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Household air pollution could make children grow shorter in sub-Saharan Africa; but can households help stem the tide on their own?

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ABSTRACT

Recently, there has been growing research interest in the influence of household air pollution on child health. Despite the increasing advocacy for households to switch from the use of polluting cooking fuels due to climate change and health-related concerns, the practice is still prevalent in Sub-Saharan Africa (SSA). The intensity of household air pollution exposure and its influence on child stunting and wasting of children is an important, but understudied, cause for public health concern. Identifying the health effects of polluting fuels, for instance, could stimulate a speedy transition to clean energy. This study, therefore, examines the association between the intensity of household air pollution exposure and child stunting and wasting of children using data from the most recent demographic and health surveys (DHS) from 33 countries in SSA using linear probability modeling. Results show that high levels of intensity of air pollution within households are associated with increased stunting probability of 2.9% − 3.2%. The findings highlight a potential negligible cost measure households can adopt to limit the intensity of pollution they are exposed to and consequently, to reduce the faltering growth in children.

1. Introduction

Childhood malnutrition is a growing public health concern, especially in Asia and Sub-Saharan Africa (Chadare et al., 2022; Tesema, Yeshaw, et al., 2021; Upadhyay et al., 2021). Stunting and wasting are the most common anthropometric indicators used in the study of chronic and more recent childhood malnutrition. Accordingly, the WHO describes child wasting as a child who is too thin for his or her height and is the result of recent rapid weight loss or the failure to gain weight whereas stunting or being too short for one's age, is defined as a height that is more than two standard deviations below the World Health Organization (WHO) child growth standards median. (World Health Organization, 2014) The SDG 2.2 *targets have been set to end all forms of malnutrition, including achieving by 2025 the internationally agreed targets on stunting and wasting in children under five years of age*. Globally, 144 million children under 5 suffer from stunting. However, Africa and Asia have been observed to have the highest prevalence of all forms of childhood malnutrition. Estimates from the WHO indicate that in 2019, about 40 percent of all stunted children under 5 years old lived in Africa, whilst about 27 percent of children in Africa were described as wasted (World Health Organization, 2020). Besides, a recent multi-country study on the adverse nutritional status of children in 31 countries in sub-Saharan Africa showed that 26 % of children in the sub-region were considered stunted whilst 6 % were described as wasted (Adedokun & Yaya, 2021). Despite the existing interventions, declines in the levels of childhood malnutrition have been slow in Sub-Sahara Africa, According to the World Health Organization, the proportion of stunted children declined from 42.9 % to 33 % between the years 2000 and 2019 in Sub-Sahara Africa compared to the 51.3 % to 33.2 % in South Asia within the same period (World Health Organization, 2020).

The health consequences of the high levels of child malnutrition are evident especially in Sub Sahara Africa (Bain et al., 2013; Christian & Dake, 2022; Drammeh et al., 2019; Gassara & Chen, 2021; Sestito et al., 2021). Malnutrition is the leading cause of morbidity and mortality in under-five children. There is strong evidence that stunting in children could result in irreversible physical and cognitive damage and that stunting before the age of 2 years predicts poorer cognitive and educational outcomes in later childhood and adolescence (Deshpande & Ramachandran, 2022). Economically, a 1 % loss in adult height due to childhood stunting is associated with a 1.4 % loss in economic productivity (World Health Organization, 2020; Haddad and Bouis, 1991).

The potential risk factors of malnutrition among children in SSA have

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received considerable critical attention (Antehunegn et al., 2021; Danaei et al., 2016; Tesema, Worku, et al., 2021). Some cross-sectional studies suggest complex associations between socio-demographic factors and childhood malnutrition (Akombi et al., 2017; Amadu, Seidu, Duku, Frimpong, et al., 2021; Simwanza et al., 2022; Vilcins et al., 2018; Woodruff et al., 2018). In a recent scoping review of the risk factors of child malnutrition in Sub-Sahara Africa, Simwanza et al., (2022), observed that most of the studies emphasized the importance of the role of maternal-related, family/household-related, child-related as well as context-related factors. Accordingly, factors that consistently appear as determinants of childhood malnutrition include; wealth, education, child's age, sex, and perceived birth weight, mother's educational status, body mass index (BMI), and place of residence type of toilet facility (Adjei-Mantey & Takeuchi, 2021; Begashaw, 2022; Darteh et al., 2014; Pomati & Nandy, 2020; Woodruff et al., 2018). Pomati & Nandy, (2020) argue that malnutrition across the region remains strongly associated with household wealth and education and that poorer, rural households are much more likely to experience malnutrition. However, despite efforts made, levels of malnutrition remain high in Sub-Sahara Africa creating a need to further study the association of the intensity of environmental exposures on child growth in conjunction with other potential confounding risk factors. This will provide evidence-based ideas that will support multisectoral approaches to effectively accelerate reductions the childhood malnutrition.

One area that has received little research attention is the potential relationship between household air pollution (HAP) from the incomplete combustion of cooking fuel and childhood malnutrition (Li et al., 2021). Most studies on child growth have only focused on the critical role of water, sanitation, and hygiene (Mela Danjin et al., 2021; Ntakarutimana et al., 2021; Patlán-Hernández et al., 2022; Soboksa et al., 2021; van Cooten et al., 2019). Exposure to HAP is related to adverse effects on children's growth (Ahmed et al., 2021; Amadu, Seidu, Afitiri, et al., 2021; Epstein et al., 2013; Geremew et al., 2020; Mandal et al., 2020; Sk et al., 2019; Woolley et al., 2022). Yet, the contribution of HAP to child growth has not been empirically examined in SSA countries where the majority of households continue to rely on the use of smoke-polluting cooking fuels that expose children to higher levels of HAP. What is less clear is the nature of the causal pathway through which HAP contributes to child malnutrition. It is plausible that the higher levels of hydrocarbons emitted from the combustion of smoke-polluting cooking fuels react with hemoglobin to form carboxyhemoglobin to reduce the level of hemoglobin in the blood of susceptible children (Caleyachetty et al., 2022; Machisa et al., 2013).

In recent years, a few researchers have begun to focus their attention on the association between the type of cooking fuel used and childhood malnutrition (Adjei-Mantey & Takeuchi, 2021; Ahmed et al., 2021; Amadu, Seidu, Duku, Okyere, et al., 2021; Balietti & Datta, 2017; Li et al., 2021; Machisa et al., 2013; Upadhyay et al., 2021). Notably, Sinharoy et al. (2020) argue that household air pollution has been ignored as a potential risk factor for stunting. They, therefore, outlined a conceptual framework to illustrate how air pollution could lead to impaired linear growth in children, whilst calling for further research to explore the interrelationships. Understanding the interrelationship between child malnutrition and household air pollution across SSA countries would therefore, be an important step in any effort to accelerate the progress towards the achievement of SDG target 7.12 and 2.2.

More recent research has established an association between the type of cooking fuel used and childhood malnutrition. Adjei-Mantey and Takeuchi (2021), for instance, observed that children born in households in Ghana that used biomass as primary cooking fuel are shorter on average after birth. They further projected that transitioning from smoking-producing cooking fuel to a much cleaner cooking fuel such as LPG could result in an increase in the average height for age Z score from –1.269 to –0.43. Similarly, Caleyachetty et al. (2022) in a cross-sectional study of about 557 098 children from 59 low- and middle-income countries (LMICs) also revealed that household use of solid cook fuel consistently increased the likelihood of childhood stunting. Another study in Bangladesh found a significant association between chronic childhood malnutrition and household biomass fuel use (Ahmed et al., 2021). Furthermore, a longitudinal study in low- and middle-income countries has further provided evidence of a strong association between household use of solid fuels and childhood stunting. This study showed that the average height-for-age z-score (HAZ score) is lower among children living in households using solid fuels than among children in households using cleaner fuels for cooking (Upadhyay et al., 2021).Ultimately, the consensus in the literature is that households using smoke-producing cooking fuels face the risk of having stunted children. In contrast, a study in Swaziland found no statistically significant association between biomass cooking fuel use and childhood stunting, after adjusting for the child's gender, age, birth weight, and preceding birth interval (Machisa et al., 2013).

Epidemiological studies on child health have gained fresh importance with some compelling evidence that suggests an association between household air pollution and cooking places (Al-Janabi et al., 2021; Li et al., 2021; Sk et al., 2019). Though a few studies have been conducted to illustrate the health of effects of exposure to HAP on child health in SSA (Amadu, Seidu, Duku, Okyere, et al., 2021; Machisa et al., 2013), these studies have relied on the type of fuel the household primarily used for cooking as the key exposure variable of interest, regardless of the place where food is cooked, and are therefore unable to capture in reality, the extent of children's risk of exposure to cooking smoke. Arguably, the levels of exposure could be dependent on the type of fuel used, however, the nature of the cooking place for the combustion could better illustrate the extent of vulnerability of the exposed population (Li et al., 2021). In most cases, women and children are the most vulnerable as they have been observed to spend more time at various cooking places.

Available evidence shows that households that cook in enclosed unventilated kitchens have 10–15 times higher exposure levels compared to households with ventilated kitchens or using outdoor cooking places (Smith, 2000 cited in Upadhyay et al., 2021). Li et al. (2021) in their study of choice household fuel types and undernutrition status of adults and children in 14 LMICs found that indoor use of high-polluting fuels was statistically and significantly associated with higher risks of stunting (PR = 1.07, 95 % CI: 1.00, 1.16) but no association with wasting. Thus, relying on household cooking fuel type alone may not be enough in exploring possible alternative risk factors for childhood malnutrition. Yet in SSA, little is known about how the type of cooking fuel used interacts with the place of cooking to affect childhood malnutrition.

Studies examining childhood malnutrition and its determinants across SSA countries, especially, those using nationally representative data are scanty. Previous studies are prevalent on individual countries and their findings may not apply to the entire population. Therefore, reliable information on this phenomenon is needed to provide enough evidence to track progress towards the achievement of SDG 2 in all countries within a sub-region where levels of malnutrition have remained consistently high. Considering the dire health consequences, and SSA's slow progress in achieving SDG 2, requires efforts for further reductions in childhood malnutrition, hence, a need for more evidence-based studies that provide a deeper understanding of a broader range set of risk factors.

Therefore, this study aims to explore the extent to which the levels of the intensity of exposure to household air pollution from the type of cooking smoke and place of cooking could be associated with malnutrition among children who are under-five years in Sub Sahara Africa by considering both the cooking fuel type and the place of cooking.

The present study seeks to contribute towards bridging the research gaps in the literature by examining the combined influence of household cooking fuel type and place of cooking on child stunting in sub-Sahara Africa; creating a pollution intensity exposure variable that accounts for both the fuel type and the cooking place, consequently generating a spectrum of household air pollution intensity as our exposure variable. This study provides new insights into underlying contextual factors. The study findings could help to inform the design of evidence-based public health interventions for reducing childhood malnutrition, and subsequently reducing child mortality in the sub-region.

2. Data and methodology

This section presents the sources of data, explains the key variables used in the analysis and how they were constructed and details the methodology adopted to analyze the data.

2.1. Data

In this study, we pooled together the latest round of the Demographic and Health Survey (DHS) from 33 sub-Saharan African countries with data on the type of cooking fuel and cooking place. Our study population was defined to include all children aged under five years that lived in households that cook food at specified cooking places in the house. The data were collected in different years for different countries between 2010 and 2020 (see Appendix A). The DHSs are household and individual level data collected from a nationally representative sample across each country. The DHSs use a multi-stage stratified and cluster sampling design to collect detailed health and demographic data on children (children under 5 years), women and men of reproductive age thus, standing tall as a reliable source of quality and comprehensive nationally representative household-level data for studies of this nature. For each selected country, the Children's Recode file was merged with Women Recode and Household Recode files to constitute a single dataset for this study. The dataset is accessible to the public upon request.[1] Permission to download data for this study was approved in December 2021. Informed consent had already been obtained from all study participants. Hence there was no need to seek any further ethical approval for this study. Our sample size is very large as a result of pooling together data from as many as 33 SSA countries and this offers more robustness to the estimated coefficients from our analyses in respect of studies across the continent.

Two response variables were examined – stunting outcome and wasting outcome in children. Following the WHO definition, a child is classified as stunted if their height for age z-score falls two standard deviations below the median of the benchmark population. For severe stunting, their height for age z-score falls three standard deviations below the median of the benchmark population. Similarly, a child is classified as wasted if their weight for height z-score falls two standard deviations below the median of the benchmark population and severely wasted if their weight for age z-score falls three standard deviations below the median of the benchmark population. Thus, for each outcome i.e., stunting and wasting, a respondent would fall in one of three categories – not stunted (not wasted); stunted (wasted); and severely stunted (severely wasted). The main explanatory variable of interest is pollution intensity. This variable is constructed to measure the intensity of pollution the household is exposed to by combining their cooking fuel type with their place of cooking. Conceptually, low polluting fuels used outdoors are at the lowest end of the intensity spectrum. This is because while emitting low levels of pollution, their usage outdoors aids in quick diffusion or dispersal of particles thus limiting the intensity of pollution the household is exposed to. On the other hand, high polluting fuels used indoors have the greatest intensity. This is due to the heavy pollution being contained indoors with limited airiness to allow for quick dispersion of the pollutants. Indeed, Lenz et al. (2023) and Langbein et al. (2017) show that higher ventilation and outdoor cooking is associated with lower kitchen concentrations of particulate matter ($PM_{2.5}$). However, for this study, we do not differentiate between outdoor use and indoor use for low polluting fuels as preliminary analysis found no statistical difference between place of cooking for low polluting fuels.[2] For high polluting fuels, outdoor usage represents lower intensity of pollution compared to indoor usage of the same fuel type due to the ability of pollutants to disperse easier with the airiness associated with outdoor usage. Cooking fuels were classified into low-polluting fuels made up of electricity, Liquified Petroleum Gas (LPG), natural gas and biogas; and high polluting fuels made up of coal, charcoal, wood, grass or shrub, kerosene and agricultural waste. Thus, intensity ranged from 0 (low pollution intensity) if the household uses low-polluting fuel as cooking fuel through 1 (moderately high pollution intensity) if the household uses a high polluting fuel outdoors to 2 (very high pollution intensity) if the household uses a high polluting fuel indoors. The other explanatory variables were selected based on existing studies suggesting that child growth conditions are determined by several inter-related household environmental, social and demographic and economic variables (Khara & Dolan, 2014) The selected variables were categorized at individual child level variables including the sex of child, and perceived size of child at birth; Maternal related variables including mothers educational attainment, marital status, age and employment status; and household related variables such as wealth, household size, and location of the household (rural or urban).

2.2. Empirical methodology

Grossman (1972) modeled demand for health as being a function of observable and unobservable characteristics of the individual. Thus, one's health could likely be determined by their characteristics and other features related to them. On the basis of Grossman (1972), we model the stunting and wasting conditions of a child respectively as follows:

$$Y_{ij} = \alpha + \beta_1 X_{ij} + \beta_2 W_{ij} + \varepsilon_i (1)$$

$$Z_{ij} = \alpha + \beta_1 X_{ij} + \beta_2 W_{ij} + \varepsilon_i (2)$$

where Y_{ij} in (1) is a categorical variable for the stunting outcome, i.e., whether a child, i, in country, j, is not stunted, stunted or severely stunted and Z_{ij} in (2) is a categorical variable for the wasting outcomes, i.e., whether a child, i, in country, j, is not wasted, wasted or severely wasted. The intensity of pollution the household is exposed to is represented by X and W is a vector of control variables. For each child, Y_{ij} and Z_{ij} could take on one of a set of related outcomes that follow a natural ordering. One would either not be stunted, stunted, or be severely stunted with each successive outcome being a worse form of the previous one. Similarly, for wasting, one would either not be wasted, wasted, or be severely wasted. Equations (1)–(2) are therefore estimated using ordered logit regression. The estimations account for country fixed effects and time effects given that the data in the sample spans a period of over ten years. The coefficients from the ordered logit regressions are then transformed by predicting the marginal effects of each outcome (i.e., not stunted (not wasted); stunted (wasted); and severely stunted (severely wasted)) which show, for each explanatory variable, the probabilities of experiencing a particular outcome We cluster the standard errors at the DHS cluster level, which generally makes the standard errors robust to heteroscedasticity. It is worthy to note that pollution intensity within a household is potentially endogenous. It is possible that households who adopt low polluting fuels also take unobservable measures to prevent faltering growth in children. This study stops short of accounting for the potential endogeneity due to the practical difficulty of obtaining a valid instrument with sufficient data for the purpose. Thus, this study's estimates best represent correlates with stunting and wasting rather than a causal relationship between pollution intensity and stunting. Another point of note is that the intensity of pollution

[1] https://dhsprogram.com/data/available-datasets.cfm.

[2] This is further evident in the robustness analysis in section 3.

Table 1
Summary statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
Stunting					
Not stunted	210,505	0.684	0.465	0	1
Stunted	210,505	0.192	0.394	0	1
Severely stunted	210,505	0.125	0.330	0	1
Wasting					
Not wasted	211,384	0.932	0.252	0	1
Wasted	211,384	0.049	0.215	0	1
Severely wasted	211,384	0.020	0.138	0	1
Pollution intensity					
Low pollution intensity	211,384	0.081	0.273	0	1
Moderately high intensity	211,384	0.338	0.473	0	1
Very high intensity	211,384	0.582	0.493	0	1
Sex of child (1 = male)	211,384	0.504	0.500	0	1
Mother's education (Ref: none)					
Primary	211,384	0.334	0.472	0	1
Secondary and above	211,384	0.256	0.436	0	1
Marital status					
Currently in a union	211,384	0.881	0.324	0	1
Formerly in a union	211,384	0.061	0.239	0	1
Mother's age (Ref: 15–24 years)					
25–34 years	211,384	0.484	0.500	0	1
35 years and above	211,384	0.241	0.427	0	1
Employment status (1 = working)	211,384	0.694	0.461	0	1
Household size (1 = 7 +)	211,384	0.462	0.499	0	1
Household wealth (Ref: poorest)					
Poorer	211,384	0.215	0.411	0	1
Middle	211,384	0.192	0.394	0	1
Richer	211,384	0.175	0.380	0	1
Richest	211,384	0.151	0.358	0	1
Location (1 = urban)	211,384	0.311	0.463	0	1

Table 2
Sub-sample descriptives of main variables.

Variable	Low intensity N = 17,090		Moderately high intensity N = 70,887		Very high intensity N = 122,528	
	Mean	Std. Dev	Mean	Std. Dev.	Mean	Std. Dev
Not stunted	0.829	0.377	0.672	0.469	0.670	0.470
Stunted	0.116	0.320	0.195	0.396	0.200	0.400
Severely stunted	0.056	0.228	0.133	0.339	0.130	0.336
Variable	**Low intensity N = 17,115**		**Moderately high intensity N = 71,345**		**Very high intensity N = 122,924**	
	Mean	Std. Dev	Mean	Std. Dev.	Mean	Std. Dev
Not wasted	0.960	0.196	0.922	0.268	0.933	0.249
Wasted	0.040	0.196	0.078	0.268	0.067	0.249
Severely wasted	0.011	0.103	0.024	0.153	0.018	0.133

exposure variable was obtained from the main type of cooking fuel used by households. However, it is likely that some households may be stacking cooking fuels by substituting smoke-polluting cooking fuels with cleaner alternatives in preparing some specific meals. Our study, however, is unable to account for this due to data unavailability. Notwithstanding these limitations, the large dataset obtained from DHS is comprehensive enough to provide evidence of how the intensity of cooking smoke could affect the growth of children in SSA. The DHS is one of the most accessible, comprehensive and nationally representative datasets for studies on demographics and health of children in SSA.

3. Results and discussion

This section presents the summary statistics of the data and describes them, as well as the findings from the data analysis and discusses them within the context of literature and the study areas. Table 1 shows the summary statistics of the data used to estimate the full model while Table 2 presents descriptive statistics of child stunting and wasting measures across groups with different levels of pollution intensity.

From Table 1, it is observed that 19.2 % of the sample of children were stunted while 12.5 % were severely stunted while about 5 % of the sample are wasted and 2 % severely wasted. With respect to the intensity of pollution, about 58.2 % of the sample were exposed to very high pollution intensity - the highest end of the intensity spectrum (i.e., those households used heavy polluting fuels such as firewood indoors) followed by 33.8 % of the sample who were exposed to moderately high pollution intensity (i.e., they used heavy polluting fuels outdoors). This shows that for majority of the sample (>90 %), heavy polluting fuels dominated their cooking fuels. This may suggest a high number of children exposed to high levels of intensity of pollutants that would likely make them susceptible to the risk of adverse health outcomes. The full summary statistics for all variables are presented in Table 1. From Table 2, it is observed that among households that are exposed to very high intensity of pollution, a fifth of them (20 %) had children who were stunted with a similar situation among households exposed to moderately high pollution intensity where stunted children were found in nearly a fifth (19.5 %) of them. However, stunted children were found in only 11.6 % of households with low intensity of pollution. With regards to severe stunting, 13.3 % of moderately high and 13 % of very high pollution intensity households had severely stunted children but among those with low pollution intensity, only 5.6 % were found to have severely stunted children. It is therefore clear that higher proportions of stunting and severe stunting are observed in households exposed to moderately and very high pollution intensity i.e., those households that use heavy polluting fuels. With regards to wasting, 4 % and 1 % of low pollution intensity households were found to have wasted and severely wasted children respectively, whereas the statistics were 7.8 % and 2.4 % in the case of moderately high intensity households and 6.7 % and 1.8 % in the case of very high pollution intensity households.

Tables 3 and 4 presents the findings from the empirical estimations for stunting and wasting respectively. Columns (1) and (4) present the marginal effects for not stunted (not wasted); columns (2) and (5) present the marginal effects for stunted (wasted); and columns (3) and (6) show the results for severely stunted (severely wasted).

The results from Table 3 show that compared to the base category of low pollution intensity, higher pollution intensity levels are associated with lower likelihoods of not experiencing stunting but higher likelihoods of stunting and severe stunting. More specifically, for children living in households that are exposed to moderately high pollution intensity level, their likelihood of association with no stunting reduces by 5.7 % while their likelihood of association with stunting and severe stunting increases by 2.9 % and 2.8 % respectively while for children who live in households with very high pollution intensity, their likelihood of association with no stunting reduces by 6.4 % while their likelihood of association with stunting and severe stunting increases by 3.2 % relative to those in low pollution intensity households when all observable factors are controlled for. This means that, children living in households exposed to higher pollution intensity levels have greater associations with stunting and severe stunting compared to children living in low pollution intensity households. At the same time, those children living in higher pollution intensity households have lower likelihoods of not being associated with stunting compared to children living in lower pollution intensity households. The findings are consistent with those of Kurata et al. (2020) who observed that postnatal exposure to air pollution was associated with stunting in both boys and girls in Bangladesh while Mishra and Retherford (2007) also found stunting to be prevalent among children in households that use biofuel

Table 3
Marginal effects after ordered logit regression for stunting.

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Not stunted	Stunted	Severely stunted	Not stunted	Stunted	Severely stunted
Intensity of pollution						
1. (moderately high intensity)	−0.057***	0.029***	0.028***	−0.057***	0.029***	0.028***
	(0.006)	(0.003)	(0.003)	(0.006)	(0.003)	(0.003)
2. (very high intensity)	−0.064***	0.032***	0.032***	−0.064***	0.032***	0.032***
	(0.006)	(0.003)	(0.003)	(0.006)	(0.003)	(0.003)
Mother's education						
Primary education	0.031***	−0.015***	−0.016***	0.031***	−0.014***	−0.016***
	(0.003)	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)
Secondary and above	0.093***	−0.047***	−0.046***	0.093***	−0.047***	−0.047***
	(0.004)	(0.002)	(0.002)	(0.004)	(0.002)	(0.002)
Marital status						
Currently in union	0.006	−0.003	−0.003	0.006	−0.003	−0.003
	(0.006)	(0.003)	(0.003)	(0.006)	(0.003)	(0.003)
Formerly in union	−0.015**	0.007**	0.008**	−0.015**	0.007**	0.008**
	(0.007)	(0.003)	(0.004)	(0.007)	(0.003)	(0.004)
Mother's age						
25–34 years	0.013***	−0.007***	−0.007***	0.013***	−0.006***	−0.007***
	(0.003)	(0.001)	(0.001)	(0.003)	(0.001)	(0.001)
35 years and above	0.023***	−0.011***	−0.012***	0.023***	−0.011***	−0.012***
	(0.003)	(0.001)	(0.002)	(0.003)	(0.001)	(0.002)
Employment status (1 = working)	−0.001	0.0004	0.0005	−0.001	0.0004	0.0004
	(0.003)	(0.001)	(0.002)	(0.003)	(0.001)	(0.002)
Household size (1 = 7 + members)	−0.013***	0.006***	0.007***	−0.013***	0.006***	0.007***
	(0.003)	(0.001)	(0.001)	(0.003)	(0.001)	(0.001)
Wealth status						
Poorer	0.017***	−0.008***	−0.010***	0.017***	−0.008***	−0.010***
	(0.004)	(0.002)	(0.002)	(0.004)	(0.002)	(0.002)
Middle	0.048***	−0.022***	−0.025***	0.048***	−0.022***	−0.026***
	(0.004)	(0.002)	(0.002)	(0.004)	(0.002)	(0.002)
Richer	0.084***	−0.041***	−0.043***	0.084***	−0.041***	−0.043***
	(0.004)	(0.002)	(0.002)	(0.004)	(0.002)	(0.002)
Richest	0.155***	−0.080***	−0.075***	0.155***	−0.080***	−0.075***
	(0.005)	(0.003)	(0.002)	(0.005)	(0.003)	(0.002)
Locality (1 = urban)	0.012***	−0.006***	−0.006***	0.012***	−0.006***	−0.006***
	(0.004)	(0.002)	(0.002)	(0.004)	(0.002)	(0.002)
Sex of child (1 = male)				−0.047***	0.023***	0.024***
				(0.002)	(0.001)	(0.001)
Observations	210,505	210,505	210,505	210,505	210,505	210,505

Robust standard errors in parentheses *** p < 0.01, ** p < 0.05, * p < 0.1.

and thus exposed to biofuel smoke in India – a finding which is also consistent with ours. Our findings also complement those of Kyu et al. (2009) and LaFave et al. (2021) on the adverse effect of biofuel smoke from household cooking on children's heights and the improvements in children heights resulting from exposure to a less polluting cookstove in Ethiopia respectively. Goyal and Canning (2018), however, found no statistically significant effect of solid cooking fuel on stunting despite a positive association.

The results for wasting are presented in Table 4.

With regards to wasting, the results show that compared to the base category of low pollution intensity, higher pollution intensity levels are associated with lower likelihoods of not wasting but higher likelihoods of wasting and severe wasting. More specifically, for children living in households that are exposed to moderately high pollution intensity level, their likelihood of association with no wasting reduces by 0.8 % while their likelihood of association with wasting and severe wasting increases by 0.6 % and 0.2 % respectively while for children who live in households with very high pollution intensity, their likelihood of association with no wasting reduces by 0.7 % while their likelihood of association with wasting and severe wasting increases by 0.5 % and 0.2 % respectively relative to those in low pollution intensity households when all observable factors are controlled for. This means that, children living in households exposed to higher pollution intensity levels have greater associations with wasting and severe wasting compared to children living in low pollution intensity households. At the same time, those children living in higher pollution intensity households have a lower likelihood of not being associated with wasting compared to children living in lower pollution intensity households.

To observe whether there are actual differences between being in a moderate pollution intensity household and high pollution intensity household, we test for equality of the coefficients of these categories in both the stunting and wasting regressions. The results are presented in Table 5.

The results from Table 5 show that with regards to stunting, the categories moderately high intensity and very high intensity yield significantly different results. This shows that while exposure to pollution intensity was found to be associated with greater likelihoods of stunting and severe stunting, moving from very high intensity (using heavily polluting fuels indoors) to moderately high intensity (using heavily polluting fuels outdoors) yields substantial positive effects as that potentially reduces likelihoods of stunting. In the case of wasting, however, the results show that the two intensity categories do not differ significantly. In other words, both those exposed to moderately high pollution intensity and very high pollution intensity have similar probabilities of experiencing wasting and severe wasting. Therefore, a change in pollution intensity exposure cannot be said to have any significant effect on associations with wasting and severe wasting. Therefore, the extent of pollution intensity is significant in its association with stunting conditions but not in its association with wasting conditions.

Overall, our findings show strongly, the potential adverse effect of the intensity of pollution exposure on the heights of children after birth. This is possibly due to the fact that early life exposure to air pollution activates reactive oxygen which potentially leads to shortening of telomere lengths in children contributing to stunting (Sinharoy et al., 2020;

Table 4
Marginal effects after ordered logit regression for wasting.

VARIABLES	(1) No wasting	(2) Wasting	(3) Severe wasting	(4) No wasting	(5) Wasting	(6) Severe wasting
Intensity of pollution						
1. (moderately high intensity)	−0.008**	0.006**	0.002**	−0.008**	0.006**	0.002**
	(0.003)	(0.002)	(0.001)	(0.003)	(0.002)	(0.001)
2. (very high intensity)	−0.007**	0.005**	0.002**	−0.007**	0.005**	0.002**
	(0.003)	(0.002)	(0.001)	(0.003)	(0.002)	(0.001)
Mother's education						
Primary education	0.019***	−0.013***	−0.006***	0.019***	−0.013***	−0.006***
	(0.002)	(0.001)	(0.0005)	(0.002)	(0.001)	(0.0005)
Secondary and above	0.020***	−0.014***	−0.006***	0.020***	−0.014***	−0.006***
	(0.002)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)
Marital status						
Currently in union	0.001	−0.001	−0.0004	0.002	−0.001	−0.0005
	(0.003)	(0.002)	(0.001)	(0.003)	(0.002)	(0.001)
Formerly in union	−0.008	0.005	0.002	−0.007	0.005	0.002
	(0.004)	(0.003)	(0.001)	(0.004)	(0.003)	(0.001)
Mother's age						
25–34 years	0.003**	−0.002**	−0.001**	0.003**	−0.002**	−0.001**
	(0.002)	(0.001)	(0.0005)	(0.002)	(0.001)	(0.0005)
35 years and above	0.006***	−0.004***	−0.002***	0.006***	−0.004***	−0.002***
	(0.002)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)
Employment status (1 = working)	0.011***	−0.007***	−0.003***	0.011***	−0.007***	−0.003***
	(0.002)	(0.001)	(0.0005)	(0.002)	(0.001)	(0.0005)
Household size (1 = 7 + members)	0.0002	−0.0001	0.0001	0.0002	−0.0001	0.0001
	(0.001)	(0.001)	(0.0004)	(0.001)	(0.001)	(0.0004)
Wealth status						
Poorer	0.016***	−0.011***	−0.005***	0.016***	−0.011***	−0.005***
	(0.002)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)
Middle	0.018***	−0.013***	−0.006***	0.018***	−0.013***	−0.006***
	(0.002)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)
Richer	0.019***	−0.013***	−0.006***	0.019***	−0.013***	−0.006***
	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)	(0.001)
Richest	0.027***	−0.019***	−0.008***	0.027***	−0.019***	−0.008***
	(0.003)	(0.002)	(0.001)	(0.003)	(0.002)	(0.001)
Locality (1 = urban)	−0.003	0.002	0.001	−0.003	0.002	0.001
	(0.002)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)
Sex of child (1 = male)				−0.014***	0.010***	0.004***
				(0.001)	(0.001)	(0.0004)
Observations	211,384	211,384	211,384	211,384	211,384	211,384

Robust standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 5
Test of equality of estimation coefficients.

	Test statistic (chi2)	p-value	Decision	Remarks
Stunting				
H_0: Moderately high intensity = Very high intensity	7.49	0.006	Reject H_0	Coefficients are statistically different
Wasting				
H_0: Moderately high intensity = Very high intensity	0.29	0.589	Do not reject H_0	Coefficients are not statistically different

Iodice et al., 2018). Thus, reducing the intensity of pollution a household is exposed to, could result in far reaching positive consequences on children's growth. One main implication of these findings for clean cooking transition policies is that even for households who cannot afford to use cleaner or less polluting fuels, changing their cooking place from indoors to outdoors or to more airy places reduces the intensity of pollution generated from their cooking fuel and subsequently, reduces the likelihoods of stunting in children. This is the point where households themselves can take control of the situation of indoor air pollution exposure even in the face of financial or cultural barriers to clean fuel transition. By merely changing their cooking places, households can reduce the intensity of pollution they are exposed to. The findings also have implications for building construction especially in locations where the use of heavy polluting fuels is prevalent. Having better ventilation in cooking spaces will help reduce the intensity of pollution and offer subsequent positive effects on children's heights.

With regards to other covariates, the study found that male children have greater associations with stunting and wasting conditions and agrees with both epidemiological and empirical literature about the higher vulnerability of male children to early life shocks including exposure to pollution compared to their female counterparts (Hsu et al., 2015; Kurata et al., 2020; Adjei-Mantey and Takeuchi, 2021).

Mothers' education is associated with lower likelihoods of stunting, severe stunting, wasting and severe wasting among children. Mothers who had up to primary education were 1.4 %, 1.6 %, 1.3 % and 0.6 % less likely to have a stunted, severely stunted, wasted and severely wasted child respectively compared to mothers with no formal education while for mothers who had secondary education or higher, the likelihood of having a stunted, severely stunted, wasted and severely wasted child reduces by 4.7 %, 4.7 %, 1.4 % and 0.6 % respectively. This finding confirms those of Chen and Li (2009) and Chou et al. (2010). Educated mothers are better able to utilize information to improve the growth of their children. Furthermore, being more highly educated, they may have knowledge of the dangers of biofuel smoke and might take steps to avoid being exposed to same. Other maternal characteristics that were found to have a significant association with stunting and wasting in children were their age and employment status (in the case of wasting). Children of older mothers were less likely to be stunted, severely stunted and wasted and severely wasted and the reduction in likelihood increases with age and consistent with earlier studies (Goyal

Table 6
Estimates of correlates of cooking place with child stunting.

VARIABLES	(1) Stunting	(2)	(3) Severe stunting	(4)
	Low polluting fuels	High polluting fuels	Low polluting fuels	High polluting fuels
Cooking place (1 = indoor)	−0.018	0.006**	0.003	0.004**
	(0.013)	(0.003)	(0.010)	(0.002)
Mother's education				
Primary education	0.006	−0.007**	−0.000	−0.029***
	(0.014)	(0.003)	(0.010)	(0.002)
Secondary and above	−0.031**	−0.045***	−0.024***	−0.058***
	(0.014)	(0.004)	(0.009)	(0.003)
Marital status				
Currently in union	0.007	−0.003	−0.008	−0.002
	(0.010)	(0.005)	(0.008)	(0.004)
Formerly in union	0.015	0.011	−0.006	0.010**
	(0.017)	(0.007)	(0.012)	(0.005)
Mother's age				
25–34 years	−0.027***	−0.010***	−0.011**	−0.003
	(0.008)	(0.003)	(0.005)	(0.002)
35 years and above	−0.033***	−0.016***	−0.017***	−0.008***
	(0.010)	(0.003)	(0.006)	(0.003)
Employment status (1 = working)	−0.006	0.011***	−0.008*	−0.005**
	(0.007)	(0.003)	(0.005)	(0.002)
Household size (1 = 7 + members)	0.027***	0.003	0.011**	0.008***
	(0.007)	(0.002)	(0.005)	(0.002)
Wealth status				
Poorer	−0.003	−0.007**	−0.026*	−0.012***
	(0.020)	(0.003)	(0.015)	(0.003)
Middle	−0.024	−0.028***	−0.031**	−0.031***
	(0.019)	(0.004)	(0.015)	(0.003)
Richer	−0.079***	−0.055***	−0.054***	−0.048***
	(0.019)	(0.004)	(0.015)	(0.003)
Richest	−0.114***	−0.101***	−0.072***	−0.080***
	(0.019)	(0.005)	(0.015)	(0.004)
Locality (1 = urban)	−0.001	−0.005	0.011*	−0.009***
	(0.009)	(0.003)	(0.006)	(0.002)
Sex of child (1 = male)	0.025***	0.030***	0.020***	0.027***
	(0.006)	(0.002)	(0.004)	(0.002)
Constant	0.307***	0.153***	0.159***	0.154***
	(0.031)	(0.036)	(0.023)	(0.039)
Control variables	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	15,841	168,118	16,768	193,415
R-squared	0.039	0.024	0.024	0.039

Robust standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

and Canning, 2018; Mishra and Retherford, 2007). Older mothers may typically give birth at a time when they are more prepared both economically and psychologically and hence may be able to pay particular attention to their children's growth compared to younger mothers in the reference category of 15–24 years. Children of working mothers were less likely to be wasted and severely wasted by 0.7 % and 0.3 % respectively while being 1.1 % more likely to have children who were not wasted.

Household wealth status was found to be significantly associated with all four conditions. The richer a household, the less likely they were to have stunted and wasted children or severely stunted and severely wasted children and the reduction in probability increases with each higher level of wealth. This is consistent with previous studies such as Kurata et al., 2020 and Goyal and Canning, 2018.

Overall, the findings of this study reveal evidence that the intensity of pollution a household is exposed to is strongly associated with child growth measures of stunting and severe stunting. This implies that households can on their own, initiate a cost effective, if not a zero cost measure of reducing the intensity of pollution they are exposed to by switching to outdoor cooking or cooking in airier spaces even if they use heavy polluting fuels to reduce the likelihood of child stunting or its severe form.

3.1. Robustness analysis

As a robust measure, the study estimates the effect of cooking place on child stunting for specific fuel types. Since the cooking place was a key variable in constructing the pollution intensity measure, this sub-section decouples the variable from the measure and includes it as a main explanatory variable in explaining variations in stuntedness for specific fuel types. The following model is estimated:

$$Y_{ij} = \alpha + \beta_1 CP_{ij} + \beta_2 W_{ij} + \varepsilon_i (3)$$

$$sY_{ij} = \alpha + \beta_1 CP_{ij} + \beta_2 W_{ij} + \varepsilon_i (4)$$

where CP is a binary variable for whether the household normally engages in outdoor cooking or indoor cooking; Y represents stunting or otherwise and sY severe stunting or otherwise. All other variables are as previously explained. Following the empirical works of Adjei-Mantey et al. (2023) and Bellemare et al. (2015) on estimating binary response variables, equations (3) and (4) are estimated using linear probability regression, instead of the more popular logit or probit regression. We estimate for low polluting fuels and high polluting fuels separately to observe how different cooking places relate to variations in stunting and severe stunting for the same fuel type. The estimations are limited to the stunting outcome since the earlier results found no evidence of different pollution intensity categories on wasting. The results are shown in Table 6.

The results show that for high polluting fuels, indoor use is associated with higher likelihoods of stunting and severe stunting. That is, among those who use high polluting fuels, using them indoors increases the likelihood of association with stunting relative to using them outdoors. Among high polluting fuel users, there is a 0.6 % and 0.4 % greater likelihood of association with stunting and severe stunting respectively, if the fuel is used indoors relative to using the fuel outdoors. Recall that indoor use of these fuels is what constitutes the very high intensity level of the pollution intensity as used in this paper. Thus, our findings of higher likelihood of significant association with stunting for the higher pollution intensity are robust. Furthermore, the results from Table 6 show that for low polluting fuels, place of cooking yields no significant association with stunting; hence validating how the low intensity level of pollution was constructed in this paper.

4. Conclusion

Despite the increasing advocacy for transitioning to clean cooking fuels in place of polluting ones, the use of heavy polluting fuel is still widespread in many countries in SSA. As such research on household air pollution has been on a surge. That notwithstanding, there is a dearth of studies on household air pollution that account for the intensity of pollution within the household. This study sought to investigate the effects of the level of intensity of exposure to household air pollution on child growth measures of stunting and wasting while controlling for mother, child and household specific characteristics. The study constructed a measure of pollution intensity based on a combination of the type of cooking fuel primarily used in the household and the household's place of cooking. The study found evidence of a positive association of

Table A1
Countries included in the sample and year of the DHS survey.

Country	Year of survey	Country	Year of survey	Country	Year of survey
Angola	2015/16	Gabon	2012	Niger	2012
Benin	2017/18	Gambia	2019/20	Nigeria	2018
Burkina Faso	2010	Ghana	2014	Rwanda	2019/20
Burundi	2016/17	Guinea	2018	Senegal	2019
Cameroon	2018	Kenya	2014	Sierra Leone	2019
Chad	2014/15	Lesotho	2014	South Africa	2016
Comoros	2012	Liberia	2019/20	Tanzania	2015/16
Congo	2011/12	Malawi	2015/16	Togo	2013/14
Congo Dem. Rep.	2013/14	Mali	2018	Uganda	2016
Cote D`Ivoire	2011/12	Mozambique	2011	Zambia	2018/19
Ethiopia	2016	Namibia	2013	Zimbabwe	2015

exposure to high intensity household air pollution with stunting among children. Children in homes exposed to high intensity air pollution had a higher likelihood of being stunted or severely stunted. There was however, no evidence of the type of pollution intensity being associated with wasting or severe wasting in children. Overall, the findings of this study reveal evidence that the intensity of pollution a household is exposed to is strongly associated with child growth measures of stunting and severe stunting. The findings of the study suggest that households can initiate their own measures to reduce the intensity of pollution they are exposed to by changing their place of cooking from indoor to outdoors or airier places. This way even heavily-polluting fuel-using households can limit the intensity of pollution they are exposed to. This is a measure households can adopt at minimum to zero financial cost while making efforts to switch to cleaner cooking fuels. Furthermore, construction of buildings, particularly in heavily polluting fuel prevalent locations, can be designed to have better ventilated cooking areas to reduce the intensity of pollution there. These recommendations are without prejudice to more conventional approaches to reducing indoor air pollution such as clean fuel transition. Thus, on the part of government, we recommend continuous efforts and interventions to aid households switch to cleaner fuels while providing education through public health and wellness campaigns for households to cook in airy places especially when using heavy polluting fuels.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Authors do not have permission to share the data but a weblink to the source from which the data can be requested has been provided.

Appendix A

References

Adedokun, S. T., & Yaya, S. (2021). Factors associated with adverse nutritional status of children in sub-Saharan Africa: Evidence from the Demographic and Health Surveys from 31 countries. *Maternal & Child Nutrition, 17*(3), e13198.

Adjei-Mantey, K., Awuku, M. O., & Kodom, R. V. (2023). Revisiting the determinants of food security: Does regular remittance inflow play a role in Ghanaian households? A disaggregated analysis. *Regional Science Policy & Practice, 15*(6), 1132–1146.

Adjei-Mantey, K., & Takeuchi, K. (2021). The effect of in utero exposure to household air pollution on child health: Evidence from Ghana. *Health Policy OPEN, 2*. https://doi.org/10.1016/j.hpopen.2020.100029

Ahmed, S., Ibrahimou, B., Kader, S. B., Chowdhury, M. A. H., Ahsan, H., & Yunus, M. (2021). Household biomass fuel use is associated with chronic childhood malnutrition: Result from a nationwide cross-sectional survey in Bangladesh. *Indoor Air, 31*(6), 2167–2175.

Akombi, B. J., Agho, K. E., Hall, J. J., Wali, N., Renzaho, A. M. N., & Merom, D. (2017). Stunting, wasting and underweight in sub-Saharan Africa: A systematic review. *International Journal of Environmental Research and Public Health, 14*(8), 863.

Al-Janabi, Z., Woolley, K. E., Thomas, G. N., & Bartington, S. E. (2021). A cross-sectional analysis of the association between domestic cooking energy source type and respiratory infections among children aged under five years: Evidence from demographic and household surveys in 37 low-middle income countries. *International Journal of Environmental Research and Public Health, 18*(16). https://doi.org/10.3390/ijerph18168516

Amadu, I., Seidu, A. A., Afitiri, A. R., Ahinkorah, B. O., & Yaya, S. (2021). Household cooking fuel type and childhood anaemia in sub-Saharan Africa: Analysis of cross-sectional surveys of 123, 186 children from 29 countries. *BMJ Open, 11*(7), 1–13. https://doi.org/10.1136/bmjopen-2021-048724

Amadu, I., Seidu, A.-A., Duku, E., Frimpong, J. B., Jnr, J. E. H., Aboagye, R. G., et al. (2021). Risk factors associated with the coexistence of stunting, underweight, and wasting in children under 5 from 31 sub-Saharan African countries. *BMJ Open, 11*(12), e052267.

Amadu, I., Seidu, A.-A., Duku, E., Okyere, J., Hagan, J. E., Hormenu, T., et al. (2021). The joint effect of maternal marital status and type of household cooking fuel on child nutritional status in sub-Saharan Africa: Analysis of cross-sectional surveys on children from 31 countries. *Nutrients, 13*(5), 1541.

Antehunegn, G., Id, T., Gebrie Worku, M., Tadesse Tessema, Z., Teshale, A. B., Alem, A. Z., Yeshaw Id, Y., Alamneh, T. S., & Liyew, A. M. (2021). *Prevalence and determinants of severity levels of anemia among children aged 6-59 months in sub-Saharan Africa: A multilevel ordinal logistic regression analysis*. https://doi.org/10.1371/journal.pone.0249978.

Bain, L. E., Awah, P. K., Geraldine, N., Kindong, N. P., Sigal, Y., Bernard, N., et al. (2013). Malnutrition in Sub - Saharan Africa: Burden, causes and prospects. *Pan African Medical Journal, 15*. https://doi.org/10.11604/pamj.2013.15.120.2535

Balietti, A., & Datta, S. (2017). *The impact of indoor solid fuel use on the stunting of Indian children*. Amsterdam, Netherlands: Elsevier.

Begashaw, B. W. (2022). Determinants of Stunting and Wasting Among Under-Five Children of Ethiopia: Analysis of Mini-demographic and Health Survey 2019 of Ethiopia. *European Journal of Preventive Medicine, 10*(3), 76–83.

Bellemare, M. F., Novak, L., & Steinmetz, T. L. (2015). All in the family: Explaining the persistence of female genital cutting in West Africa. *Journal of Development Economics, 116*, 252–265.

Caleyachetty, R., Lufumpa, N., Kumar, N., Mohammed, N. I., Bekele, H., Kurmi, O., et al. (2022). Exposure to household air pollution from solid cookfuels and childhood stunting: A population-based, cross-sectional study of half a million children in low- and middle-income countries. *International Health, ihab090*.

Chadare, F. J., Affonfere, M., Aidé, E. S., Fassinou, F. K., Salako, K. v, Pereko, K., Deme, B., Failler, P., Kakaï, R. L. G., & Assogbadjo, A. E. (2022). Current state of nutrition in West Africa and projections to 2030. *Global Food Security*, *32*, 100602.

Christian, A. K., & Dake, F. A. A. (2022). Profiling household double and triple burden of malnutrition in sub-Saharan Africa: Prevalence and influencing household factors. *Public Health Nutrition, 25*(6). https://doi.org/10.1017/S1368980021001750

Danaei, G., Andrews, K. G., Sudfeld, C. R., Fink, G., McCoy, D. C., Peet, E., et al. (2016). Risk factors for childhood stunting in 137 developing countries: A comparative risk assessment analysis at global, regional, and country levels. *PLoS Medicine, 13*(11), e1002164.

Darteh, E. K. M., Acquah, E., & Kumi-Kyereme, A. (2014). Correlates of stunting among children in Ghana. *BMC Public Health, 14*(1), 1–7.

Deshpande, A., & Ramachandran, R. (2022). Early childhood stunting and later life outcomes: A longitudinal analysis. *Economics & Human Biology, 44*, Article 101099. https://doi.org/10.1016/J.EHB.2021.101099

Drammeh, W., Hamid, N. A., & Rohana, A. J. (2019). Determinants of household food insecurity and its association with child malnutrition in Sub-Saharan Africa: A review of the literature. *Current Research in Nutrition and Food Science, 7*(3). https://doi.org/10.12944/CRNFSJ.7.3.02

Epstein, M. B., Bates, M. N., Arora, N. K., Balakrishnan, K., Jack, D. W., & Smith, K. R. (2013). Household fuels, low birth weight, and neonatal death in India: The separate impacts of biomass, kerosene, and coal. *International Journal of Hygiene and Environmental Health, 216*(5), 523–532. https://doi.org/10.1016/j.ijheh.2012.12.006

Gassara, G., & Chen, J. (2021). Household food insecurity, dietary diversity, and stunting in sub-saharan africa: A systematic review. *Nutrients, 13*(12). https://doi.org/10.3390/nu13124401

Geremew, A., Gebremedhin, S., Mulugeta, Y., & Yadeta, T. A. (2020). Place of food cooking is associated with acute respiratory infection among under-five children in Ethiopia: Multilevel analysis of 2005–2016 Ethiopian Demographic Health Survey data. *Tropical Medicine and Health, 48*(1). https://doi.org/10.1186/s41182-020-00283-y

Goyal, N., & Canning, D. (2018). Exposure to ambient fine particulate air pollution in utero as a risk factor for child stunting in Bangladesh. *International Journal of Environmental Research and Public Health, 15*(1), 22.

Grossman, M. (1972). *The demand for health: A theoretical and empirical investigation*. New York: Columbia University Press.

Haddad, L., & Bouis, H. (1991). The Impact of Nutritional Status on Agricultural Productivity: Wage Evidence from the Philippines. *Oxford Bulletin of Economics and Statistics, 53*(1), 45–68.
Hsu, H.-H., Chiu, Y.-H., Coull, B., Kloog, I., Schwartz, J., Lee, A., et al. (2015). Prenatal particulate air pollution and asthma onset in urban children. *American Journal of Respiratory and Critical Care Medicine, 192*(9), 1052–1059.
Iodice, S., Hoxha, M., Ferrari, L., Carbone, I. F., Anceschi, C., Miragoli, M., et al. (2018). Particulate air pollution, blood mitochondrial DNA copy number, and telomere length in mothers in the first trimester of pregnancy: Effects on fetal growth. *Oxidative Med Cellular Longevity*. Article ID 5162905.
Khara, T., Dolan, C. (2014). The relationship between wasting and stunting, policy, programming and research implications. Technical Briefing paper. Retrieved from Technical Briefing Paper: The relationship between wasting and stunting: policy, programming and research implications (2014) | ENN (ennonline.net).
Kurata, M., Takahashi, K., & Hibiki, A. (2020). Gender differences in associations of household and ambient air pollution with child health: Evidence from household and satellite-based data in Bangladesh. *World Development, 128*, Article 104779.
Kyu, H. H., Georgiades, K., & Boyle, M. H. (2009). Maternal smoking, biofuel smoke exposure and child height-for-age in seven developing countries. *International Journal of Epidemiology, 38*, 1342–1350.
LaFave, D., Beyene, A. D., Bluffstone, R., Dissanayake, S. T., Gebreegziabher, Z., Mekonnen, A., et al. (2021). Impacts of improved biomass cookstoves on child and adult health: Experimental evidence from rural Ethiopia. *World Development, 140*, Article 105332.
Langbein, J., Peters, J., & Vance, C. (2017). Outdoor cooking prevalence in developing countries and its implication for clean cooking policies. *Environmental Research Letters, 12*(11), Article 115008.
Lenz, L., Bensch, G., Chartier, R., Kane, M., Ankel-Peters, J., & Jeuland, M. (2023). Releasing the killer from the kitchen? Ventilation and air pollution from biomass cooking. *Development Engineering, 8*, Article 100108.
Li, J., Xu, X., Li, J., Li, D., Liu, Q., & Xue, H. (2021). Association between household fuel types and undernutrition status of adults and children under 5 years in 14 low and middle income countries. *Environmental Research Letters, 16*(5), Article 054079.
Machisa, M., Wichmann, J., & Nyasulu, P. S. (2013). Biomass fuel use for household cooking in Swaziland: Is there an association with anaemia and stunting in children aged 6–36 months? *Transactions of the Royal Society of Tropical Medicine and Hygiene, 107*(9), 535–544.
Mandal, S., Zaveri, A., Mallick, R., & Chouhan, P. (2020). Impact of domestic smokes on the prevalence of acute respiratory infection (ARI) among under-five children: Evidence from India. *Children and Youth Services Review*, *114*(December 2019), 105046. https://doi.org/10.1016/j.childyouth.2020.105046.
Danjin, M., Sawyerr, H. O., & Adewoye, S. O. (2021). Association between malnutrition and some water, sanitation and hygiene (WASH) factors among school children in Gombe State, Nigeria. *World Journal of Biology Pharmacy and Health Sciences, 5*(1). https://doi.org/10.30574/wjbphs.2021.5.1.0006
Mishra, V., & Retherford, R. D. (2007). Does biofuel smoke contribute to anaemia and stunting in early childhood? *International Journal of Epidemiology, 36*, 117–129.
Ntakarutimana, A., Kagwiza, J., Bushaija, E., Tumusiime, D., & Schuller, K. (2021). Reducing Hygiene-Related Disease and Malnutrition in Rwanda. *Journal of Social, Behavioral, and Health Sciences, 15*(1). https://doi.org/10.5590/jsbhs.2021.15.1.06
Patlán-Hernández, A. R., Stobaugh, H. C., Cumming, O., Angioletti, A., Pantchova, D., Lapègue, J., et al. (2022). Water, sanitation and hygiene interventions and the prevention and treatment of childhood acute malnutrition: A systematic review. In. *Maternal and Child Nutrition* (Vol. 18, Issue 1). https://doi.org/10.1111/mcn.13257
Pomati, M., & Nandy, S. (2020). Assessing progress towards SDG2: Trends and patterns of multiple malnutrition in young children under 5 in West and Central Africa. *Child Indicators Research, 13*(5), 1847–1873.
Sestito, P., Velásquez, S. R., Orel, E., & Keiser, O. (2021). The COVID-19 pandemic and child malnutrition in sub-Saharan Africa: A scoping review. *MedRxiv*.
Simwanza, N. R., Kalungwe, M., Karonga, T., Mtambo, C. M. M., Ekpenyong, M. S., & Nyashanu, M. (2022). Exploring the risk factors of child malnutrition in Sub-Sahara Africa: A scoping review, 02601060221090699 *Nutrition and Health*.
Sinharoy S, Clasen T, Martorell R. (2020) Air pollution and stunting: a missing link? *The Lancet* 8.
Sk, R., Rasooly, M. H., & Barua, S. (2019). Do fuel type and place of cooking matter for acute respiratory infection among Afghan children? Evidence from the Afghanistan DHS 2015. *Journal of Biosocial Science*. https://doi.org/10.1017/S002193201900035X
Soboksa, N. E., Gari, S. R., Hailu, A. B., & Mengistie Alemu, B. (2021). Childhood Malnutrition and the Association with Diarrhea, Water supply, Sanitation, and Hygiene Practices in Kersa and Omo Nada Districts of Jimma Zone, Ethiopia. *Environmental Health Insights, 15*. https://doi.org/10.1177/1178630221999635
Tesema, G. A., Worku, M. G., Tessema, Z. T., Teshale, A. B., Alem, A. Z., Yeshaw, Y., et al. (2021). Prevalence and determinants of severity levels of anemia among children aged 6–59 months in sub-Saharan Africa: A multilevel ordinal logistic regression analysis. *PloS One, 16*(4), e0249978.
Tesema, G. A., Yeshaw, Y., Worku, M. G., Tessema, Z. T., & Teshale, A. B. (2021). Pooled prevalence and associated factors of chronic undernutrition among under-five children in East Africa: A multilevel analysis. *PloS One, 16*(3), e0248637.
Upadhyay, A. K., Srivastava, S., & Mishra, V. (2021). Does use of solid fuels for cooking contribute to childhood stunting? A longitudinal data analysis from low-and middle-income countries. *Journal of Biosocial Science, 53*(1), 121–136.
van Cooten, M. H., Bilal, S. M., Gebremedhin, S., & Spigt, M. (2019). The association between acute malnutrition and water, sanitation, and hygiene among children aged 6–59 months in rural Ethiopia. *Maternal and Child Nutrition, 15*(1). https://doi.org/10.1111/mcn.12631
Vilcins, D., Sly, P. D., & Jagals, P. (2018). Environmental risk factors associated with child stunting: A systematic review of the literature. *Annals of Global Health, 84*(4), 551.
Woodruff, B. A., Wirth, J. P., Ngnie-Teta, I., Beaulière, J. M., Mamady, D., Ayoya, M. A., et al. (2018). Determinants of stunting, wasting, and anemia in Guinean preschool-age children: An analysis of DHS data from 1999, 2005, and 2012. *Food and Nutrition Bulletin, 39*(1), 39–53.
Woolley, K. E., Thomas, G. N., Kirenga, B., Okello, G., Kabera, T., Lao, X.-Q., et al. (2022). Association of household cooking location behaviour with acute respiratory infections among children aged under five years; a cross sectional analysis of 30 Sub-Saharan African Demographic and Health Surveys. *Atmospheric Environment, 119055*.
World Health Organization. (2014). *Global nutrition targets 2025: Stunting policy brief*. World Health Organization.
World Health Organization. (2020). *Levels and trends in child malnutrition: UNICEF*. World Health. *Organization.*