International Journal of Public Health (2019) 64:1183–1192
https://doi.org/10.1007/s00038-019-01285-2

ORIGINAL ARTICLE

Exploring the spatio-temporal variation in diarrhoea prevalence in under-five children: the case of Nigeria, 1990–2013

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Received: 12 June 2018 / Revised: 5 July 2019 / Accepted: 17 July 2019 / Published online: 30 July 2019

Abstract

Objectives This study (1) examines spatio-temporal variation in diarrhoea prevalence and (2) for 2013 identifies and maps the factors associated with diarrhoea prevalence at district level.

Methods Data were drawn from Demographic Health Surveys (1990, 1999, 2003, 2008 and 2013). Moran index was used to analyse spatial dependence and clustering of diarrhoea prevalence in 2008 and 2013. Geographical Weighted Poisson Regression analysis was used to identify factors associated with diarrhoea prevalence for 2013.

Results Diarrhoea prevalence was higher in rural than in urban areas. Prevalence exhibited statistically significant spatial variation, but temporal variation and spatial dependence were not significant. Locally, diarrhoea prevalence hot spots clustered among five states in the North East zone. Non-improved sanitation, children 6–23 months not breastfed, dung floor, relative poverty, unemployed mothers and Gini coefficient were main predictors of diarrhoea prevalence.

Conclusions Results of spatial analysis improved understanding of local spatio-temporal variation in diarrhoea prevalence and underlying factors. Intervention strategies should emphasize behaviour change regarding washing of hands and feeding utensils before and after feeding children, exclusive breastfeeding, safe water, improved sanitation and hygiene, particularly in hot spot states.

Keywords Diarrhoea · Spatio-temporal analysis · Geographical Weighted Poisson Regression · Under-five mortality · Nigeria

Introduction

Under-five mortality rate in sub-Saharan Africa (SSA) and Nigeria in particular was 78.4 and 104.3 per 1000 live births, respectively, in 2016 (UNICEF 2017). Most of these childhood deaths are due to conditions which could be prevented or treated with affordable interventions. Diarrhoea is the second leading cause of morbidity and mortality in under-five aged children (U5C) globally. About 1.7 billion cases and 525,000 deaths were recorded worldwide in 2015. Nigeria accounts for the highest number of deaths due to diarrhoea in Africa with 76,980 (14.6%) in 2015 (WHO 2015).

Data from Nigeria Demographic Health Surveys (NDHS) indicate that diarrhoea prevalence among U5C declined from 17.9% in 1990 to 10.2% in 2013. Interventions associated with this decline include use of oral rehydration therapy, measles vaccination, micronutrient supplementation with zinc and vitamin A, hand washing with soap and water, sanitation and hygiene educational interventions, improved water treatment and storage, and improved feeding practices (Clasen et al. 2004; Hashi et al. 2017). However, the national decline obscures spatio-temporal dynamics of disease prevalence. Understanding the nature and causes of spatial variation in diarrhoea prevalence is important for the implementation of geographically appropriate risk reduction programmes. Efforts aimed at reducing under-five mortality must focus on the reduction or elimination of diarrhoea.

Diarrhoea is the passage of three or more loose or liquid stools at least three times per day or more frequently than

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00038-019-01285-2) contains supplementary material, which is available to authorized users.

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normal for an individual (UNICEF 2009). It is a symptom of gastrointestinal infections caused by a wide range of pathogens transmitted from the stool of one person to the mouth of another. Rotavirus infection is the leading cause of diarrhoea and deaths among infants (Lanzieri et al. 2011). Diarrhoea results to fluid loss, rapid dehydration and death. Diarrhoea is prevalent in developing countries due to lack of safe water, poor environmental conditions, hygiene practices and nutrition. Most people rely on surface water which is often contaminated with pathogens (including bacteria, viruses and parasites) due to contact with human and animal waste.

Studies on diarrhoea prevalence have concentrated on risk factors linked to socio-demographic, biological, behavioural and environmental factors at individual, household, community and district levels. In rural Burundi, diarrhoea prevalence was lower in children whose caregivers received hygiene education, boiled water, and were aged 40 years and older (Diouf et al. 2014). Anteneh et al. (2017) showed that factors associated with diarrhoea in Jabithennan District, Ethiopia, were residence, child's sex, methods of complimentary feeding, water storage equipment and material used to wash hands. Lack of caregiver awareness of hygiene, knowledge of proper disposal of faeces, hand washing with soap and water treatment was significant risk factors in Bolivia (George et al. 2014). Bahartha and ALEzzi (2015) noted that children affected by diarrhoea in Yemen were mostly male, urban dwellers, incompletely vaccinated or not vaccinated at all. Children aged 12–23 months, male and residing in urban areas had a higher risk of diarrhoea in Sudan (Siziya et al. 2013). Other factors include age of mothers, mother's lack of education, use of unprotected and untreated drinking water sources, household size and bottle feeding. Studies on the spatial pattern of diarrhoea prevalence have been on coarse continental scale with limited national policy relevance (Bado et al. 2016) or at local scales requiring intensive data collection but with a limited spatial scope (Kumar et al. 2017). Very few exceptions have analysed countrywide spatial variations of diarrhoea prevalence and their drivers (Osei and Stein 2017; Bogale et al. 2017).

Studies on diarrhoea in U5C in Nigeria have examined caregiver's recognition of the disease, socio-environmental determinants, protective effect of breastfeeding, hygiene and sanitation risk factors, and care-seeking routes (Oloruntoba et al. 2014; Ahiadeke 2000; Ekpo 2016). These studies did not highlight the variation in diarrhoea prevalence and their drivers. Spatial analysis at district level is important for the identification of risk areas since regional classification masks variations in the states.

This study uses data from NDHS (1990–2013) to (1) examine spatio-temporal variation in diarrhoea prevalence in Nigeria and (2) identify for the year 2013 variables associated with diarrhoea prevalence. The goal is to map the spatial distribution of the identified factors in order to explore the associations between local diarrhoea prevalence and explanatory factors for spatial targeting of education and prevention interventions.

Methods

This study examines the hypothesis which states that diarrhoea prevalence rates are distributed randomly across states. Data on diarrhoea prevalence were drawn from the NDHS conducted in 1990–2013 (FOS and IRD 1992; NPC and ICF 2000, 2004, 2009, 2014). The survey was not conducted between 2014 and 2017. These surveys are population-based national surveys that incorporated demographic, household socio-economic characteristics and child health issues. Diarrhoea in children reported in the surveys was based on whatever mothers considered the illness to be. In all the surveys, mothers were asked if any of their U5C had diarrhoea at any time during the 2-week period preceding the survey and, if so, whether there was blood in their stool. States were used as the geographical unit of data aggregation ($N = 37$) because data sets are only available at the aggregate level. As such, spatial analysis of diarrhoea prevalence was limited to data from 2008 to 2013 surveys. Data from previous surveys were not disaggregated to state level. The procedures and questionnaires for the NDHS were reviewed and approved by ICF institutional review board and National Health Research Ethics Committee in Nigeria.

Data on prevalence for 2013 were used to determine the drivers of observed spatial variation. A total of 40,320 households were selected, of which 38,848 women (97.6%) and 1735 (95.2%) men aged 15–49 years were interviewed. Location data (latitude and longitude coordinates) of enumeration areas for the MEASURE DHS program were obtained from ICF International.

Explanatory factors were selected based on findings in the literature and availability of data at state level. The variables examined are indicators of socio-demographic characteristics of the child and mother, household hygiene and district socio-economic factors. Socio-economic data were obtained from Annual Abstract of Statistics and Nigeria Poverty Profile published by Nigeria Bureau of Statistics.

Global Moran's I analysis was used to test the hypothesis of spatial randomness of diarrhoea prevalence across states. A significant Moran's I ($p < 0.05$) leads to a rejection of the null hypothesis and indicates the presence of spatial autocorrelation. Local Moran's I statistics was used to determine how spatial autocorrelation varies across states and to identify states that exhibit spatial dependency with their neighbours along with the type of relationship. Moran's I varies from − 1 to + 1. Positive value indicates a clustered pattern, negative index is indicative of a dispersed pattern, and a zero index suggests no spatial autocorrelation and random pattern. Positive local Moran's I is obtained when states with high or low values are surrounded by states with similarly high and low values. Negative value indicates that a state is surrounded by states with dissimilar values (high–low or low–high). Spatial statistics was done using ArcGIS software.

Poisson regression models are used to analyse areal disease data set where observed count includes low numbers (Nakaya et al. 2005), but these models do not allow variation in association between geographical locations. Global models assume that processes accounting for a disease pattern are spatially stationary across the study area. Geographically Weighted Poisson Regression (GWPR) investigates the extent to which processes might vary over space and allows a combination of geographically varying and constant parameters in a model. Conventional Global Poisson Regression model (GPR) is defined as:

$$O_i \sim \text{Poisson}\left(E_i \exp_k\left(\sum \beta_k x_{k,i}\right)\right) \quad (1)$$

where is x_{ki} is kth explanatory variable in place i and the β_ks are parameters and Poisson (λ) indicates a Poisson distribution with mean λ. When parameter values vary with location (u_{xi} u_{yi}) which is the geographical coordinates of the centroid of the ith district (the location of i), the Poisson model in Eq. 1 is rewritten as:

$$O_i \sim \text{Poisson}\left(E_i \exp_k\left(\sum \beta_k(u_i, v_i) x_{ki}\right)\right) \quad (2)$$

where O_i, x_{ki}, and E_i denote, respectively, dependent variable (number of diarrhoea cases) and kth independent variable. The coefficients $\beta_k(u_i,\ v_i)$ are assumed to be smoothly varying conditional on their location. Smoothed geographical variations in parameters in the model are estimated with a spatial weighting kernel. Nearby observations are weighted more heavily than more distant ones. The weighting kernel could be Gaussian or bi-square kernel. In this study, the Akaike Information Criterion (AICc) was used to determine the weighting function, bandwidth size and the best model. The model with the smallest AICc was selected as the optimal model. Correlation matrix was produced among the independent variables to prevent multicollinearity in the model, and the variance inflation factor (VIF) was used as an indicator of multicollinearity. The software GWR version 4.0.80 was used to implement GWPR.

Results

Spatial and temporal pattern of diarrhoea prevalence

In all the surveys, mothers were asked if there U5C had diarrhoea 2 weeks preceding each survey. Diarrhoea prevalence increased from 17.9% in 1990 and peaked at 18.8% in 2003 before declining to 10.2% in 2013. A comparison of urban and rural prevalence shows a severe variable rural epidemic with a less intense urban epidemic. Prevalence declined from 19.6% in 1990 to 15.8% in 1999 in rural areas but increased from 11.7 to 13.9% in urban areas during the same period. Although the epidemic peaked in 2003 in both urban (14.5%) and rural (20.7%) areas, it was higher in rural areas. The urban epidemic declined slower between 2003 and 2013 (5.3%) than the rural (9.9%) and national (8.6%) epidemic.

Prevalence was higher in male children in 1990 (19.4%), 2003 (19.3%) and 2008 (10.6%) but higher among females in 1999 (15.4%) and 2013 (10.3%). However, the difference in prevalence between males and females in 1999 and 2013 was 0.3% and 0.1%, respectively. Between 1990 and 2013, prevalence was higher among children aged 12–23 months. Diarrhoea prevalence was higher in households with non-improved drinking water source (unprotected well and spring, tanker truck, surface and sachet water) in 2008 (12.1%) and 2013 (11.2%) compared to households with improved source of drinking water (piped into dwelling, tube well, protected well and spring, rainwater and bottled water) with prevalence of 8.4% and 9.5%, respectively. In 2013, households with non-improved sanitation facilities (open pit, bucket and bush) recorded higher prevalence (10.7%) than households with improved sanitation facilities (10.1%) such as flush/pour to septic tank, piped sewer system and ventilated improved pit latrine.

In 2008, Bauchi State recorded the highest diarrhoea prevalence with 32.0% (Fig. 1) followed by Borno (22.9%) and Yobe (18.7%) states. FCT had the lowest prevalence (1.1%). Diarrhoea prevalence was higher than the national average of 10.1% in nine states. In 2013, prevalence was highest in Yobe State (34.6%), followed by Bauchi (25.7%) and Taraba (19.7%) states. The prevalence rate in 12 states was higher than the national average of 10.2%. This is high compared with nine states in 2008. States with low prevalence include Bayelsa (1.8%), Ogun (1.9%) and Edo (2.0%) states.

Although the national prevalence rate was relatively stagnant in 2008 (10.1%) and 2013 (10.2%), prevalence rate increased in 23 states but declined in 14 states (Table 1). FCT which recorded the lowest prevalence of

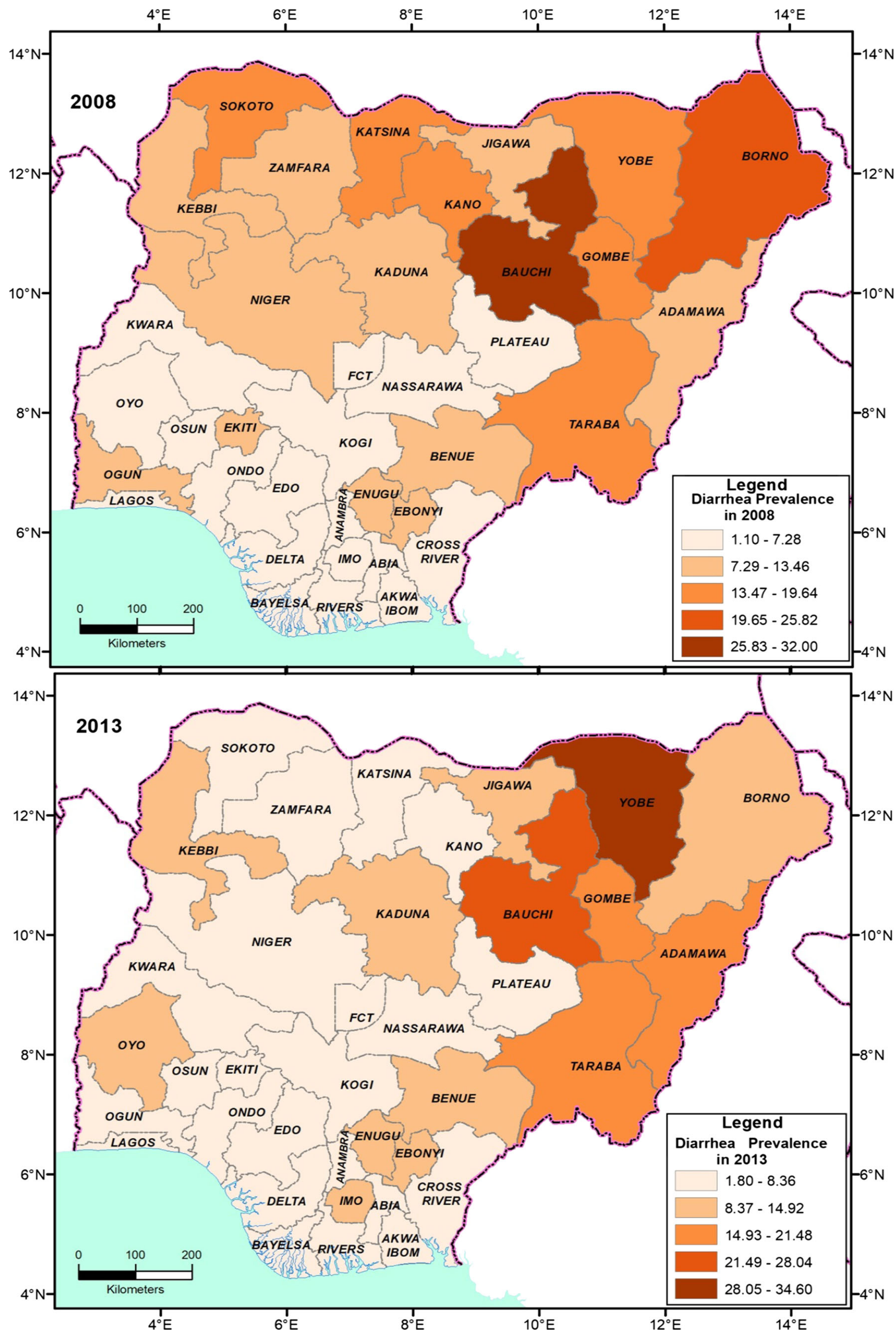

Fig. 1 Spatial distribution of diarrhoea prevalence in Nigeria 2008 and 2013

Table 1 Percentage change in diarrhoeal prevalence in Nigeria (2008 and 2013)

States	Diarrhoeal prevalence 2008	95% confidence interval	Diarrhoeal prevalence 2013	95% confidence interval
Abia	4.5	6.49–2.51	2.50	4.28–0.72
Adamawa	9	11.26–6.74	16.60	19.44–13.76
Akwa ibom	4.1	5.80–2.40	5.50	7.63–3.37
Anambra	3.1	4.38–1.82	5.70	7.54–3.86
Bauchi	32	34.87–29.13	25.70	28.13–23.27
Bayelsa	3.2	5.20–1.20	1.80	3.56–0.04
Benue	7.3	9.18–5.42	9.50	11.44–7.56
Borno	22.9	25.62–20.18	10.80	12.67–8.93
Cross River	6.7	8.86–4.54	8.00	10.38–5.62
Delta	2.5	3.74–1.26	2.80	4.22–1.38
Ebonyi	8.5	11.30–5.70	13.20	15.78–10.62
Edo	2.7	4.10–1.30	2.00	3.39–0.61
Ekiti	9.1	12.13–6.07	6.60	10.15–3.05
Enugu	7.4	9.97–4.83	14.70	17.76–11.64
FCT-Abuja	1.1	2.44–0.24	5.60	8.82–2.38
Gombe	15.3	18.56–12.04	16.70	19.88–13.52
Imo	3.2	4.71–1.69	12.20	15.06–9.34
Jigawa	8.2	9.97–6.43	14.80	16.67–12.93
Kaduna	7.8	9.40–6.20	13.50	15.31–11.69
Kano	17.2	18.84–15.56	6.50	7.43–5.57
Katsina	17.8	19.82–15.78	7.70	9.03–6.37
Kebbi	8.6	10.78–6.42	13.60	15.63–11.57
Kogi	2.9	4.47–1.33	3.30	5.10–1.50
Kwara	3.4	5.19–1.61	5.30	7.56–3.04
Lagos	6.1	7.37–4.83	7.50	8.98–6.02
Nasarawa	7.2	10.16–4.24	8.30	10.94–5.66
Niger	9.6	11.65–7.55	8.20	9.69–6.71
Ogun	8	10.09–5.91	1.90	2.92–0.88
Ondo	6.6	8.79–4.41	5.50	7.46–3.54
Osun	4.9	6.87–2.93	4.10	5.98–2.22
Oyo	4.3	5.62–2.98	9.20	10.96–7.44
Plateau	2.4	3.68–1.12	5.60	7.69–3.51
Rivers	3.8	5.09–2.51	5.00	6.64–3.36
Sokoto	14	16.36–11.64	4.60	5.90–3.30
Taraba	15.8	19.27–12.33	19.70	22.67–16.73
Yobe	18.7	21.95–15.45	34.60	37.80–31.40
Zamfara	10.2	12.41–7.99	6.00	7.26–4.74
Total	10.1		10.2	

1.1% in 2008 recorded a prevalence of 5.6% in 2013. Furthermore, prevalence in Imo, Plateau and Oyo states increased from 3.2%, 2.4% and 4.3% in 2008 to 12.2%, 5.6% and 9.2% in 2013, respectively. At the regional level, prevalence declined in all the regions (Fig. 2). North East zone consistently had the highest prevalence ranging between 20.8% and 35.1%. Prevalence was higher than the national average in North East and North West zones between 1990 and 2013. With the exception of North West zone which recorded 3.9% decline in prevalence, the rate increased by 5.4% in South East, 1.7% in North Central, 0.7% in South, 0.3% in North East and 0.1% in South West zones. South South zone had the lowest prevalence rates in 2008 and 2013 with 3.8% and 4.5%, respectively.

Results of the global Moran's I in Table 2 reveal that the null hypothesis cannot be rejected since the distribution of

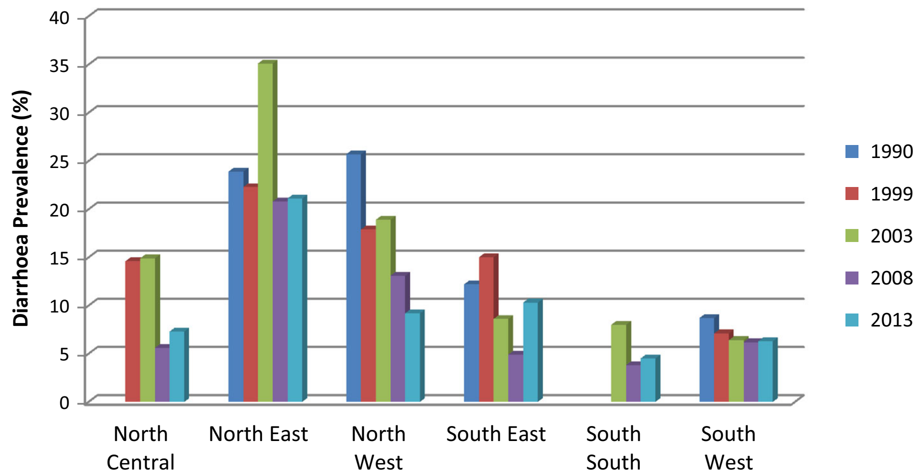

Fig. 2 Diarrhoea prevalence in the six geopolitical zones in Nigeria (1990–2013)

diarrhoea prevalence in 2008 and 2013 is random. The Moran index indicates that the degree of clustering of diarrhoea prevalence had declined over time. Local Moran's I analysis revealed that, in 2008, significant hot spots ($p < 0.05$) occurred in Kano, Bauchi, Gombe, Yobe and Borno states. There was no state with significantly low prevalence (cold spot), but Plateau State was a significant ($p < 0.05$) low–high outlier. Gombe State was the only state that exhibited significant hot spot in 2013.

Spatial association of diarrhoea prevalence

Results of the global univariate models indicate that each of the selected covariates has significant association with diarrhoea prevalence except Gini coefficient. Several GWPRs were fitted with single category and multiple categories of the explanatory variables. The models with single-category variables produced higher AICc, implying that the GWPR model with more predicting factors has better performance in fitting the data. Various combinations of the explanatory variables were calibrated and evaluated in the GWPR model. Based on the AICc, the best-fitting model was that containing all the explanatory variables except vinyl floor type. When the value of the AICc was compared, the local models showed improvement of 8–33 (GWPR-fixed Gaussian: 346.43, GWPR-fixed bi-square: 321.62 compared to GPR: 354.67). These values indicate that GWPR explains better the variation in prevalence across the states. The rule of thumb is that if the difference in AICc values between two models is less or equal to two, there is no significant difference in the performance of the two models. The GWPR model with fixed bi-square was selected as the model that better fits the data because the AICc and bandwidth are lower. The VIF of all the significant variables in the GPR varied between 1.9 and 5.9, suggesting that serious multicollinearity issues did not exist.

A summary of parameter estimates in the GWPR model is presented in Table 3. The local parameter estimates are described by the minimum, lower quartile, median, upper quartile and maximum value. Following Nakaya et al. (2005), spatial non-stationarity is determined by comparing the interquartile range (IQR) of the local estimates with the standard error of the global estimates. All the parameter estimates are at least twice the standard errors of the global estimates, suggesting that the relationships varied across space.

The distribution of the parameter estimates (Online Resource 1) shows that the parameters have patterns of spatial variation. Negatively correlated variables are non-improved water, mother's with primary education, cement floor covering, Gross National income (GNI) and absolute poverty. Positively correlated variables are non-improved sanitation, children 6–23 months not breastfed-, rural residence, dung floor (floor covered with cow dung mixed with mud and water), relative poverty, unemployed mothers and Gini coefficient. However, cement floor covering and mother's with secondary education were each positive in 30 states and negative in 16 states and the FCT. The local parameter estimates of cement floor, GNI, absolute poverty, and non-improved sanitation were high in states in the North East and South South zones. Most of the states in

Table 2 Spatial autocorrelations of diarrhoeal prevalence (2008 and 2013)

Year	Moran index	Expected index	Variance	*Z*-score	*P* value	Description
2008	0.072138	0.101026	0.000307	− 1.649279	0.099091	Random
2013	0.072564	0.101026	0.000287	− 1.679669	0.093022	Random

Table 3 Summary of global and local model statistics

Coefficients	Global Poisson Regression				Geographically Weighted Poisson Regression bi-square					Status
	Estimates	SE	Z value	Pr (> z)	Minimum	Lower quartile	Median	Upper quartile	Maximum	
Intercept	− 3.862997	0.458024	− 8.434042	< 0.00001	− 4.060498	− 3.879613	− 3.759195	− 3.694545	− 3.610273	Stationary
Non-improved water	− 0.000588	0.000150	− 3.917623	4.5E−05	− 0.000716	− 0.000633	− 0.000586	− 0.000556	− 0.000521	Non-stationary
Non-improved sanitation	0.000340	0.000135	− 2.522487	0.005834	0.000314	0.000340	0.000356	0.000369	0.000388	Non-stationary
Primary educational level	− 0.001562	0.000562	− 2.779982	0.002726	− 0.001769	− 0.001653	− 0.001596	− 0.001486	− 0.001370	Non-stationary
Secondary educational level	− 0.000601	0.000273	− 2.198474	0.013975	− 0.000689	− 0.000621	− 0.000603	− 0.000583	− 0.000558	Non-stationary
Children 6–23 months not breastfed	0.022387	0.001593	14.051241	< 0.00001	0.021613	0.021913	0.022118	0.022603	0.022973	Non-stationary
Rural residence	0.001128	0.000102	11.084891	< 0.00001	0.001078	0.001101	0.001118	0.001148	0.001199	Non-stationary
Dung floor	0.005900	0.000606	9.727778	< 0.00001	0.005490	0.005847	0.005994	0.006182	0.006380	Non-stationary
Cement floor	− 0.002572	0.000176	− 14.629016	< 0.00001	− 0.002764	− 0.002657	− 0.002563	− 0.002519	− 0.002432	Non-stationary
Gross National Income	− 3.877704	0.448779	− 8.640555	< 0.00001	− 4.116481	− 4.022445	− 3.937611	− 3.815045	− 3.525620	Non-stationary
Absolute poverty	− 0.321819	0.017302	− 18.600658	< 0.00001	− 0.334002	− 0.325218	− 0.320798	− 0.317110	− 0.313911	Non-stationary
Relative poverty	0.344970	0.016992	20.302269	< 0.00001	0.338316	0.340753	0.343951	0.346898	0.354337	Non-stationary
Unemployed mothers	0.000764	0.000093	8.232272	< 0.00001	0.000731	0.000763	0.000782	0.000793	0.000808	Non-stationary
Gini coefficient	11.012681	0.603592	18.245244	< 0.00001	10.779850	10.862585	10.956744	11.028302	11.248529	Non-stationary
Global AICc	357.67 Percentage deviance explained = 0.87									
GWPR-fixed Gaussian AICc	346.43 Percentage deviance explained = 0.88									
GWPR-fixed Bi-square AICc	321.62 Percentage deviance explained = 0.89									

GWPR Geographically Weighted Poisson Regression, *AICc* Akaike Information Criterion the South West and North West zones have high values of local estimates of dung floor, children 6–23 months not breastfed, rural residence, mothers with primary education and relative poverty. For the variables mothers with secondary education, non-improved water source and unemployed mothers, the parameter estimates are high in almost all the states.

The model estimates of the GPR show that all the variables are significant at 95% confidence level. The model explains 87% of the variation in diarrhoea prevalence. When the parameter estimates of the GPR were compared to these in the GWPR, it was found that the signs of parameters of predicting variables were consistent in the two models. However, while the GPR has a constant parameter for each variable, the GWPR has spatially varying parameters for each variable. In GPR, the parameter of a variable falls into the range of parameters of the same variable in GWPR, implying that the GPR parameter estimates represent the average effect of the variable on diarrhoea variation in all the states. A single model was developed for all the states using GPR while different models were developed for each state using the GWPR. Results of geographical variability test of each local coefficient indicate that the Diff of Criterion using AICc was negative for the parameter estimates, indicating spatial variability except for the variable Gini coefficient which was positive. The statistical performance of the global and GWPR was compared. Results of the measures of goodness of fit reveal that both deviance and DOF in the GWPR are less than those in the GPR. The deviance and DOF in the GWPR are lower by 36.99 and 1.29, respectively, compared to the GPR which had a deviance of 307.58 and DOF of 23.0, respectively. The distribution of the local deviance is characterized by high values (0.88–0.89) in all the states.

Discussion

The decline in diarrhoea prevalence reflects the impact of global and national response interventions stated earlier. The Nigerian Centre for Disease Control (NCDC) adopted strategies aimed at infection prevention and control, surveillance, care and treatment. The high prevalence in rural areas was due to poor hygienic practices, limited access to safe and adequate drinking water and sanitation, health care, and poor knowledge of diarrhoea prevention and treatment. Water, sanitation and hygiene conditions in child care centres were not considered because most children stay with their mothers until they are enrolled in a primary school.

The decline in prevalence was not uniform across the country. Some states with previously low rates recorded an alarming increase. FCT which had a prevalence rate of 1.1% in 2008 recorded a prevalence of 5.6% in 2013. Yobe State recorded high prevalence in 2008 (18.7%) and the highest (34.6%) in 2013. This can be attributed to a high number of households using non-improved sanitation facility and unsafe drinking water. The percentage of households with non-improved drinking water source in the state increased from 49.5% in 2008 to 54.7% in 2013 while households with non-improved sanitation facilities increased from 72.6% in 2008 to 73.25 in 2013, respectively. Also, fewer households used appropriate water treatment compared to 2008.

Prevalence was highest in the North Eastern states where households are in the lowest (40.4%) and second (26.1%) wealth quintile, indicative of high poverty levels. Among those with place for hand washing, 86.1% did not have water, soap or other cleansing agent. The zone also had the highest (49.4%) number of households that consume water from non-improved sources and the least (1.7%) that use appropriate water treatment method. The random spatial pattern of diarrhoea prevalence indicates that states sharing borders did not exhibit similar pattern of diarrhoea prevalence. Similar non-random pattern at national level was observed in Ethiopia (Bogale et al. 2017). Five states were significant hot spot clusters in 2008 while there was only one in 2013. This confirms the decline in diarrhoea prevalence in 2013.

The model with fixed bi-square provided the best fit among the GWPR models considered and an improvement in fit over the GPR model. Drinking water from non-improved sources is negatively correlated with diarrhoea prevalence. This suggests that by providing safe and improved water source, prevalence will decline. Prevalence was higher (11.2%) in children from households that consumed water from non-improved sources. This is consistent with findings in previous studies (Samwel et al. 2014). Non-improved sanitation is positively related to diarrhoea prevalence because most households (45%) use pit latrine without slab, bush/field and bucket. Poor sanitation leads to direct contact of human excreta with humans thereby increasing the risk of faecal contamination.

The variables mothers with primary and secondary educational level are negatively associated with diarrhoea prevalence, suggesting that an improvement in educational level of mothers will reduce diarrhoea prevalence. Diarrhoea prevalence was lowest in children whose mothers had more than secondary education (5.6%) compared with no education (11.7%), primary (9.9%) and secondary (8.8%) education similar to previous studies (George et al. 2014). Children 6–23 months not breastfed recorded the highest prevalence (16.7%). Since they are fed with milk products and solid/semisolid food, unhygienic food preparation practices expose them to diarrhoea. This corroborates the finding that the risk of diarrhoea is high among weaned and mixed-fed infants (Ahiadeke 2000). Rural residence has positive coefficient suggesting that living in rural areas is positively related to diarrhoea prevalence. Rural residents have limited access to safe water and sanitation facilities.

Children living in houses with dung floor (which are difficult to clean) are more likely to have diarrhoea than those in houses with cement floor similar to findings of Woldemicael (2001). States with high income are better able to provide adequate water and health facilities. Diarrhoea prevalence is high in states (Yobe, Adamawa and Bauchi) where absolute poverty rate is over 80%. Unemployed mothers are positively associated with diarrhoea prevalence similar to the findings of Thiam et al. (2017). The North East zone which had the highest diarrhoea prevalence equally had the highest percentage of women (52%) who were unemployed, particularly Yobe (65.3%) and Bornu (69.3%) states. Unemployment of women affects their ability to access quality food, housing, household amenities, hygiene and materials for their children. Gini coefficient is positively related to diarrhoea prevalence indicating that areas with high income inequality have high diarrhoea prevalence.

The validity of the indicator of diarrhoea disease is a limitation of this study. Since the information on diarrhoea was self-reported, mother's perception of diarrhoea as an illness and capacity to recall events may be biased. However, findings are consistent with previous studies from other countries. Further research is needed to determine within–district variation in diarrhoea prevalence and individual-level risk characteristics.

The use of population-based survey and spatial statistics in this study made it possible to understand geographical pattern of diarrhoea prevalence, spatio-temporal trends and socio-demographic, behavioural and environmental risk factors associated with the distribution of the diarrhoea in U5C in Nigeria. Although the NDHS data revealed a decline in diarrhoeal morbidity, there are huge disparities across the states. While diarrhoea prevalence declined in 14 states, it increased in 22 states and the FCT. Further, prevalence remained consistently high in some states and has increased in states with previously low rates. Efforts to reduce diarrhoea prevalence should prioritize states in the North East, North West and South East zones, particularly Borno, Gombe, Taraba, Yobe, Jigawa, Kaduna, Kebbi, Ebonyi, Enugu and Imo states. Public health workers and policymakers need to improve sensitization of households on the need for behaviour change regarding breastfeeding, water treatment, improved sanitation and hygiene. Health agencies should make rotavirus and cholera vaccines available so as to provide protection for children. Provision of safe drinking water and sanitation in communities by governments is essential. This is important as health outcomes of children in households with safe water and sanitation may be suboptimal when the environment where they live is dirty and contaminated.

Findings in this study are also relevant to countries in sub-Saharan Africa with high morbidity and mortality of U5C due to diarrhoea. Health care providers and policymakers need to provide preventive interventions such safe water, sanitation and health education interventions, particularly in areas where households have low income and educational level. Improvement in livelihood of women will increase their access to funds which they will use to care for their children. Educational programmes should be designed for women in urban and rural areas. Developed countries and international agencies involved in the reduction in child mortality and morbidity in African countries need to increase access to rotavirus vaccine and strengthen integrated community-based treatment of diarrhoea.

Acknowledgement The author is grateful to ICF International for making the MEASURE DHS program datasets freely available.

Funding The study was not funded by any individual or organization.

Compliance with ethical standards

Conflict of interest The author (Yingigba Chioma Akinyemi) declares that she has no conflict of interest.

Ethical approval This article does not contain studies with human participants or animals performed by the author. The MEASURE DHS data on diarrhoea prevalence and socio-demographic characteristics of households were obtained by the author from ICF International. The procedures and questionnaires used in the surveys were reviewed and approved by ICF institutional review board and National Health Research Ethics Committee in Nigeria. Informed consent was obtained from participants during the surveys.

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