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Effects of Urban Sprawl on Meningococcal Meningitis Incidence in Kaduna Urban Area, Nigeria

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Abstract

Meningococcal meningitis is an airborne disease that has overwhelmed the lives of many people for over a century now. There are factors that are connected to the spread of the disease. They include level of income, social behavior, housing condition, climate, environment and urbanization. The “African meningitis belt” which is a region located around west Africa is the most plagued by the disease. This study aims at exploring the deviational distribution and standard distance in relation to the effects that the urban sprawl has on the spatial pattern of the spread of the disease in Kaduna urban area. The *Meningococcal meningitis* reported cases (confirmed and unconfirmed) were used for the study and it was sourced from the public and private hospitals within Kaduna urban area. For each of those years, satellite images (quick bird) were used by digitizing the urban lands and comparing all the years together. Directional distribution and standard distance analysis were conducted using spatial statistical tools in ArcGIS 10.1. The results of the digitized imageries, the directional distribution, and the standard distance were analyzed so as to determine the relationship between urbanization and the disease spread. It was observed from the result that those years that had higher sprawl are more affected by the disease.

Keywords: Spatial Pattern, *Meningococcal meningitis*, Urban sprawl, Directional Distribution, Standard Distance

1. Introduction

Meningitis is the breakdown of the defensive sheath that is shielding the spinal cord and brain which is together called the meninges (Center for Disease Control and Prevention 2014). It is a very dangerous disease because of the ability to cause inflammation very close to brain and spinal cord. A condition like this is treated as a case that requires an urgent attention. Different kinds of germs which can both be viral and bacterial are the cause. The one that is more harmful however is caused by the bacterium *Neisseria meningitides*, which is commonly known as *Meningococcalmeningitis*. This bacterium is very dangerous because it is very harmful to the people it affects and due to the fact that it has the potential to cause epidemics unlike most other causes of *meningitis* (WHO 2000).

Environmental factors play a major role in influencing the spread of the disease. The disease is associated with poor housing condition, deprived settlements and household overcrowding (Baker *et al.* 2000; Fone*et al.* 2003; Olowokure *et al.* 2006; Tully *et al.* 2006). Overcrowded settlements that the inflow and outflow of ventilation is absent also plays a major role in the spread of the disease. A study conducted by Tully *et al.* (2006) in the United Kingdom shows that the spread of *Meningococcal meningitis* disease was common in an overcrowded settlement. Other studies by Fone *et al.* (2003) and Davies *et al.* (1996) also confirms that overcrowding and poor housing conditions are significant factors in influencing the spread of the disease. Other environmental factors like high temperature, rainfall and relative humidity plays a role in the spread of the disease. Studies by Thomson *et al.* (2006), Yaka *et al.* (2008), Teyssou & Rouzic (2007) all proved that temperature, rainfall and relative humidity influences the spread of the disease.

Due to Nigeria’s location, within the sub-Saharan Africa’s “*Meningitis* Belt”, seasonal epidemics expectedly occur in a cyclic pattern. High temperature, dusty winds, poor distribution of services in the towns and people living in an overcrowded condition has made people to be vulnerable to the respiratory disease and are among some of the reasons behind the *meningitis* belt’s high burden of *Meningococcal* disease (Greenwood 2006). A study carried out by Mohammed *et al.* (2000) reported that five major epidemics of *Meningococcal meningitis* occurred in the northern part of Nigeria within 30 years, in 1970, 1975, 1977, 1986, and 1996. According to that study, epidemic of 1996 was the worst among all of them. It was followed by comparable epidemics in Chad in1988, and that of Niger Republic in 1991 and 1994 which are sharing their borders with Nigeria. At least 1,650 people in Nigeria have died as a result of the *Meningitis* epidemic in the north of the country in 1996 (Sawa & Buhari 2011).The worst affected area includes the northern capital of Kano and the towns of Bauchi, Kebbi, and Katsina. About 7000 cases had been reported, with daily admissions to Kano's hospital almost trebling between 1996 to 2004. There was another epidemic outbreak in 2009, where the statistics of the recorded cases revealed that it was the second highest in the recorded history of *Meningococcal meningitis*. There were about 52,128 recorded number of cases with 2,488 deaths (Irving *et al*. 2012). Table 1 below shows the year, number of cases, and number of deaths due to *Meningococcal meningitis in Nigeria*.

Table 1. *Meningococcal Meningitis* Cases from 1991 to 2010 in Nigeria

Year	Cases	Deaths
1991	6,992	695
1992	6,418	563
1993	4,209	472
1994	6,014	437
1995	7,376	1,388
1996	108,568	11,231
1997	39,973	965
1998	10,793	797
1999	4,599	222
2000	5,812	509
2001	5,223	332
2002	4,168	395
2003	17,028	2,257
2004	4,823	363
2005	2,749	134
2006	5,443	214
2007	3,547	301
2008	8,888	710
2009	56,128	2,488
2010	4,833	334

Source: Federal Ministry of Health (2010)

Just the way standard deviation measure helps in explaining the distribution of numeric values, standard deviational ellipse and standard distance are used to show how a group of points spreads around the mean center. It also shows if there is a particular direction that distribution depicts (David and Wang 2005). The standard distance circle is another effective way to visualize the spatial pattern of a collection of points. Most times, the set of point locations describes a specific geographic event that has directional leaning (David and Wong 2001). An example is accidents along a part of a highway will show a linear pattern which is a result of the highway shape and it will not have a circular form. In a situation like this, using standard distance circle will not clearly show directional leaning of the geographic process.

Furfery (1927) described standard deviational ellipse as the logical extension of the standard distance circle. It has the capability to show the directional leaning within a point pattern distribution. There are three elements that are needed in describing and defining standard deviational ellipse: Angle of rotation, deviation along the major axis (longer axis) and the deviation along the minor axis (shorter axis).

If the collection of points displays a certain directional leaning, the direction can then be identified with the maximum spread of the points. At right angle to this direction is the direction with minimum spread of the points. These two axes can be seen as the X and Y axis within the Cartesian coordinate system but circled round to an angle which is consistent to the geographic orientation of the point distribution. The angle between the north and south and the Y axis which is turned clockwise is the angle of orientation θ. The Y axis that is turned can be the dominant or the lesser axis.

The method of descriptive cartographic estimation has been used in diverse studies ranging from the physical science social science and to epidemiology. A study carried out by Thapar *et al.* (1996) showed the capability of one of the point pattern of descriptor analysis. The study was based on the positional changes of the distributions of population in the United States. He did that by comparing the centroid location over censuses at various spatial extents which includes the census region, division and the state level. Another study conducted by Green (1991) estimated the spatial means and standard distances of the most deprived localities in a particular metropolis over a period of time. The study revealed the concentration, dispersion and a shift of the locations of the economically deprived people in those localities.

A study by Levine *et al*. (1995) illustrated the directional leanings of the various types of car accidents in Honolulu, United States. He did that by fixing a standard deviational ellipse for each of the accidents. In a similar study, Wong (1991) proposed estimating a deviational ellipse for each race in a population study. Afterwards, the ellipses were overlaid and those points of union and intersections were calculated. An indicator which is based on the points of intersection and union is developed to represent the degree of spatial segregation. Consequently, the method was applied by Wong (2000) which the process was on the basis of the deviational ellipse to determine the extent of segregation within the Chinese ethnic group.

A study by Kang *et al.* (2012) on the spatiotemporal analysis of microscopic patterns of urbanization and traffic safety shows how directional distribution analysis was applied. The directional distribution of the built up urban land and traffic collision in the study area were investigated from 1998 to 2008. The results show that the ellipses for both the built up urban land and traffic collision have become bigger over time. The steady increase in size means that there has been development at the outskirt of the study area over the period of the study.

Another study by Eryando *et al*. (2012) on the standard deviational ellipse model for malaria surveillance proved the relevance of the model in disease surveillance. In that study, standard deviational ellipse was used to get a clearer understanding of the spatial aspects of the malaria spread. It was discovered that temperature and rainfall anomalies were the two main environmental factors that triggers the epidemic in warm semi- arid and also the high altitude area.

Kent & Leitner (2007) conducted a study on criminal profiling, and standard deviational ellipse model was used for the study. The findings of the study reveal that standard deviational ellipse will work better than circular models. This happens due to the fact standard deviational ellipse is summarizing the minimum and maximum variance within the distribution.

The rapid spread of a city is called “urban sprawl” which refers to a complicated pattern of land use, social and economic development and transportation (Frumkin 2002; Umaru et al. 2012). Sprawl relates to the way in which land is being put into use, the pattern of people’s movement from one place to another and also how the general living conditions of the place is. A city that is sprawling grows externally through a large geographic areas, at times in a leap frogging way. One of the resultant effects of sprawl in a city is the health implications (Ho et al. 2011; Eluwa et al. 2012). It can be in these following ways: air pollution, heat, physical activity patterns, motor vehicle crashes, epidemics, pedestrian injuries, mental health, water quality and quantity.

2. Study Area

Kaduna Urban Area (KUA) is within Kaduna, the capital of Kaduna state which is located on the northern part of Nigeria and within the African *meningitis* belt. The city is made up of various strata of socio-economic level which reflects in the built environment of the city. Housing provision is not a priority of the government of Kaduna State; the condition of housing is very poor being that individuals build for themselves which at most times build below the building standards and not according to the master plan which eventually affects the urban development of KUA. The socio-economic and the built environment nature of KUA have made the variations in the incidence of *Meningococcal meningitis* to be peculiar. The growing number of the disease cases in KUA and the transmission pattern is poorly understood. In order to be able to maintain firm control over the disease, there is need to have a clearer understanding of the dynamics of the outbreak of the disease in terms of incidence as well as with respect to the local factors that are more common to KUA which support the occurrence and strengthen its transmission. The study aims at exploring the deviational distribution and standard distance in relation to the effects that the urban sprawl has on the spatial pattern of the spread of the disease in Kaduna urban area (KUA). Figure 1 shows the map of Nigeria indicating the study area.

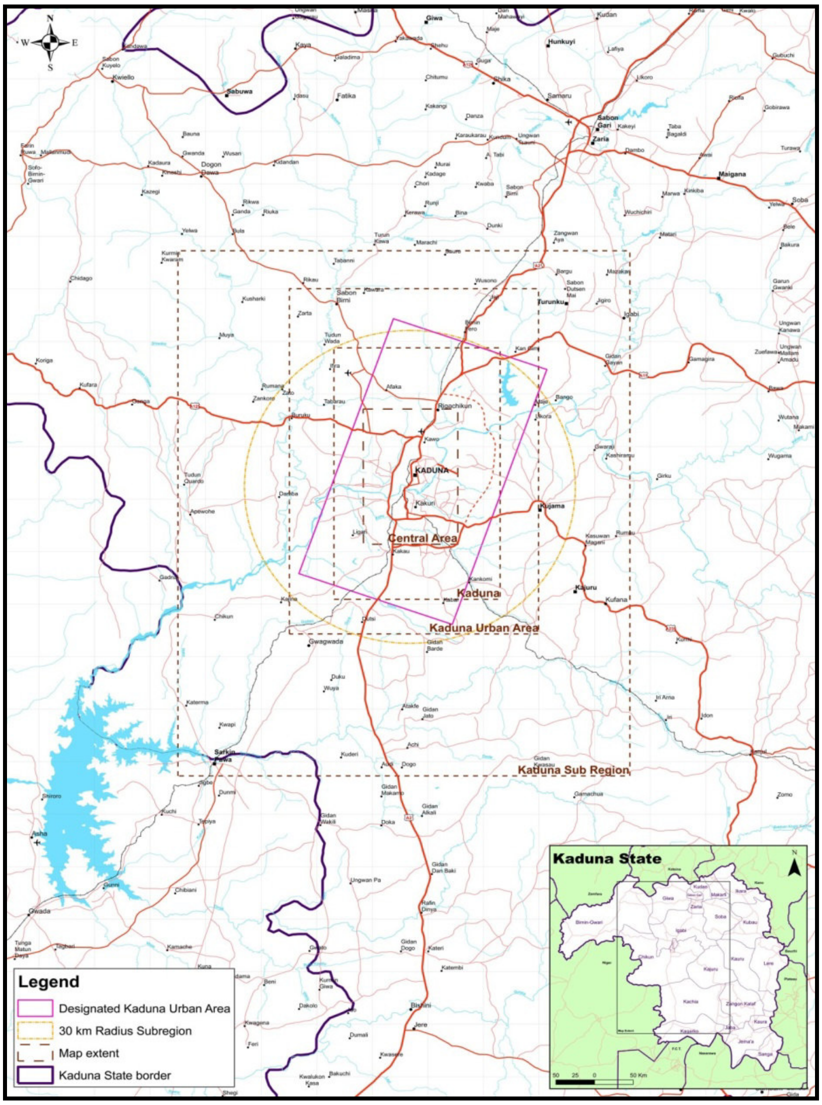


Figure 1. Map of Nigeria indicating the study area

3. Methodology

Standard Distance

The spatial equivalence of standard distance is the standard deviation in the conventional statistics. Standard deviation reveals how observation move away from the mean while standard distance shows how points or locations move away from the mean center or the spatial mean. The standard distances for the spread of meningococcal meningitis will be investigated for each year, 2007 to 2011 in order to know the differences in the spatial dispersion of the distances. The standard distance for the spread of Meningococcal meningitis in Kaduna Urban Area is expressed as this:

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x_{mc})^2 + \sum_{i=1}^{n}(y_i - y_{mc})^2}{n}} \qquad (15)$$

Where

X_{mc} and Y_{mc}= mean center of the distribution point Meningococcal meningitis

n = Number of Meningococcal meningitis source points

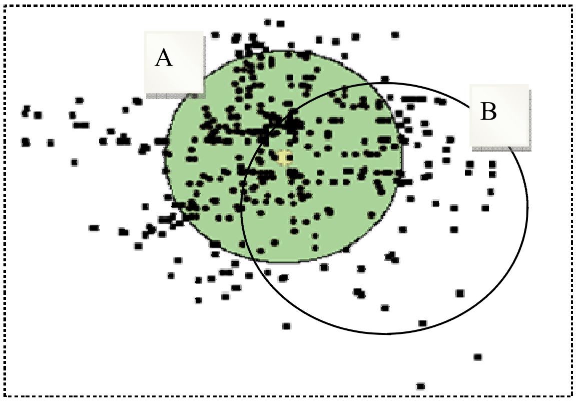


Figure 2. The elements of Standard Distance

Figure 2 shows two circles, A and B. The circle A is smaller than circle B. The standard distance for Meningococcal meningitis for a certain year is the A, and the standard distance for Meningococcal meningitis disease for another year is B. Circle B being larger than circle A implies that there are more cases of the disease in year B than A. In summary, having a larger standard distance will imply that the spread of Meningococcal meningitis disease is more dispersed in Kaduna urban area and having a less distance means that the spread of the disease is low. The circle of standard distance is an effective visualization tool to display the spatial distribution of meningococcal meningitis in Kaduna urban area.

Standard Deviational Ellipse

Another compelling addendum on the circle of standard distance is the standard deviational ellipse (Furffey 1927). It has the capacity to display the directional bias in the distribution of points. There are three major elements that are required to describe and define the standard deviational ellipse. They are: angle of rotation, the deviation on major axis and deviation on the minor axis.

The standard deviational ellipse of the spread of meningococcal meningitis in Kaduna urban area will be investigated for each of the years (2007 to 2011), to be able to detect the angle at which the ellipse is deviating to, to identify the direction that has the highest spread of the disease and also the direction that has the lowest spread of the disease.. The standard deviational ellipse for the spread of Meningococcal meningitis in Kaduna Urban Area is expressed as this:

$$\sigma_x = \sqrt{2}\sqrt{\frac{\sum_{i=1}^{n}(\tilde{x}_i \cos\theta - \tilde{y}_i \sin\theta)^2}{n}}$$
$$\sigma_y = \sqrt{2}\sqrt{\frac{\sum_{i=1}^{n}(\tilde{x}_i \sin\theta + \tilde{y}_i \cos\theta)^2}{n}} \quad (16)$$

Where

X_i and Y_i = the geographic coordinates for distribution of Meningococcal meningitis

n = Number of points for the disease

δ_x = Standard deviations for x axis

δ_y = Standard deviations for y axis

Θ = Angle of rotation

$\check{x}$i = Deviations of the xy coordinates from the mean center

$\bar{y}$i = Deviations of xy coordinates from the mean center

When there is a deviation on the ellipse to a particular direction, it will imply that the spread of Meningococcal meningitis disease is much more on the direction that the ellipse is tilted to. It will also show the direction of the maximum spread of the disease (major axis) and the direction of minimum spread of the disease (minor axis). Figure 3 shows the elements that defines the deviational ellipse.

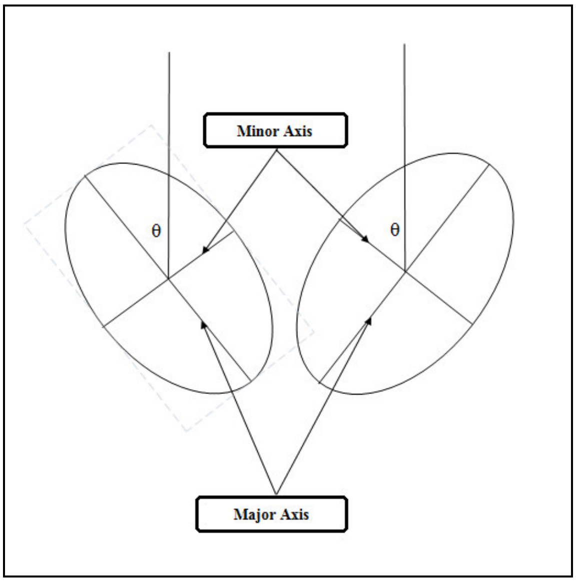


Figure 3. Elements that defines the standard ellipse

Urban Growth Measurement using Change Detection

The rapid spread of a city is called "urban sprawl" which refers to a complicated pattern of land use, social and economic development and transportation (Frumkin 2002; Duncan et al. 2012). Sprawl relates to the way in which land is being put into use, the pattern of people's movement from one place to another and also how the general living conditions of the place is. A city that is sprawling grows externally through a large geographic areas, at times in a leap frogging way. One of the resultant effects of sprawl in a city is the health implications. It can be in these following ways: air pollution, heat, physical activity patterns, motor vehicle crashes, epidemics, pedestrian injuries, mental health, water quality and quantity.

Kaduna urban area is a rapid growing metropolis that is made up of four local governments. There are three major reasons that Kaduna urban area pulls migrants, they are; in search of job opportunities, educational facilities and for family reasons. Figure 4 shows the framework of the analysis.

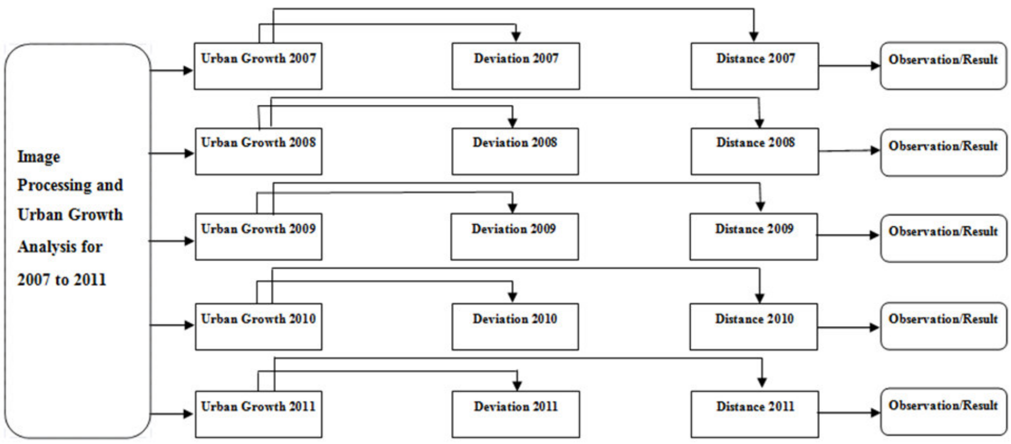


Figure 4. Framework of the analysis of urban growth and Meningococcal meningitis in Kaduna Urban Area

Quick bird image of Kaduna urban area for years 2007 to 2011 was acquired for the purpose of this analysis. Quick bird image is high resolution satellite imagery that is sold by Digital Globe. The bird satellite collects the black and white (panchromatic) imagery at a resolution of 65cm and multispectral imagery at 2.68 meter resolution. With a resolution like this, details like infrastructure, buildings and trees are easily seen. Non parametric method of image rectification will be used, which requires the use of linear polynomial correction. The quick bird image will be imported into ArcGIS 10.1 software to be able to carry out the analysis for change detection. All the built up areas in Kaduna urban area will be digitized as one polygon, for all the five images. The digitized images of Kaduna urban area for all the study years (2007 to 2011) will be compared with the results of the standard distance and standard deviational ellipse for the spread of Meningococcal meningitis in Kaduna urban area.

4. Results

In this study, the result of the standard distance for the spread of Meningococcal meningitis on figure 5 and table 2 shows the result of standard distance in the map and also the table. There was a decrease in the standard distance between 2007 and 2008, the area of coverage for the disease spread reduced in 2008.

There was a progressive increase in the standard distance from year 2008 until 2010. It then reduced in the year 2011. This implies that from year 2008 to 2010, the cluster of the disease spread was very high indicating that the various factors like housing conditions, urbanization, and level of income, housing density, and other factors were fully at work. The standard distance in 2010 was the highest which indicates that some areas that were not affected by the disease in the past years got affected that year. In 2011, the standard distance reduced a bit which shows that disease spread did not affect some areas that were afflicted with the disease in the past years and it did not affect new areas also, perhaps because some factors that influence the spread of the disease were not fully active. In all the study period, 2008 had the lowest standard distance of 5625.6357Km. Figure 5 shows the graph of standard distance for Kaduna urban area.

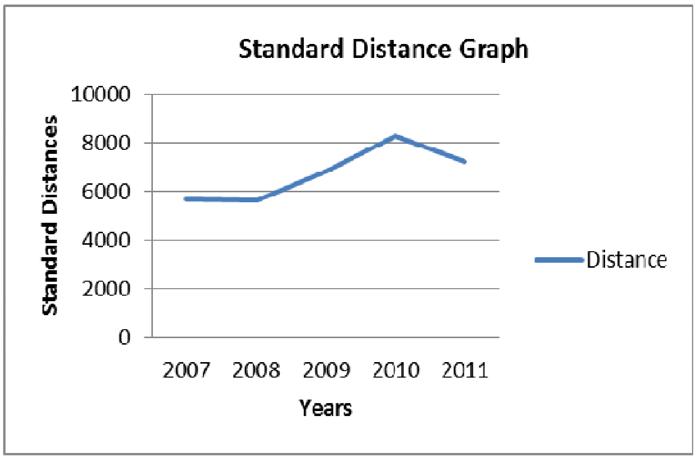


Figure 5. Standard Distance Graph for Meningococcal meningitis in Kaduna Urban Area

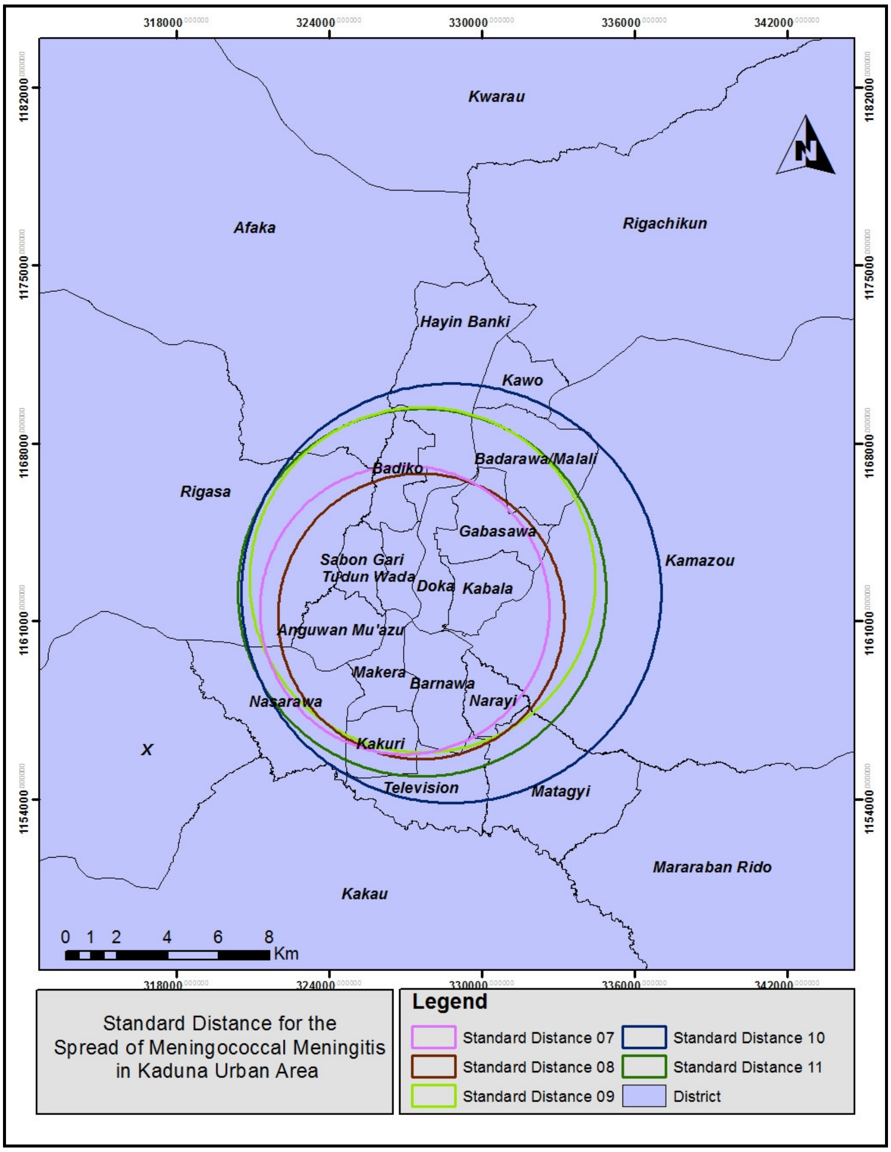


Figure 6. Map of Meningococcal meningitis spread in Kaduna metropolis, showing the Standard distance from 2007 to 2011

Standard Deviational Ellipse

The results for the analysis for standard deviational ellipse as seen on the table 2 and figure 5 reveals that there were changes in the orientation of the ellipse for all the five year period. The most significant change in the orientation was between year 2008 and 2009, having angle of 161° in 2008 and13° in 2009, and the direction tilted towards the eastern part of Kaduna urban area. It implies that there was a sudden change in the locations where the spread of Meningococcal meningitis disease is most common in Kaduna urban area. In 2009, the Y axis distance was 8352.0459Km doubling the Y axis of 2008 with 4984.6392Km. The standard deviation along Y axis was largest in 2010, indicating that new areas that were not affected with the spread of the disease were affected and also, having and angle of deviation 11° tilting towards the eastern part which is a bit different from that of 2010 confirms that direction of the spread of the disease too has changed a bit. The angle of rotation further changed to 17° in 2011 with a standard deviation on the Y axis of 9091.2031Km and X axis of 4705.8521Km. This also implies that there was a change in the direction of the spread of the disease but still remaining on the eastern direction.

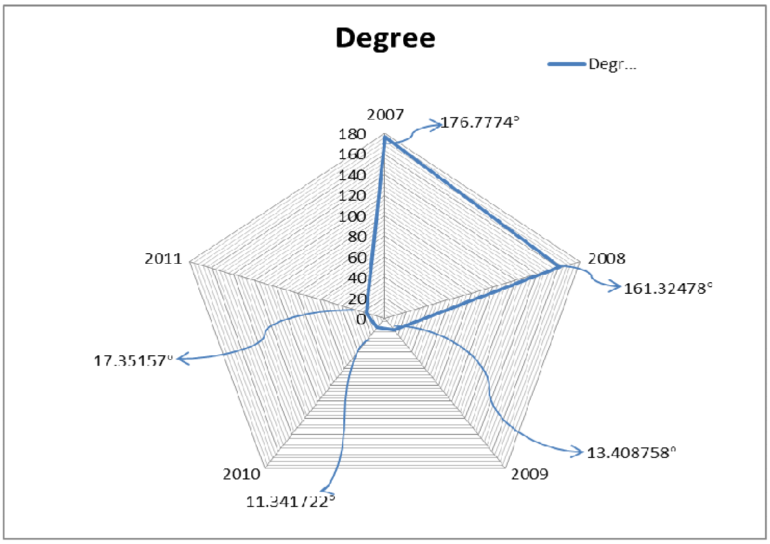


Figure 7. Radar Chart showing the angles of Deviation for Meningococcal meningitis in Kaduna Urban Area from 2007 to 2011.

Having changes in the orientation of the ellipse and with different standard deviations on both the Y and X axis indicates that the direction of the meningococcal meningitis distribution is more tilted towards the direction that the ellipse rotates to.

Table 2. Results of Deviational Ellipse

S/No	Year	Center X	Center Y	XStdDist (Km)	YStdDist (Km)	Rotation (θ)
1.	2007	326980.97	1161462.5	6468.2437	4773.5342	176.7774
2.	2008	327632.19	1161211.1	6200.7197	4984.6392	161.32478
3.	2009	327679.81	1162644.1	4753.8677	8352.0459	13.408758
4.	2010	328808.25	1162119.6	5063.3623	10516.573	11.341722
5.	2011	327659.25	1162146	4705.8521	9091.2031	17.35157

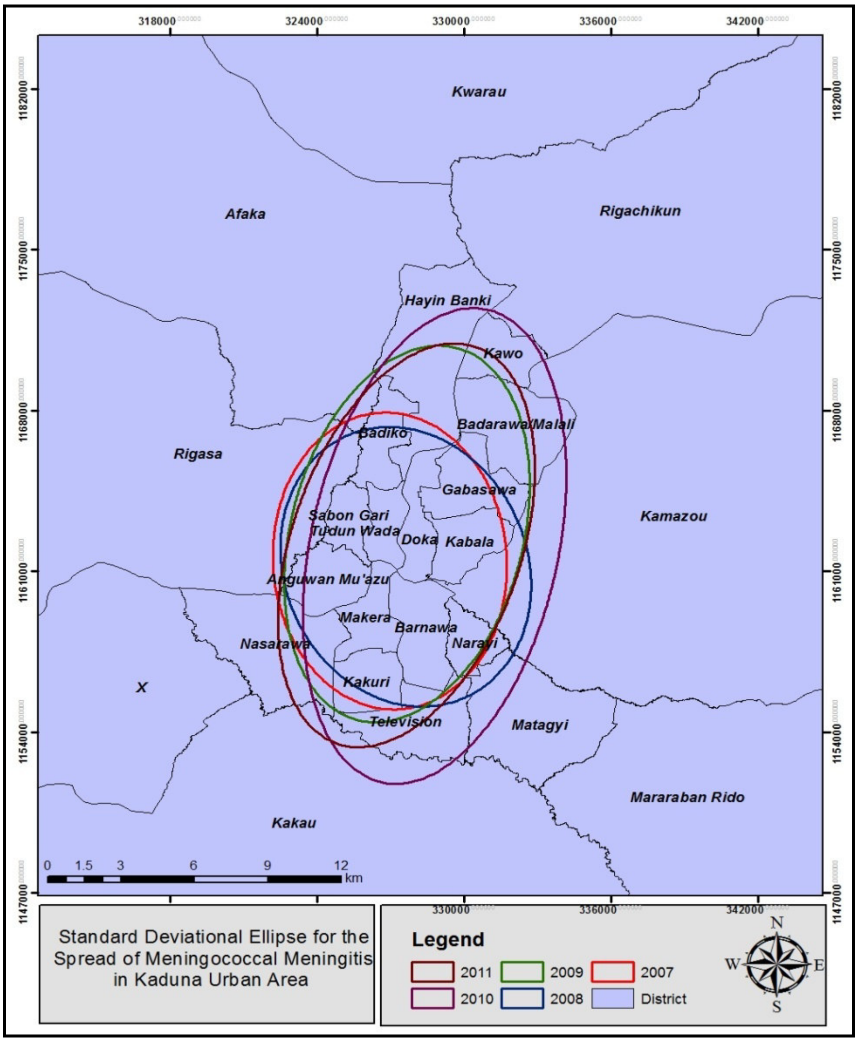


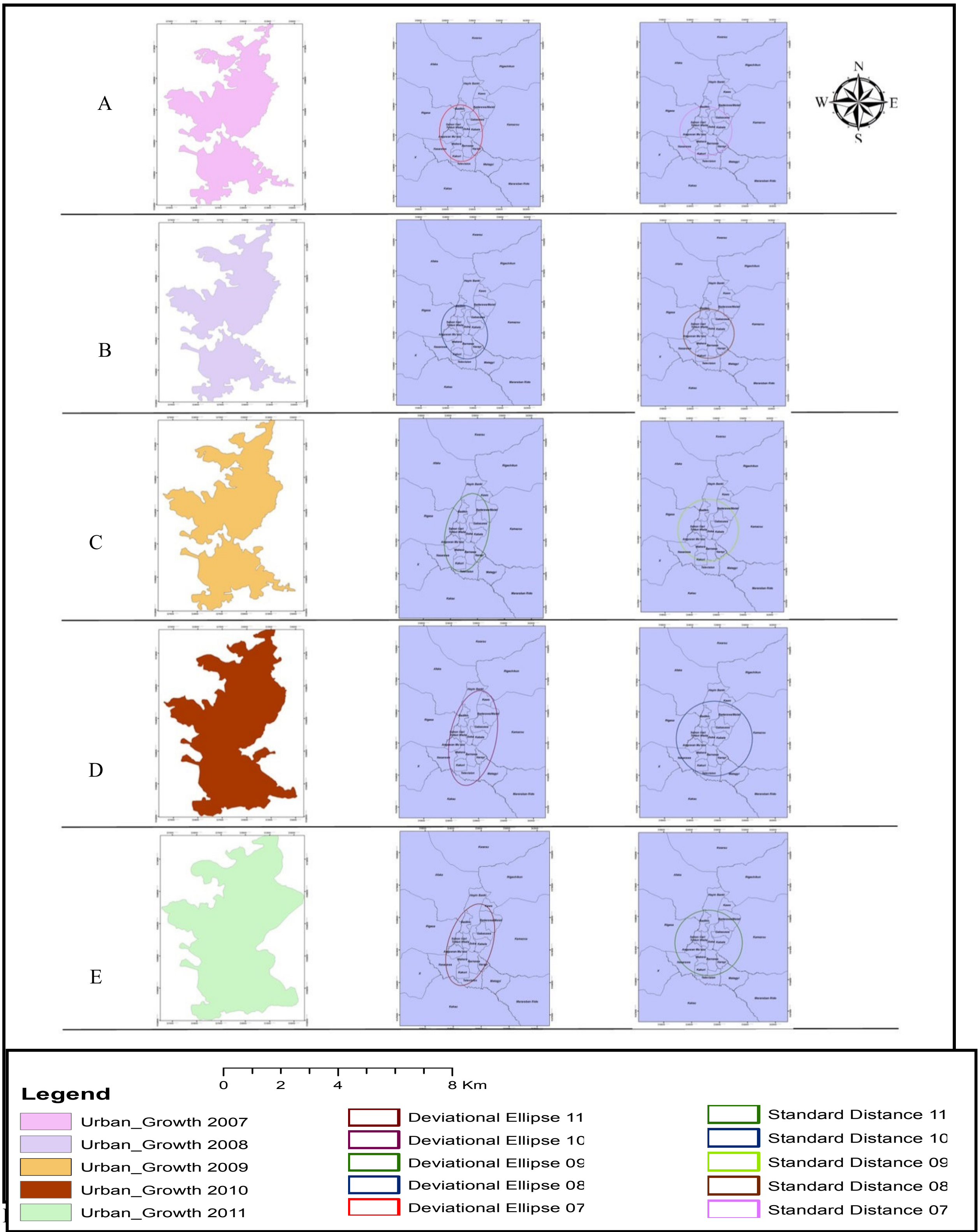
Figure 8. Map of Meningococcal meningitis spread in Kaduna metropolis, showing the deviational ellipse from 2007 to 2011

Urban Sprawl and Distribution Pattern of Meningococcal Meningitis in Kaduna Urban Area

The maps in figure 9 are the satellite images of Kaduna urban area from 2007 to 2011 and also the results of the standard deviations and standard distances for the spread of Meningococcal meningitis in Kaduna urban area from 2007 to 2011. Urban change detection analysis was conducted for each of the satellite images from 2007 to 2011, the results of the change detection for each of the year is shown the maps from A to E. Comparison was made between each of the image of change detection with the deviational ellipse and the standard distance to investigate if there is any relationship between the growth of the town and the spread of the disease in terms of the direction and also the area of coverage.

Figure 9A shows the urban growth, directional distribution and standard distance maps for the 2007. The area that the built up area is covering is 141 sq. /km, and the standard distance is 5.6km, while the angle of deviation is 176°. Comparing the three different maps together, it appears that the spread of the disease is much more concentrated on the center of the study area as seen on the result of the standard distance and also the result of the deviational ellipse. The angle of rotation is slightly tilted towards the western part. It is very likely that the concentration of the disease spread for the year 2007 was more on the western part of the study area.

Figure 9B shows the urban growth, directional distribution and standard distance maps for the year 2008. There was a slight growth in the square area to 146 km, an addition of 3sq/km. The standard distance for the disease spread is about 5 km while the angle of rotation of the ellipse changed to 161°. The results reveal that the standard area of coverage for the year 2008 is about the same with 2007, but there is a change in the angles of the ellipse. The ellipse tilted towards the western part slightly, indicating that the concentration of the disease is more on that side. When it is compared with the urban growth map, it was observed that there was a slight growth on the western part of the study area which implies that there is a relationship between the spread of the disease and the urban growth. Figure 9C shows the urban growth, directional distribution and standard distance maps for 2009. There was a major change in the growth of the town to 158sq/km. The standard distance for the disease spread increased to about 12km while there was an abrupt change in the angle of rotation to 13°. Comparing the three maps together, it shows that the direction of concentration of the disease spread changed and tilted towards the eastern side and the growth of the town is observed to be slightly increasing towards the eastern part of the town. This indicates that there is a strong relationship between the growth of the study area and the spread of the disease in the year 2009.



Kaduna Urban Area

Urban growth, directional distribution and standard distance map of the year 2010 are shown in figure 9D the growth of the study area increased further to 164km, having an increment of 6km. The standard distance of the spread of the disease increased greatly to about 8.2km and the angle of rotation slightly tilted to 11°. Comparing the three maps together, it is observed that there was a change in the shape of the urban growth. Locations that were not built up have been occupied by the growth of the town and it tilted towards the eastern direction. The direction of the ellipse is also tilted towards the eastern part. The standard distance for the year 2010 was the highest, which implies that the area of coverage for the disease spread is wider. This confirms that the growth of the study area has maintained a relationship with the disease spread.

In figure 9E the urban growth, directional distribution and standard distance maps for the year 2011 are shown. The growth of the town kept increasing to 171km. The standard distance of the disease spread reduced a bit to 7km while the angle of rotation for the ellipse changed a bit to 17°. When the three maps were compared together, it was observed that the change in the growth of the town changed slightly increasing towards the eastern part and the standard distance of the disease spread is also wide, implying that the area of coverage of the disease is wide. This also indicates that the growth of the study area has a relationship with the disease spread.

5. Conclusion

The result of the various analysis of the change detection for Kaduna urban area with results of the standard deviations and standard distance has revealed that there is a significant relationship between the spread of meningococcal meningitis and urbanization in Kaduna urban area. The results has confirmed that urbanization should be seen as one of the factors that is making a significant contribution to the spread of Meningococcal meningitis in Kaduna urban area and most likely other similar locations that are within the African meningitis belt.

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