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RESEARCH ARTICLE

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Spatio-Temporal Distribution of Malaria Incidence in Rwandan Highlands

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Abstract

Malaria remains among the top diseases that are responsible for morbidity and mortality in a big number of developing countries. Efforts are being made to control but it recurs and new incidences are emerging in areas that are known to be malaria free. This study was aimed to investigate distribution of malaria incidence in the highland regions of Karogi, Muhanga and Rubavu districts, Rwanda. Malaria cases for the period ranging from 2004 to 2014 were collected from 26 health centres and incidences were calculated to the standard ration of 1000. Findings indicated less malaria in highland, and it was distributed according to the altitude; high altitude had less malaria incidence while valleys and plains in the highlands were characterised by increased value of malaria incidence. The order of general prevalence in the study area indicated that Muhanga had 9.5/1000, Karongi with 4.39/1000 and Rubavu 1.8/1000. Nyabikenke health centre (Muhanga district) indicated high prevalence 135.5/1000 while Busasamana health centre (Rubavu district) had the lowest prevalence 2.65/1000. The prevalence order was inversely proportional to the altitude. Compared to the national situation, malaria in the highland is still lower, but much effort is needed to control new cases since population may be at the high risk of malaria than other population in endemic areas due to low malaria immunity. Further researches are needed to investigate the cause of malaria incidence in highland for proper mitigation measures.

Key Words: Malaria, Incidence, Prevalence, Highland, Rwanda, Spatio-Temporal

INTRODUCTION

The WHO (2017) reported high frequency and amplitude of malaria prevalence with an estimated one fifth of the African population leaving in malaria epidemic prone areas. Besides, re-emergence of malaria incidence in African highlands has been reported in several countries Rwanda included (Geertruyden *et al.*, 2009). The rate of re-emergence according to Bishop and Litch (2000) depends on adaptation of vectors in time and space and also to environment changes. Because of limited immunity, the populations highlands that were not known for malaria incidences are at high risk of clinical malaria (Vajda and Webb, 2017). Malaria cases in the highland areas has therefore attracted much attention in countries such as Kenya, Ethiopia and Uganda (Wanjala *et al.*, 2011). Generally in the African Highlands, malaria transmission is distributed according to the altitude and topography; Lower altitude areas are considered as malaria risk while highland are free of malaria areas.

In Rwanda the government succeeded to control malaria in the endemic zones after intensive initiative from 2005. The strategic plan of 2013-2020 has put emphasis on the use of insecticide, and entomological monitoring in twelve sentinel sites that are providing valuable entomological data (President and Initiative, 2017). However, less importance is being given to the highland areas because these are not considered malaria endemic areas in the country (MINISANTE, 2012).

Rwandan landscape is dominated by highlands (Rwanda Environmental Management Authority, 2005). It is hypothesized that for every 1000-meter gain in elevation, temperatures decrease by 6^{o} C (Kevin, 2009). Minimum temperature for parasite development of *Plasmodium falciparum* and *Plasmodium vivax* approximates 18^{o} C and 15^{o} C, respectively, limiting the spread of malaria at higher altitudes. Government of Rwanda (2011) indicated that the thermal gradient in Rwanda is (lapse rate) is 0.56° C per 100 m. This should restrict malaria in the areas of Rwandan Highlands due to limited survivor conditions, or if it happens it should be by accident not seasonal.

According to Rwanda Biomedical Centre (2017) malaria had been successfully controlled by the year 2011, with statistics indicating an 86% decline of malaria incidence; 87% decline in outpatient malaria cases; and 74% decline in inpatient malaria deaths. However, there is a resurgency of malaria morbidity from 2012 to today particularly in districts known to be high malaria burden in the country, mostly located in the eastern and southern province (Ministry of Health, 2012). Therefore there is still need to assess the spatial distribution of malaria in the hitherto "malaria free zones" to establish trends and status from field data to inform and construct credible simulation models that can inform policy makers on strategies for malaria control.

METHODS

Study Site

Rwandan highland lies in West, North and Southern part which is one of the four categories of Rwandan relief. The study area covered 3 districts; Karongi and Rubavu in Western province in the range of Congo-Nile divide and Muhanga district in southern province (Figure 1). The study area lies in 1.505^{o} and 2.317^{o}S and 29.244^{o} and 29.813^{o}E at an altitude ranging from 1,538 to 3000 m above the sea level (Karongi District, 2011) (Muhanga, 2013) (Rubavu, 2013).

Rwanda has a complex existing climate, with wide variations across the country and with very strong seasonality (DFID, 2009). It is primarily a mountainous country, with average altitude of 900 m in south-west, 1500 to 2000 m in the south and the centre of the country, 1800 to 3000 m in the highlands of the north and the west and 3000 to 4500 m in the regions of Congo-Nile Crest and the chain of volcanoes (President's Malaria Initiative, 2014). The equatorial climate is modified by this widely varying altitude across the country. It leads to a more temperate climate than much of the rest of East Africa. Average annual temperature in Rwanda ranges between 16º C and 20º C though they are much lower than this in the higher mountains (MINIRENA, 2013).

Rwandan highlands are the most suitable zones for agricultural production, which is the pivot sector of Rwandan economy. 78.5% of total population is engaged in agriculture which remains the ultimate source of income where the rate of poverty is high like Karongi District. Karongi (2013) indicated that the rate of poverty was 61.7% while the extreme poverty was 39.8%. On the other hands highland areas are more fertile especially near the volcanoes where good quality of Irish potatoes is produced. Rubavu (2013) indicated that only Rubavu district produced 17.4% of national Irish production. Due to agriculture production the highland regions are overpopulated, that exposes this area on different diseases Ministry of health (2014) published top ten causes of morbidity in health centres, they were: ARI (acute respiration infections), malaria, intestinal parasite, respiration infections acute other, physical traumas and fracture, gastro-intestinal disease, skin infection, eyes problems, diarrhoea and others.

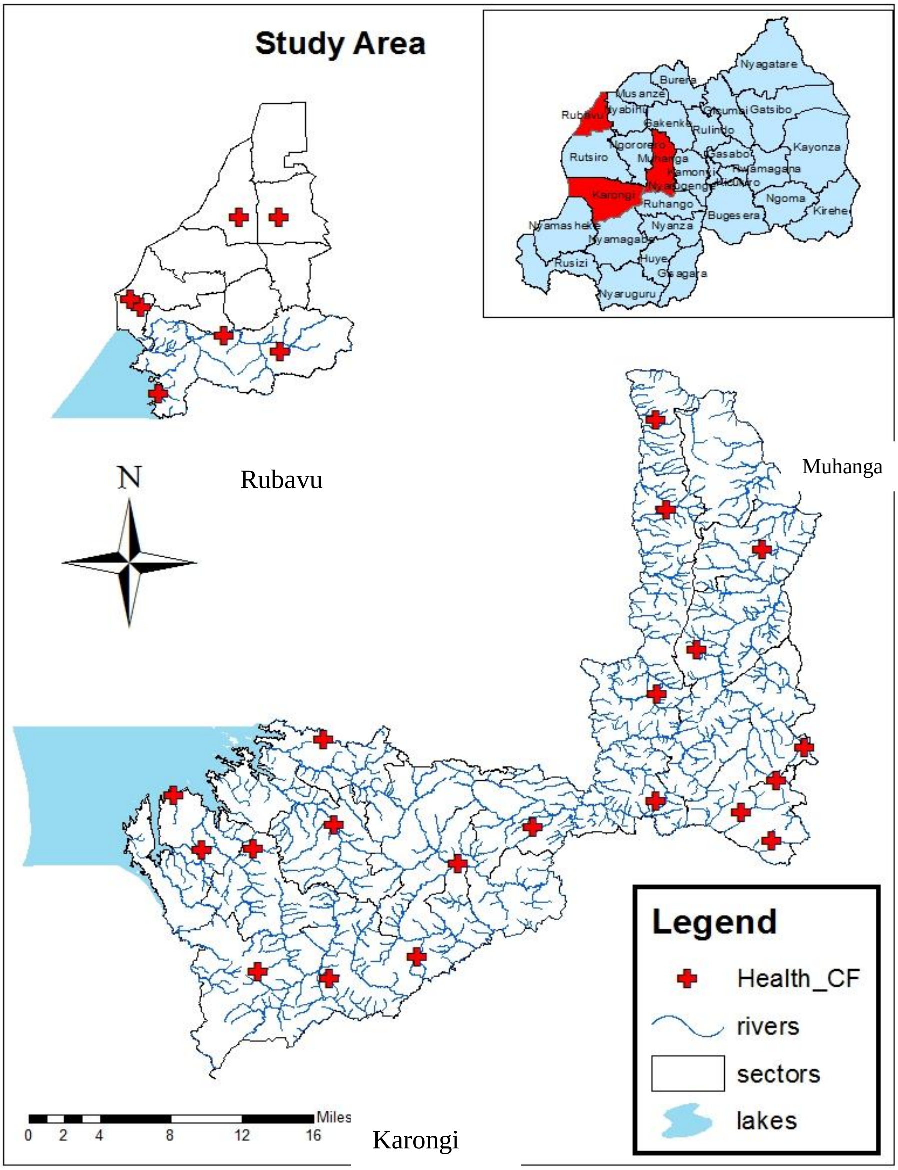


Figure 1. Location of the Study Area in Muhanga, Karongi and Rubavu Respectively

Study Design

This study was intended to analyse spatial-temporal of malaria incidence in Rwandan highlands. The design of the research was developed from the theory which states that "Altitude is a defence against malaria, so the highland was considered as shelter against malaria". The study design was descriptive survey using longitudinal data (2004-2014), collected from health centres and spatial data collected from the same areas using multistage cluster sampling of districts in highlands area of Rwanda and from district to sectors making the catchment of health centres. Data analysis used descriptive statistics, regression analysis and spatial data presentation with clinical data.

Sampling Design

Research used multistage cluster where sampling means that the sample increasingly smaller, embedded units (Hedt-Gauthier, 2014). In this case selection of malaria cases in the period of 2004-2014, embedded in (or "clustered in") Health centres, and health centre which are clustered in districts.

A multistage cluster sample of malaria identified selected districts in Rwandan highland, and purposively sampled few health centres, based on conditions that health centre was operating during the period of study (2004-2014), and record of malaria has remained uniform, with the same calibration and the same precision. Only 26 health centres had enough data for the desired study period as reports in HMIS were indicating. This was consisting of a two-stage cluster sample with District as stage one, and Health centres as stage two. Research found 145,159 cases out of 693,112 average populations from 26 identified Sectors.

Spatial Data Collection and Data Analysis Tools

Shape file of vector data storage format for health centres (at a scale of 1:250,000) obtained from Rwanda Biomedical Centre (RBC). Topographic map showing different relief of Rwanda and other maps were obtained from Rwanda Natural Resource Authority (RNA), Hand held GPS, model Unistrong G3 was used to obtain spatial coordinates, Application Soft-wares: Microsoft Excel, STATA, E-views7 and ArcGIS 10.

Data Analysis

Monthly malaria incidence was calculated for each health centre using total malaria case counts from health centres, over total annual population estimates from national census of 2002 and 2012, times 1000, or

$$\frac{Number\ of\ malaria\ cases}{Population\ in\ a\ given\ period} x1000$$

(Committee on Mathematical Foundations of Verification, Validation, and Uncertainty Quantification, 2001)

The following is the formula used to estimate population from 2004 up to 2014.

$N_t = N_0\, e^{rt}$

Where N_t =size of population at time t, N_0 =size of population at time zero, e=base of natural logarithms =2.71828, r=rate of population growth, t=time elapsed.

Percentage Change = ((Most recent number-Previous number)/Previous number)* Percentage.

Simple Regression Analysis was applied to test the relationship between malaria incidences in Rwandan highland with time period of 2004 to 2014, and to deduce coefficient of correlation and determinant coefficient R^2. This relationship was established using Excel and SPSS software.

RESULTS

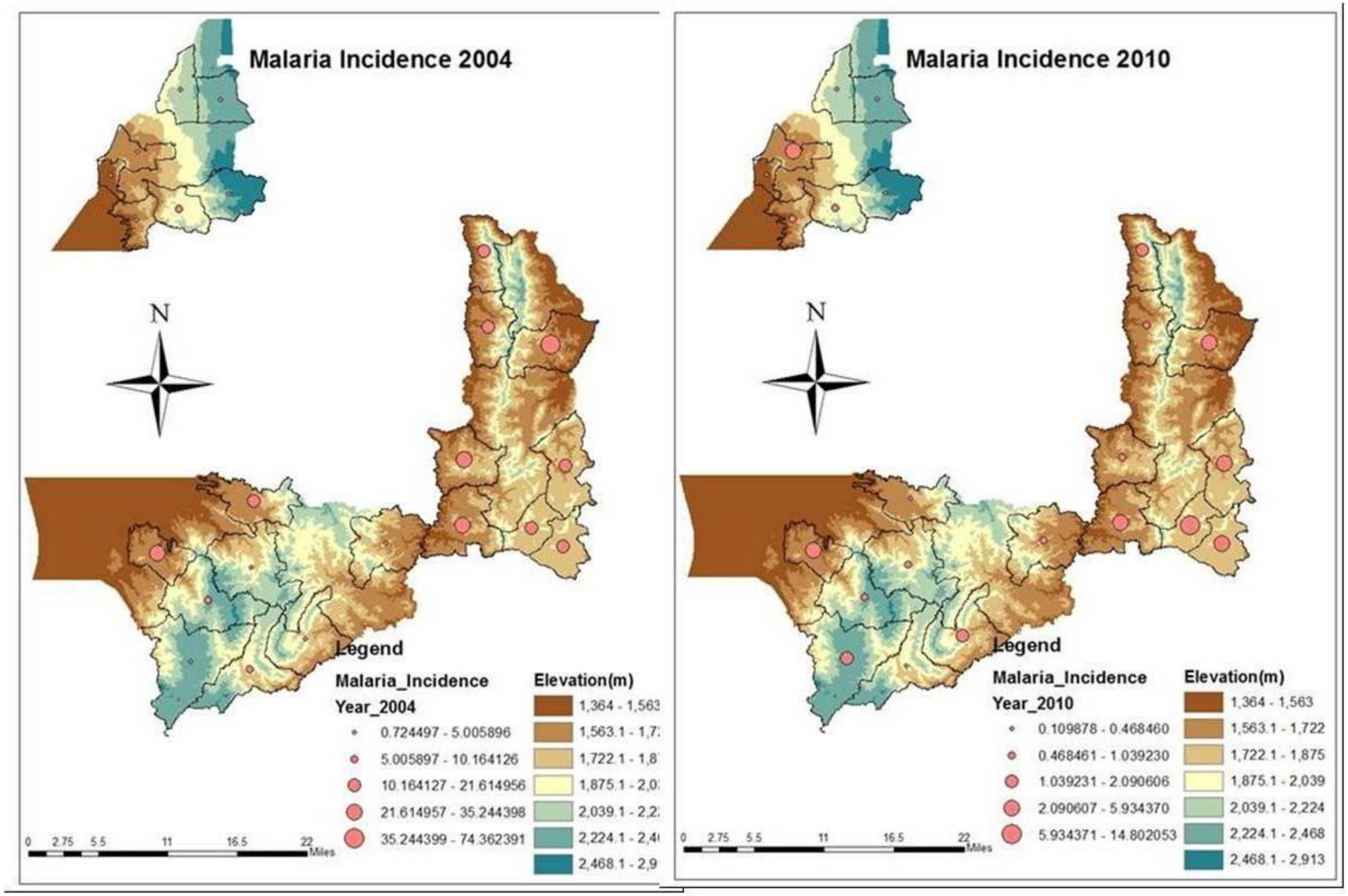
Incidence rate in the study area indicated that Muhanga had the highest incidence 28/1000 in 2004 but later came to 1.77/1000 in 2011. The second in malaria incidence was Karongi where the highest incidence was in 2006 with value of 11.47/1000, which reduced to 0.07/1000 in 2011. Rubavu had the lowest incidence among the three districts since the highest value of incidence was observed in 2006 at 4.91/1000 and the lowest value of incidence was observed in 2011 and it was 0.05/1000. The growth rate indicated the presence of malaria in Rubavu but at the lowest level.

Data indicated that the increase of altitude was accompanied with low malaria incidence, this gives an opportunity to rank the districts of study area according to their malaria incidence as follow: Muhanga, Karongi, and then Rubavu. Malaria incidence reduced from 2004 to 2010 and started rising in 2011 till 2014. Table 1 explains well malaria variation in the study area for the period of 2004 - 2014.

Table 1. Malaria Incidence and Growth Rate in Three Districts of Highland of Rwanda

Year	**Karongi**	**Growth Rate%**	**Muhanga**	**Growth Rate %**	**Rubavu**	**Growth Rate%**	**Grand Total**
2004	8.62		28.02		3.43		14.15
2005	9.37	8.7	20.29	-27	3.92	14	11.78
2006	11.47	22	22.60	11	4.91	25	13.64
2007	5.40	-52	6.64	-70	2.75	-44	5.10
2008	3.53	-34	4.25	-35	1.96	-28	3.35
2009	4.84	37	6.34	49	2.17	10	4.63
2010	1.18	-75	3.80	-40	1.16	-46	2.12
2011	0.07	-94	1.77	-53	0.05	-95	0.68
2012	0.33	371.4	1.93	9	0.12	140	0.85
2013	1.64	397	6.53	238	0.14	16.6	2.98
2014	5.04	207	11.61	77	0.45	221	6.12
Grand Total	4.39		9.05		1.80		5.35

Spatial variation of malaria in the study area is illustrated in Figure 1. Malaria in the study area for the selected years varied with altitudes – it was highest in lowlands and lowest in highlands. This was expected as Githeko, *et al*. (2014) stated that malaria was more prevalent in low relatively warm areas than in high cold areas.


Malaria Incidence 2004
N
Legend
Malaria_Incidence
Year_2004
0.724497 - 5.005896
5.005897 - 10.164126
10.164127 - 21.614956
21.614957 - 35.244398
35.244399 - 74.362391
Elevation(m)
0 2.75 5.5 11 16.5 22 Miles
Malaria Incidence 2010
N
Legend
Malaria_Incidence
Year_2010
0.109878 - 0.468460
0.468461 - 1.039230
1.039231 - 2.090606
2.090607 - 5.934370
5.934371 - 14.802053
Elevation(m)
1,364 - 1,563
1,563.1 - 1,722
1,722.1 - 1,875
1,875.1 - 2,039
2,039.1 - 2,224
2,224.1 - 2,468
2,468.1 - 2,913
0 2.75 5.5 11 16.5 22 Miles

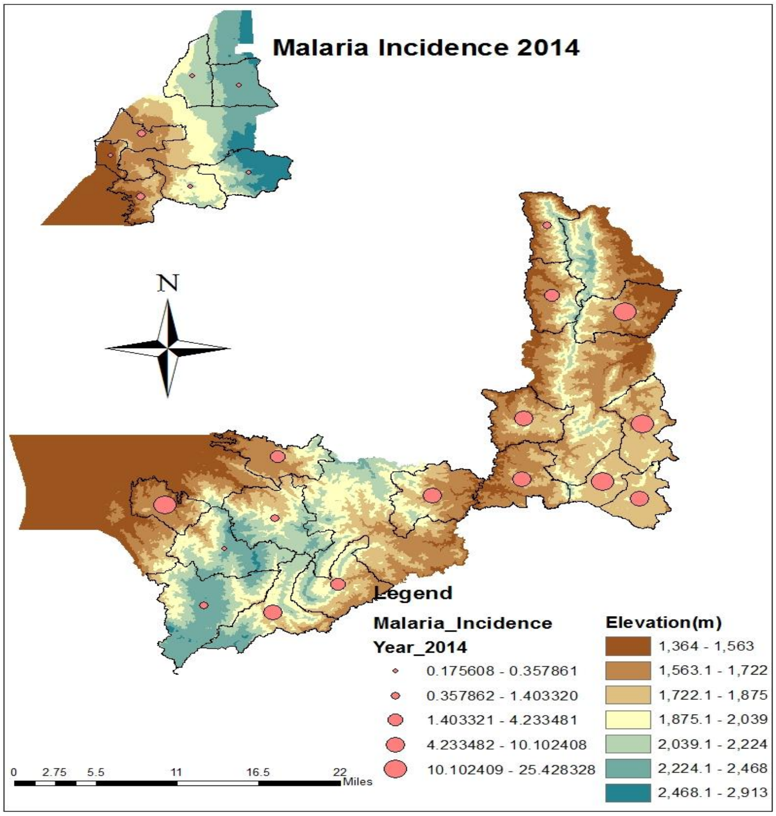


Figure 2. Spatial Presentation of Malaria Variation for the Years 2014.

Observation indicated that malaria is highly dependent on the control activities; from 2005 at national level, the launched program of malaria control significantly reduced malaria as indicated in Figure 3 which also indicates the same reduction in the highlands. But the incidence was not as high as the incidence in endemic region.

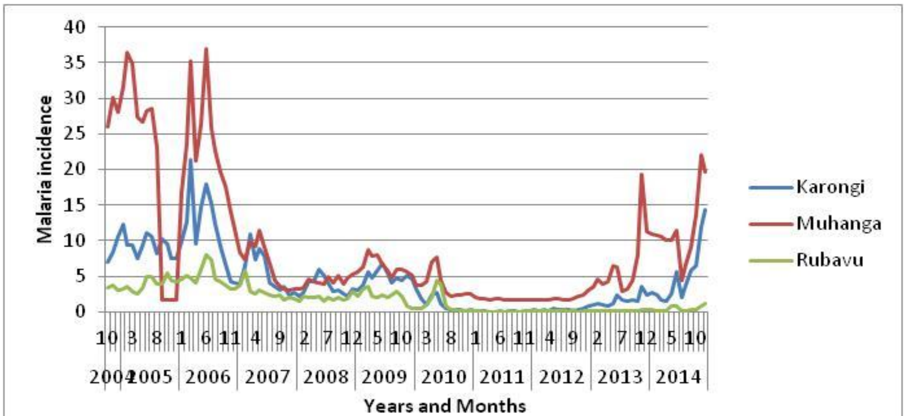


Figure 3. Malaria Variation in the Study Area for the Period of 11 years

Malaria Hotspot Analysis

Hotspot analysis was used to identify spatial distribution of malaria incidence. This analysis indicated the areas of high incidences of malaria as compared to other incidences, given the random distribution in 26 health centres for the period of 11 years. Malaria distribution followed the locations of health centre in a given catchment; a health centre can be located in a high or in a relative low altitude. What has been observed is that higher altitudes were having low incidence of malaria, while relative low altitudes were having high incidence as indicated in Figure 4 with details.

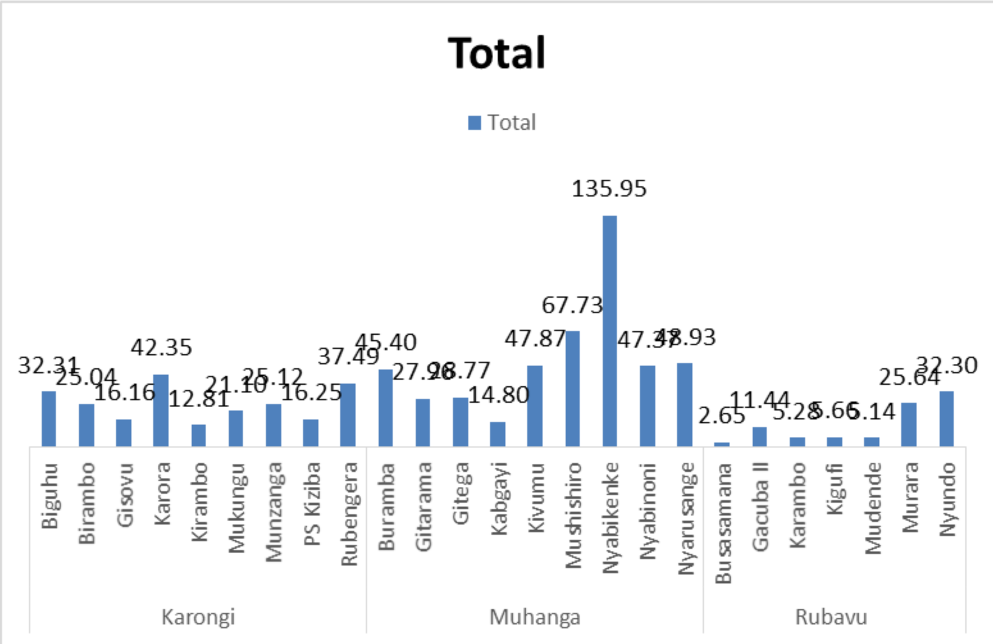


Figure 4. Malaria Hotspot Areas in Highlands of Rwanda.

Figure 4 presents the hotspot areas as data from the different health centres in study areas indicate; Muhanga was categorized an endemic transmission hotspot while Rubavu was an epidemic hotspot; the highest malaria incidence was found in Muhanga at Nyabikenke health centre with incidence of 135.95/1000, at altitude below 1500 m while the lowest incidence of 2.65/1000 was observed in Busasamana health centre in Rubavu at altitude above 2000 m.

Linear Regression Analysis

To investigate the linkage between malaria incidences with time in three districts of the study area, linear regression analysis was performed using SPSS statistics 20.0, and calculation of Pearson correlation to measure the extent to which malaria incidence varied with time. The coefficient of correlation described the strength and the direction of the relationship. Result of analysis indicated negative correlation of malaria incidence before 2010 and positive correlation coefficient after 2011 as presented in Table 2 and 3.

Table 2. Period of Malaria Decline from Control, 2004-2010

District	Regression Equation	Correlation coefficient	Coefficient of determination R^2
Muhanga	y = -4.24x + 30.12 Sig.=0.001<0.05	-0.90	0.82
Karongi	y =-1.40x + 11.96 Sig.=0.001<0.05	-0.83	0.70
Rubavu	y = -0.47x + 4.79 Sig.=0.001<0.05	-0.80	0.64

Table 3. With Malaria Increase, 2011-2014

District	Regression Equation	Correlation coefficient	Coefficient of determination R^2
Muhanga	y = 3.41x - 3.07 Sig.=0.30>0.05	0.94	0.89
Karongi	y = 1.62x - 2.28 Sig.=0.23>0.05	0.91	0.84
Rubavu	y = 0.12x - 0.11 Sig.=0.46>0.05	0.88	0.78

In Rwanda, Malaria had two distinct periods as data in Tables 2, 3 and Figure 3 indicated, the first period was 2004 – 2010 where malaria was being controlled, in some areas zero case could be recorded except 2009 where control had a problem of LLIN delay, and the second period 2011 - 2014, where malaria increased exponentially, the reason for this increase was many, as Minister of health confirmed, but climate change was among them (Gahima, 2015).

DISCUSSION

This study sought to determine how malaria incidence in Rwandan highlands varied across the period of 11 years. Malaria distribution in Rwandan highlands for the period of 2004-2014 followed the altitude pattern; findings indicated that malaria incidence was inversely proportional to the altitude, as the case of Nyabikenke in Muhanga where malaria incidence was 135.95/100 with altitude below 1500m, and Busasamana at the altitude above 2000m incidence was 2.65/1000. Again, findings of malaria incidence indicate high variation that divided data into two periods; since 2004 significant reduction of malaria incidence was observed and arrived at almost null in 2011; (14.44/1000 in 2004 to 0.08/1000 in 2011). From 2011 there was increase of malaria cases till 2014 (0.008/1000 to 5.73/1000) and onward, these results were similar to the report of President's Malaria Initiative (2017) for malaria coutrywide incidence.

Since the rate of malaria incidence from one year to the next can vary in relation to several demographic and environmental factors, the research tried to compare the spatial distribution of malaria incidences across years in a way that is independent of the temporal variation, including of long-term trends. Hence, the cumulative distribution of malaria incidence curves according to the respective areas of study, were built for the period of study across the elevation gradient.

In Karongi District, malaria growth rate is linked to poverty rate as Karongi (2013) indicated, the rate of poverty in 2013 was 61.7% while extreme poverty was 39.8% and malaria growth rate in this year was 397; it was the highest malaria incidence in the period of study, if we compare Karongi with other two remaining Districts. According to Anyanwu, *et al*. (2017) & (Rolling Back Malaria, 2017) there is a strong relationship between malaria transmission and poverty, The most endemic countries are among the poorest countries in the world.

Rubavu with average altitude above 2000 m had very low malaria incidence and the growth rate was not so important, but it is a malaria epidemic prone area since malaria incidence was strongly correlating with the period 2011-2014 (r=0.88). Reasons are multiples but we can mention; high movement of people from or to Goma DRC, tourism attractions that increase the movement of people like Lake Kivu, a part from that, Rubavu is the second populated town in Rwanda after Kigali, with a population density of 1,041 inhabitants per km^2 according to National institute of statistics (2012). Because of high population with relatively low cases, malaria incidences may appear absent in Rubavu, but most of cases are clustered in the health centres located in towns or near the main road connecting Rubavu with other cities in Rwanda. The result was similar to what was found by (Bizimana, *et al.*, 2015), they indicated that malaria cases were found near schools, towns, wetlands and areas with intensive agricultural activities.

Vector control by distribution of insecticide-treated mosquito net, spraying residual insecticides and Artemisinin-based Combination Therapy scaled-up from 2005 in different areas where malaria was endemic in Rwanda, resulted in a considerable reduction of malaria incidences, influenced malaria transmission in Rwandan highland as pointed out in Figure 3. The same report was found in Ethiopia where the combination of spraying residual insecticides and medication resulted in malaria cases reduction for the period 2002-2004 (Siraj, *et al*., 2014). World Health Organization (2014) said that between 2000 and 2013, malaria admission rates decreased by more than 75% in Eritrea, Rwanda and in Zanzibar, in the United Republic of Tanzania (McMichael and Woodruff, 2008). Comparing national incidence of malaria presented on Figure 5 and study area data on Figure 3, there was some similarities in variation but differences in reported cases.

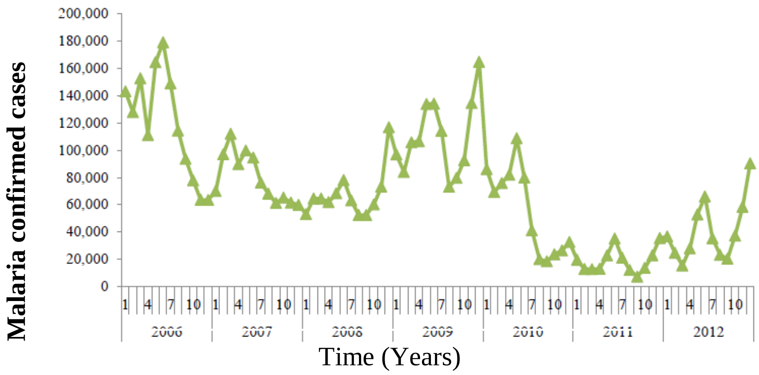


Figure 5: Rwanda Out-Patient Department Malaria Cases (Presumed and Confirmed), 2006–2012
Source: MINISANTE (2013)

Figure 5 present national malaria cases in the period of 7 years, compared to the incidence in the study area, findings indicated that malaria scaling-up from 2005 had a positive impact on malaria incidence. This was indicated by negative correlation of malaria incidence with time; from 2011 correlation of malaria incidence with time was positive. Ministry of Health (2013), reported significant increase of uncomplicated malaria cases from 478,162 in 2012 to 938,384 cases in 2013 what put malaria on the second position of morbidity in 2013, while WHO Global Malaria Program (2015) reported tripling of malaria cases onward.

CONCLUSION AND RECOMMENDATION

The study conducted in the region of Rwanda highland for the period of 11 year determined how malaria incidence varied in the given time among the different selected health centres. The location of the centre was important factor for malaria incidence where high altitude was correlating with low malaria incidence, while the low altitude was correlating with high malaria incidence. Literature review and theories indicated different thresholds for malaria development and transmission, which allowed quantifying the risk of highland areas of Rwanda to malaria incidences, which may be linked to many causes.

The study is recommending that malaria is invading new areas including highlands that used to be shelters against malaria, but the altitude above 2600 m above the sea level, Malaria is still rare and its adaptation is still impossible.

The Rwandan highlands are fragile ecosystems under pressure from rising population, deforestation, and increase farming. The upland communities do not access easily to health services and the services they benefit are patchy, control of malaria may be difficult. It needs a distinct initiative to define epidemic-prone area and use the finding from this research to develop solutions to protect vulnerable communities of highlands of Rwanda from this growing problem.

It need further research to investigate more on different cause of the raising of malaria incidence in highlands area, like land use change and climate change.

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