Deforestation and Household- and Individual-Level Double Burden of Malnutrition in Sub-saharan Africa

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Introduction: Although forests and forest-based ecosystems have been shown to influence health and sustainable diets, there is limited evidence on how deforestation affects the current nutrition transition and the double burden of malnutrition. We examined the relationship between deforestation and the individual- and household-level double burden of malnutrition in 15 countries in Sub-Saharan Africa.

Materials and methods: We combined data from geolocated Demographic and Health Surveys and the Global Forest Change dataset. We defined household-level double burden of malnutrition as the co-occurrence of an overweight woman of childbearing age (WCBA) and a stunted pre-school child (PSC) within the same household. We defined individual-level double burden in two ways: (1) as the co-occurrence of overweight and anemia within an individual WCBA, and (2) as the co-occurrence of overweight and stunting within a PSC. We used logistic regression analysis to examine the association between forest cover loss and these three measures after adjusting for potential confounders. We also assessed the mechanisms linking forest cover loss and nutritional status, such as livestock ownership and access to clean water.

Results: In our sample, the prevalence rates of the three measures of the double burden were: overweight and anemic WCBA: 8.4%, overweight WCBA and stunted PSC: 6.9%, overweight and stunted PSC: 2.7%. After adjusting for the confounders as well as country fixed effects and the month of the survey, forest cover loss was marginally associated with a higher odds of an overweight WCBA and stunted PSC [odds ratio (95% CI): 4.80 (0.82, 28.25)]. We found no association between forest cover loss and odds of an overweight and stunted PSC [odds ratio (95% CI): 2.47 (0.80, 7.60)] or the odds of an anemic and overweight WCBA [odds ratio (95% CI): 0.71 (0.15, 3.32)].

Discussion: Deforestation does not seem to be an important driver of the double burden of malnutrition in SSA. However, deforestation influences several intermediate factors which, in turn, may influence the double burden. The overall weak association between forest cover loss and double burden measures mask significant heterogeneity across regions within SSA. Future research should unpack the mechanisms behind these regional differences.

Keywords: deforestation, double burden, Sub-Saharan Africa, malnutrition, food systems
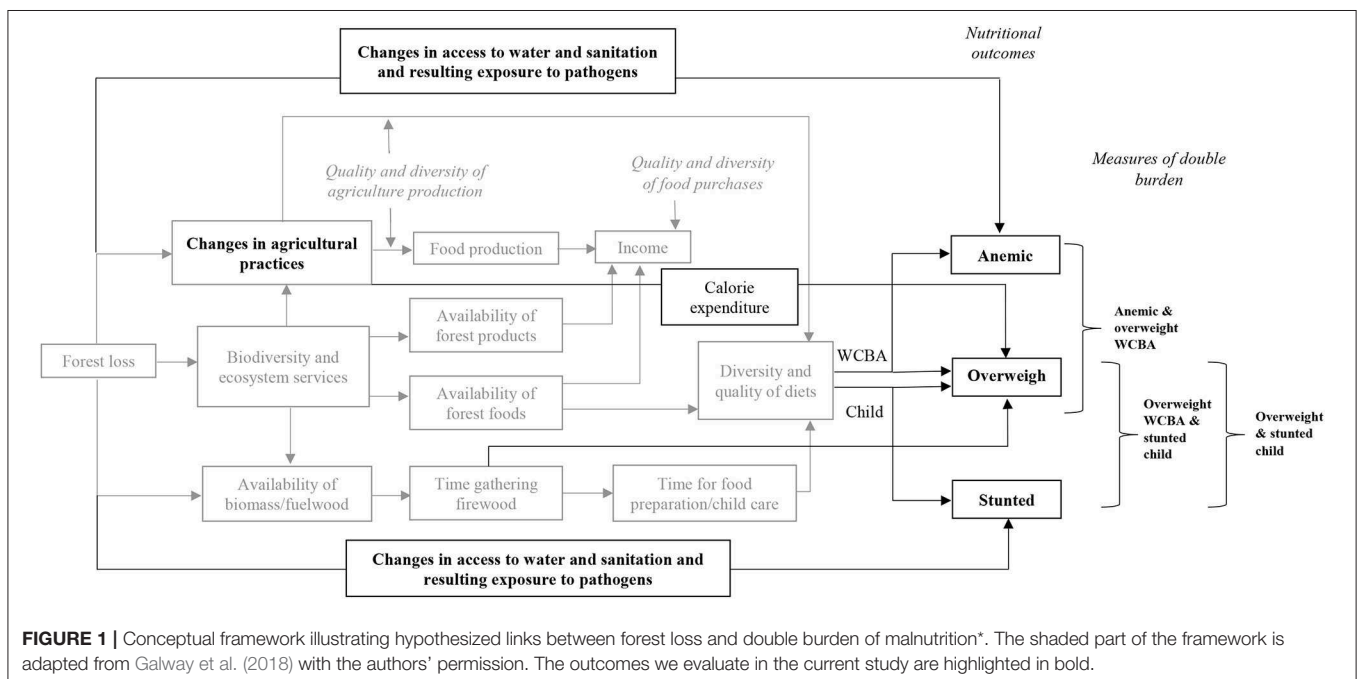
INTRODUCTION

Deforestation is occurring globally at an alarming rate (Hosonuma et al., 2012; Hansen et al., 2013), particularly in the tropics (Lindquist et al., 2012; Hansen et al., 2013), raising concerns about potential impacts on biodiversity, ecosystems services, and human health. Deforestation has been shown to be associated with a number of conditions, such as acute respiratory infection (Pienkowski et al., 2017), malaria (Bauch et al., 2015; Austin et al., 2017; Berazneva and Byker, 2017), and diarrheal disease (Johnson et al., 2013; Berazneva and Byker, 2017).

Simultaneously, many low- and middle-income countries are experiencing a rapid rise in the prevalence of the double burden of malnutrition (Dieffenbach and Stein, 2012; Oddo et al., 2012; Roemling and Qaim, 2013; Wojcicki, 2014; Berazneva and Byker, 2017), wherein obesity and diet-related chronic disease commonly co-occur with conditions of undernutrition (e.g., child growth stunting, micronutrient deficiencies, and associated anemia). An emerging body of literature has examined this double burden as well as its determinants (Lee et al., 2010, 2012; Oddo et al., 2012; Bassete et al., 2014; Aitsi-Selmi, 2015; Kosaka and Umezaki, 2017). The most commonly assessed determinants include socio-economic determinants, such as urban/rural residence, income, and maternal/household-head education level (Kosaka and Umezaki, 2017). Empirical evidence on the role of environmental determinants, such as forest cover loss, is lacking. Given the pace, urgency, and scale of global environmental changes, there is a growing need to address this knowledge gap.

Forests and forest-based ecosystem services have also been shown to be important drivers of healthy and sustainable diets (Dounias and Froment, 2011; Golden et al., 2011; Vinceti et al., 2013; Brown et al., 2014; Ickowitz et al., 2014, 2016; Powell et al.,

2015; Vira et al., 2015; Pienkowski et al., 2017; Rowland et al., 2017; Galway et al., 2018; Rasolofoson et al., 2018), suggesting that deforestation has the potential to affect the double burden of malnutrition. To our knowledge, two prior studies (Rasolofoson et al., 2018 and Galway et al., 2018) have provided frameworks for understanding the potential mechanisms linking forests to diets. Broadly speaking, the mechanisms include changes in the availability of forest foods, pollination, the availability of non-forest products, mother's time for food preparation and child care activities, and agricultural techniques (Rasolofoson et al., 2018). In Galway et al. (2018), we provide a finer breakdown of these mechanisms with supporting evidence from the literature.

The mechanisms through which forest cover loss could affect the double burden of malnutrition are likely similar, with changes in diet as an important intermediate factor. Therefore, in **Figure 1**, we adapt the framework from Galway et al. (2018) with the double burden of malnutrition as the outcome. The shaded areas of the framework are taken from Galway et al. (2018), while the darker boxes and arrows represent additional factors linking forest loss to the nutritional double burden (In **Figure 1**, the factors we evaluate in the current study are highlighted in bold). Two of the additional factors need elaboration. First, changes in the amount of time spent gathering firewood or changes in agricultural practices can affect women's calorie expenditure, which in turn can affect anthropometric status, in particular weight. Indeed, existing evidence shows that women tend to get less physical activity than men in an urban environment (Shrimpton and Rokx, 2012), which may lead to an increased risk of overweight. Second, individuals' access to clean water and sanitation may change—either because they move in response to deforestation or their existing water source gets contaminated. Such changes in access to water and sanitation can affect children by making them more vulnerable to illnesses, such as diarrheal

FIGURE 1 | Conceptual framework illustrating hypothesized links between forest loss and double burden of malnutrition*. The shaded part of the framework is adapted from Galway et al. (2018) with the authors' permission. The outcomes we evaluate in the current study are highlighted in bold.

diseases and infections, which may lead to an increased risk of anemia. If the exposure to pathogens is persistent, children may also be at higher risk of stunting.

Deforestation may also affect different population segments differently, even within the same household. For example, mothers might be impacted differently than young children. If the primary reason for deforestation is to make space for cultivation of crops, mothers, now having to work in the field, may end up having less time for breastfeeding and other caregiving activities, potentially worsening children's nutritional status. Their own nutritional status may improve or worsen, depending on how their work burden changes. By altering diets, deforestation may also affect the multiple measures of malnutrition differently even for the same child. For example, if more iron-rich crops are grown, the likelihood of being anemic may fall, but if mother's caregiving is adversely affected—for example, through reduced frequency and duration of breastfeeding—a child may be at increased risk of stunting or wasting.

The overall effect of deforestation on the nutritional double burden, both at the household level and at the individual level remains an unanswered and important empirical question. Against this backdrop, the goal of this study was to examine the association between deforestation and the household- and individual-level double burden of malnutrition. We conducted this study in the context of Sub-Saharan Africa (SSA), where the rate of deforestation is twice the world average (UNEP, 2008; FAO, 2010; Gibson et al., 2011; D'Annunzio et al., 2015; Austin et al., 2017). The nutritional double burden is also prevalent

throughout SSA and is certain to increase (Zeba et al., 2012; Wojcicki, 2014; Jones et al., 2016).

MATERIALS AND METHODS

Data

We used geolocated data collected by the USAID-funded Demographic and Health Survey (DHS) program. The DHS program collects nationally representative health, fertility and nutrition data from more than 90 countries using a two-stage cluster sampling procedure (Measure DHS/ICF International, 2012). We compiled individual and children's recode DHS data files from all countries in SSA for which the standard DHS survey was conducted between 2012 and 2016 and for which geolocated data were available. In total, datasets from 15 countries met these criteria and were included in our analyses (**Table 1**). We included all non-pregnant women of childbearing age (WCBA) from 15 to 49 years of age who were interviewed in the DHS as well as pre-school children (PSC) aged 12–59 months. In our analysis of PSC, we included all children from a mother except in few instances where two children from the same mother were coded as having the same birth index.

We obtained data on forest cover loss (a proxy of deforestation) from the publicly available Global Forest Change dataset developed (Hansen et al., 2013). The Global Forest Change dataset, developed by Hansen and colleagues, measures forest cover loss worldwide (excluding Antarctica and the Arctic) at a spatial resolution of ~30 m (Hansen et al., 2013). Hansen et al. (2013) define forest loss as stand-replacement disturbance

TABLE 1 | Demographic and Health Survey data sets used.

Country	Year	n (children)	n (mothers[a])	n (children and mothers[b])	n (clusters)
Democratic Republic of the Congo	2013–14	5,710	4,136	5,651	490
Gabon	2012	2,389	2,128	2,374	305
Zambia	2013–14	8,910	–	8,881	709
Kenya	2014	6,960	–	6,909	1,246
Rwanda	2014–15	2,758	2,534	2,753	448
Benin	2011–12	6,089	2,299	6,031	730
Cote D'Ivoire	2011–12	2,287	2,009	2,243	317
Ghana	2014	2,052	1,787	2,047	346
Guinea	2012	2,328	2,136	2,316	287
Liberia	2013	2,355	–	2,345	314
Mali	2012–13	3,513	2,789	3,468	400
Nigeria	2013	18,585	–	18,461	887
Senegal	2012–13	4,352	–	–	199
Sierra Leone	2013	3,186	3,346	3,143	417
Togo	2013–14	2,467	2,121	2,460	302
Total		73,941	25,285	69,082	6,615

[a]Countries where hemoglobin levels were not collected as part of DHS were not included in the calculation of the double burden of malnutrition among mothers. These countries include: Zambia, Kenya, Liberia, Nigeria, and Senegal.
[b]Maternal BMI was not available for Senegal. Therefore, we excluded Senegal from the analysis for the calculation of double burden of malnutrition at the household level.

or the complete removal of tree cover canopy at the pixel scale while trees are defined as vegetation taller than 5 m in height. Following our previous study (Galway et al., 2018), we used version 1.0 of the dataset which measured forest cover loss between 2000 and 2012 using a time-series analysis of more than 600,000 multispectral satellite images from Landsat 7. We used version 1.0 rather than the updated version of the dataset to ensure that our measurement of forest lost preceded the DHS survey data collection. We also used data on percent tree cover for the year 2000 from the Global Forest Change dataset (Hansen et al., 2013). Information on road location was obtained from the Global Roads Open Access Data Set (Center for International Earth Science Information Network, 2013). Finally, we used the Global Aridity Index from the Consultative Group on International Agricultural Research (CGIAR, 2009) to measure climate across DHS clusters. We combined data from the DHS and the Global Forest Change dataset at the cluster-level using a geographic information system and ArcGIS software (ESRI, 2011).

Outcome Variables

We defined overweight or obesity in WCBA using standard BMI (in kg/m^2) cutoffs ($\geq$25). Anemia in WCBA was defined as a hemoglobin concentration <120 g/L, the recommended cutoff for non-pregnant women aged $\geq$15 years. We considered children with a HAZ <2 SD below the mean according to the WHO Child Growth Standards to be stunted and those with WHZ >2 SD above the mean to be overweight.

We used three measures of double burden: two at the individual level and one at the household level. We defined individual-level double burden in two ways: (1) as the co-occurrence of overweight and anemia within an individual WCBA, and (2) as the co-occurrence of overweight and stunting within a PSC. We defined household-level double burden of malnutrition as the co-occurrence of an overweight WCBA and a stunted PSC within the same household.

In an effort to understand potential mechanisms linking deforestation to the nutritional double burden, we also examined the relationship between forest loss and five intermediate outcomes: (i) ownership of livestock, (ii) ownership of agricultural land, (iii) access to improved water, (iv) access to improved sanitation, and (v) occurrence of diarrhea among the PSCs.

As discussed in the results section below, for the overall sample, we found only a weak association between forest cover loss and the co-occurrence of overweight and stunting within a PSC and no association between forest cover loss and the two other measures of double burden. This contradicted with the negative associations we found between forest cover loss and many of the intermediate outcomes. Therefore, we also examined the association between forest cover loss and individual components of nutritional status; in these analyses, the outcome variables were the components used to construct the double-burden measures, specifically occurrences of: (i) overweight WCBA, (ii) anemic WCBA, (iii) overweight PSC, and (iv) stunted PSC.

Independent Variable

The primary independent variable we examined was deforestation measured as forest cover loss between 2000 and 2012. Though the construction of this variable has been previously described (Galway et al., 2018), briefly, the Global Forest Change dataset defines forest cover loss as stand-replacement disturbance or a change from a forest to non-forest state during the 2000–2012 period in a 30 m by 30 m grid cell. In the dataset, each 30 m by 30 m pixel is coded as "1" for forest cover loss or "0" for no loss of forest cover. The Global Forest Change data are downloadable as tiff panels; we downloaded those panels covering the spatial extent of our 15 study countries in SSA (Hansen et al., 2013). The georeferenced DHS cluster locations are randomly displaced in order to protect the confidentiality of the survey respondents (Warren et al., 2016). The large majority (99%) of the locations are displaced by 0–5 km, with a remaining 1% of rural clusters displaced to a maximum of 10 km (Measure DHS/ICF International, 2012). Using ArcGIS software (ESRI, 2011), we aggregated the original 30 m pixels to 5 km pixels to account for the displacement. We then spatially joined the aggregated pixels to the georeferenced DHS data to extract the percentage of forest cover loss in the 5 km area surrounding each DHS cluster.

Covariates

We included several covariates in analyses to adjust for potential confounding of the relationship between forest loss and the double burden of malnutrition. We selected these covariates based on previous evidence of the determinants of nutritional status (Guldan et al., 1993; Variyam et al., 1999; Vereecken et al., 2004; Black et al., 2013). The child-level covariates included sex, episode of diarrhea during the 2 weeks preceding the survey, and age in months. Other covariates included the highest attained education level of the child's mother, household access to an improved source of water and sanitation (WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation, 2012), and a measure of household wealth available from the DHS. DHS creates the wealth index from several items related to household assets (e.g., radio, refrigerator), housing characteristics (e.g., type of flooring), and utilities and infrastructure (e.g., number of persons sleeping per room) (Rutstein and Johnson, 2004). Households are divided into quintiles based on the index. In a subset of the analyses, we also include household's ownership of agricultural land and ownership of livestock as covariates. We show results from both sets of regressions (i.e., those with and without controlling for agricultural land and livestock ownership) in an attempt to shed light on changes in the double burden measures originating from changes in deforestation independent of agricultural land use (to the extent that changes in land use are reflected in the ownership of agricultural land and livestock).

At the cluster level, we adjusted for whether the cluster was urban or rural based on DHS definitions and distance of the DHS cluster to the nearest road. We calculated the Euclidian distance of the DHS cluster centroid to the nearest road using road location data from the Global Roads Open Access Data Set (Center for International Earth Science Information Network,

2013). Climatic differences may in part explain geographic variation in mother and child nutrition outcomes (Dulal et al., 2017). To adjust for such confounding, we used the Global Aridity Index (CGIAR, 2009), aggregated to the 5 km level and spatially linked to each cluster. We also adjusted for baseline forest cover using percent tree cover in year 2000 (Hansen et al., 2013). As with the forest cover loss data, we aggregated the original 30 m pixels to 5 km pixels and spatially joined the data to each DHS cluster. In an attempt to account for nutritional differences that may have been driven by factors specific to a country (e.g., country's gross domestic product and government's policies on nutrition and health) or DHS cluster, and by seasonal variation in food availability (Abizari et al., 2017), we adjusted for country fixed effects, cluster-level random effects, and the month of the DHS survey in our analyses.

Statistical Analysis

We calculated means and proportions for the outcome and independent variables, as well as for key household- and child-level characteristics. Given the binary nature of the outcome variables, we used logistic regression analysis to examine the association between forest cover loss and the measures of the double burden of malnutrition, after adjusting for potential individual-, household- and community-level confounders. Specifically, we estimated the following equation:

$$Y_{ijk} = \alpha + \beta_1 Forest\ loss_k + \delta\ X_{ijk} + \eta + \theta + \omega + \varepsilon \quad (1)$$

where Y_{ijk} is the relevant double burden of malnutrition measure for either child, mother, or child-mother pair i in household j living in DHS cluster k. Forest cover loss, the independent variable, varied by the DHS cluster. We reported odds ratios. In the equation, the odds ratio β_1 reflects the association between forest cover loss and the dependent variable. X represents child-, household- and cluster-level characteristics mentioned above that potentially influence the double burden of nutrition. η represents the country of the child, θ represents the cluster random effect, while ω represents the month of the survey.

In all models, we clustered the standard errors at the level of the DHS enumeration cluster to account for arbitrary correlation between observations within a cluster. Recall that the variation in forest cover loss is at the DHS cluster level. Clustering standard errors at the level of DHS sampling units also accounts for intra-household correlations among those households with multiple children or mothers in the sample.

The statistical significance of associations is reported at the $P < 0.1$, $P < 0.05$, and $P < 0.01$ levels. Given current debates on the arbitrary nature of these cutoffs (Wasserstein et al., 2019), we report 95% confidence intervals for all major findings. The analyses were carried out using the Stata statistical software package version 15 (StataCorp, 2017) and the ArcGIS software (ESRI, 2011). We checked the robustness of the main results by estimating the relationship between key variables in a step-wise manner, controlling for different set of covariates in each step.

RESULTS

Descriptive Data

In our analytical sample of 25,285 WCBA for whom both measures of the nutritional double burden (overweight and anemia) were available, 73,941 PSC, and 69,082 mother-child pairs, the prevalence rates of the three measures of the double burden were: overweight and anemic WCBA: 8.4%; overweight and stunted PSC: 2.7%; overweight WCBA and stunted PSC: 6.9% **(Table 2)**. The average forest cover loss between 2000 and 2012, the independent variable, was ~2%.

The average age of the child was 35 months and there were equal proportions of boys and girls in the sample. The vast majority of mothers in the sample (75%) had primary level education or lower. Among the mothers, the average age was 30 years, nearly 43% were anemic and 22% were overweight.

The average number of members in a household was 7.4. Approximately 61% households had access to an improved source of drinking water and 43% had access to improved sanitation. Two-thirds of the children lived in areas classified as rural. The average forest cover in 2000, the aridity index and the distance to the nearest road were 20%, 8, and 16 km, respectively.

Main Results

In **Table 3**, we report odds ratios from estimating equation (1), separately for the three dependent variables. In each case, we first show results from estimating the equation controlling for all covariates except household's ownership of agricultural land and livestock. We then show odds ratios from estimating the equation with all covariates, including ownership of agricultural land and livestock. As mentioned earlier, we present results in this manner in an attempt to shed light on changes in the double burden measures originating from changes in deforestation independent of agricultural land use.

In regressions that do not control for the ownership of agricultural land and livestock, forest cover loss was marginally associated with overweight and stunted PSC [odds ratio (95% CI): 4.74 (0.80, 27.88)], but not with overweight and anemic WCBA [odds ratio (95% CI): 0.71 (0.15, 3.35)] or with overweight WCBA and stunted child [odds ratio (95% CI): 2.53 (0.82, 7.81)]. The odds ratios remain largely unchanged even when we control for the ownership of agricultural land and livestock.

Among the covariates, in both set of models, primary education among WCBA was associated with higher odds of concurrent anemia and overweight relative to no education. However, there was marginal or no difference between women with no education and those with higher education. Higher education among women were associated with lower odds of overweight mother and stunted child, while secondary education was associated with overweight and stunted child. Household wealth was strongly positively associated with two of the three measures, but not with overweight and stunted child. Other factors strongly associated with concurrent anemia and overweight among WCBA included women's age, urban location, access to improved water, access to improved sanitation, and aridity index. Factors strongly associated with overweight mother and stunted child included women's age, urban location,

TABLE 2 | Descriptive characteristics of the analytic sample.

Variables	n	Mean (SD) or %
Dependent variables		
Overweight and anemic WCBA, %	25,285	8.38
Overweight and stunted PSC, %	73,941	2.67
Overweight WCBA and stunted PSC, %	69,082	6.89
Principal independent variable		
Forest cover loss (2000–2012)[a], %	73,941	2.05
Child-level covariates		
Child age, months	73,941	34.74 (13.87)
Child sex, %	73,941	
Female		49.76
Male		50.24
Highest attained education of mother, %	73,941	
None		42.99
Primary		32.32
Secondary		21.47
Post-secondary		3.22
Woman-level covariates		
Age in years	25,285	29.52 (7.38)
Anemic (hemoglobin concentration<120 g/L), %	25,285	42.92
Overweight (BMI≥25), %	25,285	21.61
Household-level covariates		
Wealth quintiles, %	73,941	
Lowest		29.14
Low		18.52
Middle		17.85
High		18.09
Highest		16.40
Household size	73,941	7.38 (4.26)
Household access to improved water source, %	73,941	60.65
Household access to improved sanitation, %	73,941	43.79
Ownership of agricultural land, %[d]	73,941	65.80
Ownership of livestock, %	73,941	57.68
Cluster-level covariates		
Cluster location, %		
Urban	73,941	33.32
Rural		66.68
Forest cover (2000)[b], %	73,941	20.23 (21.95)
Aridity index[c]	73,941	7.97 (4.72)
Distance of cluster to nearest road, km	73,941	15.84 (16.60)

Values are proportions or means. The first measure of double burden is at the mother-level, the second measure is at the child-level, and the third measure is for the mother-child pair (see text). [a]Forest cover loss is measured as the mean of 30 m by 30 m grid cell data (i.e., 0's and 1's) at a 5 km resolution, multiplied by 100. [b]Forest cover (2000) is based on forest cover data (Hansen et al., 2013) indicating percentage of forest cover per 30 m grid cell, aggregated to 5 km resolution. [c]Global Aridity Index reflects mean annual precipitation and evapotranspiration per cluster based on CGIAR Global Aridity Index dataset; a higher number indicates higher humidity. [d]For Liberia, the survey asked "if any member of the household farmed agricultural land" instead of what was asked in the remaining countries: "does your household own any agricultural land?".

household size, access to improved sanitation, child's age and gender, forest cover in 2000, and distance to the nearest road. Finally, factors strongly associated with overweight and stunted child included mother's age (negative association), access to improved sanitation, child's age, and forest cover in 2000 (negative and marginally significant association). In sum, different sets of covariates influenced the double burden measures depending on the measure we examined, and the only covariate that influenced all three measures in the same direction was improved sanitation. Ownership of agricultural land and livestock were associated with lower odds of concurrent anemia and overweight among WCBA, while only the ownership of livestock was associated with lower odds of overweight mother and stunted child. We found no association between the ownership of agricultural land or livestock and overweight and stunted PSC.

Although the association between forest loss and overweight and stunted PSC were only marginally significant (i.e., significant only at the 10% significance level), the estimated odds ratio was robust to controlling for different set of covariates, as shown in **Appendix Table A1**.

Potential Mechanisms, and Results by Region

Discussion in this subsection proceeds in the following manner. We first discuss the relationships between forest cover loss and intermediate outcomes (e.g., ownership of livestock), and between forest cover loss and the individual components of our double burden measures (e.g., anemic WCBA) for the overall sample. We then discuss the relationships by region.

For the overall sample, forest cover loss was strongly associated with lower odds of owning livestock, but not associated with ownership of agricultural land (**Table 4A**). It was strongly associated with lower odds of having access to improved source of water and marginally associated with improved sanitation. It was strongly associated with higher odds of the occurrence of diarrhea among the PSC.

In terms of the individual components of the double burden measures, forest cover loss was associated with higher odds of anemic WCBA and not associated with any of the remaining three components (**Table 5A**).

Table 5A also provides some insight into our main finding reported in **Table 3** and suggests that the strong association between forest cover loss and only one of the three double-burden measures is due to approach in which we construct the double-burden measures. In **Table 5**, among the three measures of double burden, the associations with forest cover and individual components are in the same direction only for the components related to PSC (stunted and overweight child). For the remaining two measures the associations are in the opposite direction. For example, take anemic WCBA and overweight WCBA. Forest cover loss is positively associated with the odds of anemic WCBA but negatively associated (although statistically not significant) with overweight women. Likewise, forest cover loss is positively associated with stunted PSC but negatively associated with overweight WCBA.

The wide confidence intervals reported in this table preclude an analysis at a lower geographic level (e.g., country), which would be more meaningful for designing policies. The small

TABLE 3 | Odds ratio from a logistic regression of measures of double burden on forest cover loss.

	Overweight women with anemia		Overweight mother and stunted child		Overweight and stunted child	
	(1)	(2)	(3)	(4)	(5)	(6)
Forest cover loss, 2000–2012	0.711 [0.151, 3.350]	0.713 [0.153, 3.325]	2.529 [0.818, 7.814]	2.466 [0.801, 7.596]	4.736* [0.804, 27.88]	4.801* [0.816, 28.25]
Education of mother (none)						
Primary	1.215*** [1.059, 1.393]	1.200*** [1.047, 1.376]	0.976 [0.893, 1.067]	0.976 [0.893, 1.066]	0.938 [0.818, 1.075]	0.939 [0.818, 1.076]
Secondary	1.134* [0.977, 1.316]	1.107 [0.954, 1.285]	0.921 [0.831, 1.022]	0.919 [0.829, 1.019]	0.799*** [0.677, 0.944]	0.802*** [0.679, 0.947]
Higher	1.119 [0.811, 1.543]	1.103 [0.801, 1.520]	0.681*** [0.560, 0.829]	0.678*** [0.557, 0.825]	0.728 [0.496, 1.069]	0.730 [0.497, 1.071]
Wealth quintiles (lowest)						
Low	1.382*** [1.164, 1.642]	1.377*** [1.160, 1.635]	1.165*** [1.051, 1.291]	1.176*** [1.060, 1.304]	1.161** [1.005, 1.342]	1.163** [1.006, 1.343]
Middle	1.557*** [1.315, 1.843]	1.542*** [1.303, 1.825]	1.280*** [1.156, 1.418]	1.288*** [1.163, 1.427]	0.934 [0.801, 1.088]	0.935 [0.802, 1.090]
High	2.048*** [1.722, 2.435]	1.982*** [1.666, 2.358]	1.349*** [1.210, 1.505]	1.347*** [1.207, 1.502]	0.997 [0.843, 1.178]	1.002 [0.848, 1.185]
Highest	1.988*** [1.645, 2.402]	1.894*** [1.566, 2.290]	1.484*** [1.311, 1.680]	1.471*** [1.300, 1.666]	0.835* [0.685, 1.018]	0.842* [0.690, 1.026]
Women's age in years	1.050*** [1.044, 1.058]	1.051*** [1.044, 1.058]	1.034*** [1.030, 1.039]	1.035*** [1.030, 1.040]	0.991** [0.983, 0.998]	0.991** [0.983, 0.998]
Location (rural)						
Urban	1.463*** [1.268, 1.689]	1.293*** [1.115, 1.500]	1.252*** [1.139, 1.377]	1.192*** [1.081, 1.315]	0.975 [0.840, 1.132]	0.989 [0.848, 1.153]
Household size	0.996 [0.983, 1.010]	1.005 [0.992, 1.019]	1.013** [1.003, 1.023]	1.016*** [1.006, 1.027]	0.999 [0.983, 1.014]	0.998 [0.982, 1.014]
Improved water source (no)	1.178*** [1.042, 1.333]	1.163** [1.028, 1.315]	1.017 [0.943, 1.097]	1.011 [0.938, 1.091]	0.986 [0.878, 1.108]	0.987 [0.878, 1.109]
Improved sanitation (no)	1.271*** [1.127, 1.435]	1.224*** [1.084, 1.381]	1.165*** [1.078, 1.258]	1.156*** [1.070, 1.248]	1.253*** [1.109, 1.415]	1.258*** [1.113, 1.421]
Forest cover (2000), %	1.002 [0.998, 1.005]	1.002 [0.999, 1.006]	1.004** [1.001, 1.006]	1.004*** [1.001, 1.007]	0.996* [0.991, 1.000]	0.995* [0.991, 1.000]
Aridity Index	1.032*** [1.012, 1.051]	1.024** [1.005, 1.043]	1.004 [0.992, 1.017]	1.001 [0.988, 1.013]	0.983 [0.963, 1.004]	0.984 [0.963, 1.005]
Distance of cluster to nearest road, km	0.998 [0.994, 1.002]	0.998 [0.994, 1.002]	0.995*** [0.992, 0.998]	0.995*** [0.992, 0.998]	1.000 [0.995, 1.005]	1.000 [0.995, 1.005]
Ownership of agricultural land (no)		0.727*** [0.643, 0.822]		0.939 [0.867, 1.018]		1.076 [0.947, 1.223]
Ownership of livestock (no)		0.882** [0.784, 0.993]		0.892*** [0.827, 0.962]		0.972 [0.865, 1.093]
Child's age, months			1.050*** [1.036, 1.064]	1.050*** [1.036, 1.064]	1.032*** [1.012, 1.053]	1.032*** [1.012, 1.053]
Child's age squared			0.999*** [0.999, 1.000]	0.999*** [0.999, 1.000]	1.000*** [0.999, 1.000]	1.000*** [0.999, 1.000]
Child sex (male)			1.137*** [1.069, 1.210]	1.137*** [1.069, 1.209]	0.959 [0.872, 1.054]	0.959 [0.872, 1.054]
Child had diarrhea recently			1.048 [0.953, 1.153]	1.049 [0.953, 1.154]	0.896 [0.763, 1.053]	0.896 [0.763, 1.053]
Chi-squared	1059.92***	1098.26***	705.34***	720.79***	1261.79***	1263.82***
N	25,285	25,285	69,082	69,082	73,941	73,941

*p < 0.10, **p < 0.05, ***p < 0.01. Each column represents results from a separate equation. All models were adjusted for the covariates shown as well as country fixed effects, cluster-level random effects, and the month of the survey. Standard errors were clustered at the level of DHS enumeration clusters. The reference categories for all covariates are shown in parentheses next to the name of each covariate. In columns (2), (4) and (6), we control for household ownership of agricultural land and ownership of livestock, in addition to the covariates in columns (1), (3) and (5), respectively.

TABLE 4 | Odds ratio from logistic regressions of intermediate factors on forest cover loss.

	Ownership of livestock	Ownership of agricultural land	Improved water source	Improved sanitation	Child had diarrhea recently
A: Overall					
Forest cover loss, 2000–2012	0.005*** [0.001, 0.019]	1.333 [0.230, 7.731]	0.023*** [0.003, 0.193]	0.175* [0.025, 1.228]	5.052*** [2.256, 11.310]
Chi-squared	57.92***	0.10	12.14***	3.07*	15.51***
N	73,941	73,941	73,941	73,941	73,941
B: West Africa					
Forest cover loss, 2000–2012	0.000861*** [0.000112, 0.00659]	0.0251*** [0.00195, 0.323]	10.41 [0.582, 186.2]	2.518 [0.131, 48.27]	11.02*** [3.053, 39.75]
Chi-squared	46.18***	7.99***	2.54	0.38	13.43***
N	47,214	47,214	47,214	47,214	47,214
C: Central Africa					
Forest cover loss, 2000–2012	5.212 [0.660, 41.18]	16.88* [0.881, 323.5]	0.00105*** [0.0000162, 0.068]	3.483 [0.145, 83.59]	0.296** [0.102, 0.856]
Chi-squared	2.45	3.52*	10.41***	0.59	5.04**
N	17,009	17,009	17,009	17,009	17,009

*p < 0.10, **p < 0.05, ***p < 0.01. This table shows odds ratios from estimating a logistic regression of intermediate factors linking forest cover loss to nutritional status on forest cover loss. All models include cluster-level random effects. **(A)** Shows results for the entire sample used in the main analysis. **(B,C)** Show results separately for West and Central African regions, respectively.

TABLE 5 | Odds ratio from logistic regressions of individual components of double burden measures on forest cover loss.

	Anemic women	Overweight women	Stunted child	Overweight child
A: Overall				
Forest cover loss, 2000–2012	3.288** [1.321, 8.184]	0.865 [0.288, 2.600]	1.554 [0.788, 3.064]	2.102 [0.481, 9.189]
Chi-squared	1112.10***	2316.99***	3662.12***	1408.99***
N	25,285	25,285	73,941	73,941
B: West Africa				
Forest cover loss, 2000–2012	1.317 [0.355, 4.879]	0.547 [0.110, 2.725]	2.004 [0.707, 5.682]	5.468 [0.603, 49.58]
Chi-squared	197.77***	1478.82***	2328.02***	1149.08***
N	16,487	16,487	47,214	47,214
C: Central Africa				
Forest cover loss, 2000–2012	4.636** [1.294, 16.62]	1.850 [0.360, 9.518]	1.097 [0.440, 2.733]	1.713 [0.231, 12.71]
Chi-squared	194.18***	677.07***	865.88***	106.36***
N	6,263	6,263	17,009	17,009

*p < 0.10, **p < 0.05, ***p < 0.01. The table shows odds ratios from a logistic regression of individual components of the double burden measures (shown in the top row) on forest cover loss. Each odds ratio is from a separate regression (that is, the table contains odds ratios from 12 different regressions). All models were adjusted for the covariates used in the main analysis, including country fixed effects, cluster-level random effects, and the month of the survey. Standard errors were clustered at the level of DHS enumeration clusters. The 95% confidence intervals are in brackets below the odds ratios. **(A)** Includes West, Central, and East African regions. **(A)** Shows results for the entire sample used in the main analysis. **(B,C)** Show results separately for West and Central African regions, respectively.

sample size is a concern particularly for eastern Africa (which includes only two countries: Kenya and Rwanda). Therefore, in assessing the relationship between forest cover and intermediate outcomes as well as the individual components of the double burden at the regional level, we focus on western and central Africa.

The overall results mask significant heterogeneity across geographic regions within SSA. As shown in **Table 6**, the significant association between forest cover loss and overweight and stunted PSC are driven by the association in West Africa, while no such relationship exists in Central and East Africa.

There are also significant regional differences in the association of forest cover with the intermediate factors as well as the individual measures of nutritional status. With respect to the intermediate factors, forest cover loss is associated with lower odds of owning livestock and lower odds of owning agricultural land in West Africa (**Table 4B**). It is associated with higher odds of the incidence of diarrhea among the PSCs in the region. Unlike in the overall sample, there is no association between forest cover loss and access to improved water or sanitation. In contrast, in the central region, forest cover loss is associated with *higher* odds of owning agricultural land and *lower* odds of

TABLE 6 | Odds ratio from a logistic regression of measures of double burden on forest cover loss, by region.

	Overweight woman with anemia	Overweight mother and stunted child	Overweight and stunted child
West Africa			
Forest cover loss, 2000–2012	0.31 [0.03, 2.96]	3.21 [0.60, 17.07]	16.80** [1.31, 214.2]
Chi-squared	549.00***	489.64***	1031.23***
N	16,487	42,514	47,214
Central Africa			
Forest cover loss, 2000–2012	1.98 [0.24, 15.94]	2.96 [0.58, 15.08]	2.32 [0.19, 27.78]
Chi-squared	466.25***	230.07***	62.58***
N	6,263	16,906	17,009
East Africa			
Forest cover loss, 2000–2012	0.00 [0.00, 21291700000]	0.66 [0.01, 44.11]	0.00005 [0.00, 186.10]
Chi-squared	42.13***	134.86***	115.63***
N	2,534	9,662	9,718

*p < 0.1; **p < 0.05; ***p < 0.01. This table presents odds ratios from logistic regressions of the three measures of double burden of malnutrition on forest cover loss, separately for each region. West Africa includes Benin, Cote d'Ivoire, Ghana, Guinea, Liberia, Mali, Nigeria, Senegal, Sierra Leone, and Togo. Central Africa includes the Democratic Republic of Congo, Gabon, and Zambia. East Africa includes Kenya and Rwanda. In models with overweight and anemic WCBA, we control for the women's age and education level, household wealth, household access to improved water and sanitation, household ownership of agricultural land, household ownership of livestock, DHS cluster location (i.e., urban or rural), baseline forest cover in 2000, the CGIAR Global Aridity Index, distance of cluster to nearest road, country fixed effects, cluster-level random effects, and the month of the survey. In models with overweight mother and stunted child or overweight and stunted child, we control for all the variables used in first column plus the child's age, child age squared, child gender, and whether the child had diarrhea during 2 weeks prior to survey. Standard errors were clustered at the level of DHS enumeration clusters.

the incidence of diarrhea (**Table 4C**). The association between forest cover loss and access to improved water is in the same direction as that of the overall sample. The key message from **Table 4** is that the mechanisms through which forest cover loss influences nutritional double burden differ between the regions. With respect to the individual components of the double burden measures, however, the relationships at the regional level are in agreement with those for the entire sample (**Tables 5B,C**).

DISCUSSION

The double burden of malnutrition is linked to the ongoing epidemiologic transition, whereby non-communicable conditions, such as cardiovascular diseases and diabetes, are replacing communicable conditions, such as malaria, as the primary causes of morbidity and mortality in low- and middle-income countries (Shrimpton and Rokx, 2012). An emerging body of literature has examined the socio-economic determinants (e.g., education, urbanicity, and income) of the double burden within the same household (Kosaka and Umezaki, 2017). Existing literature has also shown that environmental changes such as deforestation are linked to changes in diet, a key input to an individual's nutritional status (Rasmussen et al., 2017; Reed et al., 2017), as well as measures of malnutrition, such as

underweightness (Pienkowski et al., 2018). However, remarkably little has been written on the possible linkages between deforestation and the nutritional double burden. Generally speaking, the ecological determinants of the double burden are poorly understood. This is an important omission because the double burden of malnutrition may be an important mechanism linking environmental changes to diets and non-communicable conditions (Frumkin and Haines, 2019). More importantly, deforestation may have a temporal dimension, through which different segments of the population might be affected differently and the same individual might be affected differently based on the outcome measured. In the current study, however, we found only a marginal association between the measure of the double burden pertaining to the child (overweight and stunted PSC) and forest cover loss and no association between forest cover loss and the remaining two measures. These findings suggest that the effect of deforestation observed in other health outcomes may either not extend or extend only marginally to the nutritional double burden, although the lack of association seems in part due to the way the double burden measures are constructed.

We must interpret our findings with a number of caveats. First, as we have pointed out previously (Galway et al., 2018), the Global Forest Change dataset defines trees as vegetation taller than five meters, and therefore underestimates true forest loss. Second, the forest loss data used does not take into account reforestation that may have taken place during the period. If the current double burden of malnutrition reflects the net effect of deforestation and reforestation, our estimates are underestimates of the true association.

Third, although we controlled for a range of potential confounders in our analysis, we cannot interpret the observed associations as causal. Our data are cross-sectional and as such we are unable to employ panel data methods available for establishing causal relationships. There is limited possibility of reverse causality (i.e., double burden of malnutrition triggering deforestation), in part because, by our study design, the timing of forest cover loss (2000–2012) precedes that of the DHS surveys (after 2013). Nonetheless, there could be omitted variables—such as food availability and access to market—for which we could not control given the data. Finally, we are unable to comment fully on how land use patterns, income, and lifestyle (e.g., amount of movement, time spent on fetching water and firewood or collecting fodder for livestock) may have changed as a result of deforestation and how those changes may influence the nutritional double burden.

Notwithstanding these limitations, the association between forest cover loss and the measure having child-level indicators—although it is only marginal—is worrying from a policy perspective, given the long-lasting nature of early-life nutritional deficiencies. A large body of research has shown that poor nutritional status in childhood has lasting effects into adulthood. For example, early-life nutrition is an important determinant of one's long-term productivity, earnings, and health (Alderman et al., 2006; Dewey and Begum, 2011; Currie and Vogl, 2013). Our findings contribute to the ongoing dialogue about the need to prevent deforestation and conserve biodiversity at a range of spatial scales for multiple goals, including limiting the

potential adverse impacts on child malnutrition and children's long-term wellbeing.

More generally, we have previously shown that deforestation is associated with the diversity and quality of children's diet, and proposed various mechanisms for the association (Galway et al., 2018). The analysis presented here—using the same set of countries and periods as the previous study—showed that the association of forest cover loss may extend, albeit marginally, to children's anthropometric measures of the double burden of malnutrition, specifically the likelihood of simultaneously being overweight and stunted. One possible mechanism for this association is that reduced consumption of legumes and nuts, flesh foods, and other fruits and vegetables resulting from deforestation—as we established in the previous study—deleteriously affects child linear growth. Simultaneously, deforestation may raise the risk of overweight if calorie intake is increased by consuming energy-dense processed foods. When we examined the association between components of double burden measures—stunting and overweight—we find that both of these measures are positively associated with forest cover loss although the associations are not statistically significant.

Given the limitations of our data, we are unable to examine why deforestation is not associated with the prevalence of anemic and overweight WCBA or overweight WCBA and stunted PSC and is only marginally associated with the prevalence of overweight and stunted PSC. Additional data—including on, for example, the drivers of deforestation and usages of the deforested areas—will be needed to examine such questions. Likewise, because the prevalence of overweight also depends on lifestyle and habits (see Figure 4 in WHO, 2017), information on how deforestation influences these factors will be central to understanding the temporal dimension, if one exists. One can hypothesize, for example, that when forests are cleared for construction of building, it increases the amount of time women spend on finding fodder for cattle or firewood, thus expending more calories and reducing the chances of gaining excess weight (thus reducing the chances of being overweight and anemic). For the children, on the other hand, cleared land and development of a local marketplace may mean easier access to processed foods that contribute to unhealthy weight gains (thus increasing the chances of being overweight). Similarly, one can hypothesize that, other environmental factors that deforestation affects, such as access to clean drinking water (Mapulanga and Naito, 2019), may affect the nutritional status of young children, but not adults. These examples are only illustrative of the complex ways that deforestation may influence individual behavior and contribute to the double burden of malnutrition.

Additional research will be required to confirm the findings in our study, establish mechanisms, and to uncover any potential temporal dimensions (specifically, to examine different effects of forest cover loss among different population segments). For effective policy design, the mechanisms will need to be examined at the regional and country levels, as the mechanism may vary at those levels—as our analysis at the level of the regions within SSA suggests. For example, it is not clear why forest cover loss is negatively associated with the ownership of agricultural land in the West Africa region but positively associated in the Central Africa region. Some of the differences in potential mechanisms may be due to social and economic factors, such as education and wealth as the regions vary widely in these dimensions, but this needs to be investigated further.

For effective policy design, it is also important to understand the relative importance of different mechanisms shown in **Figure 1**. Among the various mechanisms, as mentioned before, several studies have hypothesized and assessed the association between forest cover loss and diets. This focus on diets is not surprising given SSA's reliance on forests for food. For example, 60 percent of the households in 11 African countries have been shown to collect wild food from forests (Hickey et al., 2016). Likewise, using data from 37 communities in 24 countries, including five in Africa, Rowland et al. (2017) find that more than half of the households in their sample collected forest food for consumption. However, the research linking forest cover loss to diets is far from conclusive, and the reliance on forests for food varies across regions, cultures, and population sub-groups. The strength of other mechanisms, therefore, likely varies across these dimensions as well.

CONCLUSION

Deforestation does not seem to be an important driver of the double burden of malnutrition in SSA. We found no association between deforestation and measures of the double burden pertaining to the same WCBA or mother-child pair within the household. The association we found between deforestation and the measure based on the same child is worrying from a policy perspective, even though additional research will be required to confirm it. If this association is robust, the effect of deforestation may have a temporal aspect, which also warrants further research. More generally, there is a need to better understand the potential mechanisms linking forest cover loss to health and nutrition, their relative contributions, and differences across geographic regions and countries.

DATA AVAILABILITY STATEMENT

Data used in this study were obtained from Demographic and Health Surveys (DHS) and the Global Forest Change dataset. The DHS data are available after a simple registration process (https://dhsprogram.com/data/new-user-registration.cfm). The Global Forest Change data are available from http://earthenginepartners.appspot.com/science-2013-global-forest.

ETHICS STATEMENT

Ethical approval was not required for this study as it used publicly-available de-identified data.

AUTHOR CONTRIBUTIONS

YA, LG, and AJ conceptualized the study. YA and LG prepared the dataset. YA and SN conducted the statistical analysis. All authors contributed in the preparation of the final manuscript and approved it for publication.

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APPENDIX

TABLE A1 | Odds ratio from step-wise logistic regressions of overweight and stunted child on forest cover loss.

	(1)	(2)	(3)	(4)
Forest cover loss, 2000–2012	4.801* [0.816, 28.25]	4.970* [0.846, 29.20]	5.108* [0.868, 30.07]	5.544* [0.945, 32.53]
Child sex (male)	0.959 [0.872, 1.054]			
Child's age, months	1.032*** [1.012, 1.053]			
Child's age squared	1.000*** [0.999, 1.000]			
Child had diarrhea recently (no)	0.896 [0.763, 1.053]			
Education of mother (none)				
Primary	0.939 [0.818, 1.076]	0.937 [0.817, 1.074]		
Secondary	0.802*** [0.679, 0.947]	0.801*** [0.678, 0.946]		
Higher	0.730 [0.497, 1.071]	0.730 [0.498, 1.071]		
Women's age in years	0.991** [0.983, 0.998]	0.991** [0.984, 0.999]		
Wealth quintiles (lowest)				
Low	1.163** [1.006, 1.343]	1.161** [1.005, 1.342]	1.158** [1.002, 1.337]	
Middle	0.935 [0.802, 1.090]	0.936 [0.803, 1.091]	0.928 [0.796, 1.081]	
High	1.002 [0.848, 1.185]	1.003 [0.848, 1.185]	0.977 [0.828, 1.153]	
Highest	0.842* [0.690, 1.026]	0.841* [0.690, 1.026]	0.787** [0.649, 0.955]	
Household size	0.998 [0.982, 1.014]	0.998 [0.982, 1.014]	0.996 [0.980, 1.011]	
Improved water source (no)	0.987 [0.878, 1.109]	0.988 [0.879, 1.110]	0.980 [0.872, 1.101]	
Improved sanitation (no)	1.258*** [1.113, 1.421]	1.258*** [1.113, 1.421]	1.244*** [1.101, 1.405]	
Ownership of agricultural land (no)	1.076 [0.947, 1.223]	1.076 [0.947, 1.222]	1.081 [0.951, 1.228]	
Ownership of livestock (no)	0.972 [0.865, 1.093]	0.974 [0.867, 1.095]	0.974 [0.866, 1.094]	
Forest cover (2000),	0.995* [0.991, 1.000]	0.995* [0.991, 1.000]	0.995** [0.990, 1.000]	0.995* [0.991, 1.000]
Aridity Index	0.984 [0.963, 1.005]	0.985 [0.964, 1.006]	0.979* [0.959, 1.000]	0.976** [0.956, 0.997]
Distance of cluster to nearest road, km	1.000 [0.995, 1.005]	1.000 [0.995, 1.005]	1.000 [0.995, 1.005]	1.000 [0.996, 1.005]
Location (rural)	0.989	0.989	0.966	0.927
Urban	[0.848, 1.153]	[0.849, 1.154]	[0.829, 1.125]	[0.811, 1.059]
Chi-squared	1263.82***	1254.50***	1241.00***	1213.40***
N	73,941	73,941	73,941	73,941

*p < 0.1; **p < 0.05; ***p < 0.01.
All models were adjusted for the covariates shown as well as country fixed effects, cluster random effects and the month of the survey. Standard errors were clustered at the level of DHS enumeration clusters. The reference categories for all covariates are shown in parentheses next to the name of each covariate.