Childhood malnutrition and its determinants among under-five children in Ghana: Multilevel Methods

Justice Moses K. Aheto, Thomas J. Keegan, Benjamin M. Taylor , Peter J. Diggle

Lancaster Medical School, Faculty of Health and Medicine, Lancaster University, United Kingdom

Correspondence

Justice Moses K. Aheto

Lancaster Medical School

Faculty of Health and Medicine

Lancaster University, Lancaster LA1 4YB, UK

E-mail: j.aheto@lancaster.ac.uk

Abstract

Background: Childhood malnutrition adversely affects short and long term health and economic wellbeing of children. Malnutrition is a global challenge and accounts for around 40% of under-five mortality in Ghana. Limited studies are available indicating determinants of malnutrition among children. This study investigates prevalence and determinants of malnutrition among children under-five with the aim of providing advice to policy makers and other stakeholders responsible for the health and nutrition of children.

Methods: The study used data from the 2008 Ghana Demographic and Health Survey (GDHS). Analyses were conducted on 2,083 children under-five years nested within 1,641 households with eligible anthropometric measurements, using multilevel regression analysis. Results from the multilevel models were used to compute probabilities of malnutrition.

Results: This study observed that 588 (28%), 276 (13%) and 176 (8%) of the children were moderately “stunted”, moderately “underweight” and moderately “wasted” respectively. Older ages are associated with increased risk of stunting and underweight. Longer breast feeding duration, multiple births, experience of diarrhoeal episodes, small size at birth, absence of toilet facilities in households, poor households, and mothers who are not covered by national health insurance are associated with increased risk of malnutrition. Increase in mother’s years of education and body mass index are associated with decreased malnutrition. Strong residual household-level variations in childhood nutritional outcomes were found.

Conclusion: Policies and intervention strategies aimed at improving childhood nutrition and health should address the risk factors identified and the need to search for additional risk factors that might account for the unexplained household-level variations.

Keywords: Epidemiology, Childhood malnutrition, Under-five children, Developing countries, Nutritional status, Multilevel modelling, Malnutrition determinants, Public health.

Introduction

Childhood malnutrition is a major public health issue. Not only does malnutrition bring with it illness and development issues for the children who suffer it but, along with poor sanitation and diseases such as malaria, it is an important cause of childhood mortality. Globally, about 30% of deaths among under-five children are attributable to malnutrition.[1] This percentage is higher in developing countries, at around 50%.[2] In Ghana, malnutrition accounts for around 40% of deaths in under-fives.[3-5]

Childhood malnutrition is the result of multiple factors. Environmental conditions, socio-economic circumstances and feeding practices are all important factors.[6, 7] The consequences of malnutrition in infants and young children are to limit and set back physical growth and neurological development, to lower intelligence quotient (IQ) and to increase susceptibility to disease.[8-13]

In Ghana, child mortality rates are stabilising[14], but malnutrition in children under 5 is still one of the major causes of death in children. While information on the prevalence of malnutrition in the country, and more widely the region, are known[3, 15] less has been published about the social, economic and environmental factors facing the residents of Ghana that may explain the country's relatively high rates of childhood malnutrition and, consequently, childhood and maternal mortality.

In this paper we aim to determine the major risk factors for childhood malnutrition in Ghana; particularly those individual and household characteristics indicated as risk factors for being malnourished under the age of 5 years.

The data we have used comes from the 2008 Ghana Demographic and Health Survey, which provide information on both children and the households in which they live. A specific aim of the paper is to apply multilevel modelling techniques to explore risk factors for malnutrition so that we can understand the impacts on malnutrition of children, both from factors that are specific to an individual, such as age, while recognising that some factors that affect individuals such as the amount of food available, are common to all members of a household.

Methods

Study population

This is a population-based cross-sectional study using data from the 2008 Ghana Demographic and Health Survey (GDHS).[15] The data were provided by the Ghana Statistical Service and contain information on maternal and child health, nutritional status of women and children, breastfeeding practices, fertility preferences, awareness and use of family planning methods, childhood mortality and domestic violence.

The GDHS survey methods are published elsewhere,[15] To summarise, representative samples of 12,323 households from 411 sampling units (communities) were selected nationwide. From these, 11,778 eligible households were interviewed, amongst which 5,175 and 6,603 were in urban and rural communities, respectively. Data were collected from 4,916 women aged 15-49 and 4,568 men aged 15-59. Data on 2,992 children from 1,000 and 1,992 urban and rural communities, respectively, were then generated from the sampled women during the main survey.[15]

756 children were excluded because of missing exposure data. A further 153 were excluded because their Z-scores were outside the range of biologically plausible values as determined by the World Health Organization (WHO).[16]

The analysis reported here was therefore based on 2,083 under-five children residing in 1,641 households and 400 communities across Ghana. Of these 1,641 households, 416 (25.4%) contained two or more under-five children.

Outcome variables

The primary outcome of interest was malnutrition among children under-five years of age. Malnutrition was determined using gender-specific Z-scores to obtain three WHO-derived indicators: height-for-age (HAZ), weight-for-age (WAZ) and weight-for-height (WHZ) Z-scores.[17] The Z-scores was calculated using the macro provided by WHO[16]. These measures were available for all 2,083 children in the final analysis.

The scales height-for-age (HAZ), weight-for-age (WAZ) and weight-for-height (WHZ) are also referred to as stunting, underweight and wasting, respectively. A child is categorised as malnourished on any of these scales if his/her Z-score is below minus two standard deviations from the median of the reference population.[17]

Explanatory variables

We included as potential explanatory variables those risk factors identified in the literature as significant predictors of under-five nutritional status in developing countries[6, 7, 18-21] together with additional variables that we considered to be related to the nutritional status and health of children, such as the national health insurance scheme (NHIS) status of the mother. Mothers who are covered by NHIS will be more likely to visit health facilities, thereby obtaining prescriptions and better health care when they are ill. We expect this to result in better nutrition and health outcomes for mothers and their children.

To arrive at the final set of included risk factors in our multilevel model, we used a backward elimination method.

Statistical analysis

We analysed the outcomes of interest to examine whether there were differences in the nutritional outcome of children by both individual and household level risk factors and whether or not children from different households exhibit different nutritional outcomes. To do this, we applied a random intercept multilevel regression model[22] to analyse our outcome variables on a continuous scale and obtained the parameter estimates in our model using maximum likelihood. Among competing covariance structures, the random intercept model with a within-group variance component provided a good fit to our data. Details of the model are shown in Equation 1 in the Supporting Information Appendix. The choice of multilevel regression analysis in this study is appropriate because we have data on individual children under-five nested within households. Not recognising the hierarchical structure of the data could lead to underestimation of the standard errors for the regression coefficients, which in turn would lead to spurious statistical significance and incorrect inference. We presented the description of the summary measure[23] of variance explained by households in WAZ, HAZ or WHZ among children in the Supporting Information Appendix S1 - Equation (4). We computed the probabilities of malnutrition among children as functions of their risk factors from the multilevel model (see Supporting Information Appendix S1 in Equation (3)). To examine the relationship between the probabilities of malnutrition (any of stunting, underweight and wasting) among children and the individual risk factors, the computed probabilities were plotted against each of the statistically significant risk factors for each of the three outcomes.

The statistical analysis was carried out using R.[24] For fitting the random intercept multilevel model, we used the R package 'nlme'. We used likelihood ratio tests (LRTs) to assess the significance of risk factor effects. To assess the significance of the household-level random effect, we divided the p-values from the LRT by two because the null hypothesis that $\sigma^2_H = 0$ is on the boundary of the parameter space.[25]

Results

Sample characteristics

In the data-set, 588 (28.2%), 276 (13.3%) and 176 (8.4%) of the children were moderately stunted, moderately underweight and moderately wasted, respectively (Table 1) based on the WHO classification for assessing severity of malnutrition by prevalence ranges among children under-five[26]. A total of 784 (38%) children had mothers with no formal education. All 2,083 children considered in the analysis received some amount of breast feeding, whilst 1,854 (89%) were breastfed for more than 6 months, amongst whom 1,038 (56%) belonged to poor households. The number of children who had experienced diarrhoea and fever episodes within two weeks of the survey were 456 (22%) and 444 (21%) respectively. A total of 973 (47%) children were not delivered at health care facilities (Table 1).

Risks factors associated with WAZ, HAZ and WHZ for multilevel models

Table 2 presents results of the multilevel modelling for the three measures of malnutrition WAZ (underweight), HAZ (stunting) and WHZ (wasting). Statistically significant risk factors for WAZ (underweight) were: older age; longer breast-feeding duration; multiple births; diarrhoea history; and small size at birth. Mother's BMI and years of education were positively associated with WAZ. A history of fever, no toilet facility in household, mothers without health insurance cover and mother's current age were not associated with a child's probabilities of being underweight.

Risk factors negatively associated with HAZ were: older ages of children; longer breast feeding; multiple births; small size at birth; poor household and mothers without health insurance cover. Mother's BMI and current age were positively associated with HAZ.

Factors associated with WHZ (wasting) were: a history of diarrhoea; small size at birth; and no toilet facility in household. Older ages of children and mother's BMI were also positively associated with WAZ. Longer breast-feeding, multiple births, fever history and mother's current age were not associated with wasting.

The results show significant residual household-level variation. Table 3 shows that 32%, 23%, and 20% of the variance in the nutritional outcome of children for WAZ, HAZ and WHZ respectively could be attributed to the residual household-level variations after adjusting for child and household covariates.

Probabilities of malnutrition for significant risk factors

We plotted the probabilities of stunting, underweight and wasting against the risk factors identified as statistically significant in the multilevel models presented in Table 2 (Figures 1 and 2). The probabilities of the three measures of malnutrition all decreased with increasing mother's BMI. Probabilities of stunting increased with child's age, conversely probabilities of wasting decreased with child's age. Increasing duration of breastfeeding was associated with an increase in risk of underweight and stunting. The risk of a child being underweight decreased with higher levels of mother's education but this was not seen when malnutrition was measured as stunting or wasting. Mother's age was a risk factor only for stunting.

The risk of underweight and stunting is higher among children who were products of multiple births compared to those who were singletons. Children who had diarrhoea were more at risk of underweight and wasting. The probabilities of underweight, stunting and wasting were higher among children born small in size at birth compared to those born average or large in size. Children from poor homes were more at risk of stunting compared to those from average or rich homes and children from mothers who were not covered by national health insurance had higher risk of stunting compared to those from mothers who had national health insurance. The probabilities of wasting increased among children from homes with no toilet facilities compared to those from homes with pit or flush toilet facilities.

Comment

We set out to investigate the determinants of childhood malnutrition in young children in Ghana. Our data on both individuals and their households allowed us to investigate both individual risk factors and those that stem from shared exposures by household. We also examined household-level random effects, which represent variation in household-level outcomes that cannot be explained by the available household-level covariates.

We found that out of the 2,083 children considered in the analysis, 588 (28%), 276 (13%) and 176 (8%) were moderately stunted, moderately underweight and moderately wasted respectively based on the WHO classification.[26] This evidence suggests that childhood malnutrition still remains a serious public health challenge in Ghana.

Individual child risk factors that were predictive of malnutrition were: child’s age; type of birth; child’s experience of diarrhoeal episodes; size of child at birth; and months of breast feeding. Household-level variables that were associated with malnutrition were: mother's education, current age, BMI and national health insurance status; household toilet facility ownership and wealth status.

We were particularly interested in the household-level variation in childhood malnutrition. Households constitute key determinants of socioeconomic disparities in health and general wellbeing of children as they influence each child's opportunities and, to some extent, govern exposure to risks and resources over the life course.[7, 20] This study has shown significant residual household-level variation in childhood nutrition, implying that nutritional outcomes of children vary across households in Ghana after adjusting for child and household characteristics. Our analysis shows that 32%, 23%, and 20% of the variation in the nutritional outcome of children for WAZ, HAZ and WHZ, respectively could be attributed to unobserved household-level factors. These could be social or environmental or both. For instance, the factors could be related to the location of the household and may indicate geographical differences in factors related to malnutrition in children.

The strengths of our study are that it is a large, population-based study with national coverage and good quality data on a number of child and household characteristics. The method we used, multilevel modelling, allowed the identification of household-level variation from presently unidentified factors.

The limitations of the study include the fact that, and it is known that wealth status is associated with malnutrition,[6, 20] it is difficult to directly measure household wealth status in Ghana. Because of this we used an asset-based index, which is generally considered a good proxy for household wealth status in developing countries. In addition we did not have complete data for all children for all variables, for example only 1,163 out of the 2,992 children in the main survey have measurements on their birthweight. To maximise the amount of data available for our analysis of birthweight, we used size of child at birth as perceived and reported by the mother as a proxy for birthweight. This variable is self-reported and could introduce reporting bias. We conducted a logistic regression analysis using size of child (coded as large/average=1, small=0 for the logistic regression analysis) as outcome and actual birth weight (kg) as covariate and found a strong, albeit imperfect, association. The estimated log-odds of large/average vs. small increased by 1.96 for every 1kg increase in actual birthweight. Expressed more tangibly, the probability of large/average self-reported birthweight increased from 0.14 at a birthweight of 1kg to 0.89 at a birthweight of 3kg (see Supporting Information Appendix S2).

Our study broadly supports those of previous research on malnutrition in developing countries. For example, children who were products of multiple births experienced more diarrhoeal episodes, and were smaller in size at birth, whilst children who were breast fed for longer duration had higher risks of malnutrition.[7, 19, 20, 27-31] The increase in risks of malnutrition among children who were products of multiple births could be the result of either low birth weight or competition for nutritional intake, which happens more among children who are products of multiple births than those of singletons.[20] The increase in risks of malnutrition observed among children who experienced diarrhoeal episodes could be due to the fact that diarrhoea normally results in wastage of food nutrients and loss of appetite.

The UN Food and Agriculture Organisation has reported that while breastfeeding in Ghana is common practice, only half of children under 6 months are exclusively breastfed, and complementary feeding practices are inadequate.[14] Our finding that probabilities of underweight and stunting increased among children who were breast fed for longer duration could be the result of poverty among households in Ghana; consequently, mothers may continue to breast feed beyond the recommended 6 months without supplementation.[32] In contrast, another study conducted in Jamaica reported a positive association between longer duration of breast feeding and child nutritional status.[33] This could suggest a difference in results between low-income and middle-income countries.

Except for wasting, our study observed that children's age is associated with higher malnutrition. The positive association of wasting (low height for age) with age before two years shows that children are not growing satisfactorily after cessation of breastfeeding. This could be the result of a deficit in proper complementary food and presence of progressive childhood diseases.[20, 21]

Babies small in size at birth were more likely to be malnourished. We looked at the the effect of the actual birthweight on the probability of being born large/average versus small in size at birth as reported by mother (using the children for whom we did have a birthweight) and found that the probability of a child being born large/average in size at birth increases with increasing actual birthweight (see Supporting Information Appendix S2). We also found that decreasing birthweight was associated with increased risk of malnutrition. This gives some justification for size at birth as a proxy for birthweight, and is consistent with previous findings that low birthweight is a risk factor for malnutrition in under-five children.[20, 29]

Children from mothers with high levels of education, older ages and higher BMI had decreased risks of malnutrition, while children from poor homes, with no toilet facilities and whose mothers have no national health insurance cover had increased risks of malnutrition. We were curious as to whether diarrhoea and toilet facilities are independent risk factors for malnutrition, or diarrhoea is an intermediate effect of lacking a toilet facility at home. In our analysis the association (results not shown) between diarrhoea and malnutrition was reduced but remained significantly raised when adjusted for toilet facilities at home. Toilet facilities in households have been documented in the literature as contributing to improved nutritional outcome of children and serving as a proxy for high socio-economic status in developing countries.[29]

The decrease in risks of malnutrition for children from households with mothers who were covered by the NHIS is likely to be because mothers who are covered are more likely to visit health facilities and to seek health care for them and their families, which should result in better health outcomes for mothers and their children.[34, 35] The increase in risk of malnutrition in children from poor households is likely to be because children from these households are more likely to have low quality and insufficient food intake, poorer living conditions, greater exposure to diseases and inadequate or complete lack of access to basic health services.[8, 11, 20, 27]

A decrease in malnutrition among children from mothers with high level of education suggests that improving mother's education will improve the level of child nutritional outcomes.[7, 18-20, 30] It has been shown that improvements in women's education bring many advantages to their lives and to society more generally.[20, 29] We also found that the risk of malnutrition increased as mothers' BMI decreased, especially once BMI was below approximately 20 kg/m^2. Maintaining improvement in education and adequate nutrition in mothers is important for preventing malnutrition in children.[13]

The findings from this study have key policy and intervention implications for improving childhood nutrition and health in Ghana and more widely. Public health measures should build on the work already done to implement WHO recommendations on exclusive breast feeding up to 6 months of age. Also, the need to feed infants with nutritionally adequate and safe complementary foods from six months of age together with continued breastfeeding up to age two or beyond must be emphasized. Additionally, countries should strive to provide free health care services for pregnant women, mothers and children under five years of age.

Addressing poverty is one important area that governments and non-governmental organizations (NGOs) responsible for health and nutrition of children should consider. Many of the environmental and social determinants of childhood malnutrition observed here are addressed by the UN Millennium Goals, e.g. eradication of poverty and hunger, gender equality and reduction of childhood mortality. Beyond economic redistribution, these could include subsidies for children's food and assistance for households in installing sanitary toilets in their homes to help improve the health and nutrition of young children. Better toilet facilities in homes will prevent the spread of infectious diseases, which negatively affect the health and nutrition of children. To increase levels of women's education more generally, governments such as Ghana's could make basic and secondary education more accessible, compulsory and affordable.

Our results show that there are unanswered questions about the reasons for variation in malnutrition associated with the house in which a child lives. We are undertaking research aimed at investigating the geographical predictors of malnutrition in Ghana. Results from that research may contribute useful information to the discussion about household effects. More research on household factors not measured in this study and their possible effects on malnutrition may also be warranted.

Conclusion

Policies and intervention strategies by policymakers that are aimed at improving nutrition and health of children should address the risk factors identified in this study. There is also a need to identify as-yet unidentified risk factors that might account for the unexplained household-level variations in child- hood nutritional outcomes.

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References

1. Black RE, Allen LH, Bhutta ZA, Caulfield LE, de Onis M, Ezzati M, et al. Maternal and child undernutrition: global and regional exposures and health consequences. Lancet 2008; 371: 243-260

2. WHO. *Handbook: Integrated Management of Childhood Illness (IMCI)*. Geneva: WHO, 2005. [last accessed August 2015] (http://apps.who.int/iris/bitstream/10665/42939/1/9241546441.pdf).

3. Antwi S. Malnutrition: missed opportunities for diagnosis. *Ghana Medical Journal.* 2008;4**2**:101-104.

4. ORC Macro. Nutrition of Young Children and Mothers in Ghana**:** Findings from the 2003 Ghana Demographic and Health Survey. Calverton, Maryland, USA: Africa Nutrition Chartbooks; 2005.

5. UNICEF-Ghana. Issues facing children in Ghana: UNICEF. 2008. [last accessed June 2014] (http://www.unicef.org/wcaro/Countries_1743.html).

6. Bomela NJ. Social, economic, health and environmental determinants of child nutritional status in three Central Asian Republics. *Public Health Nutrition* 2009;12:1871-1877.

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

8. The World Bank. *Repositioning Nutrition as Central to Development: A Strategy for Large-Scale Action*. Washington DC: The International Bank for Reconstruction and Development/The World Bank, 2006. [last accessed August 2014] (http://siteresources.worldbank.org/ NUTRITION/Resources/281846-1131636806329/ NutritionStrategyOverview.pdf).

9. Okoromah CA, Ekure EN, Lesi FE, Okunowo WO, Tijani BO, Okeiyi JC. Prevalence, profile and predictors of malnutrition in children with congenital heart defects: a case-control observational study. *Archives of Disease in Childhood* 2011; 96: 354-360.

10. UNICEF, WHO. The World Bank. Joint Child Malnutrition Estimates: Levels and Trends. Geneva: WHO, 2012. [last accessed April 2014] (http://www.who.int/nutgrowthdb/estimates/ en/).

11. de Onis M, Blössner M. The World Health Organization Global Database on Child Growth and Malnutrition: methodology and applications. *International Journal of Epidemiology* 2003; 32: 518-526

12. UNICEF. The State of the World's Children. New York: UNICEF, 2006. [last accessed February 2014] (http:// www.unicef.org/sowc06/pdfs/sowc06_fullreport.pdf).

13. The World Bank. *World Development Indicators*. Washington, DC: The International Bank for Reconstruction and Development/The World Bank; 2014. [last accessed May 2014] (http://data.worldbank.org/sites/default/files/wdi-2014-book.pdf).

14. Food and Agriculture Organization (FAO). *Nutrition Country Profiles*. Rome: FAO, United Nations, 2009. [last accessed May 2015] (http://www.fao.org/ag/AGN/nutrition/gha_ en.stm).

15. Ghana Statistical Service, Ghana Health Service, ICF Macro. *Ghana Demographic and Health Survey 2008*. Accra: GSS, GHS, ICF Macro, 2009. [last accessed March 2013] (http://dhsprogram.com/pubs/pdf/FR221/ FR221%5B13Aug2012%5D.pdf).

16. WHO. *WHO Anthro for Personal Computers, Version 3.2.2, 2011: Software for Assessing Growth and Development of the World's Children*. Geneva: WHO, 2010. [last accessed April 2013] (http://www.who.int/childgrowth/software/en/).

17. WHO Multicentre Growth Reference Study Group. *WHO Child Growth Standards: Length/Height-for-Age, Weight-for-Age, Weight-for-Length, Weight-for-Height and Body Mass Index-for-Age: Methods and Development*. Geneva: WHO, 2006. [last accessed April 2013] (http://www.who.int/childgrowth/standards/technical_report/en/).

18. Babatunde RO, Olagunju FI, Fakayode SB, Sola-Ojo FE. Prevalence and Determinants of Malnutrition among Under-five Children of Farming Households in Kwara State, Nigeria. *Journal of Agricultural Science.* 2011;3: 173-181.

19. Kabubo-Mariara J, Ndenge GK, Mwabu DK. Determinants of Children's Nutritional Status in Kenya: Evidence from Demographic and Health Surveys *Journal of African Economies.* 2009;18:363–387.

20. Adekanmbi VT, Kayode GA, Uthman OA. Individual and contextual factors associated with childhood stunting in Nigeria: a multilevel analysis. *Maternal and Child Nutrition* 2013; 9: 244-259.

21. Alom J, Quddus MA, Islam MA. Nutritional status of under-five children in Bangladesh: a multilevel analysis. *Journal Biosocial Science* 2012; 44: 525-535.

22. Goldstein H. *Multilevel Statistical Models.* 3rd ed. London: Arnold; 2003.

23. Steele F, Goldstein H, Rao C, Sinharay S. Multilevel Models in Psychometrics. *Psychometrics.* 2007;26:401-420.

24. R Core Team. *R: A language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing, 2014. [last accessed June 2014] (https://www.r-project.org/).

25. Self SG, Liang K-Y. Asymptotic properties of maximum likelihood estimators and likelihood-ratio tests under nonstandard conditions. *Journal of the American Statistical Association* 1987; 82:605–610.

26 de Onis M, Blössner M. *WHO Global Database on Child Growth and Malnutrition: Programme of Nutrition*. Geneva: WHO, 1997. [last accessed April 2013] (http://whqlibdoc.who.int/hq/1997/who_nut_97.4.pdf).

27. Uthman O. A multilevel analysis of the effect of household wealth inequality on under-five child under-nutrition: evidence from the 2003 Nigeria demographic and health survey. *The Internet Journal of Nutrition and Wellness* 2007; 6:1–8.

28. Hong R. Effect of multiple birth on infant mortality in Bangladesh. *Journal of Paediatrics and Child Health* 2006; 42: 630-635.

29. Madise N, Mpoma M. Child malnutrition and feeding practices in Malawi. *Food and Nutrition Bulletin.* 1997;18:190-201.

30. Griffiths P, Madise N, Whitworth A, Matthews Z. A tale of two continents: a multilevel comparison of the determinants of child nutritional status from selected African and Indian regions. *Health and Place.* 2004;10:183-199.

31. Mbago MC, Namfua PP. Some determinants of nutritional status of one- to four-year-old children in low income urban areas in Tanzania. *Journal of Tropical Pediatrics.* 1992;38:299-306.

32. Van de Poel E, Hosseinpoor AR, Speybroeck N, Van Ourti T, Vega J. Socioeconomic inequality in malnutrition in developing countries. *Bulletin of the World Health Organization* 2008; 86: 282-291.

33. Melville B, Williams M, Francis V, Lawrence O, Collins L. *Determinants of Childhood Malnutrition in Jamaica*. Vol. 10. Tokyo: Food and Nutrition Bulletin, 1988; pp. 43–48.

34. Mensah J, Oppong JR, Schmidt CM. Ghana's National Health Insurance Scheme in the context of the health MDGs: an empirical evaluation using propensity score matching. *Health Economics* 2010;19 Suppl:95-106.

35. Blanchet NJ, Fink G, Osei-Akoto I. The effect of Ghana's National Health Insurance Scheme on health care utilisation. *Ghana Medical Journal.* 2012;46:76-84.

Supporting Information

Additional Supporting information may be found in the online version of this article

Appendix S1. Supplementary material related to the random intercept multilevel regression model and computation of probabilities of malnutrition.

Appendix S2. Supplementary material relating to the logistic regression analysis of the association between self-reported birth size (large/average versus small) and actual birthweight.

Tables

Table 1 Percentage distribution of children under-five by selected background characteristics (n=2083)

Characteristics	n (%)	Characteristics	n (%)
Individual child level		Household wealth status	
Sex		Average/rich households	934 (44.8)
Male	1,045 (50.2)	Poor households	1,149 (55.2)
Female	1,038 (49.8)		
		Piped source of drinking water	666 (32.0)
Age (months)		Non-piped source of drinking water	1,417 (68.0)
<24	843 (40.5)		
24 or more	1,240 (59.5)	Flush/pit toilets facility in household	1,355 (65.0)
		No toilet facility in household	728 (35.0)
Still breast-feeding at the time of survey	801 (38.5)	Mothers without health insurance	1,232 (59.1)
Not breast-feeding	1,282 (61.5)	Mothers with health insurance	851 (40.9)
Type of birth			
Single birth	2,015 (96.7)	Mothers' BMI	
Multiple birth	68 (3.3)	BMI<18.5 kg/m^2 (underweight)	154 (7.4)
		BMI≥18.5 &<25 kg/m^2 (normal)	1,412 (67.8)
		BMI≥25.0 kg/m^2 (overweight)	515 (24.8)
Had diarrhoea	456 (21.9)		
No diarrhoea	1,627 (78.1)	Number of dead children	
		One or more	498 (23.9)
		None	1,585 (76.1)
Had fever	444 (21.3)		
No fever	1,639 (78.7)	Community characteristic	
		Rural	1,391 (66.8)
Small size at birth	304 (14.6)	Urban	692 (33.2)
Large/average size at birth	1,779 (85.4)		
Delivered at health care facility	1,110 (53.3)		
Not delivered at health care facility	973 (46.7)		
Stunted (HAZ below minus 2 SD)	588 (28.2)		
Underweight (WAZ below minus 2 SD)	276 (13.3)		
Wasted (WHZ below minus 2 SD)	176 (8.4)		
Maternal or household level			
Maternal education			
Secondary or higher	805 (38.7)		
Primary	494 (23.7)		
No formal education	784 (37.6)		

SD = standard deviations

Table 2 The effect estimate (β) for the associations between risk factors and child nutritional status (weight-for-age or WAZ (a measure from which underweight is derived), height-for-age or HAZ (a measure from which stunting is derived) and weight-for-height or WHZ (a measure from which wasting is derived) among under-five children in Ghana using random intercept multilevel regression models (n=2083).

	Parameter estimates		
Risk factors	WAZ (95% CI)	HAZ (95% CI)	WHZ (95% CI)
Child level			
Age in years	- 0.041 (-0.077, -0.005)	-0.169 (-0.217, -0.121)	0.125 (0.082, 0.168)
Months of breast feeding	- 0.015 (-0.021, -0.008)	-0.043 (-0.052, -0.034)	0.007 (0.000, 0.015)
Type of birth			
Single birth	1.000 (Reference)	1.000 (Reference)	1.000 (Reference)
Multiple birth	- 0.487 (-0.747, -0.227)	- 0.470 (-0.811, -0.130)	- 0.266 (-0.561, 0.028)
Diarrhoea			
No	1.000 (Reference)	-	1.000 (Reference)
Yes	- 0.148 (-0.253, -0.044)	-	-0.163 (-0.285, -0.041)
Fever			
No	1.000 (Reference)	-	1.000 (Reference)
Yes	- 0.094 (-0.199, 0.010)	-	-0.093(-0.215, 0.029)
Size of child at birth			
Large/average	1.000 (Reference)	1.000 (Reference)	1.000 (Reference)
Small	- 0.310 (-0.429,-0.191)	- 0.219 (-0.378, -0.060)	- 0.268 (-0.407, -0.129)
Maternal/ household			
Mother's body mass index	0.043 (0.032, 0.054)	0.034 (0.019, 0.049)	0.031 (0.018, 0.043)
Mothers' education (years)	0.014 (0.002, 0.025)	-	-
Household wealth status			
Rich or average	-	1.000 (Reference)	-
Poor	-	-0.164 (-0.291, -0.037)	-
Mothers' current age	0.005 (-0.002, 0.012)	0.021 (0.012, 0.030)	-0.007(-0.014, 0.001)
Type of toilet facility			
Flush or pit	1.000 (Reference)	-	1.000 (Reference)
No facility	- 0.099 (-0.203, 0.005)	-	-0.162 (-0.272, -0.052)
Number of dead siblings			
None	1.000 (Reference)	-	-
One or more	0.097 (-0.015, 0.209)	-	-
Mother has health insurance			
Yes	1.000 (Reference)	1.000 (Reference)	-
No	-0.090 (-0.183, 0.003)	-0.176 (-0.297, -0.055)	-

Table 3 Variance estimates with 95% confidence intervals for the random intercept multilevel regression models of weight-for-age or WAZ (a measure from which underweight is derived) , height-for-age or HAZ (a measure from which stunting is derived), and weight-for-height or WHZ (a measure from which wasting is derived) (n=2083).

	Variances		Intra-household correlation coefficients
Outcomes	Child (95% CI)	Household (95% CI)	Explained variation (%)[a]
WAZ	0.65 (0.58, 0.73)	0.31 (0.24, 0.40)	32
HAZ	1.31 (1.16, 1.47)	0.39 (0.26, 0.58)	23
WHZ	1.03 (0.91, 1.16)	0.25 (0.16, 0.40)	20

[a] Ratio of household-level variance to total variance multiplied by 100.

Figure 1. Plots showing probabilities of malnutrition for continuous risk factors, by malnutrition measure: a) Underweight (WAZ), b) Stunting (HAZ), c) Wasting (WHZ).
The solid and dotted lines respectively respresent the median values for the risk factors and their associated 95% confidence intervals.

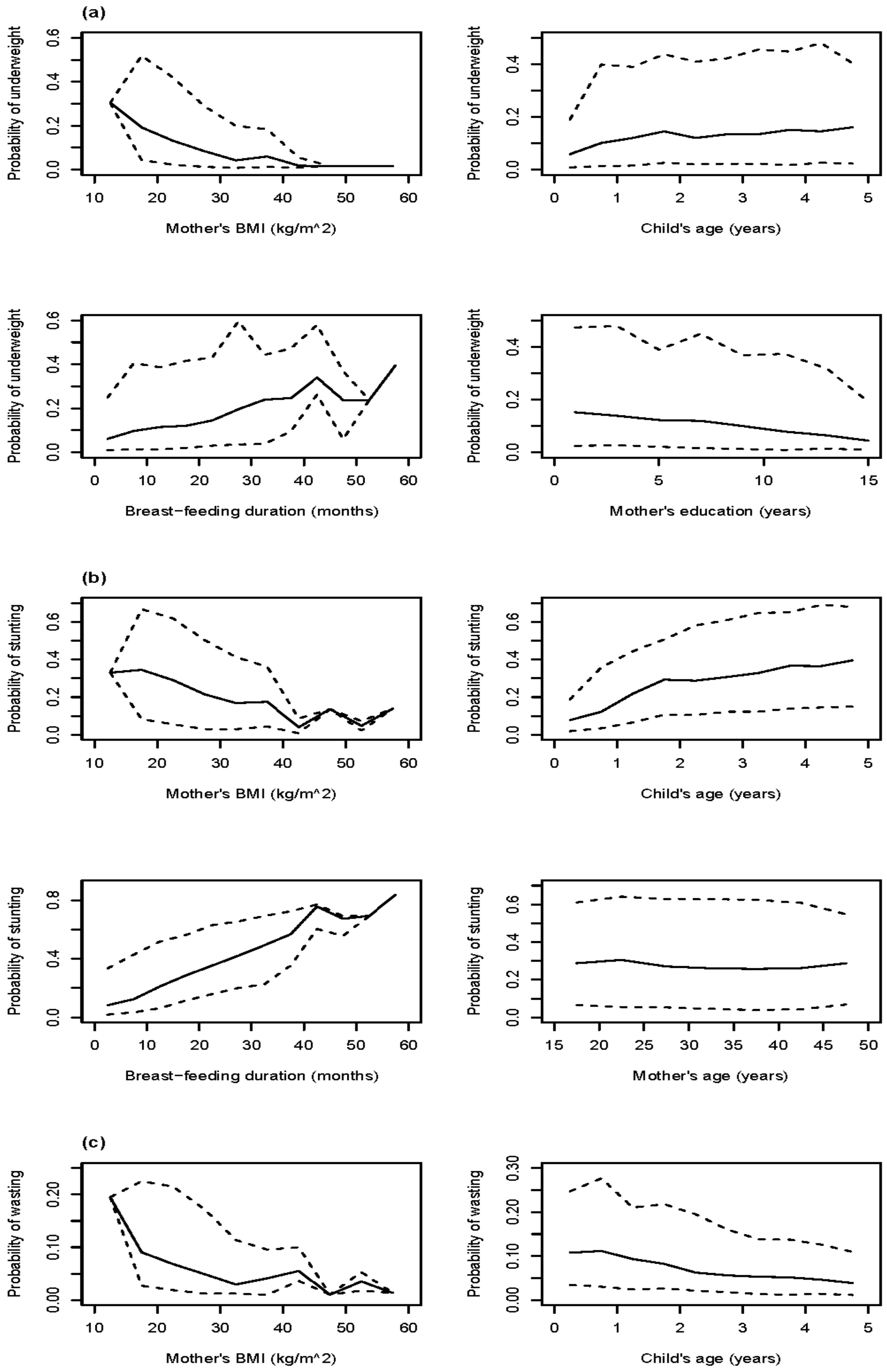
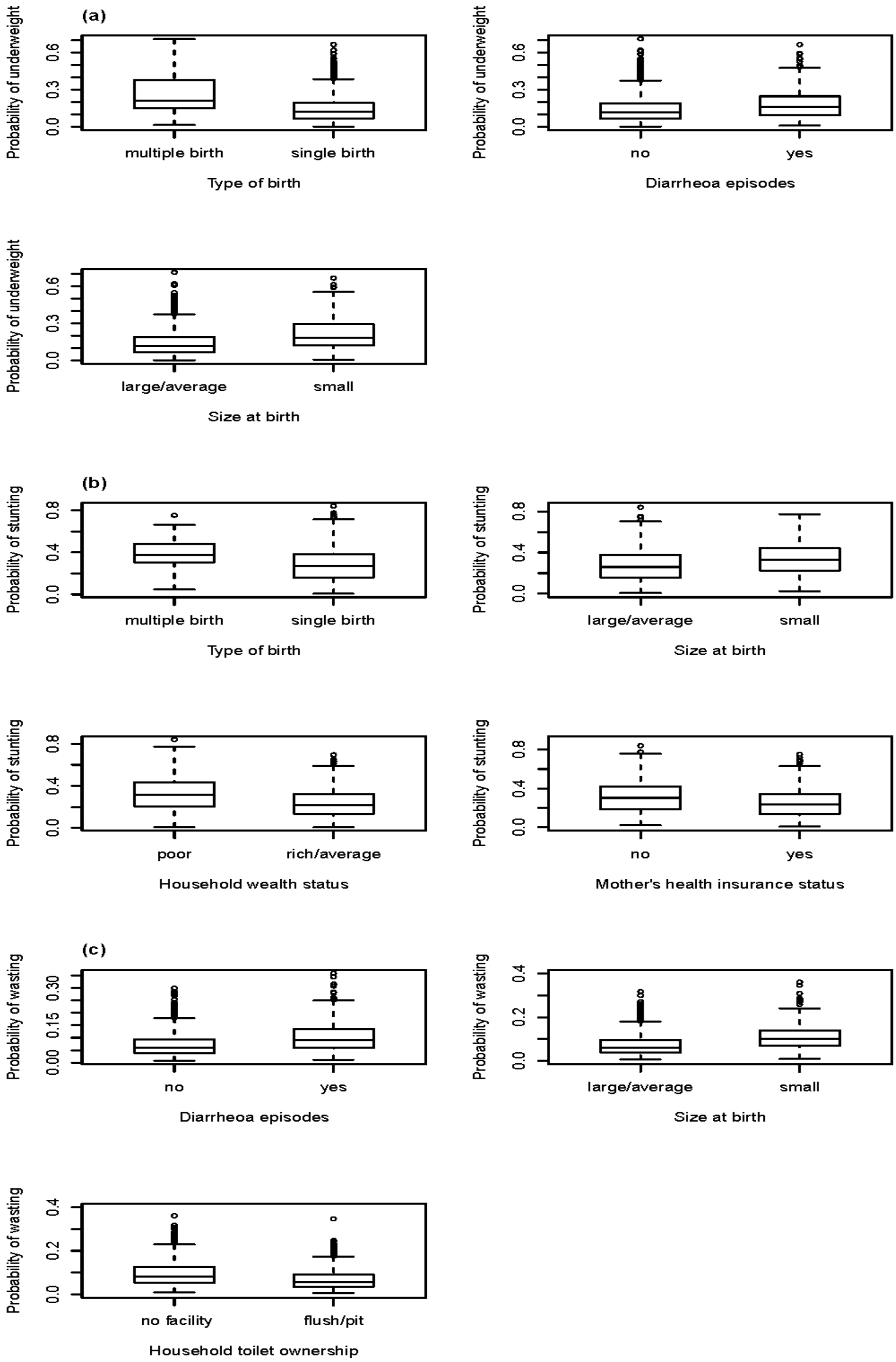


Figure 2. Box plots showing probabilities of malnutrition for categorical risk factors, by malnutrition measure: a) Underweight (WAZ), b) Stunting (HAZ), c) Wasting (WHZ).



Supporting Information Appendix S1

Our model is

$$Y_{ij} = x'_{ij}\beta + H_j + \varepsilon_{ij} \quad (1)$$

with $H_j \sim N(0, \sigma^2_H)$, and $\varepsilon_{ij} \sim N(0, \sigma^2_\varepsilon)$. Y_{ij} is the nutritional status on a continuous scale (WAZ, HAZ or WHZ) for child i in household *j*, β is a vector of regression coefficients, x_{ij} is a vector of risk factors at the child or household level, H_j is a random effect for the jth household and ε_{ij} is an individual-level residual.

We used maximum likelihood to obtain estimates $\hat{\beta}$, $\hat{\sigma}^2_H$, $\hat{\sigma}^2_\varepsilon$ of the parameters in (1), and computed the minimum mean square error predictors $\widehat{H}_j$ for each household j as the expectations of H_j conditional on the data and maximum likelihood parameter estimates .We are interested in predicting the nutritional status for a child i belonging to household j with the same covariate attributes as child i from that household i.e. x_{ij}. This ideally would involve computing [Y_{ij} | data], where the notation [.] means "the distribution of". This distribution is analytically intractable. However, $\hat{\sigma}^2_\varepsilon$ and $\hat{\sigma}^2_H$ are well estimated from the data, and we therefore use a "plug-in" approximation [Y_{ij} | data, $\hat{\sigma}^2_\varepsilon$, $\hat{\sigma}^2_H$]; in doing this, we are still able to take into account the uncertainty in the estimates of β and the predictors of the H_j. This is achieved as follows.

Our estimates of β and H_j are asymptotically Normal with means $\hat{\beta}$ and $\widehat{H}_j$ and variance equal to the inverse of the Fisher information. We replace the Fisher information by the observed information, denoted here by v_β and $\sigma^2_{H_j}$, and use the approximations [β|data] ~ N($\hat{\beta}, v_\beta$) and [H_j|data] ~ N($\widehat{H}_j, \sigma^2_{H_j}$). Using these approximations, the required distribution, [Y_{ij} | data, $\hat{\sigma}^2_\varepsilon$, $\hat{\sigma}^2_H$], becomes

$$[Y_{ij} |\, data,\, \hat{\sigma}^2_H,\, \hat{\sigma}^2_\varepsilon] = \iint [Y_{ij},\, H_j, \beta | \text{data}, \hat{\sigma}^2_H,\, \hat{\sigma}^2_\varepsilon]\, dH_j d\beta$$

$$= \iint [Y_{ij}|\ H_j, \beta, \hat{\sigma}_H^2, \hat{\sigma}_\varepsilon^2, data]\ [\ \beta, \hat{H}_j|\text{data}, \hat{\sigma}_H^2, \hat{\sigma}_\varepsilon^2]\ dH_j d\beta$$

$$= \iint [Y_{ij}|\ H_j, \beta, \hat{\sigma}_\varepsilon^2, \text{data}]\ \ [\ H_j|\text{data}\ ][\ \beta|\text{data}]\ dH_j d\beta \qquad (2)$$

The integrand in (2) invokes the further approximation of $[\ H_j|\text{data}, \hat{\sigma}_H^2, \hat{\sigma}_\varepsilon^2\ ]$ by $[\ H_j|\text{data}\ ]$. Re-writing (2) gives

$\iint N(Y_{ij}; x_{ij}'\beta\ + H_j,\ \hat{\sigma}_\varepsilon^2\ )\ \text{N}\left(H_j; \hat{H}_j, \sigma_{H_j}^2\right)\ \text{N}(\beta; \hat{\beta}, v_\beta) dH_j d\beta$. Integrating out H_j gives

$\int N(Y_{ij}; x_{ij}'\beta\ + \hat{H}_j,\ \hat{\sigma}_\varepsilon^2 +\ \sigma_{H_j}^2)\ \text{N}(\beta; \hat{\beta}, v_\beta) d\beta$. Integrating out β then gives

$$[Y_{ij}|\ data,\ \hat{\sigma}_H^2,\ \hat{\sigma}_\varepsilon^2] =\ \text{N}(x_{ij}'\hat{\beta}\ + \hat{H}_j, \hat{\sigma}_\varepsilon^2 +\ \sigma_{\hat{H}_j}^2 +\ x_{ij} v_\beta x_{ij}')$$

We therefore compute the probability of malnutrition as

$$P\left(Y_{ij} < -2\middle|\hat{\beta}, \hat{H}_j, \hat{\sigma}_\varepsilon\right) =\ \phi\left(\frac{-2 - x_{ij}'\hat{\beta} -\ \hat{H}_j}{\sqrt{\left(\ \hat{\sigma}_\varepsilon^2 + \hat{\sigma}_{\hat{H}_j}^2 +\ x_{ij} v_{\hat{\beta}} x_{ij}'\right)}}\right), \qquad (3)$$

where ϕ denotes the standard Normal cumulative distribution function.

Recall that a value below -2 in the standardised Z-score Y_{ij} is the standard reference for declaring a child as malnourished.

The individual child and household-level variances σ^2_ε and σ^2_H respectively obtained from our multilevel model are used as a summary measure of the degree of similarity between WAZ, HAZ or WHZ in children within the same household. We presented the measure of variance explained by household as the household level variance (σ^2_H) expressed as a percentage of the total variance ($\sigma^2_\varepsilon + \sigma^2_H$) from the model. Thus,

$$\rho_H = \{\sigma_H^2/(\sigma_H^2 +\ \sigma_\varepsilon^2)\} \times 100, \qquad (4)$$

Supporting Information Appendix S2

Table 4 the effect estimate (β) for the associations between size of child at birth (outcome variable) and actual birthweight from logistic regression model (n=830*).

	Parameter Estimate (β)	Standard Error	P-value
Intercept	-3.75	0.67	2.14×10^{-8}
Actual birthweight (kg)	1.96	0.24	2.32×10^{-16}

*In the logistic regression, we could not use all the 1,163 children with actual birthweight as reported in the study limitation due to incomplete data on size of child at birth as perceived by the mother.

Figure 3 Probability plot of being born large/average versus small in size at birth against actual birthweight