Associations Between Nutritional Indicators Using Geoadditive Latent Variable Models with Application to Child Malnutrition in Nigeria

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1. Introduction

Childhood undernutrition is amongst the most serious health issues facing developing countries. It is an intrinsic indicator of well-being, but it is also associated with morbidity, mortality, impaired childhood development, and reduced labor productivity (Svedberg 1996; UNICEF 1998; Sen 1999)
To assess nutritional status, the 2003 DHS obtained measurements of height and weight for all children below five years of age.(Survey 2003) Researchers distinguish between three types of malnutrition: wasting or insufficient weight for height indicating acute malnutrition; stunting or insufficient height for age indicating chronic malnutrition; and underweight or insufficient weight for age which could be a result of both stunting and wasting.
These three anthropometric variables are measured through z-scores for wasting, stunting and underweight, defined by

$$Z_i = \frac{AI_i - MAI}{\sigma}, \quad (1)$$

where AI refers to the individual anthropometric indicator (e.g. height at a certain age), MAI refers to the median of a reference population, and σ refers to the standard deviation of the reference population. Each of the indicators measures somewhat different aspects of nutritional status. Note that higher values of a z-score indicate better nutrition and vice versa. Therefore, a decrease of z-scores indicates an increase in malnutrition. This has to be taken into account when interpreting the results. The reference standard typically used for the calculation is the NCHS-CDC Growth Standard that has been recommended for international use by WHO. (WHO 1999) The reference population are children from the USA. More precisely, the children, up to the age of 24 months are from white parents with a high socio-economic status, while children older than 24 months are from a representive sample of all US children. The selection of the reference populations can affect the results, for example a higher z-score can be caused by the change of the reference population.
Latent variable model: Previous analyses are often based on Demographic and Health Surveys (DHS) as a well-established data sources with reliable information on childhood

undernutrition, and they rely on statistical inference with various forms of regression models. Because of methodological restraints, it is difficult to detect nonlinear covariate effects adequately, for example, age, and it is impossible to recover small-scale, district-specific spatial effects with common linear regression or correlation analysis. Recent research has therefore applied geoadditive regression models (Fahrmeir L 2001; Fahrmeir 2004) .They have been used in regression studies of risk factors for acute or chronic undernutrition (e.g., Kandala et al., 2001; Adebayo 2003; Khatab, 2007) and for morbidity.(Kandala 2001; Adebayo 2003; Kandala, Magadi et al. 2006; Kandala, et al. 2007; Khatab 2007) These models can account for nonlinear covariate effects and geographical variation while simultaneously controlling for other important risk factors.

However, in all these studies regression analyses are carried out separately for certain types of undernutrition such as stunting, wasting or underweight, neglecting possible association among these response variables and without aiming at the detection of common latent risk factors. Because of common and overlapping risk factors, separate analyses may fail to give a comprehensive picture of the epidemiology for the malnutrition and the joint effects of childhood malnutrition at population level.

To asses the association between the the nutritional indicators, we applied the recently developed latent variable model. This model gives us the opportunity to study the association or interrelationship between the three types of malnutrition as indicators for nutritional status. The factor loadings describe the association between these indicators and their impact on the nutritional status of a child. Latent variable model permits modeling of covariate effects on the latent variables through a flexible geoadditive predictor

The objective of this study is to determine the associations between nutritional indicators among Nigerian children under 5 and also to examine the impact of socioeconomic and public health factors on the nutritional status.

Nutritional status is known to have various risk factors including geographical locations as a proxy of socioeconomic and environmental factors that affect the disease prevalence and incidence.

Spatial heterogeneity in these factors influences the nutritional status pattern. Consequently, efforts to reduce the burden of childhood undernutrition should include investigations into the influence of the associations between the different measurements of the malnutrition status of children and their distribution among the locations on child health.

Two approaches of latent variable models (joint model) analysis of malnutrition have emerged: the measurement model which accommodates and describes the effect of the latent variables and a set of observed covariates (e.g. child's sex, mother's educational attainment, working status, etc) on the nutritional indicators such as stunting, wasting and underweight.

The structural model is linking a set of observed covariates which have indirect effects (such as child and mother's age, etc), with the latent variables.

In the latent variables overall specific risks are estimated having adjusted for covariates, and in addition, the correlation of risk between measurements of the malnutrition can be quantified.

In this study, we considered the latent variable model to jointly analyse childhood stunting, wasting and underweight, with the objective of highlighting spatial patterns of these indicators.

To build a regression model for undernutrition, we first have to define a distribution for the response variable. In this application, it is reasonable to assume that z-score is Gaussian distributed; thus in principle, could be applied.
The analysis started by employing a separate geoadditive Gaussian model to continuous response variables for wasting, stunting and underweight. The author then applied geoadditive latent variable models, based on these separate analyses results, which were reported in Khatab, 2007, where the three undernutrition variables were taken as indicators for the nutritional status of a child.
All computations have been carried out with R Programs using the MCMC package; see(Raach 2005; Khatab 2007)

2. Data & methods

DHS collects information on household living conditions such as housing characteristics, on childhood morbidity, malnutrition and child health from mothers in reproductive ages (15-49). There were 6029 children's records in the 2003 survey of Nigeria. Each record consists of information on childhood malnutrition and diseases and the list of covariates that could affect the health and nutritional status of children. In the following, we provide some more information about the nutritional indicators, which were used as response variables and information about the covariates considered in this study.
Stunting. Stunting is an indicator of linear growth retardation relatively uncommon in the first few months of life. However it becomes more common as children get older. Children with *height-for-age* z-scores below minus two standard deviations from the median of the reference population are considered short for their age or stunted.
Wasting. Wasting indicates body mass in relation to body length. Children whose *weight-for-height*'s z-scores are below minus two standard deviations (z-scores $< -2SD$) from the median of the reference population are considered wasted (i.e. too thin for their height) which implies that they are acutely undernourished otherwise they are not wasted.
Underweight. Underweight is a composite index of stunting and wasting. This means children may be underweight if they are either stunted or wasted, or both. In a similar manner to the two previous anthropometric incidences, children may be underweight when their z-score is below minus two standard deviations and they are severely or moderately so if their z-score is lower than two standard deviations. The included variables in Table 1 were considered in the analysis to study child nutritional status.

3. Statistical analysis

In the following, we focus on geoadditive Gaussian models for continuous response variables to analyze the effects of metrical, categorical, and spatial covariates on stunting, wasting and underweight response variables in latent variable analyses. Furthermore, we use "nutritional status" as the indicator in the analysis of the latent variable models as mentioned.

3.1 Geoadditive gaussian model

In this analysis, we apply a noval approach by exploring regional patterns of childhood malnutrition and possible nonlinear effects of the factor within latent model framework using geoadditive Bayesian gaussian model for continuous response variable.The model

Factor	N(%)	Coding effect
Place of residence		
Urban	2237(33.58%)	1
Rural	4424(66.42%)	-1.ref
Child's sex		
Male	3487(52.35%)	1
Female	3174(47.65%)	-1.ref
Working		
Yes	1209(18.15%)	1
No	5452(81.85%)	-1.ref
Mother's Education		
No,		
Incomp.prim,		
Comp.prim,		
Incomp.sec	4194(62.97%)	1
Compl.sec,		
Higher	2467(37.04%)	-1.ref
Pregnancy's treatment		
Yes	697(10.46%)	1
No	5964(89.54%)	-1.ref
Drinking water		
Controlled	5374(80.68%)	1
Not controlled	1287(19.32%)	-1.ref
Missing	1%	
Had radio		
Yes	5374(80.68%)	1
No	1559(19.32%)	-1.ref
Has electricity		
Yes	6203(93.12%)	1
No	458(6.88%)	-1.ref
Toilet facility		
Own flush toile facility	1768(28%)	1
Other and no toilet facility	4511(71.8%)	-1.ref
Missing	1%	
Antenatal visit		
Yes	4181(63%)	1
No	2342(35%)	-1.ref
Missing	2%	

Table 1. Factors analyzed in malnutrition study

used for this investigation has been described else where.(Raach 2005; Khatab 2007) . Basicaly in the early stage of this study we used the geoadditive Bayesian gaussian model for the separate analysis. In this model we replace the strictly linear predictor

$$\eta_{ij}^{lin} = x_{ij}'\beta_j + w_{ij}'\gamma_j \quad j = 1,..,3, \tag{2}$$

With geoadditive predicator, to have geoadditive model

$$\eta_{ij}^{geo} = \beta_{0j} + f_1(Chage_i) + f_2(BMI_i) + f_3(Mageb_i) + f_{spat_i}(s) + w_{ij}'\gamma_j \tag{3}$$

where w includes the categorical covariates in effect coding. The function f_1, f_2 and f_3 are non-linear smooth effects of the metrical covariates (body mass index, child, and mother's age) which are modelled by Bayesian P-splines, and f_{spat} is the effect of the spatial covariate $s_i \in 1;...;S$ labeling the districts in Nigeria. Regression models with predictors are referred to as geoadditive models. However, in this work we have used g**eoadditive latent variable models** to overcome the drawbacks of separate analysis.

3.2 A bayesian geoadditive LVM (latent varaible models)

A latent variable model with covariates consists of two main approaches: the measurment model for continuous response with covaraites influencing the indicators directly (direct effects); and the structural model explaining the modificatio of the latent variables by covariates (indirect effects) (Fharmeir and Raach, 2007; Khatab, 2007)

3.2.1 Mesurment model

$$y_{ij} = \lambda_0 + a_j'w_i + \lambda_j\upsilon_i + \varepsilon_{ij},\ i = 1,..,n,\ j = 1,..,p, \tag{4}$$

Where υ_i represents the nutritional status with independent and identically distributed Gaussian errors $\varepsilon_{ij} \sim N(0,\sigma^2)$. In this model, υ_i is the unobservable value of υ for individual i, λ_j is the "factor loading", and $\lambda_j\upsilon_i$ is the effect of υ_i. In addition, w_i are the direct effects which affect the observed variables directly and a_j is the vector of regression coefficients. The restriction to $\sigma_\upsilon = var(\upsilon) = 1$ is necessary for identifability reasons . (Fahrmeir L 2007; Khatab and Fahrmeir 2009).
Continuous variables are observed directly, hence the underlying variable is obsolete.

3.2.2 General geoadditive structural model

$$\upsilon_i = u_i'\alpha + f_1(x_{i1}) + ... + f(x_{iq}) + f_{geo}(s_i) + \delta_i, \tag{5}$$

with independent and identically distributed Gaussian errors $\delta_i \sim N(0,1)$. The restriction to σ_υ =var $(\upsilon) = 1$ is necessary for identifiability reasons.
RESULTS. We applied a geoadditive latent variable model, using the three types of undernutrition as indicators of latent nutritional status. The decision which covariates should be used in the measurement model, and which should be used in the structural equation, is based on the same criteria that was used in (Khatab 2007; Khatab and Fahrmeir 2009).

Our interest is in analyzing the three types of undernutrition of children using latent variable models, and in investigating how they can be established as indicators of the latent variable "undernutrition status". Based on the previous separate analyses (Khatab, 2007), we are able to determine which factors can have direct effects and which can have indirect effects on the indicators.

In order to choose the covariates used in the measurement model (which have direct effects on the disease indicators); or in the case of the structural model, those have indirect effects via their common impact on the latent variable "nutritional status," we used the following criteria: if the effects of covariates turned out to be significantly different (in terms of confidence intervals) for the three diseases, we decided to keep them in the measurement model, otherwise covariates were included in the geoadditive predictor of the structural equation for the latent variable (Khatab and Fahrmeir 2009).

We started by using the easiest model possible, a classic factor analysis for continuous indicators. The predictor of the structural equation of the model yields LMV0:

$$\eta = 0 \tag{6}$$

Estimates of factor loadings are depicted in Table 2. The estimated mean factor loadings show that indicator 2 (*weight-for-age*) has the highest factor loading. That means the most effect on the z-scores is on underweight for age and is followed by the indicator of stunting.

The classic factor analysis model has been extended by introducing direct and indirect parametric covariates, which modified the latent construct.

Parameter	Mean	Std	2.5%	97.5%
Factor Loadings				
1. stunting λ_{11}	1.244	0.02	1.206	1.28
2. underweight λ_{21}	1.36	0.08	1.353	1.38
3. wasting λ_{31}	0.770	0.015	0.739	0.801

Table 2. Results of Model LVM0 of Z-scores indicators with $\eta = 0$.

The next model was selected based on the previous separate analyses (reported in Khatab, 2007). This leads to the latent variable model.

In the fundamental analysis (LVM1), the vector a_j comprises the covariates urban, antenatal visits, educational level of mothers, access to flush toilet, and availability of electricity, with direct effects on y_j ; and u_i' comprises the remaining categorical covariates sex, work, treatment during pregnancy and access to controlled water and radio, having common effects on the latent variable υ . However, the results of model LVM1 (not reported here) have been extended or changed to model LVM2 by including some covariates that have direct effects on the parametric direct covariates in LVM2. The results of model LVM2 (Table 3) shows that most of the parametric direct covariates are significant and remained quite stable when including these covariates in the direct parametric effects. It demonstrates that the female children whose mothers are educated, had treatment during their pregnancy, had access to controlled water, had access to radio and working currently have higher Z-score of *weight-for-age* and are better nourished. However, males whose mothers are currently working are associated with a higher level of *(weight-for-height)*(at 97%). Although working status has a slight effect on the indicator of stunting, it is associated with other indicators. According to the covariate of radio, it has mostly a non-significant effect. Moreover, the results of LVM2 indicate a negative effect of the education on the indicator 2.

Parameter	Mean	Std	2.5%	10%	90%	97.5%
Factor Loadings						
stunting λ_{11}	1.041**	0.021	1.00	1.02	1.079	1.095
underweight λ_{21}	1.191**	0.007	1.178	1.187	1.208	1.210
Wasting λ_{31}	0.673**	0.017	0.644	0.656	0.703	0.714
Parametric indirect Effects						
urban	-0.057	0.049	-0.153	-0.119	0.011	0.044
anvis	0.054	0.065	-0.058	-0.013	0.153	0.198
toilet	0.142**	0.059	0.017	0.060	0.212	0.250
elect	0.0683*	0.056	-0.026	0.010	0.151	0.186
Parametric Direct Effects						
male (a_{11})	–0.238**	0.0518	-0.321	-0.285	-0.153	-0.119
work (a_{12})	0.09	0.055	-0.042	-0.007	0.134	0.168
trepr (a_{13})	0.155*	0.069	-0.004	0.041	0.226	0.274
water (a_{14})	0.083**	0.035	0.0148	0.0384	0.127	0.153
educ (a_{15})	0.216**	0.039	0.143	0.167	0.265	0.291
radio (a_{16})	0.062	0.0300	-0.029	-0.0095	0.0711	0.093
male (a_{21})	–0.064**	0.0138	-0.082	-0.067	-0.032	-0.030
work (a_{22})	0.109**	0.0176	0.051	0.056	0.085	0.107
trepr (a_{23})	0.072**	0.023	0.024	0.026	0.085	0.117
water (a_{24})	0.048**	0.007	0.039	0.043	0.057	0.065
educ (a_{25})	0.067**	0.013	0.0507	0.058	0.074	0.076
radio (a_{26})	0.047**	0.0056	0.004	0.005	0.020	0.039
male (a_{31})	0.051*	0.042	-0.015	0.010	0.119	0.148
work (a_{32})	0.096*	0.0453	-0.006	0.021	0.135	0.163
trepr (a_{33})	-0.056	0.056	-0.182	-0.141	0.005	0.045
water (a_{34})	0.001	0.028	-0.054	-0.036	0.037	0.056
educ (a_{35})	–0.076**	0.032	-0.135	-0.115	-0.035	-0.015
radio (a_{36})	0.0018	0.0248	-0.068	-0.050	0.013	0.032
Smoothing Parameters						
Chage	0.035**	0.028	0.008	0.01	0.065	0.107
BMI	0.004**	0.0056	0.0006	0.001	0.010	0.018
Mageb	0.003**	0.0045	0.0004	0.0006	0.007	0.015
reg	0.121**	0.045	0.055	0.071	0.175	0.227

Table 3. Results of LVM2, including direct and indirect effects. (**: Statistically significant at 2.5% and 10%)

The reason for this is that in the analysis of latent models, we used three indicators (which were assumed to have high level of correlations among each other) instead of one indicator, which was used by the separate analysis.

It is observed that the indicators have a higher correlation which can affect the results, so we have made a further analysis excluding the indicator of wasting (*weight-for-hight*) to examine the effects of various factors on the other indicators (underweight and stunting), and results are compared (LVM3) with analysis when all three indicators (LVM2) are present.
The results of LVM3 (Table 4) indicate that the antenatal visits and the availability of electricity are associated positively with nutritional status. With regard to the direct covariates, the females and the education level of mothers have a positive significant effect on the indicator of stunting. While, only the work status is associated positively with the indicator of underweight. The factor loadings estimates show that the *weight-for-height* is seen to be more serious in Nigeria (its higher factor loading of 1.14).

Parameter	Mean	Std	2.5%	97.5%
Factor Loadongs				
stunting λ_{11}	1.147*	0.028	1.097	1.203
underweight λ_{21}	0.987*	0.0274	0.934	1.040
Parametric Indirect Effects				
urban	0.0357	0.060	-0.357	0.152
anvis	0.346*	0.075	0.205	0.492
toilet	0.156	0.082	-0.013	0.313
elect	0.153*	0.058	0.033	0.269
Parametric Direct Effects				
male (a_{11})	–0.242*	0.059	-0.357	-0.1372
work (a_{12})	0.087	0.064	-0.028	0.211
trepr (a_{13})	0.124	0.083	-0.044	0.290
water (a_{14})	0.065	0.086	-0.1033	0.241
educ (a_{15})	0.184*	0.067	0.055	0.330
radio (a_{16})	0.019	0.0365	-0.049	0.088
male (a_{21})	-0.057	0.045	-0.150	0.026
work (a_{22})	0.118*	0.053	0.0155	0.224
trepr (a_{23})	0.022	0.060	-0.090	0.137
water (a_{24})	0.0079	0.069	-0.124	0.139
educ (a_{25})	0.046	0.0529	-0.051	0.154
radio (a_{26})	0.028	0.029	-0.027	0.089
Smoothing Parameters				
Chage	0.016*	0.018	0.064	0.143
BMI	0.004*	0.011	0.075	0.319
Mageb	0.135*	0.085	0.0003	0.009
reg	0.159*	0.054	0.081	0.291
Chage	0.016*	0.018	0.064	0.143

Table 4. Estimates of factor loadings of the LVM3 with only two indicators in Niegria.

Figure 1 shows the non-linear effect of the child's age to be associated with a malnutrition status in Nigeria for LVM1 and LVM2, respectively. It shows that the rates of malnutrition of children increase sharply from about 5 to around 20 months of age. The rates of malnutrition are at low level between 20 and 30 months of age, then rise again through the remainder of the third year. This pattern highlights the first two years of life as the most nutritionally vulnerable for children in Nigeria.

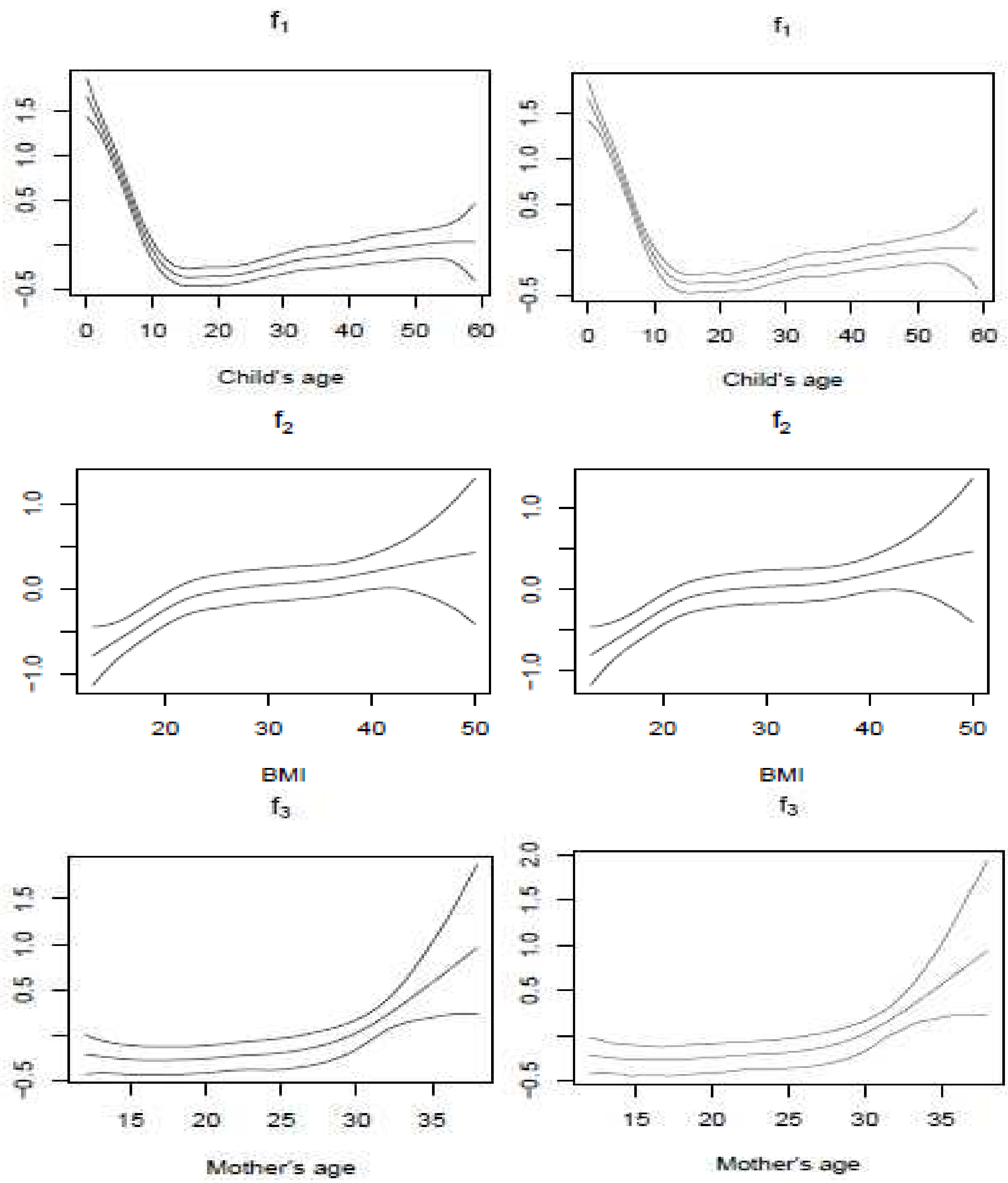


Fig. 1. Nonlinear effects from top to bottom: child's age, mother's BMI and mother's age at birth for LVM1 (left) and LVM2 (right) of "malnutrition status" of children for Nigeria, using latent varaible model for continuous responses

The nonlinear effect of the BMI of the mother shows that obesity of the mother probably poses less of a risk for the child's nutritional status, due to the fact that a very low BMI suggested acute undernutrition of the mother. The Z-score is highest (and thus stunting lowest) at a BMI of around 30-40 months.

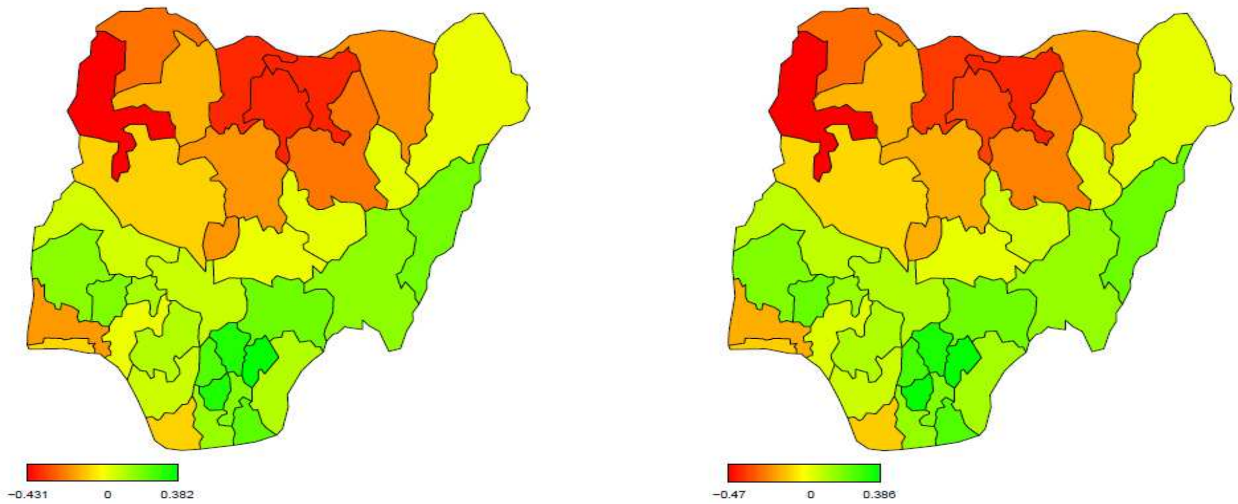


Fig. 2. Posterior mean for leatent varaiable model for LVM1 (left panel) and LVM2 (right panel) on malnutrion status for Nigeria

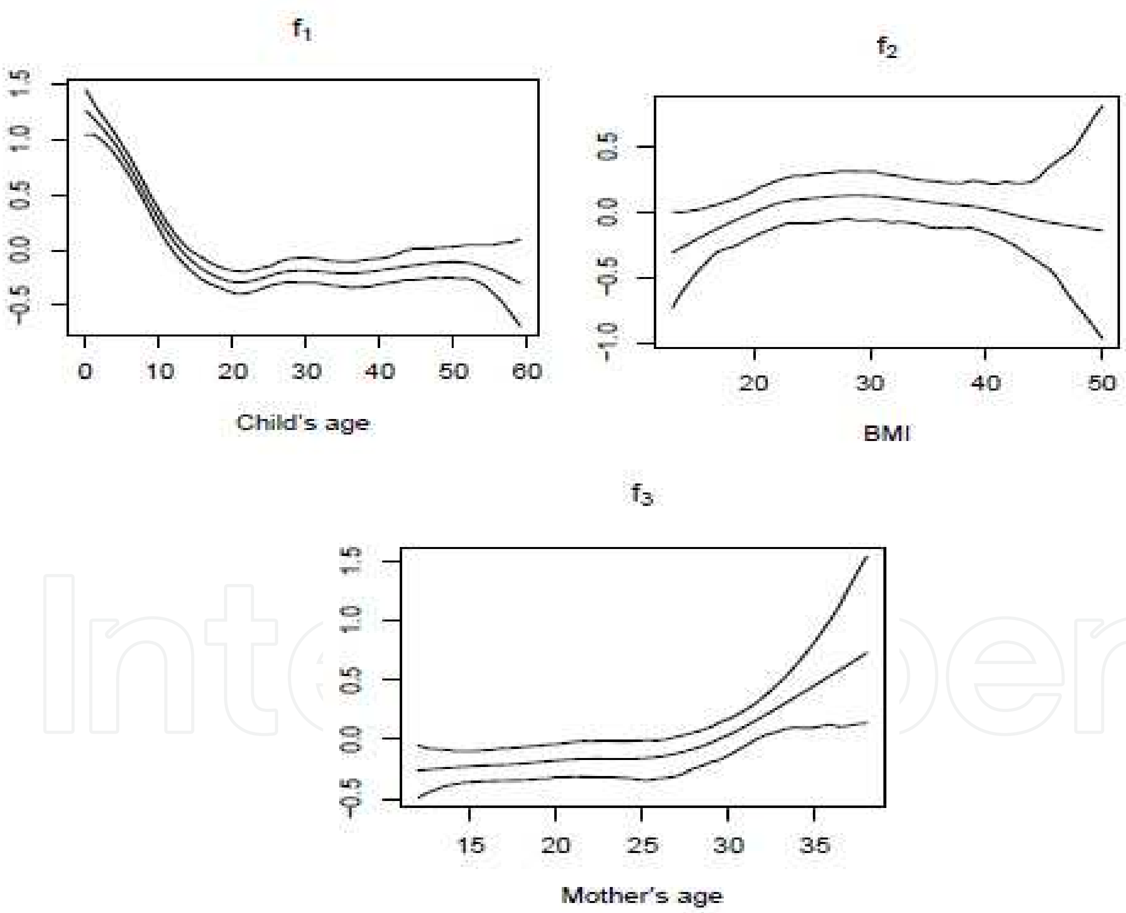


Fig. 3. Nonlinear effects from top to bottom: child’s age, mother’s BMI and mother’s age at birth using only two indicators of latent varaible “malnutrition status” of children for Nigeria, using latent varaible model for continuous responses.

The effect of the mother's age seems to be slight on the Z-scores of children up till about the age of 25 months; thereafter, there is a strong effect shown.

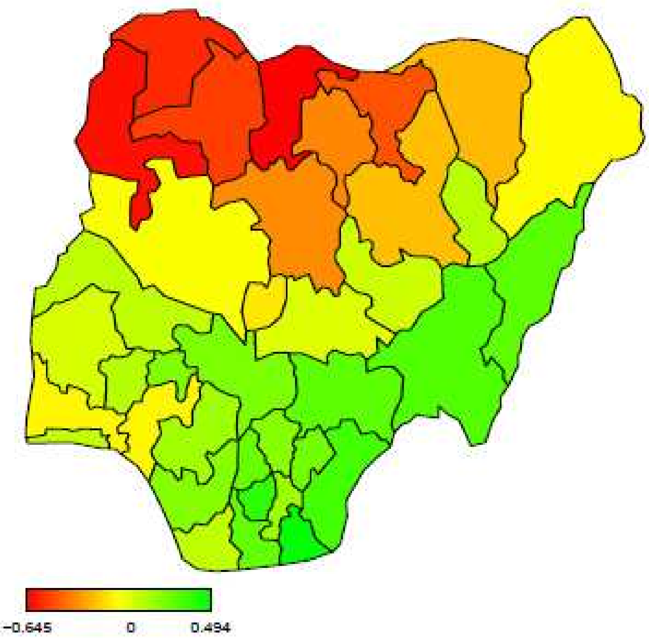


Fig. 4. Posterior mean for Latent varaible model, using only two idicators of latent varaible "Malnutrion status" for Nigeria

Fig. 5. Map of Nigeria showing the different states

In addition, the patterns of the nonlinear effect in LVM3 (Figure 3) are similar to the patterns of LVM1 and LVM2. The same is true with regard to the spatial effects of LVM3 (Figure 4). Figure 2 shows that the districts in the southeastern through the southern part of the country are associated with better nutrition of children in Nigeria.

4. Discussion

The results of estimating the geoadditive latent variable models with continuous response variables are indicated and suggest the following:

4.1 Child's sex

The likelihood of being stunted and underweight was lower for girls than for boys; a finding consistent with .(Klasen 1996; Lavy, Strauss et al. 1996; Svedberg 1996; Gibson 2001; Kandala 2001; Borooah 2002; S.B 2003); on the other hand, Gibson (2001) did not find any significant gender difference between the *height-for-age* and the *weight-for-age* in Papua, New Guinea.

4.2 Malnutrition among residences

Although, rural living was expected to have many problems, such as, poor health, use of unprotected water supplies, lack of charcoal as fuel, lack of milk consumption, and lack of personal hygiene (which assumed to be the risk factors of nutritional status), the results indicate that the place of residence is not associated with significant effects on wasting, underweight, and for stunting. This is consistent with some studies, but not with others: Adebayo (2003) found that where the mother lives (rural/urban) has no statistical significance for child's *weight-for-height*, and a similar impact of where the mother lives, as in *height-for-age*, is observed in *weight-for-age*, though Kandala found that urban areas have a statistical significance for a child's *height-for-age* in Tanzania and Malawi (Lavy, Strauss et al. 1996; Gibson 2001; Borooah 2002)

4.3 Mother's education

Maternal education, which is related to household wealth, is a determinant of good child-care knowledge and practices. The education attainment of mothers is mostly significant in the analysis of LVM.

The results with two indicators are quite similar to the results with three indicators with regard to this variable. This result supports the suggestion that an educated mother assumes the responsibility of taking a sick child to receive health care. Further, the time that mothers spend discussing their child's illness with a doctor is almost directly proportional to their level of education: consequently, illiterate women (with sick children) get much less out of visiting a doctor than literate women do. These findings are consistent with many studies in the context of developing countries (Africa Nutrition chartbooks 1996, Borooah 2002), which reported that maternal education has a strong and significant effect on stunting. They found that at primary levels of education,, effects on stunting are small or negligible, and they increase only at secondary or higher levels.(Chartbooks 1996; Borooah 2002).

4.4 Working mothers

Work has a non significant effect on the malnutrition status of children in Nigeria. The results are consistent with some previous studies and not consistent with others. Some studies reported that when mothers are working, the household income is increased and the access to better food will be increased, as well as the access to a quality level of medical care. On the other hand, when mothers are employed outside the home, the duration of full breastfeeding is shortened and necessitates supplementary feeding. This is usually preformed by illiterate care-takers, which might affect the health of children negatively.

4.5 Drinking water

A household's source of drinking water has been shown to be associated with the nutritional status of a child in Nigeria (*weight-for-age*) in separate analysis (Khatab, 2007), and it seems to be mostly significant in the results of LVM. In other words, the source of water is associated with the nutritional status of a child through its impact on the risk of childhood diseases such as diarrhea, and is affected indirectly as a measure of wealth and availability of water.

4.6 Access to toilet

The type of toilet used by a household is an indicator of household wealth and a determinant of environmental sanitation. This means that poor households, which are mostly located in rural areas, are less likely to have sanitary toilet facilities. Consequently, this results in an increased risk of childhood diseases, which contributes to malnutrition.
The results indicate that in households where a flush toilet exits, stunting and underweight (separate analysis) are significantly lower and the nutritional status of children (analysis with LVM) is better.

4.7 Availability of electricity and radio in household

Despite access to electricity and radio, which facilitates the acquisition of nutritional information allowing more successful allocation of resources to produce child health (Kandala, 2001), only the availability of electricity was significant and had a positive effect on reducing stunting, and underweight with separate analysis, and it seems to be significant on the LVM "nutritional status". This may be because mothers allocate their leisure time to radio or television, but it doesn't help improve the level of nutrition of their children. At the same time, it reduces the length of time spent engaging in their children's affairs.(Kandala 2001)

4.8 Antenatal visits

The variables that deal with access to health care, such as children of mothers who obtained clinical visits during pregnancy and had vaccines and treatment, have a positive and significant effect on malnutrition status. Therefore, health service investments are more effective in reducing stunting, wasting and underweight among indigenous communities. Our results indicate that children of mothers who had clinical visits and got medical care during pregnancy are less likely to be stunted and to be underweight than their counterparts in Nigeria. The results with two indicators also indicate that the *anvis* has a positive effect.

4.9 Child's age

In the analysis, it was discovered that the situation among children who are stunted is quite similar; however, the deterioration in nutritional status is set between 5-20 months of age.

Similarly, deterioration in child's *weight-for-height* sets during the first 4-5 months of age, as reported in much of the literature, is due to supplementation. However, it reaches its minimum level between ages 13 and 15 months, then rises again and reaches its minimum level between 16 and18 months of age; which is earlier than the case of stunting. A sudden pick-up effect is noticeable from age 18 months until about 45 months, where it attains its maximum level.

An improvement commenced after age 20 or 25 months and rose gradually until age 50 months. Previous studies assumed that it is an average effect of low *height-for-age* and *weight-for-height* during this period of life (Adebayo, 2003)

The level of wasting suggests that insufficient food intake may be an important factor in the rise of malnutrition in both countries. In addition, the implication of this finding is that wasting is not clearly noticeable in the first four months of life. As soon as a child is fed with other supplementation such as liquids or other forms of diet, which due to the unhygienic source of preparation of such supplementation, may facilitate infections and diseases such as diarrhoea, then acute malnutrition may set in.

4.10 Mother's BMI

A mother's nutritional status affects her ability to successfully carry, deliver, and care for her children and is of great concern in its own right. The BMI pattern shows linear trends with positive slopes. Malnutrition in women is assessed using BMI. When the BMI of non-pregnant women falls below the suggested cut-off point, which is around $18{:}5kg/m2$, malnutrition is indicated. Women who are malnourished (thinness or obesity) may have complications during childbirth and may deliver a child who can be wasted, stunted or underweight. The results indicate that there is an association between the thinness of the mother and the nutritional status of the child.

4.11 Mother's age at birth

The results show that the influence of mothers who are younger than 20 years is higher on the nutritional status of children.

A possible cause for this is childbirth among very young girls, whose bodies are not physically ready to endure the processes of childbirth. The problem is compounded by the fact that some African countries have poor obstetric care. Furthermore, these mothers could not reach health facilities, or, when they do, it is too late. Effective ways must be devised to delay age at first marriage and first birth. These two factors will almost certainly determine the number of children she will have in her lifetime. While early age at first birth has health implications, it also has economic implications.

In addition, one study obtained in Nigeria reported that younger mothers (teenagers) are less likely in comparison to older mothers to breastfeed their children after birth, which means that the age of the mother at birth of a child influences whether the child will receive colostrum or not, which might affect the nutritional status of children (Adebayo and Fahrmeir 2005).

Moreover, previous studies which were obtained in some developing countries have shown that some African countries do not allow girls back to go back school after they give birth. As a consequence, a girl who drops out of school will continue the cycle of poverty(Alderman H 1997; Wasao; 1999).

4.12 Malnutrition in region

As reported in the 2003 NDHS, the trend in the nutritional status of Nigerian children has worsened with regard to stunting and wasting (from 36% in 1990 to 46% in 1999 for stunting and 11% in 1990 to 12% in 1999 for wasting). The results, based on our analysis, indicate that mostly districts in the northeast and southeast and northwest are more likely to be associated with *nutritional problems*, providing a more complete picture of the situation. The result also revealed striking regional variations, with the northeast, south and southeast in much worse situations in terms of stunting and underweight than the northwest and southwest For more information about the different states in Nigeria, see figure 5 . On the other hand, the children who live in the northwest part of the country are more likely to be wasted than their counterparts in other parts of the country. These regional and zonal disparities may reflect the contribution of other factors, such as socio-cultural conditions and morbidity of children, in determining the nutritional status of children under the age of five. The high prevalence of stunting observed in the 2003 NDHS survey is in the context of large-scale deepening poverty and household food insecurity. Severe rural poverty appears to be found in the southwest of Nigeria, in the north-center, and in the extreme northeast.
These results are consistent with some previous studies which discuss the relation between poverty and malnutrition as persistent problems in Nigeria.

4.13 Summary

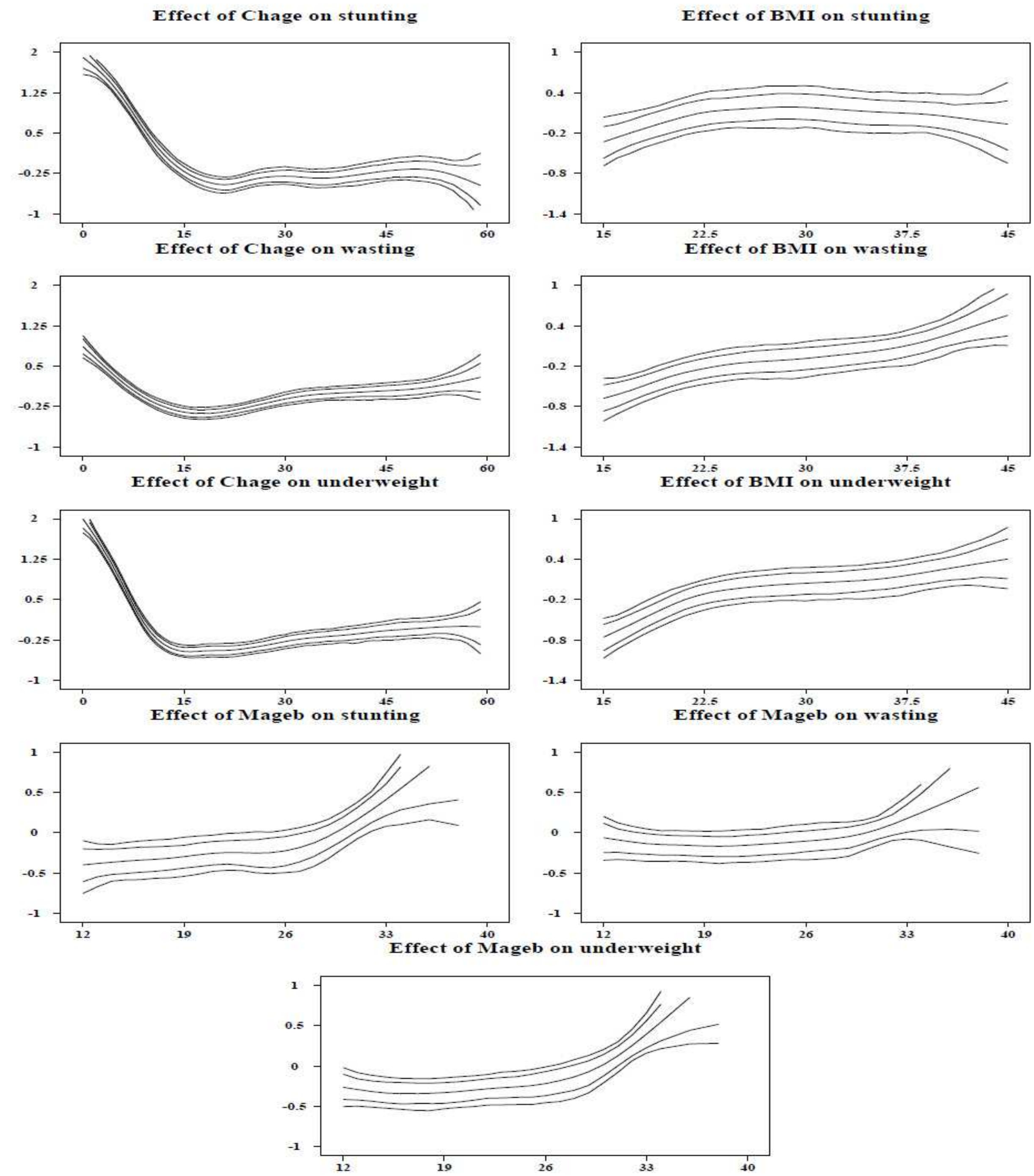
The results showed that the place of residence, mother's working, type of toilet and availability of electricity and radio in households have negligible effects on the undernutrition of children.
We find that the analysis identify the association of child's age, mother's age at birth and mother's BMI as effecting undernutrition. It was found that children are at a high risk during the first 15-20 months of life and that the risk rises again between ages 25-50 months. The effect of BMI on the child's nutritional status is approximately linear with positive slope, which means that there is an association between the thinness condition of mothers and nutritional status. According to the mother's age at birth, it shows that younger mothers are less likely to affect their children's nutritional status positively.
It is found that children living in some provinces in the southeast regions and some regions in the southern part of the country are associated with undernutrition.

4.14 Policy implications

Affected areas should improve socioeconomic conditions. Because, if living standards are improved, there will be better health care and a reduction in infant and child diseases, child malnutrition and child mortality.
The policymakers need to give more attention to some areas which have high rates of poverty, such as the southern part of Nigeria. These areas are more likely to have a higher proportion of undernutrition compared to other areas, due to poor health facilities and complications during childbirth or even carelessness and misdiagnosis during hospital care. Therefore, the most important issues to address in these areas are health care, proper food, and raising the educational level of parents.

5. Appendix

As presented in this paper, LVMs are based on the results of the separate models which were presented in Khatab, 2007. At that stage, we have used separate geoadditive probit models with the binary target variables for diarrhea, cough, and fever using covariate information from the 2003NDHS. The computations for the separate models were carried out using BayesX program (Brezger A, Kneib T, Lang S, 2005). We are showing here the results of Model 3, which was selected from a long hierarchal analysis based on its DIC (the value of deviance information criterion).



Source:Khatab, 2007

Fig. A1. Nonlinear effects of child's age, BMI, and Mother's age at birth using separate Bayesian Gaussian Model children for Nigeria using Bayesian latent variable model for continuous responses.

Variable	Mean	S.dv	10%	median	90%
const	–1.133*	0.154	-1.33	-1.133	-0.94
male	–0.117*	0.030	-0.156	-0.117	-0.077
urban	0.032	0.039	-0.020	0.032	0.083
work	0.027	0.033	-0.016	0.025	0.070
trepr	0.075*	0.039	0.026	0.074	0.128
anvis	0.147*	0.039	0.095	0.147	0.199
radio	0.017	0.037	-0.030	0.017	0.063
elect	0.131*	0.039	0.077	0.129	0.180
water	0.044	0.044	-0.008	0.043	0.106
educ	-0.543	0.943	-1.766	-0.509	0.606
toilet	0.078*	0.048	0.013	0.078	0.140

Table A1. Fixed effects of separate model using Bayesian geoadditive model on Stuniting

Variable	Mean	S.dv	10%	median	90%
const	–0.710*	0.121	-0.863	-0.718	-0.551
male	–0.032*	0.022	-0.061	-0.033	-0.004
urban	-0.022	0.030	-0.059	-0.023	0.016
work	0.044*	0.026	0.009	0.043	0.077
trepr	0.014	0.031	-0.027	0.014	0.053
anvis	0.079*	0.030	0.040	0.080	0.116
radio	0.035*	0.028	0.0007	0.034	0.072
elect	0.065*	0.029	0.024	0.067	0.101
water	0.046*	0.033	0.001	0.047	0.089
educ	0.063*	0.038	0.013	0.064	0.111
toilet	0.105*	0.044	0.051	0.106	0.159

Table A2. Fixed effects of separate model using Bayesian geoadditive model on underweight

Variable	Mean	S.dv	10%	median	90%
const	–0.041*	0.127	-0.214	-0.032	0.116
male	0.026	0.024	-0.005	0.025	0.058
urban	-0.051	0.030	-0.111	-0.050	0.006
work	0.049*	0.027	0.011	0.050	0.083
trepr	-0.046	0.034	-0.116	-0.045	0.022
anvis	-0.038	0.030	-0.076	-0.039	0.0004
radio	0.018	0.032	-0.023	0.020	0.060
elect	-0.019	0.031	-0.060	-0.019	0.020
water	0.028	0.036	-0.016	0.026	0.075
educ	0.030	0.041	-0.022	0.030	0.0847
toilet	0.0037	0.048	-0.055	0.0006	0.068

Table A3. Fixed effects of separate model using Bayesian geoadditive model on wasting

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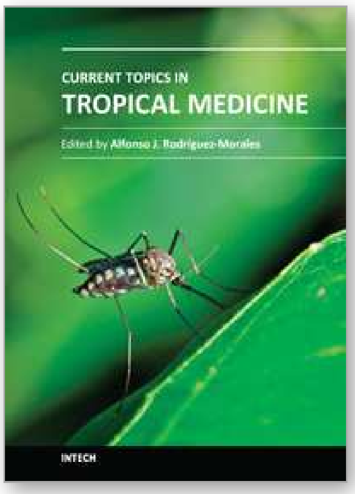

Current Topics in Tropical Medicine
Edited by Dr. Alfonso Rodriguez-Morales

ISBN 978-953-51-0274-8
Hard cover, 564 pages
Publisher InTech
Published online 16, March, 2012
Published in print edition March, 2012

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