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Article

Spatio-temporal patterns of under 5 mortality in Nigeria

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1. Introduction

In spite of remarkable reductions in under 5 mortality rates (U5MRs), 5.6 million children still die every year worldwide before their fifth birthday (i.e. about 15,000 under 5 deaths everyday). These deaths are largely concentrated in developing regions which have the highest under 5 mortality rates (45 deaths per 1000 live births respectively) compared to developed regions (6 deaths per 1000 live births respectively). Over the years, Sub Saharan Africa has consistently had the highest rate of under 5 deaths worldwide. In 2016, 2.8 million under 5 deaths (79 deaths per 1000 live births) occurred in this region alone. In addition, the proportion of global under 5 deaths occurring in this region increased from 30.1% in 1990 to almost half (49.2%) in 2016 (UN-IGME, 2017). Nigeria in particular, has the second highest absolute number of under 5 deaths (733,000) after India (1.1 million) and one of the highest U5MRs (104 deaths per 1000 live births) after Mali (111), Sierra Leone (114), Central African Republic (124), Chad (127) and Somalia (137) (UN-IGME, 2017).

A significant number of studies have been carried out on under 5 mortality in Nigeria such as studies by Caldwell and McDonald,1982; Ojikutu, 2008; Antai, 2011; Bamgboye, Clement, Adejuwolo, & Duro, 2012; Kayode, Adekanmbi, & Uthman, 2012; Akinyemi, Bamgboye, & Ayeni, 2013; Izugbara, 2014; Abu, Madu, & Ajaero, 2015; Chuckwu and Okonkwo, 2015; Ezeh, Agho, Dibley, Hall, & Page, 2015 Bako, Maiwada, Abubakar, & Akwo, 2016; Adebowale (2017); Adewemimo et al. (2017) among others. However, these studies are largely determinant studies focused on investigating differentials in and risk factors of under 5 mortality without statistically assessing spatial/geographical patterns of under 5 mortality while the few studies that have done so did not examine spatial clustering across states in Nigeria over time (Adebayo, Fahrmeir, & Klasen, 2004; Uthman, Aiyedun, & Yahaya, 2012). Nevertheless, spatial pattern analysis is fundamental to understanding and tackling the problem of under 5 mortality. The basis of spatial analysis is the theory that "everything is related to everything else but near things are more related than distant things" (Tobler, 1970). This phenomenon is referred to as spatial autocorrelation. U5MRs, like any other variable, vary over space. Hence, examining the distribution and extent to which mortality rates are spatially correlated helps to incorporate the impact of geographical/spatial effects into the assessment of under 5 mortality. Information that under 5 mortality may be concentrated in an area over time is crucial to evaluating the effectiveness/impact of child interventions/programs and in identifying high priority areas for future health planning. It can also help provide better insight into possible causes and processes linked to child mortality over space. The main aim of this study was therefore to examine the spatio-temporal patterns of under 5 mortality rates across states in Nigeria using statistical analysis and spatial autocorrelation measures. The objective was to answer a key question: what is the spatial pattern of under 5 mortality in Nigeria and has the pattern changed significantly over time.

2. Materials and methods

2.1. Study area

Nigeria lies between latitude 4° and 14° North of the Equator and longitude 3° and 15° East of the Greenwich Meridian and has a total land area of 923.768 km^2 (Fig. 1). Nigeria is the most populated country in Africa and 7th most populated country worldwide with an estimated population size of 190 million. Nigeria is a middle income country with more than 250 ethnic groups.

2.2. Study design

This study is both a descriptive and quantitative study based on secondary data from two sources: (1) The 2003, 2008 and 2013 Nigeria Demographic and Health Survey (NDHS) carried out by the National Population Commission (NPC) in collaboration with the United States Agency for International Development (USAID) and Macro International Calverton MD, USA. (2) The Institute of Health Metrics and Evaluation (IHME) open source database.

2.3. Sampling technique and data collection

Each Demographic and Health Survey adopted a two-stage stratified sampling technique based on the NPC sampling frame designed to collect data at the national, zonal, state and rural-urban levels during previous censuses. The first stage involved a stratification process

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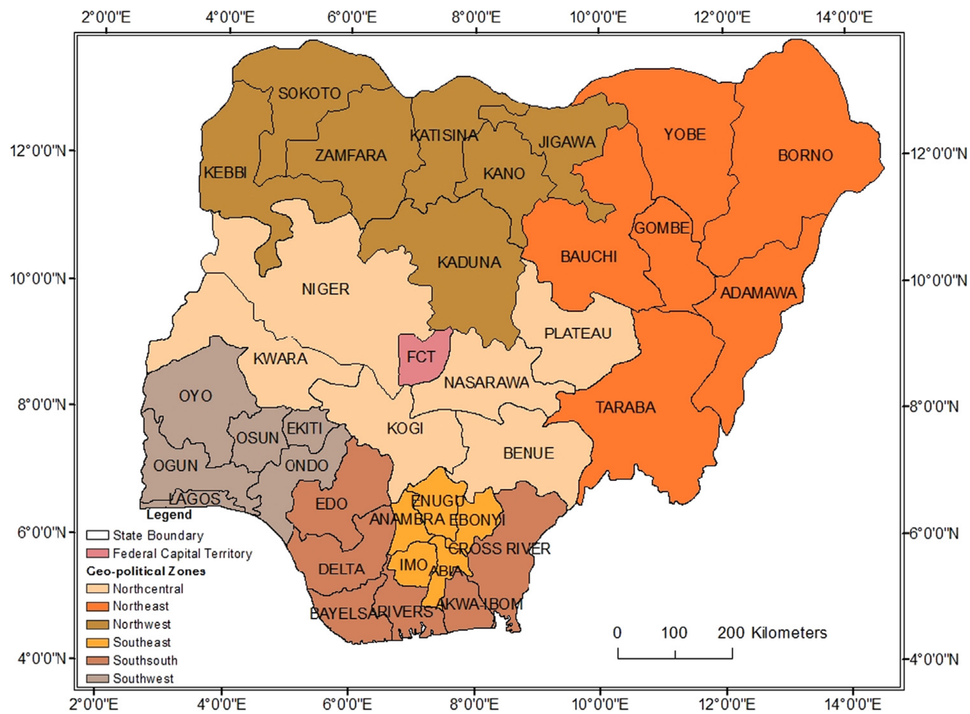

Fig. 1. Map of study area.

whereby clusters or Enumeration Areas (EAs) were selected with probability proportional to population size. The second stage involved the systematic sampling of households in each selected cluster. Representative samples of 7864 households, 36,800 households and 40,680 households were selected in the 2003, 2008 and 2013 surveys respectively. In each survey, data was collected on the sex, month and year of birth, number of births, survival status of all births, current age (if the child is alive) and age at death (if the child is dead) from women aged 15–49 for the five years prior to the survey. Data was also collected on anthropometric indicators, fertility, health care, household assets among others. Further details about the sampling technique can be obtained from individual NDHS reports available on www.measuredhs.com. State U5MRs (defined as the number of deaths before the age of 5 reported by women aged 15–49 years divided by the total number of births) was directly derived from data on birth histories for the 5 years preceding the 2003 NDHS (1999–2003), 2008 NDHS (2004–2008) and 2013 NDHS (2009–2013) covering a 15 year period. NDHS sample weights were applied.

Data was also obtained from the Institute for Health Metrics and Evaluation (IHME) launched in June, 2007 at the University of Washington, Seattle. The research institute runs the well known Global Health Data Exchange (GHDx) catalog which provides free access to health related and demographic datasets. State level U5MRs for Nigeria were derived by IHME researchers for each year from 2000–2013 by synthesizing data from multiple sources. First of all, one-year summary and complete birth history data were extracted from multiple surveys and sources such as the Demographic and Health Survey (DHS), Multiple Indicator Cluster Survey (MICS) and Malaria Indicator Survey (MIS) to estimate source year specific probabilities of death before the age of 5 years. Under 5 mortality for each year was then modeled by applying a one-knot natural spline model. Further details are available on www.healthdata.org.

Both data sources rely on complete birth histories. However, they still differ with regards to how they were collected and processed. The rationale for the choice of both data sources in this study was therefore not to evaluate and compare their data collection and processing/estimation methods but to see the differences and similarities in the spatial patterns of under 5 mortality generated by the two types of data - one at 5 year intervals and the other annual. This could help identify which dataset might be more useful for decision making purposes as Nigeria plans towards achieving the Sustainable Development Goal (SDG) 3.2 target of 25 or fewer under 5 deaths per 1,000 live births by 2030.

2.4. Ethical consideration

Ethical approval and permission to use the 2003, 2008 and 2013 NDHS datasets was obtained from the ethics committee of the USAID/ICF Macro international at Calverton, Maryland USA in conjunction with the ethics committee of the Federal Ministry of Health, Nigeria. Both oral and written informed consent was obtained from each respondent before the questionnaire was administered and all information was collected confidentially.

2.5. Techniques of analysis

1) Statistical analysis and mapping
   Descriptive statistics and choropleth maps were used to summarise and examine variations in under 5 mortality nationally and across states.
2) Spatial Pattern Analysis

a) Global Moran's Index
   The Global Moran's Index was used to investigate whether or not there was a pattern of overall clustering in U5MRs over space. Moran's I varies from -1 through 0 to +1 such that a Moran's I of +1 indicates a high positive spatial autocorrelation (clustering), 0 indicates no spatial autocorrelation (random pattern) and -1 indicates a high negative spatial autocorrelation (dispersion). When z scores are between -1.96 and +1.96 then a p value larger than 0.05 means the pattern is random. On the other hand, a p value less than the confidence level indicates a statistically significant spatial autocorrelation. Global Moran's I is expressed as:

$$I = \frac{N\sum_{i=1}^{n}\sum_{j=1}^{n} wij(Xi - \bar{X})(Xj - \bar{X})}{(\sum_{i=1}^{n}\sum_{j=1}^{n} wij)\sum_{i=1}^{n}(Xi - \bar{X})^2}$$

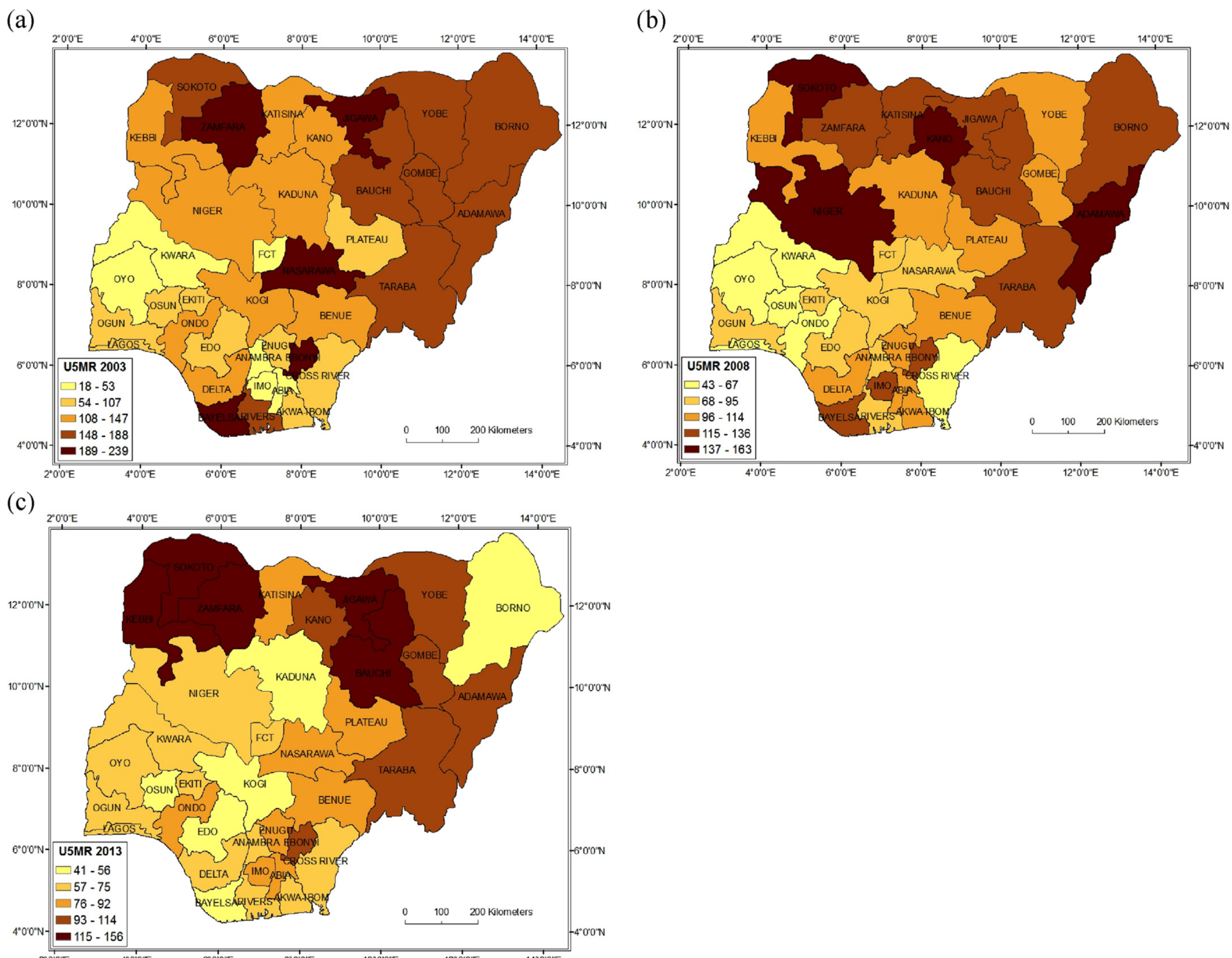

Fig. 2. a–c: The Spatial Distribution of U5MRs in Nigeria in 2003(a), 2008(b) and 2013(c).

Where,

N = no of observations Xi = variable value at a particular location

$\bar{X}$ = mean of the variable wij = weight indexing location i relative to j

Xj = variable value at another location

The global Moran's Index signifies whether the overall pattern is clustered, dispersed or random but does not indicate where specific patterns occur within the study area. Hence a local measure of spatial autocorrelation was also adopted.

b) Local Indicators of Spatial Autocorrelation

The Local Moran's Index was used to identify spatial outliers and concentrations of high and low U5MRs among states in Nigeria. The Local Moran's Index distinguishes between a statistically significant cluster of values (High-High, Low-Low) and spatial outliers (Low-High, High-Low) at the 0.05 confidence level. The local Moran's I is expressed as:

$$Ii = \frac{xi - \overline{X}}{S_i^2} \sum_{j=1, j\neq i}^{n} wi, j\,(x_j - \overline{X})$$

Where;

xi = variable value for feature i $\bar{X}$ = mean of the variable wij = spatial weight between feature i and j $S_i^2 = \frac{\sum_{j=1, j\neq i}^{n} wi,j(xj - \bar{X})^2}{n-1}$ and n = total number of features.

The Local Moran's I identifies local clusters and outliers but does not measure the degree of clustering; hence a hot spot analysis (Getis-Ord Gi* statistic) was also adopted. The Getis-Ord Gi* statistic is a local measure of spatial autocorrelation that identifies hot spots (statistically significant spatial clusters of high values) or cold spots (statistically significant spatial clusters of low values). It also provides a range of confidence levels indicating areas that deviate the most from the assumption of randomness. A high positive z score and small p value indicates the clustering of statistically significant high values (hot spots) while a low negative z score and small p values indicates the clustering of statistically significant low values (cold spots). A z score near zero indicates no obvious spatial clustering. The Getis-Ord Gi* statistic is expressed as:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j}x_j - \bar{X}\sum_{j=1}^{n} w_{i,j}}{\sqrt{\frac{s\left[\sqrt{n\sum_{j=1}^{n} w_{i,j}^2 - (\sum_{j=1}^{n} w_{i,j})^2}\right]}{n-1}}}$$

Where;.

xj = variable value for feature j wi, j = spatial weight between feature i and j.

n = total number of features $\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n}$ S = $\sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{X})^2}$

A polygon contiguity matrix which uses common boundaries to

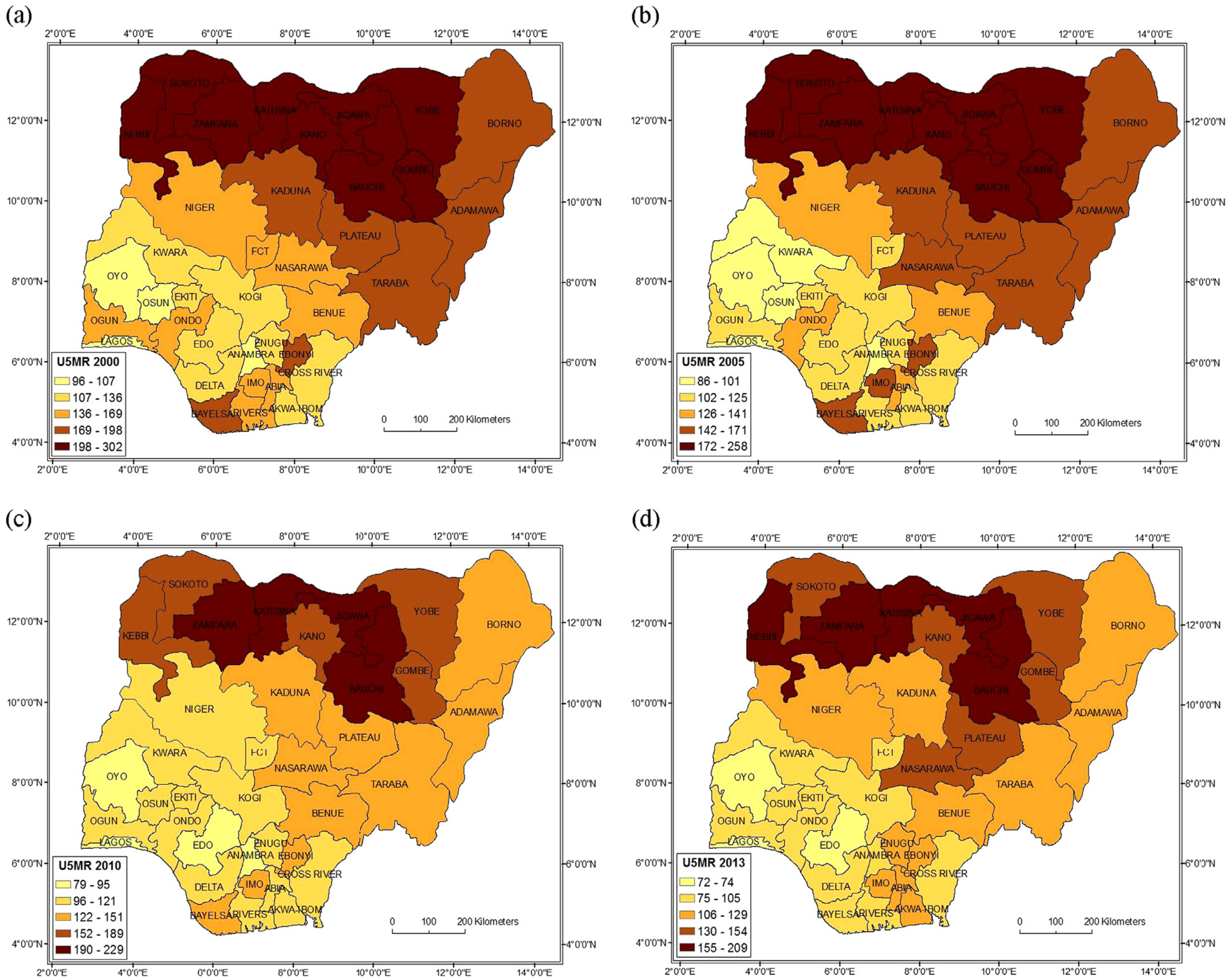

Fig. 3. a-d: The Spatial distribution of U5MRs in Nigeria in 2000(a), 2005(b), 2010(c) and 2013(d), IHME.

Table 1
Global Moran's I values for Under 5 Mortality Rates in Nigeria (NDHS).

Year	Moran's I	Z scores	P value	Remark
2003	0.278265	2.86	0.004	Clustered
2008	0.412345	4.13	0.000	Clustered
2013	0.374421	3.80	0.000	Clustered

All index values are significant at the 0.01 significance level. Calculated by Author

define neighbours (Rook's contiguity matrix) is used in this study.

3. Results and discussion

3.1. Spatial distribution of under 5 mortality rates in Nigeria

The number and proportion of under 5 deaths reported to have occurred in the five years preceding the 2003, 2008 and 2013 survey are presented in Supplementary Table 1a-b. Out of the 6029 live births in the 2003 survey, a total of 847 (14%) did not survive to the age of 5. The overall under 5 mortality rate (U5MR) of 140.5 deaths per 1000 live births implies 1 in 7 children died before their 5th birthday. Most (80%) of the children that died before age 5 were born in rural areas.

Table 2
Global Moran's I values for U5MRs in Nigeria (IHME).

Year	Moran's I	Z scores	P value	Remark
2000	0.708435	6.88	0.000	Clustered
2001	0.707129	6.86	0.000	Clustered
2002	0.704775	6.84	0.000	Clustered
2003	0.703581	6.83	0.000	Clustered
2004	0.700591	6.80	0.000	Clustered
2005	0.705267	6.85	0.000	Clustered
2006	0.707107	6.88	0.000	Clustered
2007	0.708305	6.90	0.000	Clustered
2008	0.710747	6.93	0.000	Clustered
2009	0.706283	6.90	0.000	Clustered
2010	0.703076	6.88	0.000	Clustered
2011	0.688992	6.75	0.000	Clustered
2012	0.680771	6.69	0.000	Clustered
2013	0.658497	6.48	0.000	Clustered

All index values are significant at the 0.01 significance level. Calculated by Author

U5MRs are also considerably higher in rural areas (157.9 deaths per 1000 live births) than in urban areas (97.7 deaths per 1000 live births). Regionally, U5MR ranges from 64.1 deaths per 1000 live births in the Southeast (1 in 16) to as high as 168.2 deaths per 1000 live births in the

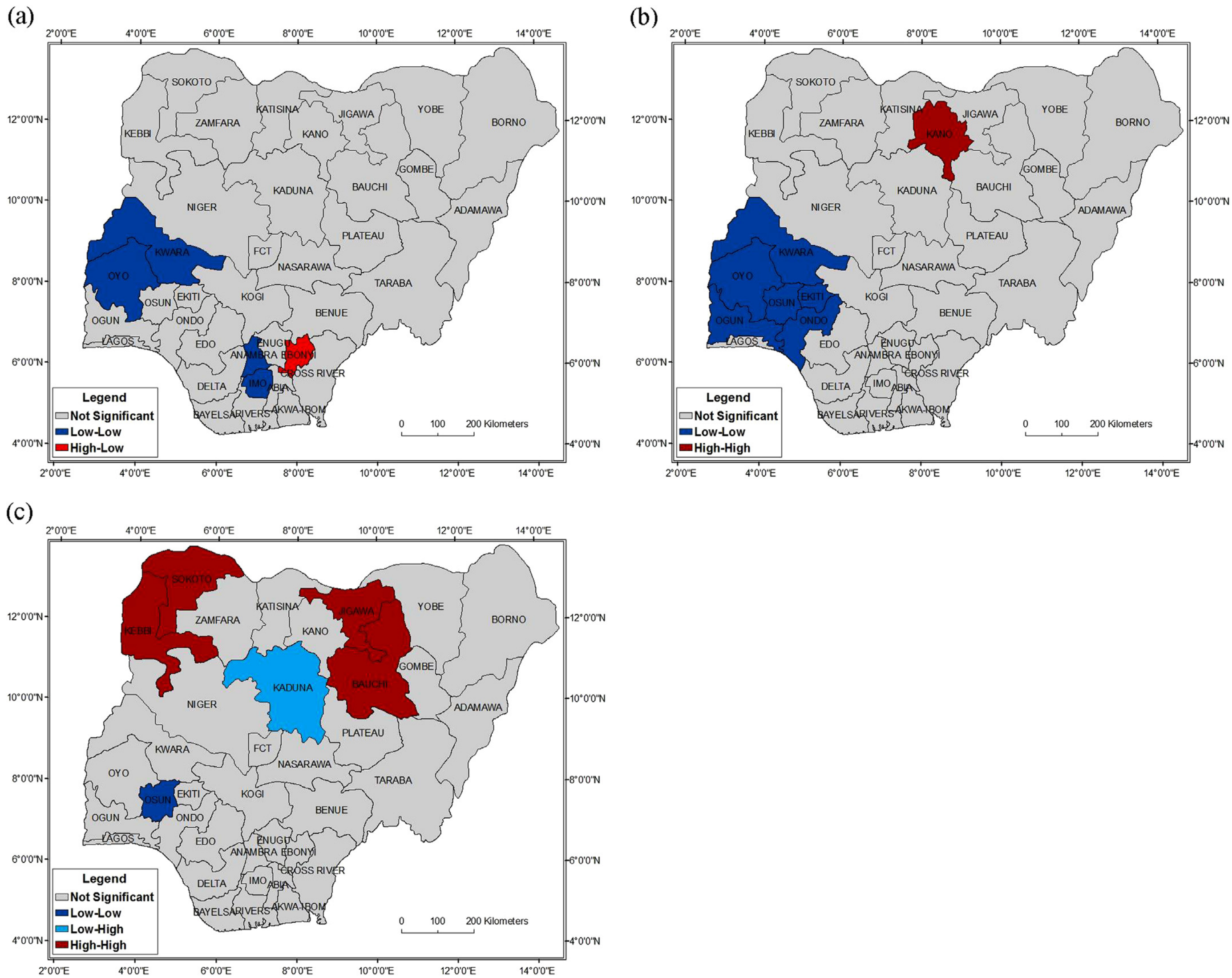

Fig. 4. a–c: LISA cluster maps for U5MRs in Nigeria in 2003(a), 2008(b) and 2013(c).

Northeast (1 in 6). Fig. 2a shows high U5MRs across states with Zamfara state having the highest U5MR (238.9 deaths per 1000 live births) followed by Bayelsa and Jigawa states (233.3 and 227 deaths per 1000 live births respectively). On the other hand Imo state had the lowest U5MR(17.7 deaths per 1000 live births) followed by Kwara and Anambra states (25 and 27.8 deaths per 1000 live births respectively). In other words, the risk/chance of under 5 death varied from 1 in 4 children in Zamfara state to 1 in 56 in Imo state.

Based on the 2008 survey, 3,187 (11.1%) out of the 28,647 live births died before their 5th birthday. The overall U5MR of 111.2 deaths per 1000 live births implies 1 in 9 children died before the age of 5. Most (79%) of the children that died before age 5 were born in rural areas. U5MRs are also significantly higher in rural areas (124.5 deaths per 1000 live births) than in urban areas (80 deaths per 1000 live births). Regionally, U5MR ranges from 66 deaths per 1000 live births in the Southwest (1 in 15) to as high as 135.1 deaths per 1,000 live births in the Northwest (1 in 7). At the state level, the highest number of under 5 deaths occurred in Kano state (404) followed by Katsina (202), Bauchi (163) and Sokoto state (160). Fig. 2b also shows high U5MRs across states with Kano state having the highest U5MR (163 deaths per 1,000 live births) followed by Sokoto and Adamawa states (159.7 and 150.7 deaths per 1,000 live births). On the other hand, Osun state had the lowest U5MR (42.6 deaths per 1000 live births) followed by Kwara and Cross River states (42.8 and 62.5 deaths per 1,000 live births). This implies that the risk/chance of under 5 death varied from 1 in 6 in Kano state to 1 in 23 in Osun state.

Based on the 2013 survey, 2,848 (9%) out of the 31,482 live births died before the age of 5. The overall U5MR of 90.5 deaths per 1000 live births implies 1 in 11 children died before the age of 5. Most (75%) of the children that died before their 5th birthday were born in rural areas. Like the previous surveys, U5MRs are also significantly higher in rural areas (104.1 deaths per 1000 live births) than in urban areas (65 deaths per 1000 live births). Regionally, U5MR ranges from 63.6 deaths per 1000 live births in the Southwest (1 in 16) to as high as 109.6 deaths per 1000 live births in the Northwest (1 in 9). Across states, the highest number of under 5 deaths occurred in Kano state (303) followed by Zamfara (250) and Jigawa (212). Fig. 2c also shows high U5MRs across states with Zamfara state having the highest U5MR (156.3 deaths per 1000 live births) followed by Jigawa and Bauchi states (134.5 and 131.4 deaths per 1000 live births). On the other hand, both Osun and Edo states had the lowest U5MR (40.9 deaths per 1000 live births). This implies that the risk/chance of under 5 death varied from 1 in 6 in Zamfara state to 1 in 24 in Osun and Edo state.

For comparative purposes, the spatial pattern of state U5MRs in Nigeria (2000–2013) from the Institute for Health Metrics and Evaluation (IHME) was examined (Supplementary Table 2). The U5MR of 184 deaths per 1000 live births in 2000 implies that 1 in 5 died before the age of 5. Across states, U5MR ranged from 96 deaths per 1000 live births in Lagos

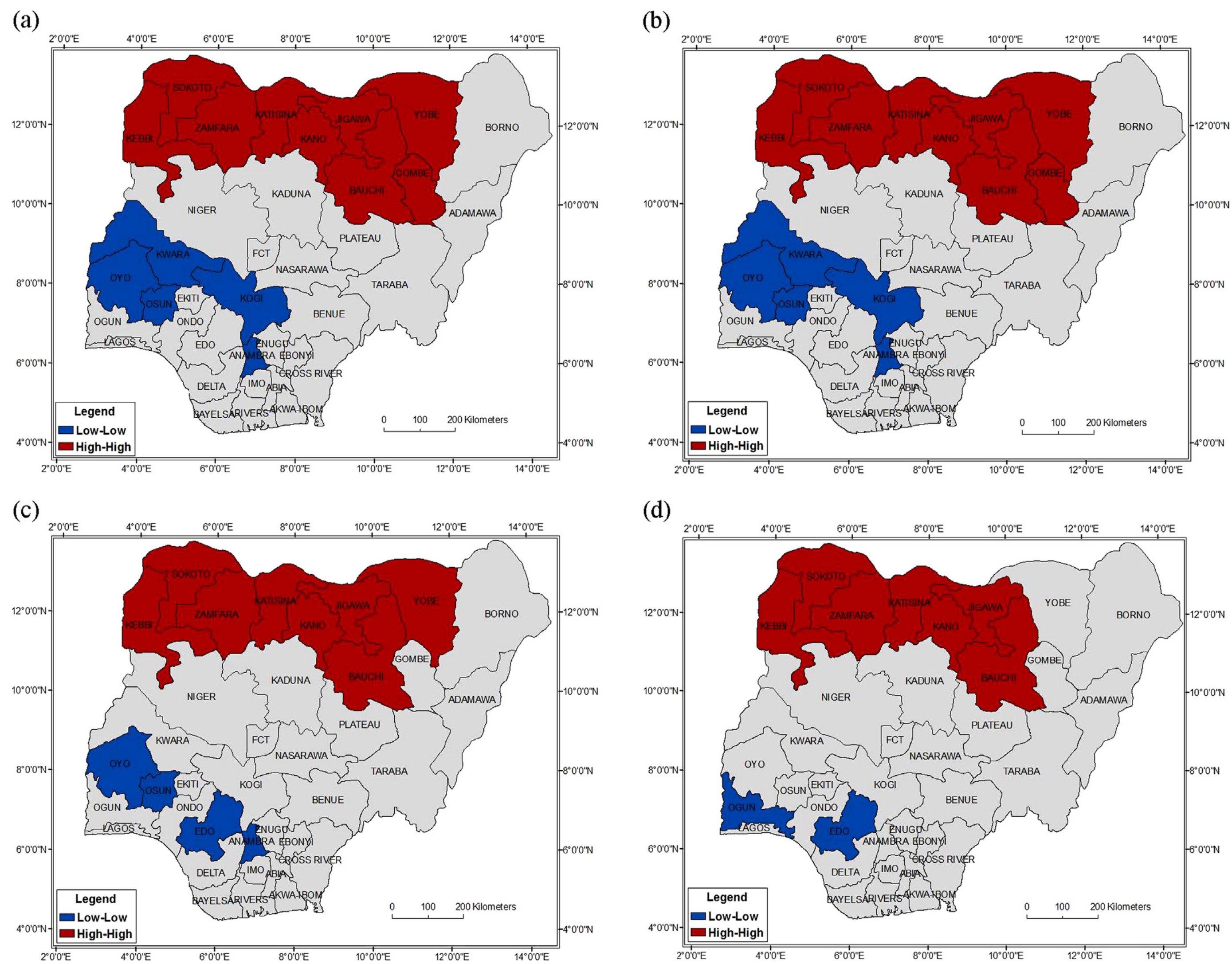

Fig. 5. a-d: LISA cluster maps for U5MRs in Nigeria in 2000(a), 2005(b), 2010(c) and 2013(d), IHME.

state (1 in 10) to as high as 302 deaths per 1000 live births in Zamfara state (1 in 3). Similarly, in 2013, the U5MR of 128 deaths per 1,000 live births implies that 1 in 8 died before the age of 5. Across states, U5MR ranged from 72 deaths per 1000 live births in Edo state (1 in 14) to 209 deaths per 1000 live births in Zamfara state (1 in 5). Fig. 3a-d show significant spatial variations across states over the 13 year period covered with distinct North-South differences in U5MRs though with some variation in 2000, 2005, 2010 and 2013.

3.2. Spatial pattern analysis and mapping

3.2.1. Global Moran's I analysis

Results of the Global Moran’s I shows a statistically significant positive spatial autocorrelation of U5MRs in Nigeria (MI = 0.28, p = 0.004). The z score (2.86) also points to a clustered pattern. Based on the 2008 survey, results show a statistically significant positive spatial autocorrelation of U5MRs in Nigeria (MI = 0.41, p = 0.00). The z score (4.13) also indicates a clustered pattern. Based on the 2013 survey, results indicate a statistically significant positive spatial autocorrelation of overall under 5 mortality rates in Nigeria (MI = 0.37, p = 0.00). The z score (3.80) also indicates a clustered pattern. Results as shown in Table 1 indicate that there is less than a 1% likelihood that the clustered pattern of U5MRs based on the 2003, 2008 and 2013 surveys is the result of random chance. The higher the Global Moran’s I value, the stronger the spatial autocorrelation/dependence. Hence results suggest that spatial autocorrelation was strongest in 2004–2008 (period covered by the 2008 NDHS) for U5MRs in Nigeria. A Global Moran’s I Analysis was also carried out based on state IHME figure for each year. Table 2 shows a statistically significant positive spatial autocorrelation of U5MRs in Nigeria for each year. In other words, results indicate that the probability of the overall clustered pattern being due to random chance is less than 1%.

3.2.2. Local Moran’s I analysis

Supplementary Table 5 lists all the states with statistically significant local spatial autocorrelation ($p < 0.05$) in U5MRs based on the three surveys. Based on the 2003 survey, two significant clusters were identified: low-low and High-Low. Oyo (Index = 1.38, p = 0.01), Kwara (Index = 0.79, p = 0.05), Imo (Index = 1.31, p = 0.02) and Anambra state (Index = 0.80, p = 0.01) were identified as statistically significant clusters of low values. In other words, they not only had low U5MRs but were also surrounded by states with low U5MRs as well (Low-Low cluster). On the other hand, Ebonyi State (Index = -1.03, p = 0.03) was identified as a High-Low cluster. The negative sign indicates dissimilar values. In other words, results indicate that Ebonyi had a high U5MR but was surrounded by states with much lower values as shown in Fig. 4a. This suggests that key factors responsible for a high U5MRs in Ebonyi are most likely state-specific. Similarly, two significant clusters

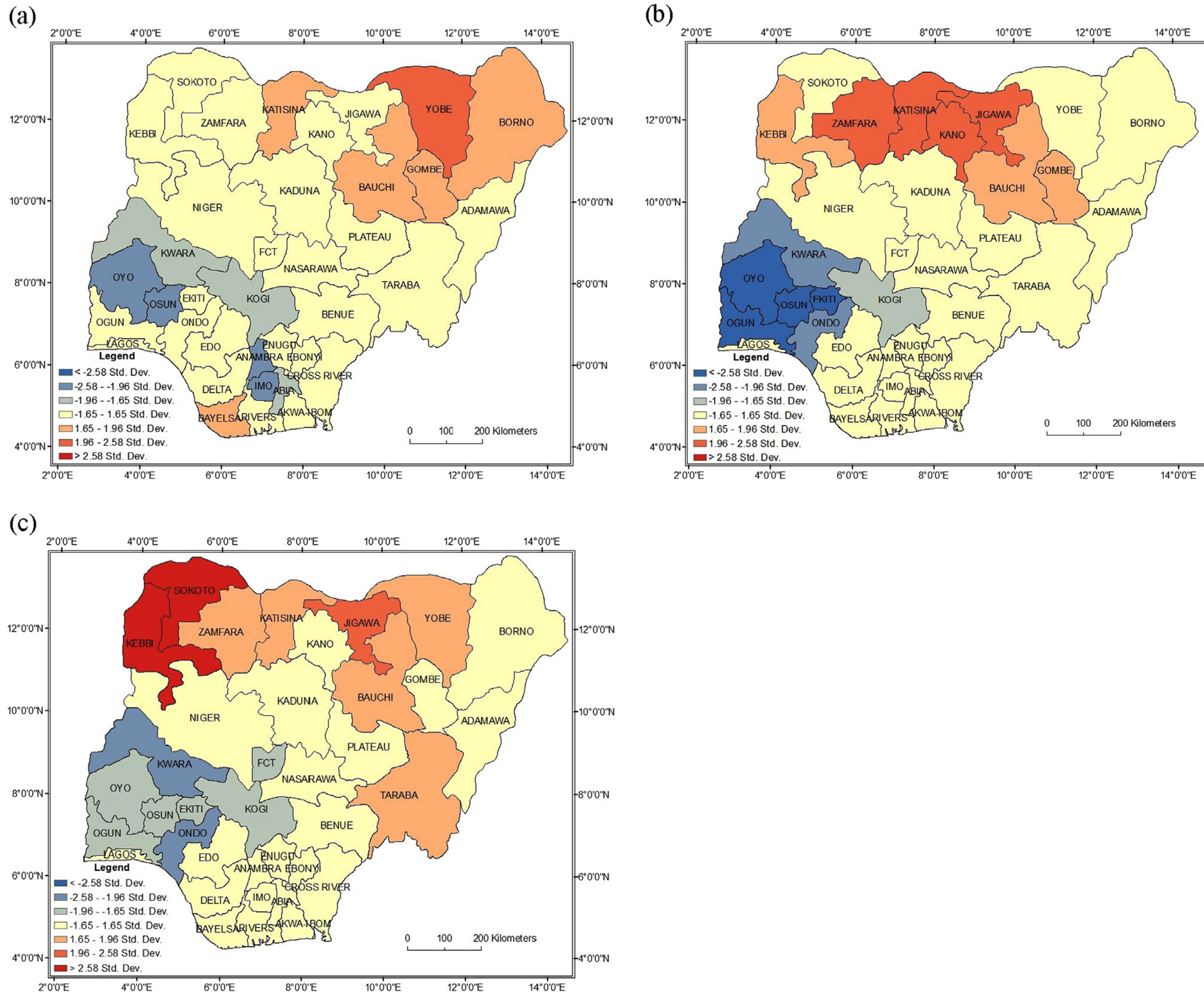

Fig. 6. a-c: Gi* statistic (Hot spot) maps for U5MRs in Nigeria in 2003(a), 2008(b) and 2013(c).

were identified: High-High and Low-Low based on the 2008 survey (Fig. 4b). Kano state with a statistically significant Index of 1.36 ($p = 0.003$) indicates that Kano state not only had a high U5MR but was also surrounded by states with high U5MRs as well (High-High cluster). All the Southwestern states (except Lagos) and Kwara state in the Northcentral region were identified as statistically significant ($p < 0.05$) clusters of low U5MRs (Low-Low cluster). This suggests that states in these regions share characteristics that may explain the concentration of significantly lower U5MRs. Based on the 2013 survey, three significant clusters were identified: High-High, Low-Low and Low-High (Fig. 4c). Osun state with a statistically significant Index of 0.83 ($p = 0.04$) was identified as a statistically significant cluster of low values (Low-Low cluster) which indicates that Osun state as well as surrounding states had significantly low U5MRs. On the other hand, 4 states: Kebbi, Sokoto, Jigawa and Bauchi were identified as statistically significant clusters of high values (High-High cluster) which indicates that they not only had significantly high U5MRs but were also surrounded by states with significantly high U5MRs as well. Kaduna State (Index = -0.66, $p = 0.04$) was identified as a Low-High cluster (outlier). The negative sign indicates dissimilar values. In other words, results indicate that U5MRs in Kaduna state are significantly lower than U5MRs in neighbouring states. This suggests that key factors responsible for a much lower U5MR in Kaduna state compared to its neighbours are most likely peculiar to Kaduna state itself.

In regards to IHME datasets, the Local Moran's I Analysis identified High-High clusters of U5MR in the Northwest and Northeast and Low-Low clusters of U5MR in the Southwest extending to Kwara state in the Northcentral region and Anambra state in the Southeast (Fig. 5). Most of the same High-High and Low-Low clusters of U5MR were detected throughout the years particularly from 2000–2007 with slight variations in cluster pattern from 2008–2013 (though Index values vary).

3.2.3. Hot spot analysis (Getis-ord Gi* statistic)

Supplementary Table 6a and Fig. 6a show the degree of clustering of U5MRs in Nigeria based on the 2003 survey. Oyo ($p = 0.03$), Osun ($p = 0.04$), Anambra ($p = 0.04$) and Imo state ($p = 0.03$) are identified as statistically significant cold spots at a 95% confidence level signifying the maximum spatial clustering of low U5MRs. Statistically significant cold spots were also identified in Kwara, Kogi and Abia states at a 90% confidence level. On the other hand, Yobe State ($p = 0.04$) was identified as a statistically significant hot spot at a 95% confidence level signifying the maximum spatial clustering of high U5MRs. Statistically significant hot spots were also identified in Katsina, Bauchi, Gombe, Borno and Bayelsa states at a 90% confidence level. Supplementary Table 6b and Fig. 6b show the degree of clustering of U5MRs in Nigeria based on the 2008 survey. The hot spot analysis result identified Oyo

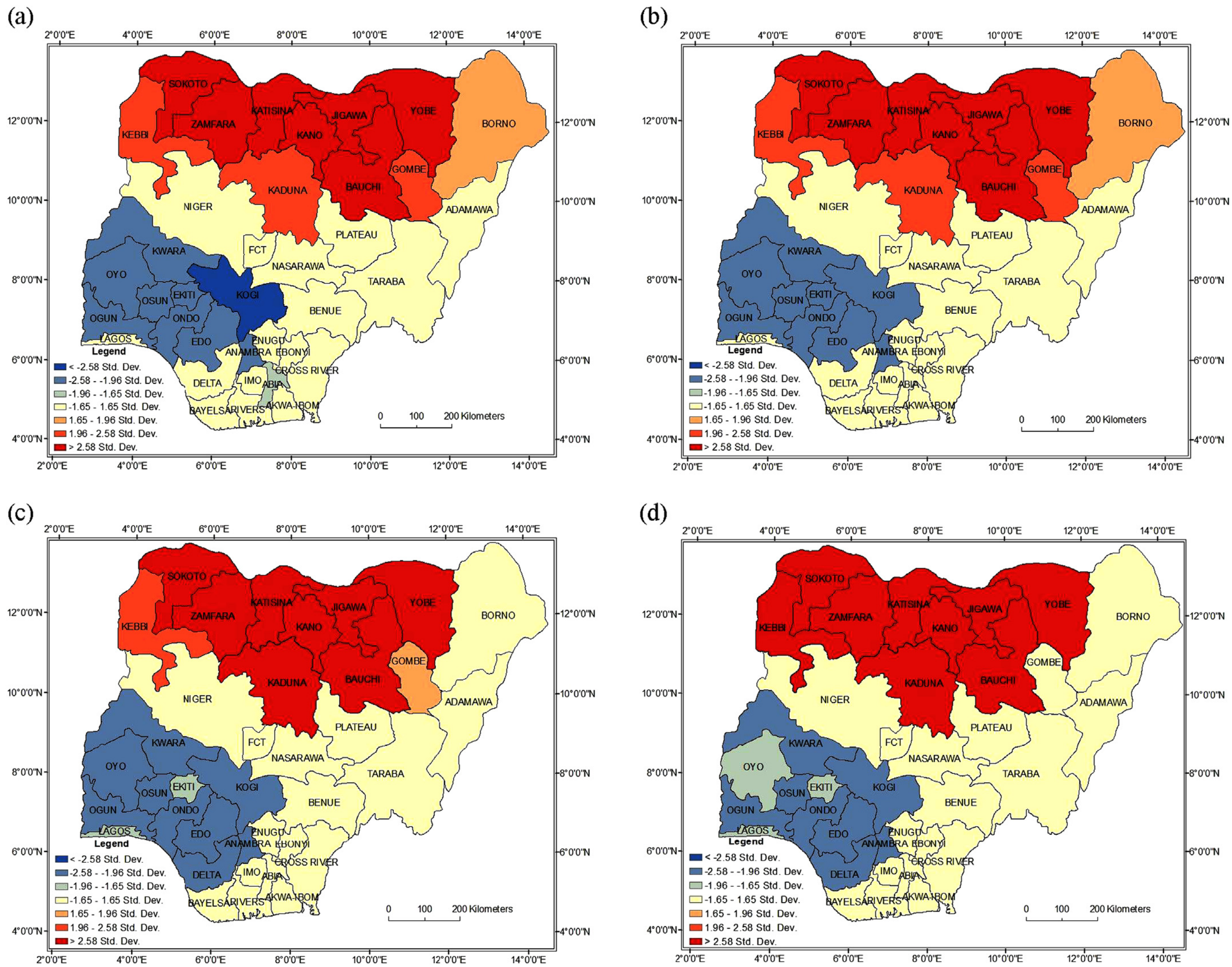

Fig. 7. a-d: Gi* statistic (Hot spot) maps for U5MRs in Nigeria in 2000(a), 2005(b), 2010(c) and 2013(d), IHME.

(p = 0.001), Ogun (p = 0.001) Osun (p = 0.00) and Ekiti State (p = 0.00) as statistically significant cold spots at a 99% confidence level signifying the maximum spatial clustering of low U5MRs. Statistically significant cold spots were also identified in Kwara and Ondo state at a 95% confidence level and in Kogi state at a 90% confidence level. On the other hand, 4 states in the Northwest were identified as statistically significant hotspots of under 5 mortality at a 95% confidence level. Statistically significant hot spots were also identified in Kebbi, Bauchi and Gombe state at a 90% confidence level. Supplementary Table 6c and Fig. 6c shows the degree of clustering of U5MRs in Nigeria based on the 2013 survey. Kwara (p = 0.02) and Ondo state (p = 0.02) were identified as statistically significant cold spots at a 95% confidence level indicating the maximum spatial clustering of low U5MRs in Nigeria. Statistically significant cold spots were also identified in 6 states including the Federal Capital Territory at a 90% confidence level. On the other hand, Sokoto (p = 0.00) and Kebbi states (p = 0.01) were identified as statistically significant hotspots of under 5 mortality at a 99% confidence level indicating the maximum spatial clustering of high U5MRs in Nigeria. Statistically significant hot spots were also identified in Jigawa, Zamfara, Katsina, Bauchi, Yobe and Taraba states.

Fig. 7a-d shows the degree of clustering of U5MRs in Nigeria for selected years with regards to IHME dataset. Based on state U5MR figures for the year 2000, Kogi state was identified as a statistically significant cold spot at a 99% confidence level signifying the maximum spatial clustering of low U5MRs. Statistically significant cold spots were also identified in the South centered mainly on Southwestern states. Statistically significant hot spots were identified in the Northwest and Northeast with the Northwestern states (with the exception of Kaduna and Kebbi) identified as being statistically significant hot spots at a 99% confidence level signifying the maximum spatial clustering of high U5MRs. Similar statistically significant hot and cold spots were detected throughout the years with some variation in the pattern of clustering in 2005 and 2008–2013.

4. Conclusion

This study has investigated spatio-temporal patterns of under 5 mortality rates across states in Nigeria using statistical techniques, spatial autocorrelation statistics and GIS. Analysis was based on data from two different sources (NDHS and IHME). Both data sources indicate that U5MRs in Nigeria are high particularly in Northeastern and Northwestern Nigeria. They also indicate wide variations across states over time.

The Global Moran's I identifies a clustered pattern of U5MRs statistically significant at the 99% level in 2003, 2008 and 2013 based on the NDHS and for each year from 2000–2013 based on IHME data. In addition, LISA maps generated based on both data sources are similar though there are some differences. NDHS LISA maps show spatial outliers in the Southeast and Northwest in 2003 and 2008 respectively while IHME LISA maps do not. Also, IHME LISA maps show clusters of low U5MRs in the Southsouth over time while NDHS LISA maps do not. Nevertheless, both NDHS and IHME LISA maps show clusters of high U5MRs in Northern Nigeria such as in Sokoto, Kebbi, Jigawa and Bauchi states (with the exception of the NDHS 2003 LISA maps that show no high-high clusters). Similarly, both show clusters of low U5MRs mainly in Southwestern Nigeria such as in Oyo and Osun states. However, areas identified in IHME LISA maps were a bit more extensive particularly from 2000–2007 with some variations in cluster pattern especially from 2008–2013.

The Gi* statistic based on both data types consistently detected hot and cold spots in similar areas with some differences. Hot spots detected based on IHME figures cover a much larger proportion of Northern Nigeria. Similarly, IHME maps show cold spots extending from the Southwest and Southeast to parts of the Southsouth such as Edo and Delta states over time while NDHS maps do not identify cold spots in the Southsouth at all.

Generally, IHME maps show more distinct variations and extensive clusters of U5MRs.Differences in findings between both datasets might be due to the fact that IHME figures were derived from multiple sources which provide more reliable annual mortality estimates. This suggests that the IHME data might be more useful in population health planning in the study area. It is important to note that the modeling approach adopted by the IHME could also have contributed to the few differences in results. However, both data sources identify the presence of statistically significant clusters in similar regions.

Findings show that U5MRs in individual states are significantly related to mortality rates in contiguous states. This shows that there are geographical influences on under 5 mortality in Nigeria. In other words, U5MRs can significantly increase (or decrease) in a given area because of conditions in that area and/or conditions in neighbouring areas. This implies that significant reductions in under 5 mortality is achievable if both individual state and region specific measures are adopted.

The Northern states are identified as high priority areas that need more attention. The North-South clustering patterns have not changed much even after more than a decade with high clusters/hot spots in Northern Nigeria persisting over time. The Nigerian government needs to improve child health and survival programs in Nigeria as a whole and in the Northern region in particular. Strategies to achieve this objective should focus on the following: (1) improving antenatal care, (2) promoting immediate and continued breastfeeding, (3) encouraging full immunization of children in their first year of life as well as routine immunization for common childhood diseases, (4) encouraging the use of family planning services crucial to birth spacing and prevention of mother-to-child-transmission (MTCT) of HIV/AIDS among others.

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Conflict of interest

There are no conflicts of interest. No funding was received for this research.

Compliance with ethical standards

Ethical approval was granted for the secondary analysis of existing data after the removal of all identifying information of the respondents by the Institutional Review Board (IRB) of the ICF Macro at Calverton, USA in conjunction with the National Health Research Ethics Committee (NHREC) of the Federal Ministry of Health, Abuja, Nigeria.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ssmph.2018.09.004.

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