colombo, Kandy, Jaffina, and Batticaloa. However, dengue incidence was quite low in the Nuwara Eliya District, in spite of the fact that it was one of the highly populated districts in the wet zone, according to Sirisena et al. In other words, high altitude seemed to play an important role in limiting the spread of *A. aegypti* in the Nuwara Eliya District, which is located at 1880 meters above sea level (Sirisena et al., 2017).

In my study, population density was not correlated with the distribution of NTDs in Sierra Leone. These findings did not support the findings of the earlier studies that population density was correlated with the distribution of NTDs. Schimidt et al. (2018) measured the impact of population density on the distribution of NTDs. During the study, two distinct dengue fever epidemics occurred between January 2005 and June 2008. Dengue cases involving individuals of all ages were included in the study. Patients were admitted to the only two hospitals that government regulations specified. Patient data were entered into a database, and this was linked between individual patients and census data (Schimidt et al., 2018). In this study, all of the households were geo-referenced using GPS receivers. The researchers randomly selected 75,000 households in Vietnam and found that population density was correlated with the distribution of NTDs. They had access to sufficient and quality data that were collected and secured properly, which was significant for their analysis.

Caminade et al. (2013, 2017) measured the impact of population density on the distribution of NTDs and tested five global climate models. They found that population density was correlated with the distribution of NTDs.

Sirisena et al. (2017) examined the effect of climatic factors and population density on the distribution of dengue in Sri Lanka. This was a secondary study, and data were obtained from the Epidemiology Unit of the Ministry of Healthcare and Nutrition in Sri Lanka. The Sri Lanka government collects data that are secured in the Epidemiology Unit, and these epidemiological data are released periodically (Sirisena et al., 2017).

These epidemiological data are useful for the evaluation of dengue both chronologically and geographically. Sirisena et al. obtained population data from the Census and Statistic Report of the Department of Statistics in Sri Lanka (2012), which was the most recent report at the time of data collection (2017). Further, they collected data for annual rainfall, temperature, and humidity from the Meteorology Department, including GPS data from meteorological stations. The data used in the studies mentioned above were obtained from significant data sources unlike mine.

Lowe, Chirombo, and Tompkins (2013) sought to determine whether population density affected the distribution of NTDs using a statistical mixed model framework. They collected data in Malawi and found that population density affected the distribution of NTDs.

Rahman (2016) sought to determine whether climate change such as temperature and precipitation affected population density and the distribution of NTDs. He used secondary data and found that population density affected the distribution of NTDs. Rahman obtained secondary data from a systematic review of journals, theses, and books on climate change and dengue diseases and performed a meta-analysis for the results.

Lugo (2015) examined if climate variables such as, temperature and precipitation affected the distribution of dengue fever, a neglected tropical disease. She used archival data and found that climate variables such as, temperature and precipitation affected the distribution of this disease. Lugo's data for cases of imported dengue diseases were obtained from the Florida.

Florida Department of Health (FDH) as well as the Centers for Disease Control and Prevention (CDC). According to Lugo (2015) some of the data came from the

Florida Morbidity Statistics Report from the FDH. The FDH was the official record to obtain data on incidence and prevalence of reportable diseases in Florida. Generally, the county and health department collect morbidity report data from various public health places and individuals such as, medical staff, hospitals, and laboratories and other public health facilities that provide services in the entire state of Florida (Lugo, 2015). All suspicious and notifiable diseases are reported to FDH which is a requirement in Florida, based on a Statute under section 381.0031 (Lugo, 2015). This is significant because the data collected provide the information on reportable diseases as well as suspicious conditions that various public health sectors such as health care workers, policymakers and researchers could find quite useful. The quality and quantity of data obtained for Lugo's study was the ideal data that would have made a difference for my study. Unfortunately, my data was collected in completely different circumstances.

According to the ecological framework (ecological theory), climate change is critical to a parasite's survival in the environment. Patz et al. (as cited in WHO, 2019) indicated that the size of the infectious agent and the associated vector organisms cause a lack of thermostatic regulation. Patz et al. reported that the local climate determines the temperature and fluid levels of these organisms.

In another study in Sierra Leone, Hodges et al. (2011) reported that hookworm infection had a negative association with population density as well as land surface temperature. However, the same study also reported that hookworm infection showed a high prevalence in other parts of the country, such as the northeastern area, where population density and land surface temperatures varied (Hodges et al., 2011).

Hodges et al. (2012) reported on the spatial risk prediction of *Haematobium* infection in the northeastern area covering two-thirds of Sierra Leone. Using a spatial model, Hodges et al. (2012) indicated that there was no clear association between the prevalence of *S. haematobium* and sex, age, and population density.

In another study, de Souza et al. (2014) indicated a lack of evidence for lymphatic filariasis transmission in major cities that were affected by civil conflicts in Liberia and Sierra Leone. The study showed that the *Anopheles* mosquito (*An. gambiae*) was found in low numbers and had microfilaria prevalence breaking threshold that was insufficient to sustain transmission of the pathogen. Other areas of Sierra Leone, such as Bo and Pujehun, showed an antigen prevalence of 0.19% and 0.67% in children examined (de Souza et al., 2014). This result was well below the 2% recommended level under the WHO guidelines to stop mass drug administration (MDA) in areas where transmission by *Anopheles* is common (de Souza et al., 2014).

In another study by Hodges et al. (2011), STH prevalence was reported to be endemic across the country, with waterborne schistosomiasis reported to be prevalent in both the northern and eastern areas of the country. Using only one Kato-Katz slide for diagnosis during the survey may have caused children with mild infection to be missed (Hodges et al., 2011). The survey showed an infection level that could have been higher than was reported, according to Hodges et al. (2011). Hookworm was found to be endemic nationwide, but at a higher prevalence in the western coastal areas as well as in Koinadugu, which is located in the northeastern area of the country (Hodges et al., 2011). According to Hodges et al. (2011), hookworm was negatively associated with population density and land surface temperature (LST).

There were disparities between the previously discussed studies on the relationship of climate change (temperature and precipitation), NTDs, and population density and the findings of my study. For instance, a study by Geisser and Reyer (2005) on the effect of temperature on population density showed a relationship because the study had a set of data sufficient to provide significant results. Similarly, other studies on the relationship between population density and NTDs showed a relationship due to the type of data set used by the researchers. In contrast, my findings revealed no relationship between either precipitation, or temperature and population density. Rahman (2016) used secondary data, Caminade et al. (2013, 2017) used five global climate models, Lugo (2015) employed archival data, and Lowe et al. (2013) used a statistical mixed model framework. Conversely, my study used archival data to examine the relationship between population density and distribution of NTDs. The differing results of my study in comparison to other studies with similar outcomes might have been due to insufficient data on the variables. Most of the studies supported the claim that the prevalence of NTDs was influenced by level of precipitation and the temperatures of the areas investigated. Moreover, budget and time constraints might have contributed to the differences in my results.

Limitations of the Study

A lag in data collection might have contributed to reporting inconsistencies. The population sample was based on districts, chiefdoms, and towns in various areas of Sierra Leone. It was difficult to obtain data from the three sub-Saharan African countries that I originally intended to focus on in my research (i.e., Ghana, Nigeria, and Sierra Leone). I made several contact attempts by email and phone to various individuals, institutions, and organizations, including national governments and NGOs, without success. In the end, I decided to drop Ghana and Nigeria from my study and focused on Sierra Leone alone. The following were the limitations of my study:

1. The Sierra Leone Health Care System was affected severely by the civil war that occurred from 1991 to 2002. The health care infrastructure was devastated, and the country had to rebuild after the war. These unfortunate circumstances adversely affected my study, in that I was not able to obtain good data. After much effort, I was finally able to obtain data for my analysis, which were insufficient but made it possible to complete the project. The findings are limited to Sierra Leone in SSA and should not be generalized to the entire region of SSA.

2. Data were collected in areas where treatment had occurred previously due to lack of coordination by NGO staff and other international organizations as well as the national government.

3. Lack of proper training of field workers may have resulted in poor data collection.

4. Much pertinent data were not collected, and only posttreatment data were available. This undoubtedly had a major effect on the results of my study compared to those of others conducting similar research. The difficulties encountered in my study highlight the urgent need for adequate public health infrastructure, trained personnel, and funding to obtain the necessary data to conduct this type of research.

I made extreme efforts to obtain quality secondary data for the study, but my efforts were futile as a result of several hindrances. I contacted institutions, NGOs, national governments, as well as individuals who might have access to secondary data, but it was difficult to obtain data for several reasons, such as restrictions by national governments on releasing data to outside entities. I could not resolve the prevailing conditions, and I had to use the only data that were made available to me by the Ministry of Health and Sanitation in Freetown, Sierra Leone.

In an extended study measuring the relationship between a change in temperature, precipitation and population density, the regression threat may occur when population density is caused by other factors. Sometimes the regression threat is also known as "regression artifact" (Trochim, 2006, 2015). The reason for the regression threat in this case was a result of the fact that the statistical analysis was a nonrandom sample from the population and the measures were imperfectly correlated. One of the reasons for regression to occur is sometimes due to sampling asymmetrically from the population (Trochim, 2006, 2015). Sampling randomly from the population would allow you to observe that both the population and the sample would have the same pretest average. This is because the sample is already at the population mean on the pretest and would make it quite impossible for them to regress towards the population mean any further (Trochim, 2006, 2015). It is not a good practice to extrapolate from small sample sizes, as the data might not be representative of the distribution. Future studies could be improved by controlling for the regression threat.

A hierarchical regression analysis could be used to measure the effect of temperature and precipitation on population density, controlling for potential confounders. Future studies could be improved by controlling for potential confounders.

I tried very hard to obtain essential data for my study without success. I did my best in my study results. Although my study results are weak, they can still contribute to the field by offering guidance for future researchers. In other words, future researchers must ensure the use of good and sufficient data for their studies. The results of my study can still contribute to research in neglected tropical diseases in Sierra Leone.

Recommendations

Researchers should control the regression threat. Researchers should measure if temperature and precipitation effects population density, controlling for potential confounders by using a hierarchical regression analysis. Researchers should not do further study on a limited budget. In addition, researchers should not do future study with severe time constraints. These limitations may be attributable to varying results in population density, climate change and distribution of neglected tropical diseases.

This study used archival data obtained from Sierra Leone. Population sample was based on some Districts, Chiefdoms and towns in various areas of Sierra Leone. Researchers should include other countries to ensure comprehensiveness of the data sets.

The data from Sierra Leone was collected after intervention to treat parasitical diseases. In a study such as this, one should have pretreatment and post-treatment data on the same populations. Thorough and complete data sets would be collected for temperature, precipitation, population movement and density, and disease prevalence. Ideally, data would be collected on the parasitical, intermediate host, and vector populations in the same regions as the human population being studied. It is advisable for future researchers to ensure that they utilize better quality data including meteorological, epidemiological, and ecological for their investigation.

The effects of population density on the distribution of infectious diseases caused by fungal pathogens were not investigated in this study. Future research could fill this gap by examining the effects of population density on the distribution of other infectious diseases, such as onchocerciasis, lymphatic filariasis, and leishmaniasis to name a few. Future research may show that population density affects the distribution of infectious diseases by performing a regression analysis.

I did not examine the impact of temperature on the distribution of plant diseases. Further research could fill this gap by examining the impact of temperature on the distribution of plant diseases. Future research may also show that temperature affects the distribution of plant diseases by performing a regression analysis.

The effect of rainfall on food-and waterborne diseases was not analyzed. Further research could fill this gap by examining the impact of rainfalls on the food-and waterborne diseases. Future research may show that precipitation affect food-and waterborne diseases by performing a regression analysis.

Final recommendation is related to a quantitative study that examines the effect of temperature and precipitation on population density internationally. Researchers should perform a regression analysis. Future research may show that temperature and precipitation affect population density internationally.

Although multiple health policies have already been implemented in the West African region, more policies are requisite to control neglected tropical diseases and improve health standards of the people in the region. Therefore, the following recommendations need consideration:

1. The escalation in active universal disease reconnaissance: An upsurge in the global scrutiny of diseases is of utmost importance. Shortage of accurate

knowledge about the current disease incidences makes it difficult to correlate the change with climatic variations in Sierra Leone.

2. Persistence of epidemiological research relating to the association between climatic factors and neglected tropical diseases: In order to conduct the epidemiological researches incidence data are needed to deliver a baseline. This data also will be beneficial for authenticating predictive models. As these data are difficult to collect, chiefly in isolated areas, it would be necessary to coordinate with the various organizations conducting intervention programs in these areas to avoid duplication. A central computer database must be formed to ease the sharing of these data among different scholars of the world. It is critical that adequate, complete, and appropriate data are collected. Without such data, you cannot validate your models, nor can you assess the effectiveness of your interventions. In order to ensure that such data will be available for assessment and validation active surveillance of disease and mapping of the types of NTDs in the districts is necessary.
3. Advancement in wide-ranging models: Statistical models can be beneficent to forecast the health conditions, NTDs growth, and the effectiveness of NTDs control programs in relation to the climatic factors of West Africa. Socio-cultural, environmental and economic factors influence can also be forecast. Additional expansion of the wide range of models can be advantageous in anticipating probable health effects in a relationship with variations in the climate.

4. Enhancements in communal health framework: Communal health infrastructure includes health awareness programs and training, the response in emergency conditions and prevention programs. Improved awareness in the NTDs affected individuals is the need of the hour to cope up with climatic and hygiene factors which are catalyzing the growth of neglected tropical diseases in Sierra Leone.

Social Change Implications

The study used a correlational design. As the purpose of this study was to measure the relationship among temperature, precipitation, population density and prevalence of NTDs, the hypotheses were answered by a correlational study. The results from the study imply that correlation analyses are appropriate for measuring the relationship between several variables. The strength of the study was that the sample was large.

The challenges of this study illustrate the urgent need for more and better public health infrastructure, personnel, and funding. Without these, such studies cannot be undertaken and necessary health interventions guided by the results of these studies cannot be developed and implemented.

Africa traps some of the most defenseless populations in a vicious cycle of poverty and illness, NTDs are a clear threat to progress in the region. The heightened levels of poverty in sub-Saharan Africa are contributing to spread of the NTDs. Poor governance that does not make it a priority to address health care issues contributes to the prevalence of NTDs. Such issues undermine the struggles to accomplish the desired Millennium Development goals by prolonging poverty and its extremely negative effects on economic progress, sustenance, education, and health of mother and child. These must be addressed to safeguard long-lasting economic progress.

Healthcare practitioners can take the findings of this study as an indication of the need for more complete studies to understand the way migration patterns affect the spread of NTDs and the SSA population. Additional studies are needed to examine if temperature and precipitation can predict population density. This study can provide an incentive to improve public health infrastructure and data gathering capabilities to conduct the studies that will address these public health concerns.

Conclusion

The study concludes that climate patterns, as measured by temperature and precipitation changes, are not correlated with population density in Sierra Leone. In addition, there is no relationship between population density and the distribution of neglected tropical diseases in Sierra Leone. Standardized regression analysis and correlation results indicate that there is no relationship among temperature and NTDs and precipitation and NTDs. Results of my statistical analysis have shown there is no relationship between population density and control of neglected tropical diseases in the West African nation of Sierra Leone, or in other words, the high population density is not hindering the control of NTDs. Bah et. al. (2019) reported that in 2016 there was a decrease in the prevalence of soil-transmitted helminth (STH) infections in Sierra Leone. It was later discovered that there was no coordination of the treatments provided by many organizations to avoid duplication and improve coverage in the areas of treatment. The NTD program in Sierra Leone started advocacy among all of the NGOs involved including other organizations in NTD treatment in an effort to coordinate and conduct treatment twice a year (six months apart), with the hope that this will eventually prevent duplication for treatment and will also improve geographic area of coverage. This study postulates the need for stakeholders and all of those involved in NTD research in sub-Saharan Africa to be cognizant of better data collection that includes meteorological, epidemiological, and ecological. Public health infrastructure is critical in any community and governments have to ensure the safety and health of its citizens. Unfortunately for Sierra Leone, the health care infrastructure was ruined during the devastating war the country experienced for more than a decade. However, it is the responsibility of any government to address the public health needs of its citizens, and one of the important ways to achieve that is to have adequate public health infrastructure and proper health services. This can be accomplished by providing the necessary funding by the government and requesting help from various donor organizations such as NGOs, Foundations, and philanthropists. The success of such an effort by governments depends fundamentally on good governance in ensuring that available funds are used appropriately.

There exists a strong need to have responsible leadership on this matter that should play a vital role convincing states to help develop necessary strategies to control and eradicate NTDs in the country by 2020. Countries like Sierra Leone must be encouraged and assisted to give proper means to implement NTD control and eradication program by involving the whole community. Some incentive should also be given to develop partnerships to increase efforts for eradication and control.

Stakeholders within the region should make an effort in using technology such as geo-spatial technology in NTD modelling for the most common infections affecting

Sierra Leone. Although technological advancements including drugs are the key elements to eradicate NTDs from the region, usually, funding is not available to achieve the goals. If the USA should allocate 1%–2% of their whole international health support, it will amount roughly US$100–US$200 million for product development combatting NTDs. The importance of good data collection for such a study cannot be overemphasized considering the impact of NTDs in Sierra Leone. The fight against NTDs should start with good data for all stakeholders including researchers. Without this information, it will be a futile effort to pursue research in this area. Hopefully, conditions in Sierra Leone would improve and future researchers would be able to acquire good data to conduct their studies.

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Appendix A: Tables

The following abbreviations apply to all tables: SM = *Schistosoma mansoni;* SH = *Schistosoma haematobium;* ASC = *Ascaris;* HW = Hookworm; Tri = *Trichuris; S.ster* = ***Strongyloides stercoralis***

Table A1

Midterm Impact Assessment Results by Chiefdoms in BO Central

Village	#Exam-ined	SM # cases	SH # cases	HW %	HW # cases	Tri %	Tri # cases	Elevation (m)	Temperature °C	Precipitation (mm)	Population den
Ngelehun	50	7	2	12.0	6.0	2.0	1.0	244	25.4	2755	1.703
Kowama Section	50	0	2	4.0	2.0	0.0	0.0	91	26.4	2658	1.488
Njala	50	0	4	12.0	6.0	0.0	0.0	107	26.4	2627	3.269
Sumbuya	48	3	0	6.3	30.2	0.0	0.0	89	26.7	2969	2.444
Sahn	49	1	16	22.4	11.0	4.1	2.0	131	26.4	3450	1.946
Mongere	50	1	2	0.0	0.0	0.0	0.0	88	26.5	3047	2.758

Note. There were no reported cases of ASC or *S.ster*.

Table A2

Location Details of Chiefdoms Assessed in BO Central

Chiefdom	Village	Longitude	Latitude
Badjia	Ngelehun	N08°05.954'	W011°25.172'
Kakua	Kowama Section	N07°56.981'	W011°44.799'
Komboya	Njala	N08°12.023'	W011°27.644'
Lugbu	Sumbuya	N07°39.202'	W011°58.032'
Niawa Lenga	Sahn	N08°09.318'	W011°36.005'
Valunia	Mongere	N08°19.114'	W011°44.049'

Table A3

Midterm Impact Assessment Results by Chiefdoms in Bombali Northwest

Village	# Exam-ined	SM # cases	SH # cases	ASC %	ASC # cases	HW %	HW # cases	Tri %	Tri # cases	Sster %	Sster # cases	Elevation (m)	Temperature °C	Precipitation (mm)	Population den
Gbanti	51	4	0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	1.1	88	26	1911	1.258
Kagbere	50	13	1	8.0	4.0	6.0	3.0	0.0	0.0	4.0	2.0	102	27.2	2703	1.82
Kamalo	49	9	2	0.0	0.0	0.0	0.0	0.0	0.0	4.1	2.0	99	27.4	2554	2.932
Kakissy	49	10	0	4.1	2.0	10.2	5.0	2.0	1.0	0.0	0.0	119	27.5	2782	0.446
Kabba Ferry	40	6	3	10.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	96	NA	NA	1.513

Table A4

Location Details of Chiefdoms Assessed in Bombali Northwest

Chiefdom	Village	Longitude	Latitude
Gbanti Kamaranka	Gbanti	N09°14.798'	W012°15.662'
Magbaimba Ndorhahun	Kagbere	N09°13.359'	W012°08.386'
Sanda Loko	Kamalo	N09°24.034'	W012°14.580'
Sella Limba	Kakissy	N09°27.634'	W012°14.386'
Tambaka	Kabba Ferry	N09°36.518'	W012°12.805'

Table A5

Midterm Impact Assessment Results by Chiefdoms in Kailahun Eastern

Village	# Examined	SM # cases	SH # cases	ASC %	ASC # cases	HW %	HW # cases	Tri %	Tri # cases	Sster %	Sster # cases	Elevation (m)	Temperature °C	Precipitation (mm)	Population den
Koindu	50	10	1	2.0	1.0	10.0	5.0	2.0	1.0	0.0	0.0	444	25.3	2542	3.606
Jojoima	50	4	1	2.0	1.0	4.1	2.1	0.0	0.0	0.0	0.0	200	26	2530	4.714
Magbema	50	5	0	2.0	1.0	8.0	4.0	0.0	0.0	0.0	0.0	196	25.8	2684	1.055
Bandajuma	50	11	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	189	25.5	2670	0.849

Table A6

Location Details of Chiefdoms Assessed in Kailahun Eastern

Chiefdom	Village	Longitude	Latitude
Kissi Teng	Koindu	N08°45.434'	W010°33.370'
Malema	Jojoima	N07°87.656'	W010°78.465'
Njaluahun	Magbema	N08°03.196'	W010°92.281'
Yawei	Bandajuma	N08°31.091'	W010°85.172'

Table A7

Midterm Impact Assessment Results by Chiefdoms in Kenema Southeast

Village	# Examined	SM # cases	SH # cases	ASC %	ASC # cases	HW %	HW # cases	Tri %	Tri # cases	Sster %	Sster # cases	Elevation (m)	Temperature °C	Precipitation (mm)	Population den
Kambema	49	6	0	8.0	3.9	10.0	4.9	0.0	0.0	0.0	0.0	159	24.8	2793	0.162
Lalehun	50	22	0	0.0	0.0	6.0	3.0	0.0	0.0	0.0	0.0	176	25.6	2692	0.149
Sendumei	49	0	0	0.0	0.0	2.0	1.0	0.0	0.0	0.0	0.0	108	NA	NA	0.671
Faama	49	3	0	4.1	2.0	10.2	5.0	0.0	0.0	0.0	0.0	121	NA	NA	0.248
Gendema	50	3	2	0.0	0.0	6.0	3.0	0.0	0.0	0.0	0.0	210	26.6	3301	0.453

Table A8

Location Details of Chiefdoms Assessed in Kenema Southeast

Chiefdom	Village	Longitude	Latitude
Dama	Kambema	N07°70.752'	W011°07.890'
Lower Bambara	Lalehun	N08°12.033'	W011°04.825'
Niawa	Sendumei	N07°42.863'	W011°23.262'
Nomo	Faama	N07°31.473'	W010°59.761'
Wandor	Gendema	N08°13.774'	W011°20.879'

Table A9

Midterm Impact Assessment Results by Chiefdoms in Komadugu Northeast

Village	# Examined	SM # cases	SH # cases	ASC %	ASC # cases	HW %	HW # cases	Tri %	Tri # cases	Sster %	Sster # cases	Elevation (m)	Temperature °C	Precipitation (mm)	Population den
Sinkunia	50	25	0	2.0	1.0	4.0	2.0	2.0	1.0	4.0	2.0	363	25.4	1855	0.408
Alikalia	50	6	1	20.0	10.0	28.0	14.0	0.0	0.0	4.0	2.0	430	25.2	2455	2.081
Krubonla	50	11	0	4.0	2.0	10.0	5.0	0.0	0.0	8.0	4.0	430	NA	NA	3.984
Alusainya	49	7	2	8.2	4.0	10.2	5.0	2.0	1.0	0.0	0.0	417	NA	NA	0.915

Table A10

Location Details of Chiefdoms Assessed in Komadugu Northeast

Chiefdom	Village	Longitude	Latitude
Dembelia Sinkunia	Sinkunia	N09°51.680'	W011°25.702'
Neini	Alikalia	N09°08.954'	W011°23.391'
Neya	Krubonla	N09°11.888'	W010°56.794'
W. W Yagala	Alusainya	N09°30.595'	W011°35.344'

Table A11

Midterm Impact Assessment Results by Chiefdoms in Kono Eastern

Village	# Examined	SM # cases	SH # cases	ASC %	ASC # cases	HW %	HW # cases	Tri %	Tri # cases	Sster %	Sster # cases	Elevation (m)	Temperature °C	Precipitation (mm)	Population den
Small Sefadu	50	21	0	0.0	0.00	8.2	4.1	0.0	0.0	0.0	0.0	370	NA	NA	1.18
Senehun	51	12	3	7.8	4.0	13.7	7.0	0.0	0.0	2.0	1.0	421	26.2	2829	0.137
Kainkordu	50	9	0	4.0	2.0	6.0	3.0	0.0	0.0	0.0	0.0	503	24.5	2498	0.422

Table A12

Location Details of Chiefdoms Assessed in Kono Eastern

Chiefdom	Village	Longitude	Latitude
Gbense	Small Sefadu	N08°65.309'	W010°99.634'
Lei	Senehun	N08°44.237'	W010°46.297'
Soa	Kainkordu	N08°37.249'	W010°43.418'

Table A13

Midterm Impact Assessment Results by Chiefdoms in Tonkolili Central

Village	# Examined	SM # cases	SH # cases	ASC %	ASC # cases	HW %	HW # Cases	Tri %	Tri # cases	Sster %	Sster # cases	Elevation (m)	Temperature °C	Precipitation (mm)	Population den
Yele	52	1	0	0.0	0.0	0.0	0.0	1.9	1.0	0.0	0.0	83	26.6	2907	3.911
Bumbuna	50	33	2	8.0	4.0	6.0	3.0	0.0	0.0	8.0	4.0	94	26.8	2850	3.242
Mabang	50	0	1	2.0	1.0	2.0	1.0	0.0	0.0	6.0	3.0	78	26.7	3044	1.68
Magburaka	50	1	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	104	26.9	3095	3.683
Matotoka	51	1	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	126	26.7	3067	1.949
Yonni Bana	51	1	0	3.9	2.0	21.6	11.0	0.0	0.0	11.8	6.0	72	26.3	3008	2.004

Table A14

Location Details of Chiefdoms Assessed in Tonkolili Central

Chiefdom	Village	Longitude	Latitude
Gbonkolenkeh	Yele	N08°24.830'	W011°49.879'
Kalansogoia	Bumbuna	N09°02.792'	W011°44.625'
Kholifa Mabang	Mabang	N08°34.074'	W012°10.319'
Kholifa Rowalla	Magburaka	N08°42.798'	W011°57.264'
Tane	Matotoka	N08°39.445'	W011°51.662'
Yoni	Yonni Bana	N08°26.562'	W012°14.352'