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Nutrition Mapping in Tanzania

An Exploratory Analysis

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Abstract

For effective decisionmaking, policymakers and program managers often need detailed information about the welfare of the population, including knowledge about which specific areas are most affected by poverty and undernutrition. Household sample surveys are an important source of information, yet because the typical sample size is only a few thousand observations, the information is only useful for inferences at high levels of aggregation, such as the nation or large regional units. In contrast, data sources with wider coverage, such as national censuses, rarely capture detailed information on welfare levels. Recently small-area estimation techniques have been applied to the study of poverty to produce estimates of poverty, or poverty maps, for small geographic units.

This paper uses household survey and unit record census data from Tanzania to explore the possibility of applying small-area estimation methods to the study of children's nutritional status as measured by anthropometry. Overall, undernutrition models have had lower explanatory power than poverty models, which has important implications for the precision of the small-area estimates. The analysis finds that applying small-area estimation techniques to anthropometric data is feasible, although the relatively low explanatory power of the regressions does limit both the degree of disaggregation possible and the power to detect significant differences in undernutrition prevalence between districts and subdistricts. In the case of Tanzania, the nutrition mapping approach reveals considerable heterogeneity in nutritional status within regions and within districts. The most striking finding is the much lower levels of undernutrition in areas classified as urban, including relatively small district centers.

Key words: nutrition mapping, malnutrition, anthropometry, small area estimation, Tanzania

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1. Introduction

Poverty and underdevelopment have many dimensions. Although measures such as GDP per capita and the poverty headcount ratio tend to garner the most attention, other aspects of development, such as child mortality, life expectancy, literacy, food security, access to clean water, physical security, and political freedom, are also important barometers of living conditions.

Among non-income measures of welfare, children's nutritional status is arguably one of the most important and widely used. Children's nutritional status is important because it provides critical information about the living conditions of some of the most vulnerable members of society: young children. It also reflects how much investment is being made in the students and workers of the future. The popularity of children's nutritional status as a measure of well-being is attributable in part to the relative ease of collecting information. Anthropometry-based assessments of nutritional status require only collection of information about children's heights, weights, and ages, which is relatively noninvasive. Moreover, the international reference standards that form part of the assessment are widely accepted and easy to apply.

One of the targets of the first Millennium Development Goal is to reduce by one-half the proportion of people who suffer from hunger. One of the indicators adopted to measure progress toward this target is a measure based on anthropometry: the percentage of children under the age of five years who are underweight (that is, weigh substantially less than they should, given their age and sex).

Although collecting anthropometry data is reasonably straightforward, most national surveys collect such information on only a few thousand children.[1] Although that may seem like a large number, it usually only provides sufficiently precise estimates at the national level and for large subnational groupings, such as breakdowns by region,

[1] Health clinics and growth monitoring programs typically measure many more children on an ongoing basis, but these data are generally not representative of nutritional status in the larger population, because those who attend clinics are a self-selected group that may systematically differ in some ways from the rest of the population.

gender, or age group. Nutritional status estimates for large areas typically mask the high within-country variability that exists, including pockets of severe undernutrition[2] or "hunger hot spots." Developing policies and programs to improve nutritional status requires a more disaggregated picture of undernutrition, especially as countries move to greater levels of decentralization.

Over the past few years new methodologies have been developed that permit estimation of welfare measures for finely disaggregated population groups. These methods combine the strengths of household survey data (detailed information about a relatively small sample) with national census data (limited information about all or most of the country's population). In particular, small-area estimation methods have been applied to the measurement of poverty to produce high-resolution "poverty maps," which show the distribution of poverty for small geographic units (see, for example, Alderman et al. 2003, Elbers, Lanjouw, and Lanjouw 2003, Minot 2000, and Simler and Nhate 2005). Poverty maps can be useful in various research and programmatic settings: for example, they can be used to inform geographic targeting of antipoverty efforts, to explore the geographic determinants of poverty, or to investigate the interrelationship between poverty, inequality, and crime.

This paper applies the small-area estimation methodology to the analysis of child undernutrition in Tanzania. Although the steps for adapting poverty mapping analysis to undernutrition appear to be fairly clear, it remains uncertain whether it is possible to produce small-area estimates of undernutrition that are precise enough to be useful. This uncertainty arises because a large part of the precision of poverty maps is determined by the explanatory power of the first-stage regression model that is estimated from the survey data. Overall, researchers have been less successful at explaining the variation in undernutrition than they have in explaining the variation in household income and expenditure. The only two nutrition mapping studies that we are aware of have yielded

[2] Generally speaking, malnutrition encompasses both nutrient inadequacies (undernutrition) and nutrient excesses (overnutrition). Although the term malnutrition is used more often in everyday speech, this paper focuses exclusively on undernutrition and will use that term.

mixed results. Fujii (2005) made use of an unusually rich geographic information system (GIS) database and an elaborate variance structure to describe the spatial patterns of child undernutrition in Cambodia with a reasonable level of precision down to the level of communes. Gilligan and Veiga (2004) generate point estimates of nutritional status at the *município* level in Brazil, but since they do not report standard errors, it is not possible to assess the precision of their estimates.

This research contributes to the literature by applying nutrition mapping to another country setting, Tanzania, which to the best of our knowledge is the first nutrition map for an African country. There are two main research questions. First, is nutrition mapping feasible? And second, if it is feasible, what does a nutrition map for Tanzania look like, or more specifically, what is the spatial distribution of undernutrition in Tanzania?

This paper is organized as follows. The next section describes the methods used to measure child nutritional status, estimate nutritional status regressions, and project those regressions onto the census population. The third section presents the results of the estimations, showing the spatial distribution of child undernutrition in Tanzania. The last section summarizes the findings and presents some concluding comments.

2. Methods and Data

This section presents information about the indicators used to measure children's nutritional status, the approach used to generate the small-area estimates of undernutrition in Tanzania, and a summary of the data used in this study. We begin with a review of the calculation of Z-scores, which is a standard method for comparing child growth to an international reference standard.

Measuring Children's Nutritional Status

Anthropometry—or measuring the human body—is commonly used to evaluate children's nutritional status. It is a relatively noninvasive method of collecting basic information about a child's growth status, from which one can make inferences about current and past nutritional status. Assessments of children's nutritional status using anthropometry are based on a comparison of measured height and weight with the age- and sex-specific heights and weights of a well-nourished reference population (WHO 1983, 1995). Despite observed differences across ethnic groups in adult height and weight, it has been consistently demonstrated that—given adequate nutrition and healthy environments—the growth patterns of children up to the age of five years are remarkably similar (Habicht et al. 1974; Graciter and Gentry 1981; Martorell 1985; WHO 1995).[3]

The most common way of expressing a child's nutritional status, especially for international work, is by calculation of a Z-score. A Z-score is defined as the number of standard deviation units a child's weight or height is from the median value for children of the same age and sex in the reference population. For example, in the reference population the median height of girls 32 months old is 91.0 centimeters, with a standard deviation of 3.6.[4] Therefore, a 32-month-old girl who is 85.6 centimeters tall has a height-for-age Z-score of –1.5 (85.6 – 91.0 / 3.6). Children with Z-scores less than –2 are generally classified as undernourished according to that indicator. The principal indicators are height-for-age, weight-for-height, and weight-for-age. The proportion of children with Z-scores below –2 is the prevalence of stunting (low height-for-age), wasting (low weight-for-height), and underweight (low weight-for-age).

Stunting, or linear growth faltering, is often viewed as a measure of chronic deprivation. Stunting is usually a result of a combination of insufficient nutrient intake and repeated illness. It is a cumulative process that in most cases cannot be reversed, especially in developing-country settings where the resources for "catch up" growth are lacking. Wasting, on the other hand, indicates acute thinness and is a measure of current

[3] Minor exceptions to similarities in growth patterns of young children have been detected in some Asian populations (WHO 1995), but these are not relevant to the present study population.

[4] For some combinations of age and sex, the reference distribution is asymmetric, with positive skewness. In these instances the standard deviation above the median is larger than that below the median, and the Z-score is calculated using the standard deviation that corresponds to the child's height or weight relative to the median.

nutritional status. Wasting is evident most often when a child is severely ill and in times of crisis such as famines. Weight-for-age is a composite indicator of nutritional status. A child whose current health and nutrition are adequate may be underweight because he or she is stunted. That is, past events caused stunting, and the child is now shorter and lighter than the standards for his or her age. Alternatively, a child who is not stunted could be underweight because of current acute nutritional stress, so that the child is much lighter than the standards, even though his or her height corresponds to the standards. In this study we will examine height-for-age and weight-for-age.

Estimating Z-scores as a Function of Individual, Household, and Community Characteristics

The basic principles of the small-area estimation methodology are fairly simple. Household survey data—in this case the 1991–92 Demographic and Health Survey (DHS)—are used to estimate the statistical relationship between children's anthropometric Z-scores and a set of independent variables that are expected to be correlated with nutritional status. The set of variables considered for the right-hand side of the regression equations are limited to those variables that appear in both the household survey and the population census. Estimating the regression parameters from the survey data is commonly referred to as "Stage 1." In Stage 2, the estimated regression coefficients are applied to the census data to produce estimates of anthropometric Z-scores for each child less than five years old who is recorded in the census. The Z-score estimates are used in turn to estimate the prevalence of stunting and underweight. Because the Stage 2 nutritional status estimates are available for the entire population, it is possible to calculate undernutrition prevalence rates for small subgroups of the population.

The explanatory variables in the first-stage regressions capture characteristics at various levels that are hypothesized to be related to the child's achieved growth. At the individual level, characteristics specific to the child—such as the child's age and sex—are typically significant explanatory variables. At the household level, there are several variables that reflect the household's socioeconomic status, which is also usually correlated with nutritional status. Potential household-level variables may include the education level of the head of household and other adults, the number of members in the household and the proportion that are of working age, the age of the head of the household, and dwelling characteristics such as type of water source, type of sanitation facilities, and access to electricity.

Even after accounting for household and individual characteristics, there is usually some variation in children's nutritional status that is captured by community-level characteristics. In other words, nutritional status levels often move together in a particular area, being systematically higher or lower than other areas even after controlling for household and individual characteristics. Accounting for this spatial correlation, or "location effect," in children's Z-scores is important for maximizing the precision of the small-area estimates. The two main sources of community-level variables are geographic variables drawn from GIS data sets, and community-level variables constructed from the unit record data in the census; these data sources are described later in this section. As it was not possible to match enumeration areas in the survey with enumeration areas in the census, the community-level variables were constructed at the level of the district. Candidate variables include demographic patterns (for example, proportion of the district population less than five years old, proportion of female-headed households, population density, sex ratio), housing conditions (for example, proportion of dwellings with electricity, proportion without toilet or latrine), and geographic characteristics (for example, elevation, mean annual rainfall, distance to market centers).

Before estimating the first-stage regressions, it is first necessary to identify which potential correlates of children's nutritional status were collected in both the census and the DHS. This is accomplished by examining the respective questionnaires. However, even questions that appear to be worded the same sometimes actually have different underlying definitions, or are implemented differently in the field, so that they are not measuring the same concept. The means and variances of the candidate variables are compared between the census and the DHS to ensure that they are capturing the same information; this process is sometimes called "Stage 0." If the distribution of a variable is substantially different in the two data sets, that variable is eliminated from consideration as a regressor. This issue only arises for the individual- and household-level variables, as all of the district-level variables are calculated either from the census alone or a separate geographic database.

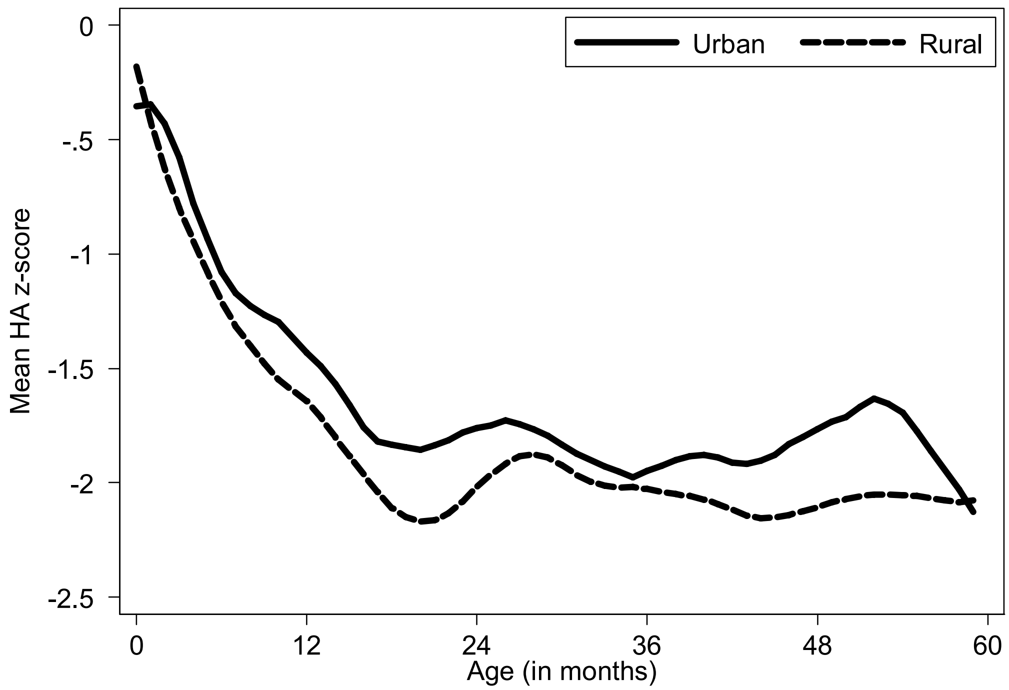
More formally, the first-stage regressions estimate children's anthropometric Z-scores as a function of observable individual, household, and community characteristics, using a linear approximation of the form

$$z_{chi} = X'_{chi}\beta + W'_{ch}\gamma + V'_{c}\lambda + \varepsilon_{chi}\,, \tag{1}$$

where z_{chi} is the Z-score of child i in household h in community c. X_{chi} , W_{ch} , and V_c are vectors of individual, household, and community characteristics, respectively, and ε_{chi} is a child-specific stochastic disturbance term with mean zero and variance σ^2. β, γ, and λ are vectors of regression coefficients to be estimated. The DHS is not a self-weighting survey, as the probability of selection varies by enumeration area. Thus the regressions are estimated using sample weights, which are the inverse of the probability of selection in the DHS sample.

Rather than impose the assumption that the quantitative relationship between Z-scores and the regressors is uniform throughout Tanzania, separate regressions are estimated for each of the survey strata. The 1991–92 DHS is stratified by rural and urban area of residence. Separate models were also estimated for children less than 24 months old and children 24 to 60 months old. This was done because the relationship between nutritional status and age—an important correlate of nutritional status—is clearly nonlinear in Tanzania, as Figure 1 shows. The figure shows that mean height-for-age starts between 0 and -0.5 Z-scores, and then deteriorates rapidly until the age of approximately 20 months, followed by a plateau around –2 Z-scores. This is a pattern seen in most low-income countries. A similar pattern is exhibited for weight-for-age,

Figure 1—Mean height-for-age Z-scores, by age and area of residence

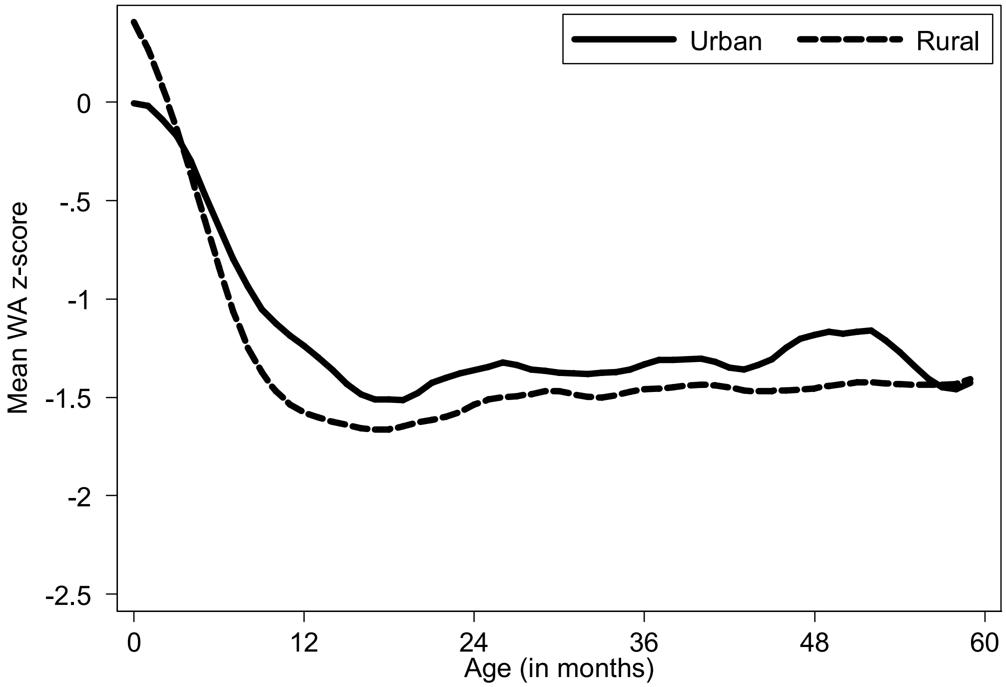


Source: Author's calculations from 1991-92 DHS.

except the mean starts closer to zero, and the decline bottoms out slightly earlier and at a slightly less negative value, around –1.5 (Figure 2). One approach to accommodating the nonlinear relationship between age and Z-score would be to estimate a single model in each stratum for all under-fives, but including a quadratic term for the age of the child. We opted not to use that approach because (1) the descriptive data suggest more of a piecewise linear relationship than a quadratic relationship,[5] and (2) we wanted to allow for the possibility that the coefficients on other variables also vary between the two age groups. Even though the quantitative relationship between nutritional status and age appears to change near 20 months of age, we are forced to divide the age groups at 24 months because the census data used in Stage 2 only measure age in years, not months. Regressions for height-for-age Z-scores and weight-for-age Z-scores were estimated

[5] This was confirmed by estimating models with linear and quadratic age terms, and finding that they had lower explanatory power than the piecewise linear models presented in this paper.

Figure 2—Mean weight-for-age Z-scores, by age and area of residence



Source: Author's calculations from 1991-92 DHS.

separately for each of the four groups of children. The combination of two strata, two age groups within each stratum, and two nutritional status measures for each stratum-age combination yields a total of eight regression models.

The same set of candidate variables is considered for each of the models, with final variable selection determined by a stepwise procedure supplemented with extensive ex post diagnostics. A backward elimination procedure was used to select variables, requiring a coefficient's *p*-value to be less than 0.05 for the variable to remain in the model.[6]

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[6] Because of software limitations, this threshold is not as strict as it might seem. The significance levels in the stepwise procedure did not take into account the cluster sample design, so the true significance threshold for inclusion in the model is lower. Ex post analysis showed it to be in the neighborhood of 0.10.

Estimating Z-scores in the Census Data

After estimating the regressions, the estimated regression coefficients are applied to the corresponding set of explanatory variables in the census data. The procedure followed is analogous to that described in Hentschel et al. (2000) and Minot (2000) for poverty mapping, but with some minor modifications. Specifically, the cutoff value for undernutrition prevalence of –2 Z-scores is used in place of a monetary poverty line, and there is no need for a logarithmic transformation because the distribution of Z-scores tends to have a normal or near-normal distribution, unlike income or consumption which tends to be highly skewed.

For each child with long-form census data, the expected value of the probability that child *i* is stunted or underweight (U_i) conditional on observable characteristics (in this case, from the census and GIS data) is

$$E\left(U_i \mid X_{chi}^C, W_{ch}^C, V_c^C, \hat{\beta}, \hat{\gamma}, \hat{\lambda}, \hat{\sigma}\right) = \Phi\left[\frac{-2-(X_{chi}'^C\hat{\beta}+W_{ch}'^C\hat{\gamma}+V_c'^C\hat{\lambda})}{\hat{\sigma}}\right], \qquad (2)$$

where Φ is the cumulative standard normal distribution, the superscript *C* denotes census data, the circumflexes denote coefficients estimated from the DHS data, and $\hat{\sigma}$ is the estimated standard error of the regression. The estimated stunting or underweight prevalence for a given population subgroup, such as a district or a ward, is calculated by taking the mean of these probabilities over all children in that subgroup, using sample weights as appropriate.

Standard errors of the point estimates of undernutrition prevalence for small-areas are calculated using the Huber/White/sandwich estimator. There are three sources of statistical error in the estimation process. One source is idiosyncratic error, or the part of the variation in children's Z-scores that is not explained by the variables in the regression. A second source is model error, which arises because the estimated coefficients are not known with certainty. Rather, the estimated coefficients are random variables that have confidence intervals, and the wider are these confidence intervals, the less precise the small-area estimates will be. Third, because the long form of the census was only administered to a random subset of households, there is a sampling error associated with the long-form census variables, which also affects the overall precision of the Stage 2 estimates.

Data

This study uses three data sources: the 1988 Population Census, the 1991–92 Demographic and Health Survey (BS/MI 1993), and a collection of GIS variables compiled by Corbett et al. (2000).

The 1988 Population Census was carried out in August 1988, and was Tanzania's third census since attaining independence. Like the earlier censuses, it used two data collection forms. The short form was administered universally, to meet the principal census objective of enumerating the entire population and determining the basic demographic composition of the country. A long form was administered to a randomly selected sample of approximately 20 percent of all households. The long form collected a range of socioeconomic information, including employment, education levels, and housing conditions. Long-form data are available for approximately 766,000 children under the age of five years. It should be noted that the 1988 Population Census was used because the 2002 Census data were not available for this study.

The 1991–92 DHS is the source of information about child anthropometry and many of the explanatory variables in the anthropometry regressions. Tanzania has DHS data for several years; the 1991–92 survey was chosen for this study because it was collected closest in time to the 1988 Census. As it is likely that the relationship between children's Z-scores and the explanatory variables evolves over time, it is preferable that the data set used for estimating the relationship (Stage 1) is as close as possible in time to the data set used to generate the small-area estimates (Stage 2).

The 1991–92 DHS was conducted by the Bureau of Statistics, in collaboration with the Ministry of Health. Macro International, Inc., provided technical assistance for the implementation and analysis of the survey. The main objective of the survey was to collect information on health, fertility, and family planning in Tanzania. The survey collected information on 8,327 households located throughout Tanzania, with interviews taking place from October 1991 through March 1992. The main target group of the survey was women of reproductive age (15–49 years old at the time of the interview). The sample includes approximately 5,500 children under the age of five, and the survey collected information on their height, weight, and age in months. The stratified, three-stage-cluster sample design was intended to be nationally representative and also to support disaggregation by rural and urban areas. Because of the sampling procedures used and the sample size, the 1991–92 DHS is not representative at the level of the region or smaller administrative units.

In addition to the 1988 Population Census and the 1991–92 DHS data, geographic data are also used as explanatory variables in the nutrition regressions. These publicly available geo-referenced data include information on geographic features (for example, elevation, distance to coast, distance to primary or secondary road), climatic conditions (for example, mean annual rainfall, mean temperature), and human settlement (for example, population density, cattle density). To integrate the geo-referenced data with the tabular data from the DHS and the census, the relevant variables are summarized at the district level by calculating the mean or median value for each district. For example, the variable representing surface elevation is constructed by calculating the median of the elevation data points within each district, and then merged with the child-level anthropometry data on the basis of district identifiers. Note that the same geographic data set is used in both Stage 1 and Stage 2. This is acceptable because all of the variables used can be considered reasonably constant over the period between the 1988 Census and the 1991–92 DHS, because they change very slowly.[7]

[7] In this context, it bears emphasizing that the average annual rainfall variable is a long-term (usually 30 year) average, and not the annual rainfall level itself.

3. Results

In this section we present the results of the analysis, organized as follows. First, we present the results of the regression analysis, including an examination of the models' goodness of fit and ability to predict undernutrition prevalence rates within the DHS sample. Then the models are applied to the 1988 Census data, showing the undernutrition prevalence rates at progressively higher resolution, starting with region-level results, and proceeding to district and subdistrict estimates. The precision of the small-area estimates is then assessed, with respect to the size of the standard errors and the ability to identify areas where the estimates for larger areas mask significantly higher or lower rates in constituent subareas.

Regression Results

As noted earlier, all variables common to the 1988 Census long form and the 1991–92 DHS were identified and then compared to see that the distribution of each variable was similar in the two data sources. When the distribution of a census variable was very different from the distribution of the corresponding variable in the DHS, that variable was eliminated from consideration for the models. Approximately 30 explanatory variables were retained as candidate variables, and the stepwise procedure described earlier was used to select the variables that contributed the greatest explanatory power. The subset of variables selected was allowed to vary across the eight models, guided by the stepwise selection procedure and ex post diagnostics described in the preceding section. For example, the age of the head of household might be included in the model for rural children less than two years of age, but not in the model for urban children less than two years of age. Or a variable might be included in the height-for-age regression, but not in the weight-for-age regression.

Table 1 shows the means for the variables that were selected for the final models, along with the standard errors of the means. The descriptive statistics are shown separately for each of the four categories of children, split by age and rural/urban area of residence. A few unusual aspects of the data bear mentioning. Most are a result of the limitations of census data, which are rarely as detailed as survey data because of the census's more comprehensive coverage of households. Most notably, although most anthropometry analyses use age in months as an explanatory variable, the census only has age in years, so that is how it is measured in the Stage 1 regressions as well. Birth order is also frequently used in anthropometry regressions, but the census does not link mothers and children, so we constructed a variable called "age order" that indicates a child's age rank among under-fives in the household.[8] Also note that some covariates commonly found in anthropometry regressions, such as maternal height, are not included among the explanatory variables because they were not collected in the census.

Finally, the definition of the education variables is a bit unusual, although not because of limitations in the census data. Rather than define education on the basis of the household head, these models follow the approach used by Jolliffe (2002), who finds that it is often the highest level of education of any adult household member (rather than a specific member, such as the head) that is most closely related to household welfare. In this case education is operationalized as a set of dummy variables for four different educational levels: incomplete primary education, complete primary education, incomplete secondary education, and complete secondary education. The omitted category is no schooling whatsoever. The dummy variables take the value 1 if at least one adult in the household has reached that level of education and 0 otherwise.[9]

The height-for-age regressions are shown in Table 2. Between 8 and 15 variables are retained in each of the four different models. Despite having relatively few

[8] The age order variable differs from birth order in at least three ways. First, it doesn't count children five years or older. Second, it does not count children who have died or who are not living in the household for some reason. Third, when there is more than one mother of a child under age five in the household, it combines the children into one ordering, rather than establishing separate orderings for each mother.

[9] Following the advice of an anonymous reviewer, I also experimented with specifying the education variables as the proportion of household members that had completed each of the four educational levels. This alternative specification did not add to the explanatory power of the model or affect the other estimated parameters, so the original specification was retained.

Table 1—Means and standard errors of mean for variables used in first-stage regressions

Variable	Rural less than 24 months	Rural 24 months and older	Urban less than 24 months	Urban 24 months and older
Height-for-age Z-score	-1.578	-2.035	-1.376	-1.823
	(0.038)	(0.049)	(0.143)	(0.140)
Weight-for-age Z-score	-1.185	-1.471	-1.022	-1.303
	(0.043)	(0.039)	(0.089)	(0.100)
Child's age in years	0.512	2.939	0.496	
	(0.012)	(0.018)	(0.038)	
Male child	0.499			
	(0.013)			
Age order	1.143	1.842	1.074	
	(0.017)	(0.050)	(0.012)	
Number of household members	8.339			
	(0.302)			
Number of children less than 5 years old		2.410		
		(0.094)		
Age of head of household		42.373		41.000
		(0.495)		(0.904)
Highest education level in household is incomplete primary		0.227	0.105	
		(0.013)	(0.016)	
Highest education level in household is incomplete secondary	0.058	0.053		0.223
	(0.010)	(0.008)		(0.041)
Highest education level in household is completed secondary			0.033	0.032
			(0.011)	(0.012)
Household has electricity				0.232
				(0.046)
Household has no toilet or latrine		0.176		
		(0.022)		
District sex ratio minus 100		-6.665		
		(0.475)		
District mean years of education for household heads	3.385	3.415		4.101
	(0.052)	(0.053)		(0.238)
District proportion of female-headed households	0.319	0.317		0.304
	(0.004)	(0.004)		(0.007)
District proportion of population less than 5 years old	0.145	0.145	0.130	
	(0.001)	(0.001)	(0.005)	
District proportion of households using piped water				0.536
				(0.033)
District proportion of households with no toilet			0.106	
			(0.017)	
District median elevation of district (meters)		1052.038		
		(35.505)		
District median annual rainfall (millimeters)		956.015		
		(17.673)		
District mean population density (persons per km^2)		79.199	420.294	457.229
		(10.044)	(100.438)	(95.949)
District mean distance to regional headquarters (kilometers)	90.997	89.855		
	(3.312)	(3.156)		
District mean distance to primary / secondary roads (kilometers)	25.408			
	(1.674)			
District mean distance to Dar es Salaam (kilometers)		602.278	410.605	
		(22.393)	(41.198)	
District mean distance to Tanzania coast (kilometers)	495.856			
	(23.245)			

Source: Author's calculations from 1991–92 Tanzania DHS.

Note: Standard error of mean in parentheses, taking into account stratified cluster sample design.

Table 2—Regressions for height-for-age Z-scores

Variable	Rural less than 24 months	Rural 24 months and older	Urban less than 24 months	Urban 24 months and older
Child's age in years	-0.8685***	-0.0872*	-0.7463***	
	(12.36)	(1.80)	(6.34)	
Male child	-0.2161***			
	(3.49)			
Age order	-0.1680*	0.1501**	-0.5422**	
	(1.78)	(2.07)	(2.21)	
Number of household members	0.0206**			
	(2.53)			
Number of children less than 5 years old		-0.068		
		(1.34)		
Age of head of household		0.0100***		-0.0127**
		(4.26)		(2.58)
Highest education level in household is incomplete primary		-0.1366	-0.7014**	
		(1.36)	(2.61)	
Highest education level in household is incomplete secondary	0.3319**	0.3603**		0.3933***
	(2.18)	(2.16)		(3.14)
Highest education level in household is completed secondary			0.8604***	1.0718***
			(2.99)	(3.88)
Household has electricity				0.4590***
				(3.58)
District sex ratio minus 100		0.0217*		
		(1.80)		
District mean years of education for household heads	0.1935***	0.1877**		0.3906***
	(3.33)	(2.43)		(6.91)
District proportion of female-headed households	1.5643**	2.1005**		2.6762**
	(2.09)	(2.06)		(2.58)
District proportion of population less than 5 years old	5.8480***	10.0210***	-15.6651***	
	(2.86)	(3.19)	(3.02)	
District proportion of households using piped water				-1.7649***
				(7.65)
District proportion of households with no toilet			2.7290***	
			(2.76)	
District median elevation of district (meters)		-0.0003**		
		(2.34)		
District median annual rainfall (millimeters)		-0.0008***		
		(3.43)		
District mean population density (persons per kilometer^2)		0.0006***	0.0004***	0.0003***
		(2.91)	(3.28)	(3.30)
District mean distance to regional headquarters (kilometers)	-0.0023**	-0.0043***		
	(2.28)	(3.73)		
District mean distance to primary / secondary road (kilometers)	-0.0040**			
	(2.54)			
District mean distance to Dar es Salaam (kilometers)		0.0009***	0.0012***	
		(4.27)	(4.08)	
Constant	-2.7195***	-4.0579***	0.7194	-3.1484***
	(5.18)	(6.04)	(1.23)	(8.62)
Number of observations	2,154	2,413	409	479
Number of primary sampling units	232	232	88	87
Adjusted-R^2	0.1406	0.0756	0.2357	0.1930

Source: Author's calculations from 1991–92 Tanzania DHS.
Notes: Absolute value of *t* statistics in parentheses. *Significant at 10 percent; ** significant at 5 percent; *** significant at 1 percent.

observations, the urban models performed better than the rural models, explaining between 19 and 24 percent of the variation in height-for-age Z-scores in the 1991–92 DHS data. The rural models for older children performed the worst of the four groups, with an adjusted-R^2 of only 0.08.

The weight-for-age regressions are shown in Table 3. The results are largely similar to those observed in the height-for-age estimations, although in the urban stratum the explanatory power is generally lower in the weight-for-age models. The adjusted-R^2 values for all of the models are lower than those typically found in poverty mapping applications, in which the natural logarithm of consumption is the dependent variable. Even with the constraints of census data, Stage 1 regressions for poverty mapping usually have an adjusted-R^2 value between 0.3 and 0.7, often being in the neighborhood of 0.5. As noted in the introduction, the lower explanatory power of the nutrition models means that the small area estimates will be less precise than the estimates usually obtained when analyzing poverty.

As the regression equations are not intended to be causal models, one should not dwell on interpreting the signs and magnitudes of the regression coefficients. This is especially true because of the collinearity among the explanatory variables. With those caveats in mind, we note the expected negative sign on the age coefficient and positive signs on the higher levels of education. Also note that, other things being equal, in rural areas, boys less than two years old are also significantly more stunted and underweight than girls. This suggests intrauterine growth retardation (IUGR), usually a result of poor maternal health and nutrition during pregnancy. Males are more susceptible to IUGR than females, and this may explain the significantly lower Z-scores of rural boys less than two years old. The coefficient on sex of the child was not significant in urban areas or for rural children 24 to 59 months, indicating no gender difference in nutritional status for those groups after controlling for other variables.

One simple test for assessing the quality of the regressions is to examine their ability to predict accurately within the estimation sample. This test is not very

Table 3—Regressions for weight-for-age Z-score

Variable	Rural less than 24 months	Rural 24 months and older	Urban less than 24 months	Urban 24 months and older
Child's age in years	-0.8819***		-0.7916***	
	(12.15)		(5.74)	
Male child	-0.1548**			
	(2.40)			
Age order		0.1288***		
		(3.15)		
Female-headed household		-0.2026***	0.3728	
		(2.82)	(1.36)	
Number of children less than 5 years old		-0.0557		
		(1.62)		
Age of head of household		0.0070***		
		(3.52)		
Highest education level in household is incomplete primary		-0.1358*	-0.369	
		(1.95)	(1.43)	
Highest education level in household is incomplete secondary	0.2942	0.2821**		0.2483*
	(1.23)	(2.56)		(1.76)
Household has electricity			0.3262**	0.3604***
			(2.07)	(3.05)
Household has no toilet or latrine		0.2028***		
		(2.65)		
District mean years of education for household heads	0.2117***			0.2179***
	(3.54)			(3.45)
District proportion of female-headed households	2.3277***			
	(3.24)			
District proportion of population less than 5 years old				-12.5533***
				(3.21)
District proportion of households using piped water				-1.0931***
				(4.67)
District median elevation of district (meters)				0.0003***
				(2.77)
District median annual rainfall (millimeters)		-0.0005***		
		(3.15)		
District mean population density (persons per kilometer^2)		0.0006***	0.0003***	
		(3.49)	(2.67)	
District mean distance to regional headquarters (kilometers)	-0.0045***	-0.0033***		
	(5.10)	(3.18)		
District mean distance to primary / secondary roads (kilometers)		0.0040***		
		(2.96)		
District mean distance to Dar es Salaam (kilometers)		0.0009***	0.0004*	
		(8.21)	(1.85)	
District mean distance to Tanzania coast (kilometers)	0.0004**			
	(2.19)			
Constant	-1.9064***	-1.8386***	-1.0420***	-0.3921
	(5.34)	(9.50)	(6.93)	(0.64)
Number of observations	2,154	2,413	409	479
Number of primary sampling units	232	232	88	87
Adjusted-R^2	0.1327	0.0800	0.1383	0.1388

Source: Author's calculations from 1991–92 Tanzania DHS.

Notes: Absolute value of *t* statistics in parentheses. * Significant at 10 percent; ** significant at 5 percent; *** significant at 1 percent.

demanding, because the predicted values from the regressions should closely mimic the actual values when using the same data that were used to estimate the models. Table 4 presents the actual and predicted stunting and underweight prevalence rates at national, urban, and rural levels. The table shows that the within-sample predictive power of the models is very good. Most of the predictions are within one-tenth of a percentage point of the actual values, and none of the differences between the actual values and the predicted values are statistically significant.

Table 4—Within-sample prediction of stunting and underweight prevalence

Prevalence	Actual 1991-92	Estimated 1991-92
	(percent)	
Stunting — all	43.6	43.9
Rural	45.1	45.0
Urban	37.8	39.5
Underweight — all	29.2	29.4
Rural	30.3	30.3
Urban	24.8	25.9

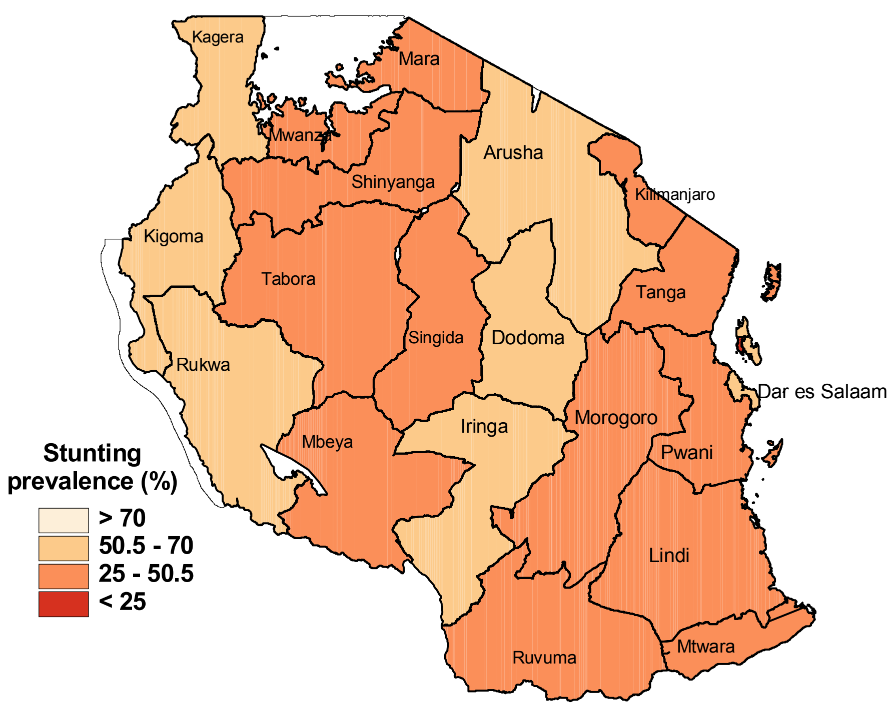
Source: Author's calculations from 1991–92 Tanzania DHS.

Clearly, besides being a useful benchmark for evaluating the predictive power of the regression models, Table 4 shows the seriousness of undernutrition in Tanzania, as was already suggested by Figures 1 and 2. Nationally, 44 percent of children less than five years old have height-for-age Z-scores less than –2, with the stunting rate higher in rural areas. Underweight prevalence is also high at 29 percent and is also significantly higher in rural areas than urban areas.

Small-Area Estimates of Stunting and Underweight

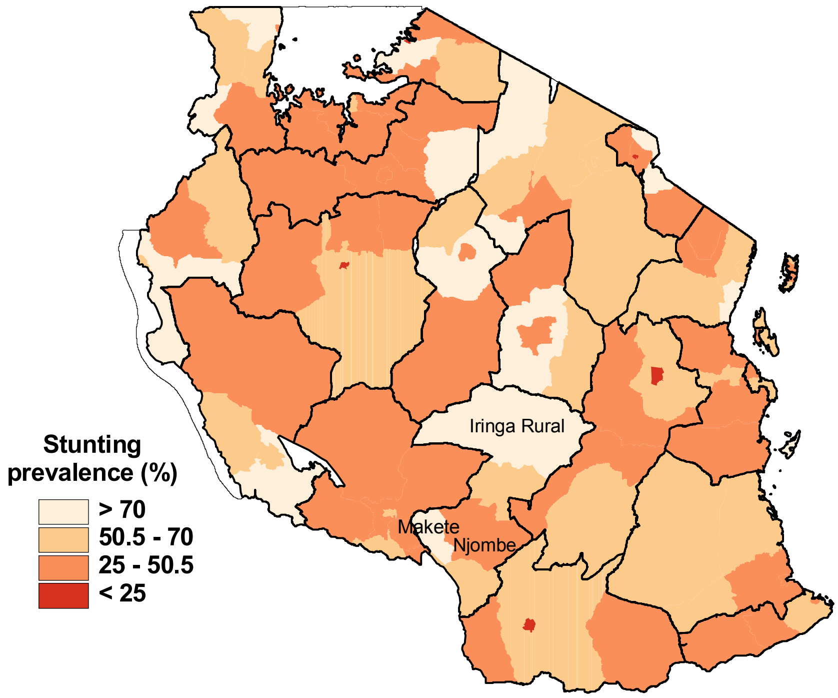
Table 4 represents the highest degree of disaggregation that the 1991–92 DHS is designed to support on its own, but one can get a more detailed geographic picture from the Stage 2 estimation using the regression results and the census data. Figures 3 through 5 show the estimated stunting rates in 1988 (the census year) at the regional, district, and “grouped ward” levels.[10] The darker shaded areas are those in which the stunting prevalence is less than the national mean of 50.5 percent, while the areas with higher than average stunting are shown with a relatively lighter shading. The progressively higher resolution maps show that there is often a great deal of heterogeneity underlying region- or district-level means. Among the many illustrative examples, one of the most striking is Iringa Region. Figure 3 shows that the estimated stunting prevalence for Iringa Region in 1988 is between the national average of 50.5 and 70 percent (the actual estimate is 65 percent). Moving to the district-level map in Figure 4, we see that Makete and Iringa Rural districts have estimated stunting rates over 70 percent, whereas less than 40 percent

Figure 3—Estimates of stunting prevalence at region level



[10] Technically it is possible to use the small-area estimation procedure to estimate undernutrition rates for units as small as a ward. However, the combination of the small size of many wards and the limitation of the 20 percent sample for the census long form means that most ward-level estimates are too imprecise to be useful. To get subdistrict estimates, adjacent wards were grouped so that each of the resulting “grouped wards” has approximately 1,000 observations on children less than five years of age.

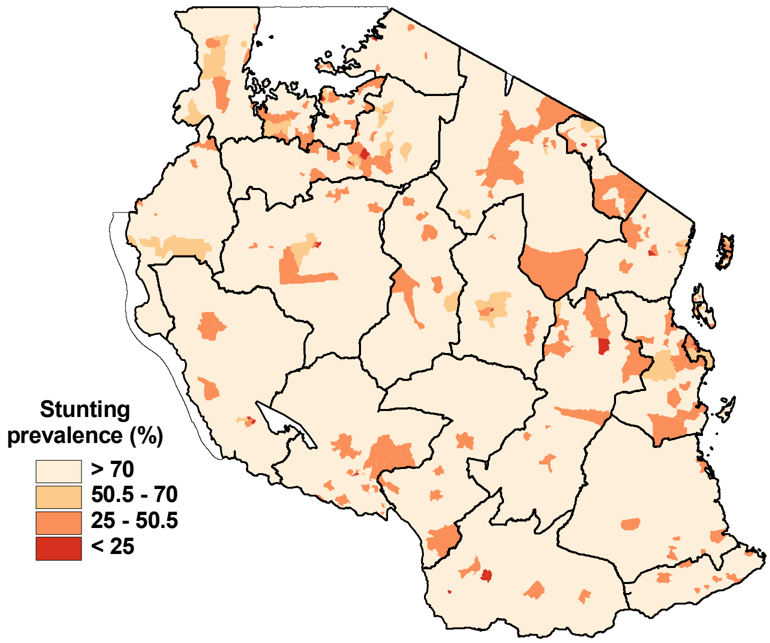
Figure 4—Estimates of stunting prevalence at district level



of the under-fives in Njombe District are estimated to be stunted. Zooming in one step closer to the subdistrict ("grouped ward") level (Figure 5) reveals that the relatively low stunting rate in Njombe District is largely attributable to low stunting rates in a few wards, while the rest of the district has stunting rates of 70 percent or higher. Similar, albeit somewhat less dramatic, stories may be seen in other regions, including Arusha and Kilimanjaro. Mwanza and Ruvuma regions show the converse picture, with a regional stunting prevalence that is below the national average, but that is driven by low stunting in a few of the more densely populated areas, and above average stunting over most of the rest of the region.

Nutrition maps for underweight (low weight-for-age) prevalence are shown in Figures 6 through 8. Like the stunting maps, the map shading becomes increasingly darker with lower rates of underweight prevalence, with two levels of shading on either

Figure 5—Estimated stunting prevalence, by grouped wards



side of the national underweight prevalence of 15.9 percent. Although there are several differences between the stunting and underweight patterns, the overall impression is consistent in the two sets of maps. In addition to the heterogeneity that exists at the district and subdistrict levels, one of the patterns that emerges with some consistency is the generally lower rates of undernutrition (both stunting and underweight) in urban areas compared to rural areas, even for small urban areas. That said, it should also be noted that urban areas are themselves heterogeneous, with some areas showing as much undernutrition as rural areas.

How many of the differences at the district and subdistrict levels are statistically significant? One way to answer the question is by doing pairwise tests for all possible combinations. Rather than undertaking that tedious exercise, another useful way to look at the question is to see which districts or grouped-wards have undernutrition estimates that are significantly different from the regional or district means. In other words, what new information do we gain from the small-area estimation?

Figure 6—Estimated underweight prevalence, by region

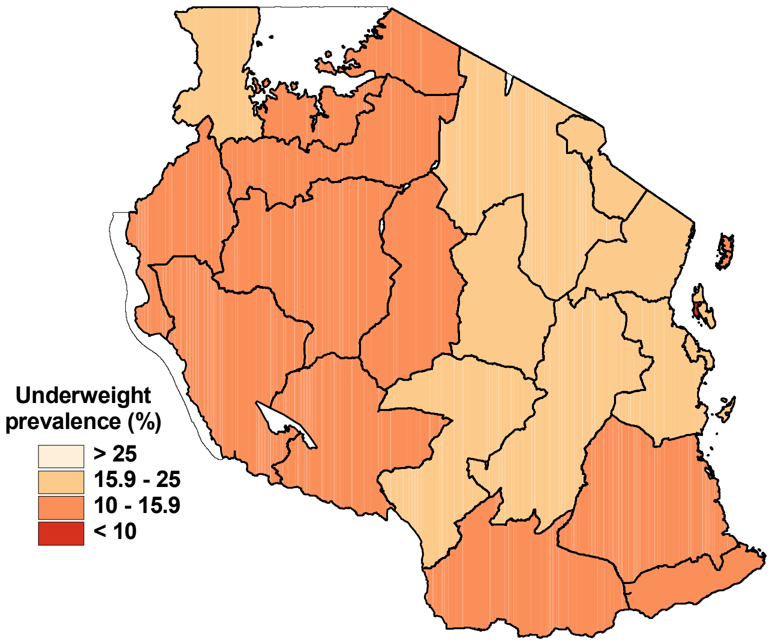


Figure 7—Estimated underweight prevalence, by district

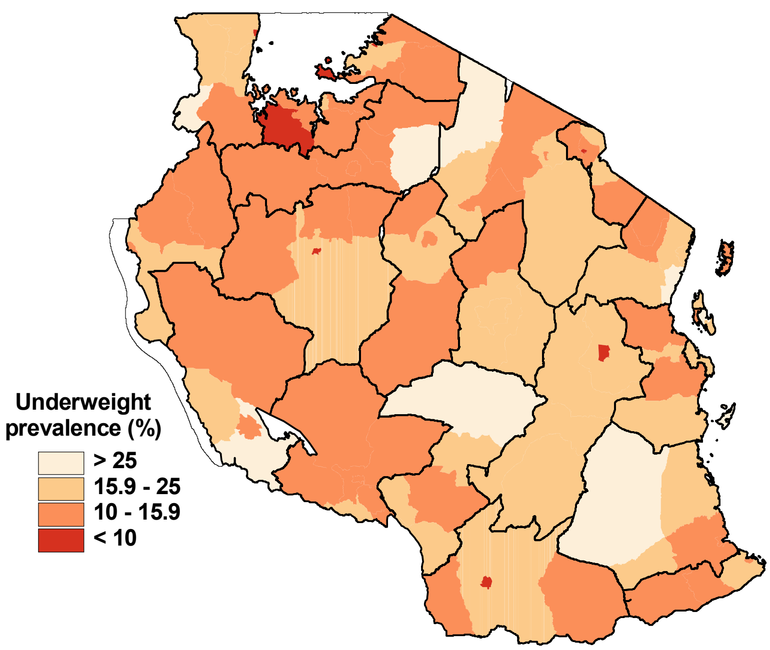


Figure 8—Estimated underweight prevalence, by grouped wards

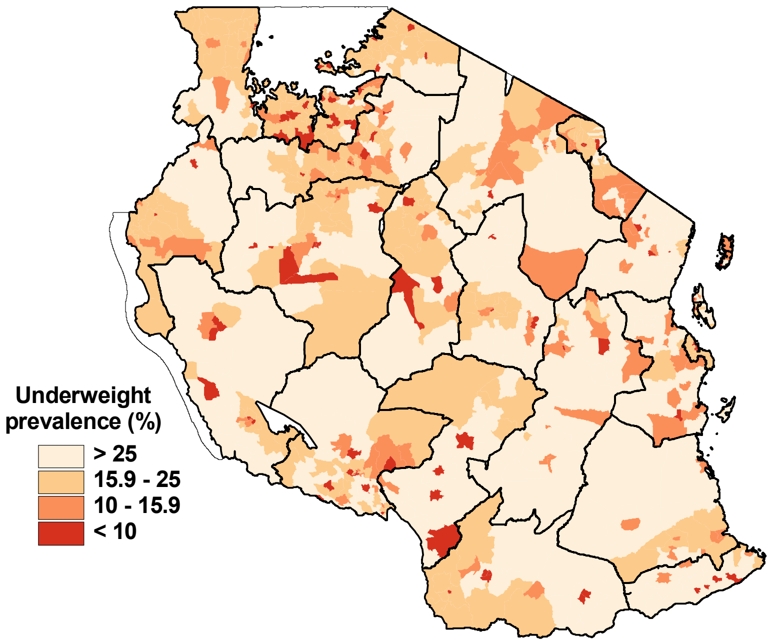


Figure 9 shows the grouped wards in which the stunting prevalence is significantly different from the prevalence at the district level. For most of the country the differences are not statistically significant, which is shown as the unshaded area. The areas where subdistrict stunting is significantly worse than the district mean (shaded grey) are largely rural areas in southern and southeastern Tanzania. A roughly similar number of subdistricts have stunting rates that are significantly better than the district mean, but most are not visible in the map because they are populous but geographically small urban areas. These urban areas are scattered across the country, and include parts of Dar es Salaam, Pangani, Tanga, Mwanza, Mbeya, Liwale, and Mafia. Figure 10 presents analogous information for differences in underweight prevalence, showing that significant within-district differences in underweight occur in many of the same places where significant differences in stunting are observed, including many of the same urban areas.

Figure 9—Significant differences in stunting prevalence between district and subdistrict

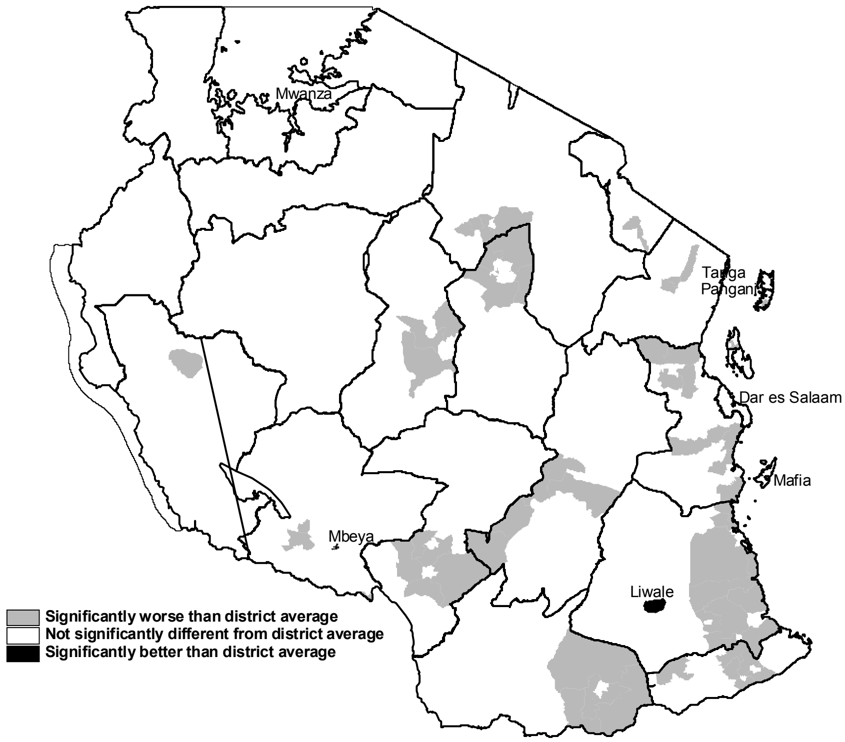
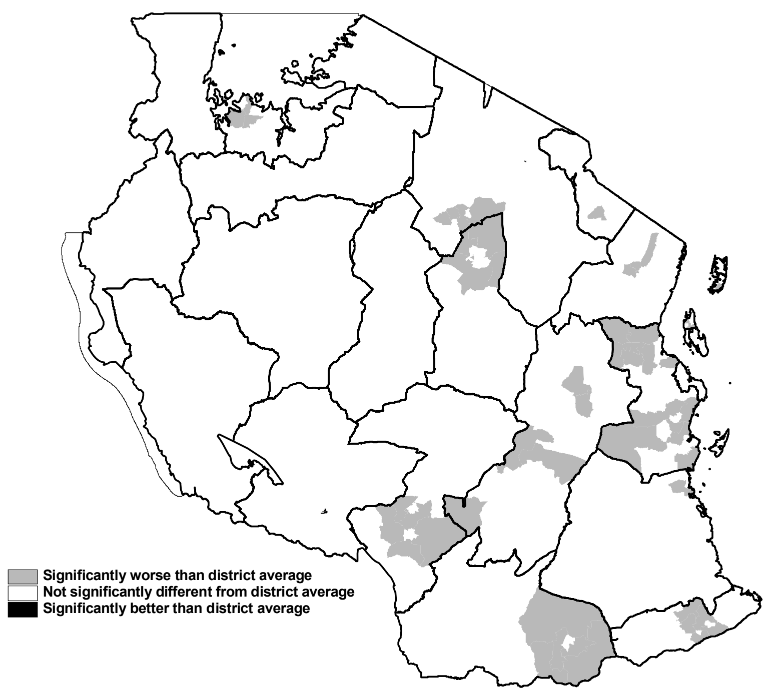


Figure 10—Significant differences in underweight prevalence between district and subdistrict



Although there appear to be considerable differences in the point estimates, most are not statistically significant because of the relatively large standard errors associated with the regional, district, and subdistrict estimates. For all three levels of aggregation the median standard error—expressed as a percentage of the point estimate—is around 12 percent. So a subdistrict with a stunting prevalence of 50 percent would typically have a standard error of around 6 percentage points, which implies a rather broad 95 percent confidence interval that ranges from 38 percent to 62 percent.

4. Summary and Conclusions

This paper describes an approach for adapting small-area estimation, or poverty mapping, methodology for the analysis of child nutritional status. It briefly discusses the main anthropometric measures used to assess nutritional status of children less than five years old, focusing on height-for-age and weight-for-age. The paper presents the three-stage approach that has become familiar in the poverty mapping literature, with modifications as required for estimating prevalence of undernutrition instead of poverty. The essence of the method is to combine the strengths of "narrow and deep" detailed household surveys with "broad and shallow" census data to arrive at estimates of undernutrition for finely disaggregated subgroups of the population.

The first stage, logically dubbed "Stage 0," involves identification of common variables in the survey and the census, and careful comparison of the distributions of the variables to ensure that variables that appear to be similar are indeed comparable. Stage 1 then uses regression analysis on the household survey data set to estimate the quantitative relationship between standardized anthropometric measures and a set of characteristics available in both data sets that are expected to correlate with nutritional status. In Stage 2, the estimated regression coefficients are applied to the census data to estimate anthropometric Z-scores for every child less than five years old recorded in the long form of the census. The predicted Z-scores are then transformed into the expected probability of being stunted or underweight, and prevalence rates are calculated for various levels of geographic aggregation. In Tanzania, the levels are the region, the district, and subdistricts defined by the grouping of adjacent wards.

The Stage 1 regression results were somewhat disappointing. Although a good number of explanatory variables were identified, they only accounted for about 20 percent of the variation in Z-scores in urban areas, and less than 15 percent in rural areas. As a result, the Stage 2 estimates have wide confidence intervals, so it is difficult to detect statistically significant differences.

That said, the point estimates are suggestive of distinct spatial patterns in undernutrition in Tanzania. While there is some variation in undernutrition rates between regions, there is a much greater range of undernutrition among the districts and subdistricts that make up a region. A pattern that emerges frequently is an urban center—including small urban centers such as district headquarters—with lower than average undernutrition rates surrounded by rural areas with rates that are higher than average. One of the clearest examples of this appears in the subdistrict level stunting map (Figure 5), where the urban centers along the east-west Kigoma to Dar es Salaam railroad line stand out as dark spots, indicating lower stunting rates than is found in the surrounding countryside. This suggests the need for greater attention to meeting nutrition needs in rural areas. This entails not only ensuring a sufficient supply of nutritious food but also adequate health care, nutrition extension, safe water supplies, and other factors that determine nutritional outcomes. Of course, this needs to be balanced with programs to address undernutrition in urban areas; even though undernutrition rates are lower in urban areas, the absolute numbers of undernourished are still substantial.

Returning to the first of the research questions posed at the outset of this paper, is nutrition mapping feasible? We believe the answer is a qualified yes. Although the models are not as successful as poverty mapping models in explaining variation in the dependent variable, that was expected. Even with the lower adjusted-R^2, the spatial pattern of undernutrition appears perfectly plausible, and it is possible to detect some significant differences at the subregional level.

The findings in this study indicate that it would be worthwhile to attempt to update these nutrition maps by using the 2002 Population Census and a recent DHS survey. Drawing from the experience of this study, high priority should be given to improving the precision of the estimates, in order to strengthen the inferences that can be made from the analysis. One potential avenue for achieving this is greater use of spatial variables from GIS and other sources. For future work, perhaps more resources should be devoted to intensive development of these data sources. Another avenue would be to try to improve the efficiency of the estimates by following the approach of Fujii (2005), incorporating information about contemporaneous correlation of the error terms of an individual's height-for-age and weight-for-age Z-scores, as well as modeling a common household component to the error term for multiple under-five children in the same household.

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