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Spatial and social factors drive anemia in Congolese women

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Abstract

Anemia is common in women of child-bearing age in the Democratic Republic of the Congo (DRC). As part of the 2007 DRC Demographic and Health Survey (DHS), 4,638 women of childbearing age (including 526 pregnant women) were tested for HIV and had the hemoglobin content of their blood recorded. We assessed malaria prevalence using laboratory methods. The DHS provided extensive information for individuals, as well as household cluster coordinates which enabled us to derive several spatial variables. Multilevel analyses were conducted to determine individual and contextual risk factors for anemia. Prevalence varied geographically and was associated with both one's ethnic group and the amount and type of nearby agriculture. In contrast, prevalence was not affected by HIV or malaria status.

Keywords

anemia; Congo; malaria; spatial; multilevel

Background

Anemia globally and in the DRC

Anemia is a global public health problem. Since 1985, global prevalence estimates for anemia have risen drastically (Stoltzfus, 2001). Estimates are particularly high in sub-Saharan Africa, where 40-80% of women are estimated to be anemic (Ngnie-Teta et al., 2007b, Ngnie-Teta, 2009). In the Democratic Republic of the Congo (DRC), 52.8% of non-pregnant women and 67.3% of pregnant women were estimated by the WHO to be anemic

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(less than 11 g/dl hemoglobin in the blood), making anemia a severe public health problem in the country (Who, 2008). In women, anemia is associated with higher risk for maternal morbidity and mortality and lower productivity, and pregnant women are furthermore at higher risk for anemia. Maternal anemia may also lead to higher risks for premature births, perinatal and neonatal death, and low birth weight (Ngnie-Teta, 2009). Common symptoms include fatigue, weakness, fainting, chest pain, and even heart attacks in severe cases.

There are a variety of causes of anemia. The principal cause, malnutrition, is common in sub-Saharan Africa (Conway and Sechler, 2000). Anemia in adults is also the result of deficiencies in specific nutrients such as iron and vitamin B-12. Infectious diseases such as malaria, HIV, schistosomiasis, and hookworm have also been implicated as major causes of anemia (Guyatt, 2001, van Eijk et al., 2002, Ter Kuile et al., 2004), but the relative contributions of these potential causes to the overall anemia burden are not known. Guyatt and Snow (2001) estimated that 26% of cases of anemia in pregnant women in sub-Saharan Africa are due to malaria (Guyatt, 2001). However, there has never been a large epidemiological study using biomarkers in this region to correlate the risks of malaria and anemia.

Public health interventions which may control anemia include iron supplementation, mass de-worming, and malaria control programs. Iron supplementation programs are common and thought to mitigate anemia, although the evidence for their success is mixed (Stoltzfus, 2001, Scholl, 1994, Palupi, 1997). More information about the causes of anemia could lead to more appropriate applications of these interventions.

Disease ecology of anemia

The examination of population, behavioral, and habitat factors simultaneously falls under the medical geographic theory of the cultural ecology of disease. Although several twentieth century scientists including Jacques May, René Dubos, and Ralph Audy contributed to the formulation of this theory, it was synthesized by Melinda Meade in the 1970s (Meade, 1977) and continues to be an important focus of medical geographic research (Meade and Earickson, 2000, Meade and Emch, 2010, Mayer and Meade, 1994, Mayer, 1996, Mayer, 2000, Emch, 1999, Meade, 1986, Learmonth, 1988, Gesler et al., 1997). Meade established the “triangle” of human ecology in which habitat, population, and cultural behavior are considered as three nexuses. Habitat is meant as the social, natural, and built environments in which people live, population considers humans as biological organisms with age, gender, and genetic characteristics which make them more or less likely to be hosts of specific diseases, and behavior encompasses the beliefs, social organization, and technologies specific to a culture in which a disease may occur.

While much past work has focused on the population and behavioral factors associated with anemia risk and prevalence (Guyatt, 2001, Ayoya et al., 2006, Pasricba et al., 2008, Lartey, 2008, Thomson et al., 2011, Rogerson et al., 2000, Levine et al., 2001, Antelman et al., 2000), little work has explicitly explored habitat factors in relation to anemia. While Jacques May described the ecology of malnutrition in west Africa up until 1965 (May, 1965), no studies clearly addressed the prevalence of anemia in African women from a disease ecology perspective. This represents an important gap in anemia literature. Other important gaps include a lack of estimation of highly localized anemia rates in any sub-Saharan African country, as well as an absence of studies which unambiguously examine the relationship between malaria parasitemia and blood hemoglobin levels. Although malaria has been found to contribute to higher anemia prevalence (Steketee et al., 2001, Faich and Mason, 1975), much evidence has been anecdotal (Crawley, 2004) or has not been derived from molecular surveillance results which can detect submicroscopic infections.

DRC geography and socio-political context

The 2007 DRC DHS is the first of its kind in the country, making this study an important starting point for assessing the effects of population, behavioral, and environmental change on the nutritional status of the country's population. The enormous, low-lying central area of the country is a basin-shaped flat terrain which slopes toward the west and is covered by tropical rainforest. This area is surrounded by mountain terraces in the west, plateaus which merge into savannas in the south and southwest, and dense grasslands in the north which extend beyond the Congo River. The extreme eastern region is characterized by high mountains. Influenced by topography, climate, and hydrography, the soil of the DRC offers varied mineral and agricultural potential, but decades of chronic violence and population displacement have negatively affected the physical landscape. Progress has also declined in terms of land restoration, human rights, and the economy, meaning that priorities such as health, education, and infrastructure are extremely difficult to address in the absence of a minimally functioning state (Reyntjens, 2001). As such, many deaths in the country occur as a result of malnutrition despite the vast agricultural potential (Coghlan et al., 2006, Coghlan et al., 2009). The lack of effective health care systems also means that the distribution and burden of highly prevalent diseases like anemia are poorly understood in the DRC.

Study aims

Here, in addition to estimating the subnational distribution of anemia in the DRC using the 2007 DRC Demographic and Health Survey (DHS) (Scholl et al., 1994a), population factors such as pregnancy and malaria parasitemia, behavioral factors such as ethnic group and wealth, and habitat factors such as proximity to urban areas, agricultural land cover, and population density are all considered in relation to anemia prevalence. While our data for anemia outcome is from 2007 only and thus does not allow us to directly compare the anemia response over time to important factors such as war, migration, or displacement, in light of the political context, we include all available spatial information regarding the DRC conflict in our analysis. The rich information provided by the DHS survey along with the consideration of an array of individual, environmental, and socio-political factors allows us to provide the broadest, most comprehensive understanding of the determinants of anemia prevalence in the DRC using a framework which has not been used to study anemia in past literature.

Methods

Demographic and Health Surveys

DHSs provide accurate demographic data in developing countries via large representative population-based surveys and in some countries also includes blood sampling for HIV surveillance. Nine thousand households were surveyed in the 2007 DRC DHS and 99.3% were successfully identified and interviewed. This included 9,995 women aged 15-59 years, 4,638 of whom were tested for HIV and had the hemoglobin content of their blood recorded using a portable device (HemoCue). Hemoglobin level was communicated immediately to all participants, and those with severe anemia (<7g/dL for non-pregnant women, and < 9g/dL for pregnant women) were referred to local medical care facilities. Of these 4,638 women, 526 reported being pregnant at the time of the interview. HIV serostatus was determined as part of the survey. Genomic DNA was extracted from the dried blood spots for testing in real-time PCR assays for Plasmodium falciparum, malariae, and ovale (Taylor et al., 2010, Taylor, 2010) as previously described. For the current study, altitude-adjusted hemoglobin levels were used and high malaria parasitemia was defined as a cycle threshold (Ct) value lower than 30. Data on clinical symptoms are unavailable in the DHS database.

Mapping of anemia prevalence in the DRC

Geographic coordinates of clusters of households were collected with global positioning system receivers. To ensure privacy, the coordinates of these 300 clusters were randomly displaced by 5 km in rural areas and 2 km in urban areas. The number of female respondents per cluster ranged from 6 to 30, with an average of 15. Anemia prevalence was computed for each cluster using the survey's sampling weights and altitude-adjusted hemoglobin levels. The percent anemic in each cluster was computed with a cutoff of 11 g/dl hemoglobin in the blood according to World Health Organization standards for moderate anemia (mild anemia = 11-12 g/dL, moderate anemia = 8-11 g/dL, severe anemia). A smoothed map of the spatial pattern of anemia prevalence in the DRC was then created in a geographic information system (GIS) using inverse distance weighting (IDW) spatial interpolation in ArcGIS 9.3 (ESRI, Redlands CA). IDW uses nearby values to predict prevalence in unmeasured locations. The prevalence values of the 12 closest clusters to an unmeasured location were used to interpolate its prevalence value, with closer communities having a greater influence than those farther away. Compared to other geostatistical interpolation techniques which eliminate high and low values, inverse distance weighting maintains the entire probability distribution of values, making it appropriate for visualization of active surveillance data.

Assessing drivers of anemia prevalence in the DRC

A comprehensive database was created which included population, behavioral and habitat variables hypothesized to have a relationship with anemia prevalence. The variables are laid out according to a disease ecological framework in Figure 2, which highlights those variables which were hypothesized to have a direct effect on anemia outcome, as well as those which were hypothesized to have an indirect effect via factors such as dietary decisions and practices, individual food supply, access to a diverse diet, and nutritional and medical support. Descriptive statistics for each variable are also provided in Table 1, along with the causal mechanisms supporting their inclusion in our models.

While we did not have explicit information about individuals’ nutritional intake, we aimed to account for their access to a nutritious diet based upon several individual- and community-level factors such as household wealth, urban versus rural residence, and amount and type of agriculture nearby. All population and behavioral variables were obtained from the DHS survey, as well as the time to a health facility and urban versus rural community type. The wealth index was computed by scoring households according to assets and household characteristics using principal components analysis and then classifying the scores into quintiles, resulting in an index of 1-5 ranging from the poorest to the richest. Ethnic groups were reported by individuals in the DHS questionnaire according to eight broad categories: Bakongo, Basele, Bas-Kasai and Kwilu-Kwongo, Cuvette Centrale, Ubangi, Uele (Lac Albert), or Lunda.

The remaining habitat/environment variables were computed in the GIS. A GIS database of armed conflict and refugee camp locations was compiled in order to examine the effects of ongoing warfare in the DRC on anemia outcome. The Armed Conflict Locational Event Dataset (ACLED) includes locations and dates of individual battle events and rebel activity in states affected with civil war (Raleigh and Hegre). For the DRC and its surrounding countries, information dating from 1960 onward is available. Fighting in the eastern DRC increased in 1994, and conflict variables were computed between 1994 and 2006 (the year before the DHS survey was conducted). The variables used in this study included battle events within 100 km, rebel activities within 100 km, and all conflict events combined within 100 km. This distance was chosen as population migration from conflict is expected to occur across larger distances. The locations of current and recently closed (post-2004) refugee camps and settlements in the DRC and its surrounding countries were obtained from the United Nations Human Rights Council. Recently closed camps were included as they were likely still inhabited. The distance of a community centroid to a refugee camp was computed, as well as the density of camps within 100 km of the communities.

The percent of agricultural land cover within 25 km of one's community was computed using 2005 GlobCover data which was classified using the United Nations Land Cover Classification System by the Global Land Cover Network (http://www.glcn.org). Dominant agricultural type was derived by the Consultative Group on International Agricultural Research (http://www.cgiar.org) from the United States Geological Survey Earth Resources Observation System Data Centre (http://eros.usgs.gov) 1998, 1 km resolution, global land cover characteristics database. Agricultural types included forest, highland perennial, cereal root crop mixed, maize mixed, root crop, and tree crop. The majority of the DRC's land area is dominated by forest agriculture.

The population per square kilometer within 25 km of each survey community was also computed using a population density grid from the Gridded Population of the World database (GPW v3, http://sedac.ciesin.columbia.edu), and areas with international aid were delineated by health district by the DRC Minister of Health as of 2003. Aid agencies included Cooperation Belge, African Development Bank, 9th European Union Development Fund , USAID, Minimum Partnership Program for Transition and Recovery, Emergency Multisectorial Rehabilitation and Reconstruction Project, Corporation for Technical Cooperation, and Health Sector Rehabilitation Support Project.

Statistical methods

The population, habitat, and behavioral indicators listed in Table 1 were entered into four multilevel regression models: (1) logistic regression with dichotomous dependent variable for anemia (<11 g/dl Hgb) or no anemia in all women (2) linear regression with a continuous hemoglobin level dependent variable in all women, and (3) and (4) are the same as (1) and (2), respectively, except in pregnant women only. Individual response variables related to age, gender, pregnancy, HIV and malaria status and behaviors were entered into the model along with the array of community-level variables. Multilevel analysis was chosen because the nested structure of the data required simultaneous examination of group- and individual-level variables (Diez-Roux, 2000, Duncan, 1998). Additionally, the multilevel approach produces correct standard errors and parameter estimates if outcomes for individuals within groups are correlated (and thus the standard regression assumption of independence of observations is violated). Multilevel models consist of two sets of equations, one explaining variation at the individual level, and the other explaining variation at the group level. Bivariate correlations between all variables were tested prior to entering variables into the models in order to avoid multicollinearity. The models were built in SAS v. 9.2 (SAS Institute, Cary, N.C.) using PROC GENMOD and using the sampling weights of the survey. The best-fitting models were chosen using Akaike's Information Criterion (AIC).

Results

Anemia prevalence

Table 1 provides descriptive statistics for all variables entered into the analysis according to population, behavioral, and environment (habitat) categories. Table 2 of weighted frequency computations showed that in all women, 32.2% were anemic at less than 11 g/dl Hgb, while 0.67% were anemic at less than 8 g/dl Hgb. In pregnant women, 56.8% were anemic while 0.5% were severely anemic. The IDW interpolation mapping results for anemia at less than 11 g/dl Hgb in all women are shown in Figure 1, with a range of 0-92% prevalence estimated across the DRC. In general, the southeast portion of the country has lower anemia rates, as well as areas surrounding major cities. The central part of the country contains higher anemia rates.

Table 3 provides a summary of the percent that were found to be anemic (< 11g/dl Hg) or severely anemic (< 8 g/dL Hg) according to malaria parasitemia. Slightly more women with malaria parasitemia were found to be anemic than those who were not parasitemic (34.5% as compared to 31.2%). In pregnant women, 60 percent of those with malaria parasitemia were found to be anemic as compared to 54.7 percent of non-parasitemic pregnant women. All differences between groups were significant at $p < 0.01$.

Multivariate analysis

Figure 3 provides a summary of variables that significantly raise the risk for anemia in any of the four models, those which significantly lower risk, and those for which no significant relationship was found in any model. Tables 4 through 7 show the results of the multilevel regression models. Of the 4,368 female respondents, 4,356 were included in the first two models due to missing values. Of the 526 pregnant respondents, 497 were included in the second two models.

In all women, being pregnant significantly raises the likelihood of being anemic; specifically, pregnant women were at 3.74 times the risk of being anemic at less than 11 g/dl Hgb than non-pregnant women and also had significantly lower hemoglobin levels overall. This merited examination of separate models for pregnant women alone whose results are discussed later. Older women had a higher prevalence of anemia, along with Lunda women who exhibited lower hemoglobin levels. At the community level, living in a community dominated by maize mixed agriculture significantly lowered women's odds of being anemic at less than 11 g/dl Hgb (74% less likely) as well as raised their hemoglobin levels. Conversely, living in a community dominated by tree crop agriculture significantly raised women's odds of being anemic at less than 11 g/dl Hgb (68% more likely) as well as lowered their hemoglobin levels. Highland perennial and root crop agriculture were associated with lower odds of being anemic as well. While urban residence was not associated with greater or lesser risk for anemia in all women, living in a more densely populated area raised the odds of being anemic. Living farther from a refugee camp was associated with lower hemoglobin levels.

In pregnant women, more significant associations were found with the continuous hemoglobin-dependent variable than the dichotomous anemia variable. This is probably due to the fact that the number of pregnant women is relatively small (526). Having a refrigerator was significantly associated with both lowered odds for anemia (29.5% less likely) as well as raised hemoglobin levels. Women who identified themselves as Bakongo, Cuvette Centrale, or Ubangi exhibited significantly lowered hemoglobin levels, as well as more educated women. At the community level, both living in an urban area and one with more agricultural land cover put a women at lower odds of being anemic as well as raised her hemoglobin levels overall. More densely populated areas exhibited higher odds for anemia as well, and living further from a town significantly raised women's hemoglobin levels. Tree crop agriculture was associated with lowered hemoglobin levels as well. People in these areas need money to buy food and such expenditures, especially by men for women and children, may not be a priority.

Strikingly, malaria parasitemia was not associated with anemia in any of the models. Even when malaria parasitemia was replaced in the models with high parasitemia alone, it remained a non-significant predictor of anemia in all women and pregnant women alone (data not shown). High parasite density was rare in the sample population, with 135 women, including 19 pregnant women, found to have such high levels of parasites in their blood. Other factors which were not associated with anemia include HIV and wealth. Among habitat variables, the time to a health facility, nearby conflict density, and presence of international aid also had no significant effect on anemia or hemoglobin level outcome.

Discussion

Anemia prevalence was found to vary geographically and to be dependent on a variety of individual-level and community-level variables. At the individual level, several population and behavioral factors were found to be significant, with pregnancy unsurprisingly being the single largest risk factor for being anemic. While the relatively low prevalence of HIV in our study population (1.3%, (Messina et al., 2010)) may explain its lack of association with anemia, it is remarkable that malaria parasitemia was not a significant predictor of anemia outcome even at high parasite levels. Although the bivariate analyses in Table 3 suggest that malaria parasitemia may be associated with anemia, its lack of statistical significance in the multivariate models indicates that other factors are more important in accounting for anemia prevalence. An overall 29.3% malaria parasitemia prevalence was found across the DRC in 2007, with some areas exhibiting up to 82% prevalence (Messina et al., 2011). This is comparable to rates of peripheral malaria found in pregnant women across all of sub-Saharan Africa (32%, (Chico et al., 2012)), but a direct comparison between this rate and rates of anemia across sub-Saharan Africa have not been made. Price et al. (2001) found that children under the age of 5 were more likely to become anemic following illness from malaria than older children or adults, which may partially account for our findings (Price et al., 2001). Furthermore, although several studies have found associations between malaria and anemia, few have been based upon molecular evidence, which may account for differences in our findings. For example, Ter Kuile et al. (2004) and van Eijk et al. (2002) employed microscopy for the detection of malaria parasites, a method whose results are not directly comparable to those of PCR, while Guyatt and Snow (2001) performed a meta-analysis of pre-published malaria parasite ratio data throughout sub-Saharan African countries. Erhardt et al. also found that malnutrition plays a more important role in predicting anemia outcome than malaria-associated morbidity (Ehrhardt et al., 2006). Thus, it is possible that asymptomatic malaria is not a major cause of anemia in adults when accounting for other factors which are indicative of the nutritional status of the individual.

The importance of ethnic group with respect to anemia outcome was a significant finding of this study at the individual-level. Unfortunately there exists a near complete lack of published information with regards to the dietary habits of specific Congolese ethnic groups besides the Bakongo, who are centered mainly in the southwest region of the country near Kinshasa and are known to have dietary habits different than those of the eastern regions, with diets consisting primarily of dry fish and fewer vegetables (MacGaffey, 1986). The DHS database does not include dietary information for the individuals surveyed, presenting a significant opportunity for future research relating regional or local diets to anemia outcome. However, our data shows that the Lunda ethnic group is highly correlated with tree crop agriculture in the south of the DRC, which may explain increased anemia in this group, while the Cuvette Centrale and Ubangi groups are both highly clustered in regions with little high-nutrient agriculture (cereal, highland perennial, or maize) and no major urban centers.

Also at the individual level, owning a refrigerator was important for pregnant women, suggesting that their ability to keep a wider variety of foods in their household may prevent pregnancy-related anemia. While other studies found a negative association between household wealth or socioeconomic status and anemia outcome (Hirve and Ganatra, 1994, Ngnie-Teta et al., 2007a, Cheng et al., 2009), neither individual wealth, household wealth, nor number of household members was significantly associated with individual anemia outcome in our study. Education level also did not appear to be associated with anemia. Some studies have found increased risk for anemia in pregnant or post-partum women with less education (Bodnar et al., 2001, Hirve and Ganatra, 1994, Fowles, 2002) and others have found no association (Scholl et al., 1994b, Bondevik et al., 2001). In our continuous hemoglobin model of pregnant women only, more years of education was unexpectedly associated with lower hemoglobin levels, although it had no effect in any other model. This positive relationship is attributable to a small number of outliers; 3% of the pregnant women had education levels above 12 years (representing the completion of required academic education in the DRC) and were also anemic. Removing these outliers leads to no significant relationship being found between education and haemoglobin in pregnant women, and with such a low number of highly educated women, it is not possible to test the relationship between anemia and education in this sub-sample.

Both living in an urban area and one with more agriculture are associated with lower risk for anemia. This dichotomous finding suggests that while living in an urban area associated with greater access to a variety of foods is protective, if one does not live in an urban area (the case for the majority of the DRC population), having improved access to certain agricultural outputs is important. Thus, once having controlled for urban residence, a negative relationship can be expected between less densely populated areas and risk for anemia. It also means that living in a town would be disadvantageous to one's nutritional health, having less agriculture nearby than in a rural area, as well as lacking the availability of a diverse range of foods which may be associated with more densely populated urban areas.

Considering our findings regarding the importance of agriculture, it is not surprising that differences in the dominant agricultural type in one's community were also important predictors of risk for anemia. In Table 8, the average iron content per metric ton of output for each agricultural type is estimated using the USDA's Nutrient Data Laboratory (Service, 2011), according to the types of crops included under each agricultural category in the CGIAR database. While the actual output per CGIAR agricultural type is not known, it can be seen that overall, tree crop agriculture produces the least amount of iron-rich nutrients. While forest agriculture is associated with a relatively high iron content, it is likely not associated with reduction in anemia risk due to the foraging nature of the system, whereby individuals are not obtaining high amounts of each product. Although highland perennial crops contain overall low average iron content per metric ton of output, Belgian policy pre-independence created an elite class of Congolese in which the prosperity generated from cash crops was concentrated (May, 1965). This legacy may persist in highland perennial areas in the eastern part of the Congo, where coffee is a dominant cash crop.

Less than one third of the cities in the DRC are actually highly populated (50,000 people or more). As our results indicate a positive relationship with nearby agriculture, once controlling for urban residence, less densely populated areas would be at decreased risk for anemia as opposed to lower-population cities, due to a greater proportion of agricultural land cover. This would mean that living in a smaller town would be disadvantageous to one's nutritional health, as these people would not have access to large amounts of imported food as in the highly urban areas, nor large amounts of agricultural outputs as in the more rural areas. This is supported by our results which show that after controlling for urban residence, living closer to a town is actually detrimental for pregnant women's health, and less densely populated areas have lower risk for anemia.

Although international aid was not an important predictor of anemia risk, living closer to a refugee camp was associated with higher hemoglobin levels, meaning that access to the food and disease-prevention resources provided in these camps is important to consider for a nutritional disease in the DRC. Overall, our study highlights that community factors are important in preventing anemia in women.

A key limitation of this study was the inability to more comprehensively measure other correlates of anemia (i.e. B12, folate, hookworm infection, etc.). Data were also limited in that individuals could only be located within the nearest 5 kilometers in rural areas and the nearest 2 km in urban areas, and not to their actual place of residence. This may affect several of the community-level variables which were computed in the GIS, such as agricultural land cover and type, distance to a town or refugee camp, and population density. However, compared to current global estimates which are not based upon population-representative data and do not consider local-scale geographic heterogeneity, this study provides the best estimates to date of the populations and locations at highest risk for anemia in the DRC.

Conclusion

Effective resource allocation and implementation of control measures is important for a disease that affects 32% of all women in the DRC and 57% of pregnant women. The measured prevalence in pregnant women is similar to the WHO estimates for Africa as a whole from 1993-2005 at 56%, although striking when compared to rates in North America and Europe (6% and 19%, respectively) (Who, 2008). Despite the limitations discussed above, this study provides the most accurate population-based estimates to date of anemia and its drivers in the DRC. The map and model terms presented in this paper provide important insight into the social and agricultural factors that contribute to anemia risk in the DRC as well as the relatively small contribution of asymptomatic malaria. In addition to increasing understanding of patterns and drivers of anemia in the DRC, this study provides an example of how population-representative surveillance can be combined with spatial analyses under a disease ecology framework to improve understanding of the burden of chronic nutritional diseases.

More accurate and geographically localized estimates of disease burden are necessary for allocating health resources. This study also underscores the importance of studying sub-national patterns in disease prevalence, as several spatial variables were found to be important predictors of anemia risk. The map we have generated is useful to the DRC government or international agencies in resources and food aid decision-making. For example, the map indicates numerous localized areas within the DRC where anemia rates exceed 50%; these areas should be given priority when allocating limited resources aimed at improving the nutritional status of Congolese people. Pregnant women living in smaller towns found in these areas should be targeted first and special attention given to improving nutritional variety in regions characterized by Bakongo, Cuvette, Ubangi, or Lunda ethnic groupings.

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JM wrote the manuscript and performed the statistical and GIS analyses. KM and ST helped write the manuscript. ME and SM are responsible for the overall study design and helped write the manuscript.

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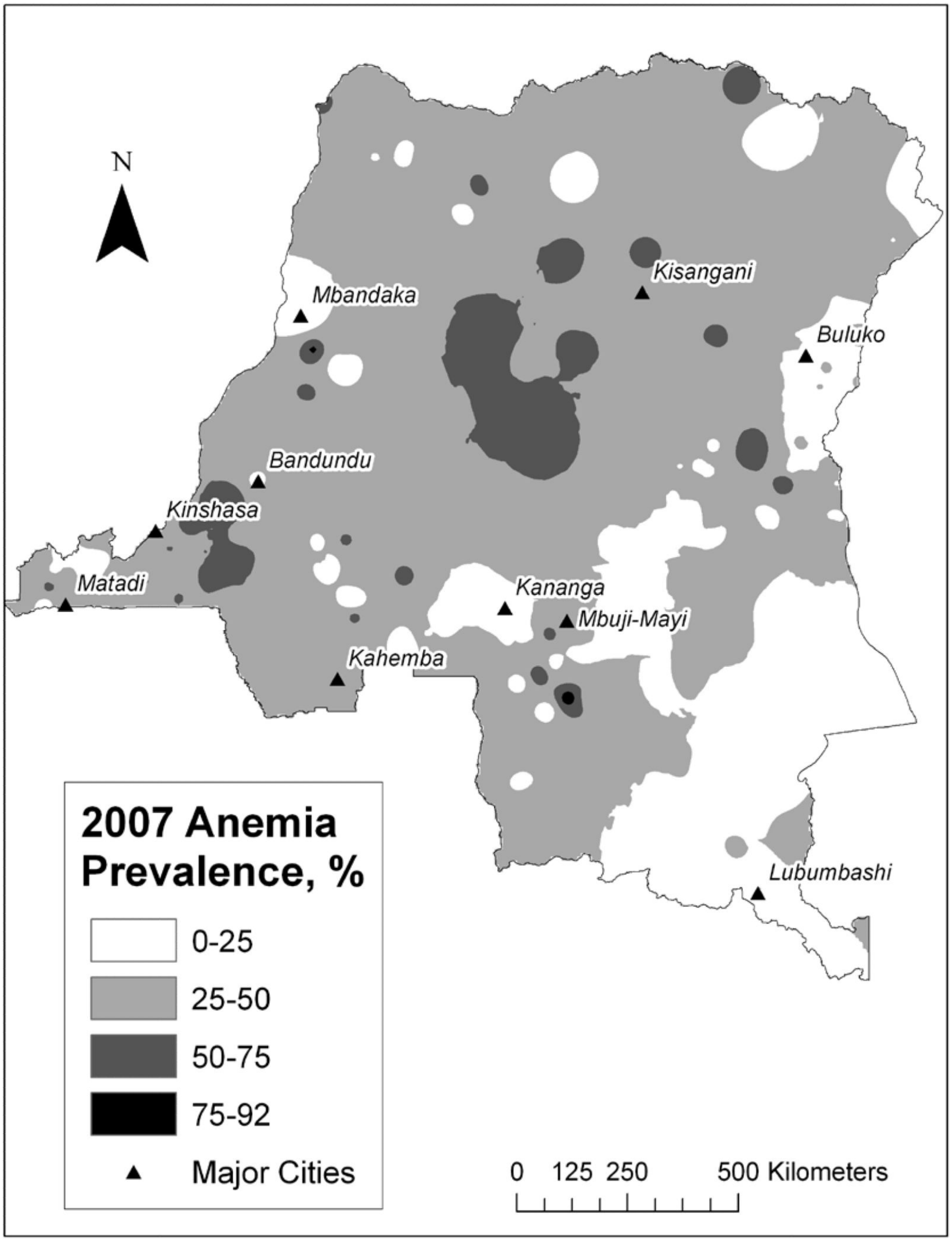

Figure 1.
Inverse distance-weighted map of anemia prevalence in the DRC, 2007.

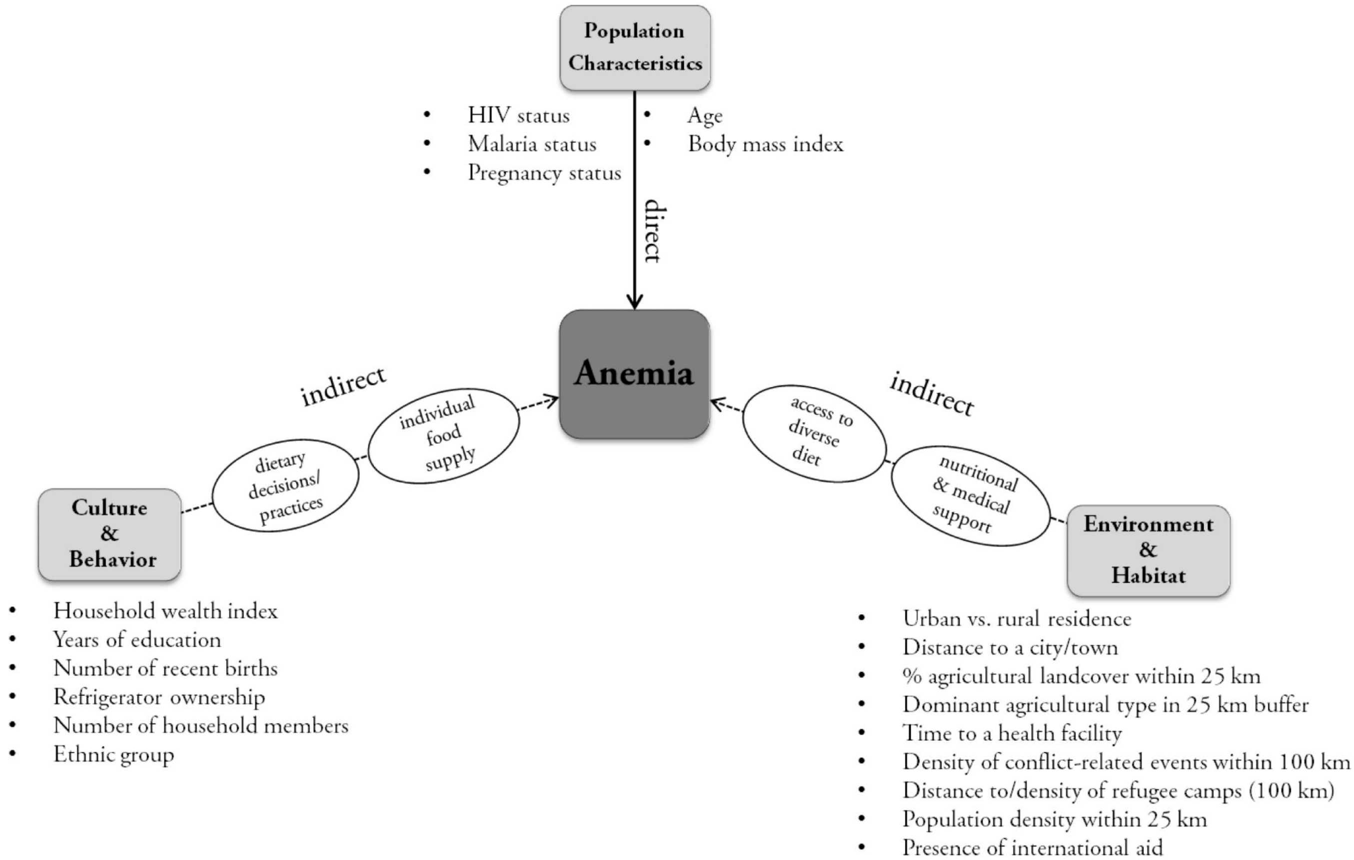

Figure 2.

Disease ecology framework for variables entered into multilevel analyses of individual anemia outcome.

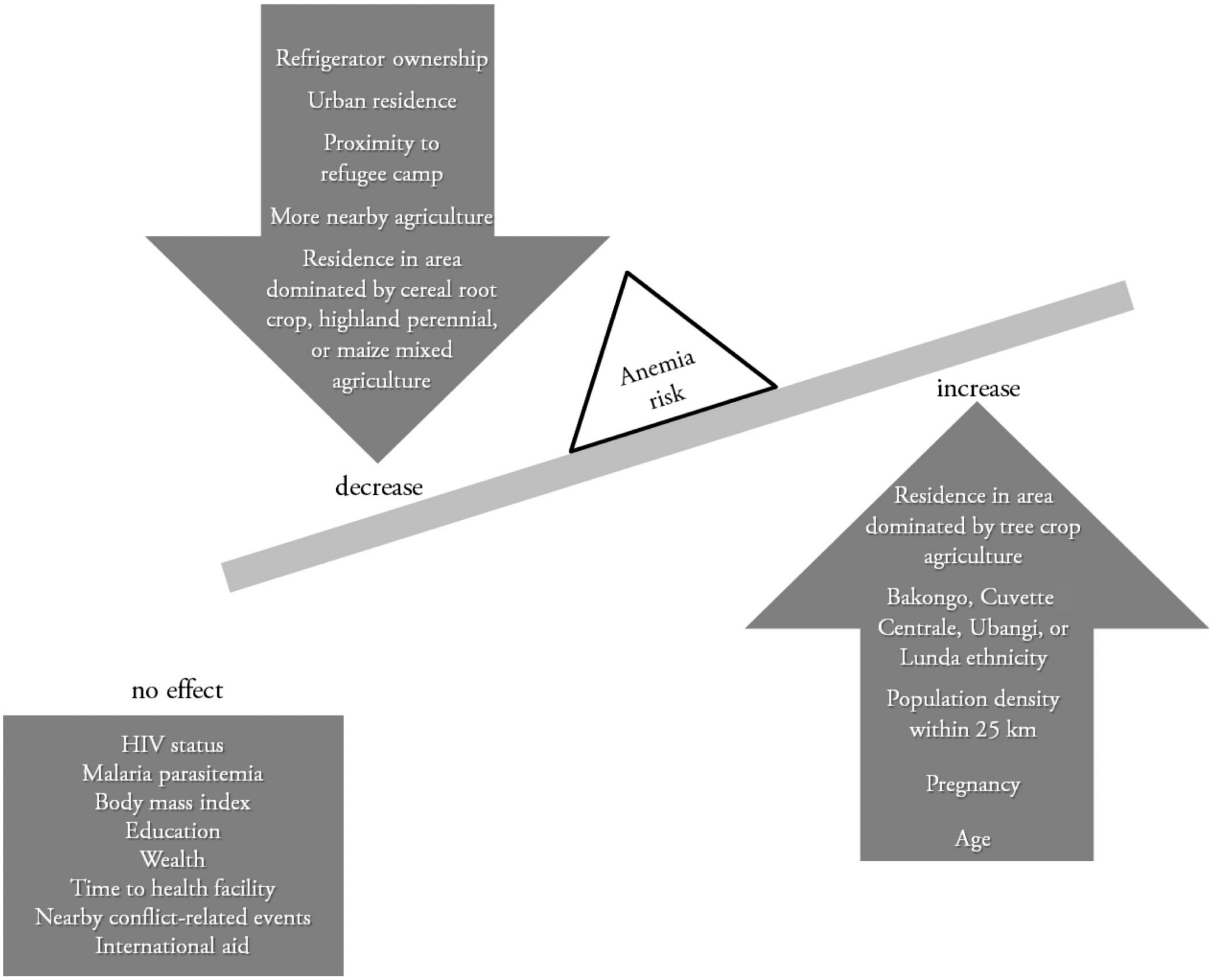

Figure 3.

Variables entered into multilevel analysis according to their found relationship with anemia and/or lowered hemoglobin risk in DRC women.

Table 1

Descriptive statistics for variables entered into multilevel regression models. Total sample size was 4,638 women of which 32.2 percent were anemic.

	Anemic (<11 g/dl Hgb)	Not Anemic (>11 g/dl Hgb)	Causal mechanism
Individual Level (1)			
Population			
Average Age (years)	29.1	28.3	direct effect
Average Body Mass Index	21.3	22.1	indicator of poor nutrition
% HIV-Positive	29.9	33.1	direct effect
% Malaria-parasitemic	33.5	30.2	direct effect
% With high malaria parasitemia	3.2	2.8	direct effect
% Pregnant	20	7.2	direct effect
Culture/ Behavior			
Avg. Wealth Index (1-5)	3	3.1	household food supply
Avg. Years of Education	4.8	5.1	dietary knowledge
Avg. Births in Past Year	0.2	0.2	direct effect
Avg. Births in Past 5 Years	1	0.9	direct effect
Avg. # of Household Members	6.9	6.9	household food demand
% Owning Refrigerator	23.1	19.2	ability to maintain diverse diet
% Bakongo (N& S of River)	10.5	8.9	dietary practices
% Cuvette Centrale	14.7	9	dietary practices
% Ubangi	9.4	6.7	dietary practices
% Uele; Lac Albert	2.9	6.9	dietary practices
% Kasai	26.3	33.5	dietary practices
% Lunda	0.9	1.1	dietary practices
% Basele	8	8	dietary practices
% Bas-Kasai & Kwilu-Kwongo	25.4	18.5	dietary practices
Community Level (2)			
Habitat / Environment			
Avg. Distance to a City (km)	118.5	111.8	access to diverse diet
Avg. Distance to a Town (km)	40.5	37.3	access to diverse diet
Avg. Time to Health Facility (min)	63.9	56.7	medical support
Avg. # Conflict Events since 1994 w/in 100 km	28.4	36.9	access to nutritional aid
Avg. Pop. Density within 25 km (pop/sq. km)	475.8	421.3	community food supply/demand
Avg. Agricultural Landcover w/in 25 km (km2)	3	562.7	access to diverse diet
% Urban	40.8	46.1	access to diverse diet
% with International Aid	66.5	66	access to nutritional aid
% Forest Agriculture	83.3	69	dietary richness
% Highland Perennial Agriculture	2.6	6.7	dietary richness
% Maize Mixed Agriculture	1.9	6.5	dietary richness
% Cereal Root Crop Mixed Agriculture	2.6	3.2	dietary richness
% Root Crop Agriculture	7.5	12.3	dietary richness

	Anemic (<11 g/dl Hgb)	Not Anemic (>11 g/dl Hgb)	Causal mechanism
% Tree Crop Agriculture	1.7	0.8	dietary richness

Table 2

Weighted frequency of anemia and mean hemoglobin level by pregnancy status.

	Anemic at <11 g/dl Hgb - % (N)	Anemic at <8 g/dl Hgb - % (N)	Average Hgb level (g/dl)
Pregnant	56.8 (298.24)	0.5 (11.3)	10.6
Not Pregnant	29.1 (1193.7)	0.7 (88.7)	11.8

Table 3

Anemia and severe anemia prevalence according to malaria parasitemia.

		Malaria Parasitemia in all Women		
		No (weighted N=3114)	**Any (weighted N=1435)**	**High parasitemia (weighted N=143)**
Anemic	% (N)	31.6% (984)	34.5% (495)	33.2% (48)
	95% CI	29.6%-32.8%	32.1%-37.0%	25.5%-40.1%
	p-value		<.0001	0.008

		Malaria in Pregnant Women		
		No (weighted N=325)	**Any (weighted N=192)**	**High parasitemia (weighted N=13)**
Anemic	% (N)	54.7% (178)	60.0% (115)	67.8% (9)
	95% CI	49.3%-60.0%	52.8%-66.6%	42.5%-93%
	p-value		0.007	0.1980

P-values for Pearson's chi-square test are given.

Table 4

Multilevel logistic regression results with anemia defined as less than 11 g/dl Hgb; all women.

Parameter	Odds Ratio	95% Lower	95% Upper	p-value
Intercept	0.2367	0.1032	0.5428	0.0007
Individual-Level Variables				
Age	**1.0127**	**1.0022**	**1.0233**	**0.0178**
Currently Pregnant	**3.7430**	**2.7701**	**5.0581**	**<.0001**
Has Refrigerator	1.0720	0.9832	1.1687	0.1151
Births in Past 5 Years	1.0375	0.9385	1.1469	0.4717
Body Mass Index	1.0000	0.9997	1.0003	0.8903
Years of Education	0.9767	0.9496	1.0044	0.0983
Culture of Origin: Bakongo	1.3596	0.9338	1.9794	0.1090
Culture of Origin: Bas-Kasai & Kwilu-Kwongo	1.2609	0.9207	1.7267	0.1485
Culture of Origin: Cuvette Centrale	1.3531	0.9639	1.8993	0.0806
Culture of Origin: Ubangi	1.2933	0.8032	2.0826	0.2900
Culture of Origin: Uele; Lac Albert	0.7661	0.5324	1.1022	0.1510
Community-Level Variables				
Population Density within 25 km	**1.0003**	**1.0001**	**1.0005**	**0.0030**
Highland Perennial Agriculture	**0.4247**	**0.2639**	**0.6834**	**0.0004**
Maize Mixed Agriculture	**0.2607**	**0.1311**	**0.5185**	**0.0001**
Root Crop Agriculture	**0.6208**	**0.3922**	**0.9828**	**0.0419**
Tree Crop Agriculture	**1.6839**	**1.2173**	**2.3291**	**0.0016**
Cereal Root Crop Mixed Agriculture	0.7722	0.4669	1.2772	0.3140
Urban	0.7984	0.6027	1.0575	0.1164
Distance to a Refugee Camp	1.0012	1.0000	1.0024	0.0501
Agricultural Land Cover within 25 km	1.0000	0.9997	1.0003	0.9854
Has International Aid	1.1663	0.8591	1.5831	0.3241

Parameters significant at p=.05 or better are highlighted in bold.

N=4356 (out of 4638)

Initial Model: 33 parameters, AIC = 5127.7974

Final Model: 21 parameters, AIC= 5121.4494

Table 5

Multilevel linear regression model with continuous hemoglobin level outcome variable; all women.

Parameter	Beta Estimate	95% Lower	95% Upper	p-value
Intercept	113.9761	106.4643	121.4878	<.0001
Individual-Level Variables				
Currently Pregnant	**−13.0274**	**−15.3883**	**−10.6666**	**<.0001**
Culture of Origin: Lunda	**−7.2706**	**−13.7798**	**−0.7614**	**0.0286**
Culture of Origin: Bakongo	−3.6384	−7.7915	0.5147	0.0860
Culture of Origin: Cuvette Centrale	−2.3271	−7.8774	3.2232	0.4112
Culture of Origin: Ubangi	−3.5231	−8.8272	1.7810	0.1930
Culture of Origin: Uele; Lac Albert	2.0519	−2.1626	6.2665	0.3400
Culture of Origin: Kasai	1.2866	−2.2284	4.8016	0.4731
Births in Past Year	−0.8847	−3.0373	1.2680	0.4205
Body Mass Index	0.0019	−0.0017	0.0056	0.2992
Years of Education	0.0672	−0.2551	0.3896	0.6828
Community-Level Variables				
Distance to a Refugee Camp (km)	**−0.0127**	**−0.0247**	**−0.0007**	**0.0373**
Highland Perennial Agriculture	**7.2711**	**2.2012**	**12.3411**	**0.0049**
Maize Mixed Agriculture	**11.4979**	**6.4935**	**16.5023**	**<.0001**
Tree Crop Agriculture	**−5.6149**	**−8.4299**	**−2.7999**	**<.0001**
Urban	2.2115	−0.5637	4.9866	0.1183
Distance to a City (km)	0.0088	−0.0082	0.0258	0.3091
Population Density within 25 km	−0.0014	−0.0037	0.0009	0.2254
Agricultural Land Cover within 25 km	0.0000	−0.0024	0.0023	0.9881

N=4356 (out of 4638)

Initial Model: 33 parameters, AIC = 40780.3114

Final Model: 18 parameters, AIC = 40775.3978

Table 6

Multilevel logistic regression results with anemia defined as less than 11 g/dl Hgb; pregnant women only.

Parameter	Odds Ratio	95% Lower	95% Upper	p-value
Intercept	2.4663	0.3473	17.5157	0.3668
Indivdual-Level Variables				
Has Refrigerator	**0.7154**	**0.5463**	**0.9369**	**0.0149**
Age	0.9809	0.9449	1.0184	0.3139
HIV-Positive	0.6283	0.3435	1.1492	0.1315
Births in Past Year	2.2710	0.8325	6.1941	0.1092
Malaria Parasitemia	1.2960	0.7537	2.2282	0.3484
Body Mass Index	0.9997	0.9988	1.0007	0.5736
Years of Education	1.0509	0.9823	1.1241	0.1498
Number of Household Members	1.0665	0.9612	1.1834	0.2248
Culture of Origin: Bakongo	3.4823	0.7344	16.5122	0.1161
Culture of Origin: Cuvette Centrale	1.5275	0.7116	3.2789	0.2770
Culture of Origin: Ubangi	1.8329	0.8693	3.8644	0.1114
Culture of Origin: Uele; Lac Albert	1.9531	0.6800	5.6086	0.2136
Community-Level Variables				
Urban	**0.4933**	**0.2863**	**0.8498**	**0.0109**
Population Density within 25 km	**1.0007**	**1.0002**	**1.0012**	**0.0096**
Agricultural Land Cover within 25 km	**0.9993**	**0.9988**	**0.9999**	**0.0162**
Cereal Root Crop Mixed Agriculture	**0.1326**	**0.0185**	**0.9485**	**0.0441**
Maize Mixed Agriculture	0.6211	0.1577	2.4464	0.4960
Distance to a Refugee Camp (km)	1.0019	0.9990	1.0049	0.2029
Conflict Events since 1994 within 100 km	0.9979	0.9941	1.0017	0.2728

N=497 (out of 526)

Initial Model: 30 parameters, AIC =644.044

Final Model: 19 parameters, AIC= 636.5256

Table 7

Multilevel linear regression model with continuous hemoglobin level outcome variable; pregnant women only.

Parameter	Beta Estimate	95% Lower	95% Upper	p-value
Intercept	106.3526	93.1556	119.5496	<.0001
Individual-Level Variables				
Has Refrigerator	**1.7749**	**0.3091**	**3.2407**	**0.0176**
Years of Education	**−0.7671**	**−1.3075**	**−0.2268**	**0.0054**
Culture of Origin: Bakongo	**−18.1920**	**−32.1398**	**−4.2441**	**0.0106**
Culture of Origin: Cuvette Centrale	**−5.8628**	**−10.4353**	**−1.2903**	**0.0120**
Culture of Origin: Ubangi	**−9.3103**	**−16.6813**	**−1.9394**	**0.0133**
Births in Past 5 Years	−1.0755	−2.8709	0.7199	0.2404
Malaria Parasitemia	−2.5313	−6.4037	1.3411	0.2001
Body Mass Index	0.0000	−0.0063	0.0062	0.9902
Community-Level Variables				
Urban	**6.0013**	**1.5086**	**10.4940**	**0.0088**
Distance to a Town (km)	**0.0475**	**0.0097**	**0.0852**	**0.0138**
Agricultural Land Cover within 25 km	**0.0051**	**0.0018**	**0.0084**	**0.0026**
Cereal Root Crop Mixed Agriculture	**19.9249**	**3.9417**	**35.9082**	**0.0146**
Tree Crop Agriculture	**−14.0964**	**−17.9475**	**−10.2454**	**<.0001**
Highland Perennial Agriculture	9.7585	−0.1519	19.6690	0.0536
Maize Mixed Agriculture	3.9994	−4.6567	12.6554	0.3652

N=497 (out of 526)

Initial Model: 30 parameters, AIC=4344.9692

Final Model: 19 parameters, AIC=4339.1694

Table 8

Average iron content by agricultural type.

Agriculture Type	Average grams of Iron per metric ton of output
Cereal-Root Crop	16,442
Maize Mixed	14,318
Root Crop	12,354
Forest	8,352
Highland Perennial	7,636
Tree Crop	1,090