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Original Article

Joint Spatial Analysis of Low Birth Weight and Stunting in West African Countries

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ABSTRACT

Introduction: The burden of childhood morbidity and mortality are still huge in most sub-Saharan African countries with West African sub-region contributing largely to the burden. Previous findings have demonstrated strong link between early life events such as low birth weight (LBW) with later events particularly malnutrition. We aim at estimating the specific and shared spatial patterns of LBW and stunting among under-five children in multiple West African countries.
Methods: Data set for the study was sourced from the Demographic and Health Surveys conducted in fourteen West African countries. We used a Bayesian shared component model allows us to split the spatial surface into those specific to each of the outcomes and one shared by the two, with inference based on a Bayesian approximation procedure through the integrated nested Laplace approximation.
Results: The findings show spatial clustering in the shared and specific effects of the health outcomes, demonstrating high likelihood in northern Nigeria spanning through Niger and that the spatial pattern for the shared effects are similar to those of the specific effects of stunting. Furthermore, mother's level of education, attendance in antenatal care and household wealth index are strongly associated with the shared health outcomes.
Conclusion: The study provides insight into the spatial pattern of LBW and stunting among West African children and can be useful in targeted interventions in regions with high burden of LBW and malnutrition which may include more advocacy that promote the use of antenatal care services during pregnancy.

Introduction

Considerable attention has been drawn to issues that affect children's health including their nutritional status in low- and middle-income countries.[1] However, the burden of childhood morbidity and mortality are still huge and persisted in the majority of these countries particularly Africa.[2] The prevention of low birth weight (LBW) is an integral part of public health policy towards ameliorating newborn and maternal health in many countries.[3] There

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is considerable variation in the prevalence of LBW across regions and within countries; however, the great majority of low weight at births occur in low- and middle-income countries and especially among the most vulnerable populations.[4] Babies born with a weight lower than 2500g is either as a result of preterm birth (before 37 weeks of gestation) or restricted fetal (intrauterine) growth.[5]

Low weight at birth has been linked to several neonatal and postnatal adverse health outcomes.[6] There is a strong consensus that birth weight plays an important role in infant mortality, morbidity, development, and future health of the child.[7] LBW is the most significant risk factor of common childhood diseases[7] and undernutrition (i.e., stunting and wasting).[8] Undernutrition is thought to be the primary cause of 144 million stunted children under five years of age and accounts for around half of all childhood fatalities (WHO, 2020). Stunting reduced by 22% throughout the rest of the globe between 2000 and 2016, but climbed by 20% in West and Central Africa, going from 23 to 28 million.[9, 10] Stunting or insufficient height-for-age could be an indication of chronic malnutrition. It is the most common structure of undernutrition in infants and develops slowly and cumulatively over time. Once established, stunting and its consequences usually last forever.[11]

Given the established link between LBW and the nutritional status of young children,[1, 12-15] there are high tendencies of similar geographical patterns of occurrence of LWB and stunting, particularly in places where they are prevalent. Many health outcomes often demonstrate shared risk factors, indicating that a common approach could be well suited in addressing multiple health challenges.[16] Consequently, a modeling approach that jointly considers these outcomes could be advantageous. For instance, if patterns of geographic variation among related health outcomes are established through a multivariate analysis, they could offer more convincing proof of true clustering in the underlying risk surface than would be available from the analysis of a single disease. Also, neighboring locations often share similar cultural and socio-demographic characteristics, which often shape their health behavior, leading to similar patterns of health outcomes. In this regard, a multivariate multilevel modeling strategy was used by Langford, Leyland[17] to analyze the spatial distribution of mortality counts from two separate sources. Duah, Amankwa[18] analysed the joint patterns of anaemia and diarrhea among children in Ghana; Adebayo, Gayawan[19] considered malaria and anemia while Gayawan, Orunmoluyi[20] combined acute respiratory infection, diarrhea and stunting in a single modeling framework, in a bid to identify areas of similar risk behaviour.

We consider a joint modeling of LBW and stunting in multiple contiguous West African countries using a shared component geostatistical model that allows us to quantify the common and specific spatial surfaces for the two outcomes. The approach divides the underlying location-specific risk surface for each outcome into the spatial pattern that is shared by both outcomes and another that is outcome-specific, to capture the distinction between the specific pattern and the spatial shared component. Our focus on these countries is important for a number of reasons. One, some of the countries have the highest rates of adverse child health outcomes, including malnutrition necessitating focused and strategic interventions. Second, many of the contiguous countries share similar cultural, social, and economic values that shape the health belief of the populace leading to similar health outcomes that transcends international boundaries. Third, identifying similar geographical patterns of multiple health outcomes within and between the West African countries would provide useful information for targeted public health interventions by governments across various strata and international honor agencies who are interested in the health and well-being of sub-Saharan African children. The study provides estimates that reflect the specific and shared burden of LBW and stunting among young children, allowing for the understanding of the burden within and between the West African countries considered in a manner that transcends national boundaries.

Methods

Data Source

The study used Demographic and Health Survey (DHS) data from 14 countries in West Africa namely Benin, Bukina Faso, Cameroon, Cote d'Ivoire, Gambia, Ghana, Guinea, Niger, Nigeria, Liberia, Mali, Senegal, Sierra Leone, and Togo. The surveys are nationally representative household utilizing a multistage stratified cluster sampling methodology. They provide data for a wide range of indicators in the areas of population, reproductive health, and nutrition. At the first stage of the sampling, enumeration areas (cluster) are selected from a list of sampling frame previously used for a population of housing survey while at the second stage, households are selected from the identified clusters following a random process. Majorly, the survey targets women of reproductive age (15 − 49 years) and children below the age of five years in the selected households. The two primary response outcomes, LBW and stunting were measured as follows: LBW was defined as weight at birth less than 2.5 kg. Stunting was measured through the height-for-age z-score (HAZ) that was computed based on the height and weight measurement of the children. A child is considered stunted if the z-score is less than minus two standard deviation from a reference population. Such a child is said to be short for their age or chronically malnourished. The following bio-demographic and socio-economic variables known to be associated with the response outcomes were extracted from the most recent DHS database in each of the 14 West African countries: type of place of residence, household wealth index, household water source and type of toilet facility being used, maternal age, number of antenatal visit, whether or not the child had diarrhea or fever in the two weeks before the survey.

Statistical Method

We adopt a bivariate logit spatial model with correlated random effects described as follows: Let

$$Y_{1ji} \sim Binomial(1, p_{1i})$$

$$Y_{2ji} \sim Binomial(1, p_{2i})$$

where Y_{1ji} and Y_{2ji} are, respectively, the observed binary outcomes for LBW and stunting for child *j* residing in region *i*, *i*=1,…,I (where I is the total number of regions in the West African countries), while $p1_i$ and $p2_i$ are the associated probabilities (prevalence) for each outcome. The probabilities are linked to the covariates through a logit link function expressed as

$$\log\left(\frac{p_{1i}}{1-p_{1i}}\right)=\alpha_i+\beta_1 X_{1ji}+S_{1i}+U_{1i} \quad (1)$$

$$\log\left(\frac{p_{2i}}{1-p_{2i}}\right)=\alpha_i+\beta_2 X_{2ji}+S_{2i}+U_{2i} \quad (2)$$

Here, α_k is an intercept term for each outcome (k = 1, 2), β_k are regression coefficients corresponding to the covariates X_{kij} which can be similar or different set of variables for each outcome, though in our case, we consider similar variables for the two outcomes. The spatial components are introduced through spatially structured (S_{ki}) and unstructured (U_{ki}) random effects, corresponding to a particular region where each child was residing. The structured term permits the modeling of similarities across areas, taking the neighbourhood structure of the regions into account thereby allowing clusters to emerge, while the unstructured term captures the possible within-region heterogeneity in the outcomes. The random effects also control for the complex survey design inherent in the sampling of the data.

The unstructured spatial heterogeneity term, U_i was modeled assuming an exchangeable Gaussian prior with mean zero and variance σ^2 *i.e* $U_i \sim N(0,\sigma^2)$. The parameter σ^2 controls the smoothness of U_i. For the structured spatial components S_i a Markov random field (MRF) prior was contemplated which has a conditional distribution of the form

$$S_i\sigma^2 \sim N\left(0,\sigma^2 Q^{-1}\right)$$

where σ^2 is also an unknown variance parameter that controls the degree of the smoothness and Q is the spatial precision matrix. The $(i,j)^{th}$ element of the matrix Q is given by

$$Q=\begin{cases} m_i, & i=i' \\ 1, & i\sim i' \\ 0, & elsewhere \end{cases}$$

where $i \sim i'$ denotes that region i is adjacent to i', m_i is the number of adjacent regions to i in the set of all adjacent regions (δ_i). Regions are defined to be neighbors if they have common boundaries. Thus, region S_i, given neighboring region S_{-1}, such that $S_{-1}=(S_1, S_2,\ldots S_{i-1},S_{i+1},\ldots,S_1)^T$, has the following conditional distribution

$$\left\{S_i|S_{-1,\sigma^2}\right\} \sim N\left(\frac{1}{m_i}\sum_{i'\varepsilon\delta_i} S_i^{'},\frac{\sigma^2}{m_i}\right) \quad (3)$$

The total spatial risk surface for the structured terms can be partitioned into components which are shared by both outcomes and specific to each of them respectively as:

$$S_{1i}= \theta\tau_i + w_{1i}$$
$$S_{2i}= \theta/\tau_i + w_{2i}$$

Therefore equation 2 becomes

$$\log\left(\frac{P_{1i}}{1-P_{1i}}\right)=\propto_1+\beta_{X1i}+U_{1i}+\theta\tau_i+w_{1i} \quad (4)$$

$$\log\left(\frac{P_{2i}}{1-P_{2i}}\right)=\propto_2+\beta_{X2i}+U_{2i}+\frac{\theta}{\tau_i}+w_{2i} \quad (5)$$

where θ is the shared spatial component, w_{1i} and w_{2i} are the specific spatial components for LBW and stunting respectively, and τ_i is the gradient weight which measures the di fferent risk gradients for the shared component on the two health outcomes, allowing each disease to have unique association in the underlying shared surface.

Results

Descriptive Statistics

Table 1 presents the frequency distribution of the 36,922 under five children that were included in the study from the fourteen West African countries. Of these children, 20,352 (55.12%) reside in rural areas and about 55% are males. For the household wealth index category, those from the poorest households had the highest frequency of 12,436 (33.68%) followed by the poorer with 10,075 (27.29%), while those from the richest had the smallest with 2,090 (5.66%). About 36% of the mothers did not receive antenatal care during their pregnancies while just 18% were able to receive up to four times. Additionally, the majority of the mothers had no education (18,259 (49.45%)) while only about 5% (1,727) attained higher level of education. About 15% of the children had diarrhea in the two weeks before the survey while 19% had fever. Furthermore, about 57% of the children had received a dose of vitamin A. Mothers of aged 20-29 years had the highest frequency, followed by those aged 30-39 years while ages 40-49 years had the lowest.

Table 1. Socio-demographic background of the respondents

Characteristics	Frequency (Percentage)	Characteristics	Frequency (Percentage)
Place of residence		Country	
Urban	16,570 (44.878%)	Cote D'ivoire	1,897 (5.138%)
Rural	20,352 (55.122%)	Gambia	2,822 (7.643%)
Gender		Ghana	1,592 (4.312%)
Male	20,462 (55.420%)	Guinea	1,526 (4.133%)
Female	16,460 (44.580%)	Liberia	775 (2.099%)
Wealth Index		Mali	3,044 (8.244%)
Poorest	12,436 (33.682%)	Niger	1,405 (3.805%)
Poorer	10,075 (27.287%)	Nigeria	3,148 (8.526%)
Middle	7,501 (20.316%)	Senegal	3,036 (8.223%)
Richer	4,820 (13.055%)	Sierra Leone	2,392 (6.479%)
Richest	2,090 (5.661%)	Benni	7,368 (19.956%)
Mother's education		Bukina Faso	4,417 (11.968%)
No education	18,259 (49.453%)	Cameroon	2,934 (7.946%)
Primary	7,327 (19.845%)	Togo	566 (1.533%)
Secondary	9,609 (26.025%)	Mother's age	
Higher	1,727 (4.677%)	15-19	7,908 (21.418%)
Diarrhea		20-29	16,318 (44.196%)
Yes	5,529 (14.975%)	30-39	10,449 (28.300%)
No	31,391 (85.025%)	40-49	2,247 (6.086%)
Fever		Antenatal care	
Yes	7,270 (19.690%)	None	13,053 (35.353%)
No	29,652 (80.310%)	1 time	4,121 (11.161%)
Cough		2-3 times	13,088 (35.448%)
Yes	10,457 (28.322%)	4 times and above	6,660 (18.038%)
No	26,465 (71.678%)		
Vitamin			
Yes	21,059 (57.036%)		
No	15,863 (42.964%)	Total	36,922 (100.00%)

Results of the linear effects

Table 2 presents the estimated odds ratio for stunting, LBW and the shared effect (stunting and LBW) for the linear effects with their 95% credible intervals. The findings show that mothers who had primary or secondary/ higher education were less likely to have stunted children, low weight children or those who suffer from both health outcomes, though the estimate for LBW is not significant. The estimates for wealth index indicate significantly lower likelihood for children from the poorer/ middle households in the case of LBW and the shared effects. Further, female children were less likely to be stunted when compared with their male counterpart while mothers who were 20 years or older were less likely to have LBW children or those with LBW and stunted. Compared with women who had no antenatal care attendance, those who had at least one attendance were less likely to have LBW children or a combination of LWB and stunted, but the estimate for the specific effect for stunting is not significant. The findings however show that children who received vitamin A supplementation were more likely to be stunted but less likely to have low weight at birth. All the other estimates are not significant.

Spatial effects

The estimates for the spatial effects are presented in Figure 1, showing the specific spatial effects for stunting (a part), LBW (b part) and the shared effects (c part). The findings indicate that of the fourteen countries, stunted children are more concentrated in Niger, Nigeria, Burkina Faso, Cote d'Ivoire, Guinea, Benin, Sierra Leone, Camerron, and Togo. Specifically, the likelihoods oare higherthroughout Niger, spanning through some northern part of Nigeria (Kebbi, Sokoto, Zamfara, Katsina, Kano, Jigawa, Yobe, Borno, Kaduna and Bauchi states), and contagious regions of Burkina Faso; northern part of Cote d'Ivoire; in Boke region of Guinea; Atacora and Alibori of Benin; Southern region of Sierra Leone; East and Southwest regions of Cameroon; and Centrale region of Togo. However, children from most parts of southern Nigeria, Ghana, and Koulikoro and Kayes of Mali extending to most parts of Guinea are less likely to be stunted.

In the case of LBW, there are high risks among children living in most parts of Niger and Mali; in Borno, Katisina and Kaduna states of Nigeria; Atacoda and Alibori regions in the northern fringe of Benin; and Centrale region of Togo. Similarly, the chances for LBW are also high in Ashanti, Eastern and Western regions of Ghana; Zanza and Lacs in Cote d'Ivoire; and in Mamou, Boke, and Kindia regions of Guinea. However, the risks are lower in sourthern Nigeria, in Guinea extending to neighbouring Sierra Leone and Liberia. For the shared spatial effects, the results indicate co-existence of high risk pattern of stunting and LBW among the children living Niger extending through northern Nigeria, most part of Mali, and Burkina Faso. The risks are also high in East and Southwest regions of Cameroon; in Zanzan and Savana regions of Cote d'Ivoire; and in Boke region of Guinea. Like in the case of LBW, there are low risks for the combined effects of stunting and LWB in southern Nigeria, Ghana, most part of Guinea, Sierra Leone and Liberia.

Table 2. The Odds Ratio (OR) estimates of the covariate effects and 95% credible interval for stunting, Low Birth Weight (LBW) and joint (Stunting and LBW)

Variables	Stunting		Low Birth Weight		Stunting & LBW	
	OR	95% CI	OR	95% CI	OR	95% CI
Place of residence						
Rural (Ref. Cat.)	1.000		1.000		1.000	
Urban	0.916	0.810,1.035	1.023	0.944,1.161	0.956	0.847 ,1.080
Educational Status						
No Education (Ref. Cat.)	1.000		1.000		1.000	
Primary	0.983	0.869,1.112	0.923	0.812,1.049	0.852	0.754 ,0.963
Secondary or Higher	0.848	0.749,0.961	0.964	0.847,1.096	0.847	0.749 ,0.957
Wealth Index						
Poorest (Ref. Cat.)	1.000		1.000		1.000	
Poorer or Middle	1.053	0.930,1.192	0.875	0.770,0.994	0.833	0.737 ,0.941
Richer or Richest	0.900	0.791, 1.024	0.965	0.844, 1.104	0.910	0.802 ,1.033
Access to water						
Easily accessible (Ref. Cat.)	1.000		1.000		1.000	
Not easily accessible	1.038	0.919, 1.172	0.946	0.835,1.071	0.956	0.848 ,1.078
Toilet facilities						
No (Ref. Cat.)	1.000		1.000		1.000	
Yes	0.895	0.792,1.011	0.991	0.874,1.125	0.921	0.816 ,1.039
Gender						
Male (Ref. Cat.)	1.000		1.000		1.000	
Female	0.798	0.708,0.899	1.182	1.047,1.335	0.943	0.838 ,1.061
Mother's age						
15-19 (Ref. Cat.)	1.000		1.000		1.000	
20-29	1.060	0.933,1.203	0.721	0.633,0.820	0.659	0.582 ,0.745
30-39	1.046	0.920,1.188	0.672	0.590,0.766	0.609	0.538 ,0.690
40-49	1.047	0.914,1.199	0.677	0.588,0.781	0.601	0.526 ,0.686
Diarrhea						
No (Ref. Cat.)	1.000		1.000		1.000	
Yes	1.034	0.912,1.171	1.033	0.907,1.175	1.107	0.979 ,1.251
Fever						
No (Ref. Cat.)	1.000		1.000		1.000	
Yes	1.050	0.929,1.188	0.976	0.859,1.108	1.086	0.962 ,1.225
Cough						
No (Ref. Cat.)	1.000		1.000		1.000	
Yes	0.950	0.832,1.084	1.027	0.894,1.179	0.997	0.868 ,1.145
Vitamin						
No (Ref. Cat.)	1.000		1.000		1.000	
Yes	1.133	1.005,1.277	0.883	0.781,0.997	0.937	0.821,1.070
Antenatal care visits						
None (Ref. Cat.)	1.000		1.000		1.000	
1-3 times	1.035	0.907,1.182	0.564	0.492, 0.646	0.447	0.394,0.509
4 times and above	1.062	0.933,1.210	0.531	0.465,0.607	0.396	0.349 ,0.450

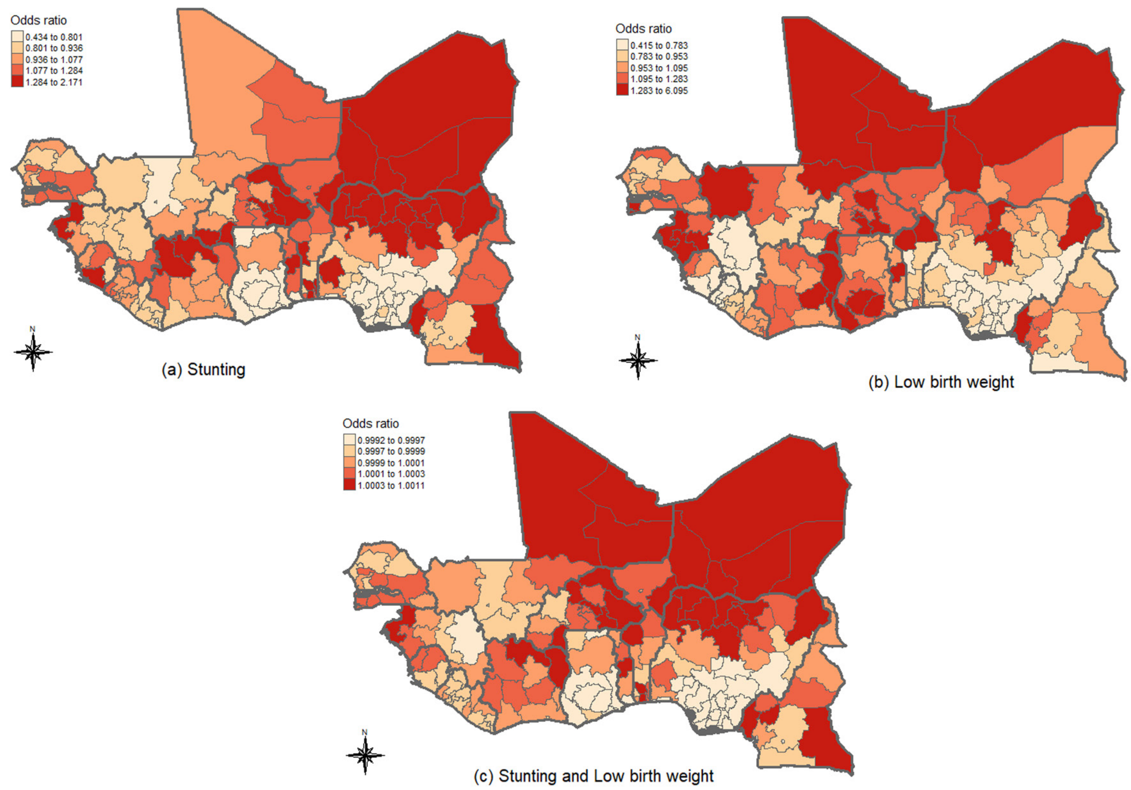

Figure 1. Maps of West African Countries showing the specific and shared spatial effects.

Discussion

The joint spatial modeling of health outcomes has remained a valuable tool for understanding and addressing complex interactions among multiple health concerns particularly in places with high burden of adverse outcomes as experienced in West Africa. Here, we used a shared component spatial model[21] to assess the pattern of co-existence of stunting and LBW in West African countries. The approach, implemented through a Bayesian hierarchical technique, is efficient even in situation of low count of cases or rare events in some of the spatial units.[22] It availed us the opportunity of splitting the spatial risk surface and the effects of the determinants into those specific to each health outcome and those common to both, thereby allowing for more understanding of the locations where children stand the risk of suffering from a combination of the health outcomes and places with minimal risks. The study is important considering the shared burden of adverse health outcomes that young children suffer in sub-Saharan Africa and particularly in the West African sub-region[16] and that the occurrence of LBW exacerbates undernutrition, particularly stunting.[8] We found that stunted children are more concentrated in Niger, Nigeria, Burkina Faso, Cote d'Ivoire, Guinea, Benin, Sierra Leone, Camerron, and Togo. LBW was found to be highly prevalent in Niger, Mali, part of Nigeria, northern Benin, and Centrale region of Togo, Ashanti, Eastern and Western regions of Ghana, Zanza and Lacs in Cote d'Ivoire, and in some regions of Guinea.

The findings reveal high spatial clustering of the health outcomes particularly in northern Nigeria. extending through neighboring Niger and Mali, while clusters of lower rates abound in southern Nigeria, Ghana, part of Mali and Guinea. The clustering could be attributed to the impact of factors beyond those considered in this study, which exact strong spatial influence. For instance, the highlighted countries and regions with high clusters are among those accounting for the highest burden of malnourished children in world, as indicated by previous studies.[23, 24] Moreover, access to maternal and child healthcare, particularly the uptake of antenatal care services is also limited in these places, and this could impact on birth outcome which eventually set the pace for other adverse outcomes for the newborn.[25] Gayawan and Omolofe[25] reported low uptake of antenatal care services in northern Nigeria soanning through Mali and Niger, and this could altimatetly impact of birth outcomes. Poverty and poor maternal nutrition during pregnancy could lead to LBW because the fetus would lack adequate nutrient for proper growth and development.[26]

Furthermore, religion and cultural beliefs that confine women, restricting their ability to take decisions regarding their health and those of their children without permission from their partners or mother-in-laws contribute to spatial clustering of maternal and child adverse health outcomes particularly malnutrition in places where these are practiced.[15, 27] Other studies have attributed variations in nutritional outcomes particularly stunting to non-exclusive breastfeeding, early weaning and introduction of unhygienic supplementary foods, and missed immunization, practices that have been reported to be common in West African countries.[10, 28-30] While all these factors are no doubt important in explaining spatial clustering of LWB and stunting, other local compositional to contextual factors could as well have strong impact on these outcomes and there is the need for careful identification so that appropriate intervention strategies can be deployed.

The findings from the linear covariates are in agreements with those from previous studies.[5, 31] Maternal education and household wealth index were found to lower the chances of the occurrence of either or both adverse outcomes. Maternal education has been reported as an important social determinants of inequality in birth weight in developing countries; studies by Silvestrin, da Silva[32] showed that high maternal education contribute to about 33% protective effect against LBW. Education empowers women and offers them opportunities to garner resources with which they can use to provide adequate nutritional intake for themselves and their households. They would also be able to patronize the right health services for themselves and their children, leading to better health outcome. Furthermore, we found that advancement in maternal age reduces the chances of LBW and the shared effects of both outcomes though estimates for stunting are not significant. Maternal age and behavior during pregnancy have been reported to impact on LWB with risk, increasing with age till around age 36 years, implying that younger women are at high risk.[33] Younger women particularly those experiencing first pregnancy may initially fail to recognize the symptoms of pregnancy. They initiate care at later stage of pregnancy thereby limiting the likelihood of receiving adequate care that could prevent adverse birth outcomes including LBW. These women could also lack knowledge of child care practice or lack resources to cater for the children, thereby subjecting the child to malnutrition.[13]

The effects of antenatal care attendance show, as expected, that women who had at least one attendance were less likely to have LBW children, which is similar to findings from other sub-Saharan African countries.[33] During antenatal visit, protective services including intermittent preventive treatment in pregnancy (IPTp) for malaria control and tetanus toxoid-diphtheria vaccination, both of which are important for the health of the mother and fetus development, are among the services rendered to pregnant women. We also found urban residency and being a female child to significantly reduce stunting but not significant for LBW and the shared effects. These could be a result of the social amenities available to urban women which improved nutritional intake while the findings on gender might reflect child preference that often favours female children because of the perceived future bride price to be collected as also reported by [31]. Our findings do not reflect that children who suffered from fever, diarrhea or cough in the two weeks before the survey experience the adverse health outcomes when compared with their other counterparts though studies in some of the countries have linked these indicators with malnutrition particularly wasting.[23]

Conclusion

Using a geographical shared component modeling approach that jointly assess LBW and stunting in fourteen West African countries allows us to split the spatial surface into those specific to each of the outcomes and one that is shared by the two. The approach is advantageous because most health outcomes share comparable risk pattern which can be identified through some joint modeling approaches rather than modeling each outcome separately. The study provides insight into the spatial pattern of these health outcomes, reflecting strong spatial structure of high clustering among neighboring locations particularly in northern Nigeria and Niger. Interventions in regions with high burden of LBW and malnutrition may include more advocacies that promote antenatal care utilization, enlightment on pregnancy care among younger women, and women empowerment through educational opportunities and social welfare.

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