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Small Area Estimation for Policy Development: A Case Study of Child Undernutrition in Ghana

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SUMMARY

The demand for Small (local-level) Area Statistics has increased tremendously, particularly in countries where a decentralised approach to governance and service provision has been adopted. Most of these countries lack local-level statistics to aid policy decisions and planning. Sample surveys such as the Demographic and Health Survey provide a wide range of invaluable data at the national and regional level but cannot be used directly to produce reliable district-level estimates due to small sample sizes. This paper illustrates the application of Small Area Estimation (SAE) techniques to derive model-based district-level estimates of child undernutrition in Ghana linking data from the 2003 Ghana Demographic and Health Survey (GDHS) and the 2000 Ghana Population and Housing Census (GPHC). The diagnostics measures show that the model-based estimates are robust when compared to the direct survey estimates. The model-based estimates reveal considerable heterogeneity in the prevalence of undernutrition, with children living in the Northern part of the country being most disadvantaged. The estimates clearly highlight the districts where targeted child health interventions need to be strengthened. In countries where small area statistics are non-existent, SAE techniques could be crucial for designing effective policies and strengthening local-level governance.

Keywords : Small area estimation, Child undernutrition, Ghana, Demographic and Health Survey, Population and Housing Census, Policy, Stunting, Underweight.

1. INTRODUCTION

In the past four decades, there has been extensive methodological development in the field of Small Area Estimation (SAE) techniques; in parallel with increasing demand for small area statistics, particularly in countries where local level statistics are almost non-existent. This has been the case as most countries of the world (both developed and developing) have adopted a decentralised approach to governance for effective health care delivery and other social services. In this regard, local-level statistics have become increasingly important in policy decisions, resource allocation, monitoring of programmes and evaluation of initiatives. Nonetheless, despite the methodological development in the field of SAE, its application in demography and health research has been very limited, particularly in data scarce regions.

In many of these regions, small area statistics are only available for those indicators that can be derived directly from Census which provide limited information on socioeconomic and population indicators. Health care indicators such as child undernutrition are not

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covered in the Census. Nonetheless, cross-sectional surveys, such as the Demographic and Health Surveys (DHS), are more regular and collect substantial amount of nationally representative data on these indicators. However, they cannot be used to derive reliable direct estimates at the local-level due to small sample sizes, which lead to high levels of sampling variability (Rao 2003; Pfeffermann 2002). SAE techniques have been used to understand the local area distribution of diseases, food production and poverty incidence (Demombynes *et al*. 2007; Elbers *et al*. 2003; Datta *et al*. 2000), but have received little attention in population and health research particularly in regions where it is urgently needed, for example sub-Saharan Africa.

In Ghana, where a decentralised approach to health care provision is adopted (Bossert and Beauvais 2002), the availability of district level estimates of demographic and health indicators could be crucial for designing and targeting interventions. The 2003 GDHS reported that 29.9% and 22.1% of children in Ghana were stunted and underweight, respectively. At the regional level the prevalence of stunting and underweight varies from 13.9% to 48.8% and 11.5% to 35.5% in the Greater Accra Region and Northern Region respectively. At the district level, where health policies and programmes are enacted, implemented and evaluated, in conformity with the 1996 Ghana Health Service and Teaching Hospitals Act (Mayhew 2003; Bossert and Beauvais 2002), estimates of stunting and underweight are unavailable.

The Millennium Development Goals (MDGs) which has been the yardstick for measuring development targets set by member countries of the United Nations (to be achieved by 2015), strongly affirms the importance of child nutrition (Goal 1) and survival (Goal 4). An evaluation of the MDGs shows that countries not on track to reaching the health related MDGs also lack local-level statistics of key demographic and health indicators (UN 2009). In this study we adopt a Generalised Linear Mixed Model (GLMM) approach (Amoako Johnson *et al*. 2010) to derive district level estimates of child undernutrition in Ghana, defined in terms of the proportion of children stunted and underweight, linking data from the 2003 Ghana Demographic and Health Survey (GDHS) and 2000 Ghana Population and Housing Census (GPHC).

2. DATA

The data for the analysis are drawn from the 2003 GDHS (covers 2927 children born during the five years preceding the survey) and 2000 GPHC. In deriving small areas estimates, two types of variables are required – the dependent (or target) variable which is derived from the GDHS and for which small area estimates are required and the auxiliary (covariates) variables known for the entire population, which in this case are drawn from the GPHC. The target variable of interest is the proportion of children aged 0-59 months who are (1) stunted and (2) underweight. Stunting or low height-for-age is measured as children below minus two standard deviations (SD) from the median height-for-age of the reference population [The assignment of z-scores are based on the National Centre for Health Statistics/ Centres for Disease Control and Prevention/ World Health Organisation International Reference Standard which is done through a complicated interpolation function accounting for age and sex (de Onis and Blossner 1997)]. This is a measure of chronic nutritional deficiency. The effects of stunting are largely irreversible and include delayed motor development, impaired cognitive function and poor school performance. Underweight or low weight-for-age is measured as below minus two SD from the median weight-for-age of the reference population. It indicates both acute and chronic malnutrition resulting mainly from acute starvation and or disease and is a strong predictor of child death. Children with height-for-age or weight-for-age z-score of below minus six SD or above plus six SD are flagged as having invalid data and are therefore excluded from this analysis. [http://www.measuredhs.com/help/Datasets Children_s_Nutritional_Status.htm (date accessed 11.05.2011)]. At the district level, the sample size for estimating stunting varies from 1 to 47 with an average of 11, while that for underweight ranges from 1 to 51 with an average of 8.

The covariates derived from the 2000 GPHC include district-level data on population density, urban population, sex ratio, total fertility rate, region of residence. In addition, a covariate that indicates road density [Source: Department of Feeder Roads, Government of Ghana, 2000]. measured in terms of kilometre of road per square kilometre of the land area is used. Using Principal Component Analyses (PCA) two composite scores are derived: (1) socioeconomic development based on literacy rate, employment rate, educational levels, and employment in different sectors of the economy and (2) access to health care services based on information of the distance to the nearest traditional health facility, hospital and clinic. In each case, the first principal component was selected for the analysis. The methodology explaining the construction of scores is explained elsewhere (Amoako Johnson *et al*. 2010). The 2000 GPHC listing of Enumeration Areas provided the sample frame of Primary Sample Units (PSUs) for the 2003 GDHS. PSUs were sampled from all the 110 districts. The districts in this study refer to the 110 districts created during the political decentralisation of Ghana in 1988 and adopted for the 2000 Ghana Population and Housing Census and 2003 Ghana Demographic and Health Survey of Ghana. Since the 2000 GPHC was the sample frame for the 2003 GDHS, the matching of survey information to the census covariates at the district level was straightforward.

3. METHOD

We used a special case of the Generalized Linear Mixed Model (GLMM) with logit link function (Breslow and Clayton 1993) which Saei and Chambers (2003) described in the context of small area estimation. Generalized linear mixed models (GLMM) are an extension to the classic GLM containing both fixed and random effects. They can account for dependence between observations imposed by the structure of the data, i.e. clustered or repeated. For such data, random cluster effects can be added into the regression analysis to account for the dependence between observations. The reader is referred to Agresti *et al*. (2000), Fahrmeir and Tutz (2001) and McCulloch and Searle (2001) for detailed discussions and applications of GLMM. As with a standard GLM, the link functions usually adopted for binary or binomial data are the logit and probit (Pendergast *et al*. 1996).

Note that in this study, the covariates are available at area (or district) level. In such circumstances, SAE is carried out under area level and not at the individual level (see Rao 2003). This model relates small area direct survey estimates to area-specific covariates. The SAE under this model is one of the most popular methods because of its flexibility in combining different sources of information and explaining different sources of errors. Such model was first used by Fay and Herriot (1979) for the prediction of mean per-capita income in small geographic areas (less than 500 persons) within counties in the United States. The Fay and Herriot method for SAE is based on the area level linear mixed model and their approach is applicable to continuous outcome variables. However, in our analysis the target variable is binary. It is important to note that the Fay and Herriot model is not applicable in this case.

In contrast, GLMM with a logit link function (Breslow and Clayton 1993) which is suitable for discrete variables (particularly binary variables) is applied. Alternative approaches to estimating the logistic model in the small area estimation case include empirical Bayes and hierarchical Bayes approaches (Rao 2003). We have not considered these options; instead we have applied a special case of GLMM with logit link function due to the binomial nature of the outcome variable. Details of the methodology are reported in Amoako Johnson *et al*. (2010).

4. DIAGNOSTIC MEASURES

We implemented two types of diagnostics to validate the reliability of the model-based estimates- the model diagnostics (used to verify if the model assumptions are satisfied) and the diagnostics for the small area estimates which are described below.

4.1 Model Diagnostics

Under the logit link function, the district level random effects were assumed to have a normal distribution with mean zero and fixed variance (Goldstein 1995). If the model assumptions are satisfied then the area (district) level residuals are expected to be randomly distributed and not significantly different from the regression line $y = 0$. Fig. 1(A) shows the distribution of the district level residuals. The figure shows that the district level residuals are randomly distributed and the line of fit do not significantly differ from the line $y = 0$ as expected. The Q-Q plots

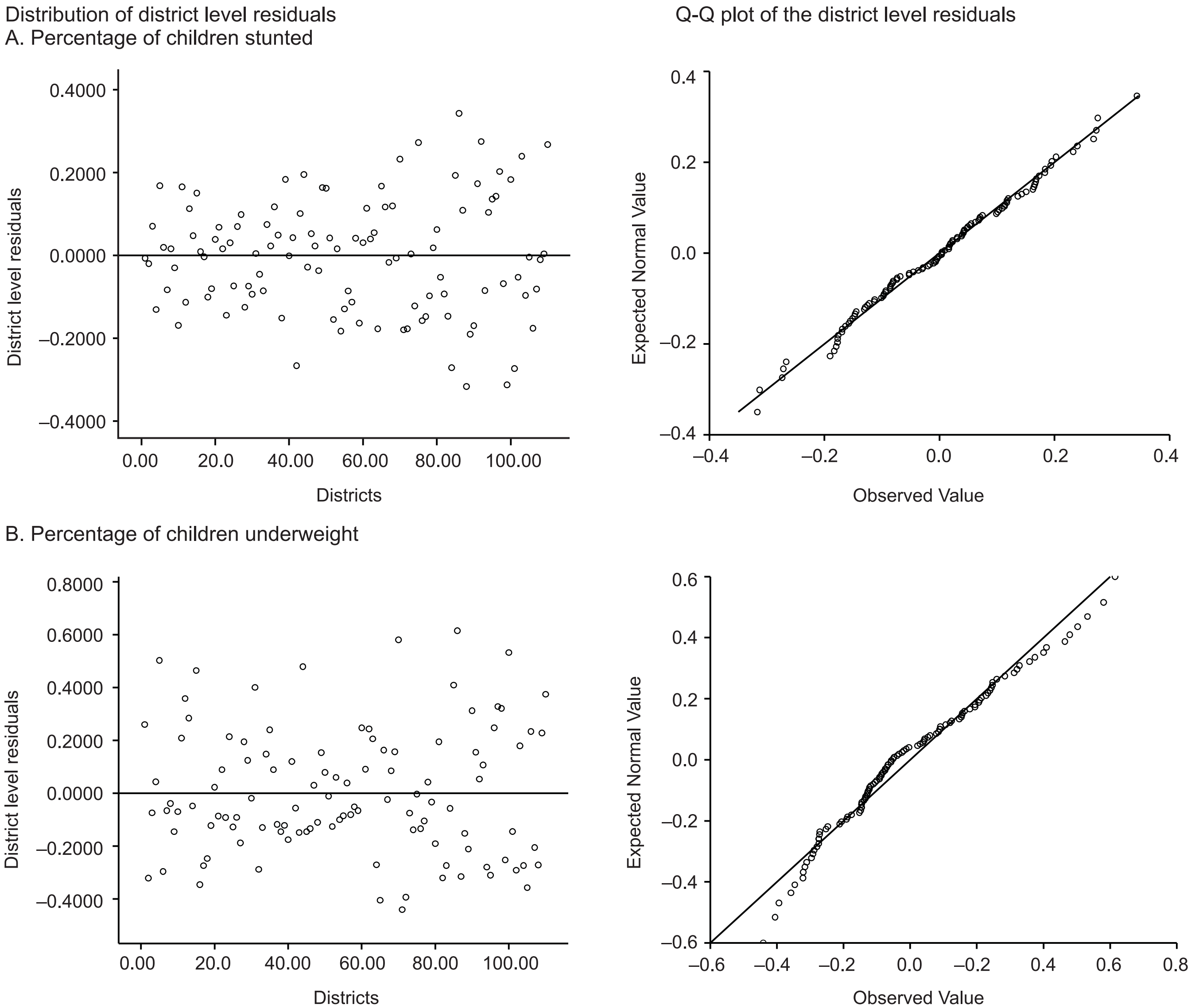

Fig. 1. Model diagnostics

(Fig. 1B) confirm that the normality assumption is reasonably well approximated.

4.2 Diagnostics for Small Area Estimates

The diagnostic measures for the small area (district-level) estimates are conducted to validate the reliability of estimates generated under the model. We used the bias diagnostics, the coefficient of variation and the 95% Confidence Intervals (CIs) of the model-based and direct survey estimates to investigate the robustness of the model-based estimates relative to the direct survey estimates. The bias diagnostics are used to investigate if the model-based estimates are less extreme when compared to the direct survey estimates. Fig. 2 shows that the model-based estimates are less extreme when compared with the direct survey estimates. It demonstrates the typical SAE outcome of shrinking more extreme values towards the mean.

Further validation of the model-based estimates was conducted by computing the coefficient of variation (CV) to assess the improved precision of the model-based estimates when compared to the direct survey estimates – this shows the sampling variability as a percentage of the estimate. Estimates with large CVs are considered unreliable. Although there are no internationally accepted gold standard to judge what is 'too large', the estimated CVs (Fig. 3) show that the model-based estimates have a higher degree of reliability than the direct survey estimates.

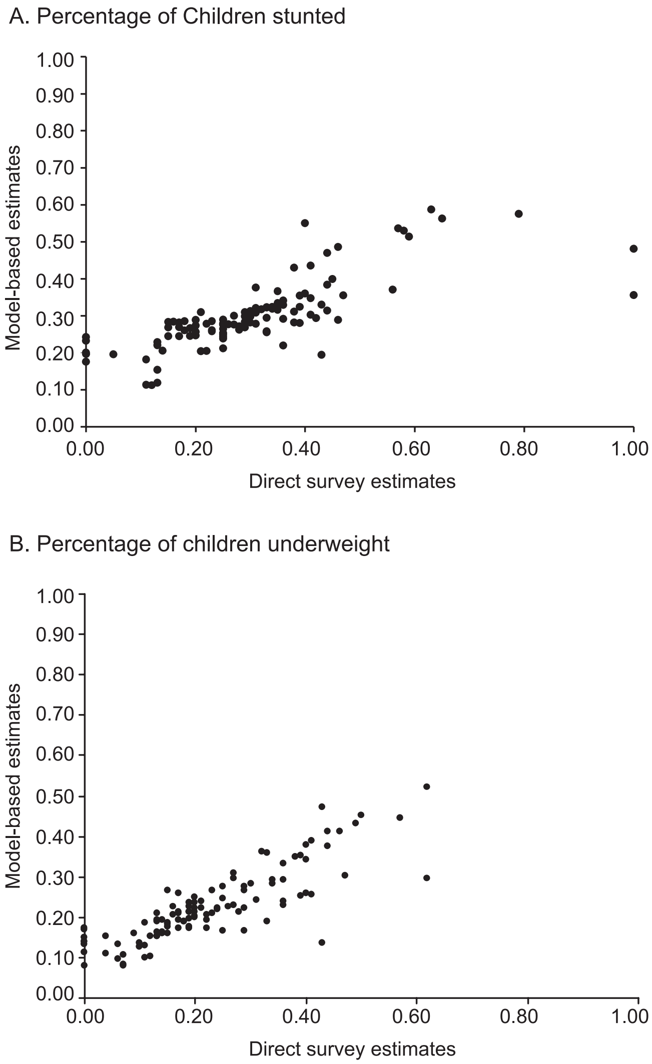

Fig. 2. Bias diagnostic plots

We have also computed approximate CIs for the direct survey estimates assuming that a simple random sample generated the weighted proportions. This ignores the effects of differential weighting and clustering within districts that would further inflate the true standard errors of the direct estimates. The 95% CIs for the model-based and direct survey estimates are shown in Appendix I and II. The estimated 95% CIs for the direct survey estimates indicate that their standard errors are too large and hence unreliable.

5. DISTRICT-LEVEL ESTIMATES OF STUNTING AND UNDERWEIGHT

The diagnostic measures discussed in the previous section confirm reasonably good precision of the model-based estimates compared to the direct survey estimates. For ease of understanding, we present the results in terms of percentages and not proportions. The model-based estimates are categorised to show the top and bottom 10% of districts with the highest and lowest child undernutrition and the remaining categorised into quintiles (Fig. 4). The regional level direct survey estimates are also mapped alongside the model-based estimates to show how national and regional estimates mask district level variations (Fig. 4). A comparison of the district-level model-based estimates and the regional level direct survey estimates confirm this assertion (Fig. 4). Hence, using regional estimates as the bases for local-level policy decisions, resource allocation and monitoring and evaluation of programmes could be ambiguous. Moreover, relying on national and regional estimates as markers for assessing progress towards the MDGs could overlook a large number of local areas lagging behind within a country.

The estimates show a high degree of variation in child undernutrition at the district level. The prevalence of stunting ranges from 11.2% in the Accra Metropolitan Assembly of the Greater Accra Region to 58.7% in the Bole District of the Northern Region, while underweight ranges from 7.9% in the Tema Municipal Authority of the Grater Accra Region to 52.2% in the Ketu District of the Volta Region. With regard to stunting, it is evident from the estimates that all districts in Ghana have rates higher than the World Health Organisation (WHO) intervention threshold of 10% and only three districts (Accra Metropolitan Assembly, Ga District and the Tema Metropolitan Assembly) have rates below the emergency threshold of 15% (Guerrier *et al*. 2009; Grobler-Tanner 2006) (See Appendix I). Only 4.5% of the districts have underweight rates below the intervention threshold and 14.5% below the emergency threshold (See Appendix II). These estimates indicate that not all districts of Ghana will reach the Millennium Development Goals by 2015.

The estimates show that stunting and underweight are critical in the northern part of the country, particularly within the Northern Region where stunting ranges from 35.4% in the Tamale Metropolitan Assembly to 58.7% in the Bole District and underweight varies from 26.5% in the Savelugu-Nanton District to 47.2% in the West Gonja District. This clearly suggests that a high proportion of children across the districts of the Northern region suffer from

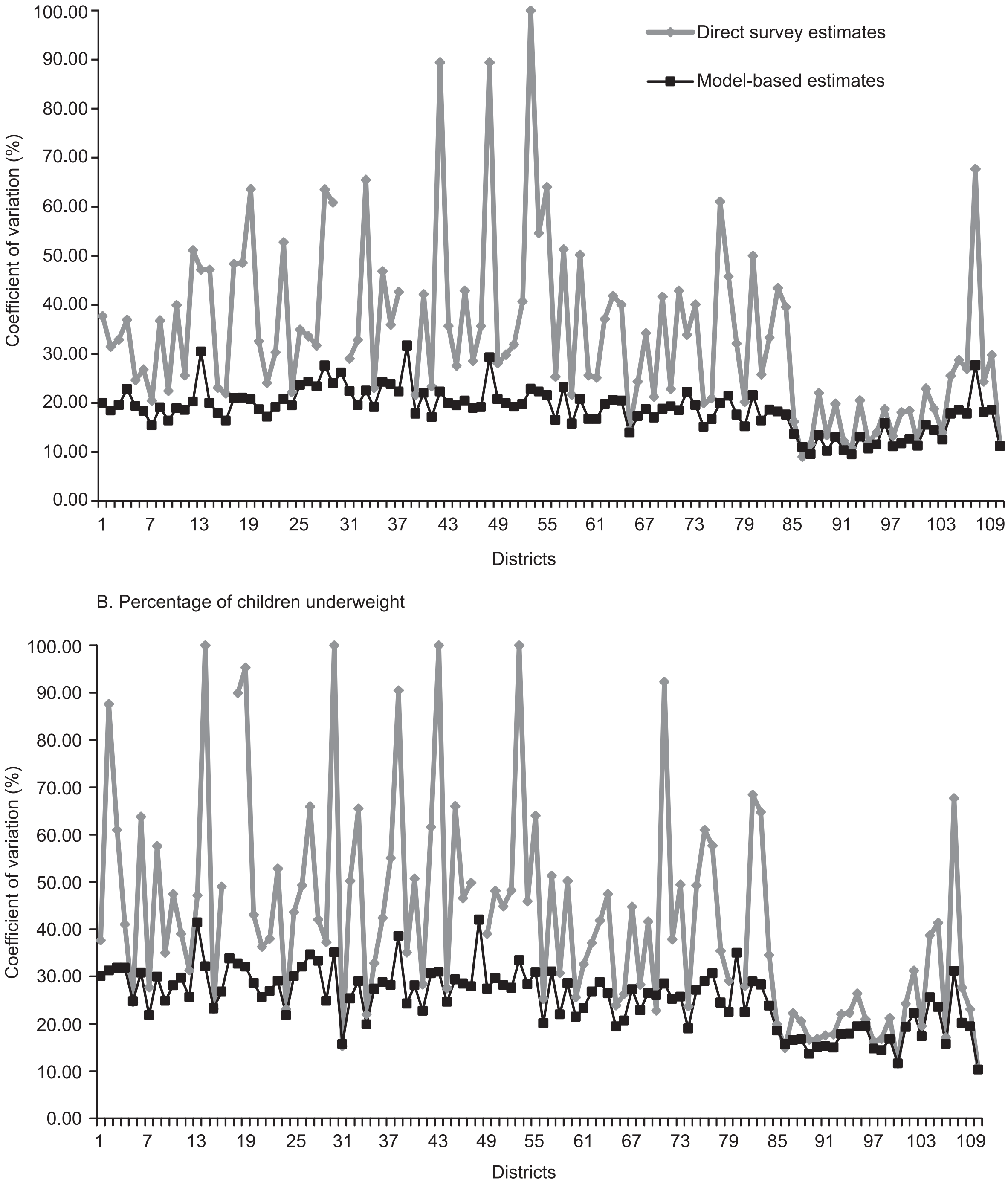

Fig. 3. Coefficient of variation

undernutrition. The results for the northern part of the country emulates the spatial variation in poverty – more than 40% of the people in this region live in poverty (World Bank 2003) and are the most deprived with regards to access to health services (GSS, MoH and ORC Macro 2003). Aside the districts of the Northern Region, Ashanti Akim South, Mfantsiman, Ejura Sekodumasi, Bawku West, Sissala, Asutifi, Atebubu, Jirapa-Lambuse and Sene all have stunting in excess of 35%, while the Kasena-Nankana, Bawku West, Bawku East, Sene and Ketu districts also have underweight in excess of 35%.

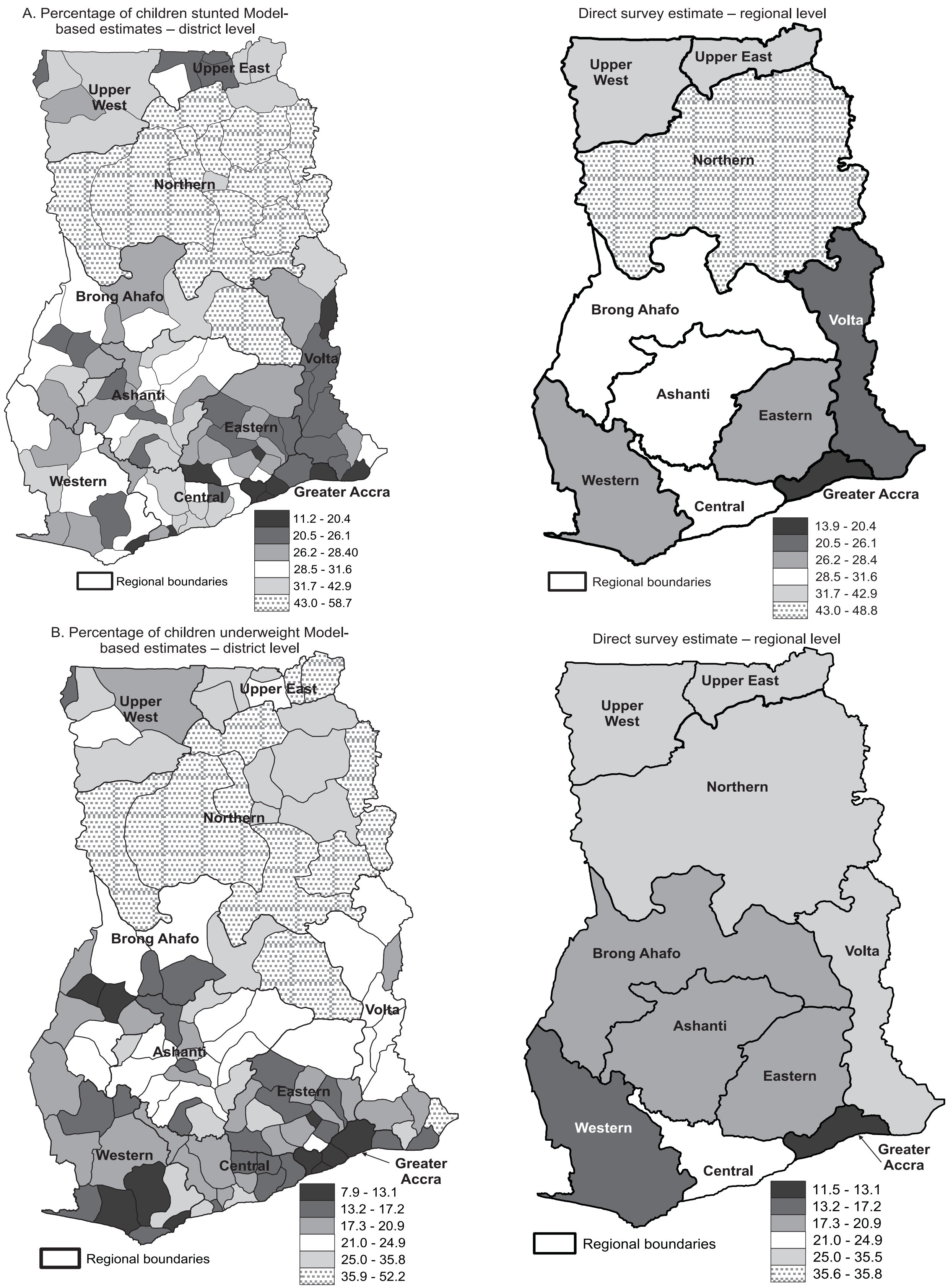

Fig. 4. Model-based and direct survey estimates showing percentage of children stunted and underweight

6. DISCUSSION

We used a special case of the GLMM with a logit link function linking data from the 2003 GDHS and 2000 GPHC to estimate the proportion of under-five children who are stunted and underweight for each district in Ghana. An assessment of the diagnostic measures confirms reasonably good precision of the model-based district estimates. Most districts in Ghana have stunting and underweight in children above the WHO emergency threshold of 15%, coupled with a high degree of inequalities across the districts. The variations in stunting and underweight identified in this study highlight an imperative need for appropriate policy interventions and programmes aimed at improving the health status of children.

The Ghana Millennium Development Goals Report published by National Development Planning Commission (NDPC) and the United Nations Development Programme (UNDP) Ghana (2010) indicates that Ghana is not on track to achieving the target of reducing infant and child mortality by two-thirds by 2015. The report concludes that this can only be achieved with an increase and effective coverage of child survival interventions. The estimates derived in this study reveal striking differences in undernutrition among children, pointing to specific geographical areas where child survival programmes should be strengthened. In the case of Ghana which has high levels of under five mortality – 80 deaths per 1,000 live births (GSS, GHS, ICF Macro 2009) , the availability of district-level statistics on health indicators is vital for monitoring and facilitating a decentralised model of health policy and planning. Small area statistics and the mapping of such estimates are important visual and statistical tools for policy development, resource allocation, and monitoring and evaluation of community interventions.

7. APPENDIX

Appendix 1. Model-based and direct survey estimates of proportion of children stunted and their corresponding 95% confidence intervals

Region/District	Model-based estimates			Direct survey estimates		
	Estimate	95% CI Lower bound	95% CI Upper bound	Estimate	95% CI Lower bound	95% CI Upper bound
WESTERN REGION						
JOMORO	0.268	0.163	0.373	0.290	0.079	0.501
NZIMA EAST	0.276	0.177	0.376	0.260	0.099	0.421
AHANTA WEST	0.311	0.192	0.430	0.380	0.132	0.628
SHAMA-AHANTA EAST	0.176	0.097	0.254	0.000	—	—
MPOHOR-WASSA EAST	0.302	0.188	0.417	0.410	0.213	0.607
WASSA WEST	0.249	0.160	0.339	0.250	0.119	0.381
WASSA AMENFI	0.299	0.208	0.389	0.290	0.176	0.404
AOWIN-SUAMAN	0.320	0.200	0.440	0.310	0.088	0.532
JUABESO-BIA	0.314	0.213	0.414	0.310	0.175	0.445
SEFWI WIASO	0.266	0.168	0.365	0.190	0.041	0.339
SEFWI BIBIANI	0.314	0.200	0.428	0.440	0.221	0.659
CENTRAL REGION						
KOMENDA-EDINA-EGYAFO -ABIREM	0.273	0.165	0.382	0.200	0.000	0.400
CAPE COAST	0.194	0.078	0.309	0.430	0.034	0.826
ABURA-ASEBU-KWAMANKESE	0.330	0.201	0.458	0.430	0.034	0.826

Region/District	Model-based estimates			Direct survey estimates		
	Estimate	95% CI Lower bound	95% CI Upper bound	Estimate	95% CI Lower bound	95% CI Upper bound
MFANTSIMAN	0.355	0.230	0.479	0.470	0.256	0.684
GOMOA	0.323	0.219	0.426	0.330	0.187	0.473
EFUTU-EWUTU-SENYA	0.289	0.171	0.408	0.250	0.013	0.487
AGONA	0.260	0.153	0.368	0.180	0.012	0.348
ASIKUMA-ODOBEN-BRAKWA	0.288	0.171	0.406	0.200	–0.049	0.449
AJUMAKO-ENYAN-ESIAM	0.322	0.204	0.439	0.330	0.117	0.543
ASSIN	0.324	0.215	0.433	0.340	0.178	0.502
LOWER DENKYIRA	0.299	0.187	0.411	0.300	0.119	0.481
UPPER DENKYIRA	0.269	0.159	0.378	0.170	–0.002	0.342
GREATER ACCRA REGION						
ACCRA METROPOLITAN	0.112	0.069	0.154	0.120	0.070	0.170
GA	0.114	0.061	0.166	0.110	0.038	0.182
TEMA	0.118	0.062	0.175	0.130	0.042	0.218
DANGME WEST	0.212	0.115	0.309	0.250	0.095	0.405
DANGME EAST	0.182	0.083	0.280	0.110	–0.028	0.248
VOLTA REGION						
SOUTH TONGU	0.257	0.136	0.377	0.200	–0.039	0.439
KETA	0.195	0.095	0.296	0.000	—	—
KETU	0.308	0.173	0.443	0.310	0.135	0.485
AKATSI	0.264	0.163	0.365	0.250	0.089	0.411
NORTH TONGU	0.232	0.130	0.334	0.000	—	—
HO	0.205	0.128	0.281	0.220	0.121	0.319
KPANDU	0.204	0.107	0.301	0.210	0.013	0.407
HOHOE	0.220	0.117	0.322	0.360	0.108	0.612
JASIKAN	0.238	0.134	0.342	0.250	0.041	0.459
KADJEBI	0.200	0.076	0.324	0.000	—	—
NKWANTA	0.324	0.211	0.437	0.390	0.226	0.554
KRACHI	0.279	0.158	0.399	0.250	0.043	0.457
EASTERN REGION						
BIRIM NORTH	0.281	0.187	0.375	0.300	0.163	0.437
BIRIM SOUTH	0.195	0.110	0.280	0.050	–0.038	0.138
WEST AKIM	0.294	0.179	0.409	0.420	0.129	0.711
KWAEBIBIREM	0.280	0.173	0.386	0.390	0.180	0.600
SUHUM-KRABOA-COALTAR	0.276	0.165	0.386	0.270	0.046	0.494
EAST AKIM	0.243	0.153	0.334	0.250	0.110	0.390
FANTEAKWA	0.283	0.177	0.390	0.290	0.084	0.496
KOFORIDUA	0.153	0.066	0.241	0.130	–0.089	0.349

Region/District	Model-based estimates			Direct survey estimates		
	Estimate	95% CI		Estimate	95% CI	
		Lower bound	Upper bound		Lower bound	Upper bound
AKWAPIM SOUTH	0.288	0.171	0.406	0.460	0.206	0.714
AKWAPIM NORTH	0.282	0.172	0.392	0.380	0.161	0.599
YILO KROBO	0.278	0.173	0.382	0.310	0.114	0.506
MANYA KROBO	0.242	0.148	0.335	0.000	—	—
ASUOGYAMAN	0.255	0.141	0.369	0.330	–0.323	0.983
AFRAM PLAINS	0.283	0.160	0.407	0.150	–0.011	0.311
KWAHU SOUTH	0.229	0.132	0.325	0.130	–0.037	0.297
ASHANTI REGION						
ATWIMA	0.276	0.187	0.365	0.250	0.126	0.374
AMANSIE WEST	0.309	0.169	0.450	0.210	–0.005	0.425
AMANSIE EAST	0.319	0.220	0.418	0.340	0.194	0.486
ADANSI WEST	0.220	0.130	0.310	0.130	0.007	0.253
ADANSI EAST	0.341	0.229	0.453	0.360	0.178	0.542
ASHANTI AKIM SOUTH	0.348	0.234	0.462	0.410	0.207	0.613
ASHANTI AKIM NORTH	0.271	0.167	0.376	0.280	0.078	0.482
EJISU-JUABEN	0.291	0.174	0.408	0.360	0.062	0.658
BOSOMTWI KWANWOMA	0.245	0.147	0.342	0.170	0.034	0.306
KUMASI METROPOLITAN	0.263	0.191	0.334	0.280	0.200	0.360
KWABRE	0.294	0.194	0.394	0.330	0.171	0.489
AFIGYA SEKYERE	0.297	0.189	0.406	0.300	0.099	0.501
SEKYERE EAST	0.316	0.211	0.421	0.350	0.203	0.497
SEKYERE WEST	0.300	0.189	0.410	0.270	0.052	0.488
EJURA SEKODUMASI	0.355	0.221	0.490	1.000	—	—
OFFINSO	0.282	0.180	0.384	0.170	0.024	0.316
AHAFO-ANO SOUTH	0.246	0.139	0.353	0.190	0.066	0.314
AHAFO-ANO NORTH	0.329	0.203	0.455	0.360	0.075	0.645
BRONG AHAFO REGION						
ASUNAFO	0.277	0.195	0.359	0.250	0.151	0.349
ASUTIFI	0.370	0.249	0.492	0.560	0.330	0.790
TANO	0.268	0.164	0.373	0.150	–0.034	0.334
SUNYANI	0.205	0.119	0.291	0.140	0.012	0.268

Region/District	Model-based estimates			Direct survey estimates		
		95% CI			95% CI	
	Estimate	Lower bound	Upper bound	Estimate	Lower bound	Upper bound
DORMAA	0.285	0.187	0.384	0.230	0.083	0.377
JAMAN	0.301	0.211	0.390	0.300	0.182	0.418
BEREKUM	0.258	0.149	0.366	0.330	0.003	0.657
WENCHI	0.310	0.210	0.409	0.290	0.143	0.437
TECHIMAN	0.261	0.166	0.356	0.230	0.083	0.377
NKORANZA	0.285	0.184	0.387	0.180	0.025	0.335
KINTAMPO	0.284	0.186	0.382	0.160	0.036	0.284
ATEBUBU	0.384	0.282	0.486	0.440	0.301	0.579
SENE	0.575	0.452	0.698	0.790	0.652	0.928
NORTHERN REGION						
BOLE	0.587	0.478	0.696	0.630	0.487	0.773
WEST GONJA	0.550	0.406	0.695	0.400	0.227	0.573
EAST GONJA	0.470	0.376	0.563	0.440	0.326	0.554
NANUMBA	0.429	0.320	0.539	0.380	0.233	0.527
ZABZUGU-TATALI	0.530	0.423	0.637	0.580	0.441	0.719
SABOBA-CHEREPONI	0.563	0.459	0.667	0.650	0.513	0.787
YENDI	0.435	0.324	0.547	0.410	0.244	0.576
GUSHIEGU-KARAGA	0.536	0.424	0.649	0.570	0.438	0.702
SAVELUGU-NANTON	0.481	0.372	0.589	1.000	—	—
TAMALE	0.354	0.244	0.463	0.390	0.245	0.535
TOLON-KUMBUNGU	0.514	0.402	0.626	0.590	0.437	0.743
WEST MAMPRUSI	0.486	0.374	0.598	0.460	0.296	0.624
EAST MAMPRUSI	0.376	0.283	0.468	0.310	0.199	0.421
UPPER WEST REGION						
WA	0.333	0.260	0.407	0.350	0.269	0.431
NADAWLI	0.278	0.194	0.363	0.220	0.120	0.320
SISSALA	0.366	0.262	0.470	0.350	0.221	0.479
JIRAPA-LAMBUSSIE	0.399	0.301	0.497	0.450	0.327	0.573
LAWRA	0.257	0.168	0.347	0.230	0.114	0.346
UPPER EAST REGION						
BUILSA	0.312	0.199	0.426	0.300	0.129	0.471
KASENA-NANKANA	0.246	0.160	0.332	0.200	0.092	0.308
BONGO	0.245	0.112	0.378	0.150	–0.054	0.354
BOLGATANGA	0.253	0.163	0.343	0.250	0.131	0.369
BAWKU WEST	0.318	0.202	0.433	0.320	0.133	0.507
BAWKU EAST	0.360	0.281	0.439	0.400	0.310	0.490
NATIONAL AVERAGE	0.302	0.198	0.406	0.302	0.129	0.475

Appendix 2. Model-based and direct survey estimates of proportion of children underweight and their corresponding 95% confidence intervals

Region/District	Model-based estimates			Direct survey estimates		
		95% CI			95% CI	
	Estimate	Lower bound	Upper bound	Estimate	Lower bound	Upper bound
WESTERN REGION						
JOMORO	0.165	0.068	0.262	0.290	0.079	0.501
NZIMA EAST	0.110	0.043	0.178	0.040	–0.035	0.115
AHANTA WEST	0.158	0.060	0.257	0.150	–0.034	0.334
SHAMA-AHANTA EAST	0.104	0.039	0.169	0.120	0.024	0.216
MPOHOR-WASSA EAST	0.256	0.132	0.381	0.410	0.213	0.607
WASSA WEST	0.096	0.038	0.154	0.060	–0.009	0.129
WASSA AMENFI	0.188	0.108	0.269	0.180	0.083	0.277
AOWIN-SUAMAN	0.182	0.075	0.289	0.150	–0.023	0.323
JUABESO-BIA	0.175	0.090	0.260	0.150	0.044	0.256
SEFWI WIASO	0.161	0.072	0.249	0.140	0.007	0.273
SEFWI BIBIANI	0.167	0.070	0.264	0.250	0.059	0.441
CENTRAL REGION						
KOMENDA-EDINA-EGYAFO-ABIREM	0.261	0.130	0.392	0.400	0.155	0.645
CAPE COAST	0.137	0.026	0.249	0.430	0.034	0.826
ABURA-ASEBU-KWAMANKESE	0.193	0.071	0.314	0.140	–0.140	0.420
MFANTSIMAN	0.303	0.165	0.442	0.470	0.256	0.684
GOMOA	0.151	0.071	0.230	0.000	—	—
EFUTU-EWUTU-SENYA	0.140	0.047	0.233	0.000	—	—
AGONA	0.132	0.047	0.217	0.000	—	—
ASIKUMA-ODOBEN-BRAKWA	0.171	0.063	0.278	0.000	—	—
AJUMAKO-ENYAN-ESIAM	0.192	0.084	0.300	0.220	0.033	0.407
ASSIN	0.195	0.097	0.292	0.190	0.057	0.323
LOWER DENKYIRA	0.206	0.098	0.315	0.220	0.058	0.382
UPPER DENKYIRA	0.193	0.083	0.302	0.170	–0.002	0.342
GREATER ACCRA REGION						
ACCRA METROPOLITAN	0.099	0.056	0.141	0.110	0.061	0.159
GA	0.083	0.034	0.132	0.070	0.010	0.130
TEMA	0.079	0.029	0.129	0.070	0.006	0.134
DANGME WEST	0.108	0.035	0.181	0.070	–0.022	0.162
DANGME EAST	0.172	0.060	0.284	0.220	0.037	0.403
VOLTA REGION						
SOUTH TONGU	0.343	0.176	0.510	0.400	0.108	0.692
KETA	0.163	0.051	0.274	0.140	–0.140	0.420

Region/District	Model-based estimates			Direct survey estimates		
		95% CI			95% CI	
	Estimate	Lower bound	Upper bound	Estimate	Lower bound	Upper bound
KETU	0.522	0.361	0.682	0.620	0.436	0.804
AKATSI	0.209	0.105	0.313	0.130	0.007	0.253
NORTH TONGU	0.209	0.090	0.328	0.170	–0.044	0.384
HO	0.220	0.134	0.305	0.240	0.138	0.342
KPANDU	0.238	0.110	0.366	0.360	0.130	0.590
HOHOE	0.224	0.098	0.351	0.290	0.053	0.527
JASIKAN	0.214	0.096	0.332	0.170	–0.010	0.350
KADJEBI	0.186	0.045	0.326	0.110	–0.087	0.307
NKWANTA	0.225	0.118	0.332	0.190	0.057	0.323
KRACHI	0.237	0.106	0.367	0.190	0.004	0.376
EASTERN REGION						
BIRIM NORTH	0.208	0.115	0.301	0.230	0.105	0.355
BIRIM SOUTH	0.136	0.054	0.218	0.100	–0.021	0.221
WEST AKIM	0.172	0.068	0.277	0.080	–0.083	0.243
KWAEBIBIREM	0.253	0.131	0.375	0.390	0.180	0.600
SUHUM-KRABOA-COALTAR	0.190	0.081	0.300	0.130	–0.042	0.302
EAST AKIM	0.131	0.058	0.203	0.110	0.009	0.211
FANTEAKWA	0.189	0.086	0.293	0.180	0.008	0.352
KOFORIDUA	0.079	0.014	0.145	0.000	—	—
AKWAPIM SOUTH	0.244	0.113	0.375	0.310	0.075	0.545
AKWAPIM NORTH	0.172	0.072	0.272	0.190	0.013	0.367
YILO KROBO	0.177	0.080	0.275	0.190	0.025	0.355
MANYA KROBO	0.163	0.075	0.252	0.130	0.007	0.253
ASUOGYAMAN	0.191	0.066	0.316	0.330	–0.323	0.983
AFRAM PLAINS	0.236	0.105	0.367	0.200	0.020	0.380
KWAHU SOUTH	0.154	0.061	0.247	0.130	–0.037	0.297
ASHANTI REGION						
ATWIMA	0.244	0.148	0.341	0.250	0.126	0.374
AMANSIE WEST	0.239	0.093	0.384	0.210	–0.005	0.425
AMANSIE EAST	0.223	0.127	0.319	0.210	0.085	0.335
ADANSI WEST	0.154	0.068	0.240	0.130	0.007	0.253
ADANSI EAST	0.294	0.170	0.418	0.360	0.178	0.542
ASHANTI AKIM SOUTH	0.265	0.144	0.386	0.290	0.102	0.478
ASHANTI AKIM NORTH	0.213	0.101	0.325	0.280	0.078	0.482
EJISU-JUABEN	0.230	0.100	0.359	0.360	0.062	0.658
BOSOMTWI KWANWOMA	0.192	0.092	0.291	0.130	0.009	0.251

	Model-based estimates			Direct survey estimates		
		95% CI			95% CI	
Region/District	Estimate	Lower bound	Upper bound	Estimate	Lower bound	Upper bound
KUMASI METROPOLITAN	0.152	0.094	0.210	0.130	0.071	0.189
KWABRE	0.281	0.167	0.395	0.300	0.146	0.454
AFIGYA SEKYERE	0.199	0.092	0.305	0.200	0.024	0.376
SEKYERE EAST	0.224	0.123	0.324	0.240	0.110	0.370
SEKYERE WEST	0.228	0.110	0.346	0.270	0.052	0.488
EJURA SEKODUMASI	0.295	0.145	0.446	0.620	0.345	0.895
OFFINSO	0.154	0.068	0.240	0.040	–0.039	0.119
AHAFO-ANO SOUTH	0.226	0.114	0.338	0.160	0.044	0.276
AHAFO-ANO NORTH	0.295	0.146	0.444	0.270	0.006	0.534
BRONG AHAFO REGION						
ASUNAFO	0.213	0.134	0.293	0.190	0.100	0.280
ASUTIFI	0.212	0.099	0.325	0.190	0.009	0.371
TANO	0.185	0.080	0.291	0.150	–0.034	0.334
SUNYANI	0.125	0.050	0.200	0.100	–0.008	0.208
DORMAA	0.203	0.106	0.301	0.200	0.061	0.339
JAMAN	0.174	0.097	0.250	0.170	0.073	0.267
BEREKUM	0.114	0.036	0.193	0.000	—	—
WENCHI	0.227	0.127	0.326	0.260	0.119	0.401
TECHIMAN	0.134	0.058	0.210	0.060	–0.027	0.147
NKORANZA	0.158	0.071	0.246	0.090	–0.025	0.205
KINTAMPO	0.212	0.113	0.311	0.200	0.065	0.335
ATEBUBU	0.282	0.179	0.384	0.340	0.207	0.473
SENE	0.446	0.309	0.583	0.570	0.403	0.737
NORTHERN REGION						
BOLE	0.361	0.244	0.478	0.320	0.182	0.458
WEST GONJA	0.472	0.317	0.626	0.430	0.255	0.605
EAST GONJA	0.358	0.262	0.454	0.330	0.221	0.439
NANUMBA	0.413	0.291	0.535	0.460	0.309	0.611
ZABZUGU-TATALI	0.378	0.264	0.491	0.400	0.262	0.538
SABOBA-CHEREPONI	0.388	0.274	0.502	0.410	0.269	0.551
YENDI	0.350	0.227	0.472	0.380	0.216	0.544
GUSHIEGU-KARAGA	0.309	0.201	0.417	0.270	0.151	0.389
SAVELUGU-NANTON	0.264	0.164	0.365	0.230	0.112	0.348
TAMALE	0.294	0.181	0.407	0.340	0.200	0.480
TOLON-KUMBUNGU	0.431	0.306	0.555	0.490	0.335	0.645
WEST MAMPRUSI	0.452	0.324	0.579	0.500	0.336	0.664
EAST MAMPRUSI	0.277	0.186	0.368	0.250	0.146	0.354

Region/District	Model-based estimates			Direct survey estimates		
	Estimate	95% CI Lower bound	95% CI Upper bound	Estimate	95% CI Lower bound	95% CI Upper bound
UPPER WEST REION						
WA	0.333	0.257	0.408	0.360	0.278	0.442
NADAWLI	0.221	0.137	0.305	0.200	0.103	0.297
SISSALA	0.205	0.116	0.294	0.160	0.060	0.260
JIRAPA-LAMBUSSIE	0.277	0.183	0.371	0.290	0.177	0.403
LAWRA	0.153	0.076	0.229	0.120	0.032	0.208
UPPER EAST						
BUILSA	0.260	0.140	0.380	0.170	0.029	0.311
KASENA-NANKANA	0.352	0.243	0.460	0.390	0.260	0.520
BONGO	0.267	0.104	0.430	0.150	-0.054	0.354
BOLGATANGA	0.249	0.150	0.347	0.200	0.089	0.311
BAWKU WEST	0.375	0.232	0.518	0.440	0.241	0.639
BAWKU EAST	0.413	0.329	0.497	0.440	0.349	0.531
NATIONAL AVERAGE	**0.226**	0.122	0.331	**0.231**	0.058	0.403

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