A-Geo-Informatics-Technique-for-the-Management-of-Meningitis-Epidemic-Distributions-in-Northern-Nigeria

Article *in* Information Resources Management Journal · July 2015

DOI: 10.4018/IRMJ.2015070102

A Geo-Informatics Technique for the Management of Meningitis Epidemic Distributions in Northern Nigeria

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ABSTRACT

This study aims at examining and mapping the spatiotemporal distribution of meningitis epidemic, in relation to climate variability, using GIS and Remote Sensing techniques. Using the northern part of Nigeria as a case study, data on meningitis epidemic were obtained from the archive of National Bureau of Statistics, Nigeria for the periods between 1998 and 2013. The data were updated with collection from Nigeria Demographic and Health Survey (NDHS). Also, Nigerian Ministry of Health has compiled consistent statistics on meningitis incidence for the periods. A meningitis distribution map was derived from an environmentally-driven form of predicted probability of epidemic experience as it is in International Research Institute for Climate and Society (IRI) Database. The results showed that Meningitis Epidemic is very high during months with low rainfall. Thus, seasonality of rainfall and temperature are important determinants of Meningitis Epidemic incidence in the Northern part of Nigeria. Therefore, it can be confirmed, as cited in some literatures, that the distribution of the epidemics has a strong association with the environment, especially climate variability. Although meningitis surveillance systems in Nigeria have improved, they still fall short of the sensitivity required to demonstrate incidence changes in vaccinated and non-vaccinated cohorts and complementary approaches may be needed to demonstrate the impact of the vaccines. There is however, a need for a new technology and innovation like an integrated GIS, and other environmental modeling system, to allow health practitioners as well as policy makers, for better management, productivity and profitability.

Keywords: *Geo-Informatics, Meningitis Epidemic, Nigeria*

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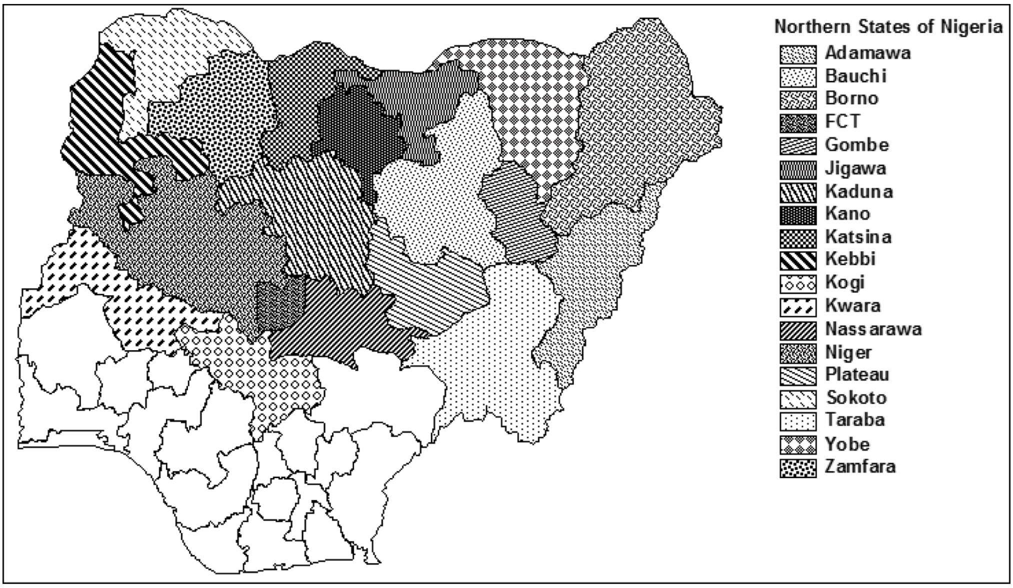
1. INTRODUCTION

The understanding of environmental change impacts on human health has received increasing recognition in recent scientific researches. Risk maps of vector-borne diseases like meningitis in Africa based on environmental data, have received considerable attention in recent years and have become tools with public health potential (Brooker 2002; McMicheal *et al.*, 2003; Thomson *et al.* 2006a). There is at present an overabundance of research and policy activity regarding climate-sensitive diseases, particularly meningitis, malaria, dengue, diarrhoeal diseases and under-nutrition, by individual researchers and international research organizations (Lanham, 2014). Typical among the international research organization are the studies by WHO and Intergovernmental Panel on Climate Change (IPCC) which acknowledged the fact that human population health is influenced by "upstream" environmental and social conditions (WHO 1998; Kovats *et al.*2000; IPCC2001). Meningitis Epidemic disease is an infection of the fluid that surrounds a person's brain and spinal cord (the meninges). Meningitis spreads mainly through kisses, sneezes, coughs, and in close living quarters, especially when people share cups, forks, and spoons. Although many bacteria can cause meningitis, most epidemics are due to a small number of meningococcal serogroups, especially groups A, C, X, Y and W135, with more than 90% of these epidemics due to group A *Neisseria meningitides* (Ouedraogo *et al.*, 2001; Stephens *et al.*, 2007), which usually occurs in a cycle of 10-12 years.

Meningitis epidemic is characterized by a sudden onset of intense headache, fever, nausea, vomiting, photo-phobia and stiff neck, in association with neurological symptoms (lethargy, delirium, coma and convulsions). The WHO (2003a; 2013) recommends that the clinical diagnosis should include an examination for meningeal rigidity, neurological signs, purpura, blood pressure and focal infection. Other potential drivers include the potential impact of dust on preceding viral infection and the fluid dynamics of airborne transmission of the bacteria through dust. Another factor is the impact of high dust levels on human including crowding and reduced ventilation and the climatic variables such as absolute humidity and temperature. Meningitis epidemic in Africa remains an important and unresolved public health problem because it is one of the most feared diseases in Africa due to its rapid onset and high mortality and morbidity rate; those it doesn't kill often suffer brain damage or deafness as a result of the infection of the thin lining that surrounds the brain and spinal cord. Epidemics of meningococcal meningitis affecting West Africa and the Sudan between 1905 and 1908 were amongst the earliest documented in Sub-Saharan Africa (Bulto *et al.*, 2006). Subsequently, an epidemic event was reported with increasing frequency throughout the region and increasingly becomes a permanent and severe problem, and has plagued the African continent for over a century creating public health emergencies with considerable morbidity and mortality. The recent outbreak of meningitis in parts of Northern Nigeria did not catch the nation's health authorities unawares. Investigations by Vanguard (2009) showed that preparations were already in place to contain the disease in the nation's "meningitis belt" long before the outbreak.

Moreover, it is observed from literature that many of the previous studies in Nigeria used different techniques, such as parametric and non-parametric tests, for testing the spread of meningitis. To explore the association of the climate with the epidemics, it is desirable to categorize geographical areas within Nigeria that contain the environmental features of the meningitis belt. In this study, meningitis belt is environmentally vulnerable to the epidemic with massive populations at risk. Although epidemics may occur outside of this belt, but they are often less frequent. There is therefore the need for an integrated Geographical Information System (GIS), Remote Sensing Techniques (RST) and Meningitis Early Warning System (MEWS) that offer health practitioners, as well as policy makers, access to informed decision options for effective proactive management of

Figure 1. Map of Nigeria showing the Northern States where the study was carried out



meningitis in the country. Therefore, this study aims at examining and mapping the spatiotemporal distribution of meningitis epidemic as a result of climate variability/change, using GIS and Remote Sensing techniques. The study examines distribution of meningitis epidemics in the study area and maps its geographical distribution in the study area between 1998 and 2008. The studies mainly focuses on relationship between environment and meningitis epidemics at seasonal time-scales and develop a dynamic meningitis risk mapping and early warning system approach that can contribute to more effective future vaccines.

2. MATERIALS AND METHODS

Nigeria lies between $4^0$16’ and $13^0$53’ North latitude and between $2^0$40’ and $14^0$41’ East longitude. The country is in the West African sub region and borders the Republics of Niger and Chad in the North, the Cameroon Republic on the East and the Republic of Benin in the West. The Gulf of Guinea delimits the Southern boundary. With a total land area of 923,768 square kilometers, stretching from the Gulf of Guinea on the Atlantic coast in the South to the fringes of the Sahara Desert in the North. This study was carried out in the Northern part of Nigeria (see Figure 1).

Generally, the climate of Nigeria is tropical in nature, which is occasionally subjected to variations, depending on the rainfall. The temperature of the country is generally hot all year round, with little variation between wet and dry season temperature. Seasons are defined as the wet season, from April to October, and the dry season, from November till March. The dry season witnesses the prevailing influences of the dry and dusty northeast winds. The wet season is particularly noticeable on the South-eastern coast, where annual rainfall reaches about 130 inches (330cm). During summer, major portion of the country comes under the influence of moisture-laden tropical maritime air. Temperatures are high throughout the year, averaging from 25° to 28°C. Northern Nigeria experiences greater temperature extremes than the South. Rainfall varies widely over short distances from year to year. The Northern part of Nigeria is the study area and comprises about fifteen (15) states which include Kano, Kaduna, Adamawa, etc.

Data on meningitis epidemic were obtained from the archive of National Bureau of Statistics, Nigeria for the periods between 1998 and 2013. The data were updated with collection from Nigeria Demographic and Health Survey (NDHS). Also, Nigerian Ministry of Health has compiled consistent statistics on meningitis incidence for the periods. This data include national, regional and state data on cases of laboratory-confirmed meningitis. For the analysis, population and epidemiology data were obtained from Ministry of Health Epidemiology Unit and Disease Control Unit, and National Population Commission. Confirmed incidences of meningitis per 1000 population were compared with unconfirmed meningitis incidence for the periods to test for potential biases in the data over the periods.

GIS and remote sensing being recent innovative approaches are of great help in overcoming the challenges of traditional approaches in managing information and data in the global context. This is because of the high speed at which remote sensing data can be acquired even in inaccessible areas that traditional methods would not be applicable. GIS allows integration of all types of data together based on geographical and locational components of data; frequent revision of digitized GIS data is possible and changes over time can easily and rapidly be monitored through GIS. GIS techniques were used to analyze and map the geographical distribution of meningitis. Application of GIS in spatial demographic studies is concerned with finding good description of spatial incidence of demographic issues such as meningitis as well as the modeling of such incidence. Meningitis cases in the study area for the period considered, (1998–2013) were interpolated. Three spatial interpolation methods were chosen for this research work: Inverse Distance Weighting (IDW) method and the Spline (completely regularized) as the determinist methods; and Ordinary Kriging as the stochastic method. In order to analyze the interpolation quality, an evaluation by cross validation was carried out. The three different spatial interpolation methods were then applied to estimate the missing value on the basis of the remaining observed ones. This process was carried out on each Northern state. For each interpolation based on the three methods, the rainfall observed values Z(x) have been considered, the estimated values Ž(x), and the errors e(x) = Z(x)–Ž(x). The mean of the errors and its standard deviation were then calculated for each interpolation method. That was developed to calculate and optimize thin plate smoothing splines to data sets of unlimited size and distribution. Other available programs include ArcGIS, which was used for the kriging method, with runtime advantages. ArcGIS Geostatistical Analyst was chosen as the tool to implement the kriging interpolation method. Inverse Distance Weighting method and the Spline are the less efficient interpolation methods for this research work. On the contrary, Ordinary Kriging is the method that allows the sharpest interpolation rainfall data and is the most representative. One way of describing the spatial distribution of this meningitis epidemic is by visualizing the GIS maps that show its spatial distribution in the study area. For this study, the states in the study area (Northern part of Nigeria) were divided into three zones (Zones A, B and C), based on the similarity in the number of months they experience rainfall, and for easy analysis and comparism as below:

Zone A: Five states - Niger, Benue, Nasarawa, Taraba and Abuja

Zone B: Four states - Kebbi, Kaduna, Bauchi and Gombe

Zone C: Seven states - Sokoto, Zamfara, Katsina, Kano, Jigawa, Yobe and Borno

A meningitis distribution map was derived from an environmentally-driven method of predicted probability of epidemic experience as it is in International Research Institute for Climate and Society (IRI) Database. The map is based on rainfall and temperature parameters. The WHO proposes the use of epidemic thresholds for the early detection of epidemics

Table 1. Monthly probability of meningitis epidemic. States in Zones B and C have higher number of months with meningitis epidemic

Zone	Numbers of Months with High probability of Meningitis Epidemic	Months with High probability of Meningitis Epidemic	Name of states within the zone	Illustration
Zone A	6 months	No, De, Ja, Feb, Ma, Ap,	Niger, Benue, Nasarawa, southern part of Taraba, Abuja and Kwara	**Ja- January Feb- February Ma-March, Ap- April, My-May, Ju- June, Jy-July, Ag-August, Sp-September, Oc-October, No-November De- December**
Zone B	7 months	Oc, No, De, Ja, Feb, Ma, Ap,	Kebbi, Kaduna, Bauchi, Gombe	
Zone C	9 months	Oc, No, De, Ja, Feb, Ma, Ap, My, Ju.	Sokoto, Zamfara, Katsina, Kano, Jigawa, Yobe and Borno	

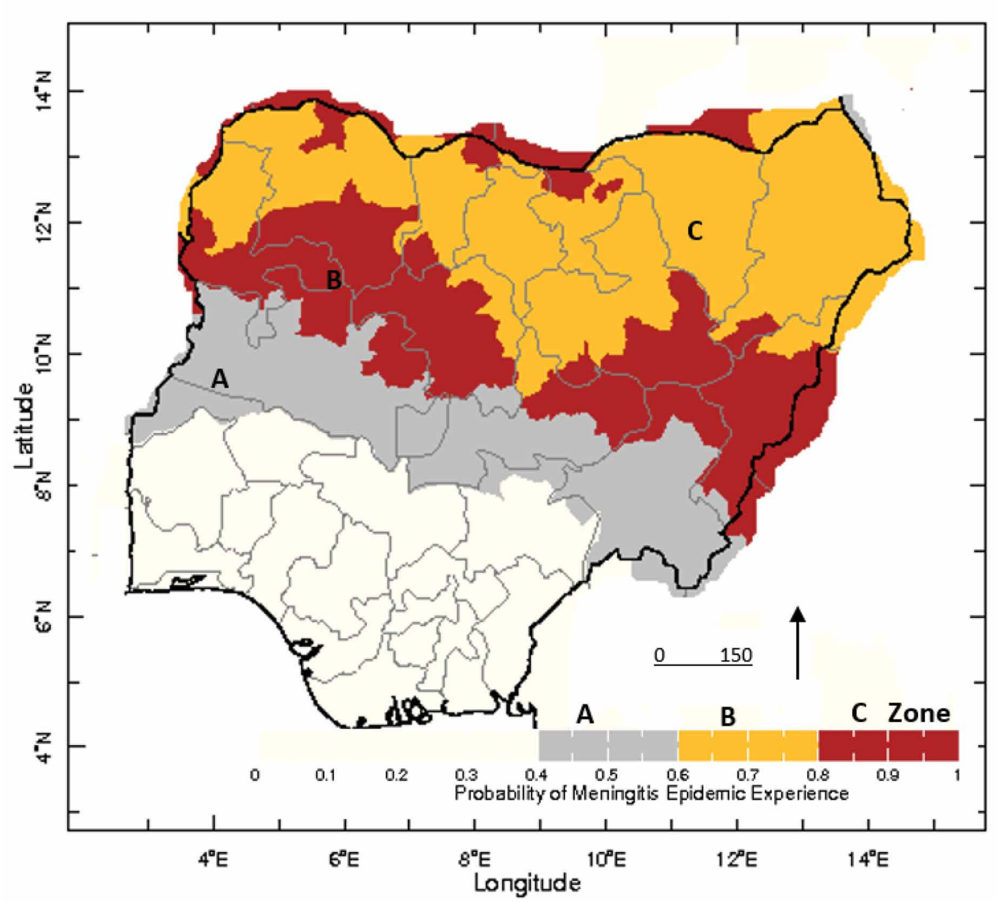
and improved control responses. Defining an 'at-risk' area therefore has important implications for increased monitoring activities and epidemic preparedness. It should be noted that these data are based on a statistical analysis that exhibited a sensitivity and specificity of 83% and 67% respectively. It did not include the impact of non-environmental factors likely to be related to meningitis epidemics, such as population movement, vaccination coverage and recent epidemics in the area.

3. RESULTS AND DISCUSSION

Table 1 shows monthly probability of meningitis epidemic, while Figure 2 shows the spatial distribution of meningitis incidence also in the study area from 1998 to 2013. The distribution of the epidemic has a strong association with the environment especially climate variability. These associations were used to map spatial-temporal distribution of Meningitis Epidemic incidence with varying degrees of success. Figure 2 describes the characteristics of epidemic meningitis in Northern part of Nigeria, its association with the environment, the approaches currently available for control and the advantages of the new vaccines. The results showed that Meningitis Epidemic is very high during months with low rainfall. Table 1 and Figures 2, 3 and 4 show that zone A receives very low amounts of rainfall in the months of November through April and stumpy rainfall occurs in the months of December to February (Table 1 and Figures 2 and 3). Thus, the results showed that six months (November to April) were months of meningitis epidemic in the Northern part of the country. Moreover, the observations (see Figure 2) also showed that six states fall within zone A (Niger, Benue, Nasarawa, Southern part of Taraba, Abuja and Kwara).

Figure 3 shows a meningitis risk map derived from an environmentally-driven model of predicted probability. Dark shaded areas are the location where probability of occurrence and risk of meningitis are very high. From the results, it is obvious that epidemics of meningitis occur across all the states in the Northern Nigeria. But, States within Zones B and C could be regarded as the "meningitis belt" in the Northern part of Nigeria (Figure 3), because they have the greatest incidence of the disease. Epidemics occur throughout the Northern part of the country in the dry season. They typically coincide with periods of very low rainfall, low humidity, high temperature and dusty conditions and disappear with the onset of the rains, suggesting that these environmental factors may play an important role in the occurrence of the disease (Figure 3).

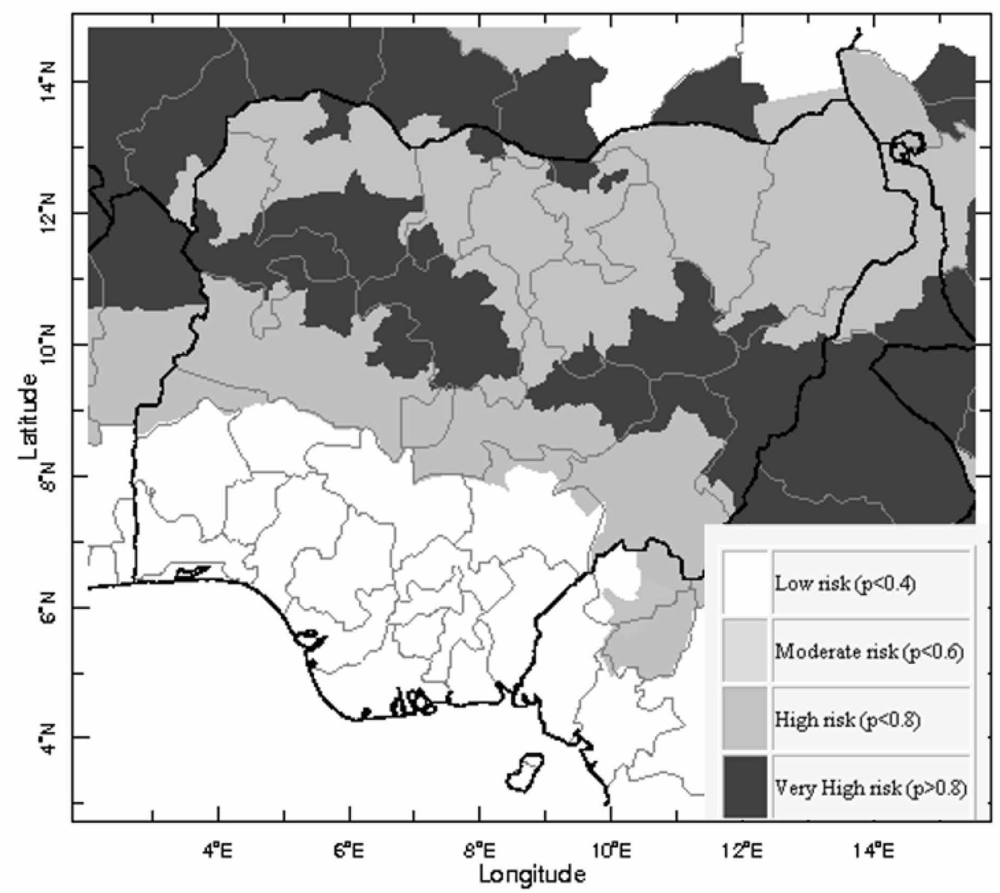
Figure 2. Spatial distribution of meningitis incidence in the Northern Part of Nigeria (1998 to 2013). States in Zones B and C have higher number of months with meningitis epidemic and states in this category include Sokoto, Zamfara, Katsina, Kano, Jigawa, Yobe and Borno



As shown in Figures 2, 5 and 6, it was observed that the scourge of Meningitis has become an annual epidemic in Nigeria. Probability of meningitis epidemic was very high in the months with low rainfall. Previous studies have noted that the information from the many states where the disease has manifested, point to a picture of death and pain. Almost a hundred people are said to have died of the disease, with the highest death toll of 54 persons coming from Maiduguri in Borno states. Other high death tolls include Kano, 21 people and Gombe, 14. In all, about 2000 cases have been recorded in Gombe, Kano, Borno, Yobe, Jigawa and Kaduna states.

The results show that anomalies in annual meningitis incidence at district level were related to monthly climate anomalies (Figures 3-6). Significant relationships were found for both estimates of rainfall and dust in the pre, post and epidemic season, while present in all land-cover classes, these relationships were strongest in savannah areas. Predicting epidemics of meningitis could be feasible. To fully develop this potential, two major things are required (a) a better understanding of the epidemiological and environmental phenomena underpinning epidemics and how satellite derived climate proxies reflect conditions on the

Figure 3. Meningitis risk map derived from a climatologically-driven model (1998 to 2013)



ground and (b) more extensive epidemiological and environmental datasets. Climate forecasting tools capable of predicting climate variables 3-6 months in advance of an epidemic would increase the lead-time available for control strategies. The increased capacity for data processing; the recent improvements in meningitis surveillance in preparation for the distribution of the impending conjugate vaccines and the development of other early warning systems for epidemic diseases in Africa, favours the creation of these models.

This study has several implications. The findings corroborate the earlier findings (Anna *et al.* 2003, Bulto *et al*., 2006, IPCC 2001, McMicheal *et al*., 2003) that the epidemic trend is associated to climate variability and change. The ascending trend of the meningitis epidemic curve is still above those of 2007 and 2008 in northern part of Nigeria. As opposed to 2008, where the epidemic was located in Northern West of Nigeria, the epidemic of 2013 is mainly located in the Northern Central region with eastward extension. Among favorable conditions for the resurgence and then the dispersion of the disease, climatic condition is important as environmental forces inducing periodic fluctuations of disease incidence. The number of reported cases climbed more than eightfold to 47,902 over the same period. About two-thirds of Nigeria's 36 states are affected by the epidemic, the ministry said, in Nigeria

Figure 4. Monthly Rainfall in Zone A (1998 to 2013). Probability of meningitis epidemic was very high in the months with low rainfall

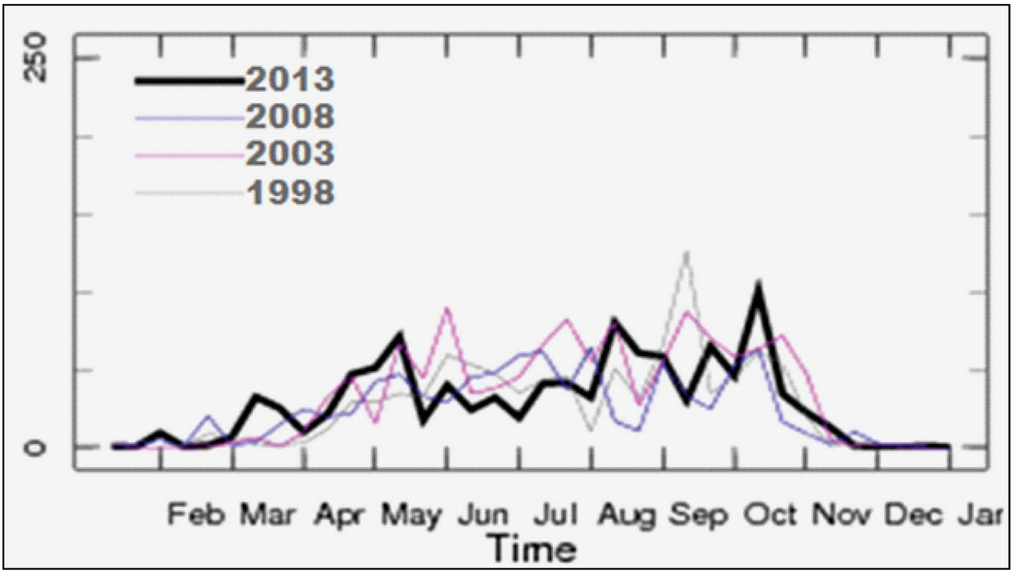


Figure 5. Monthly Rainfall in zone B (1998 to 2013). Probability of meningitis epidemic was very high in the months with low rainfall

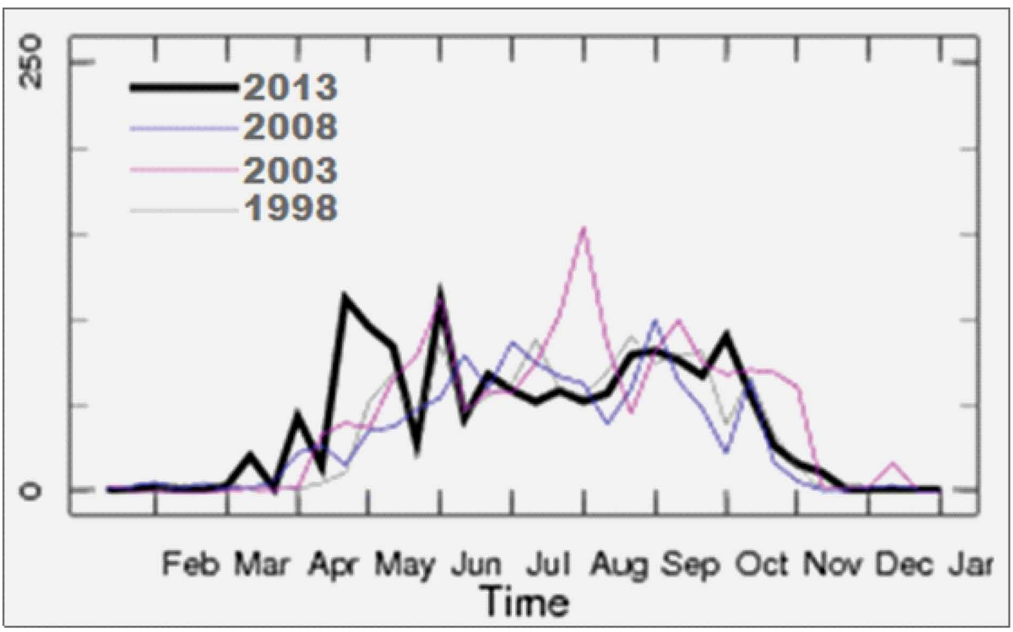
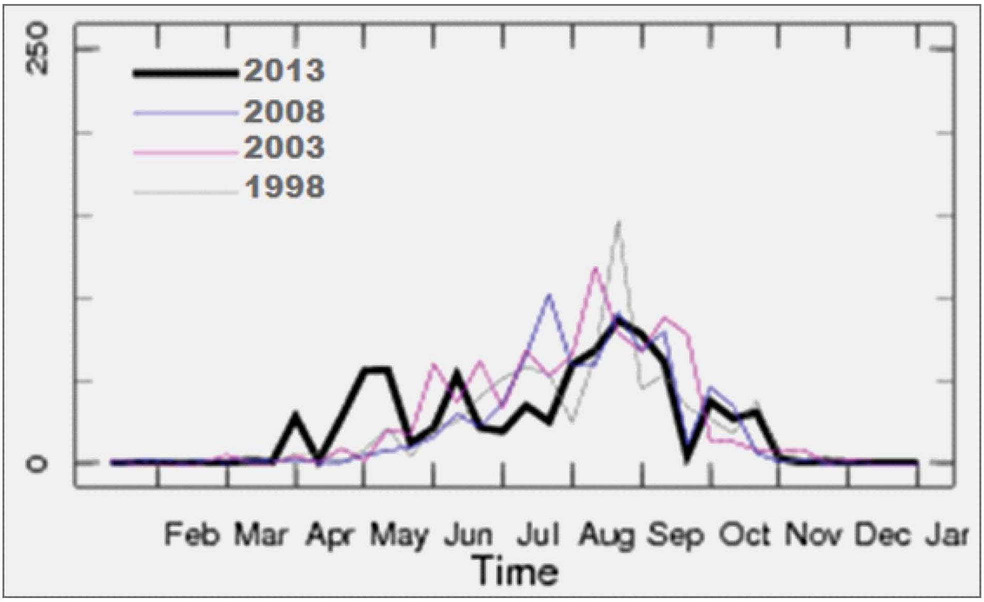


Figure 6. Monthly Rainfall in zone C (1998 to 2013). Probability of meningitis epidemic was very high in the months with low rainfall



which is Africa's most populous country, with a population of more than 140 million. Some of the classic symptoms of the disease are high fever, vomiting, intense headache, stiffness in the neck and sometimes seizures. Even when the disease is diagnosed early and adequate therapy instituted, 5% to 10% of patients die, typically within 24-48 hours of onset of symptoms, according to WHO (1996), while most victims suffer irreversible neurological consequences. It is noted that the disease occurs with remarkable seasonality in the country because outbreaks occur every year between December and May, beginning with the dry season around November and disappearing with the first rains in May or June. The dry season, with strong dusty winds and cold nights make people more prone to respiratory infections and facilitates the spread of the bacteria. Previous studies in other part of the world has shown that meningitis epidemic susceptible areas have a strong correlation with the environment; with a striking correspondence to the 300-1100mm mean annual rainfall isohyets (Alan and Jay, 2005, Sultan *et al*., 2005, Yaka *et al*., 2008). Findings by Molesworth *et al.* (2003) have already quantified the relationship between the environment and the location of the epidemics by proposing a model based on environmental variables and identified regions at risk for meningitis epidemics. Thus, the findings from this present study and several other studies show that meningitis is an environmental disease whose spatial and seasonal distribution is readily described by climatic characteristics (Cuevas *et al,* 2007). In sub-Saharan Africa earlier study by Molesworth *et al.,* 2002b has shown that climatic and other environmental characteristic has significant effects on occurrence of meningitis resulting to what can be called 'Meningitis Belt', that stretches from the Sahelian zone of West Africa to the Horn of Africa. In Nigeria, although, there are no precise boundaries for such belt, but the result from the present study show that the more dry areas are the more often the occurrence of meningitis, and rainforest areas are usually spared. There is no doubt that meningitis may occur outside Northern part of Nigeria, as shown in the result of this study, but this is often smaller, usually during drought years. For instance, it has been reported in the literature that low rainfall together with increasing intensity dust laden winds during Harmattan periods, has a relationship with meningitis epidemic in Northern African countries, leading to a rise in hospital admissions for meningococcal meningitis . Therefore, an important factor associated with the distribution of epidemics was rainfall (Jackou-Boulama *et al*., 2005). Areas without a marked distinction between wet and dry seasons were less likely to have had meningitis epidemics than those with contrasting seasons. The areas without distinction between wet and dry seasons include deserts and the humid parts of coastal and central Africa, much of which are forested, while the areas with contrasting seasons comprise the semiarid savannah and grasslands of the Sahel and east and southern Africa (Anna, 2003). Meningitis occurs annually during the dry season (January to May), and stops with the first rains. The epidemic occurs throughout Africa in the dry season, coincide with periods of very low humidity and dusty conditions, and disappear with the onset of the rains, suggesting that these environmental factors play an important role in the occurrence of the disease (Molesworth *et al*., 2002a; Karen 2010; and Bulto *et al*., 2006).

The major finding from the present study is that the most important factor associated with the distribution of epidemics was rainfall (as also in Figures 4 to 6). Areas without a marked distinction between wet and dry seasons were less likely to have had epidemics than those with contrasting seasons. The areas without distinction between wet and dry seasons include deserts and the humid parts of coastal and central Africa, much of which are forested, and the areas with contrasting seasons comprise the semiarid savannah and grasslands of the Sahel and east and southern Africa (Anna *et al*, 2003). Epidemics occur throughout Africa in the dry season, coincide with periods of very low humidity and dusty conditions, and disappear with the onset of the rains, suggesting that these environmental factors may also play an important role in the occurrence of the disease (Bulto *et al*., 2006, Molesworth *et al*., 2002b, Karen 2010). Epidemics of meningococcal meningitis affecting West Africa and the Sudan between 1905 and 1908 were amongst the earliest documented in Sub-Saharan Africa (Bulto *et al*., 2006). Subsequently, epidemic events were reported with increasing frequency throughout the region and over the next 50 years, epidemics became a permanent and severe problem. This belt was subsequently extended and currently includes the Sahelian parts of Benin, Cameroon, Ethiopia, The Gambia, Ghana, Mali and Senegal. Over two-thirds of all meningitis epidemics occur in this belt (Molesworth *et al*., 2003). Countries with these characteristics include Guinea-Bissau, Guinea, Cote d'Ivoire, Togo, the Central African Republic, Eritrea and countries around the Rift Valley and Great Lakes regions extending as far south as Mozambique, Angola and Namibia (Molesworth *et al*., 2002a). Moreover, findings by Molesworth *et al*. (2003) have already quantified the relationship between the environment and the location of the epidemics to propose a model based on environmental variables and to identify regions at risk for meningitis epidemics. Meningitis epidemic susceptible areas have a strong correlation with the environment, with a striking correspondence to the 300-1100mm mean annual rainfall isohyets (Alan and Jay, 2005) and that their distribution has changed over time. Jackou-Boulama *et al* (2005) described the relationship between rainfall and meningococcal meningitis incidence in Niger between 1996 and 2002. Meningitis incidence increased during the dry season, decreased at the beginning of the rainy season, and had a negative correlation coefficient with rainfall (Jackou-Boulama *et al*, 2005). Thomson et al, (2006b) also reported that changes in the incidence of meningitis in Burkina Faso, Niger, Mali and Togo were associated with dust, rainfall, vegetation greenness (NDVI) and cold cloud duration (CCD) anomalies, defined as the mean minus the observed (Thomson and Connor, 2000). Epidemic prediction could be feasible by analyzing environmental anomalies in long and medium-term patterns and that, in addition to the continental-wide models (Molesworth *et* *al*, 2003), regional climate variability may also influence epidemic onset.

4. CONCLUSION

This study examines the spatiotemporal distribution of meningitis using GIS techniques. It was observed from literature that many of the previous studies in Nigeria used different techniques, such as parametric and non-parametric tests, for testing the spread of meningitis. There is a need, however, for an integrated GIS, RST and MEWS modeling system, to allow health practitioners as well as policy makers for better management. Now that the health communities attention is increasingly focused on climate-health interactions, it has become essential for health decision makers to better understand the role that climate plays in driving disease burdens and health outcomes (both now and in the future). Moreover, the opportunity for integrating climate knowledge and information into health decision- making processes to mitigate the negative and strengthen the positive of climate-health interactions has to be understood. Here, we explore the potential climatic indicators and the climate information relevant to the meningitis prevention and control in the community engaged in the African 'meningitis belt'. Although meningitis surveillance systems in Nigeria have improved, they still fall short of the sensitivity required to demonstrate incidence changes in vaccinated and non-vaccinated cohorts and complementary approaches may be needed to demonstrate the impact of the vaccines. The demonstration that districts, countries or regions introducing the vaccine have a lower incidence of epidemics than unvaccinated population in locations with similar ecological risk could provide a useful monitoring tool both to complement surveillance systems and a powerful visual tool for advocacy.

If, as expected, these vaccines are successful, early warning systems may receive a lower priority for development. However, the lag time between vaccine development and large scale vaccine coverage may still warrant their development for the next decade and should be encouraged. In the light of this, it is necessary to require a combination of the risk maps, identifying areas ecologically susceptible to epidemics to facilitate prioritizing the deployment of conjugate vaccines in the areas with the highest risk: support for the evaluation of vaccine efficacy; and the rapid development of 'early warning systems' that provide support for the control of epidemics in areas where the population has not had access to the new vaccines. The government ought to prepare for this meningitis epidemic annually, since it is an illness whose causes and season of outbreak are well-known. An emphasis on prevention through a well-coordinated enlightenment campaign could have saved many of those currently groaning in pain over the neck-stiffing scourge. The current efforts of the National Emergency Management Agency (NEMA) to contain the epidemic in the North-East would have made greater impact if it had come earlier, by way of a preventive campaign. It is highly recommended that the State ministry of health should take urgent steps to initiate and sustain climate/ health early warning systems management for better health care.

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