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Research article

Assessing the combined effect of household cooking fuel and urbanicity on acute respiratory symptoms among under-five years in sub-Saharan Africa

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ABSTRACT

Background: This study sought to investigate the association between urbanicity (rural-urban residency), the use of solid biomass cooking fuels and the risk of Acute Respiratory Infections (ARIs) among children under the age of 5 in sub-Saharan Africa (SSA).
Methods: Cross-sectional data from the most recent surveys of the Demographic and Health Survey Program conducted in 31 sub-Saharan African countries were pooled for the analysis. The outcome variables, cough and rapid short breath were derived from questions that asked mothers if their children under the age of 5 suffered from cough and short rapid breath in the past two weeks preceding the survey. To examine the associations, multivariable negative log-log regression models were fitted for each outcome variable.
Results: Higher odds ratios of cough occurred among children in urban households that use unclean cooking fuel (aOR = 1.05 95% CI = 1.01, 1.08). However, lower odds ratios were observed for rural children in homes that use clean cooking fuel (aOR = 0.93 95% CI = 0.87, 0.99) relative to children in urban homes using clean cooking fuel. We also found higher odds ratios of short rapid breaths among children in rural households that use unclean cooking fuel compared with urban residents using clean cooking fuel (aOR = 1.12 95% CI = 1.08, 1.17).

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Conclusion: Urbanicity and the use of solid biomass fuel for cooking were associated with an increased risk of symptoms of ARIs among children under five years in SSA. Thus, policymakers and stakeholders need to design and implement strategies that minimize children's exposure to pollutants from solid biomass cooking fuel. Such interventions could reduce the burden of respiratory illnesses in SSA and contribute to the realization of Sustainable Development Goal 3.9, which aims at reducing the number of diseases and deaths attributable to hazardous chemicals and pollution of air, water and soil.

1. Introduction

Exposure to indoor pollution otherwise referred to as Household Air Pollution (HAP) from the use of solid biomass fuel is a major risk factor for morbidity and mortality. Solid biomass fuel includes wood, charcoal, crop residues and animal dung which are mostly used indoors for cooking and heating purposes. Approximately, one-third of the global population, mainly in Low- and Middle-Income Countries (LMICs), use solid biomass fuel for cooking [1]. In 2017, an estimated 1.64 million deaths and 59.5 million Disability-Adjusted Life Years (DALYs) worldwide were attributed to indoor air pollution from solid biomass fuel. Further, about 459, 000 of these deaths and 25.9 million DALYs were due to acute respiratory infections (ARIs) and Acute Lower Respiratory Infections (ALRI) from air pollutants emanating from the burning of solid biomass or unclean household cooking fuels [2]. Solid biomass fuel-related diseases, disabilities and deaths occur mainly in LMICs, especially in sub-Saharan Africa (SSA) where an estimated 80% of the population rely on solid biomass fuels for cooking [3]. The majority of the victims are women and children due to their prolonged exposure to the cooking environment at home [4,5].

The use of these fuel sources is higher in rural settings relative to urban settlements although many urban dwellers in SSA still rely on solid biomass fuel for cooking [6]. Due to their low combustion capacity, solid biomass fuel remains one of the most pervasive and important sources of air pollution in the world [6–8]. In SSA, pollutants from burning solid biomass fuels during cooking remain the primary source of indoor air pollution [3]. Emissions and their inefficient combustion are associated with increased risk for several respiratory and non-respiratory diseases, including acute respiratory infections [4,9], chronic obstructive pulmonary disease [10], infection-induced asthma [11], lung cancer, tuberculosis [1], ischaemic heart disease, ischaemic stroke, intracerebral haemorrhage, diabetes mellitus, cataract [2], and oesophagal cancer [12].

Since air pollutants from burning solid biomass fuels enter the body through inhalation, the respiratory system experiences the highest disease burden, especially in children below the age of 5 years due to their fragile airway structure and defence mechanism [13]. It is believed that the pollutants from burning solid biomass fuels alter the innate immunity in children which predisposes them to the high incidence of ARIs such as pneumonia, one of the leading causes of death in children under five years [14,15]. Thus, there is a growing evidence of the association between exposure to indoor air pollution from solid biomass cooking fuels and the incidence of ARIs in children under five years [5,16–18]. In Nepal for instance, Acharya et al. [4] reported that children from households using solid biomass fuels for cooking had a 1.79 times higher risk of suffering from ARIs compared to children from households using clean fuels such as electricity and Liquefied Petroleum Gas (LPG). Similar associations between solid biomass fuel use and acute respiratory infections were reported in Sri Lanka [11], Ethiopia [19], Nigeria [20] and elsewhere [18,21]. Meanwhile, available evidence suggests that minimizing indoor air pollution from solid biomass cooking fuels significantly reduces respiratory symptoms and improves sleep quality in children [7].

Due to global recognition of the burden of air pollution, including indoor air pollution, one of the 13 targets of Sustainable Development Goal 3 (SDG3.9) is to reduce the number of deaths and illnesses associated with hazardous chemicals, water, soil and air pollution [22]. Meanwhile, despite the high prevalence of the use of unclean fuels for cooking in SSA and the associated negative health impacts, particularly on a child's respiratory system, few studies have assessed the relationship between the use of solid biomass fuels for cooking and the risk of ARIs among children under-five in SSA. Aside from Al-Janabi, Woolley, Thomas and Bartington (2021) [24], many previous studies on the prevalence and factors associated with ARIs among children in the region mainly concentrate on single specific countries such as Ethiopia [19], Nigeria [20] and Malawi [23]. But country-level analyses are often limited by sample sizes eroding the potential of reaching generalizable findings that could inform regional and sub-regional level programs and interventions aimed at tackling ARIs among children under five in SSA. Further, the potential moderating effect of rural-urban differences in place of residence, here, referred to as "urbanicity" in the relationship between household cooking fuel and respiratory infections among children in LMICs remains a dark spot in the literature.

Meanwhile, urbanicity, thus, residency in rural or urban household plays a critical role in children's extent of exposure to indoor air pollution from solid biomass cooking fuel in households and health challenges [25]. Similar studies have found a higher risk of child morbidity as a result of household air pollution from cooking fuels in rural areas [26]. Consequently, this study examined the association between urbanicity, the use of solid biomass cooking fuels and the risk of symptoms of ARIs among children under the age of 5 years in SSA. Understanding the relationship between the use of solid biomass cooking fuels and respiratory health outcomes is essential in designing and implementing targeted interventions. These planned programmes could help reduce exposure to pollutants from solid biomass cooking fuels and to minimize its associated negative health impacts, especially among vulnerable groups such as children.

2. Methods

2.1. Data source

In this study, cross-sectional data from the most recent surveys of the Demographic and Health Survey (DHS) Program conducted between 2010 and 2019 in 31 sub-Saharan African countries (Fig. 1) were pooled for the analysis (Supplementary Table S1). The DHS Program provides nationally-representative data on health indicators collected using multi-stage sampling [27]. First, clusters called enumeration areas (EAs) were selected and then followed by the selection of households in each EA in the second phase. These surveys are implemented every 5 years in more than 90 LMICs globally [28]. The program uses standardized protocols, including sampling techniques, instruments, data management and analysis procedures in all these countries to provide for cross-national comparisons [29]. Data from mothers with children under the age of 5 years before the most recent survey (N = 320,319) were extracted from the Children's Recode (KR) file for the analyses. DHS program maintains ethically sound procedures, including oral or written consent of participants before recruitment in the survey. Local ethics committees in each country and the institutional review board of ICF International are mandated to review and approve protocols to ensure that they conform to both local regulations and meet international standards. Freely available shapefile containing geographical boundaries of Counties across the world, including the 31 study countries in SSA was sourced from Carlos Efraı'n Porto Tapique'n. Geografı'a, SIG y Cartografı'a Digital. Valencia, Spain (http://tapiquen-sig.jimdofree.com). The study was carried out in accordance with the Helsinki Declaration.

2.2. Measurements

2.2.1. Outcome variables

The outcome variables were cough and short rapid breath. They were derived from questions that asked respondents (mothers) if their child under the age of 5 years suffered from cough and short-rapid breath in the past two weeks preceding the survey. Previous studies [11,23] indicate that these questions serve as important for ARIs. Importantly, the DHS Program has used cough and short breaths as symptoms of ARIs in children under age 5 years over the years [30]. Experience of cough and short-rapid breath were dichotomous variables with responses coded as 0 for "No" and 1 for "Yes". Since the child's experience of cough was the main question that was followed up with the question on the experience of short-rapid breath, missing responses for the former were dropped.

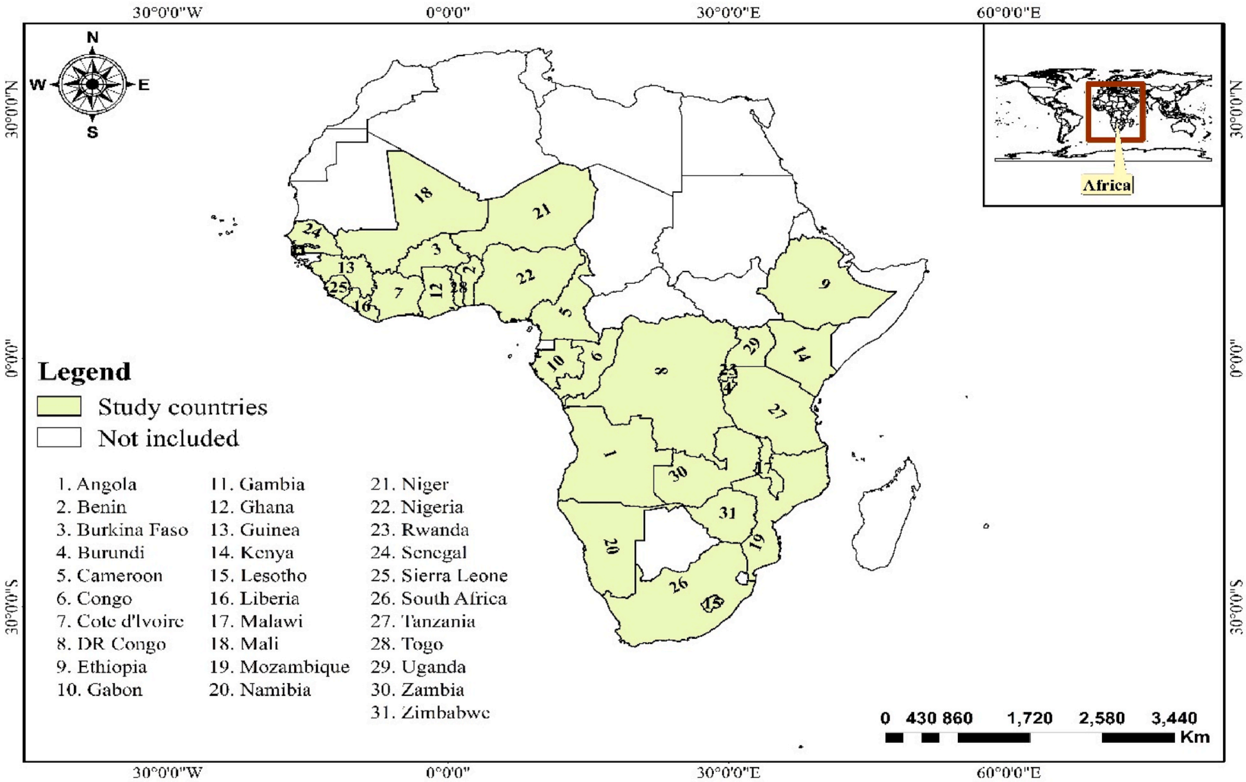

Fig. 1. Spatial distribution of the study countries in Sub-Saharan African. Source: Constructed based on shapefiles from https://tapiquen-sig.jimdofree.com/descargas-gratuitas/mundo/ with permission from Carlos Efrain Porto Tapiquen, 2021.

2.2.2. Independent variables

The key independent variables were derived from the household type of cooking fuel and location (rural-urban) of the household "urbanicity". This classification was based on the mounting evidence of widespread use of "unclean", solid biomass cooking fuels for many rural households, and noted as a major contributor to indoor air pollution in many LMICs, especially in SSA [11,31–33]. This phenomenon had been linked to the high prevalence of ARIs in children under the age of 5 years in some sub-Saharan African countries [15,31]. The variable "Urbanicity" is dichotomous with response categories "rural" and "urban". Following previous studies [34,35], household cooking fuel is re-coded into a binary response variable with response categories "Unclean" consisting of wood, grass, agricultural waste/crop residues, animal dung, charcoal and kerosene, and "Clean" which includes electricity, natural gas, LPG, and biogas. The variable "Urbanicity-type of household cooking fuel" with four (4) mutually exclusive response categories "Urban-clean" (Urban households using clean cooking fuel), "Urban-unclean" (Urban households using unclean cooking fuels), "Rural-clean" (Rural households using clean cooking fuel) and "Rural-unclean" (Rural households using unclean cooking fuel) was then derived from a combination of the two dichotomous variables. To empirically observe the effect of unclean cooking fuel use in rural households on a child under the age of 5 years, ARIs symptoms at the multi-country level, children in urban households using clean cooking fuels (Urban-clean) were used as the reference/base category. Missing responses for this variable were then dropped in the analyses.

2.2.3. Covariates

Studies on children under the age of 5 years with respiratory infections at both local and national levels have identified various predisposing factors associated with ARIs in children under 5. These factors span across child characteristics, maternal characteristics, household characteristics and place-based factors [36].

i. Child characteristics: The variables include the age of the child in years (<1, 1, 2 and 4); birth order of the child (1, 2 to 4, and 5 and above); sex of child (female and male); weight at birth (re-coded as "underweight" for children weighing less than 2.5 kg, "normal" for children weighing 2.5 kg and above, and "Not taken" for children no weight record [37] and perceived size at birth (small, average and large).

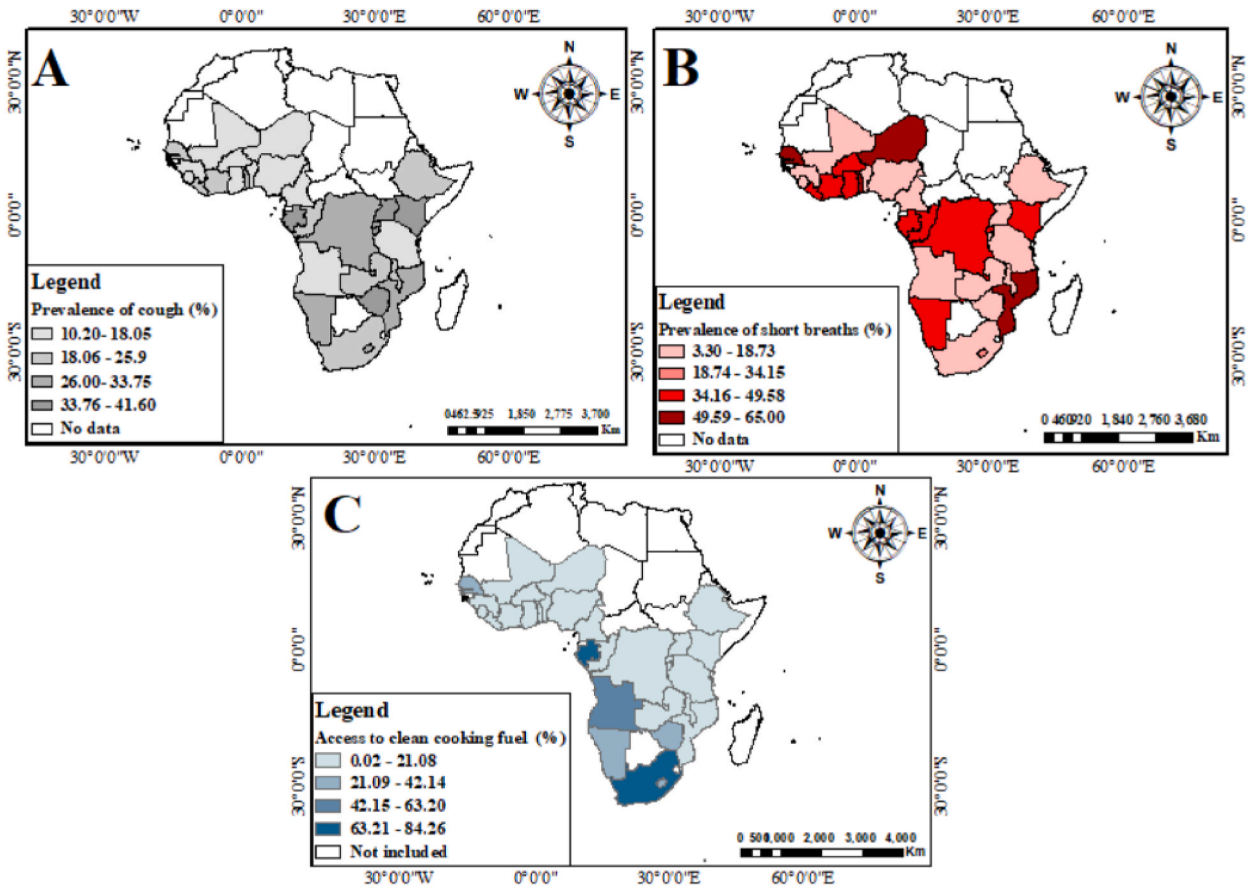

Fig. 2. Maps showing the prevalence of cough (A), the prevalence of short breath (B), and access to clean cooking fuel (C) among 31 Sub-Saharan African countries. Source: Constructed based on shapefiles from https://tapiquen-sig.jimdofree.com/descargas-gratuitas/mundo/ with permission from Carlos Efrain Porto Tapiquen, 2021.

ii. Mother's characteristics: The variables include age at childbirth (re-coded into two categories "15–19" years and "20–49" years [38]; educational attainment (no formal, primary, secondary and higher); working status (working and not working); antenatal visits during pregnancy (yes, no, and "Don't know"); postnatal check within 2 months (yes and not); and place of delivery (home, health facility, other).
iii. Household-level: The important variables are the age of the household head (recoded as ages below 35 years "young adults", between 35 and 55 years "middle-aged adults" and those above 55 years "Old-aged adults"; sex of household head (male and female); access to electricity (yes and no); type of toilet facility (re-coded into "improved" and unimproved"; source of drinking water (re-coded as "improved" and "unimproved" [39]; and access to media (yes, no) which was derived from the three variables "access to television", "radio" and "newspaper". The household wealth status is a variable generated from the wealth index—a composite measure constructed from households' assets including televisions and bicycles, materials used for housing construction and basic services by the DHS Program that reflects the general living standard of the household [39,40]. The DHS Program categorises households into five (5) wealth quintiles (poorest, poor, middle, rich, richest). For parsimony, the wealth status was re-coded as "poor", "middle" and "rich" [39].
iv. Place-based factors: The contextual or place-based variable considered is the geographic region of the participants' country in SSA. No or missing responses constituting less than 5% of the total responses for the independent variables were dropped.

2.3. Data analyses

Stata SE version 14.2 was used in the statistical analyses of data. The survey data declaration command "svyset" was executed to allow for the adjustment of differences as a result of the multi-stage sampling design. We first performed descriptive statistics using frequencies, percentages (weighted) and 95% confidence intervals (CIs) to understand the distributions of the variables and underlying characteristics. The data was integrated into the ArcGIS software (Version 10.7) and the relevant variables were presented in map images (Figs. 2 and 3). The chi-square test of independence was used to determine the associations between the outcome variables and each of the independent variables and the covariates. This procedure was followed by multicollinearity diagnoses of the independent variables and the covariates. To examine the effect of urbanicty and unclean cooking fuel on the prevalence of symptoms of ARIs in children under the age of 5 years, five (5) multivariable negative log-log regression models were fitted for each outcome variable. This statistical approach was deemed the most plausible technique considering that the outcome variables have Bernoulli distributions with

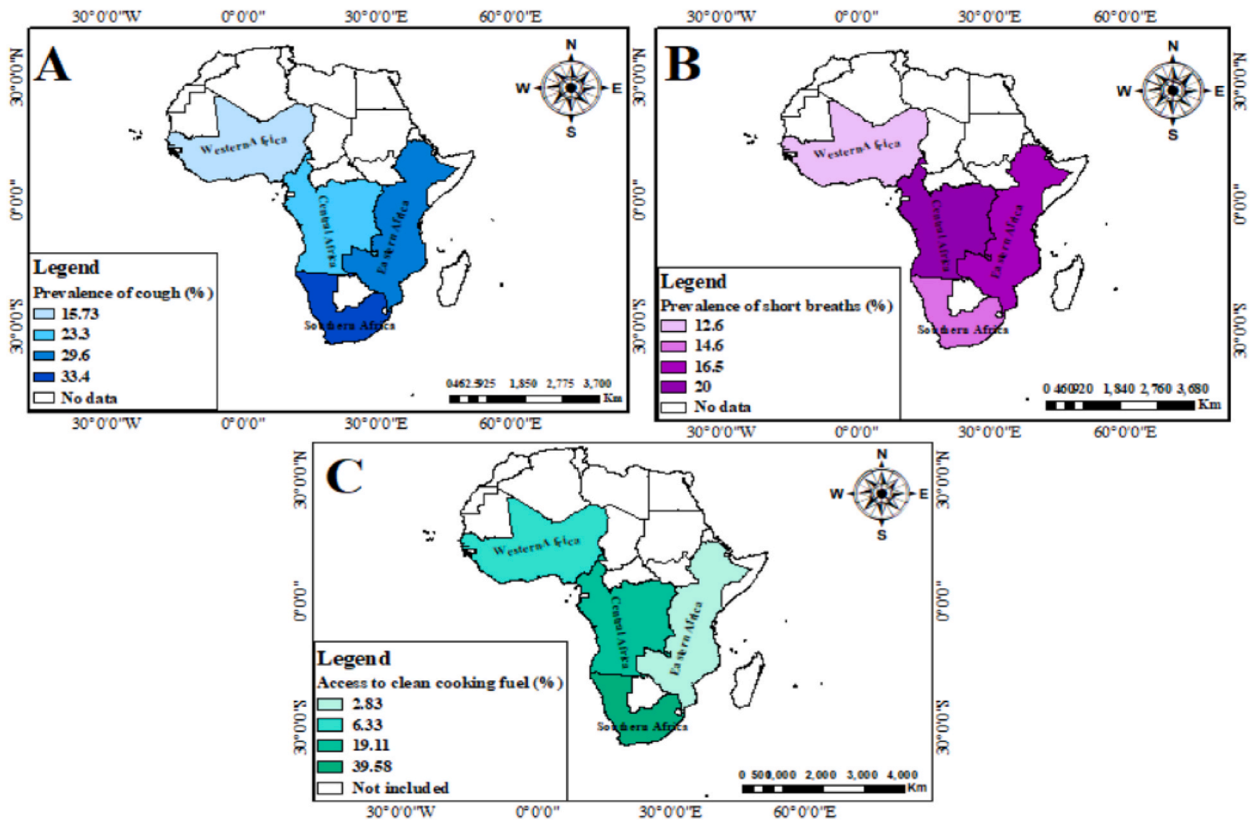

Fig. 3. Maps showing the prevalence of cough (A), the prevalence of short breath (B), and access to clean cooking fuel (C) by region of Sub-Saharan Africa. Source: Constructed based on shapefiles from https://tapiquen-sig.jimdofree.com/descargas-gratuitas/mundo/ with permission from Carlos Efrain Porto Tapiquen, 2021.

non-affirmative responses (No) and exceeding affirmative responses (Yes) under each category by more than 50% (see 29,32,34). The first model (Model 1) fitted consisted of only the key independent variables (Household cooking fuel and urbanicity). A sequential addition (adjustment) of the categories of covariates in the order considering child characteristics (Model 2); mother's characteristics (Model 3); household characteristics (Model 4); and contextual factors (Model 5) was implemented. Odds ratios (ORs) and adjusted odds ratios (aORs) at $p < 0.05$ were used in the presentation of the results. The consideration of the cluster and sample weight variables

Table 1
Distribution of characteristics of child, mother and household and contextual factors.

Variable	N	%	Variable	N	%
Key predictor variable			**Age of household head**		
Urbanicity-type of cooking fuel			Young-adults	139,027	43
Urban-unclean	75,114.10	23.45	Middle-aged adults	139,857	44
Urban-clean	27,133.61	8.47	Old-aged adults	41,426	13
Rural-unclean	214,486.44	66.97	**Sex of household head**		
Rural-clean	3554.12	1.11	Male	257,561	80
Child characteristics			Female	62,758	20
Age in years			**Access to electricity**		
<1	69,130	22	No	222,922	70
1	65,105	20	Yes	97,358	30
2	62,157	19	**Type of toilet facility**		
3	63,194	20	Improved	140,490	44
4	60,733	19	Unimproved	179,739	56
Sex			**Source of drinking water**		
Male	161,416	50	Improved	209,985	66
Female	158,903	50	Unimproved	110,284	34
Birth order			**Access to media (tv/radio/newspaper)**		
1	68,729	21	No	115,304	36
2 to 4	153,867	48	Yes	205,015	64
5 and above	97,722	31	**Contextual factors**		
Perceived size at birth			**Urbanicity**		
Large	107,329	35	Urban	102,254	32
Average	145,164	48	Rural	218,065	68
Small	48,618	16	**Country**		
Don't know	4392	1	Angola	12,419	4
Weight at birth			Benin	12,338	4
Underweight	17,198	6	Burkina Faso	13,601	4
Normal	160,025	52	Burundi	12,717	4
Not taken	128,239	42	Cameroon	8946	3
Mother's characteristics			Congo	26,463	8
Marital status			Cote d'Ivoire	6522	2
Never married/widowed/separated	39,252	12	DR Congo	16,550	5
Married/living with a partner	281,067	88	Ethiopia	10,207	3
Age at childbirth			Gabon	4405	1
15–19	18,860	6	Gambia	7155	2
20–49	301,459	94	Ghana	5233	2
Educational attainment			Guinea	7056	2
No formal	129,245	40	Kenya	18,126	6
Primary	105,612	33	Lesotho	2584	1
Secondary	74,531	23	Liberia	5669	2
Higher	10,931	3	Malawi	16,246	5
Working status			Mali	9390	3
Not working	115,360	37	Mozambique	5212	2
Working	195,193	63	Namibia	4138	1
Antenatal visits during pregnancy			Niger	11,853	4
No	22,747	10	Nigeria	30,428	10
Yes	198,967	88	Rwanda	7498	2
Don't know	4094	2	Senegal	10,350	3
Postnatal check within 2 months			Sierra Leone	8665	3
No	119,833	57	South Africa	3162	1
Yes	89,787	43	Tanzania	8900	3
Don't know	567	0	Togo	6081	2
Place of delivery			Uganda	13,731	4
Home	108,769	34	Zambia	8964	3
Health facility	205,818	65	Zimbabwe	5710	2
Other	3276	1	Geographic region		
Household characteristics			Western Africa	134,340	42
Wealth status			Eastern Africa	101,603	32
Poor	141,513	44	Central Africa	68,783	21
Middle	64,372	20	South Africa	15,594	5
Rich	114,435	36	N=	320,319	

Table 2
Association between the prevalence of cough and short breaths and characteristics of the child, mother and household, and contextual factors.

Independent variables	Cough	Chi2	Short rapid breaths	Chi2
	Weighted % (95% CI)		Weighted % (95% CI)	
Key predictor variable				
Urbanicity-type of cooking fuel		p < 0.001		p < 0.001
Urban-unclean	23.4 (23.1–23.7)		14.3 (14.0–14.6)	
Urban-clean	25.0 (24.5–25.5)		13.8 (13.3–14.3)	
Rural-unclean	22.0 (21.8–22.2)		16.2 (16.0–16.4)	
Rural-clean	23.5 (22.1–24.9)		11.5 (10.3–12.9)	
Child characteristics				
Age of child in years		p < 0.001		p < 0.001
<1	23.7 (23.4–24.0)		17.9 (17.5–18.2)	
1	26.6 (26.2–26.9)		18.2 (17.8–18.6)	
2	23.7 (23.4–24.0)		15.9 (15.5–16.2)	
3	20.8 (20.4–21.1)		13.5 (13.2–13.9)	
4	17.9 (17.6–18.3)		11.4 (11.0–11.7)	
Sex of child		p = 0.651		p = 0.024
Male	22.7 (22.4–22.8)		15.8 (15.5–16.0)	
Female	22.6 (22.3–22.8)		15.2 (15.0–15.4)	
Birth order		p < 0.001		p < 0.001
1	24.4 (24.1–24.7)		15.6 (15.3–15.9)	
2–4	22.8 (22.6–23.0)		15.3 (15.0–15.5)	
5 and above	21.0 (20.8–21.3)		15.8 (15.5–16.1)	
Perceived size at birth		p < 0.001		p < 0.001
Large	23.3 (23.0–23.5)		16.5 (16.2–16.8)	
Average	20.5 (20.3–20.7)		12.4 (12.2–12.6)	
Small	25.1 (24.7–25.5)		18.9 (18.5–19.3)	
Don't know	12.8 (11.8–13.8)		7.8 (6.8–8.8)	
Weight at birth		p < 0.001		p < 0.001
Underweight	26.2 (25.5–26.9)		17.7 (17.0–18.4)	
Normal	24.8 (24.6–25.0)		15.2 (15.0–15.4)	
Not taken	18.2 (17.9–18.3)		13.6 (13.3–13.8)	
Mother's characteristics				
Marital status		p < 0.001		p = 0.257
Never married/widowed/separated or divorced	26.6 (26.2–27.0)		16.3 (15.9–16.8)	
Married/living with a partner	22.05 (21.9–22.2)		15.4 (15.2–15.5)	
Age at childbirth		p < 0.001		p < 0.001
15–19	25.2 (24.6–25.8)		17.3 (16.6–18.0)	
20–49	22.4 (22.2–22.6)		15.4 (15.2–15.5)	
Educational attainment		p < 0.001		p < 0.001
No formal	16.7 (16.5–16.9)		14.4 (14.1–14.6)	
Primary	26.8 (26.6–27.1)		17.8 (17.6–18.1)	
Secondary	26.3 (26.0–26.7)		14.4 (14.1–14.7)	
Higher	26.4 (25.6–27.3)		11.8 (11.1–12.6)	
Working status		p < 0.001		p = 0.481
Not working	20.8 (20.5–21.0)		15.1 (14.8–15.4)	
Working	23.0 (22.8–23.2)		14.8 (14.7–15.0)	
Antenatal visits during pregnancy		p < 0.001		p < 0.001
No	18.2 (17.7–18.7)		13.5 (13.0–14.0)	
Yes	25.7 (25.525.9)		17.5 (17.3–17.7)	
Don't know	20.7 (19.5–22.0)		13.6 (12.2–14.9)	
Postnatal check within 2 months		p < 0.001		p < 0.001
No	23.3 (23.1–23.6)		14.0 (13.7–14.2)	
Yes	26.1 (25.8–26.4)		19.5 (19.11–19.8)	
Don't know	20.3 (17.0–23.8)		17.7 (14.0–22.2)	
Place of delivery		p < 0.001		p = 0.675
Home	18.9 (18.6–19.1)		15.1 (14.8–15.3)	
Health facility	24.5 (24.3–24.7)		15.6 (15.4–157)	
Other	27.8 (26.3–29.4)		14.8 (13.5–16.2)	
Household characteristics				
Wealth status		p < 0.001		p < 0.001
Poor	21.6 (21.4–21.8)		15.8 (15.6–16.0)	
Middle	22.3 (21.9–22.6)		15.6 (15.3–16.0)	
Rich	24.0 (23.8–24.3)		15.1 (14.8–15.3)	
Age of household head		p < 0.001		p < 0.001
Young-adults	24.1 (23.9–24.3)		16.0 (15.8–16.3)	
Middle-aged adults	21.4 (21.1–21.6)		14.7 (14.5–15.0)	
Old-aged adults	21.7 (21.3–22.1)		16.2 (15.8–16.7)	
Sex of household head		p < 0.001		p < 0.001
Male	21.9 (21.7–22.1)		15.0 (14.9–15.2)	

(*continued on next page*)

Table 2 (*continued*)

Independent variables	Cough	Chi2	Short rapid breaths	Chi2
	Weighted % (95% CI)		Weighted % (95% CI)	
Female	25.5 (25.2–25.8)		17.3 (16.9–17.7)	
Access to electricity		p = 0.013		p < 0.001
No	22.6 (22.2–22.8)		16.7 (16.5–16.9)	
Yes	22.6 (22.3–22.8)		13.0 (12.8–13.2)	
Type of toilet facility		p < 0.001		p < 0.001
Improved	23.32 (23.1–23.5)		13.8 (13.6–14.0)	
Unimproved	22.05 (21.9–22.2)		17.0 (16.8–17.2)	
Source of drinking water		p < 0.001		p < 0.001
Improved	23.0 (22.8–23.2)		15.1 (14.9–15.3)	
Unimproved	21.9 (21.6–22.1)		16.3 (16.0–16.6)	
Access to media (TV/radio/newspaper)		p < 0.001		p < 0.001
No	19.9 (19.6–20.1)		13.8 (13.6–14.1)	
Yes	24.1 (24.0–24.3)		16.5 (16.3–16.7)	
Contextual factors				
Urbanicity		p < 0.001		p < 0.001
Urban	23.8 (23.6–24.1)		14.2 (14.0–14.4)	
Rural	22.0 (21.9–22.2)		16.1 (15.9–16.3)	
Geographic region		p < 0.001		p < 0.001
Western Africa	15.7 (15.5–15.9)		12.6 (12.4–12.9)	
Eastern Africa	29.6 (29.3–30.0)		16.5 (16.3–16.8)	
Central Africa	23.3 (22.9–23.6)		20.0 (19.6–20.4)	
Southern Africa	33.4 (32.6–34.1)		14.6 (13.9–15.2)	

Chi2: p-values for chi-square test of independence.
95% CI: 95% Confidence interval (Lower bound-Upper bound).

allowed for adjustment of effect sizes to avoid potential challenges of oversampling or under-sampling and clustering of samples emerging from the multi-stage sampling technique used in the data collection.

3. Results

3.1. Distribution of characteristics of child, mother, household and contextual factors

As illustrated in Table 1, the proportion of rural participants who were using unclean cooking fuel (66.97%) was about three times the number of urban residents who were using unclean cooking fuel (23.45%). Access to clean cooking fuels was highest in South Africa and Gabon (63.2%–84.2%) and lowest in Ghana, Nigeria, Togo and Congo DR among others (<21.1%) as shown in Fig. 2. At the sub-regional level (Fig. 3), access to clean cooking fuel was high (39.6%) in Southern Africa whereas low (2.8%) access was recorded in Eastern Africa. A significant proportion of the children were below 1 year (22%), half were males (50%) and 48% occupied 2nd to 4th birth order. Nearly half of the children were perceived to be of average size at birth (48%), whilst 52% were born with normal weight. On maternal characteristics, 88% were married/living with a partner, 94% gave birth between the ages of 20 and 49, and 40% had no formal education. Almost two-thirds of the women were working (63%), 88% had ANC visits during pregnancy, whilst 57% did not have a postnatal check within 2 months. A significant proportion of them gave birth at the health facility (65%) and belonged to the poor wealth quintile (44%). Male (80%) and middle-aged adult (44%) household heads dominated. Seven out of ten had no access to electricity (70%), and 56% were using unimproved toilet facilities. A greater section of the sample had improved drinking water (66%) and access to media (64%). Most of the participants were in rural locations (68%), resided in Nigeria (10%) and were in Western Africa (42%).

3.2. Association between the prevalence of cough and short breaths and characteristics of the child, mother and household, and contextual factors

As shown in Fig. 2, the cough was most prevalent (33.8%–41.6%) among children in countries including Congo DR, Uganda, Zimbabwe and Kenya while lowest (10.2%–18.1%) in countries such as Ghana, Nigeria and Angola. Cough was commonly reported among urban children in households with clean cooking fuel (25%), those at age one (26.6%), males (22.7%), first-birth older children (24.4%), perceived small children at birth (25.1%) and those underweight at birth (26.2%). Similarly, the prevalence of cough was high among children whose mothers had never married/widowed/separated or divorced, given birth at age 15–19 (25.2%), had primary education (26.8%), working (23.0%), had an antenatal care visit (25.7%), and those who had a postnatal check within 2 months (26.1%). Similarly, childhood cough was dominant among children who were born at other locations outside health facilities and homes (27.8%). On household characteristics, the cough was prevalent among children of the rich wealth quintile (24.0%), those with young-adult household heads (24.1%) and female household heads (25.5%). However, the phenomenon was the same for those with (22.6%) or without access (22.6%) to electricity. The analysis also showed that cough dominated among children in households with improved toilet facilities (23.32%), those with media access (24.1%), those in urban locations (23.8%), and children of South

Table 3
Negative log-log regression models showing relationships between prevalence of cough and predictor variables.

Variables	Key predictor		Child characteristics		Mother's characteristics		Household characteristics		Contextual factors	
	Model 1		Model 2		Model 3		Model 4		Model 5	
	OR (95% CI)	P-value	AOR (95% CI)	P-value	AOR (95% CI)	P-value	AOR (95% CI)	P-value	AOR (95% CI)	P-value
Urbanicity-type of cooking fuel (Urban-Clean)										
Urban-unclean	0.956 (0.932–0.980)	**<0.001**	0.976 (0.951–1.001)	0.065	1.014 (0.983–1.046)	0.391	0.984 (0.954–1.016)	0.328	1.047 (1.013–1.082)	**0.006**
Rural-unclean	0.916 (0.895–0.938)	**<0.001**	0.988 (0.964–1.012)	0.315	1.062 (1.030–1.094)	**<0.001**	1.002 (0.969–1.035)	0.927	1.013 (0.979–1.049)	0.449
Rural-clean	0.957 (0.908–1.007	0.093	0.979 (0.929–1.032)	0.438	0.978 (0.920–1.039)	0.473	0.967 (0.909–1.028)	0.282	0.928 (0.872–0.987)	**0.017**
Age of child in years (Ref: <1)										
1			1.085 (1.066–1.103)	**<0.001**	1.082 (1.063–1.101)	**<0.001**	1.083 (1.064–1.102)	**<0.001**	1.081 (1.062–1.101)	**<0.001**
2			1.000 (0.983–1.017)	0.984	1.032 (1.012–1.052)	**0.002**	1.034 (1.014–1.054)	**0.001**	1.023 (1.003–1.043)	**0.023**
3			0.918 (0.902–0.934)	**<0.001**	1.008 (0.985–1.032)	0.478	1.014 (0.991–1.038)	0.232	0.993 (0.971–1.017)	0.579
4			0.843 (0.828–0.858)	**<0.001**	0.944 (0.919–0.969)	**<0.001**	0.950 (0.925–0.976)	**<0.001**	0.922 (0.898–0.947)	**<0.001**
Sex of child (Ref: Male)										
Female			0.997 (0.986–1.008)	0.610	0.991 (0.977–1.004)	0.171	0.991 (0.977–1.004)	0.183	0.991 (0.977–1.004)	0.169
Birth order (Ref: 1)										
2–4			0.973 (0.959–0.987)	**<0.001**	0.976 (0.957–0.997)	**0.023**	0.976 (0.956–0.997)	**0.023**	0.967 (0.948–0.988)	**0.002**
5 and above			0.945 (0.930–0.960)	**<0.001**	0.970 (0.948–0.992)	**0.008**	0.989 (0.965–1.012)	0.342	0.964 (0.942–0.988)	**0.003**
Perceived size at birth (Ref: Large)										
Average			0.925 (0.914–0.937)	**<0.001**	0.917 (0.904–0.931)	**<0.001**	0.917 (0.903–0.931)	**<0.001**	0.902 (0.889–0.916)	**<0.001**
Small			1.076 (1.057–1.096)	**<0.001**	1.088 (1.064–1.112)	**<0.001**	1.085 (1.062–1.109)	**<0.001**	1.063 (1.040–1.087)	**<0.001**
Don't know			0.793 (0.756–0.831)	**<0.001**	0.785 (0.741–0.833)	**<0.001**	0.788 (0.743–0.835)	**<0.001**	0.767 (0.723–0.813)	**<0.001**
Weight at birth (Ref: Underweight)										
Normal			1.015 (0.989–1.043)	0.259	0.998 (0.966–1.031)	0.893	0.995 (0.964–1.028)	0.772	0.982 (0.951–1.015)	0.285
Not taken			0.838 (0.817–0.861)	**<0.001**	0.914 (0.882–0.947)	**<0.001**	0.912 (0.880–0.944)	**<0.001**	0.969 (0.936–1.004)	0.085
Age at childbirth (Ref: 15–19)										
20–49							1.004 (0.974–1.034)	0.816	0.988 (0.959–1.018)	0.445
Marital status (Ref: Never married/widowed/divorced/separated)										
Married/living with a partner							0.963 (0.940–0.985)	**0.001**	1.013 (0.990–1.037)	0.276
Educational attainment (Ref: Higher)										
No formal							0.789 (0.755–0.825)	**<0.001**	0.893 (0.854–0.933)	**<0.001**
primary							1.018 (0.974–1.063)	0.429	1.006 (0.963–1.051)	0.786
secondary							1.000 (0.958–1.043)	1.000	1.004 (0.962–1.047)	0.862
Working status (Ref: Not working)										
Working							1.044 (1.029–1.059)	**<0.001**	1.074 (1.058–1.090)	**<0.001**
Antenatal visits during pregnancy (Ref: No)										
Yes							1.058 (1.032–1.084)	**<0.001**	1.071 (1.045–1.097)	**<0.001**
Don't know							0.910 (0.862–0.961)	**0.001**	0.932 (0.882–0.984)	**0.012**
Postnatal check within 2 months (Ref: No)										
Yes							1.037 (1.022–1.052)	**<0.001**	1.069 (1.053–1.084	**<0.001**
Don't know							0.860 (0.743–0.996)	**0.044**	0.873 (0.754–1.012)	0.072
Place of delivery (Ref: Home)										
Health facility							0.983 (0.963–1.003)	0.100	0.973 (0.953–0.993)	**0.009**
Other							1.153 (1.081–1.230)	**<0.001**	1.090 (1.022–1.162)	**0.009**
Wealth status (Ref: Poor)										
Middle							0.972 (0.952–0.993)	**0.009**	0.981 (0.961–1.002)	0.079
Rich							0.973 (0.952–0.994)	**0.012**	0.986 (0.965–1.007)	0.187
Age of household head (Ref: Young adults)										
Middle-aged adults							0.944 (0.929–0.959)	**<0.001**	0.973 (0.957–0.989)	**0.001**
Old-aged adults							0.942 (0.922–0.963)	**<0.001**	0.993 (0.972–1.016)	0.562

(*continued on next page*)

Table 3 (*continued*)

Variables	Key predictor		Child characteristics		Mother's characteristics		Household characteristics		Contextual factors	
	Model 1		Model 2		Model 3		Model 4		Model 5	
	OR (95% CI)	P-value	AOR (95% CI)	P-value	AOR (95% CI)	P-value	AOR (95% CI)	P-value	AOR (95% CI)	P-value
Sex of household head (Ref: Male)										
Female							1.042 (1.023–1.062)	**<0.001**	1.029 (1.010–1.049)	**0.003**
Access to electricity (Ref: No)										
Yes							1.108 (1.086–1.130)	**<0.001**	1.030 (1.010–1.051)	**0.004**
Type of toilet facility (Ref: Improved)										
Unimproved							1.050 (1.034–1.067)	**<0.001**	1.073 (1.056–1.090)	**<0.001**
Source of drinking water (Ref: Improved)										
Unimproved							1.004 (0.989–1.019)	0.622	1.006 (0.991–1.021)	0.465
Access to media (TV/radio/newspaper) (Ref: No)										
Yes							1.080 (1.063–1.096)	**<0.001**	1.108 (1.091–1.125)	**<0.001**
Geographic region (Ref: Western Africa)										
Eastern Africa									1.446 (1.419–1.474)	**<0.001**
Central Africa									1.273 (1.248–1.300)	**<0.001**
Southern Africa									1.568 (1.517–1.620)	**<0.001**

Table 4
Negative log-log regression models showing relationships between prevalence of short rapid breaths and predictor variables.

Variables	Key predictor		Child characteristics		Mother's characteristics		Household characteristics		Contextual factors	
	Model 1		Model 2		Model 3		Model 4		Model 5	
	OR (95% CI)	P-value	AOR (95% CI)	P-value	AOR (95% CI)	P-value	AOR (95% CI)	P-value	AOR (95% CI)	P-value
Urbanicity-type of cooking fuel (Urban-Clean)										
Urban-unclean	1.017 (0.985–1.050)	0.307	1.010 (0.978–1.044)	0.548	0.972 (0.935–1.010)	0.144	0.933 (0.897–0.970)	**0.001**	1.028 (0.986–1.071)	0.200
Rural-unclean	1.087 (1.056–1.120)	**<0.001**	1.096 (1.063–1.130)	**<0.001**	1.060 (1.021–1.100)	**0.002**	0.988 (0.949–1.029)	0.550	1.124 (1.076–1.174)	**<0.001**
Rural-clean	0.915 (0.858–0.975)	**0.006**	0.935 (0.877–0.998)	**0.043**	0.912 (0.846–0.984)	**0.017**	0.901 (0.835–0.973)	**0.008**	0.959 (0.886–1.037)	0.292
Age of child in years (Ref: <1)										
1			1.004 (0.983–1.025)	0.717	0.998 (0.977–1.020)	0.884	1.001 (0.978–1.022)	0.989	1.002 (0.981–1.024)	0.854
2			0.931 (0.911–0.952)	**<0.001**	0.944 (0.922–0.967)	**<0.001**	0.946 (0.924–0.970)	**<0.001**	0.952 (0.929–0.975)	**<0.001**
3			0.860 (0.841–0.879)	**<0.001**	0.896 (0.871–0.922)	**<0.001**	0.901 (0.876–0.927)	**<0.001**	0.913 (0.887–0.940)	**<0.001**
4			0.792 (0.775–0.810)	**<0.001**	0.832 (0.805–0.860)	**<0.001**	0.836 (0.808–0.864)	**<0.001**	0.847 (0.819–0.876)	**<0.001**
Sex of child (Ref: Male)										
Female			0.983 (0.970–0.997)	**0.020**	0.980 (0.964–0.997)	**0.019**	0.981 (0.965–0.998)	**0.029**	0.981 (0.964–0.997)	**0.022**
Birth order (Ref: 1)										
2 to 4			0.996 (0.978–1.015)	0.687	0.971 (0.946–0.995)	**0.020**	0.970 (0.946–0.995)	**0.018**	0.959 (0.935–0.984)	**0.001**
5 and above			1.013 (0.993–1.034	0.201	0.980 (0.952–1.008)	0.157	0.992 (0.963–1.021)	0.577	0.963 (0.935–0.992)	**0.013**
Perceived size at birth (Ref: Large)										
Average			0.867 (0.854–0.881)	**<0.001**	0.870 (0.853–0.886)	**<0.001**	0.869 (0.853–0.885)	**<0.001**	0.880 (0.863–0.897)	**<0.001**
Small			1.078 (1.054–1.103)	**<0.001**	1.078 (1.049–1.107)	**<0.001**	1.073 (1.044–1.102)	**<0.001**	1.084 (1.055–1.114)	**<0.001**
Don't know			0.725 (0.682–0.771)	**<0.001**	0.743 (0.689–0.801)	**<0.001**	0.748 (0.693–0.807)	**<0.001**	0.734 (0.680–0.792)	**<0.001**
Weight at birth (Ref: Underweight)										
Normal			0.983 (0.951–1.017)	0.331	0.981 (0.943–1.021)	0.346	0.976 (0.937–1.016)	0.231	0.973 (0.935–1.013)	0.189
Not taken			0.911 (0.881–0.942)	**<0.001**	0.944 (0.905–0.985)	**0.008**	0.937 (0.897–0.978)	**0.003**	0.959 (0.919–1.002)	**0.059**
Age at childbirth (Ref: 15–19)										
20–49					1.040 (1.003–1.078)	**0.034**	1.036 (0.999–1.074)	**0.054**	1.060 (1.022–1.099)	**0.002**
Marital status (Ref: Never married/widowed/divorced/separated)										
Married/living with a partner					1.001 (0.976–1.026)	0.937	1.023 (0.994–1.052)	0.125	1.040 (1.011–1.071)	**0.007**
Educational attainment (Ref: Higher)										
No formal					1.159 (1.100–1.221)	**<0.001**	1.161 (1.101–1.225)	**<0.001**	1.180 (1.118–1.245)	**<0.001**
Primary					1.239 (1.177–1.305)	**<0.001**	1.227 (1.164–1.294)	**<0.001**	1.208 (1.146–1.274)	**<0.001**
Secondary					1.124 (1.069–1.182)	**<0.001**	1.114 (1.059–1.172)	**<0.001**	1.079 (1.025–1.136)	**0.004**
Working status (Ref: Not working)										
Working					1.007 (0.989–1.026)	0.427	1.002 (0.984–1.020)	0.868	1.001 (0.983–1.019)	0.936
Antenatal visits during pregnancy (Ref: No)										
Yes					1.092 (1.060–1.126)	**<0.001**	1.089 (1.057–1.123)	**<0.001**	1.110 (1.077–1.145)	**<0.001**
Don't know					0.975 (0.911–1.043)	0.455	0.969 (0.906–1.036)	0.355	1.011 (0.944–1.082)	0.756
Postnatal check within 2 months (Ref: No)										
Yes					1.202 (1.180–1.224)	**<0.001**	1.196 (1.174–1.218)	**<0.001**	1.223 (1.200–1.246)	**<0.001**
Don't know					1.018 (0.844–1.230)	0.849	1.029 (0.848–1.249)	0.769	0.998 (0.822–1.212)	0.986
Place of delivery (Ref: Home)										
Health facility					1.052 (1.026–1.079)	**<0.001**	1.047 (1.021–1.074)	**<0.001**	1.021 (0.995–1.047)	0.112
Other					0.998 (0.932–1.068)	0.952	0.992 (0.926–1.062)	0.819	0.994 (0.928–1.065)	0.870
Wealth status (Ref: Poor)										
Middle							0.905 (0.881–0.929)	**<0.001**	0.895 (0.871–0.919)	**<0.001**
Rich							0.942 (0.917–0.967)	**<0.001**	0.928 (0.904–0.953)	**<0.001**
Age of household head (Ref: Young adults)										
Middle-aged adults							0.961 (0.942–0.980)	**<0.001**	0.969 (0.950–0.988)	**0.002**
Old-aged adults							0.980 (0.954–1.006)	0.135	0.994 (0.967–1.022)	0.669

(*continued on next page*)

Table 4 (*continued*)

Variables	Key predictor		Child characteristics		Mother's characteristics		Household characteristics		Contextual factors	
	Model 1		Model 2		Model 3		Model 4		Model 5	
	OR (95% CI)	P-value	AOR (95% CI)	P-value	AOR (95% CI)	P-value	AOR (95% CI)	P-value	AOR (95% CI)	P-value
Sex of household head (Ref: Male)										
Female							1.066 (1.041–1.091)	**<0.001**	1.064 (1.039–1.089)	**<0.001**
Access to electricity (Ref: No)										
Yes							1.147 (1.120–1.174)	**<0.001**	1.127 (1.100–1.155)	**<0.001**
Type of toilet facility (Ref: Improved)										
Unimproved							1.150 (1.128–1.172)	**<0.001**	1.137 (1.116–1.158)	**<0.001**
Source of drinking water (Ref: Improved)										
Unimproved							1.036 (1.017–1.056)	**<0.001**	1.024 (1.005–1.044)	**0.012**
Access to media (TV/radio/newspaper) (Ref: No)										
Yes							1.130 (1.109–1.152)	**<0.001**	1.156 (1.135–1.179)	**<0.001**
Geographic region (Ref: Western Africa)										
Eastern Africa									1.040 (1.017–1.064)	**0.001**
Central Africa									1.361 (1.323–1.400)	**<0.001**
Southern Africa									1.069 (1.026–1.113)	**0.001**

Africa (33.4%) as shown in Table 2 and Fig. 2.

Concerning short-rapid breaths, we found significant prevalence among children in rural locations with unclean cooking fuel (16.2%), that aged one (18.2%), males (15.8%), first birth orders (15.6%) as well as children perceived to be small (18.9%) and underweight (17.7%) at birth. Similarly, short breaths were common among children whose mothers had never married/widowed/separated or divorced (16.3%), children whose mothers gave birth at age 15–19 (17.3%), had primary educated women (17.8%), non-working women (15.1%), women who had an antenatal visit (17.5%) and women who had a postnatal check within two months (19.5%). Also, children of women who gave birth in a health facility (15.6%), and those from poor households (15.8%) had a significantly high proportion of short breaths. The analyses further revealed higher prevalence among children in old-aged adults (16.2%) and female (17.3%) headed households, households without electricity (16.7%), unimproved toilet facilities (17.0%) and unimproved sources of drinking water (16.3%) as well as those with media access (16.5%). At the country level, short breaths were the most prevalent (49.6%–65.0%) among under-five children from Niger, Mozambique, and Togo (Fig. 2). The lowest prevalence of short breaths (3.3%–18.7%) was observed in countries including South Africa, Angola, Zambia, Tanzania, Uganda, Nigeria, Cameroon, and Mali. Short breaths were similarly profound among urban children (14.2%) and those in Central Africa (20.0%) as illustrated in Table 2. The lowest prevalence (12.6%) of short breaths among children under five was observed in Western Africa (See Fig. 3).

3.3. Relationships between the prevalence of cough and predictor variables

From the final model (Model 5) in Table 3, higher odds ratios of cough occurred among children in urban households that use unclean cooking fuel (aOR = 1.05 95% CI = 1.01, 1.08), however, lower odds ratios were observed for rural children in homes that use clean cooking fuel (aOR = 0.93 95% CI = 0.87, 0.99) relative to children in urban homes using clean cooking fuel. Children from South Africa had higher odds ratios of cough as well compared with those in Western Africa (aOR = 1.57, 95% CI = 1.52, 1.62).

3.4. Relationships between the prevalence of short rapid breaths and predictor variables

As shown in Model 5 of Table 4, higher odds ratios of short rapid breaths were noted among children in rural households that use unclean cooking fuel compared with urban residents using clean cooking fuel (aOR = 1.12 95% CI = 1.08, 1.17). Children from Central Africa had higher odds ratios of short breaths compared with those in Western Africa (aOR = 1.36, 95% CI = 1.32, 1.40).

4. Discussion

This study investigated the association between urbanicity, the use of solid biomass cooking fuels and the risk of symptoms of ARIs (as manifested by cough and short-rapid breaths) among children under 5 years in SSA. This analysis departs from previous multi-country studies that examined the independent effect of household cooking fuel on respiratory infections among under-five children [24]. The findings showed that children in urban households where unclean fuels were used for cooking were more likely (47.0%) to experience cough compared to those in urban households where clean fuels were used.

Also, children in rural households where clean fuels were used for cooking were 7.2% less likely to experience cough relative to children in urban households where clean fuels were used. For short-rapid breaths, the study revealed that children in rural households where unclean fuels were used for cooking were far more likely (124.0%) of experiencing short-rapid breaths compared to their counterparts in urban households where clean fuels were used. These findings are in congruent with previous studies that indicated a high risk of mortality among children in rural households where unclean cooking fuels are used [26,41]. According to Kim et al. [1], the widespread use of unclean cooking fuels among rural households in many developing countries is associated with the relatively high prevalence of diseases including ARIs. Surprisingly, children born to mothers who made antenatal and postnatal visits were more likely to experience cough as compared to those whose mothers did not make antenatal and postnatal visits. This observation could be due to either ineffective education; failure of mother's to put to practice knowledge relative to risk factors of ARIs or both.

The increased likelihood of cough among children in urban households where solid biomass fuels were used for cooking relative to children in urban households that used clean fuels as found in the present study had been reported in previous studies in Uganda [42], Rwanda [43], Ethiopia [6,44] and in SSA [45]. Even though the current study found a significant association between childhood cough and the use of solid biomass fuels for cooking in urban settings, it does not infer causality because of the study's cross-sectional design. However, considering the large-scale multi-country nature of the present study, the findings add to the mounting evidence on the possible impact of pollutants from solid biomass cooking fuels on the respiratory health of children, especially in urban settings in SSA. However, despite the relatively high household access to clean cooking fuels in Southern Africa, coughs among children under five were more prevalent in the region. This outcome could be a result of the synergistic effect of outdoor air pollution which could vary by urbanicity [25]. The exact mechanism by which pollutants from solid biomass fuels increase the risk of respiratory tract infections remains unclear [16,46]. Also, differences in access to quality healthcare at the sub-regional level as well as between rural-urban residences could account for the disparities in the prevalence of ARI symptoms among under-five children [47]. However, studies have suggested that the phenomenon may be mediated by the inhalation of particulate matter from burning solid biomass fuels [15,17,46]. The particulate matter forms an organic compound within the respiratory tract which could alter the innate immunity or respiratory defence mechanisms and thereby predispose children to respiratory infections including ARIs [4,15]. Therefore, the high levels of particulate matter in urban households that used solid biomass fuels for cooking might have increased the susceptibility of children in those houses to coughs (one of the cardinal symptoms of ARIs) compared to children in houses that use clean fuels for cooking. A recent longitudinal study in Sri Lanka found a higher prevalence of respiratory tract infection among children in households that used solid biomass cooking fuels with higher levels of particulate matter in households that used solid biomass fuels compared to those that used clean fuels when air quality was assessed [11].

Children in rural households that used clean fuels for cooking had lower odds ratios of cough relative to children in urban households that also used clean fuels for cooking. Similar findings were reported by Khalequzzaman et al. [48].The increased likelihood of cough among children in urban households compared to those in rural households, in the absence of exposure to pollutants from solid biomass fuels, could be attributed to the higher levels of ambient or outdoor air pollution in urban settings relative to rural settings [49,50]. Urbanisation is associated with increased levels of outdoor air pollutants, most often from industrial processes and road traffic emissions [50]. Besides, densely populated urban neighbourhoods are often characterized by relatively high within-community solid waste burning often associated with a high concentration of particulate matter and carbon monoxide compared to rural settings [51,52]. Perhaps, the high level of particulate matter in the atmosphere in urban settings predisposes children in these settings to higher odds ratios of cough compared to children in rural settings. For example, Ranathunga et al. [11] reported that having an industry emitting pollutants close to a child's home is associated with a significant increase in the risk of respiratory tract infection. Additionally, the high population density and overcrowding of buildings in urban settings significantly reduce ventilation [48,53] and prolong the suspension of particulate matter in the atmosphere [52]. This scenario could also contribute to the increased risk of symptoms of ARIs among children in urban settings compared to those in rural settings.

This study also found that children in rural households that used unclean fuel for cooking had a higher likelihood of experiencing short-rapid breaths compared to children in urban households where clean fuels were used for cooking. Similar studies had reported an increased risk for short-rapid breaths among children in rural households where unclean fuels were used for cooking [6,43,54]. In a meta-analysis of studies that examined the impact of exposure to pollutants from solid biomass cooking fuels on the respiratory health of women and children in rural settings, Po, FitzGerald and Carlsten [55] reported that children who were exposed to pollutants from burning solid biomass cooking fuels had 3-folds increased risk for acute respiratory infections. The higher odds ratios of symptoms of ARIs among children from rural households that used solid biomass fuels relative to children from urban households that used clean fuels as found in the present study was expected because air pollutants from burning solid biomass cooking fuels had been strongly linked to ARIs [17,43,48]. However, the finding re-echoes the need for urgent interventions that could help minimize children's exposure to air pollutants from unclean cooking fuel, especially, solid biomass cooking fuels since about 91.9% of children under five living in rural areas in SSA are exposed to this pollutants [3].

4.1. Practical implications

The World Health Organisation recognises indoor air pollution from the use of solid biomass cooking fuels as one of the major environmental risk factors for respiratory tract infections such as pneumonia, which accounts for 15% of all deaths of children under five years worldwide [56]. There are over 2–3 billion people in the world who rely on wood, coal and animal waste for cooking and heating, and 2.7 billion people without access to modern forms of energy such as liquefied Petroleum Gas (LPG) and electricity for cooking and heating including children who are at risk of getting infected with respiratory tract illness [57,58]. Our study presents large-scale multi-country findings that add to the existing literature on the health impact of the use of unclean fuels for cooking, especially among children under five years in SSA. Thus, the study findings established a link between SDG 3 and 7 where the provision and usage of modern fuels to women to use in urban centres could reduce indoor air pollution as an alternative to traditional fuels such as solid biomass. This would reduce the risk factors for respiratory tract infections among children in urban areas. This, therefore, re-emphasises the need for an integrated approach to meeting the SDGs. The study findings could also guide policy interventions aimed at reducing the burden of ARIs including pneumonia among children in SSA. Because the risk of respiratory infections from solid biomass cooking fuels is modifiable, implementing community-based education and campaign strategies could influence behavioural changes such as cooking outdoors and keeping children away from the "cooking" environment. Other interventions such as identifying people living within the energy poverty bracket within urban areas and providing them with targeted support in the forms of energy subsidies in access to modern energy such as free gas cylinders to households and subsidized electricity, especially for the urban poor and rural dwellers could reduce the use solid biomass fuels for cooking and heating thereby minimize the risk of exposure to pollutants from solid biomass fuels. If this is properly implemented the results would be meeting SDG 3, 7 and 11 of improving child health, providing access to modern energy for poor urban households and therefore building urban households to be resilient.

4.2. Strengths and limitations

This study used pooled datasets from DHS of 31 countries in SSA conducted between 2010 and 2019 to investigate the association between urbanicity, household cooking fuel and the risk of symptoms of ARIs. Thus, our findings are generalizable to children under five years in SSA. Additionally, our analyses were based on the symptoms of ARIs (cough and short-rapid breaths) and therefore provide new dimensions on the association based on specific symptoms but not composite measures. Despite these strengths, there are some limitations inherent in this study that need to be acknowledged. First, the analysis was based on cross-sectional datasets and therefore causality could not be inferred. Second, ARIs were determined based on recall of past symptoms of cough and short-rapid breaths by the mothers. Thus, there is a possibility of recall bias which needs to be acknowledged. It is also important to note when interpreting the findings of this study that there are predisposing factors such as obstructive lung diseases such as asthma that may cause some coughs. Also, available evidence suggests that the level of exposure to pollutants from solid biomass cooking fuels, as well as exposure to other risk factors such as second-hand smoke from parental tobacco smoking, also increases the risk of symptoms of ARIs in children [3,5]. These factors could not be controlled for in the present study. Also, exposure to pollutants from the burning of unclean cooking fuels including the various solid biomass fuels (e.g. wood, grass, charcoal and animal dung) may contribute differently to the risk of ARIs [59]. Further, exposure levels to air pollutants from unclean cooking fuel use in households could vary based on ambient air quality. This scenario calls for careful interpretation of findings because ambient air quality could vary by urbanicity as well as across countries in SSA. However, the current analysis could not segregate the association between each type of solid biomass fuel and its association with respiratory symptoms. Moreso, breastfeeding as a potential confounder was not considered due to insufficient data. Additionally, datasets used were gathered from cross-sectional surveys across different years. Even though the DHS Program uses standardized survey protocols in all its surveys, trends across the socio-demographic factors could also be dynamic across time and geographical boundary (country, region).

5. Conclusions

This study found that urbanicity and the use of solid biomass fuels for cooking were associated with an increased risk of symptoms of ARIs among children under five years in SSA. Thus, policymakers and stakeholders need to design and implement strategies that minimize children's exposure to pollutants from solid biomass cooking fuels. Such policies could be targeted at increasing awareness of the harmful effects of air pollutants from solid biomass cooking fuels through community education as well as the provision of easily accessible and affordable sources of clean fuels. Policy interventions could reduce the burden of respiratory illnesses in SSA and contribute to the realization of SDG 3, 7 and 11 which aim at substantially reducing the number of diseases and deaths attributable to hazardous chemicals and pollution of air, water and soil; providing universal access to modern energy and; making urban household resilient towards health problems. Given disparities in the prevalence of symptoms of ARIs among children under-five were observed across the geographic regions of SSA, future studies should focus on distilling the geographic-region-specific predictors of the symptoms of ARIs to better inform targeted and coordinated regional interventions.

Patient consent for publication

No consent to publish was needed for this study as we did not use any details, images or videos related to individual participants. In addition, the data used are available in the public domain.

Ethics approval and consent to participate

DHS reports ethical clearance is provided by the Ethics Committee of ORC Macro Inc. as well as Ethics Boards of partner institutions (e.g. Ministries of Health) from studied countries. The DHS procedures require that principles for the protection of respondents' anonymity and confidentiality have adhered to. Inner City Fund International also guarantees that the survey protocols meet the United States Department of Health and Human Services' regulations for the respect of human subjects. The current study used secondary data, hence, no further ethical approval was sought. The datasets are freely available for download and usage at https://dhsprogram.com/data/available-datasets.cfm.

Author contribution statement

Iddrisu Amadu; Abdul-Aziz Seidu; Bright Opoku Ahinkorah: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Aliu Mohammed; Eric Duku; Michael K. Miyittah; Edward Kwabena Ameyaw; John Elvis Hagan Jr; Mohammed Hafiz Musah: Analyzed and interpreted the data; Wrote the paper.

Data availability statement

The datasets are freely available for download and usage at https://dhsprogram.com/data/available-datasets.cfm.

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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e16546.

References

[1] K.-H. Kim, S.A. Jahan, E. Kabir, A review of diseases associated with household air pollution due to the use of biomass fuels, J. Hazard Mater. 192 (2011) 425–431.
[2] J.D. Stanaway, et al., Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease St, Lancet 392 (2018) 1923–1994.
[3] P.O. Owili, M.A. Muga, W.-C. Pan, H.-W. Kuo, Cooking fuel and risk of under-five mortality in 23 Sub-Saharan African countries: a population-based study, Int. J. Environ. Health Res. 27 (2017) 191–204.
[4] P. Acharya, S.R. Mishra, G. Berg-Beckhoff, Solid fuel in kitchen and acute respiratory tract infection among under five children: evidence from Nepal demographic and health survey 2011, J. Community Health 40 (2015) 515–521.
[5] C. Torres-Duque, D. Maldonado, R. Pérez-Padilla, M. Ezzati, G. Viegi, Biomass fuels and respiratory diseases: a review of the evidence, Proc. Am. Thorac. Soc. 5 (2008) 577–590.
[6] Z.A. Anteneh, H.Y. Hassen, Determinants of acute respiratory infection among children in Ethiopia: a multilevel analysis from Ethiopian demographic and health survey, Int. J. Gen. Med. 13 (2020) 17.
[7] R.A. Accinelli, et al., Adherence to reduced-polluting biomass fuel stoves improves respiratory and sleep symptoms in children, BMC Pediatr. 14 (2014) 1–5.
[8] R. Prasad, S. Abhijeet, R. Garg, G.B. Hosmane, Biomass fuel exposure and respiratory diseases in India, Biosci. Trends 6 (2012) 219–228.
[9] A.-A. Seidu, et al., Prevalence and determinants of acute lower respiratory infections among children under-five years in sub–Saharan Africa: evidence from demographic and health surveys, SSM-Population Heal. 8 (2019), 100443.
[10] A. Sana, S.M.A. Somda, N. Meda, C. Bouland, Chronic obstructive pulmonary disease associated with biomass fuel use in women: a systematic review and meta-analysis, BMJ Open Respir. Res. 5 (2018), e000246.
[11] N. Ranathunga, et al., Effect of household air pollution due to solid fuel combustion on childhood respiratory diseases in a semi urban population in Sri Lanka, BMC Pediatr. 19 (2019) 1–12.
[12] S. Okello, et al., Biomass fuel as a risk factor for esophageal squamous cell carcinoma: a systematic review and meta-analysis, Environ. Health 18 (2019) 1–11.
[13] V. Van Tran, D. Park, Y.-C. Lee, Indoor air pollution, related human diseases, and recent trends in the control and improvement of indoor air quality, Int. J. Environ. Res. Publ. Health 17 (2020) 2927.
[14] R.A. Accinelli, J.A. Leon-Abarca, Solid fuel use is associated with anemia in children, Environ. Res. 158 (2017) 431–435.
[15] A. Lee, P. Kinney, S. Chillrud, D. Jack, A systematic review of innate immunomodulatory effects of household air pollution secondary to the burning of biomass fuels, Ann. Glob. Heal. 81 (2015) 368–374.
[16] D.G. Fullerton, N. Bruce, S.B. Gordon, Indoor air pollution from biomass fuel smoke is a major health concern in the developing world, Trans. R. Soc. Trop. Med. Hyg. 102 (2008) 843–851.
[17] R.J. Laumbach, H.M. Kipen, Respiratory health effects of air pollution: update on biomass smoke and traffic pollution, J. Allergy Clin. Immunol. 129 (2012) 3–11.
[18] R.A. Accinelli, J.A. Leon-Abarca, D. Gozal, Ecological study on solid fuel use and pneumonia in young children: a worldwide association, Respirology 22 (2017) 149–156.
[19] A. Admasie, A. Kumie, A. Worku, Children under five from houses of unclean fuel sources and poorly ventilated houses have higher odds of suffering from acute respiratory infection in Wolaita-Sodo, Southern Ethiopia: a case-control study, J. Environ. Public Health 2018 (2018).
[20] J.O. Akinyemi, O.M. Morakinyo, Household environment and symptoms of childhood acute respiratory tract infections in Nigeria, 2003–2013: a decade of progress and stagnation, BMC Infect. Dis. 18 (2018) 1–12.
[21] M. Dherani, et al., Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: a systematic review and meta-analysis, Bull. World Health Organ. 86 (2008) 390–398C.
[22] World Health Organization, World Health Statistics 2019: Monitoring Health for the SDGs, Sustainable Development Goals, 2019. https://apps.who.int/iris/bitstream/handle/10665/324835/9789241565707-eng.pdf.
[23] K.C. Piddock, et al., A cross-sectional study of household biomass fuel use among a periurban population in Malawi, Ann. Am. Thorac. Soc. 11 (2014) 915–924.
[24] Z. Al-Janabi, K.E. Woolley, G.N. Thomas, S.E. Bartington, 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, Int. J. Environ. Res. Publ. Health 18 (2021) 8516.
[25] I. Amadu, A.-A. Seidu, A.-R. Afitiri, B.O. Ahinkorah, S. Yaya, 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 (2021), e048724.
[26] S. Naz, A. Page, K.E. Agho, Household air pollution from use of cooking fuel and under-five mortality: the role of breastfeeding status and kitchen location in Pakistan, PLoS One 12 (2017), e0173256.
[27] B.O. Ahinkorah, et al., Prevalence and factors associated with the triple burden of malnutrition among mother-child pairs in sub-Saharan Africa, Nutrients 13 (2021) 2050.
[28] DHS Program, Description of the Demographic and Health Surveys Program, 2021. https://dhsprogram.com/data/Guide-to-DHS-Statistics/Description_of_The_Demographic_and_Health_Surveys_Program.htm.
[29] DHS Program, Methodology, 2021. https://dhsprogram.com/methodology/.
[30] DHS Program, Prevalence and Treatment of Symptoms of Acute Respiratory Infection (ARI), 2021. https://dhsprogram.com/data/Guide-to-DHS-Statistics/Prevalence_and_Treatment_of_Symptoms_of_Acute_Respiratory_Infection_ARI.htm.
[31] I. Das, P. Jagger, K. Yeatts, Biomass cooking fuels and health outcomes for women in Malawi, EcoHealth 14 (2017) 7–19.
[32] A.O. Mocumbi, S. Stewart, S. Patel, W.K. Al-Delaimy, Cardiovascular effects of indoor air pollution from solid fuel: relevance to sub-Saharan Africa, Curr. Environ. Heal. Reports 6 (2019) 116–126.
[33] M. Njenga, et al., Innovative biomass cooking approaches for sub-Saharan Africa, Afr. J. Food Nutr. Sci. 19 (2019) 14066–14087.
[34] S. Nandasena, A.R. Wickremasinghe, N. Sathiakumar, Biomass fuel use for cooking in Sri Lanka: analysis of data from national demographic health surveys, Am. J. Ind. Med. 55 (2012) 1122–1128.
[35] F.A. Armah, et al., Predictive Probabilities of Access to Clean Cooking: Evidence from the Demographic and Health Surveys in 31 Countries in Sub-saharan Africa vol. 12, 2019, pp. 320–322.
[36] A. Geremew, S. Gebremedhin, Y. Mulugeta, T.A. Yadeta, 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, Trop. Med. Health 48 (2020) 1–13.
[37] S. Yaya, O.A. Uthman, M. Ekholuenetale, G. Bishwajit, V. Adjiwanou, Effects of birth spacing on adverse childhood health outcomes: evidence from 34 countries in sub-Saharan Africa, J. Matern. Neonatal Med. 33 (2020) 3501–3508.
[38] Z.Y. Amare, M.E. Ahmed, A.B. Mehari, Determinants of nutritional status among children under age 5 in Ethiopia: further analysis of the 2016 Ethiopia demographic and health survey, Global. Health 15 (2019) 1–11.
[39] F.A. Armah, et al., Access to improved water and sanitation in sub-Saharan Africa in a quarter century, Heliyon 4 (2018), e00931.
[40] DHS Program, Construction of Wealth Index, 2021. https://dhsprogram.com/topics/wealth-index/Wealth-Index-Construction.cfm.
[41] O.K. Ezeh, K.E. Agho, M.J. Dibley, J.J. Hall, A.N. Page, Risk factors for postneonatal, infant, child and under-5 mortality in Nigeria: a pooled cross-sectional analysis, BMJ Open 5 (2015), e006779.
[42] E. Coker, A. Katamba, S. Kizito, B. Eskenazi, J.L. Davis, Household air pollution profiles associated with persistent childhood cough in urban Uganda, Environ. Int. 136 (2020), 105471.
[43] I. Das, J. Pedit, S. Handa, P. Jagger, Household air pollution (HAP), microenvironment and child health: strategies for mitigating HAP exposure in urban Rwanda, Environ. Res. Lett. 13 (2018), 45011.

[44] H. Sanbata, A. Asfaw, A. Kumie, Association of biomass fuel use with acute respiratory infections among under-five children in a slum urban of Addis Ababa, Ethiopia, BMC Public Health 14 (2014) 1–8.

[45] H. Buchner, E.A. Rehfuess, Cooking and season as risk factors for acute lower respiratory infections in African children: a cross-sectional multi-country analysis, PLoS One 10 (2015), e0128933.

[46] L.E. Bautista, A. Correa, J. Baumgartner, P. Breysse, G.M. Matanoski, Indoor charcoal smoke and acute respiratory infections in young children in the Dominican Republic, Am. J. Epidemiol. 169 (2009) 572–580.

[47] M.E. Rutherford, K. Mulholland, P.C. Hill, How access to health care relates to under-five mortality in sub-Saharan Africa: systematic review, Trop. Med. Int. Heal. 15 (2010) 508–519.

[48] M. Khalequzzaman, et al., Indoor air pollution and health of children in biomass fuel-using households of Bangladesh: comparison between urban and rural areas, Environ. Health Prev. Med. 16 (2011) 375–383.

[49] P.D.M.C. Katoto, et al., Ambient air pollution and health in Sub-Saharan Africa: current evidence, perspectives and a call to action, Environ. Res. 173 (2019) 174–188.

[50] R. Masekela, A. Vanker, Lung health in children in sub-Saharan Africa: addressing the need for cleaner air, Int. J. Environ. Res. Public Health 17 (2020) 6178.

[51] E. Carter, et al., Assessing exposure to household air pollution: a systematic review and pooled analysis of carbon monoxide as a surrogate measure of particulate matter, Environ. Health Perspect. 125 (2017), 76002.

[52] N. Hamatui, C. Beynon, Particulate matter and respiratory symptoms among adults living in Windhoek, Namibia: a cross sectional descriptive study, Int. J. Environ. Res. Public Health 14 (2017) 110.

[53] E.L. Murray, et al., Cooking fuel type, household ventilation, and the risk of acute lower respiratory illness in urban Bangladeshi children: a longitudinal study, Indoor Air 22 (2012) 132–139.

[54] J.H. Kilabuko, S. Nakai, Effects of cooking fuels on acute respiratory infections in children in Tanzania, Int. J. Environ. Res. Public Health 4 (2007) 283–288.

[55] J.Y.T. Po, J.M. FitzGerald, C. Carlsten, Respiratory disease associated with solid biomass fuel exposure in rural women and children: systematic review and meta-analysis, Thorax 66 (2011) 232–239.

[56] World Health Organization, Pneumonia, 2019. https://www.who.int/news-room/fact-sheets/detail/pneumonia.

[57] UNEP, Ensure Access to Affordable, Reliable, Sustainable and Modern Energy for All, 2021. https://www.unep.org/explore-topics/sustainable-development-goals/why-do-sustainable-development-goals-matter/goal-7.

[58] IIED, Improving People's Access to Sustainable Energy, 2021. https://www.iied.org/improving-peoples-access-sustainable-energy.

[59] R.E. Arku, et al., Characterizing exposure to household air pollution within the prospective urban rural epidemiology (PURE) study, Environ. Int. 114 (2018) 307–317.