Household air pollution makes children grow shorter in sub-Saharan Africa; but can households help stem the tide?

Michael Larbi Odame and Kwame Adjei-Mantey*

University of Environment and Sustainable Development, Ghana

*Correspondence: kadjei-mantey@uesd.edu.gh

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 modelling. Results show that high levels of intensity of air pollution within households are associated with increased stunting probability of 1.8% to 2.6% while low intensity is associated with a reduced probability of severe wasting by 1.0%. 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.

Keywords: Household air pollution; pollution intensity; stunting; wasting; cooking place

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 forty 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 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).

The potential risk factors of malnutrition among children in SSA have 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 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., 2013a; Upadhyay et al., 2021). Notably, Sinharoy et al (2019) 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, Caleyachette et al (2021) 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 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. 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 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). 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 5years), 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.

Four response variables were examined – stunting, severe stunting, wasting and severe wasting 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. 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

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

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 better 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

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

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:

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

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

$$SY_{ij} = \alpha + \beta_1 X_{ij} + \beta_2 W_{ij} + \varepsilon_i \qquad (3)$$

$$SZ_{ij} = \alpha + \beta_1 X_{ij} + \beta_2 W_{ij} + \varepsilon_i \qquad (4)$$

where Y_{ij} in (1) is a dummy for whether a child, i, in country, j, is stunted or otherwise and Z_{ij} in (2) is a dummy for whether a child, i, in country, j, is wasted or not; SY_{ij} in (3) is a dummy for severe stunting or otherwise and SZ_{ij} in (4) is a dummy for severe wasting or otherwise. The intensity of pollution the household is exposed to is represented by X and W is a vector of control variables. Equations (1-4) are estimated using the linear probability model controlling for country fixed effects and time effects given that the data in the sample spans a period of over ten years. This estimation approach is preferred over the widely adopted logit or probit models for dichotomous dependent variables. As argued by Greene (2002), in the presence of fixed effects, there is bias in the estimates of the logit or probit. Thus, following Angrist and Pischke (2009) on linear probability modelling for microeconomic applications and the empirical work of Bellemare et al. (2015), this study estimates a linear probability model since it is better suited for the fixed effects. This estimation technique also prevents identification issues via the specific functional form that is often assumed in a standard logit or probit estimation (Bellemare et al., 2015). The coefficients from the linear probability model represent changes in probability without further transformation as in the case of the logit or probit. The linear probability model is not without a weakness, however. One of such being that the linear probability model such as in this instance, suffers from heteroscedasticity due to the variance of the binary dependent variable (Angrist and Pischke, 2009). We address this by clustering 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 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.

Table 1: Summary statistics

Variable	Obs	Mean/Proportion	Std. Dev.	Min	Max
Stunted (1=yes)	197,099	0.318	0.466	0	1
Severely stunted (1=yes)	197,099	0.126	0.332	0	1
Wasted (1=yes)	197,912	0.069	0.253	0	1
Severely wasted (1=yes)	197,912	0.020	0.139	0	1
Intensity of pollution					
1 = moderately high intensity	197,099	0.348	0.476	0	1
2 = very high intensity	197,099	0.569	0.495	0	1
Sex of child (1= male)	197,099	0.504	0.500	0	1
Size of child at birth					
1.very large					
2.larger than average	197,099	0.235	0.424	0	1
3.average	197,099	0.485	0.500	0	1
4.smaller than average	197,099	0.109	0.312	0	1
5.very small	197,099	0.054	0.225	0	1
Mother's education					
0.no education					
1. primary	197,099	0.326	0.469	0	1
2. secondary and above	197,099	0.259	0.438	0	1
Marital status					
0.never in a union					
1. currently in a union	197,099	0.882	0.322	0	1
2. formerly in a union	197,099	0.060	0.238	0	1
Mother's age					
0.15-24					
1.25-34	197,099	0.484	0.500	0	1
2.35 and above	197,099	0.242	0.428	0	1
Employment					
0.not working					
1.working	197,099	0.682	0.466	0	1
Household size					

0.1-6 members					
1.7+ members	197,099	0.467	0.499	0	1
Wealth					
1.poorest					
2. poorer	197,099	0.214	0.410	0	1
3. middle	197,099	0.194	0.395	0	1
4. richer	197,099	0.178	0.382	0	1
5. richest	197,099	0.154	0.361	0	1
Locality					
0.rural					
1.urban	197,099	0.313	0.464	0	1

About 32% of the sample of children were stunted while 12.6% were severely stunted while 7% of the sample are wasted and 2% severely wasted. With respect to the intensity of pollution, about 57% of the sample were exposed to the highest end of the intensity spectrum (i.e., those households used heavy polluting fuels such as firewood indoors) followed by 34.8% of the sample who were a step below the highest end of the intensity spectrum (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.

Tables 2 and 3 presents the findings from the empirical estimations for stunting and severe stunting respectively. Column 1 examines the association between the dependent variable and main explanatory variable, intensity only. Columns 2, 3 and 4 increasingly adds mother’s features, household level characteristics, and child characteristics to the estimations respectively.

Table 2: Linear probability estimates for stunting

VARIABLES	(1) Stunting	(2) Stunting	(3) Stunting	(4) Stunting
Intensity of pollution				
1. (moderately high intensity)	0.158***	0.105***	0.039***	0.039***
	(0.005)	(0.005)	(0.005)	(0.005)
2. (very high intensity)	0.167***	0.115***	0.046***	0.046***
	(0.005)	(0.005)	(0.005)	(0.005)
Mother's education				
Primary education		-0.048***	-0.027***	-0.027***
		(0.003)	(0.003)	(0.003)
Secondary and above		-0.142***	-0.085***	-0.085***
		(0.004)	(0.004)	(0.004)
Marital status				
Currently in union		-0.005	-0.004	-0.005
		(0.005)	(0.005)	(0.006)
Formerly in union		0.019***	0.017**	0.015**
		(0.007)	(0.007)	(0.007)
Mother's age				
25-34 years		-0.020***	-0.013***	-0.012***
		(0.003)	(0.003)	(0.003)
35 years and above		-0.029***	-0.023***	-0.020***
		(0.003)	(0.003)	(0.003)
Employment status (1= working)		0.009***	0.004	0.007**
		(0.003)	(0.003)	(0.003)
Household size (1= 7+ members)			0.011***	0.011***
			(0.003)	(0.003)
Wealth status				
Poorer			-0.017***	-0.015***
			(0.004)	(0.004)
Middle			-0.047***	-0.045***
			(0.004)	(0.004)
Richer			-0.085***	-0.081***
			(0.004)	(0.004)
Richest			-0.151***	-0.147***
			(0.005)	(0.005)
Locality (1=urban)			-0.011***	-0.010***
			(0.004)	(0.004)
Sex of child (1=male)				0.049***
				(0.002)
Size of child at birth				
Larger than average				0.014***
				(0.004)

Average				0.047*** (0.004)
Smaller than average				0.107*** (0.005)
Very small				0.131*** (0.006)
Constant	0.140*** (0.035)	0.238*** (0.033)	0.288*** (0.035)	0.218*** (0.036)
Country fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	210,538	210,505	210,505	197,099
R-squared	0.031	0.043	0.052	0.062

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

Table 3: Linear probability estimates for severe stunting

VARIABLES	(1) Severe stunting	(2) Severe stunting	(3) Severe stunting	(4) Severe stunting
Intensity of pollution				
1. moderately high intensity	0.073*** (0.003)	0.042*** (0.003)	0.007** (0.003)	0.006* (0.003)
2. (very high intensity)	0.078*** (0.003)	0.047*** (0.003)	0.011*** (0.003)	0.011*** (0.003)
Mother’s education				
Primary education		-0.041*** (0.002)	-0.029*** (0.002)	-0.029*** (0.002)
Secondary and above		-0.089*** (0.002)	-0.058*** (0.003)	-0.057*** (0.003)
Marital status				
Currently in union		-0.004 (0.003)	-0.003 (0.003)	-0.003 (0.004)
Formerly in union		0.010** (0.005)	0.009* (0.005)	0.008 (0.005)
Mother’s age				
25-34 years		-0.007*** (0.002)	-0.003* (0.002)	-0.001 (0.002)
35 years and above		-0.011*** (0.002)	-0.009*** (0.002)	-0.006** (0.003)
Employment status (1= working)		-0.001 (0.002)	-0.004** (0.002)	-0.003* (0.002)
Household size (1= 7+ members)			0.008***	0.007***

			(0.002)	(0.002)
Wealth status				
Poorer			-0.013***	-0.012***
			(0.003)	(0.003)
Middle			-0.032***	-0.031***
			(0.003)	(0.003)
Richer			-0.049***	-0.048***
			(0.003)	(0.003)
Richest			-0.079***	-0.078***
			(0.003)	(0.003)
Locality (1=urban)			-0.008***	-0.008***
			(0.002)	(0.002)
Sex of child (1=male)				0.029***
				(0.001)
Size of child at birth				
Larger than average				0.010***
				(0.003)
Average				0.022***
				(0.003)
Smaller than average				0.057***
				(0.003)
Very small				0.074***
				(0.005)
Constant	0.061*	0.128***	0.157***	0.124***
	(0.036)	(0.036)	(0.036)	(0.037)
Country fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	210,538	210,505	210,505	197,099
R-squared	0.026	0.035	0.040	0.046

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

The results show that compared to the base category of low pollution intensity, higher pollution intensity levels are associated with higher likelihoods of stunting. More specifically, for children living in households that are exposed to moderately high pollution intensity level, their likelihood of association with stunting increases by 3.9% while for children who live in households with very high pollution intensity, their likelihood of association with stunting increases by 4.6% relative to those in low pollution intensity households when all observable factors are controlled for. With regards to severe stunting, the association is highly significant at the at the very high intensity level and significant at 10% at the moderately high significance level when all factors are controlled for. That is, children living in households exposed to higher pollution intensity levels have greater associations with stunting and severe stunting. 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 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, however, found no statistically significant effect of solid cooking fuel on stunting despite a positive association.

The results for wasting and severe wasting are presented in Tables 4 and 5 with columns 1, 2, 3, and 4 showing results for pollution intensity and complemented increasingly with mother's characteristics, household level characteristics, and child characteristics respectively.

Table 4: Linear probability estimates for wasting

VARIABLES	(1) Wasted	(2) Wasted	(3) Wasted	(4) Wasted
Intensity of pollution				
1. moderately high intensity	0.019***	0.012***	0.004	0.004
	(0.002)	(0.003)	(0.003)	(0.003)
2. (very high intensity)	0.018***	0.010***	0.003	0.003
	(0.002)	(0.002)	(0.003)	(0.003)
Mother's education				
Primary education		-0.024***	-0.020***	-0.016***
		(0.002)	(0.002)	(0.002)
Secondary and above		-0.027***	-0.019***	-0.016***
		(0.002)	(0.002)	(0.002)
Marital status				

Currently in union		-0.000	-0.001	-0.000
		(0.003)	(0.003)	(0.003)
Formerly in union		0.007**	0.006*	0.006*
		(0.003)	(0.003)	(0.004)
Mother’s age				
25-34 years		-0.004***	-0.003*	-0.002
		(0.001)	(0.001)	(0.002)
35 years and above		-0.007***	-0.006***	-0.004**
		(0.002)	(0.002)	(0.002)
Employment status (1= working)		-0.011***	-0.011***	-0.010***
		(0.002)	(0.002)	(0.002)
Household size (1= 7+ members)			-0.000	-0.001
			(0.001)	(0.001)
Wealth status				
Poorer			-0.016***	-0.014***
			(0.002)	(0.002)
Middle			-0.019***	-0.016***
			(0.002)	(0.002)
Richer			-0.019***	-0.017***
			(0.002)	(0.002)
Richest			-0.028***	-0.025***
			(0.003)	(0.003)
Locality (1=urban)			0.003	0.002
			(0.002)	(0.002)
Sex of child (1=male)				0.017***
				(0.001)
Size of child at birth				
Larger than average				0.007***
				(0.002)
Average				0.021***
				(0.002)
Smaller than average				0.045***
				(0.003)
Very small				0.068***
				(0.004)
Constant	0.065***	0.097***	0.112***	0.080***
	(0.021)	(0.021)	(0.021)	(0.021)
Country fixed effects				
Year fixed effects				
Observations	211,417	211,384	211,384	197,912
R-squared	0.018	0.021	0.022	0.027

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 5: Linear probability estimates for severe wasting

VARIABLES	(1) Severely wasted	(2) Severely wasted	(3) Severely wasted	(4) Severely wasted
Intensity of pollution				
1. moderately high intensity	0.007***	0.004***	0.001	0.002
	(0.001)	(0.001)	(0.001)	(0.001)
2. very high intensity	0.006***	0.003**	0.000	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Mother's education				
Primary education		-0.009***	-0.008***	-0.007***
		(0.001)	(0.001)	(0.001)
Secondary and above		-0.011***	-0.008***	-0.007***
		(0.001)	(0.001)	(0.001)
Marital status				
Currently in union		-0.001	-0.001	-0.001
		(0.001)	(0.001)	(0.001)
Formerly in union		0.002	0.001	0.001
		(0.002)	(0.002)	(0.002)
Mother's age				
25-34 years		-0.002**	-0.001	-0.001
		(0.001)	(0.001)	(0.001)
35 years and above		-0.002*	-0.001	-0.001
		(0.001)	(0.001)	(0.001)
Employment status (1= working)		-0.004***	-0.004***	-0.004***
		(0.001)	(0.001)	(0.001)
Household size (1= 7+ members)			-0.001	-0.001
			(0.001)	(0.001)
Wealth status				
Poorer			-0.005***	-0.005***
			(0.001)	(0.001)
Middle			-0.006***	-0.005***
			(0.001)	(0.001)
Richer			-0.007***	-0.007***
			(0.001)	(0.001)
Richest			-0.009***	-0.009***
			(0.001)	(0.001)
Locality (1=urban)			0.001	0.001
			(0.001)	(0.001)
Sex of child (1=male)				0.006***
				(0.001)
Size of child at birth				
Larger than average				0.002*
				(0.001)
Average				0.006***

				(0.001)
Smaller than average				0.012***
				(0.001)
Very small				0.023***
				(0.002)
Constant	0.002	0.015**	0.020**	0.010
	(0.007)	(0.008)	(0.008)	(0.008)
Country fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	211,417	211,384	211,384	197,912
R-squared	0.009	0.010	0.011	0.012

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

With regards to wasting and severe wasting, the results show no evidence of a significant association between intensity of pollution a household is exposed to and their likelihood of experiencing wasting in the full model even though the estimates from Columns 1-2 (Tables 4 and 5) show that higher intensity levels of pollution may associated with an increasing likelihood of wasting. This significance, however, disappears when controlling for household level features and child characteristics (Columns 3-4).

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; 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 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 are more likely to be stunted 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). Furthermore, children who were smaller at birth stood a higher chance of being stunted, severely stunted, wasted and severely wasted. Children born very small had a 13.1%, 7.4%, 6.8% and 2.3% greater likelihood of being stunted, severely stunted, wasted and severely wasted respectively compared to children who were born very large in each of those conditions.

Mothers' education reduced the likelihood of stunting, severe stunting, wasting and severe wasting among children. Mothers who had up to primary education were 2.7%, 2.9%, 1.6% and 0.7% 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 8.5%, 5.7%, 1.6% and 0.7% 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 employment status and age. Children of older mothers were less likely to be stunted, severely stunted and wasted and the reduction in likelihood increases with age and consistent with earlier studies (Goyal 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 severely stunted, wasted and severely wasted by 0.3%, 1% and 0.4% respectively.

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.

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:

$$Y_{ij} = \alpha + \beta_1 CP_{ij} + \beta_2 W_{ij} + \varepsilon_i \qquad (5)$$

$$SY_{ij} = \alpha + \beta_1 CP_{ij} + \beta_2 W_{ij} + \varepsilon_i \qquad (6)$$

where CP is a binary variable for whether the household normally engages in outdoor cooking or indoor cooking. All other variables are as previously explained. Equations (5) and (6) are estimated for low polluting fuels and high polluting fuels separately to observe how different cooking places relate to variations in stunting for the same fuel type. The estimations are limited to stunting seeing that the earlier results found no evidence of intensity on wasting. The results are shown in Table 5.

Table 5: Estimates of correlates of cooking place with child stunting.

	(1)	(2)	(3)	(4)
VARIABLES	Stunting		Severe stunting	
	Low polluting fuels	High polluting fuels	Low polluting fuels	High polluting fuels
Cooking place (1= indoor)	-0.009	0.008***	0.005	0.004**
	(0.015)	(0.003)	(0.010)	(0.002)
Mother’s education				
Primary education	0.005	-0.028***	-0.002	-0.029***
	(0.017)	(0.004)	(0.010)	(0.003)
Secondary and above	-0.049***	-0.085***	-0.024***	-0.058***

	(0.015)	(0.004)	(0.009)	(0.003)
Marital status				
Currently in union	-0.002	-0.004	-0.009	-0.001
	(0.011)	(0.006)	(0.008)	(0.004)
Formerly in union	0.005	0.016**	-0.009	0.010**
	(0.019)	(0.008)	(0.012)	(0.005)
Mother’s age				
25-34 years	-0.034***	-0.009***	-0.011**	-0.001
	(0.009)	(0.003)	(0.005)	(0.002)
35 years and above	-0.043***	-0.018***	-0.016**	-0.005**
	(0.011)	(0.003)	(0.006)	(0.003)
Employment status (1= working)	-0.010	0.009***	-0.007	-0.003
	(0.008)	(0.003)	(0.005)	(0.002)
Household size (1= 7+ members)	0.034***	0.008***	0.011**	0.007***
	(0.008)	(0.003)	(0.005)	(0.002)
Wealth status				
Poorer	-0.031	-0.014***	-0.029*	-0.012***
	(0.022)	(0.004)	(0.015)	(0.003)
Middle	-0.055***	-0.045***	-0.032**	-0.031***
	(0.021)	(0.004)	(0.015)	(0.003)
Richer	-0.121***	-0.079***	-0.055***	-0.048***
	(0.021)	(0.005)	(0.015)	(0.003)
Richest	-0.171***	-0.145***	-0.073***	-0.079***
	(0.021)	(0.006)	(0.016)	(0.004)
Locality (1=urban)	0.008	-0.012***	0.011*	-0.009***
	(0.011)	(0.004)	(0.006)	(0.003)
Sex of child (1=male)	0.045***	0.050***	0.021***	0.030***
	(0.007)	(0.002)	(0.004)	(0.002)
Size of child at birth				
Larger than average	-0.000	0.015***	-0.000	0.011***
	(0.011)	(0.004)	(0.007)	(0.003)
Average	0.034***	0.048***	0.009	0.023***
	(0.011)	(0.004)	(0.006)	(0.003)
Smaller than average	0.092***	0.107***	0.029***	0.059***
	(0.015)	(0.005)	(0.009)	(0.004)
Very small	0.152***	0.130***	0.062***	0.075***
	(0.022)	(0.007)	(0.015)	(0.005)
Constant	0.394***	0.234***	0.153***	0.133***
Control variables	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes

Year fixed effects	Yes	Yes	Yes	Yes
Observations	16,162	180,616	16,162	180,616
R-squared	0.064	0.053	0.027	0.043

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

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. 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 5 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 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 pollution intensity being associated with wasting or severe wasting in children. 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 heavy 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 heavy 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.

Declarations of interests:

None

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APPENDIX:

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