Ayansina Ayanlade, Nathaniel Olugbade Adeoye, Oyekanmi Babatimehin

Intra-annual climate variability and malaria transmission in Nigeria

Bulletin of Geography. Socio-Economic Series nr 21, 7-19

2013

Artykuł został opracowany do udostępnienia w internecie przez Muzeum Historii Polski w ramach prac podejmowanych na rzecz zapewnienia otwartego, powszechnego i trwałego dostępu do polskiego dorobku naukowego i kulturalnego. Artykuł jest umieszczony w kolekcji cyfrowej bazhum.muzhp.pl, gromadzącej zawartość polskich czasopism humanistycznych i społecznych.

Tekst jest udostępniony do wykorzystania w ramach dozwolonego użytku.

MUZEUM HISTORII POLSKI

Bulletin of Geography. Socio–economic Series No. 21 (2013): 7–19

ISSN 1732–4254 quarterly

BULLETIN OF GEOGRAPHY. SOCIO–ECONOMIC SERIES

journal homepages:
http://www.bulletinofgeography.umk.pl
http://versita.com/bgss

Intra-annual climate variability and malaria transmission in Nigeria

Ayansina Ayanlade[1, CDFMR], Nathaniel Olugbade Adeoye[2, CDFMR], Oyekanmi Babatimehin[3, CDFMR]

Obafemi Awolowo University, Departament of Geography, Ile-Ife, Nigeria; [1]e-mail: sinaayanlade@yahoo.co.uk (*corresponding author*); [2]email: nadeoye@yahoo.com; [3]e-mail: oyebabatimehin@yahoo.com

Ayanlade, A., Adeoye, N.O. and Babatimehin, O., 2013: Intra-annual climate variability and malaria transmission in Nigeria. In: Szymańska, D. and Chodkowska-Miszczuk, J. editors, *Bulletin of Geography. Socio-economic Series,* No. 21, Toruń: Nicolaus Copernicus University Press, pp. 7–19. DOI: http://dx.doi.org/10.2478/bog-2013-0016

Abstract. This study develops an integrated innovation for malaria early warning systems (MEWS), based on vulnerability monitoring, seasonal climate variability data, and epidemiologic surveillance. The main aim of the study is to examine the relationship between intra-annual climate variability and malaria transmission in Nigeria. For this study, climatic conditions considered suitable for the development of the malaria parasite and its transmission through the mosquito stage of its life cycle are temperatures within the range from 18°C to 32°C. Below 18°C the parasite development decreases significantly, while above 32°C the survival of the mosquito is compromised. Relative humidity greater than 60% is also considered a requirement for the mosquito to survive long enough for the parasite to develop sufficiently to be transmitted to its human host stage. The research findings show that seasonality of climate greatly influences the seasonality of malaria transmission. Specifically, rainfall plays an important role in the distribution and maintenance of breeding sites for the mosquito vector. Rainfall and surface water is required for the egg laying and larval stages of the mosquito life cycle and monthly rainfall above 80 mm is considered a requirement. Also, it is temperature that regulates the development rate of both the mosquito larvae and the malaria parasite (*Plasmodium* species) within the mosquito host. Relative humidity and temperature play an important role in the survival and longevity of the mosquito vector. This study is in conformity with the findings of the IPCC (2001) that malaria is caused by four distinct species of the *Plasmodium* parasite, transmitted by mosquitoes of the genus *Anopheles,* which are most abundant in tropical/subtropical regions, although they are also found in limited numbers in temperate climates.

© 2013 Nicolaus Copernicus University Press. All rights reserved.

Article details:
Received: 08 July 2012
Revised: 08 March 2013
Accepted: 29 May 2013

Key words:
climate variability,
malaria transmission,
Nigeria.

Contents

1. Introduction

Malaria is one of the most common and overwhelming public health concerns in Nigeria. The impact of climate change and variability on human health has received increasing recognition since it was first mentioned in the First Assessment Report by the IPCC (Intergovernmental Report on Climate Change). Health and climate have been linked since antiquity and this is one of the reasons why the Second Assessment Report of the IPCC dedicated a chapter to health (McMicheal et al., 2003). Climate variability is widely considered to be a major driver of inter-annual variability of malaria incidence in Africa (Afrane et al., 2005). Several researches have suggested that climate can affect infectious disease patterns because disease agents (viruses, bacteria and other parasites) and their vectors (such as insects or rodents) are clearly sensitive to temperature, moisture and other ambient environmental conditions (Appawu et al., 2004; Ameneshewa et al., 1995). The best evidence for this sensitivity is the characteristic geographic distribution and seasonal variation of many infectious diseases. It has been observed that vector species behaviour, density, and the number of infective bites a person can receive per time unit are dependent on seasonal changes in climatic variables. Malaria is caused by four distinct species of the *Plasmodium* parasite, transmitted by mosquitoes of the genus *Anopheles,* which are most abundant in tropical and subtropical regions, although they are also found in limited numbers in temperate climates (WHO, 2001, 2002; Thomson, Connor, 2001; Toulmin, 2005). Transmission is associated with the changes in temperature, rainfall, humidity as well as the level of immunity in humans.

The IPCC Special Report on Regional Impacts of Climate Change (IPCC, 2001) acknowledges that climate has an impact on vector-borne diseases. Climate change affects potential geographical distribution and transmission of vector-borne infectious diseases such as malaria. There are many substantial research challenges associated with studying linkages among climate, ecosystems and infectious diseases. For instance, climate-related impacts must be understood in the context of numerous other forces that drive infectious disease dynamics, such as rapid evolution of drug- and pesticide-resistant pathogens, swift global dissemination of microbes and vectors through expanding transportation networks, and deterioration of public health programs in some regions (Appawu et al., 2004). In Nigeria malaria is the cause of one in four deaths recorded in infants and young children and, worse still, for every 10 women that die around childbirth, one is caused by malaria. About half of Nigerian adults have at least one episode of malaria each year, while in younger children malaria occurs up to 3–4 times a year. Malaria is also the reason for hospital attendance in 7 out of every 10 patients seen in Nigerian hospitals (Wagbatsoma, Ogbeide, 1995). Detailed studies of the interaction of rainfall and malaria in the general community in Africa are limited. There are many reasons for this deficiency. These include the general weakness of the health information systems in most African countries, the lack of diagnostic facilities resulting in a paucity of extended times series of confirmed case data, and difficulties in accessing appropriate rainfall data for the specific locations and time periods for which case data are available. Furthermore, in recent years studies on the interaction between climate and malaria have focused on the potential role of climate change in determining recent increases in malaria transmission in highland areas in Africa where temperature rather than rainfall has been the parameter of greatest interest. These studies have served to highlight the significant methodological difficulties in undertaking such analyses (WHO, 2003, 2004, 2005).

Therefore, this study aims to examine the relationship between the intra-annual climate variability and malaria transmission in Nigeria. The relationships of variability in rainfall, relative humidity and temperatures to malaria transmission are assessed at the national level. Knowledge of the magnitude of these spatial variations is critical to understanding the transmission dynamics of the disease and the evaluation of the efficacy of malaria control measures.

2. Study area

Nigeria is a tropical country which lies on the southern coast of West Africa between latitudes 4° and 14°N and longitudes 2°45' and 15°30'E (Fig. 1). The Republic of Niger borders it to the north, the Republic of Chad and Cameroon to the east, the Republic of Benin to the west and the Atlantic Ocean to the south. It has a total landmass of about 924,000 sq. km with a coastline of about 853 km. The country's vegetation changes from the Sahel savannah in the far north, followed by the Sudan savannah merging into the Guinea savannah in the middle belt, then tropical rainforest in the south and mangrove forest in the coastal areas. The geographical location, size and shape of Nigeria allows it to experience an array of ecological zones, ranging from the mangrove swamps and tropical rainforest belts in the coastal areas to the open woodland and savannah on the low plateau which extends through much of the central part of the country, to the semiarid plains in the north and the highlands to the east. Between the arid north and the moist south lies the Guinea savannah zone, sometimes referred to as the middle belt. This type of the environment is determined mainly by climate. Two climatic regimes associated with the Intertropical Discontinuity (ITD) are experienced in Nigeria: the wet and the dry seasons. These two seasons are highly influenced by the two prevailing air masses moving over the country at different times of the year. These are the warm and moist tropical maritime air mass (south Westerlies) that originates above the Atlantic Ocean and brings rainfall, while the other one is the cool dry and dust-laden continental air mass (Harmattan winds) that originates above the Sahara Desert.

The mean annual rainfall in the south-east of the country varies between 2,540 and 4,060 mm, while in the north – 500–1,500 mm. The annual rainfall in Nigeria is the highest in the coastal areas and decreases inland towards the north. The mean temperature ranges between 25°C and 30°C towards the interior as a result of the moderating influence of the sea. In the dry season, temperature reflects more extreme conditions ranging between 20°C and 30°C. Much of the southern half of the country is characterised by a long growing period of 200–365 days with a bimodal rainy season and the annual rainfall of 1,500–3,000 mm. The onset of the wet season in this region is as early as February or March. The rain continues to the end of November (Walter, 1968; Ayoade, 1970). However, the northern half has a much shorter unimodal rainy season of about 90–200 days with the annual rainfall levels of 400–1,300 mm. The onset of the wet season may be as late as June, while its cessation may be as early as September.

In 1991 the population of Nigeria was 88,992,220 based on the National Population Census, but by 2001 it increased to 126,635,626 with the growth rate of 2.61% and the density of 95.8 people per square kilometre according to the estimate of the National Population Commission (NPC). Based on the last national census of 2006, presently the NPC puts the population at 133 million. However, it is expected the population will have risen to about 255.6 million by the year 2025 at the growth rate of 2.8%. Nigeria is made up of six geopolitical zones and 36 states (Fig. 1) including the Federal Capital Territory (NPC, 2006).

Malaria still constitutes a serious public health problem in Nigeria. It is responsible for 60% outpatient visits to health facilities, 30% of childhood deaths, 25% of death in children under one year and 11% of maternal deaths (4,500 die yearly). In Nigeria, a child will be sick with malaria between 2 and 4 times a year and 70% of pregnant women suffer from malaria contributing to maternal anaemia, low birth weight, still birth, abortion and other pregnancy-related complications. The annual financial loss due to malaria is estimated to be approximately 132 billion NGN (Naira; 1 NGN is 0.01 USD) in form of treatment costs, prevention and loss of man-hours among others. Yet, it is a treatable and completely evitable disease (Wagbatsoma, Ogbeide, 1995).

Fig. 1. Study area: Nigeria and its administrative division (incl. Abuja FCT, i.e. the Federal Capital Territory)

Source: http://www.nigeriahc.org.uk/about-nigeria

3. Materials and methods

3.1. Data acquisition and geospatial analysis

Climate suitability for malaria transmission was defined as the coincidence of the monthly rainfall greater than 80 mm, mean temperature between 18°C and 32°C, and relative humidity greater than 60%. These are the thresholds that are intended to describe conditions suitable for both the development of the *Plasmodium falciparum* parasite and the life cycle of the mosquito vector. Therefore, both climate and malaria data were used in this study. The climate parameters include monthly rainfall, relative humidity and temperature. The monthly precipitation, monthly temperature and monthly specific humidity data (converted to relative humidity) over land areas were extracted from the Climate Research Unit (CRU, Nowich, UK) Time Series (CRU TS). The monthly data on clinical malaria cases from health facilities in 774 local government areas of Nigeria were used in a novel stratification process. The malaria cases were summed over two age groups (under and over 5 years). The malaria incidence per 1,000 persons per month was estimated using the 2006 population by the NPC.

3.2. Statistical analysis

The methods of Principal Component Analysis (PCA) and Non-hierarchical Clustering were used to define eight areas with distinct malaria intensity and climate seasonality suitability patterns, to guide future interventions and development of an epidemic early warning system. The PCA is a technique for simplifying a data set by reducing multidimensional data sets to lower dimensions in the data. The reduction in the dimensions of the data sets is necessary to run and accelerate the clustering analysis, which is a classification of objects into different groups such that each group shares a common trait. A total of eight principal components were generated from the monthly average incidence data. The data were initially clustered into eight clusters for analysis. The clusters were visualised in the maps using the Geographic Information System (GIS) techniques. The GIS raster techniques were used to convert the climate data to climate suitability maps. The maps depict fractions between 1 and 12 which represent months suitable for malaria transmission. For this study, the climatic conditions considered suitable for the malaria parasite development and transmission through the mosquito stage of its life cycle are temperatures within the range of 18°C to 32°C. Below 18°C the parasite development decreases significantly, while above 32°C the survival of the mosquito is compromised. Relative humidity greater than 60% is also considered a requirement for the mosquito to survive long enough for the parasite to develop sufficiently to be transmitted to its human host stage. Rainfall and surface water is required for the egg laying and larval stages of the mosquito life cycle and the monthly rainfall above 80 mm is considered a requirement. To improve epidemic control based on the climate sensitive for the country, this study has developed a framework for the development of the integrated malaria early warning systems (MEWS), based on vulnerability monitoring, seasonal climate variability data, and epidemiologic surveillance. This study used a framework developed by the International Research Institute for Climate & Society (IRI), The Earth Institute at Columbia University, Lamont Campus, Palisades, New York, USA. The IRI framework and climate tools were explored in the development of the malaria early warning system in Nigeria.

4. Results and discussion

4.1. Climatic suitability for malaria transmission

The country is divided into eight zones which represent the climatic suitability for malaria transmission based on the rainfall, temperature and humidity, which are the most significant parameters (Table 1 and Fig. 2). Figure 2 shows the regional differences in how long the combination of climatic conditions may be suitable for malaria transmission in Nigeria. The map displays the number of months during the year that are suitable for malaria transmission, based on monthly climatological averages. The map was derived from the climate-driven malaria transmission models used to indicate monthly climate suitability for malaria and thereby indicates areas vulnerable to climate related malaria epidemics. Figure 2 clarifies the seasonal pattern and intensity of malaria transmission in different areas within the country.

Table 1. Number of months suitable for malaria transmission in Nige

Zone	Numbers of months suitable for malaria transmission	Months suitable for malaria transmission	Names of states within the zone
A	8½ months	March, April, May, June, July, August, September, October, November	Bayelesa, Rivers, Akwa-Ibom and the southern part of the Cross Rivers state
B	7½ months	April, May, June, July, August, September, October	Osun, Edo, Delta, Imo, Abia, Anambra and the southern part of Ondo and Ogun
C	6½ months	May, June, July, August, September, October	Oyo, Ogun, Kogi, Benue, Nasarawa, the southern part of Taraba, Abuja and Kwara
D	5 months	May, June, July, August, September	Niger, Pleteau, Kwara, Taraba and the northern part of Abuja
E	4½ months	June, July, August, September	Kebbi, Kaduna, Bauchi and Gombe
F	4 months	June, July, August, September	Adamawa and the southern part of Borno
G	3 months	July, August, September	Sokoto, Zamfara, Katsina, Kano and Jigawa
H	1½ months	August, September	Yobe and Borno

Source: Authors' computation from the data obtained from the International Research Institute for Climate & Society (IRI), The Earth Institute at Columbia University, Lamont Campus, Palisades, New York, USA

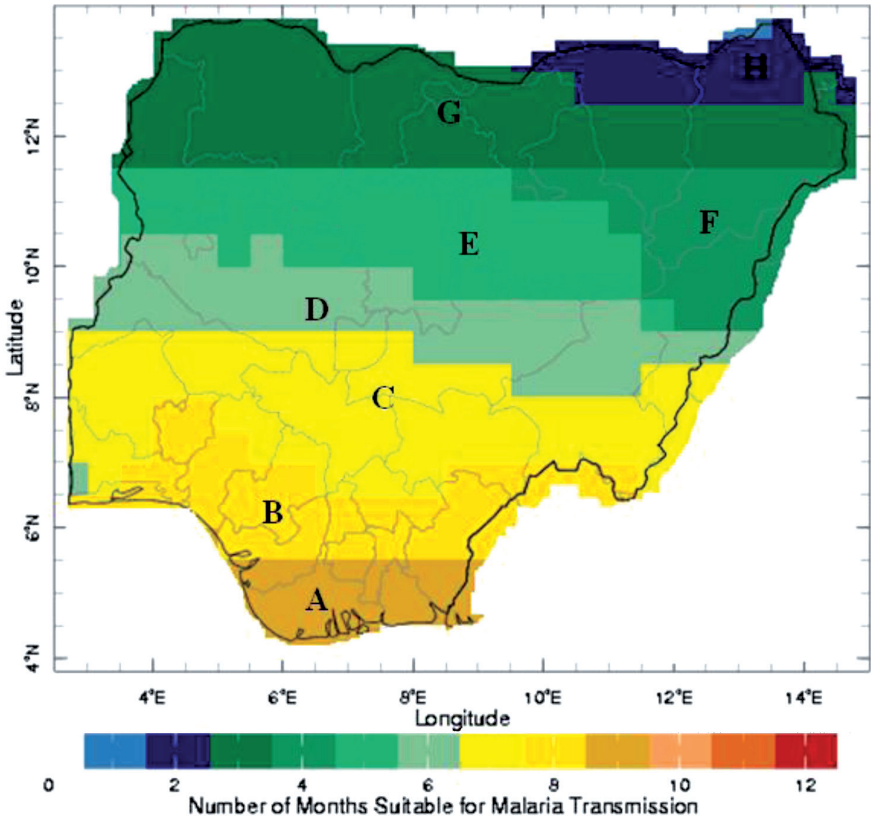

Fig. 2. Number of months suitable for malaria transmission in Nigeria

Explanation: zone A: the states of Bayelesa, Rivers, Akwa-Ibom, and the southern part of Cross Rivers; zone B: the states of Osun, Edo, Delta, Imo, Abia, Anambra and the southern part of Ondo and Ogun; zone C: the states of Oyo, Ogun, Kogi, Benue, Nasarawa, the southern part of Taraba, Abuja and Kwara; zone D: the states of Niger, Pleteau, Kwara, Taraba and the northern part of Abuja; zone E: the states of Kebbi, Kaduna, Bauchi and Gombe; zone F: the states of Adamawa and the southern part of Borno; zone G: the states of Sokoto, Zamfara, Katsina, Kano and Jigawa: zone H: the states of Yobe and Borno

Source: Authors' computation from the data obtained from the International Research Institute for Climate & Society (IRI), The Earth Institute at Columbia University, Lamont Campus, Palisades, New York, USA

Table 1 and Figures 3–10 show the number of months suitable for malaria transmission in Nigeria calculated on the basis of the percentage of monthly rainfall, temperature, humidity and malaria occurrence. The figures show how often all these circumstances were concurrently observed at the measurement point for each month of the year, based on a historical record. The analyses and the figures show the proportional occurrence of the climatic conditions for each month. Generally, the rainfall averages over 2,000 mm per annum in the south-east, 1,000 mm in the centre reducing to as low as 500 mm in the north-east of the country. Thus, it is observed from the figures that the seasonality of climate greatly influences the seasonality of malaria transmission. Specifically, rainfall plays an important role in the distribution and maintenance of breeding sites for the mosquito vector (*Anopheline* species). Moreover, temperature regulates the development rate of both the mosquito larvae and the malaria parasite (*Plasmodium* species) within the mosquito host. Relative humidity and temperature play an important role in the survival and longevity of the mosquito vector. For example, the coastal part of Nigeria (zone A) receives substantial amounts of rainfall in the months of

April through to October (9 months) and the greatest rainfall concentration occurs in the months of July to September (Table 1 and Fig. 3). Nine months (between May and November) were fund suitable for malaria transmission in the coastal part of the county. The observations (Fig. 2) also show that three states fall within the zone A (Bayelesa, Rivers, Akwa-Ibom and the southern part of the Cross Rivers state). Within the nine months, in this zone the total monthly precipitation is greater than 80 mm, the mean temperature is between 18°C and 32°C, and the relative humidity is greater than 60% from April to October which makes these months suitable for malaria transmission.

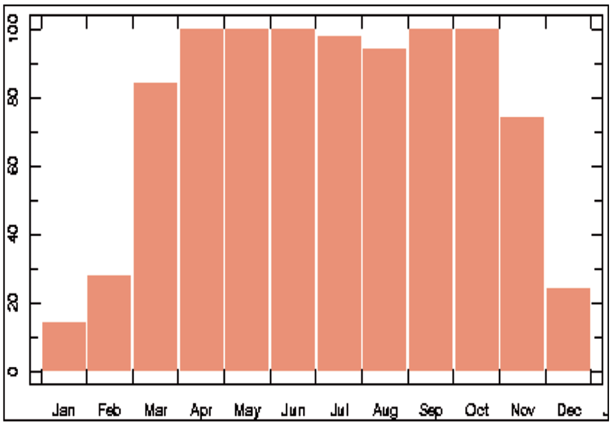

Fig. 3. Monthly climate conditions suitable for malaria transmission in the zone A (the states of Bayelesa, Rivers, Akwa-Ibom and the southern part of Cross Rivers)

Source: Authors' computation from the data obtained from the International Research Institute for Climate & Society (IRI), The Earth Institute at Columbia University, Lamont Campus, Palisades, New York, USA

In the zone A (Bayelesa, Rivers, Akwa-Ibom and the southern part of the Cross Rivers state) the rainfall pattern is bimodal, the first peak occurring in June–July, and the second in September, with August relatively dry. Variations in annual rainfall make it difficult to draw a strict geographical boundary between these two distribution patterns in relation to malaria transmission. In reality, the zone A is within the coastal area and usually receives more rainfall than the inland locations. It ranges from 1,487.9 to 2,865.2 mm annually. Malaria transmission, based on climatic parameters, occurred between April and October in the zone B (Osun, Edo, Delta, Imo, Abia, Anambra and the southern part of Ondo and Ogun). In zone C (Oyo, Ogun, Kogi, Benue, Nasarawa, the southern part of Taraba, Abuja and Kwara) about six and half months of rainy season between May and October are responsible for malaria transmission (see Fig. 4 and 5). Variability in rainfall totals for the period between May and September accounts for more than two-thirds of the inter-annual variability in malaria transmission in the zone D (Niger, Pleteau, Kwara, Taraba and the northern part of Abuja). The results show that 6½ and 5½ months are suitable for malaria transmissions in the zones C and D respectively (Fig. 5 and 6). The zone B is in the southern part of the country and has April as the onset month, while October is the cessation month. These zones are characterised by two peaks of rainfall in June/July and September while the northern stations have only one peak per year. Rainfall starts earlier in the southern stations (April/May) and ceases last in this region in October (Table 1). The period when rainfall ceases within the wet season exists in the south, and is referred to as the 'August break' or the 'little dry season' (Odekunle, 2004).

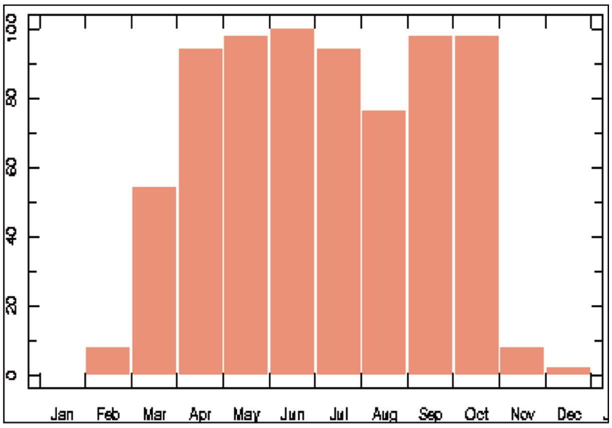

Fig. 4. Monthly climate conditions suitable for malaria transmission in the zone B (the states of Osun, Edo, Delta, Imo, Abia, Anambra and the southern part of Ondo and Ogun)

Source: Authors' computation from the data obtained from the International Research Institute for Climate & Society (IRI), The Earth Institute at Columbia University, Lamont Campus, Palisades, New York, USA

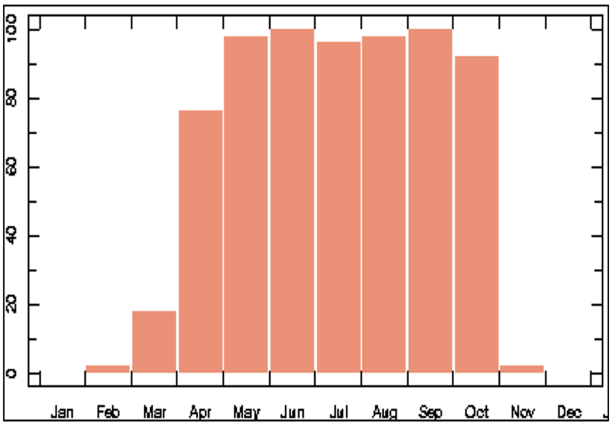

Fig. 5. Monthly climate conditions suitable for malaria transmission in the zone C (the states of Oyo, Ogun, Kogi, Benue, Nasarawa, the southern part of Taraba, Abuja and Kwara)

Source: Authors' computation from the data obtained from the International Research Institute for Climate & Society (IRI), The Earth Institute at Columbia University, Lamont Campus, Palisades, New York, USA

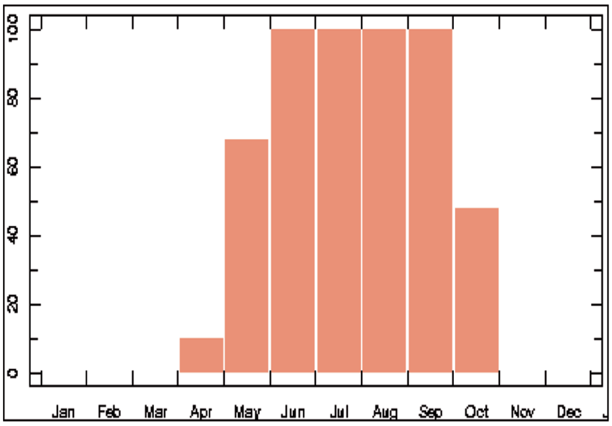

Fig. 6. Monthly climate conditions suitable for malaria transmission in the zone D (the states of Ni ger, Pleteau, Kwara, Taraba and the northern part of Abuja)

Source: Authors' computation from data obtained from International Research Institute for Climate & Society (IRI), The Earth Institute at Columbia University, Lamont Campus, Palisades, New York, USA

The zones E (Kebbi, Kaduna, Bauchi and Gombe) and F (Adamawa and the southern part of Borno) receive substantial amounts of rainfall in the months of July through to September (see Fig. 7 and 8). This actually indicates that only four months are suitable for malaria transmission in these zones. Three months of rainfall and temperature anomalies are observed to be a major driver of inter-annual variability of malaria transmission in the zone G (Sokoto, Zamfara, Katsina, Kano and Jigawa) while one and half month is suitable for malaria transmission in the zone H (Fig. 9 and 10). Rainfall together with the temperature accumulations from August to September were significant predictors of log-confirmed malaria transmission in the zone H (Yobe and Borno).

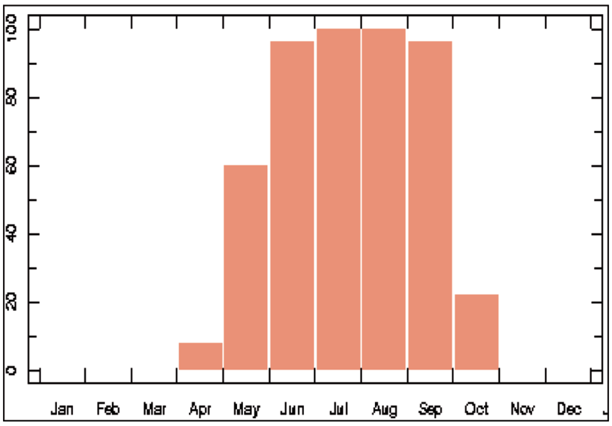

Fig. 7. Monthly climate conditions suitable for malaria transmission in the zone E (the states of Kebbi, Kaduna, Bauchi and Gombe)

Source: Authors' computation from the data obtained from the International Research Institute for Climate & Society (IRI), The Earth Institute at Columbia University, Lamont Campus, Palisades, New York, USA

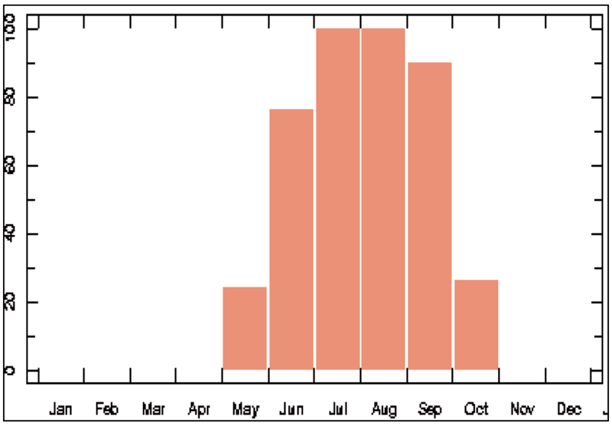

Fig. 8. Monthly climate conditions suitable for malaria transmission in the zone F (the state of Adamawa and the southern part of Borno)

Source: Authors' computation from the data obtained from the International Research Institute for Climate & Society (IRI), The Earth Institute at Columbia University, Lamont Campus, Palisades, New York, USA

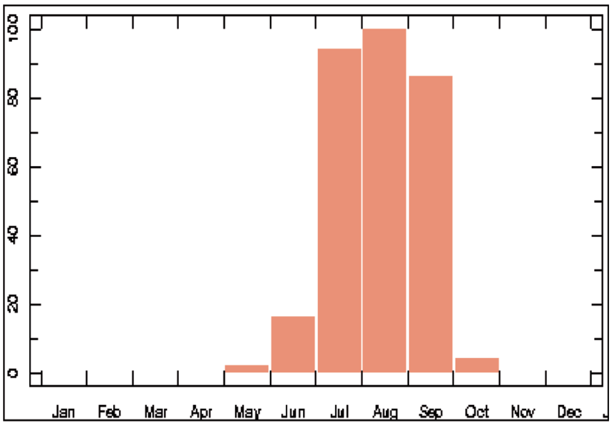

Fig. 9. Monthly climate conditions suitable for malaria transmission in the zone G (the states of Sokoto, Zamfara, Katsina, Kano and Jigawa)

Source: Authors' computation from the data obtained from the International Research Institute for Climate & Society (IRI), The Earth Institute at Columbia University, Lamont Campus, Palisades, New York, USA

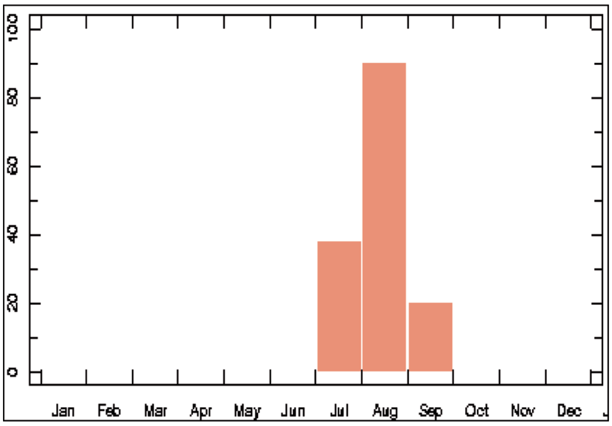

Fig. 10. Monthly climate conditions suitable for malaria transmission in the zone H (the states of Yobe and Borno)

Source: Authors' computation from the data obtained from the International Research Institute for Climate & Society (IRI), The Earth Institute at Columbia University, Lamont Campus, Palisades, New York, USA

The observations show that the zones A to C have the bimodal rainfall distribution, while the zones D to H – the unimodal rainfall distribution. This actually affects the transmission of malaria in the zones (Fig. 3 to 10). In addition to clarifying the seasonal pattern and intensity of transmission in different areas, the figures are useful for targeting and timing interventions, such as indoor residual spraying in the highest risk areas. These zones are in the northern part of the country. The northern part usually receives less rainfall than the southern locations (Fig. 8 to 10). The onset period for the northern stations is May/June, while the cessation period is September/October. The northern stations have only one peak, which is in August. The annual trend of precipitation is positive in most of the southern stations, while it is negative in most of the northern stations. At the 99% confidence limits, all the stations have the mean annual rainfall close to or within the limits except during the

El Niño Southern Oscillation (ENSO) years. These zones have the unimodal rainfall distribution in which rains increase in frequency and amount, beginning in May and peaking in August. The period of rainfall in these zones lasts 3 to 5 months; the onset month is May/June, while the cessation month is September/October (Table 1). These findings are factual because generally rainfall in Nigeria is governed by the annual passage of the Intertropical Convergence Zone (ITCZ), the meeting point of a dry north-eastern low-pressure air mass and a moist south-western high-pressure air mass. The north-eastern movement of the ITCZ and the rain-bearing winds that accompany it mark the onset of the rainy season. Its south-westward movement and the accompanying Harmattan winds mark the beginning of the dry season (Ayoade, 1970; Olaniran, 1985, 1988a, 1988b). Nigeria receives rainfall from the south Westerlies which invade the country from the Gulf of Guinea coast, i.e. the tropical Atlantic. This moist airstream is overlain by the north-east Trades which originate from above the Sahara and are thereby dry and dust-laden. The zone of contact of the two air masses at the surface is a zone of moisture discontinuity and it is known as the Intertropical Discontinuity (ITD) zone. The position of the ITD fluctuates seasonally and the different ITD zones affect different areas of the country at various times. Between January/February and August, the ITD migrates northward and there is a corresponding shift northward of the area of the rainfall activity. However, from the end of August, when the ITD is at its most northerly position, it migrates a short distance inland causing a period of reduced rainfall in the coastal area, a phenomenon known as the 'little dry season' or the 'July/August break'. During this period the south Westerlies become deflected into Westerlies which bring little or no rain. This causes rainfall to increase eastwards over the southern Nigeria during the July/August period.

4.2. Seasonality of climate influences the variation in malaria transmission

The results of this study show that seasonality of climate influences the variation in malaria transmission in Nigeria. It is observed that rainfall plays an important role in the distribution of breeding sites for the mosquito vector and thereby influences malaria transmission. Though relative humidity and temperature play an important role in the survival and longevity of the mosquito vector, it is rainfall that regulates the development rate of the mosquito larvae. A high relative humidity lengthens the life of the mosquito and helps the parasite to complete the necessary life cycle so that it can transmit the infection. When the relative humidity drops below 60%, it is believed that malaria transmission cannot occur because of the reduced lifespan of mosquitoes. The relative humidity throughout the year ranges from 69% to 93%, so it is probably not a limiting factor for malaria transmission in this tropical rainforest area. Rainfall generally increases the number of breeding places for mosquitoes. It was noted that both temporary and permanent water bodies are dependent on rainfall. The results of this study are inconsistent with a few studies in the literature, which find a negative or neutral effect of rainfall. Provided that rainfall has a linear dose-response effect on fluctuations in malaria transmission, this effect would emerge after filtering out the seasonal component. The inconsistent relationship between rainfall and malaria transmission could result from the saturating effect of rainfall, for an increase in rainfall fails to produce additional malaria cases when aquatic breeding sites are not limiting for mosquitoes.

In addition, the duration of the rainfall season is important. Heavy rainfall or storms may destroy existing breeding places, interrupt the development of mosquito eggs or larvae, or simply flush the eggs or larvae out of the pools. However, in the case of Nigeria, rainfall is also related to humidity and saturation deficit (the factor that affects the mosquito survival). In the region where temperature is high but rainfall is limited, such as the northern part of the country, the mosquito population increases rapidly at the onset of rain. This is as result of a short development cycle. Thus, two to three months of rainfall may be sufficient to constitute one transmission season. However, where temperature is limiting during the colder season, as is the case of the southern part of the country and upland areas like Jos, mosquito populations increase slowly at the onset of rain. This is so because the area is known for gradual rising in temperature and a long mosquito development cycle.

The findings of this study support other results (Craig et al., 1999; Connor et al., 1999; McMicheal et al., 2003; Thomson et al., 2005a, 2005b) that transmission of malaria depends on the weather, which affects the ability of the main carrier of malaria parasites, *Anopheline* mosquitoes, to survive or not. The tropical areas, including Nigeria, have the best combination of adequate rainfall, temperature and humidity allowing for breeding and survival of *Anopheline* mosquitoes. The burden of malaria varies across different regions of the world and even within a country. This is driven by the variation in parasite–vector–human transmission dynamics that favours or limits the transmission of malaria infection and the associated risk of disease and death. Of the four species of *Plasmodium* that infect humans – *P. falciparum, P. vivax, P. malariae* and *P. oval*, *Plasmodium falciparum* causes most of the severity and deaths attributable to the disease. It is most prevalent in Africa south of the Sahara, where Nigeria has the largest population. Also the results of this study concur with the report of the World Health Organization (WHO, 2000), that approximately 50% of the Nigerian population experience at least one episode of malaria per year as a result of climate variability. However, official estimate suggests as much as four bouts per person per year on the average (WHO, 1995, 2002). The trend is rapidly increasing due to the current malaria resistance to the first line anti-malarial drugs (WHO, 2000). The magnitude of incidence and death due to it is a multiple of all other tropical diseases put together.

Also, the results of this study are in conformity with the findings of the IPCC (2001) that malaria is caused by four distinct species of *Plasmodium* parasite, transmitted by mosquitoes of the genus *Anopheles*. They are most abundant in tropical and subtropical regions, although they are also found in limited numbers in temperate climates. Transmission is associated with changes in temperature, rainfall, humidity as well as the level of immunity in humans. Very high temperatures are lethal for the parasite. In the areas where the annual mean temperature is close to the tolerance limit of the parasite, a small temperature increase would be lethal for the parasite. The IPCC noted that at low temperatures, a small increase in temperature can greatly increase the risk of malaria. Hence, the most susceptible to malaria are the areas at the fringes of its current distribution, such as Central Asia and Eastern Europe. In this context, climate change is unlikely to affect overall mortality and morbidity in tropical Africa as environmental conditions are already favourable for malaria transmission. The vulnerable areas are those where transmission is currently limited, mainly by highland temperatures, such as in East Africa (Kenya highlands, for example). This study adds to the growing evidence linking human diseases to climate fluctuations and suggests that variations in the transmission of malaria in Nigeria and elsewhere are associated to annual changes in climatic conditions. Recently, Craig and others studied the relationship between climatic and non-climatic factors based on a 30-year series of malaria case data in KwaZulu-Natal, South Africa. They found significant linear relationships between seasonal changes in case totals and mean maximum daily temperatures (January–October) of the preceding season, and total rainfall in the current summer months of November–March. A combination of these climatic factors explained approximately 30–50% of the variance in differential case numbers depending on the climate data source used. Although climate appears to account for much less of the variance of malaria in KwaZulu-Natal than in Botswana (where a quadratic function of rainfall alone accounted for more than 60% of standardised malaria incidence anomalies), it is interesting to note that the key high malaria years in KwaZulu-Natal area, e.g. 1988, 1993, 1996, and 2000, correspond with the high malaria anomaly years in Botswana, suggesting that regional rather than local processes are likely to be responsible for much of the inter-annual variation. Given the substantial burden of disease associated to vector-borne diseases in developing tropical countries, it is of utmost relevance to incorporate climate change into public health thinking.

The National Malaria Control Program in Nigeria and other endemic countries should be intensified to reduce the devastating effects the disease exerts on both the economy and human lives. The development of an effective vaccine, along with other malaria control measures, is needed for reducing the burden of malaria in sub-Saharan Africa and worldwide. Although this study may have some limitations, such as a lack of incorporation of other meteorological factors into the analysis, it is strongly believed that the findings are relevant from a public health perspective to better understand the ecoepidemiology of this and other tropical infections. However, further research is considered necessary in this region and in other endemic areas to develop monitoring systems that will help to predict the impact of climate variability on malarial incidence in the region.

5. Conclusion

Climate variability is widely considered to be a major driver of inter-annual variability of malaria incidence in Africa. The relationships of variability in rainfall, relative humidity and temperatures to malaria transmission in Nigeria were assessed in this study. Malaria still constitutes a serious public health problem in Nigeria. It is responsible for 60% outpatient visits to health facilities, 30% of childhood deaths, 25% of deaths in children under one year and 11% of maternal deaths (4,500 die yearly). In this study, climate suitability for malaria transmission was defined as the coincidence of monthly total precipitation greater than 80 mm, mean temperature between 18°C and 32°C, and relative humidity greater than 60%. Monthly precipitation, monthly temperature and monthly specific humidity data (converted to relative humidity) over land areas were extracted from the Climate Research Unit (CRU, Nowich, UK) Time Series (CRU TS). The results of this study show that seasonality of climate influences the variation in malaria transmission in Nigeria. It is observed that rainfall plays an important role in the distribution of breeding sites for the mosquito vector and thereby influences malaria transmission. The findings of this study are relevant from a public health perspective to better understand the ecoepidemiology of this and other tropical infections.

Acknowledgements

The authors are grateful to the International Research Institute for Climate & Society (IRI), The Earth Institute at Columbia University, Lamont Campus, Palisades, New York, USA for training on the initial methodology of climate and malarial data analysis on which this study is based.

References

Afrane, Y.A., Lawson, B.W., Githeko, A.K. and Yan, G., 2005: Effects of microclimatic changes due to land use and land cover on the duration of gonotrophic cycles of *Anopheles gambiae* Giles (Diptera: Culicidae) in western Kenya highlands. In: *Journal of Medical Entomology*, Vol. 42, pp. 974–980. DOI: http://dx.doi.org/10.1603/0022-2585(2005)042[0974:EOMCCB]2.0.CO;2

Ameneshewa, B. and Service, M.W., 1996: Resting habits of *Anopheles arabiensis* in the Awash River valley of Ethiopia. In: *Annals of Tropical Medicine and Parasitology*, Vol. 90, pp. 515–521. PMID: 8915128

Appawu, M., Owusu-Agyei, S., Dadzie, S., Asoala, V., Anto, F., Koram, K., Rogers W., Nkrumah, S., Hoffman, S.L. and Fryauff, D.J., 2004: Malaria transmission dynamics at a site in northern Ghana proposed for testing malaria vaccines. In: *Tropical Medicine & International Health*, Vol. 9, pp. 164–170. DOI: http://dx.doi.org/10.1046/j.1365-3156.2003.01162.x

Ayoade, J.O., 1970: Rain gauge networks and the areal extension of rainfall records. In: *Occasional Papers*, No. 10, London: University of London, Department of Geography, p. 15.

Burkot, T.R. and Graves, P.M., 1995: The value of vector-based estimation of malaria transmission. In: *Annals of Tropical Medicine and Parasitology*, Vol. 89, pp. 125–134. PMID:7605122

Connor, S., Thomson, M. and Molyneux, D., 1999: Forecasting and prevention of epidemic malaria: new perspectives on an old problem. In: *Parassitologia*, Vol. 41, pp. 439–448. PMID:10697900

Craig, M.H., Snow, R.W. and le Sueur, D., 1999: A climate-based distribution model of malaria transmission in sub-Saharan Africa. In: *Parasitology Today*, Vol. 15, pp. 105–111. PII: S0169-4758(99)01396-4

CRU TS Database: Tyndall Centre for Climate Change Research, Norwich: University of East Anglia, School of Environmental Sciences, NR 4 7TJ, UK, available from: http://www.cru.uea.ac.uk/cru/data/hrg/, DoA: 21 October 2010.

Final Report to Environmental Health Project, Washington, DC: USAID.

Intergovernmental Panel on Climate Change (IPCC), 1990: First Assessment Report: Scientific Assessment of Climate Change. Contribution of Working Group I to the Intergovernmental Panel on Climate Change, Cambridge: Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC), 1996: Second Assessment Report: Contribution of Working Group I to the Intergovernmental Panel on Climate Change, Cambridge: Cambridge University Press.

IRI Database, 2006: International Research Institute for Climate & Society (IRI), Lamont Campus, Palisades, New York: The Earth Institute at Columbia University.

McMicheal, A.J. and Githeko, A., 2001: Intergovernmental Panel on Climate Change (IPCC). Human Health. In: McCarthy, J., Canziani, O.F., Leary, N.A., Dokken, D.J. and White, K.S. editors, *Climate change. Impacts, adaptation and vulnerability, contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge: Cambridge University Press.

McMicheal, A.J., Campbell-Lendrum, D.H., Corvalan, C.F., Ebi, K.L., Githenko, A.K., Scheraga, J.D. and Woodward, A. editors, 2003: Climate change and human health: risks and responses, Geneva: WHO, available from: www.who.int/globalchange/climate/summary/en, DoA: 21 December 2007.

National Population Commission (NPC), 2006: Population census and household data survey for Nigeria, Abuja: Federal Government of Nigeria.

Odekunle, T.O., 2004: Rainfall and the length of the growing season in Nigeria. In: *International Journal of Climatology*, Vol. 24, pp. 467–479. DOI: http://dx.doi.org/10.1002/joc.1012

Olaniran, O.J., 1985: On the distribution of rainfall in storms of different sizes in Nigeria. In: *Nigerian Geographical Journal*, Vol. 28, pp. 95–113.

Olaniran, O.J., 1988a**:** The distribution in space of rain days of rainfall of different daily amounts in the tropics: Nigeria as a case study. In: *Geoforum*, Vol. 19, No. 4, pp. 507–520. DOI: http://dx.doi.org/10.1016/S0016-7185(88)80021-6

Olanrian, O.J., 1988b: The July – August rainfall anomaly in Nigeria. In: *Climatological Bulletin,* Vol. 22, No. 2, pp. 26–38.

Thomson, M., Graves, P.M., Barnston, A.G., Bell, M., Ceccato, P., Connor, S., del Corra, l.J., Giannini, A., Obsomer, V., Wolde-Georgis, T., Jaiteh, M., Levy, M. and Lukang, L., 2005a: Towards a malaria early warning system for Eritrea. Final Report to Environmental Health Project, Washington, DC: USAID.

Thomson, M.C. and Connor, S.J., 2001: The development of malaria early warning systems for Africa. In: *Trends in Parasitology*, Vol. 17, pp. 438–445. DOI: http://dx.doi.org/10.1016/S1471-4922(01)02077-3

Thomson, M.C., Connor, S.J, Phindela, T. and Mason, S.J., 2005b: Use of rainfall and sea- surface temperature monitoring for malaria early warning in Botswana. In: *The American Journal of Tropical Medicine and Hygiene*, Vol. 73, pp. 214–221.

Toulmin, C., 2005: Africa and climate change. In: *Tiempo*, Vol. 57, Special Issue on climate change and Africa, pp. 12–15.

Wagbatsoma, V.A. and Ogbeide, O., 1995: Towards malaria control in Nigeria. In: *The Journal of the Royal Society for the Promotion of Health*, Vol. 115, No. 6, pp. 363–365. DOI: http://dx.doi.org/10.1177/146642409511500607

Walter, M.W., 1968: Length of the rainy season in Nigeria. In: *Samaru Research Bulletin*, No. 103, Zaria: Ahmadu Bello University.

WHO, 2000: Severe and complicated malaria. In: *Transactions of the Royal Society of tropical medicine and hygiene*, 94 (supplement).

WHO, 2001: Malaria early warning systems, concepts, indicators and partners. A framework for field research in Africa, Geneva.

WHO, 2002: Final Report on the third meeting of the RBM technical resource network on epidemic prevention and control, Geneva.

WHO, 2003: The Africa malaria report 2003, Vol. WHO/CDS/MAL/2003.1093.

WHO, 2004: Field Guide for malaria epidemic assessment and reporting. Draft for field testing, Geneva, available from: www.WHO/HTM/MAL/2004.1097, DoA: 11 January 2008.

WHO, 2005: World malaria report, Geneva.

http://www.nigeriahc.org.uk/about-nigeria

© 2013 Nicolaus Copernicus University Press. All rights reserved.