J Hum Ecol, 54(3): 138-149 (2016)

Spatial Distribution of Determinants of Malnutrition of Children under Five Years in Rwanda: Simultaneous Measurement of Three Anthropometric Indices

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KEYWORDS Joint Modeling. Stunting. Underweight. Wasting. Z-Score

ABSTRACT The main objective of this paper was to identify the risk factors of malnutrition among children under five years in Rwanda and produce the maps of prevalence of joint distribution of stunting, underweight and wasting. Each of these anthropometric indicators is categorized as malnourished (z-score <-2.0) and nourished (z-score $\geq$-20). The spatial multivariate generalized linear mixed model is used to simultaneously identify the spatial distribution of risk factors of malnutrition of the children under five years. The 2010 Rwanda Demographic and Health Survey data was used in the analysis. The paper revealed that the age of child, birth order, gender of child, birth weight, fever, mother's education level, mother's age at the birth, body mass index, mother's knowledge on nutrition, anemia, province, source of drinking water, multiple birth, and wealth index have significant effects on malnutrition status of the children under five years of age in Rwanda.

INTRODUCTION

Children's malnutrition has specific significant health consequences in childhood development and adulthood (Takele 2013; Tathiah et al. 2013;Walker et al. 2007). Childhood malnutrition, is also attributed to impairments of cognitive capacity in early life, consequently, it leads to low productivity at adulthood (Tathiah et al. 2013).

Children are more likely to suffer from malnutrition deficiencies than adults because they are in a physiologically less stable situation (Kandala et al. 2011; Tharakan and Suchindran 1999). Child malnutrition is known as a clinical sign of nutrient deficiency manifested as underweight, stunting and wasting. These nutritional status of the child can be evaluated using clinical signs, biochemical indicators or anthropometric indicators (Group 1986; Onis 2000; Zere and McIntyre 2003). But anthropometric measures are frequently used because of its less cost and readily available (Folasade 2000). In case of the extreme malnutrition, it is better to use Biochemical and clinical signs (Onis 2000; Zere and McIntyre 2003).

Malnutrition of children under the age of five is frequently measured based on three anthropometric measurements (WHO 1995) known as: wasting or insufficient weight-for-height which indicates inadequate food intake in the period prior to the survey or a recent episode of illness causing the child to lose the weight. Stunting or insufficient Height-for-age which indicates chronic malnutrition; and underweight which is a composite index of weight-for-height and Height-for-age. This means that a child may be underweight if is either wasted or stunted, or both. A higher prevalence of stunting in the community is associated with poor socio-economic status (Skoufias 1998). These three anthropometric variables are measured in Z-scores values for stunting, wasting and underweight and given as follows

$$Z_i = \frac{AI_i - \mu}{\sigma} \qquad (1)$$

where Al_i is the child or individual anthropometric indicator, μ and σ refer respectively to median and standard deviation of the reference population. The higher the value of Z-score the better nutrition status of the child and the lower value of Z-score indicates an increase in malnutrition.

One of the main targets adopted by Millennium Development Summit (AbouZahr and Wardlaw 2001; Wagstaff 2004) is to reduce the

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rate of malnutrition by half in 2015. In Rwanda, similar to other developing countries, malnutrition is a serious problem to national health system. The prevalence of stunting among children under age five is approximately 44.0 percent, underweight 11.0 percent and wasted 3.0 percent (NISR et al. 2012). However, the government of Rwanda has engaged in alleviating the malnutrition of children under five years in particular and the population of Rwanda in general (NISR et al. 2012).

There are some studies in literature done on spatial model and applied to malnutrition of children under five years (Kandala et al. 2011; Damaris et al. 2015). However, all these studies considered separately the three anthropometric indicators (Kavosi et al. 2014; Sahu et al. 2015; Yu et al. 2016). But, a child may be well nourished or malnourished (stunted, or underweight, or wasted, or wasted and underweight, or underweight and stunted). In addition malnutrition status of the child might have spatial variability between primary sampling unit or villages.

Therefore, the main objective of this paper is to jointly identify the key determinants of wasting, stunting and underweight of children under five years of age in Rwanda, and to incorporate the spatial variability between the villages and to henceforth produce the spatial prevalence maps of their prevalence.

Multivariate joint modeling has a pretty advantage over separate modeling because it has an relative efficiency to estimate the model (Gueorguieva 2001; Verbeke 2005). Based on the author's knowledge, there is no study in the literature using spatial joint model for multivariate generalized linear mixed model and simultaneously find the key determinants of underweight, stunting and wasting of children under age five in Rwanda.

METHODOLOGY

Source of Data

The 2010 Rwanda Demographic Health Survey data was used in the current research. The 2010 RDHS contains information on women aged 15-49 and 4,356 children under five years of age, on height in centimeters, weight in kilograms and age in months, birth-weight, anemia, gender, multiple birth, province, body mass index, wealth quintile index, birth order, parent's education, mother's knowledge on nutrition, residence, housing characteristics, toilet, sickness of the child such as cold, cough, diarrhea, or others in two weeks prior to the survey, mother's marital status, child's caretaker, breastfeeding, and feeding index. More variable included in the survey can be found in (NISR et al. 2012).

The 2010 RDHS offers the data on three anthropometric. The GIS coordinates for primary sampling unit was also included in the survey. The current paper considered Mother's characteristic variables, the characteristic of the household and child's characteristic variables. In the current paper, the children's nutrition status was categorized as nourished *(z-score value $\geq$ -2.0)* and malnourished *(z-score value <-2.0),* and this made the response variable to be binary. The details on sampling methodology used in the survey can be found in (NISR et al. 2012).

Spatial Multivariate Joint Generalized Linear Mixed Model

Model Overview

The specification of linear model entails three components: the linear predictor that in generalized linear model (GLM) expresses the model parameters as a linear function of covariates, the link function and the distribution. In order to capture the spatial random effects, the likelihood of the location s (s denotes in general the location of the observation) should be specified.

GLM is classically formulated as $g(\mu)=X\beta$, with X is the design matrix (AbouZahr and Wardlaw 2001). In order to include spatial process, let us assume $y(s_i|\alpha)$ to be conditionally independent to any location s_i and $E[y(s_i)|\alpha] = \mu(s_i)$ be its conditional mean, where α is utilized to define the distribution of s. Hence, the model with spatial correlated random effects is defined as follows:

$$g(\mu) = X\beta + Z\alpha \qquad (2)$$

with X and Z the design matrices. The random effect at location s_i is distributed as $a \sim Gau(0, \alpha(\theta))$ and $\varepsilon \sim Gau(0, \sigma_\varepsilon^2 I)$ and , where the spatial correlation is parameterized by θ in.

The spatial correlation is in general described by three main functions in Geostatistics: semivariogram also known as variogram, covariogram and correlogram (Ayele et al. 2013). But in geostatistics, variogram function is the most utilized for fitting spatial correlation models. The variogram also represents the random aspects of the data of interests.

Spatial Prediction

Spatial prediction is a method that includes spatial dependence. The simple and popular spatial prediction model is ordinary kriging that produces predicted values and their associated standard errors. Ordinary kriging necessitates a model of spatial dependence and this model is in the form of semivariogram or covariance.

Kriging has a number of advantages among others such as: compensation of data clustering effect, assigning individual points within a cluster less weight than isolated data point, giving estimation error, along with an estimate of the variable, and allowing simulation of possible realization.

The main objective of geostatistics is not only to find out the significant covariates but also to produce the maps of the outcome variables by predicting it at unsampled locations. Let us consider a vector of binary response Y_{01} for unobserved locations response, i=1,2,…, n_0. Based on maximum likelihood methodology, the distribution is formulated by (Gemperli 2003) as

$$P\left(Y_{01}|\hat{\beta},\widehat{W},\hat{\sigma}^2,\hat{\varphi}\right) = \int P\left(Y_{01}|\hat{\beta},W_{01}\right) P\left(W_{01}|\widehat{U},\hat{\sigma}^2,\hat{\sigma}\right) d\,W_{01} \quad (3)$$

where β, σ^2 and φ are the maximum likelihood estimates of the corresponding parameters, $P(Y_{01}|\hat{\beta},\widehat{W}_{01})$ is Bernoulli-likelihood at s_{oi}, and $\widehat{W}$ is derived as part of iterative estimation process in penalized quasi-likelihood (Breslow and Clayton 1993), and the spatial random effect W_{oi} at new locations is given by

$P(\widehat{W}_{01}|\widehat{\sigma}^2, \varphi)$, given $\widehat{W}$ at observed sites and is normally distributed as

$$P(Y_{01}|\widehat{\beta},\widehat{W},\widehat{\sigma}^2,\varphi) = N(\Sigma_{01}\Sigma_{11}^{-1}\widehat{W},\ \Sigma_{00}-\Sigma_{11}^{-1}\Sigma_{10}) \quad (4)$$

where, $\Sigma_{11} = E(UU^1)$, $\Sigma_{00} = E(W_0W_0')$ and $\Sigma_{01} = \Sigma_{01}'$ $\Sigma_{00} = E(W_0W_0')$ Moran's I and Geary's C statistics are the most commonly used measure of spatial autocorrelation test. These tests indicate the degree of spatial association as reflected in the data set as a whole.

Model Formulation

Let y_{ijk} be child's nutrition status (where 1 denotes malnourished and 0 denotes nourished) of the anthropometric indicators k, with $k=1$ for wasting, $k=2$ for underweight and $k=3$ for a stunting child j, in district i, $i=1,2,...,30$. Consider a trivariate response p_{ijk} as a probability of anthropometric indicator k occurring in child j in district i, therefore the outcome is modeled based on GLMM with spatial random effect as follows

$$g(\mu_k) = X_{ijk}\beta_k + Z_{jk}\alpha_k \quad (5)$$

where k=1,2,3, β_k are vectors of fixed regression parameters, X_{ijk} and Z_{jk} are the design matrices and α_k are random the spatial variation.

$$\alpha_k = \begin{pmatrix}\alpha_1\\ \alpha_2\\ \alpha_3\end{pmatrix} \sim \text{i.i.d. MVN}(0,\Sigma) = \text{MVN}\left[\begin{matrix}0\\0\\0\end{matrix}\right], \left(\begin{bmatrix}\Sigma'_{11}, & \Sigma'_{12}, & \Sigma'_{13},\\ \Sigma'_{12}, & \Sigma'_{12}, & \Sigma'_{23},\\ \Sigma'_{13}, & \Sigma'_{23}, & \Sigma'_{33},\end{bmatrix}\right) \quad (6)$$

where equation (6) is the covariance matrices of the spatial effects Σ_{11}, Σ_{22}, Σ_{33}, are the variance components of wasting, underweight and stunting status respectively and Σ_{12}, Σ_{13}, and Σ_{23}, are correlation components between wasting and underweight, wasting and stunting and underweight and stunting respectively.

Analysis

In this paper, SAS 9.3 PROC GLIMMIX procedure was utilized in the analysis by fitting generalized linear mixed model to the data. In order to choose the best covariance structure, the researchers considered the following various covariance structures: SP(EXP) (Exponential), SP(EXPA) (Anisotropic Exponential), SP(EXPGA) (2D Exponential, Geometric Anisotropic), SP(GAU) (Gaussian), SP(GAUGA) (2D Gaussian, Geometrically Anisotropic), SP(POWA) (Anistropic power), SP(SPH) (Spherical), SP(SPHGA) (2D Spherical, Geometrically Anisotropic), SP(LIN) (Linear), SP(LINL) (Linear Log), SP(Matérn) (Matérn) and SP(MATHSW) (Matérn (Handcok-Stein-Wallis)) and ArcGIS was used to produce smooth maps of malnutrition prevalence corresponding to each outcome variable.

RESULTS

The results from Figure 1 represent the scatter plot for malnutrition prevalence for joint distribution of stunting, underweight and wasting. As can be seen from the figure, the plot suggested that distribution is not an indicative of

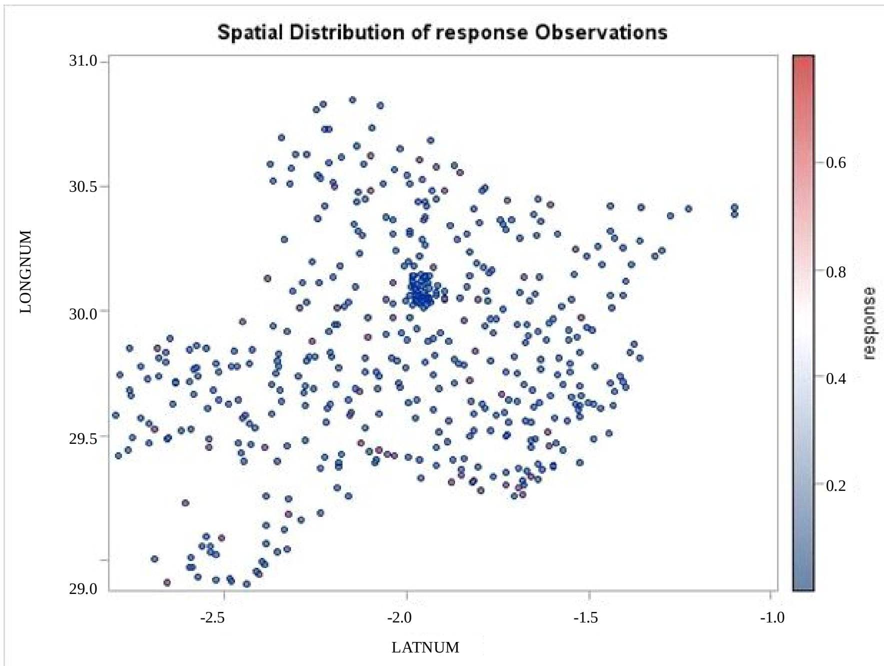

Fig. 1. Scatter plot for the malnutrition prevalence for joint distribution of stunting, underweight and wasting

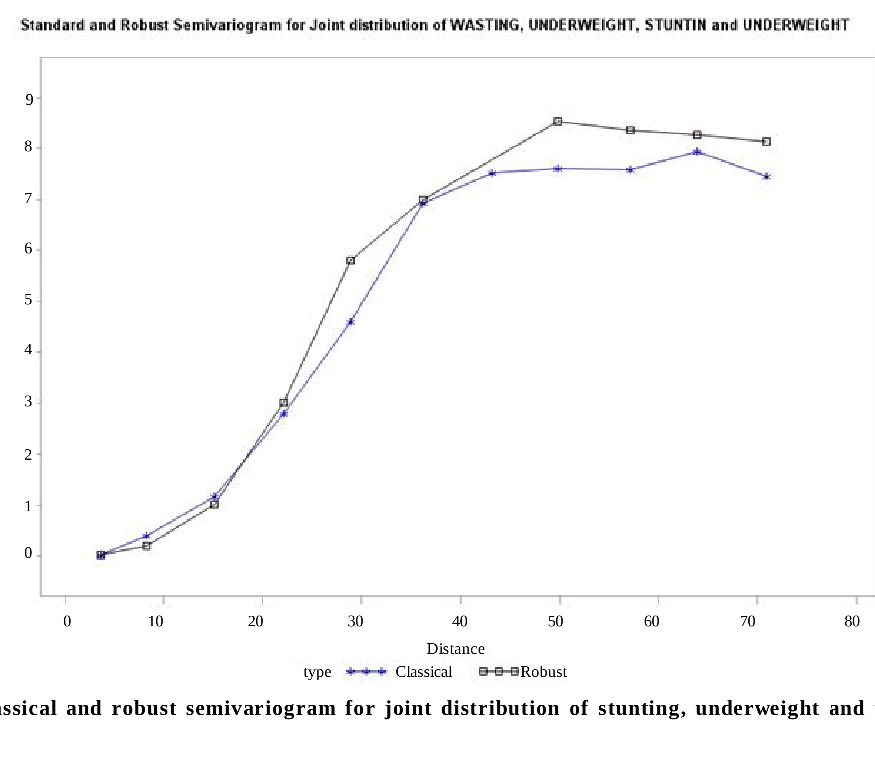

Fig. 2. Classical and robust semivariogram for joint distribution of stunting, underweight and wasting

uniform distribution but is an indication of random spread of the response.

Classical representation of Gaussian semivariogram is presented together with the robust semivariogram in Figure 2 Based on this graphical representation, the Gaussian structure was found to perform better than any other spatial structure considered. Therefore, the variogram analysis was performed based on Gaussian structure. It is observed from the figure that the origin of Y-axis does not correspond to that of x-axis; this indicates the possible presence of nugget effect.

This paper considered different child malnutrition factors such as gender of the child, birth weight, birth order, child age, child had fever in two weeks before the survey, diarrhea, mother's education level, mother's age at the birth, body mass index of the mother, anemia, mother's knowledge on nutrition, assistance at delivery, antenatal visits, region or province, source of drinking water, place of residence, toilet facilities, wealth index, access to toilet, the size of household, and household wealth index. But in Table 1, any variable which is at least significant at one of the three anthropometric indicators is

Table 1: Parameter estimates for a spatial joint model for anthropometric measurements of malnutrition

	Wasting			*Underweight*			*Stunting*		
Indicator Variable	*Estimate*	*SE*	*p-value*	*Estimate*	*SE*	*p-value*	*Estimate*	*SE*	*p-value*
Intercept	-.817	0.790	0.3012	2.644	2.113	0.2108	1.250	1.063	0.2396
Child Age in Moths(Ref=0-11 Months)									
12-23	-0.991	0.304	0.0011	-0.015	0.1539	0.9207	1.355	0.1625	<.0001
23+	0.588	0.300	0.0499	-0.200	0.107	0.0617	-0.148	0.1028	0.1507
Birth Order(Ref=First)									
2-3	0.040	0.3542	0.9109	0.239	0.1252	0.056	0.137	0.1308	0.2935
4-5	-0.388	0.3625	0.2847	0.296	0.1351	0.0285	0.148	0.1409	0.2922
6+	0.971	0.4521	0.0317	1.044	0.1602	<.0001	0.536	0.1472	0.0003
Mother's Age(Ref=≥21)									
<21	0.280	0.6759	0.6781	0.109	0.2576	0.6724	0.628	0.2313	0.0066
Mother's Education(Ref=No Education)									
Primary	-0.482	0.4857	0.3212	-2.172	0.3556	<.0001	-0.738	0.1992	0.0002
Secondary andHigher	-0.3069	0.5555	0.5806	-2.350	0.3676	<.0001	-0.968	0.222	<.0001
Gender of the Child (Ref=Female)									
Male	0.361	0.2469	0.1436	0.458	0.0918	<.0001	0.503	0.0892	<.0001
Birth Weights (Ref=2500g)									
<2500g	1.132	0.2013	0.0035	1.132	0.2013	<.0001	0.543	0.2458	0.0271
Province (Ref=Kigali)									
South	-0.603	0.5163	0.2428	-0.043	0.2068	0.8356	0.537	0.1955	0.0061
West	-1.000	0.5126	0.0511	0.428	0.2071	0.0389	0.118	0.1975	0.5502
North	-0.384	0.5246	0.4646	-0.332	0.2021	0.1008	-0.030	0.193	0.8777
East	-1.178	0.6444	0.0667	-0.167	0.2885	0.5625	0.667	0.2736	0.0147
Knowledge on Nutrition (Ref=Yes)									
No	0.112	0.2564	0.6628	-0.334	0.1045	0.0014	-0.323	0.0996	0.0009
Wealth Index (Ref=Poor)									
Rich	-1.325	0.5604	0.0181	-0.307	0.1944	0.1145	-0.437	0.1785	0.0143
Middle	-0.805	0.4784	0.0924	-0.122	0.1688	0.4692	-0.260	0.1549	0.0931
Multiple Birth (Ref=Singleton)									
First multiple	0.029	1.0717	0.9781	1.308	0.3479	0.0002	0.376	0.4534	0.4063
Second multiple and more	-0.019	1.3151	0.9883	0.411	0.4473	0.3584	0.016	0.5875	0.9777
Anemia (Ref=No Anemic)									
Anemic	0.490	0.2593	0.0586	0.3729	0.0958	<.0001	0.101	0.0948	0.2841
BMI (ref= BMI 18.5)									
BMI<18.5	1.359	0.4006	0.0007	1.1693	0.1813	<.0001	0.173	0.2124	0.4144
Fever (Ref=Yes)									
no	-0.533	0.2814	0.0582	-0.497	0.1149	<.0001	-0.005	0.1216	0.9697
Source of Drinking Water (Ref=Other Source of Drinking Water)									
Piped into dwelling/yard	1.396	0.696	0.0045	0.096	0.4057	0.8122	-0.601	0.3427	0.0.079
Public tap	1.998	0.7249	0.0058	0.056	0.4071	0.891	-0.463	0.3431	0.1774
Protected spring/well	0.633	0.3236	0.1472	-0.219	0.3934	0.578	-0.046	0.1329	0.1571

considered as determinant of malnutrition and is reported. For the test of model fit, the AIC and -2log likelihood (deviance) are the same and smaller for Gaussian, Exponential power and Spherical than AIC and -2log likelihood of any other considered model. However, based on graphical representation, Gaussian was found to be the best spatial covariance structure for this paper. From Table 2 it is observed that the estimated variance parameter is 0.757 and the estimated range is 1.59. Therefore based on the result from Table 2, it is seen that there is a spatial variability among the villages.

Table 2: Random effect estimates

Effect	*Estimate*	*SE*	*Pr>Z*
Variance	0.7571	0.0924	<.0001
SP(GAU)	1.5864	0.4224	0.0165

Stunting

This paper revealed that birth order, mother's age, mother's education, child's age, gender of the child, birth weight, province, mother's knowledge on nutrition and wealth index are the determinants of stunting of children under five years in Rwanda.

From Table 1, it is observed that the age of a child is significantly affecting height-for-age of the child. It is noted from the same table that the prevalence of stunting is higher among children aged between twelve months and twenty three months (OR= 3.8768, p-value<.0001) compared to an infant children. This may be explained by introduction of supplementary food to most of children at this age**.** But the height-for-age of a child aged twenty three months or more was not significantly influenced as compared to infant. It is noted from the results that stunting is higher among children aged twelve to twenty three months compared to all other age groups considered in this paper.

The birth order is significantly influencing child's height-for-age (Table 1). It was noted that a child born at six order or more has 70.9 percent higher odds of being stunted (OR=1.7092, p-value=0.0003) compared to an infant.

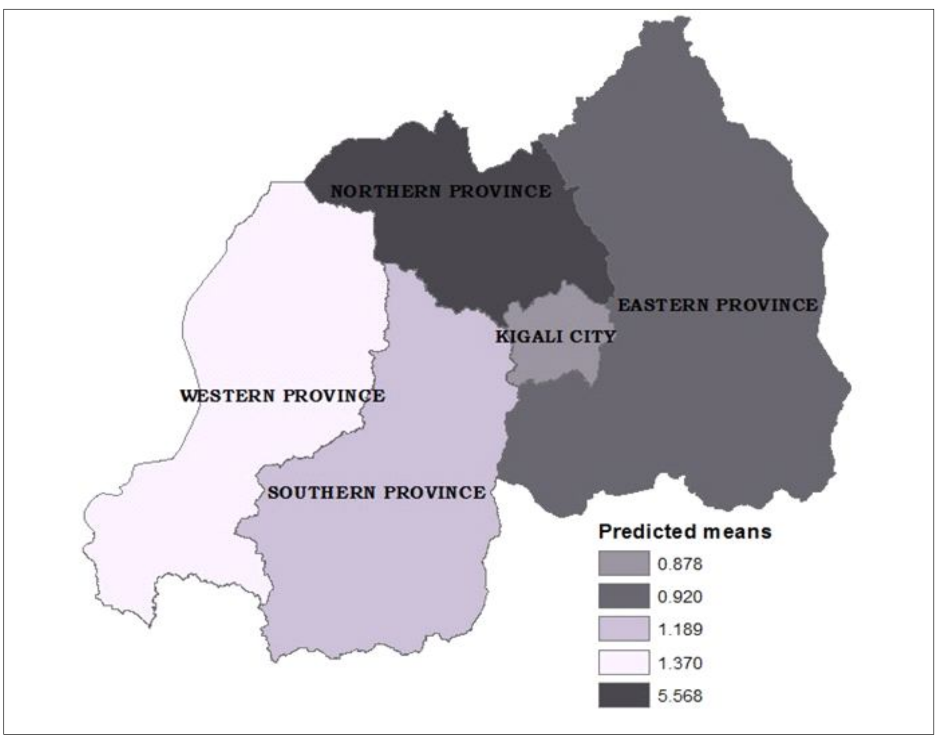

Fig. 3. Predicted average spatial effects from the joint model for stunting

Mother's age at the birth is significantly affecting height-for-age of the child (Table 1). A child born to mother aged less than twenty one years old has 87.4 percent higher odds of being stunted (OR=1.8738, p-value=0.0066) than a child born to mother aged twenty one years old or more.

Birth weight is significantly affecting height-for-age of the child (Table 1). It is noted that stunting is higher among children born with low weights (weights <2500g) (OR= 1.7212, p-value=0.0271) compared to children born with weights greater or equal to 2500g. The cause of birth weight is multidimensional for instance, maternal education, maternal health, mother's age, environmental factors and others (Metgud et al. 2012).

Mother's education level is significantly affecting height-for-age of the child (Table1). A child born to mother with primary education or mother with secondary or higher level is 0.4781 (p-value <.0001) or 0.3798 (p-value=0.0002) times respectively less likely to be in stunting status than a child born to mother with no formal education. This confirmed the fact that the mother's level of education is inversely proportional to the rate of the stunting status of the child.

Gender of child is also significantly influencing child's height-for-age (Table 1). The researchers observe from the same table that stunting is higher among male children (OR= 1.6537, p-value <.0001) compared to female children.

Birth weight is significantly affecting height-for-age of the child (Table 1). A child born with low weights (weights <2500g) is 1.7212 (p-value=0.0271) times more likely to have stunting status than a child born with weights greater or equal to 2500g (weights).

Province is found to influence height-for-age of the child (Table 1). A child born in Southern or Eastern Province is 1.7109 (p-value=0.0061) or 1.9484 (p-value=0.0147) times respectively more likely to be stunted than a child born in Kigali city.

Mother's knowledge on nutrition is a significant predictor for height-for-age of the child (Table 1). The results show that a child born to mother with some knowledge on nutrition has 27.6 percent lower odds of being stunted (OR=0.7240, p-value=0.0009) compared to a child born to mother without knowledge on nutrition.

Wealth quintile index is also significantly affecting height-for-age of the child (Table 1). The results show that a child born in rich family has 35.4 percent lower odds of being stunted (OR= 0.6460, p-value=0.0143) compared to a child born in poor family. This may be explained based on the health facilities available to the rich family and possibly to maternal health background of the mother.

The prevalence of stunting is higher in Northern Province and lower in Kigali city (Fig. 3); this is consistent with other findings such as (NISR et al. 2012).

Wasting

This paper revealed that source of drinking water; fever, wealth index, birth weight, birth order and age of the child are the determinants of wasting of children under five years of age. The age of the child is a significant predictor of child's height-for-weight (Table 1). It is observed from the results that the prevalence of wasting lower among children aged between twelve months and twenty three months (OR=0.3712, p-value=0.00011) compared to infant.

Birth order is also significantly influencing child's height-for-weight (Table 1). It is noted from the results that wasting is higher among children born at six order (OR=2.6406, p-value=0.0317) than children born at the first order.

Birth weight of the child is also significantly affecting height-for-weight of the child (Table 1). A child born with low weight is 3.1018 (p-value=0.0035) times more likely to be wasted than a child born with weight.

The wealth index is also significantly affecting height-for-weight of the child (Table 1). The results show that the prevalence of wasting is lower among children born in rich family (OR=0.2658, p-value=0.0181) compared to children born in poor family. This finding is not surprising because the rich families normally have sanitation facilities, health facilities among others which contribute to the child's health status.

Body mass index of the mother is a significant predictor of child's height-for-weight (Table 1). It is also noted that wasting higher among children born to underweight mother (BMI<18.5) (OR= 3.8923, p-value=0.0007) compared to a child born to normal mother or obese (BMI).

Source of drinking water is significantly influencing child's height-for-weight (Table 1). Children born in a family where they use water piped in their dwelling or from a public tap are 4.0390 (p-value=0.0045) or 7.3749 (p-value=0.0058) re-

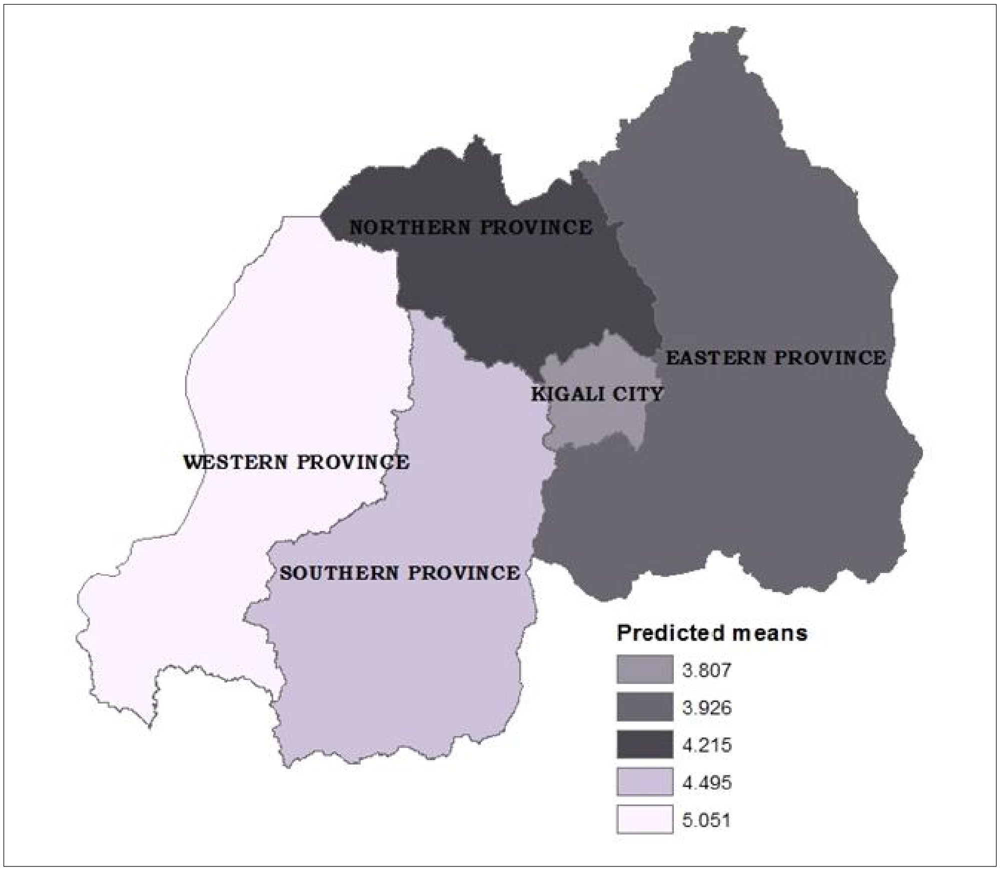

Fig. 4. Predicted average spatial effects from the joint model for wasting

spectively times more likely to have wasting status compared to children born in family where they use water from other sources of water apart from piped and protected spring or well. The prevalence of wasting is higher in Western Province and lower in Kigali city (Fig. 4).

Underweight

This paper revealed that birth order, mother's education, gender of the child, birth weights of the child, province, mother's knowledge on nutrition, multiple birth, anemia, body mass index of the mother and fever are the key determinants of underweight of children under age five in Rwanda.

Birth order is significantly affecting child's weight-for-age (Table 1). It is observed from same table that underweight is higher among children born at fourth to fifth order and sixth order or more (OR=1.344, p-value=0.0285 and 2.8405, p-value <.0001 respectively) compared to children born at the first order respectively.

Mother's level of education is significantly influencing child's weight-for-age (Table 1). It is noted from the results that a child born to mother with primary education or secondary or higher education level has 88.6 percent or 90.5 percent lower odds of having underweight status respectively (OR= 0.1139, p-value <.0001 and OR=0.0954, p-value<.0001) compared to a child born to mother with no formal education respectively. This means that the underweight status decreases with increasing the mother's level of education.

Gender of the child is also significantly affecting weight-for-age of the child (Table 1). A male child has 58.1 percent higher odds of having underweight status (OR=1.5809, p-value <.0001) compared to a female child. The similar trend is also found in stunting case.

Birth weight of the child is also significantly affecting weight-for-age of the child (Table 1). It is noted from the same table that the prevalence of underweight is higher among children born with low weight (OR= 3.1018, p-value <.0001) compared to children born with higher weight. This finding is common in most research. Metgud et al. (2012) found in their research that the causes of lower or higher birth weight are multidimensional.

Province is significantly affecting weight-for-age for child (Table 1). The results show that a child born in Western Province has 53.4percent higher odds of being underweight (OR=1.534, p-value=0.0389) than a child born in Kigali.

Mother's knowledge on nutrition is significantly affecting weight-for-age of the child (Table 1). It was observed from the results that the prevalence of underweight is lower among children born to mother with some knowledge on nutrition (OR= 0.7160, p-value=0.0014) compared to children born to mother without knowledge on nutrition.

Multiple birth is significantly affecting weight-for-age of the child (Table 1). A child born at the first multiple is 3.6988 (p-value=0.002) times more likely to be in underweight status than a singleton child.

Anemia is significantly affecting the weight-for-age of the child (Table 1). A child born to anemic mother has 45.2 percent higher odds of having underweight status (OR=1.4519, p-value<.0001) compared to a child born to not anemic mother.

Body mass index of the mother is a significant predictor of child's weight-for-age (Table 1).It is observed that underweight is higher

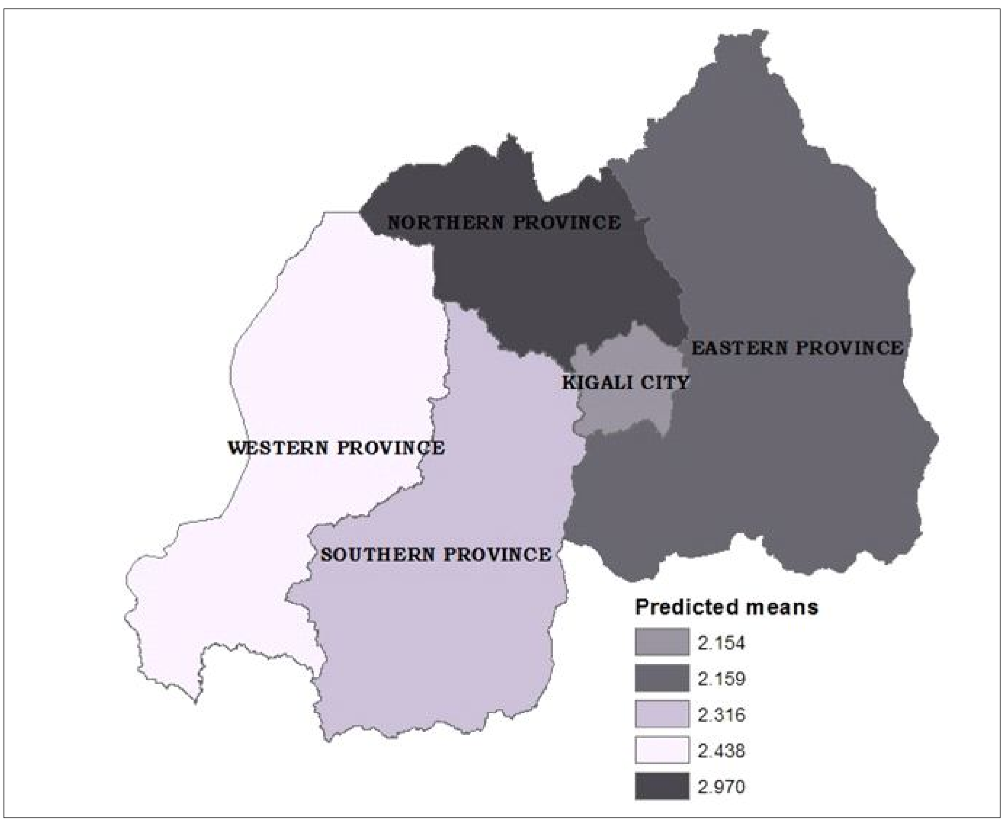

Fig. 5. Predicted average spatial effects from the joint model for underweight

among children born to thin mother (BMI<18.5) (OR=3.2197, p-value <.0001) than children born to normal mother or obese.

Fever is also significantly influencing child's weight-for-age. It is noted from the (Table 1) that a child who had no fever two weeks prior to the survey has 39.2 percent lower odds of having underweight status (OR= 0.6083, p-value <.0001) compared to a child who had fever in two weeks preceding the survey. The prevalence of underweight is higher in Northern Province and lower in Kigali city (Fig. 5). These findings are consistent with (NISR et al., 2012).

DISCUSSION

Recently, Habyarimana et al. (2015) in another paper explored the determinants of stunting, underweight and wasting of children under five years of age and the existence of correlation between underweight and stunting and underweight and wasting. The present work extended abovementioned paper of Habyarimana et al. (2015) to include spatial variability among the villages and to produce the maps of the prevalence of stunting, underweight and wasting by predicting the unsampled location.

Kandala et al. (2011) examined the spatial variation based on stunting and found that malnutrition is spatially structured; in addition they also produced the map of prevalence of stunting.

It is noted from Table 1 that birth weight significantly affects all three anthropometric indices, where a child born with low weight is more likely to be affected by any of these three types of malnutrition. This may itself be the results of many factors such as maternal education, maternal weight, environmental factors, and maternal health status among others (Metgud et al. 2012).

It is observed from Table 1 that malnutrition reduces with increasing the mother's level of education and her body mass index. This finding is consistent with Elham et al. (2014), Aheto et al. (2015), Ayana et al. (2015), Alemu et al. (2015) and Habyarimana et al. (2016). This may explained as follows: improving the level of education of women enhances maternal health outcomes, family income and therefore improve the health of the child.

It is also observed that the children from 12-23 age groups are more likely to be stunted. This might be the consequence of the fact that most of children are introduced to supplementary foods at this age. This finding is uniform with that of Chukwuma et al. (2015), Damaris et al. (2015) and Habyarimana et al. (2016).

It was also found that malnutrition increases with increasing the birth order of the child. This finding is in line with many other papers such as Habyarimana et al. (2014), Chukwuma et al. (2015) and Habyarimana et al. 2015). This paper found that male children are more likely to be malnourished than female children. This finding is similar to those from the research carried out by Irena et al. (2011), Chukwuma et al. (2015) and Habyarimana et al. (2015) among authors. However, there is a challenge to explain these differences due to the presence of extraneous and suppressor variables. The prevalence of wasting is higher in Western Province and lower in Kigali city (Fig.4). In general most researchers their findings highlight higher prevalence of stunting, underweight and wasting among children born in rural areas than urban (Ibidolapo et al. 2016; Meshram et al. 2016; Yu et al. 2016) The existence of spatial variability between villages was noted from Table 2 and this slightly changed the results found by Habyarimana et al. (2015). There was no statistical significance of the following variables i.e. marital status of the mother, assistance of the mother at delivery, feeding index, breastfeeding, child's caretaker, toilet facilities and place of residence.

CONCLUSION

Based on spatial logistic joint model this research revealed that child's age, birth order, sex of the child, birth weight, fever, multiple birth, mother's level of education, mother's age at the birth, anemia, body mass index of the mother, mother's knowledge on nutrition, wealth index of the family, source of drinking water and province are the key determinants of malnutrition of children under age five in Rwanda This paper found that prevalence of wasting is higher in Western Province and lower in Kigali city, the prevalence of stunting is higher in Northern Province and lower in Kigali city and the prevalence of underweight is higher in Northern Province and lower in Kigali city.

RECOMMENDATIONS

Improving the access (distance traveled to feature) to potable water may help to reduce the diseases such as diarrhea, fever and consequently reduce the rate the incidence of wasting. This will involve some intervention strategies on behalf of the relevant public administration that deal with water services. Educating the population about nutrition for instance through the media and *umuganda* (a mandatory community service on each last Saturday of every month) may reduce stunting and underweight as well as wasting.

Also improving the basic, primary, secondary and tertiary education level of women may help to improve the family health outcomes and therefore contribute to improve the nutrition status of the children.

Sensitizing and also possibly improve the existing policy on family planning may reduce stunting, underweight and wasting.

For further study, the structured additive model which includes the semiparametric and spatial variability to identify the risk factors of malnutrition is recommended.

ACKNOWLEDGEMENTS

The authors acknowledge National Institute of Statistics of Rwanda (NISR) [Rwanda], Ministry of Health (MOH) [Rwanda], ICF International for data and University of Rwanda-College of Education (UR-CE) for financial support.

REFERENCES

AbouZahr C, Wardlaw T 2001. Maternal mortality at the end of a decade: Signs of progress? *Bulletin of the World Health Organization,* 79(6): 561-573.

Aheto JM, Keegan TJ, Tayilor BM, Diggle PJ 2015. Childhood malnutrition and its determinants among under-fev children in Ghana. *Paediatr Perinat Epidemiol,* 29(6): 552-561.

Ayana AB, Hailemaria TW, Melke AS 2015. Determinants of acute malnutrition among children aged 6-59 months in public hospitals, Oromia region, West Ethiopia: A case-control study. *BMC Nutrition,*1(1): 1. DOI 10.1186/s40795-015-0031-9.

Ayele DG, Zewotir T, Mwambi H 2013. Spatial distribution of malaria problem in three regions of Ethiopia. *Malar J,* 12: 207.

Breslow NE, Clayton DG 1993. Approximate inference in generalized linear mixed models. *Journal of the American Statistical Association,* 88(421): 9-25.

Chukwuma BD, Uche RO, Kelechi AU, Kelvin CD, Irene AM, Ifeadike OC, Anthony CI 2015. Prevalence and sociodemographic determinants of malnutrition among under-five children in rural communities in Imo state, Nigeria. *American Journal of Public Health Research,* 3(6): 199-206.

Damaris KK, James AB, Graine MM, Ngianga BK, Abdisalam MN 2015. Predictors of malnutrition among children under the age of 5 years in Somalia. *Public Health Nutrition,* 18(17): 3125-3133.

Folasade IB 2000. Environmental factors, situation of women and child mortality in southwestern Nigeria. *Social Science and Medicine,* 51(10): 1473-1489.

Gemperli A 2003. *Development of Spatial Statistical Methods for Modelling Point-Referenced Spatial Data in Malaria Epidemiology.* Doctoral Dissertation. Switzerland: University of Basel.

Group WW 1986. Use and interpretation of anthropometric indicators of nutritional status. *Bulletin of the World Health Organization,* 64(6): 929.

Gueorguieva R 2001. A multivariate generalized linear mixed model for joint modelling of clustered outcomes in the exponential family. *Statistical Modelling,* 1(3): 177-193.

Habyarimana F, Zewotir T, Ramroop S 2014. A proportional odds model with complex sampling design to identify key determinants of malnutrition of children under five years in Rwanda. *Mediterranean Journal of Social Sciences,* 5(23):1642.

Habyarimana F, Zewotir T, Ramroop S 2015. Joint models of key determinants of malnutrition of children under five years in Rwanda: Simultaneous Measurement of Three Anthropometric Indices. *African Population Studies,* in Press.

Habyarimana F, Zewotir T, Ramroop S 2016. Joint modeling of poverty of households and malnutrition of children under five years from demographic and health survey data: case of Rwanda. *Journal of Economics and Behavioral Studies,* 8(2): 108-114.

Ibidolapo TI, Oluwapelumi AA, Akinola F 2016. Urban-rural disparities and determinants of nutritional status of under-five children: An example of Akinyele local government area, Ibadan. *International Journal of Tropical Disease and Health,* 16(1): 1-11.

Kandala NB, Madungu TP, Emina JB, Nzita KP, Cappuccio FP 2011. Malnutrition among children under the age of five in the Democratic Republic of Congo (DRC): Does geographic location matter? *BMC Public Health,* 11(1): 261.

Kavosi E, Hassanzadesh RZ, Kavosi Z, Nasihatkon A, Moghadami M, Heidari M 2014. Prevalence and determinants of under-nutrition among children under six: A cross-sectional survey in Fars province, Iran. *Int J Health Policy Manag,* 3(2): 71-76.

Meshram II, Mallikharjun RK, Reddy CG, Ravindranath M, Sharad KS, Sreerama KK, Hari KR,Venkaiah K, Laxmaiah A 2016. Prevalence of under nutrition and its predictors among under 5 year children in Surat region, Gujarat, India. *Clinical Nutrition and Dietetics,* 2(1): 1-12.

Metgud CS, Naik VA, Maheshwar DM 2012. Factors affecting birth weight of a newborne- a community based study in rural Kamataka, India. *PloS one,* 7(7): e40040.

NISR, ICF, MoH 2012. *Rwanda Demographic and Health Survey 2010.*

Onis MD 2000. Measuring nutritional status in relation to mortality. *Bulletin of the World Health Organization,* 78(10): 1271-1274.

Sahu SK, Kumar SG, Bhat BV, Premarajan KC, Sarkar S, Roy G, Joseph N 2015. Malnutrition among under -five children in India and strategies for control. *Journal of Natural Science, Biology and Medicine,* 6(1): 18-23.

Skoufias E 1998. Determinants of child health during the economic transition in Romania. *World Development,* 26(11): 2045-2056.

Takele K 2013. Semi-parametric analysis of children nutritional status in Ethiopia. *International Journal of Statistics and Applicaitons,* 3(5): 141-154.

Tathiah N, Moodley I, Mubaiwa V , Denny L, Taylor M 2013. South Africa's nutritional transition: Overweight, obesity, underweight and stunting in female primary school learners in rural KwaZulu-Natal, South Africa. *SAMJ: South African Medical Journal,* 103(10): 718-723.

Tharakan CT, Suchindran CM 1999. Determinants of child malnutrition—an intervention model for Botswana. *Nutrition Research,* 19(6): 843-860.

Verbeke G 2005. *Models for Discrete Longitudinal Data. Springer Series in Statistics*. New York: Springer.

Wagstaff A 2004. *The Millennium Development Goals for Health: Rising to the Challenges*. Washington: World Bank Publications.

Walker I, Marini A, Lucchetti L, Waters W, Lastra A 2007. Nutritional failure in Ecuador: Causes consequences and solutions. *International Journal of Statistitcs and Application,* 3(5): 141. doi: 10.5923/j.stattistics.20130305.01

WHO 1995. *Physical Status: The Use and Interpretation of Anthropometry: Report of a WHO Expert Committe*. Geneva: WHO

Yu DM, Zhao LY, Yang ZY, Chang SY, Yu WT, Fang HY, Xun WANG, Dan YU, Guo QY, Xu XL , Fang YH 2016. Comparison of undernutrition prevalence of children under 5 years in China between 2002 and 2013. *Biomedical and Environmental Sciences,* 29(3): 165-176.

Zere E, McIntyre D 2003. Inequities in under-five child malnutrition in South Africa. *International Journal for Equity in Health,* 2(1): 7. Doi:10.1186/1475-9276-2-7.

Paper received for publication on February 2016
Paper accepted for publication on June 2016