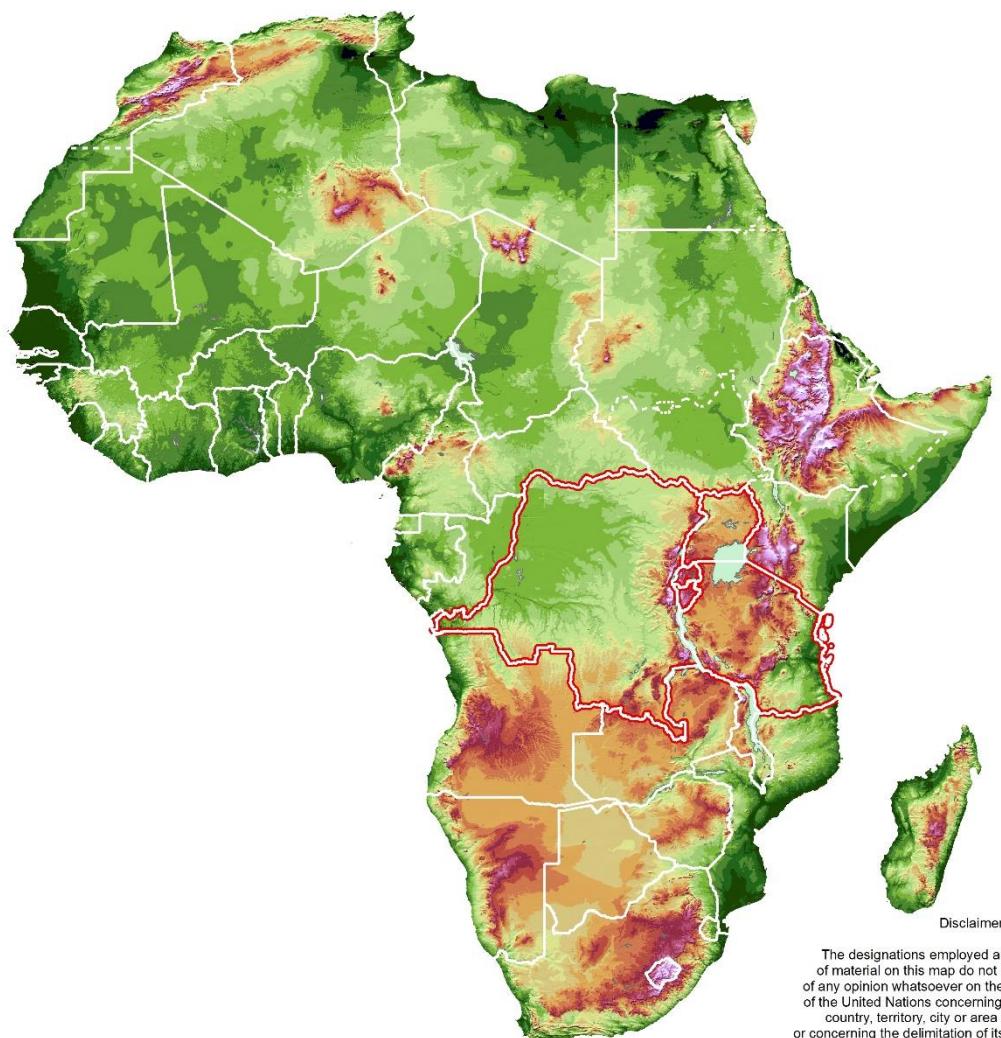


Malaria control among slum children in the Great Lakes Region of Africa: using the power of geospatial intelligence



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Abstract

The present study is an assessment of the geospatial childhood malaria distribution and patterns among children living in slums and is aimed at enhancing policymaking and decision-making for malaria eradication and control in five countries in the Great Lake Region: Burundi, the Democratic Republic of the Congo, Rwanda, Uganda and the United Republic of Tanzania. By using the spatial statistical analytical approach, policymakers will be able to better understand the behaviours of the childhood malaria phenomenon in slums, while relating the prevention, control and eradication of the disease to geographical locations. Through the interpolation of results, the relationship between slums and malaria intensities was mapped out, indicating high and low clustering of the disease in the five countries. In addition, the study also provided an examination of the effects of environmental factors such as inland waters, cropland, tree covered areas, shrub-covered areas and herbaceous vegetation on the occurrence of the disease. The results not only have demonstrated the spatial distribution of childhood malaria in slums but also have indicated the principal factors responsible for the spatial distribution of the phenomenon. Accordingly, indicated in the study area areas of intervention for the control, prevention and eradication of childhood malaria in slums and suggestions for a priority scheme to be followed for rapid policy action within the five countries.

Key words: spatial statistics, geospatial intelligence, malaria control, slum children, Great Lakes Region of Africa.

1. Introduction

1.1 Background and justification

The overwhelming health, morbidity and mortality impact of malaria and its social and economic burden have contributed to attention being placed on the elimination of the disease by national and international communities, with an emphasis on the need to control and interrupt its transmission. This awareness has resulted in many initiatives aimed at combating malaria (Arrow and others, 2003).

1.1.1 Current financial resources to fight malaria

Bill and Melinda Gates called upon global leaders to embrace “an audacious goal—to reach a day when no human being has malaria, and no mosquito on earth is carrying it”. (Bill and Melinda Gates Foundation, 2007).

There is an overwhelming financial cost to fight malaria globally. An assessed monetary sum of \$2.7 billion was raised for malaria control and eradication initiatives worldwide by the governments of malaria-prevalent countries and international partners in 2016. The World Health Organization (WHO), through its Regional Office for Africa spent more than 74 per cent of its annual budget in 2016 on malaria control and eradication. In the total spent globally to eradicate malaria in Africa in 2016, the governments of malaria-prevalent countries contributed 31 per cent of the total earmarked to eradicate malaria (\$800 million), while \$1.9 billion of the overall total was donated internationally. The United States of America was the main international source of malaria funding in 2016, accounting for \$1 billion (38 per cent), followed by the United Kingdom of Great Britain and Northern Ireland and other international donors, including France, Germany and Japan. More than half (57 per cent) of the malaria control and eradication resources in 2016 were directed through the Global Fund to Fight AIDS, Tuberculosis and Malaria (World Health Organization, 2017b). The \$2.7 billion used towards malaria control and eradication in 2016 was far below the \$6.5 billion annual investment budgeted for the elimination of malaria by 2020 (World Health Organization, 2017a).

1.1.2 Malaria control and eradication through the Sustainable Development Goals

Strategies to eliminate malaria have gathered impetus through inspired and guided discussions on the elimination of malaria through the achievement of the Sustainable Development Goals. The 2030 Agenda for Sustainable Development includes a Goal on health, with specific targets on malaria eradication. This represents an opportunity not only to maintain gains made in malaria prevention, but also to accelerate efforts to control and eradicate malaria in countries and areas with a high concentration of the disease and to direct these efforts to the most vulnerable and marginalized people. In support of the aim of the 2030 Agenda to eliminate malaria, two strategies were developed by the Roll Back Malaria Partnership: the Global Technical Strategy for Malaria 2016-2030 and Action and Investment to Defeat Malaria 2016-2030 – For a Malaria-Free World (World Health Organization, 2015).

1.2 Progress in and challenges of malaria control and eradication in Africa

The various efforts made to develop innovative malaria control tools and strategies have contributed to the expansion of malaria control interventions and to tremendous achievements in the global effort to control the disease (Tanner and others, 2005). Since the adoption of the

Millennium Development Goals, the world has witnessed an impressive decline in morbidity and mortality rates associated with malaria. Between 2000 and 2013, the incidence of malaria fell by 30 per cent worldwide and by 34 per cent in Africa (World Health Organization, 2015). In addition, the number of malaria cases worldwide fell from 262 million in 2000 (range: 205–316 million) to 214 million in 2015 (range: 149–303 million), representing a drop of 18 per cent. However, 88 per cent of those incidents or cases in 2015 were in Africa (World Health Organization, 2016).

Improved malaria control contributed significantly to the decline in the mortality rate globally (47 per cent) and in Africa (54 per cent) during the period 2000–2015, in particular among children under five years of age. Specifically, the number of deaths caused by malaria globally fell from an estimated 839,000 in 2000 to 438,000 in 2015. WHO corroborated that progress and showed that, between 2000 and 2015, the global malaria incidence rate had declined by 37 per cent, while the malaria-related death rate had declined by 60 per cent (World Health organization, 2016). That improvement resulted in saving the lives of 6.2 million people between 2001 and 2015, including 5.9 million children under five years of age (United Nations Children's Fund, 2016).

Progress in reducing the child mortality quickened during the period 2000–2016, compared with the 1990s. Globally, the annual drop in the under-five mortality rate rose from 1.9 per cent in 1990–2000 to 4.0 per cent in 2000–2016. That improvement saved the lives of 50 million children under five years of age (World Health Organization, 2016).

Notwithstanding notable progress in malaria control, the disease remains a global challenge and its burden is heavier in Africa. In 2012, there were an estimated 207 million cases of malaria globally, with 80 per cent of them occurring in Africa (World Health Organization, 2016). The number of the malaria-related deaths globally in 2012 was estimated to be 627,000, with 90 per cent of those deaths occurring in Africa and more than 75 per cent (462,000) of them involving children under five years of age (*Ibid.*). The number of malaria-related deaths in children under five years of age is estimated to have dropped from 723,000 globally in 2000 to 306,000 in 2015. The majority of this reduction occurred in Africa, where the estimated number of deaths fell from 694,000 in 2000 to 292,000 in 2015. Sub-Saharan Africa, however, continues to have the highest under-five mortality rate in the world. With regard to the Great Lakes countries, they account for almost 2 million deaths among children (1,987,580) aged 1 to 49 months from 2000 to 2015.

Two African countries, namely, the Democratic Republic of the Congo and Nigeria, accounted for more than 35 per cent of the global total of estimated malaria-related deaths during the period 2000–2015. In the light of that statistic, considerable efforts are still necessary in Africa, where malaria remains a serious public health problem that affects development. Nevertheless, the situation is different according to which countries are studied. Substantial progress has been made in North Africa, where most countries are on track to eliminate malaria. In sub-Saharan Africa, notwithstanding significant steps taken by some countries to eliminate malaria, namely, Botswana, Cabo Verde, Namibia, South Africa and Swaziland, in most countries malaria remains endemic and continues to be a leading cause of morbidity and mortality, in particular among the most vulnerable groups of society who are unable to gain access to prevention tools and drugs.

The economic, social and health toll of malaria and its undermining effect on development efforts in Africa are well documented. Malaria has a direct impact on economic growth on the continent: it was found that the incidence of malaria slowed down annual

economic growth. The annual direct costs of malaria prevention and treatment are estimated to be \$12 billion, while its indirect costs include lost productivity and income associated with illness or death. Given that malaria is confined primarily to the world's poorest regions and countries, it is safe to assume that there is a strong impact of malaria on economic performance, even though it is difficult to understand clearly the mechanisms behind the impact (Breman and others, 2001).

In Africa since 2008, substantial economic growth has been recorded in most countries. That economic performance, however, did not lead to a corresponding reduction in poverty and, on the contrary, resulted in greater social inequality. In sub-Saharan Africa, the number of people living in extreme poverty increased from 289.7 million in 1990 to 413.8 million in 2010. Rural poverty and increased social and economic inequality between rural and urban populations led to the increased emigration of population from rural to urban areas. That exodus, combined with rapid population growth, resulted in rapid urbanization, which, in turn, was accompanied by illegal and unplanned settlements that lead to the proliferation of slums. Consequently, in most sub-Saharan countries, rapid urbanization is associated with poor living and environmental conditions. This led to drastic changes in the social, economic and environmental landscape of urban life and health conditions (United Nations Human Settlements Programme, 2017).

Slums are associated with poor living conditions, high population density, insecure and inadequate housing, an unhygienic and hazardous physical environment, poor health infrastructure and intervention coverage and poor access to infrastructure such as sanitation, sewage, drainage, water supply and roads. They are also more likely to be located in vulnerable physical environments that can serve as mosquito breeding sites (e.g., standing water, rivers, springs, swamp and altitude). They are also vulnerable to other natural conditions and human activities associated with the development of malaria such as high, humid temperatures, heavy rainfall, seasonal climates, type of soil, land use, urban agriculture and the use of irrigation systems. Such characteristics have made slums vulnerable to environmental and human factors favourable to the development of malaria. These environmental risks, combined with the low socioeconomic status of slum dwellers, expose them, especially children, to a higher risk of contracting malaria. An analysis of urban slum diseases in Abuja corroborated the assertion that environmental risks, combined with the low socioeconomic status of slum dwellers, exposed them, especially children, to a higher risk of contracting malaria and demonstrated a strong correlation between the exposure to malaria and the location of the slum and the impact of mosquito breeding sites, poor living conditions, poor access to infrastructure (e.g., sanitation, water supply and electricity) and poor access to health basic services (Badaru and others, 2005).

Urbanization is thought to lead to a reduction in cases of malaria owing to better living conditions, better access to health services, sanitation and other infrastructure (Qi and others, 2012). The pattern of transmission in urban areas in most malaria-infested African countries belies this assumption, however, given that the rapid urbanization has resulted in the proliferation of slums in most African cities, which, in turn, has resulted in a resurgence of malaria in urban area (International Organization for Migration, 2014). Cases of malaria in urban areas are not homogeneous, given that the distribution of the malaria vector is influenced by the geographical and socioeconomic configuration of the area, such as location (e.g., altitude and proximity to a sea, river or floodplain), climate, land use, human movement patterns, local vector species, vector breeding sites, waste management and local malaria intervention programmes (Kim and others, 2016). Given the specific geographical features of urban settlements in African countries, this environmental dependency leads to complex patterns of

geographical variation in malaria transmission at almost every scale (Dalrymple and others, 2015).

This heterogeneity in malaria epidemiology shows that the effective control and eventual elimination of malaria requires a multi-sectorial approach that integrates conventional approaches with others required to address socioeconomic and environmental issues relating to the disease. The failure to complement existing conventional malaria control strategies with concrete measures to address the pandemic is one of the reasons that led to the failure of the global eradication campaigns of the 1950s and 1960s (Roll Bak Malaria Partnership and United Nations Development Programme, 2013). In the absence of a vaccine, the tools used to control malaria are the following: insecticide-treated mosquito nets, indoor residual spraying, rapid diagnostic tests and treatment (drugs such as artemisinin-based combination therapy). These tools have their limits and have been challenged by the increasing resistance of the malaria parasite to antimalarial treatments and insecticide (Sinha and others, 2014). The need to address resistance issues and the subsequent resurgence of malaria led WHO to adopt the Roll Back Malaria Partnership (Zhao and others, 2012). The main focus of this global strategy is the control of the disease through the diagnosis and treatment of infected people, as opposed to controlling the risk of infection (Hemingway and others, 2016). To address the malaria pandemic, in September 2013, the Partnership and the United Nations Development Programme launched the Multisectoral Action Framework for Malaria. In it, actions are identified to address the social and environmental determinants of malaria and it contains calls for an inclusive and coordinated multisectoral approach in combating malaria and for current malaria strategies to include a socioeconomic development approach. It contains four levels of analysis (society, environment, population group and households and individuals) and identifies action to be taken on the social and environmental determinants of malaria.

In the light of the above, urbanization, human behaviour and activities, as well as climate and environmental factors, are key factors behind malaria transmission. A better understanding of the interaction of these factors with the epidemiological and ecological characteristics of malaria is key to the effective prevention and control of the disease in urban areas (de Souza and others, 2010), given that it enables the determination of the spatial and temporal patterns of the transmission, distribution and magnitude. This information is of great importance to the implementation of suitable malaria prevention, control and treatment interventions because it allows the better targeting of populations at risk, in particular in urban settlements (Kelly-Hope and McKenzie, 2009).

In recent decades, the use of the Geographic Positioning System (GPS), the geographic information system (GIS) and remote sensing technologies has revolutionized the management and prevention of malaria because it enables the determination, location and monitoring of socioeconomic, geographical, climate and environmental factors influencing the occurrence and spread of the malaria epidemic in a given area. The use of GIS for the analysis of data allows the classification of factors behind the occurrence and spread of malaria and a better understanding of the heterogeneity resulting from the interaction of these factors. It constitutes a fundamental tool for monitoring, decision-making and resource allocation, given that it enables a better understanding of the vector and the disease risk (Tanser and le Sueur, 2002).

1.3 Tests for malaria and the main factors in transmitting the disease

Children aged six months to five years are at great risk in highly endemic regions, such as the countries of the Great Lakes Region. This age group is considered to be a vulnerable one, given that children have yet to develop a partial resistance to malaria. In Demographic and Health Surveys, children aged 6 to 59 months that spent the night before the survey in the household are tested for malaria and anaemia. Two types of malaria tests are normally conducted: a rapid diagnostic test and a test that uses a blood smear test on slides to be viewed under a microscope. While microscopy has been used for many years, rapid diagnostic tests are also very useful for detecting infection and are not subject to variability among technicians based on skill and experience. These tests are also easier to use and provide rapid results, which is not possible through microscopy.

There are various biological, environmental and socioeconomic factors that affect the transmission of malaria in the Great Lakes Region. Biological host factors such as age, sex and genetic causes affect the spread of malaria. Socioeconomic circumstances also play a role in transmission. An underlying contributing factor of transmission is poverty due to poor housing, undernourishment and lack of access to interventions and proper treatment. Poor sanitation can create breeding grounds for mosquitoes. Education affects the ability to understand the how malaria spreads and the capacity to control malaria with the resources available.

Environmental aspects such as temperature, wind, rainfall and altitude also affect the spread of malaria. Temperature has effects on the growth of the parasite. In temperatures below 16 degrees Celsius, parasites are incapable of growing. The perfect conditions for their growth is a mean temperature of 20 to 30 degrees Celsius and a relative humidity of at least 60 per cent. A high relative humidity extends the life of the mosquito. Relative humidity below 60 per cent is needed for the survival of adult Anopheles. Strong winds may prevent mosquitoes from laying eggs. In addition, the wind may extend the flight range of mosquitoes, thereby enabling them to infect more people. Rainfall is a major cause of mosquito reproduction. Moderate rainfall and distribution patterns create breeding grounds for mosquitoes. Extreme rain has the potential to terminate breeding places and sweep away larvae. Altitude makes some areas too difficult and cold for mosquitoes to breed or to live. Typically, there is no malaria in altitudes of more than 2,500 m owing to low temperatures and/or low rainfall. For elevations between 2,000 and 2,500 m, with low temperatures or arid conditions, there is a discrepancy in terms of the risk of malaria. In these regions, populations do not have immunity because they are not constantly exposed to malaria parasites. Lower elevations tend to have more constant risk of malaria, although there is often seasonal variation (Florey, 2014).

Demographic and Health Surveys and malaria indicator surveys usually involve both the rapid diagnostics test and the smear test for malaria. The former is easier to conduct in the field and identifies a larger number of positive cases, compared with microscopy readings. They also detect antigens and not parasites. Moreover, they allow for the identification of children with malaria in the field. Reading blood smears is very time consuming. Even experienced microscopists read only 7 to 11 slides per hour. Microscopy reading requires trained microscopists. Even skilled microscopists have to be trained in the microscopic protocol and recording system. In addition, most countries have few skilled microscopists.

When the results of the rapid diagnostics and smear tests are finalized, the data are merged with those from the individual interviews. During the survey, bar codes are used to protect the confidentiality of respondents. When test results are merged with data from the individual interviews, all information that could potentially identify a respondent is removed so

that there is no way for a respondent to be linked to his/her malaria test results. This produces a data set that links individual characteristics to malaria prevalence. In other words, this makes it possible to link malaria prevalence with a household's education, residence and income (United States Agency for International Development, 2014).

1.4 Spatial statistics and identification of the relation between slums and the spread of malaria

Spatial statistics uses explanatory methods to determine patterns, processes, distribution and relationships between slums and malaria variables. Specific methods were used to determine distance, space and relationships as part of the computation process. The mean and standard deviations were applied to determine the spatial relations among features. By using the spatial statistics analytical method, policymakers can better understand the behaviours of the childhood malaria phenomenon as it relates to geography. The decision made can be assessed through statistically significant levels and the distribution can be summarized in single digits when working with larger data sets such as spatial data sets.

Because resources are limited to control malaria, it is imperative to make the right decisions in allocating them. In addition, slums and malarial hot and cold spots are identified for better decision-making and increasing targeted interventions. In order to solve some of these problems, professionals in the geo-information field have often used density maps. The result has been the classification of different densities that rely on various parameters. The selection of features can therefore be subjective because varying distances will produce different results, thereby hindering well-informed decision-making. The density maps also have problems associated with rendering and symbolizing, given that there are no specified standards.

1.5 Global objective of the study

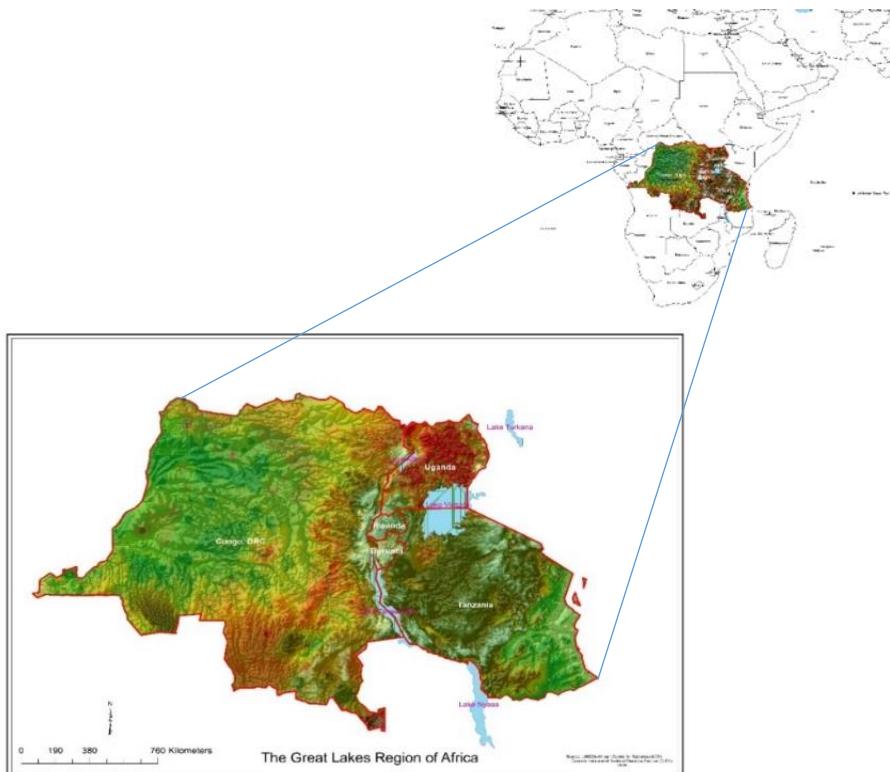
This study provides an assessment of the geospatial childhood malaria distribution and patterns among children living in slums and is aimed at enhancing policymaking and decision-making on malaria eradication and control in five countries in the Great Lakes Region.

The specific objectives of the study are the following:

- (a) Determine the spatial distribution of children under five years of age with malaria and living in slums;
- (b) Establish the land use and land cover patterns that contribute to the prevalence of malaria among children living in slums;
- (c) Promote the development of policy options relating to preventive measures in controlling childhood malaria in the slums of the Great Lake Region.

1.6 Methodology

Figure I
Map of the Great Lakes Region



1.6.1 Study area

The Great Lakes Region is located in East Africa. A total of 8 of the 15 lakes in this region are considered to be “great lakes” because they are recognized accordingly owing to their size and depth. The main lakes are Lake Victoria, Lake Tanganyika, Lake Malawi, Lake Turkana, Lake Albert, Lake Rukwa, Lake Mweru, Lake Kivu and Lake Edward. Lake Victoria is the second largest freshwater lake in the world in terms of surface area and Lake Tanganyika is the world's second largest in volume and the second deepest. It should be noted that the abundance of water in the region, coupled with a higher relative humidity, have resulted in the rapid growth of mosquito parasites. The Region covers the following countries: Burundi, the Democratic Republic of the Congo, Rwanda, Uganda and the United Republic of Tanzania, with a total population of 199 million as of 2016 (Economic Commission for Africa and others, 2016).

The study also sampled 1,981 enumeration areas, or clusters, representing the entire region. The sampled areas covered the period 2010-2014, covering 50,038 households. Of those households sampled, 44,179 had characteristics that met the requirements to be considered slums. Those slums were classified according to [potable water , access to toilets], crowdedness and the types of floors. In the 50,038 households, 4,796 smear tests and 26,999 rapid diagnostics tests for malaria were conducted for children under five years of age. The analysis was done using the results of both tests.

Households in the study were grouped into the 1,981 enumeration areas, and each enumeration area was represented by a geographical coordinate. The spatially linked variables were the following:

- (a) Weighted number of children who tested positive to malaria using the smear test;
- (b) Weighted number of children who tested positive to malaria using the rapid diagnostics test;
- (c) Weighted number of children;
- (d) Number of slums;
- (e) Number of households without water facilities (e.g., running taps and flushing toilets);
- (f) Number of households without toilets;
- (g) Number of overcrowded households;
- (h) Number of households with poor-quality floor material;
- (i) Weighted number of households;
- (j) Weighted number of slums;
- (k) Weighted number of households without water facilities;
- (l) Weighted number of households without toilets;
- (m) Weighted number of overcrowded households;
- (n) Number of household with poor-quality floor material;
- (o) Number of children who tested positive to malaria using the smear test;
- (p) Number of children who tested positive to malaria using the rapid diagnostics test.

The 1,981 geographical coordinates representing clusters were linked with the above-mentioned Demographic and Health Survey attributes for spatial analysis. The cluster coordinates were collected in the field using GPS receivers, usually during the survey sample listing process. In general, the GPS readings for most clusters were accurate to less than 15 m. In order to ensure that respondent confidentiality was maintained, the GPS latitude/longitude positions for all surveys were randomly displaced within each enumeration area. The displacement was randomly carried out so that urban clusters contained a minimum of 0 and a maximum of 2 km of positional error. Rural clusters contained a minimum of 0 and a maximum

of 5 km of error, with a further 1 per cent of the rural clusters displaced at a minimum of 0 and a maximum of 10 km. The displacement was restricted so that the points stayed within the country and within the Demographic and Health Survey region. The displacement was confined to the country's second administrative level where possible. For clusters without GPS readings, other methods were used to determine the coordinates. Coordinates were extracted from paper maps or a gazetteer of settlement names. For some surveys, cluster coordinates were extracted from pre-existing census data provided by the country's census agency/ministry. Regardless of the source, all collected coordinates were always checked for accuracy before they were displaced and released to the public. The source of the coordinates (GPS, map and gazetteer) were reported in the geographic data file that were released to the public (Ren, 2006).

1.6.1.1 Identifying clusters for malaria among children living in slums in the Great Lake Region

The study identified the geographic distribution of malaria in children by grouping the incidences that were in close proximity using critical distance analysis and aligning similar and low values, usually known as hot and cold spots. The statistically significant spots and spatial outliers were spatially located. The geospatial cluster analysis of the data was deployed, which enabled the spatial auto-correlation to scan and group the entire attribute data set linking the data to geographical coordinates.

1.6.1.1.1 Field data sources

The concept of slum used in this study adopts a household-level deprivation approach suggested by the United Nations Human Settlements Programme (UN-Habitat). According to UN-Habitat, a slum household is defined as a group of individuals living under the same roof lacking one or more of the following conditions: (a) improved access to water; (b) access to improved sanitation; (c) housing with adequate space; (d) durability of housing (to protect against climatic conditions); and (e) land rights and ownership. This definition unites theoretical and methodological considerations and is simple, operational and pragmatic, with clear measurable indicators. On the other hand, it fails to incorporate spatial component, and issues relating to the type of shelter deprivation are excluded. The spatial locational components relating to space have been linked to attribute data generated from the various Demographic and Health Surveys used in the study. (United Nations Human Settlements Programme, 2017).

1.6.2. Data selection

1.6.2.1 Malaria parasites

There are five species of malaria parasites, but the most common and most dangerous one in sub-Saharan Africa is *plasmodium falciparum*, which results in the highest rates of incidence and mortality. It is a recurring strain of malaria, living in the liver for long periods of time and leading to relapses many years after initial infection. The parasite is transmitted through the bite of an infective female Anopheles mosquito during a blood meal from one person carrying the parasite to another.

Because this study focuses on malaria, slum and geo-referenced data, it was obvious that the data needed for analysis should include variables on those three components, which were collated from the Demographic and Health Survey. The Survey supports a range of data-collection options that can be tailored to fit the specific monitoring and evaluation needs of countries. The Survey has earned a worldwide reputation for collecting and disseminating

accurate, nationally representative data on topics such as fertility, family planning, maternal and child health, gender, HIV/AIDS, malaria, nutrition and environmental health. The Survey's health data were collected through interviews with women and men, as well as the collection of biological samples to test for HIV and other sexually transmitted infections, malaria, vitamin deficiencies and many other health conditions. The Survey implements demographic and health surveys, AIDS indicator surveys, malaria indicator surveys and service provision assessment surveys. It routinely collects geographic information in all surveyed countries. Malaria indicators, such as prevalence, are normally produced with malaria indicator surveys. It has also developed a detailed module on slums that is sometimes incorporated into the standard Survey, depending on what the country wishes. The standard survey on slums has been used in the study to determine the spatial distribution of slums in the Great Lakes Region.

Given that data in the Demographic and Health Survey are not routinely collected within the programme in every country, as well as data needed for identifying the slums and malaria parasitemia test, the study area was selected according to the availability of data. First African countries were identified where national data collection had been conducted within the Survey from 2010 to 2015 and where household geo-coordinates had been collected to represent clusters. Second, the selection was restricted to surveys with parasitemia tests of malaria among children under five years of age. Lastly, countries were filtered to where the Survey collected data required to operationalize all five criteria suggested by UN-Habitat for identifying the slums (Ren, 2006).

Given that the model needed sufficient cases to conduct the analysis as a whole for various countries in the same region, the Great Lake countries were selected. Because Kenya has not conducted parasitemia tests of malaria among children under five years of age in the past 10 years, it was excluded from the study (see table 1).

Table 1
Area of study and data used

<i>Countries</i>	<i>Demographic and Health Survey (2010-2014)</i>	<i>Combined smear test and rapid diagnostics test sample sizes for children with malaria</i>	<i>Survey information (sample size, number of enumeration areas)</i>	<i>An average cluster size of 100-300 households</i>	
				Average cluster size of 150 households per enumeration area	Maximum cluster size of 300 households per enumeration area
Burundi	2012 malaria indicator survey	4 476.56	200	30 000	60 000

Democratic Republic of the Congo	2013-2014 Demographic and Health Survey	10 068.31	536	80 400	160 800
Rwanda	2010 Demographic and Health Survey	4 052.69	492	73 800	147 600
Uganda	2011 AIDS indicator survey	5 101.20	170	25 500	51 000
United Republic of Tanzania	2011-2012 Demographic and Health Survey	7 699.44	583	87 450	174 900
Total		31 398.20	1 981	297 150	594 300

Source: Demographic and Health Surveys data. Available at: <https://dhsprogram.com/Data/>.

1.6.3 Measurements and the operationalization of the United Nations Human Settlements Programme definition, malaria parasitemia test and geographic information system model

The study used Demographic and Health Survey data to identify and collate slums at the household level within each enumeration area, estimate and sum the number of slum households in each enumeration area and estimate the number of children with malaria in households and slums identified in clusters or enumeration areas. The following standardized definitions were made to operationalize each criterion used to identify slum were classified according to the guidelines on water and sanitation developed by WHO and the United Nations Children’s Fund (UNICEF) and implemented in the Demographic and Health Surveys as follows:

(a) Access to improved drinking water: water sources that are considered to be “improved” or “unimproved”, following guidelines on water and sanitation developed by WHO and UNICEF and implemented in the Demographic and Health Surveys. A household was considered to have access to improved drinking water if the main source of it is one the following elements: piped water in the dwelling unit, piped water to the yard, public tap/standpipe, tube well, rain water, bottle water or a borehole;

(b) Access to improved sanitation: these are sanitation facilities considered to be “improved” or “unimproved”, following guideline on water and sanitation developed by WHO and UNICEF and implemented in the Demographic and Health Surveys. A household was considered to lack access to improved sanitation if toilet facilities are unimproved. This means that the toilet facilities were classified into the following categories: flush to piped, sewer system, flush to septic tank, flush to pit latrine and pit latrine with slab. UN-Habitat indicated the following:

(a) Housing with adequate space: this indicator is related to overcrowding. The number of rooms in the house used for sleeping and the number of household members were used to calculate the number of people per room for each household. UN-Habitat

guidelines suggest a threshold of three people per room to determine overcrowding. A household was considered to lack adequate space if the number of people per room in the household is more than three;

(b) Durability of housing: according to UN-Habitat, a house is considered to be “durable” if it is built on a non-hazardous location and has a structure sufficiently permanent and adequate to protect its inhabitants from the extremes of climatic conditions, such as rain, heat, cold and humidity. Unfortunately, these questions have not been integrated into the Demographic and Health Survey in the area of study. Only the floor material is used to classify housing in term of durability. A household was therefore considered to lack durability of housing if the floor is ground or sand;

(c) Security of tenure: given that this information was not collected in the Survey in the working area, it was decided to remove this component from the definition of a slum.

1.6.3.1 Global Land Cover

The Global Land Cover-SHARE used in the study is a new land cover database created by the Food and Agriculture Organization of the United Nations (FAO). It makes available a set of thematic land cover layers created from a combination of high resolution national and regional and/or subnational land cover databases, with the weighted average land cover information derived from large-scale data sets available. The database is created with a resolution of 30 arc seconds (1 km). The method implemented is grounded on the exploitation of the Land Cover Classification System and SEEA legend systems for the harmonization of the various global, regional and national land cover legends. The most important benefit of the Global Land Cover-SHARE product is its capacity to preserve the existing and available high resolution land cover information at the regional and country level attained by spatial and multi-temporal source data, integrating them with the best combination of global data sets. An initial authentication campaign was done using 1,000 random points statistically scattered over each land cover class. The database is distributed in 11 data layers, in raster format (GeoTIFF), whose pixel values represent the percentage of density coverage in each pixel of the land cover type. The main layer, representing the value of the dominant land cover type, is also available, along with a legend in LYR ESRI format. Information on each layer's source is retrievable in sources layers by joining the raster values with an Excel table. The 11 data layers are artificial surfaces, cropland, grassland, tree-covered area, shrub-covered area, herbaceous vegetation, aquatic or regularly flooded, mangroves, sparse vegetation, bare soil, snow and glaciers and water bodies. These layers have been overlaid with malaria maps to determine their interlinkages for evidence-based decision-making (Latham and others, 2014).

2. Data analysis

During the period 2000-2015, WHO recorded the mortality rate of children between 1 and 59 months of age in the Great Lakes Region. The totals indicated a decline in deaths. The decline was attributed to the control and eradication measures carried out. The Democratic Republic of the Congo, Uganda and the United Republic of Tanzania recorded the highest number of deaths, with Rwanda the least affected country in the region (see table 2).

Table 2

Number of deaths by malaria of children aged 1 to 59 months in the Great Lakes Region, 2000-2015

(Thousands)

<i>Country</i>	<i>2015</i>	<i>2014</i>	<i>2013</i>	<i>2012</i>	<i>2011</i>	<i>2010</i>	<i>2009</i>	<i>2008</i>	<i>2007</i>	<i>2006</i>	<i>2005</i>	<i>2004</i>	<i>2003</i>	<i>2002</i>	<i>2001</i>	<i>2000</i>
Burundi	2 392	2 490	2 566	2 753	2 722	2 889	3 135	3 362	3 746	4 235	4 836	5 928	6 450	7 096	8 021	8 518
Democratic Republic of the Congo	36 285	40 190	44 054	51 655	63 050	76 229	90 701	96 287	104 595	111 439	110 098	110 738	105 251	102 353	99 925	100 577
Rwanda	549	600	673	750	821	896	930	1 035	1 172	1 374	1 668	2 084	2 709	3 249	3 471	3 495
Uganda	6 375	6 941	7 611	9 365	11 989	15 051	18 087	20 655	22 895	26 021	30 978	36 180	39 851	43 852	45 094	45 595
United Republic of Tanzania	4 977	5 122	5 237	4 960	5 254	5 805	6 421	6 629	7 776	9 290	11 069	13 233	15 722	17 530	19 980	21 993
Total	50 578	55 343	60 141	69 483	83 836	100 870	119 274	127 968	140 184	152 359	158 649	168 163	169 983	174 080	176 491	180 178
Grand Total	1 987 580															

Source: World Health Organization Global Health Observatory, Number of deaths caused by malaria. Available at: <http://apps.who.int/gho/data/view.main.ghe1002015-CH8?lang=en>.

2.1 Spatial data quality analysis

Step 1

The Global Moran's I and Global Getis-Ord General G spatial statistical methods were used to assess the entire data set to determine any spatial autocorrelation clustering in the data set for slums and the combined smear test for malaria. The Global Moran's I compared features and feature values from a hypothetical random distribution and determined the degree of dispersion and clustering from the random distribution of tests conducted and identified slums characteristics.

Moran's I is defined as:

$$I = \frac{N}{\sum_i \sum_j w_{ij}} \frac{\sum_i \sum_j w_{ij} (X_i - \bar{X})(X_j - \bar{X})}{(\sum_i X_i)^2}$$

Where N is the number of spatial units indexed by i and j , X is the variable of interest, \bar{X} is the mean of X and w_{ij} is an element of a matrix of spatial weights.

The expected value of Moran's I under the null hypothesis of no spatial autocorrelation is

$$E(I) = \frac{-1}{N - 1}$$

Its variance equals:

$$\text{Var}(I) = \frac{NS_4 - S_3 S_5}{(N - 1)(N - 2)(N - 3)(\sum_i \sum_j w_{ij})^2} - \langle E(I) \rangle^2$$

Where:

$$S_1 = \frac{1}{2} \sum_i \sum_j (w_{ij} + w_{ji})^2$$

$$S_2 = \frac{1}{2} \sum_i (\sum_j w_{ij} + w_{ji})^2$$

$$S_3 = \frac{N^{-1} - \sum_i (X_i - \bar{X})^4}{N^{-1} - \sum_i (X_i - \bar{X})^2)^2}$$

$$S_4 = (N^2 - 3N + 3)S_1 - NS_2 + 3 \left(\sum_i \sum_j (w_{ij})^2 \right)$$

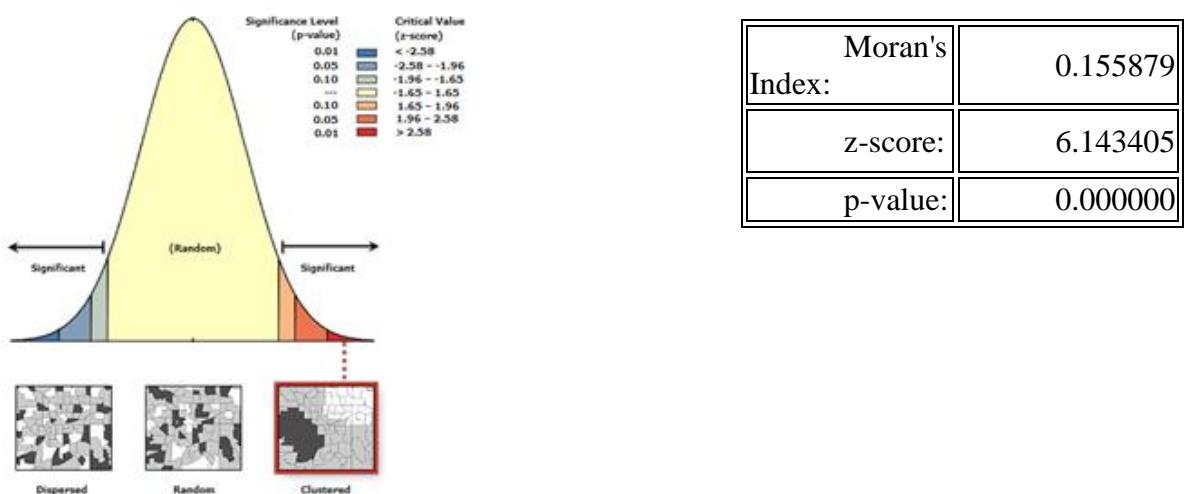
$$S_5 = (N^2 - N)S_1 - 2NS_2 + 6 \left(\sum_i \sum_j (w_{ij})^2 \right)$$

The values of I range from -1 to $+1$. Negative values indicate negative spatial autocorrelation and positive values indicate positive spatial autocorrelation. A zero value indicates a random spatial pattern. For statistical hypothesis testing, Moran's I values can be transformed to Z-scores.

Moran's I is inversely related to Geary's C, but it is not identical. Moran's I is a measure of global spatial autocorrelation, while Geary's C is more sensitive to local spatial autocorrelation. The analysis strongly affirmed a strong autocorrelation in the data, as indicated in figure II.

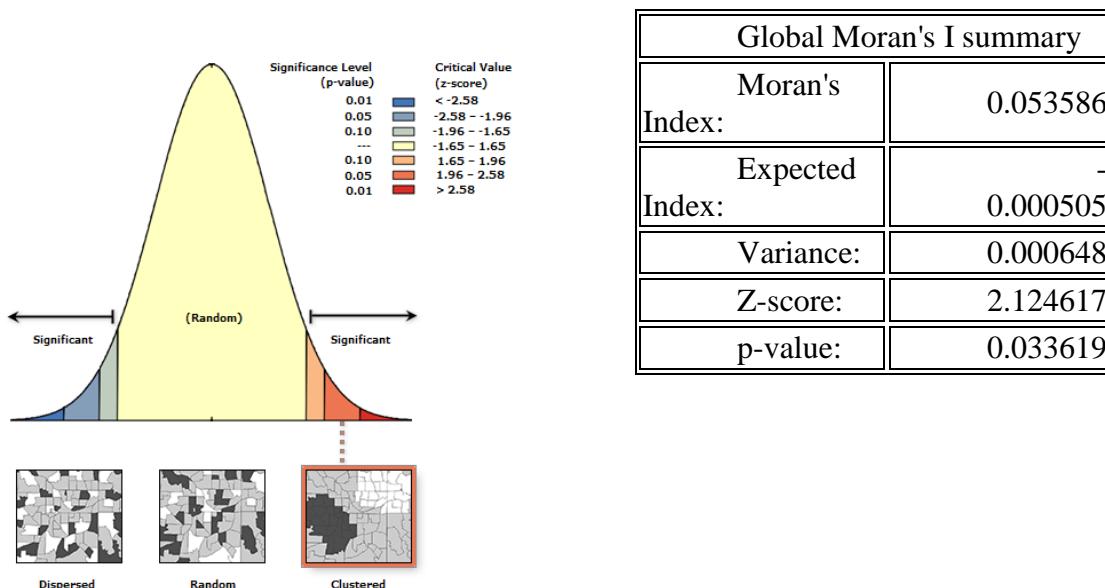
Figure II

Spatial autocorrelation report for slums using the weighted slums method in the Great Lakes Region



Given the Z-score of 6.1, there is a less than 1 per cent likelihood that this clustered pattern could be the result of random chance, indicating that there is no clustering in the patterns observed. The Moran's Index of 0.16 indicated that there no clustered pattern were observed in the spatial distribution of slums, and this indicates that the results are good enough for further analysis. A positive value of 1 indicated that the geographical coordinates with attribute data on slums had similar high or low values, indicating randomness. A negative value for 1 depicted the fact that the geographical coordinates with attribute data on slums had dissimilar high or low values, and these are outliers. The p value of the slums in the data set must be small enough for the cluster or outlier to be considered statistically significant. The Getis-Ord GI* was used to identify statistical significant hot spots and cold spots, and hot spots are selected with features having high values and surrounded by other hot spots.

Figure III
Spatial autocorrelation report for malaria in children through the use of the smear test and rapid diagnostics tests in the Great Lakes Region



Given the Z-score of 2.1, there is a less than 5 per cent likelihood that this clustered pattern could be the result of random chance, indicating randomness. A positive value of 1+ indicated that the geographical coordinates with attribute data on malaria had similar high or low values. A negative value for -1 showed that the geographical coordinates with attribute data on malaria had dissimilar high or low values, and these are outliers. The p value of the malaria incidence in the data set must be small enough for the cluster or outlier to be considered statistically significant. The Getis-Ord GI* was used to identify statistical significant hot spots and cold spots, and hot spots are selected with features having high values and surrounded by other hot spots.

Step 2

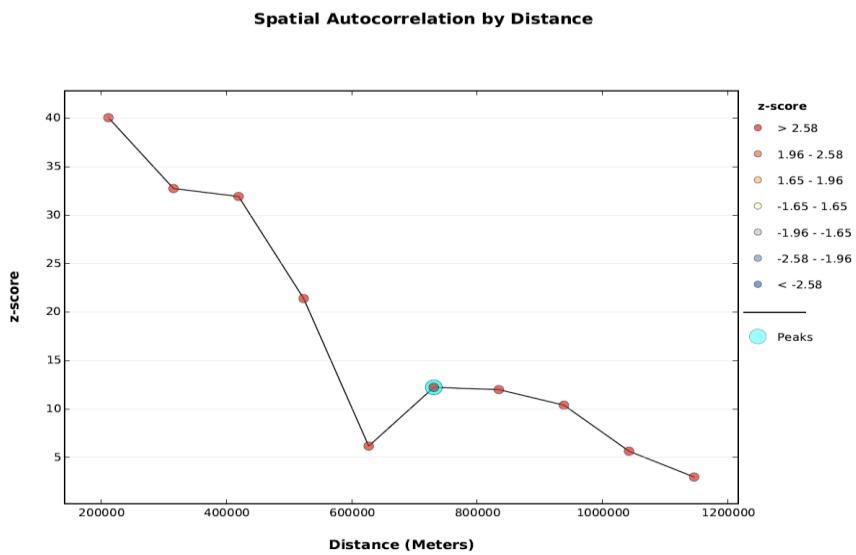
The scale between the bandwidths or distance between the geographical coordinates in which clustering occurred were determined in the spatial data set. The cluster analysis process looked into the closeness between relevant neighbouring spatial features. The Ripley's K-function and the Incremental Global Moran's I tools were used to determine the maximum spatial autocorrelation of childhood malaria in the data set. After the critical distance was determined, the local statistical distances were determined by using the Local Global Moran's I and the Local Getis-Ord GI* to compute data for each of the 1,981 geographical coordinates and attribute data used in the study. The Global Moran's I provided an average for the entire data set, while the Local Global Moran's I and the Local Getis-Ord GI* provided a number for each feature, thereby allowing visual inspection of the data set to determine clustering.

The occurrence of clustering can occur in various scales, and it is important to identify the best scale to conduct the clustering of childhood malaria from the smear tests and rapid diagnostics tests in the spatial data. In order to determine the scale, the Incremental Spatial Autocorrelation has to be determined, and the highest data point will indicate the right scale to use in determining clustering. A starting distance has to be determined, and this is the distance in which each given spatial coordinate has at least one neighbour, and the distance band has to be calculated from the smear tests and rapid diagnostics tests spatial data. The average distance

of 14,707,000 m was determined for all the geographical coordinates in the data set representing the region using the Distance Band from Neighbour Count in spatial statistics. This returns the minimum, the maximum and the average distance to the specified Nth nearest neighbour (N is an input parameter) for a set of features.. This number should be any integer between 1 and the total number of features in the feature class. A list of distances between each feature and its Nth neighbour is compiled and the maximum, minimum and average distances are outputted to the results window. Distances are calculated from each feature to neighbouring features.

Figure IV

Incremental spatial autocorrelation for malaria in children through the use of the smear test and rapid diagnostics tests in the Great Lakes Region



Global Moran's I Summary by Distance

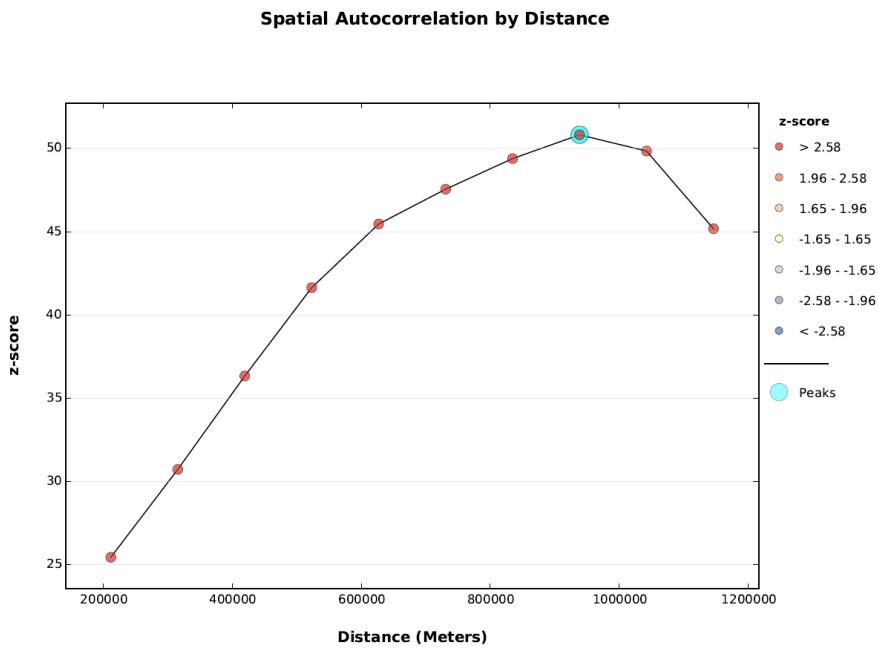
Distance	Moran's Index	Expected Index	Variance	z-score	p-value
211638.00	0.051545	-0.000505	0.000002	40.077615	0.000000
315476.17	0.035415	-0.000505	0.000001	32.768111	0.000000
419314.34	0.029512	-0.000505	0.000001	31.947606	0.000000
523152.50	0.016604	-0.000505	0.000001	21.416952	0.000000
626990.67	0.003766	-0.000505	0.000000	6.180081	0.000000
730828.84	0.006932	-0.000505	0.000000	12.243316	0.000000
834667.01	0.005898	-0.000505	0.000000	12.010269	0.000000
938505.17	0.004305	-0.000505	0.000000	10.406528	0.000000
1042343.34	0.001798	-0.000505	0.000000	5.658038	0.000000
1146181.51	0.000537	-0.000505	0.000000	2.989630	0.002793

First Peak (Distance, Value): 730828.84, 12.243316

Max Peak (Distance, Value): 730828.84, 12.243316

Distance measured in Meters

Figure V
Incremental spatial autocorrelation for slums in the Great Lakes Region



Global Moran's I Summary by Distance

Distance	Moran's Index	Expected Index	Variance	z-score	p-value
211638.00	0.097544	-0.000505	0.000015	25.443748	0.000000
315476.17	0.082322	-0.000505	0.000007	30.723560	0.000000
419314.34	0.075217	-0.000505	0.000004	36.331838	0.000000
523152.50	0.071323	-0.000505	0.000003	41.635202	0.000000
626990.67	0.066906	-0.000505	0.000002	45.459771	0.000000
730828.84	0.061913	-0.000505	0.000002	47.549344	0.000000
834667.01	0.057541	-0.000505	0.000001	49.387884	0.000000
938505.17	0.053756	-0.000505	0.000001	50.816681	0.000000
1042343.34	0.048498	-0.000505	0.000001	49.839215	0.000000
1146181.51	0.040605	-0.000505	0.000001	45.174791	0.000000

First Peak (Distance, Value): 938505.17, 50.816681

Max Peak (Distance, Value): 938505.17, 50.816681

Distance measured in Meters

Step 3

The results were combined with fundamental data sets such as the digital elevation model and hydrological networks to establish the correlation with these spatial features, thereby determining the existence of malaria with the purpose of suggesting appropriate measures to be taken to eradicate the pandemic. The Cluster and Outer analysis (Anselin Local Global Moran's I) was used to identify statistically significant hot spots, cold spots and spatial outliers by using the maximum peak value distance of 730,828.84 m for malaria and 938,505.17 m for slums (see figure VI).

Figure VI

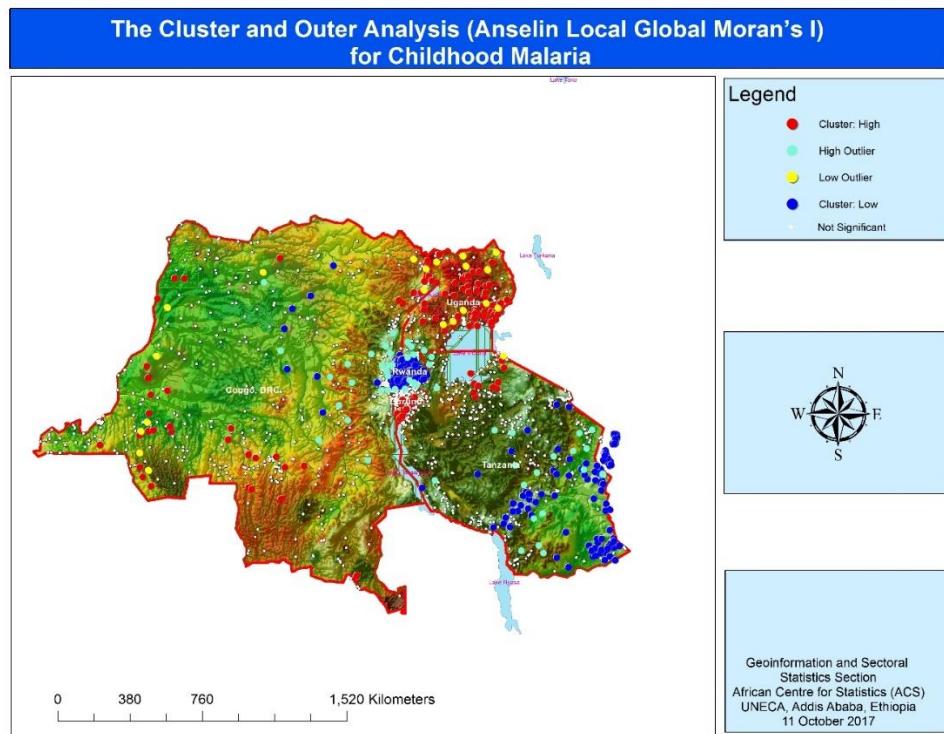
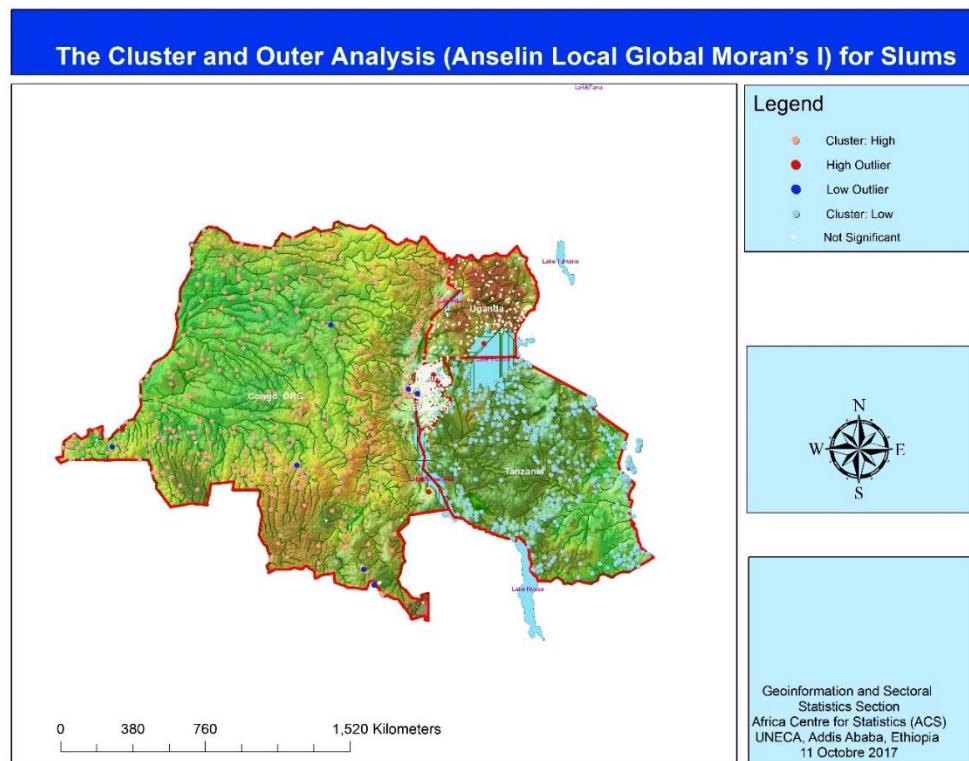


Figure VII



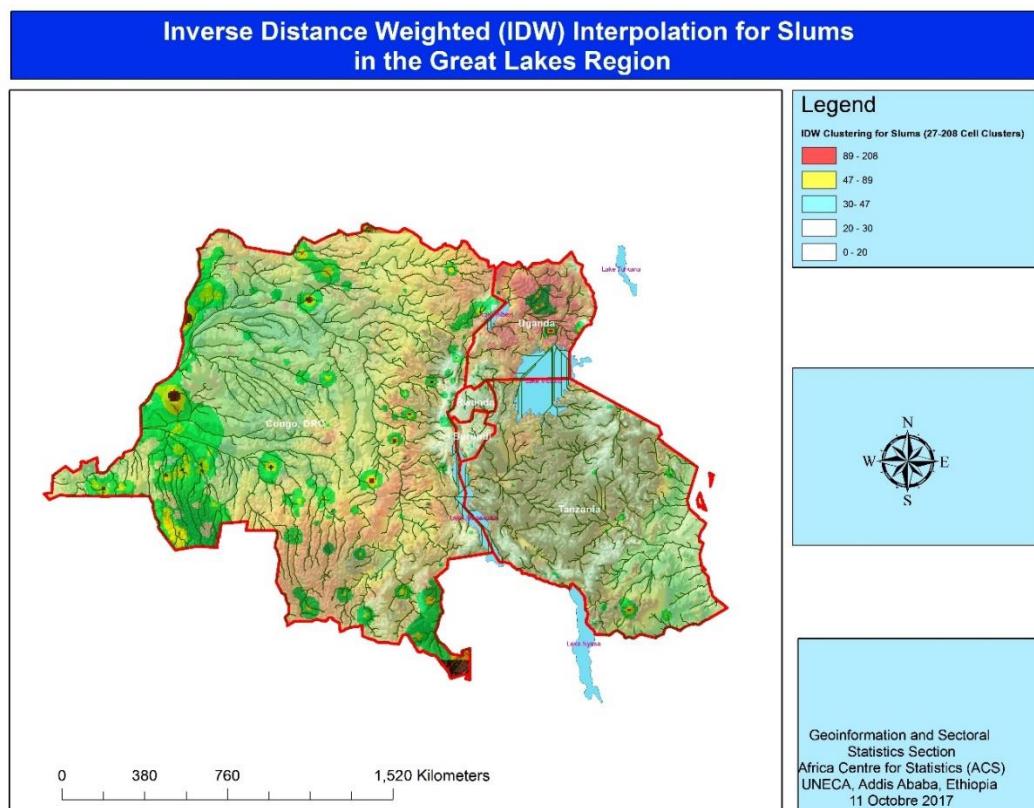
The Cluster and Outer analysis (Anselin Local Global Moran's I) for childhood malaria (see figure VII) indicates that highest clusters were in Uganda, followed by Burundi. The United Republic of Tanzania has fewer cases in the north, while the concentrations in the Democratic Republic of the Congo are predominantly in the southern parts of the country. With regard to slums, the highest clusters are found in the Democratic Republic of the Congo, followed by Uganda, while the United Republic of Tanzania exhibited the lowest clustering.

3. Results

The Inverse Distance Weighted interpolation was used to determine cell values using a linearly weighted combination for a set of sample points. The Inverse Distance Weighted for malaria used the maximum peak value distance of 730,828.84 m bandwidth for malaria and 938,505.17 m for slums in the computation. The weight is a function of inverse distance. The surface being interpolated used the slum and childhood malaria and slum data for the region as a dependent variable. That method assumed that the variable being mapped decreased in influence with distance from its sampled location.

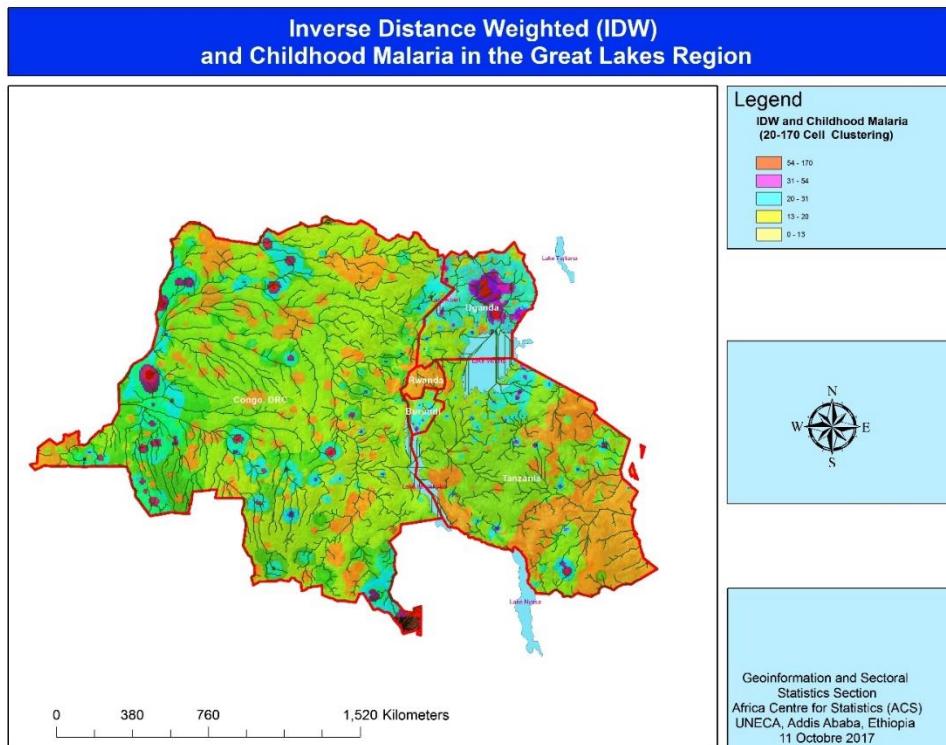
3.1 Determining the spatial distribution of children under five years of age having malaria and living in slums

Figure VIII



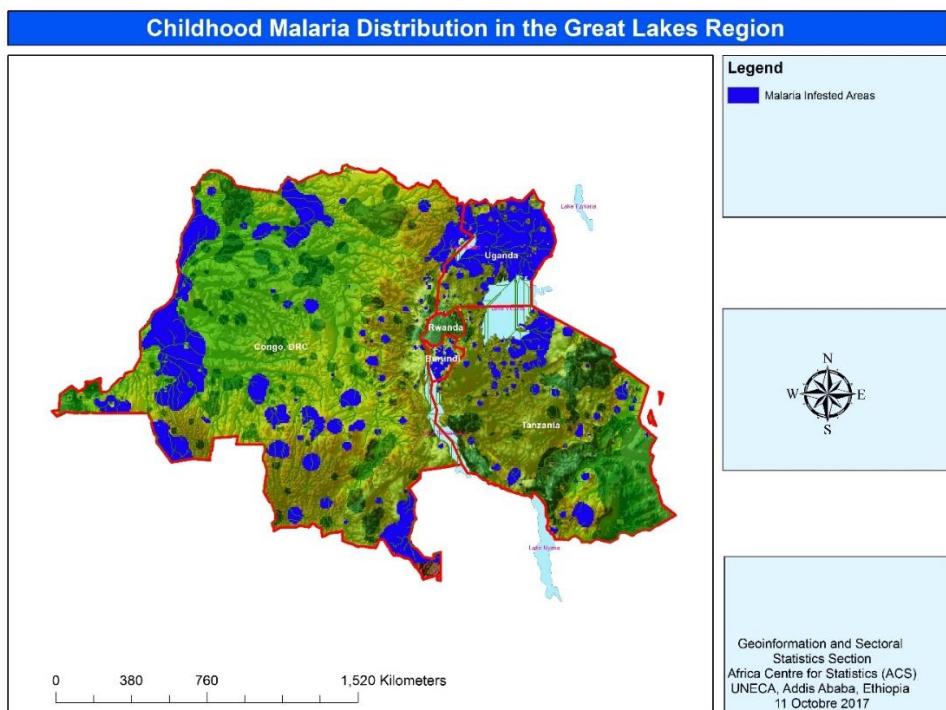
The Inverse Distance Weighted interpolation for slums indicated that the cell values that corresponded to high clustering ranged in intensity from 27 to 208 and were categorized into four ranges. The interpolated results indicated a high correlation between slum intensity and the high clustering of enumeration areas.

Figure IX



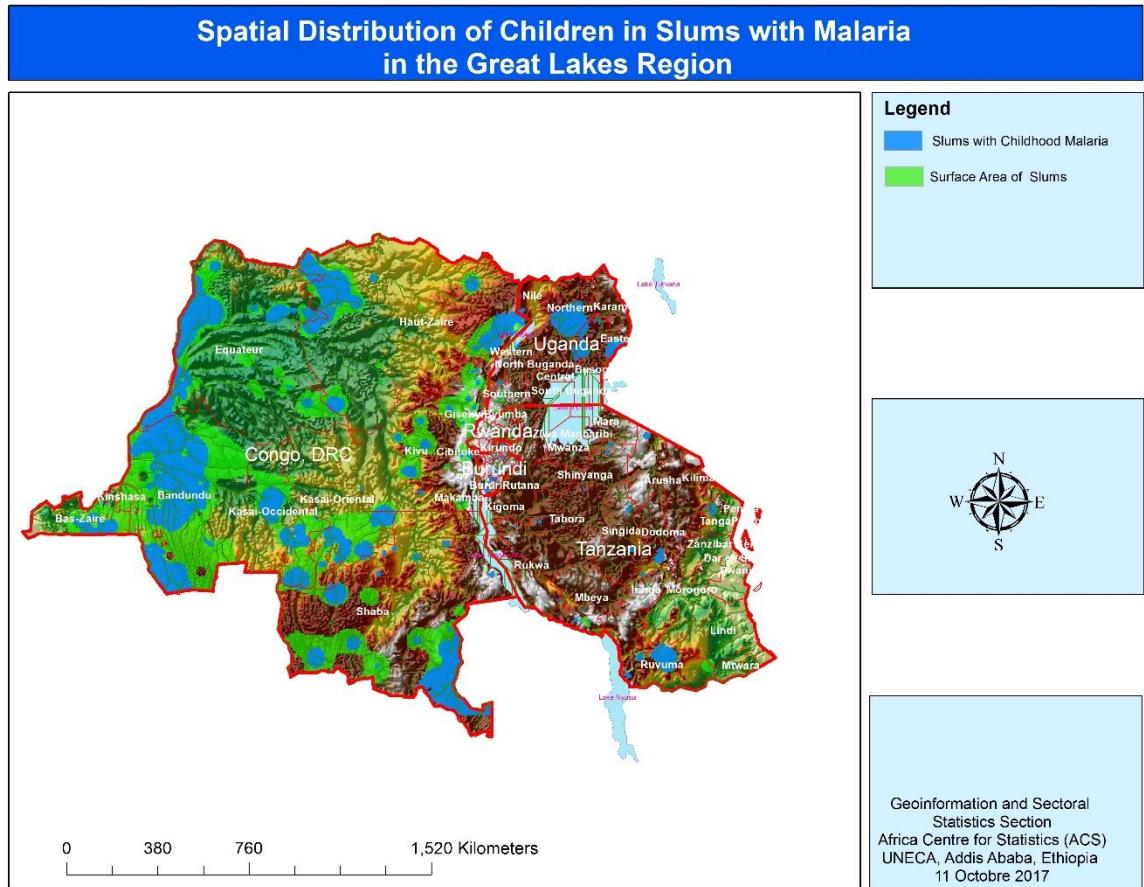
The Inverse Distance Weighted interpolation for slums indicated that the cell values that corresponded to high clustering ranged in intensity from 20 to 170 and were categorized into four ranges. The interpolated results indicated a high correlation between malaria intensity and the high clustering of enumeration areas.

Figure X



Areas in the region where Inverse Distance Weighted and Childhood Malaria (20-170 Cell Clustering) ≥ 20 were calculated, and figure X portrays the entire areas in the region where children are affected by malaria. This area is not limited to slums, but include other affected zones. Areas in the region where Idw_Slums ≥ 27 were calculated, and figure X portrays the entire areas in the region where slums are present.

Figure XI

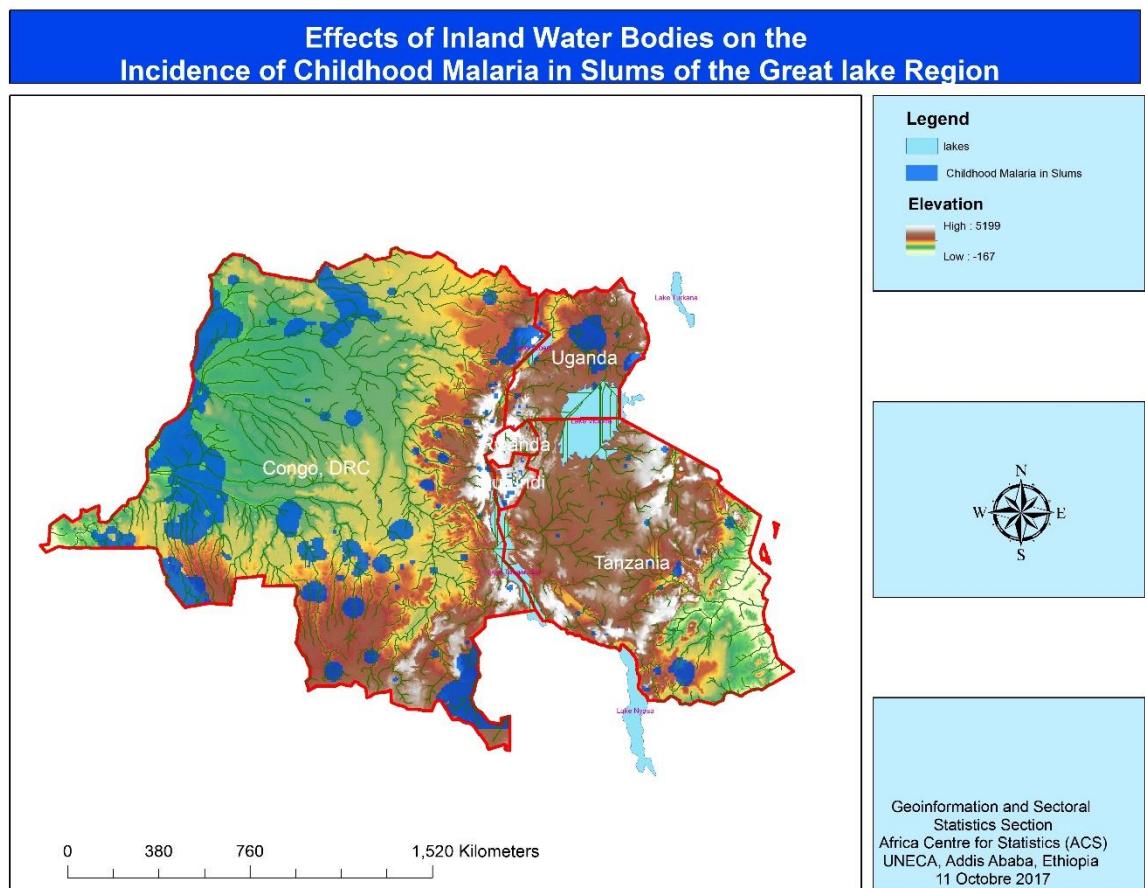


Areas in the region where (Childhood Malaria Distribution == 1) and (Slum Areas == 1) were calculated, and figure XI portrays the entire areas in the region where slums and malaria are united. This indicates the suitable areas for effective malaria control for children living in slums.

3.1.1 Establishing the land use and land cover patterns inducing malarial prevalence among children living in slums

3.1.2 Inland waters

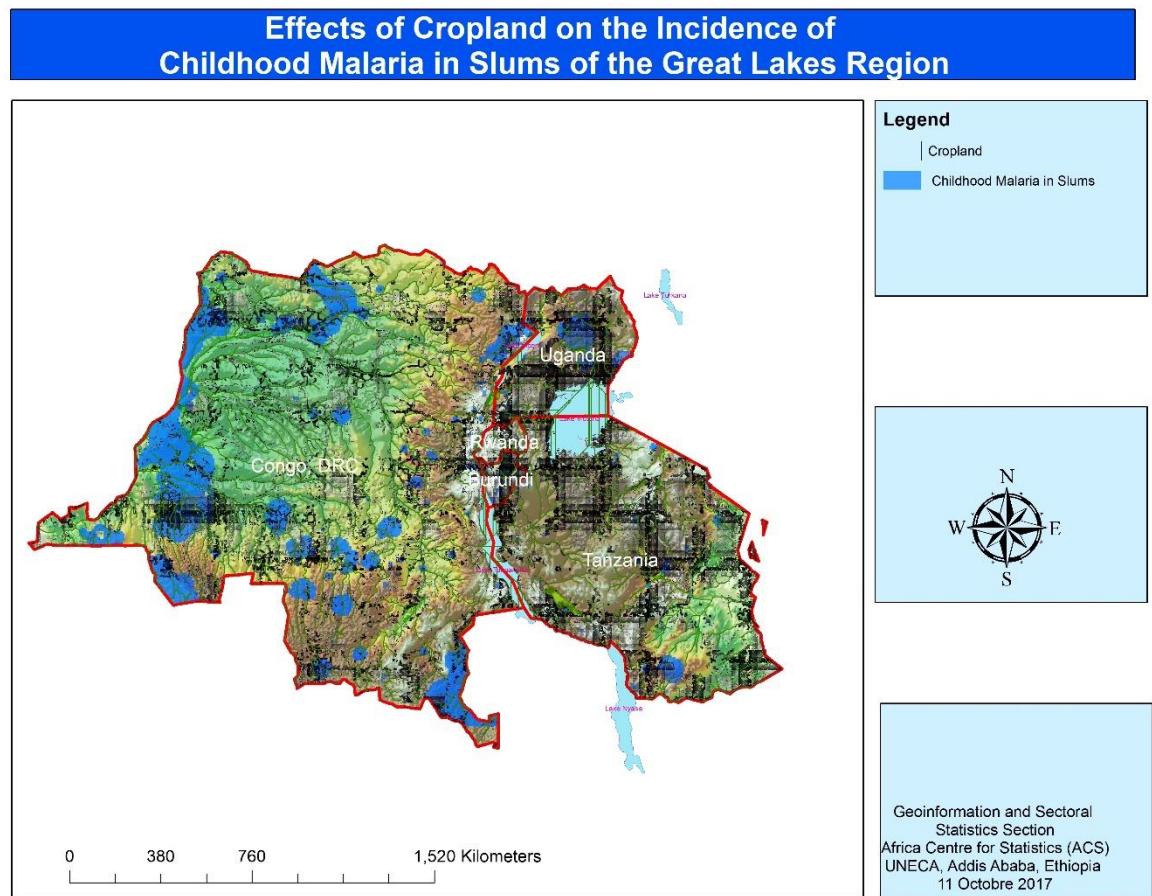
Figure XII



The incidence of childhood malaria in slums is highest in the Democratic Republic of the Congo because the country is drained by inland waters.. Permanent water bodies are inland in nature and not found in the coastal zone and areas. These inland waters are dominated by the permanent, seasonal or intermittent occurrence of flooding that fosters the growth of the malaria parasite. Inland waters include rivers, lakes, floodplains, reservoirs, wetlands and inland saline systems. Owing to the influence of rainfall, humidity and the spatial distribution of the Congo River and tributaries, there is a high concentration of water. This situation is not as serious in Burundi, Rwanda, Uganda and the United Republic of Tanzania. Figure XII indicates areas of intervention for the control and prevention of childhood malaria in slums.

3.1.3 Cropland

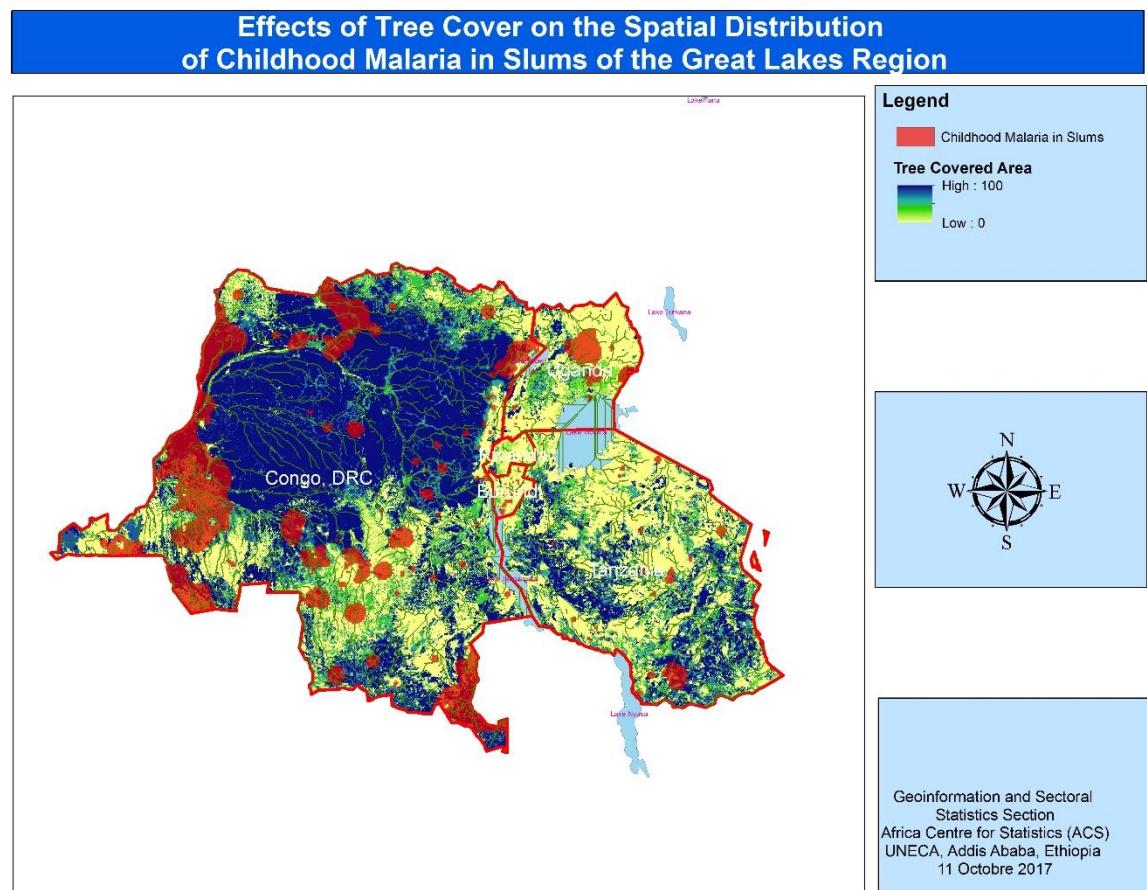
Figure XIII



According to FAO, cropland is composed of a main layer of cultivated herbaceous plants (graminoids or forbs). It includes herbaceous crops used for hay. All the non-perennial crops that do not last for more than two growing seasons and crops such as sugar cane, in which the upper part of the plant is regularly harvested while the root system can remain for more than one year in the field, are included in this class. According to the results, cropland has little influence on the spread of the malaria parasite in slums. Cropland covers most of Burundi, Rwanda, Uganda and the United Republic of Tanzania, and these countries have fewer cases childhood malaria in slums.

3.1.4 Tree-covered area

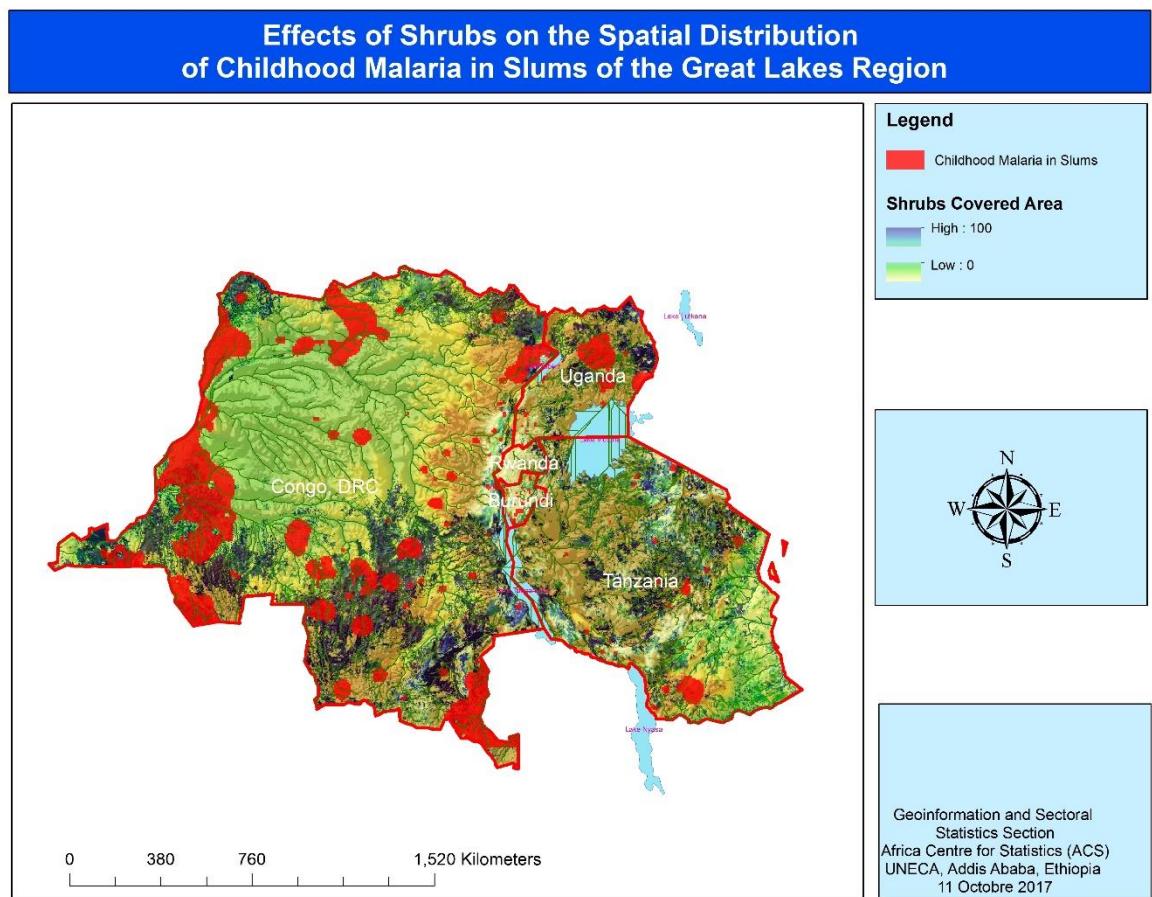
Figure XIV



Tree cover includes any geographic area dominated by tree plants with a coverage of 10 per cent or more. Other types of plants (shrubs and/or herbs) can be present, even with a density higher than trees. Areas planted with trees for forestation purposes and forest plantations are included in this class. This class includes areas seasonally or permanently flooded with fresh water. It excludes coastal mangroves (>07). The incidence of childhood malaria in slums is highest in the Democratic Republic of the Congo because the country has the highest level of tree cover and drainage by inland waters, compared with the other countries of the Great Lakes Region. This situation has been worsened by high levels of precipitation and humidity, culminating in the endemic nature of the parasite in the Democratic Republic of the Congo, compared with the other neighbouring countries (see figure XIV).

3.1.5 Shrub-covered area

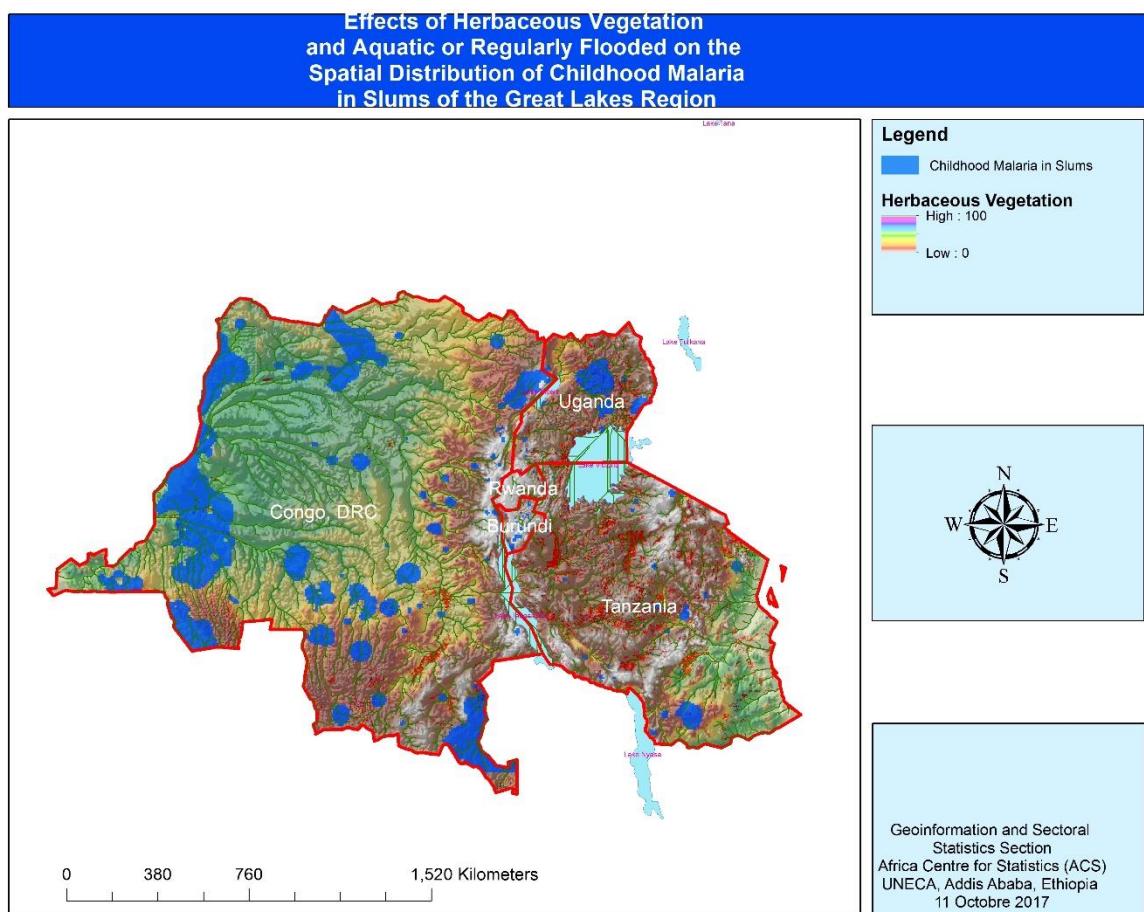
Figure XV



Shrub-covered areas include any geographical area dominated by natural shrubs with a coverage of 10 per cent or more. Trees can be present in scattered form if their coverage is less than 10 per cent. Herbaceous plants can also be present at any density. The class includes shrub-covered areas permanently or regularly flooded by inland fresh water. It excludes shrubs flooded by salt or brackish water in coastal areas (>07). According to the results, owing to the dense forest cover, there is little development of shrubs and few quantities of shrubs occupy childhood malaria-infested zones (see figure XV).

3.1.6 Herbaceous vegetation and aquatic or regularly flooded

Figure XVI



The herbaceous vegetation, aquatic or regularly flooded areas includes any geographic area dominated by natural herbaceous vegetation (coverage of 10 per cent or more) that is permanently or regularly flooded by fresh or brackish water (e.g., swamps and marshland). Flooding must persist for at least two months annually to be considered regular. Woody vegetation (trees and/or shrubs) can be present if its coverage is less than 10 per cent. The relationship between herbaceous vegetation and childhood malaria in slums is limited, as shown in figure XVI.

4. Conclusion and recommendations

Inland water concentration and dense tree cover, coupled with other factors such as humidity, precipitation and sanitation, are the major factors contributing to the failure to eradicate childhood malaria in slums. The Democratic Republic of the Congo, followed by Uganda and the United Republic of Tanzania, require rapid interventions in terms of fundraising in order to control and eradicate childhood malaria in slums. Specific attention should be placed on the western and south-western parts of the Democratic Republic of the Congo, and areas around Lake Albert in the north-east of the country should be another focus area of intervention. With regard to Uganda and the United Republic of Tanzania, specific attention should be given to the north-east and south-east, respectively. In Burundi, the urgency is less, although the spread of childhood malaria in slums occurs throughout the country. In Rwanda, which is

mostly mountainous, few resources are needed because the country is the least affected by childhood malaria in slums.

4.1 Recommendations

The following are the key recommendations:

- Resources to control and prevent malaria should be allocated to specific endemic areas such as the western and south-western parts of the Democratic Republic of the Congo and areas around Lake Albert in the north-east. With regard to Uganda and the United Republic of Tanzania, specific attention should be given to the north-east and south-east, respectively. In Burundi, the urgency is less, although the spread of childhood malaria in slums occurs throughout the country. A wider programme for the eradication of childhood malaria should be carried out in the western, south-western and north-eastern parts of the Democratic Republic of the Congo, north-eastern Uganda, the north-eastern region of the United Republic of Tanzania and all of Burundi.
- ECA, in collaboration with the WHO Regional Office for Africa, UNICEF and other stakeholders such as the Global Fund to Fight AIDS, Tuberculosis and Malaria should develop strategies to combat childhood malaria in the slums of the Great Lakes Region.

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