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The Independent Contribution of Household Air Pollution from Cooking fuels, Maternal Educational Status and Neighbourhood Deprivation on Acute Respiratory Infection Among Under-Five Children in Chad: A Multilevel Analysis

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Abstract: Background: Exposure to household air pollution (HAP) is one of the primary risk factors for acute lower respiratory infection (ARI) morbidity and mortality among children in low-income settings. This study aimed to examine the relative contribution of residing in deprived neighbourhoods and exposure to HAP on the occurrence of ARI among children using data from the 2014-15 Chad Demographic and Health Survey (DHS). Methods: We applied multilevel modelling techniques to survey data of 2,882 children from 372 communities to compute the odds ratio (OR) for the occurrence of ARI between children of respondents exposed to clean fuels (e.g., electricity, liquid petroleum gas, natural gas, and biogas) and respondents exposed to polluting fuel (e.g., kerosene, coal/lignite, charcoal, wood, straw/shrubs/grass, and animal dung). Results: The results showed that children exposed to household polluting fuels in Chad were 215% more likely to develop ARI than those not exposed to household air pollution (215%; OR = 3.15; 95% CI 2.41to 4.13); Further analysis revealed that the odds of ARI were 185% higher (OR = 2.85; 95% CI 1.73 to 4.75) among children living in rural residents and those born to teenage mothers (OR = 2.75; 95% CI 1.48 to 5.15) who were exposed to household polluting fuels compared to their counterparts who were not exposed. In summary, the results of the study show that the risk of ARI is more common among children who live in homes where household air-polluting cooking fuel is widely used, those living in rural areas, those living in socioeconomically deprived neighbourhoods and from least wealthy households, and those born to teenage mothers in Chad. Conclusions: In this study, an independent relative contribution of variables such as HAP from cooking fuel, neighbourhood deprivation, living in rural areas, being from a low-income household, having a mother who is a manual labourer worker, being given birth to by a teenage mother to the risk of ARI among children is established.

Keywords: children; household air pollution; acute respiratory infection; neighborhood disadvantage; polluting fuel; Chad

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1. Introduction

Although childhood morbidity and mortality are global problems, the difference in childhood deaths between the less developed and economically endowed regions is evident. [1].Of the estimated half a million under-five deaths that occur worldwide, nearly all are in low-and middle-income countries (LMICs) [1–3]. Most of these deaths and the disease burden among children are mainly due to modifiable factors. Children's health outcomes, including their chances of survival, depend primarily on the nature of the household environment in which they reside. [1,4]. Several factors, such as the availability of portable drinking water, secured toilet facilities, and non-polluting cooking fuel, can shape the household environment. Sadly, these amenities are lacking in most LMICs[5,6]. Even when present, they are sources of either household injuries or health hazards. As a result, a more significant number of these children die before reaching their fifth birthday from environmental-induced health problems such as diarrhoea, malaria, and acute respiratory infections (ARI) [5,7,8].

Together, these three infectious diseases contribute significantly to the global burden of the disease [3,9–11]. Deaths caused by these diseases are largely preventable through breastfeeding practices, vaccinations, hand washing with soap, safe drinking water, and basic sanitation [12,13]. A clean home environment and adequate ventilation are crucial to reducing the transmission of pathogens that cause diarrhoea, ARI, and fever[14].

However, more than ever before, solid fuel use has increased considerably worldwide. According to estimates, no fewer than three billion people worldwide depend on solid fuels (wood, animal dung, crop residues, charcoal, and coal) for cooking and heating. [15,16]. Nearly three-quarters of users reside mainly in the developing regions of sub-Saharan Africa and Asia.[15]Unlike clean fuels, Biomass fuels rank low on the energy ladder regarding combustion efficiency and cleanliness.[16]. Many studies on household air pollution (HAP) link the incomplete combustion of biomass fuel to undesirable health outcomes.[5,17]. HAP from cooking fuel is one of the potential risk factors which increases the severity of ARI by destroying respiratory tract defences and makes children, especially those under the age of five, more susceptible to disease-causing microorganisms[18].In sub-Saharan Africa (SSA), as well as other resource-limited settings, women and young children are disproportionately disadvantaged in terms of their vulnerability to the damaging effects of HAP [10]. Although evidence has shown that continuous exposure to HAP may cause adverse health effects and impact the health of women and their unborn children, the consequences of HAP as one of the factors that increase the severity of ARI for children under the age of five are even greater [5,18,19]. Children under five spend more time indoors at home and are more vulnerable to several health problems, such as recurrent respiratory infections due to indoor pollution.[19].ARIs represent a significant economic burden to households, and the financial hardship caused by ARIs is untold.[3].

Chad is a landlocked country in Central Africa. As is the case with several other countries in the region, more than 85% of the population depends on solid fuels for cooking and their energy needs. [20]. According to estimates from the Global Burden of Disease (GBoD) study, $PM_{2.5}$ (that is, particulate matter smaller than 2.5 microns diameter) air pollution, mean annual exposure (micrograms per cubic meter) in Chad was 64.06[21], thereby making it one of the countries with the worst air quality compared to other countries worldwide [21,22]. Chad has several policies and programs to control air pollution and improve air quality.[20,23]. These policies have focused on reducing the emissions from industries, transportation, and open waste burning. However, HAP continues to be responsible for an estimated 9,600 premature deaths every year in the country. [21]As a result, coupled with other factors, Chad could not meet the millennium development goal of reducing under-five mortalities. Previous studies in SSA and Southeast Asia have identified several potential exposures, including HAP, which could increase the risk of respiratory illness, ARI, in particular.[5,14,24]. None of these studies have explored the moderating effect of neighbourhood socioeconomic disadvantage, a marker of deprivation together with the exposure to HAP due to cooking fuel on risk of ARIs. A thorough understanding of the influence of deprivation on the composition of the living environment and the exposure to and occurrence of childhood infectious diseases such as ARIs is essential. Currently, there is no information to inform policy on factors associated with exposure to HAP in Chad. Cutting household air pollution and its adverse consequences on under-five mortality are the key targets in Sustainable Development Goal 3. Therefore, this study aims to provide additional evidence and look at available data to understand the association between various individual, neighbourhood and household level factors, including HAP from the use of polluting cooking fuel, on the risk of respiratory infection among under-five

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children in Chad. Insight into such information will be of policy relevance to policymakers and environmental health planners in Chad and other resource-limited settings.

2. Materials and Methods

2.1. Study Design and Sampling Technique

This study was based on the 2014-2015 Chad Republic Demographic and Health Survey (CDHS). The sample size for this research was limited to individual data on 2882 mothers aged 15- 45 and 2882 children aged 0-59 months from 372 communities. Demographic and Health Surveys, or DHS as commonly referred to, are a series of nationally representative surveys typically conducted in most low- and middle-income countries by various in-country bodies with technical assistance from ICF Macro International. The United States Agency for International Development provided financial assistance for this survey. In the case of Chad, since 1993, the authority of the Institut National de la Statistique, des Études Économiques et Démographiques (INSEED) N'Djamena, with technical assistance from ICF international in Maryland, USA, has been conducting Demographic and Health Surveys.[25]. The United States Agency for International Development (USAID) and the Global Fund funded the field surveys reported in this study. Briefly, the CDHS was conducted using a multistage stratified sampling procedure to select a randomly stratified sample of clusters. In the initial stage, a probability proportional to the size was used to select clusters. The size represents the number of households within the cluster. Clusters are administratively defined areas sometimes used to denote communities or neighbourhoods. The second phase involves a systematic sampling of households in urban and rural areas from each cluster. After this, a face-to-face personal interview was conducted for a random sample of women aged 15-49 years and men aged 15-59 from each household using a semi-structured questionnaire. The questionnaire, which had been translated into local major languages, detailed various questions relating to the respondents' socio-demographic and health characteristics, including those of the members of their households. All participants were informed of the purpose of the survey interview and allowed to give their consent before the commencement of the interview. The full details of the methodology and procedures used in sample collection for the CDHS have been published elsewhere[25].

2.2. *Outcome Variable*

The study's primary outcome variable was the probability of a child developing respiratory symptoms such as rapid breathing, blocked nose, runny nose, and catarrh due to exposure to HAP from cooking fuel two weeks before the interview date. The responses were coded as "1" = Yes or "0" = No.

2.3. Exposure Variable

The primary exposure variable was the cooking fuel used in households. As recorded in the DHS survey questionnaire, the respondents were asked, 'What type of fuel does your household mainly use for cooking?' In response, 12 types of cooking fuel have been reported. In this study, cooking fuels were grouped into two categories: "clean fuels" (electricity, liquid petroleum gas, natural gas, and biogas) and "polluting fuels" (kerosene, coal/lignite, charcoal, wood, straw/shrubs/grass, crops, and animal dung). Previous studies have reported kerosene as a polluting fuel and found significant associations between HAP and ARIs in children and kerosene fuel use[7]. Therefore, kerosene is categorised as a polluting fuel.

2.4. Control Variables

The DHS did not collect direct information on household income and expenditure. Consequently, the DHS wealth index was used as a proxy indicator for the socioeconomic position of the participants, the mother's education (categorised as "secondary or higher", "primary", or "no education") and the mother's working status ("manual" not working, professional") were included

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as markers of socioeconomic status. Place of residence (categorised as "urban" or "rural"), and "breastfeeding status" (categorised as ever, never and still breastfeeding "yes" or "no"). Other variables include "parity," "place of delivery," "maternal access to media," "child's gender," maternal age and "child's age.".

Neighbourhood level variable, the neighbourhood socioeconomic disadvantage index, was developed using principal component analysis(PCA)[26]. The index comprises four variables: the proportion of respondents living in rural areas, the proportion of respondents who were not working, the proportion of respondents living below the poverty level (those below the 20% quintile on the wealth index), and the proportion of uneducated respondents. Several scholars have widely adopted this index to examine the effect of neighbourhood socioeconomic status on health[27–29]The scores obtained from the continuous index had a mean value of 0 and a standard deviation of 1. These were then used to stratify neighbourhoods into two categories: most socioeconomically disadvantaged neighbourhoods, if the scores were higher (1), and least socioeconomically disadvantaged neighbourhoods, if the scores on the index were lower (0).

2.5. Statistical Analysis/Analytical Procedure

Multilevel logistic regression modelling and Model Specification

Given the hierarchical structure of the sample and the binary outcome, a multilevel logistic modelling approach was adopted. The model written below was specified as follows:

$$\log it\left(\pi_{ijk}\right) = \log\left(\frac{\pi_{ijk}}{1-\pi_{ijk}}\right) = \beta_0 + X_{ijk} + u_{0jk} + v_{0k} \quad (1)$$

where π_{ijk} is the probability of child *i* residing in household *j* in community k developing symptoms of ARI. The right-hand side of the equation comprises the fixed parts X_{ijk} and β_0, which estimate the vectors attributable to the explanatory coefficients at both the child and neighbourhood levels, respectively, and the last two vectors u_{0jk} and v_{0k} are the random effects that denote unobserved factors at both the child and neighbourhood levels. This analysis was performed in three steps. In Model 1 (base model), no explanatory variable was included. In Model 2, only individual-level factors are included. In Model 3, neighbourhood-level factors were added to Model 2. The fixed effects results (measures of association) are shown as odds ratios (ORs) with 95% confidence intervals (CIs). The results of the random effects (measures of variation) are presented as the variance partition coefficient and percentage change in variance. All parameters were estimated using the Adaptive Gaussian Quadrature maximum likelihood estimator (AGQ), with $p < 0.05$ considered statistically significant. Model fitness was appraised using the deviance information criterion (DIC). All analyses used Stata 15.1 (College Station, TX, USA).

Fixed effects (measure of association).

The exposure variables determine the likelihood of a child experiencing respiratory symptoms. These values were reported as odds ratios (ORs) at 95% confidence intervals (95% CIs).

Random effects (measure of variation)

The results of random effects were summarised as the variance partition coefficient (VPC) and the proportional change in variance (PCV)[30]The VPC estimates the likelihood of a child developing ARI, which is attributed to the neighbourhood-level variables. A large VPC value implies a high clustering of the possibility of developing ARI in the neighbourhood, and a low VPC shows a homogenous likelihood of developing ARI. PCV evaluates the proportional difference in the community-level variance among the models (Models 1 to 3). Finally, the deviance information criterion (DIC) was used to appraise the model's fitness.

The first analysis consisted of a multilevel linear regression model of acute respiratory infections. This fitted model provided values for individual and community variances. These values were used to calculate the VPC as a percentage of the total individual variance (V) in acute respiratory infection attributed to the community level, as shown in Equation 1[31].

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3. Results

3.1. Descriptive Statistics

The individual and neighbourhood characteristics of the study sample, according to the child's ARI status, are shown in Table 1. Most of the children lived in rural areas with their mothers 2,146 (74.5%), had mothers who gave birth at home 1,320(77.8%), had mothers without access to any of the three mass media (television, radio, and magazines), had married 1,232(72.3%), and 1, 272 (76.3 %) were manual workers. Around half (1,704, 48.8%) of the respondents belonged to the age group 25-34 years and had attained at least primary education 1,870 (64.9%) (Table 1). Half of the children were male, 1,463 (50.8%) and 438 (22.7%) were less than 11 months old, while 1,762(61.1%) were born to mothers with more than four children.

Table 1. Sample Characteristics of Proportion of Children, aged 0–59 Months, by ARI Status Based on CDHS 2014-2015.

Variables	ARI Yes N (%)	ARI No N (%)	Total N (%)
Child's age (months)			
0–10	284 (24.8)	154 (19.6)	438 (22.7)
11–21	205 (17.9)	176 (22.4)	381 (19.7)
22–32	203(17.7)	167 (21.3)	370 (19.2)
33+	454 (39.6)	288(36.7)	742(38.4)
Child's sex			
Male	866(50.8)	597 (50.7)	1,463 (50.8)
Female	838 (49.2)	581(49.3)	1,419 (49.2)
Mother's age (years)			
15–24	503 (29.5)	384 (32.6)	887(30.8)
25–34	843 (49.5)	562(47.7)	1,704 (48.8)
35+	358(21.0)	232 (19.7)	590 (20.4)
Mother's education			
No education	8(0.5)	9(0.8)	17(0.6)
Primary	1,119(65.6)	751(63.7)	1,870 (64.9)
Secondary and higher	577(33.9)	418 (35.5)	995(34.5)
Place of delivery			
Home	1,320(77.8)	871 (74.1)	2,191(76.3)
Hospital	377 (22.2)	305 (25.9)	682 (23.7)
Media access(radio,tele&magazine)			
None	1,232 (72.3)	793(67.3)	2,024 (70.2)
1	258 (15.1)	189(16.0)	447(15.5)
2	50(2.9)	50(4.2)	100 (3.5)
3	164(9.6)	147(12.5)	311(10.8)
Mother's occupation			
Not working	92 (5.5)	77(6.7)	169 (6.0)
Manual	1,272(76.3)	854(74.6)	2,126(75.6)
Professional	304(18.2)	214(18.7)	517(18.4)
Wealth index			
Poorest	373(21.9)	225(19.1)	598 (20.7)
Poorer	329(19.3)	226(19.2)	555(19.3)
Middle	375 22.0)	239(20.2)	614(21.3)
Richer	322(18.9)	215(18.3)	537(18.6)
Richest	305(17.9)	273(23.2)	578(20.1)
Types of cooking fuel			

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Polluting	1,670(98.0)	1,136(96.4)	2,806(97.4)
Clean	34(2.0)	42(3.6)	76(2.6)
Parity			
1-3	645(37.9)	475(40.3)	1,120(38.9)
4+	1,059(62.1)	703(59.7)	1,762(61.1)
Maternal breast-feeding status			
Never breastfed	75(4.4)	53(4.5)	128(4.4)
Ever breastfed	896(52.3)	640(54.8)	1,536(53.3)
Still breastfeeding	742(43.3)	476(40.7)	1,218(42.3)
Place of residence			
Rural	1,293(75.9)	853(72.4)	2,146(74.5)
Urban	411(24.1)	325(27.6)	736(25.5)
Neighbourhoods' economic disadvantage			
Least disadvantaged	770(45.2)	572(48.6)	1,342(46.6)
Most disadvantage	934(54.8)	606(51.4)	1,540(53.4)

Table 2. Multilevel Logistic Regression Modeling of Factors Associated with ARI Among Chadian Children, CDHS 2014-2015.

Variables	**Model 1**	**Model 2**	**Model 3**
	OR (95% CI)	OR (95% CI)	OR (95% CI)
(Individual Characteristics)			
Mother's age(years)			
35+		1(reference)	1(reference)
25-34		6.93[10.52-12.40] ***	5.10[3.88- 12.42] **
15-24		2.75 [1.48-5.15] ***	2.78[3.85- 5.20] **
Parity			
1-3		1(reference)	1(reference)
4+		0.10 [0.17-0.66] *	0.10[0.02-0.65] *
Highest level of education			
No education		1(reference)	1(reference)
Primary		3.02 [0.73-4.60]	3.35[0.72-5.62]
Secondary and above		0.67 [0.54-0.82] ***	0.66[0.72-5.62] ***
Media Access			
None		1(reference)	1(reference)
1		0.66 [0.17-2.60]	0.67 [0.17-2.60]
2		0.91 [1.01-1.51] **	0.66 [0.17-2.60] **
3		0.18 [0.10-0.54] **	0.16[0.17-0.60] **
Household wealth index			
Poorest		1(reference)	1(reference)
Poorer		0.78 [0.42-1.43]	0.76 [0.41-1.40]
Middle		0.69 [0.36-1.34]	0.54 [0.52-1.11]
Richer		0.42 [0.19-0.88]**	0.40[0.17-0.90]**
Richest		0.34 [0.14-0.83]**	0.34 [0.14-0.89]**
Occupation			
Not working		1(reference)	1(reference)

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Manual	1.14 [0.44-2.79]	0.80 [0.44-2.79]
Professional	0.80 [0.65-0.90]*	0.79 [0.63-0.91]*
Sex of child		
Male	1(reference)	1(reference)
Female	0.56 [0.36-0.89] **	0.54 [0.40-0.89] **
Child age in months		
0 -10	1(reference)	1(reference)
11-21	0.56 [0.39-0.79] ***	0.54 [0.39-0.80] ***
22-32	0.59 [0.42-0.85] **	0.57 [0.49-0.80] **
33+	0.75 [0.56-1.20]	0.80 [0.57-1.31]
Types of cooking fuel		
Clean fuel	1(reference)	1(reference)
Polluting fuel	3.15 [2.41-4.13] ***	3.10 [2.39- 4.10] ***
Breastfeeding status		1(reference)
Not currently breastfeeding	1(reference)	
Never breastfed	3.50 [0.52-8.56]	2.96[0.46-10.00]
Still breastfeeding	0.48 [0.07-3.08]	0.68[0.46-1.00]
Place of birth Delivery		
Home	1(reference)	1(reference)
Hospital	0.90 [0.69-1.16]	0.89 [0.65-1.10]
Community level variables		
Place of residence		
Urban		1
Rural		2.85 [1.73-4.75] ***
Neighbourhood Economic disadvantaged index		
Most disadvantaged		1
Least disadvantaged		0.56 [0.44-0.70] ***

Table 3. Measures of variation (random effects).

	Model 1	Model 2	Model 3
	OR (95% CI)	OR (95% CI)	OR (95% CI)
Intercept	0.15[0.16-0.20] ***	1.14[0.03] ***	1.12 [0.03] ***
Community-level variance (SE)	1.30[0.04] ***	1.14[0.03] ***	1.12 [0.03] ***
VPC (%)	25	23.5	20.0
Explained variation PCV (%) *Model fit statistics*	Reference	12.3	17.5
DIC(-2log likelihood)	3651.40	3012.20	2601.10

Abbreviations: OR, odds ratio; CI, confidence interval; SE, standard error; DIC, Deviance Information Criterion: Successively smaller values of Deviance Information Criterion (DIC) with each subsequent model in the bottom of Table 3 show that each model represents a significant improvement over the previous model and indicates the goodness-of-fit of the model used in this analysis. *p < 0.05, **p < 0.01, and ***p < 0.001; ref, reference category; VPC, variance partition coefficient; PCV, proportional change in variance.

Model 1 was the base model with no exposure variables. Model 2 was adjusted for the child's characteristics (age, sex), mother, and household characteristics (education, occupation, and wealth index). Model 3 was sequentially adjusted for community socioeconomic disadvantage and place of residence, in addition to all the included variables in Model 2.

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3.4. Results

Table 2 depicts the log odds of a child developing an acute respiratory infection due to exposure to household air pollution. The base model showed significant variability in the log odds of developing ARI across the neighbourhoods (τ = 1.30, p = 0.001). Based on the VPC estimated by the intercept variance component, 25% of the variability in the log odds of a child developing an ARI was due to community-level factors. Next, Model 2 was adjusted for the following explanatory variables: age of the child, sex, mother's occupational status and educational attainment, breastfeeding status, type of cooking fuel used in the household, family access to mass media, maternal age, place of delivery, and household wealth status. This adjustment shows that log odds of a child suffering from ARI were 44% lower for children ages 11–22 months and 41% lower for children ages 22–32 months, compared with the reference category (0– 11 months). Children born to mothers aged 15–24 years and those born to mothers aged 25-34 years had 175% and 593% higher log odds of developing ARI, respectively, compared to children of mothers aged 35 years and above in the reference category.

In line with expectations, compared to the children whose mothers cook with clean fuel, the children whose mothers cook with polluting fuel had 215% significantly higher log odds of developing acute respiratory infection. In contrast, the log odds of developing acute respiratory infection were 44 % lower for female children compared to their male counterparts. Similarly, compared to children from the poorest households, children from the wealthiest households had significantly lower log odds of developing acute respiratory infection, and children from households in the fourth quintile(richer) of the wealth index had 58% lower log odds of developing acute respiratory infection than their counterparts from the poorest households.

In addition, compared to children whose mothers were uneducated, children from households with mothers with secondary and higher education had almost 33% less log odds of developing acute respiratory infections. Likewise, compared to children born to mothers without any livelihood, children born to mothers who are professionals or work in white-collar jobs had 20% lower log odds of developing acute respiratory infection.

This adjustment indicated that there is still significant variability in log odds of developing ARI (τ = 1.14, p = 0.001), with a slight decrease in community-level variance as compared to the empty model. As reported by VPC, 23.5% of the variability in log odds of developing ARI across communities and neighbourhoods was explained by various individual children and household-level compositional characteristics at the neighbourhood level.

The fully adjusted model, Model 3, in Table 2 ascertain their effects on log odds of a child developing acute respiratory infection due to several explanatory variables, including household air pollution from cooking oil. As can be seen from Table 2, the log odds of a child developing ARI due to the mothers living in rural areas is increased by 185% as compared to those living in urban areas. Independent of other factors, children of mothers living in the least deprived neighbourhoods had 44 % lower log odds of developing an acute respiratory infection than those of the reference category. As shown by the community-level variance, compared to Model 2, the community-level variability in log odds of developing ARI remains significant (τ = 1.12, p = 0.001), with 20% of the variance being attributed to both individual- and community-level variables in Model 3. Thus, after controlling various variables at both individual and community levels, young maternal age, neighbourhood-level socioeconomic disadvantage, a marker of deprivation, and use of pollution for cooking in the household, along with the place of residence, remain statistically significant.

4. Discussion

Using nationally representative data in Chad, this study assessed the effect of individual child and maternal level characteristics, including household air pollution from cooking activities, place of residence and residency in socioeconomic neighbourhoods, on a crucial health outcome of respiratory infection among children under five in the Chad Republic. The result of this study shows that neighbourhood-level socioeconomic disadvantage, markers of deprivation, use of polluting fuel

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for cooking in the household, young maternal age and place of residence were the significant drivers of acute respiratory infection among under-five children in Chad based on the country's 2014-2015 CDHS. To the best of the authors' knowledge, this article is the first nationally representative population-based study to document the moderating effect of socioeconomic development of neighbourhoods and exposure to household air pollution on the likelihood of a child developing ARI in Chad Republic using multilevel methodology.

The results showed that children living in the least socioeconomically disadvantaged communities were 44% less likely than their peers residing in most socioeconomically disadvantaged communities to develop ARI due to several factors, including exposure to polluting cooking fuels. The analysis showed that children who were residents of most socioeconomically disadvantaged communities were likely to have mothers who were not working, were rural dwellers, and belonged to the lowest 20% of the wealth quintile.

However, the effect of household wealth status, which had been demonstrated in previous studies [8,14,32–40] to be an essential factor in acute respiratory infection incidence among children was also confirmed in this study, showing that children from the wealthiest households have a lower likelihood of suffering from ARI as compared to their peers from the poorest families. Similarly, a Bangladeshi study found an association between upper respiratory infections and poverty [1,36]. Poverty may predispose families to domestic pollution caused by the use of inappropriate fuels for cooking[34,41–43]. Indeed, wealth is often associated with providing the mother a good understanding of caring for the home environment [12,33,42]. However, this finding contrasts with those reported by the ESCALA study in Latin America [44], where there were no differences in the incidence of acute respiratory infections based on household wealth status.

Individual measures of maternal socioeconomic characteristics, such as education and occupation, had been shown to increase the uptake of preventive child-survival health promotion strategies, including exclusive breastfeeding [12,43,45,46]. More specifically, analysis from this research showed that, with all other factors controlled, children born to mothers with secondary or higher education were less likely to suffer from acute respiratory infection than their peers whose mothers were not educated at all.

Breast-feeding has previously been shown to offer significant protection against infectious diseases and may be associated with lowering the risk of disease related to HAP, especially in the neonatal and infancy period[4,7,19,42,47,48]. Earlier studies have found an association between maternal breastfeeding practice and reduced incidence of acute respiratory infection [19,38,44,48–53]However, this study showed no significant relationship between the two variables. This could be attributed to the effect of other variables that may serve as confounders of acute respiratory infection predisposition.

As noted from the analysis, the incidence of ARI decreased with increasing age among children; this finding is not new but in consonance with those of previous studies [11,54]. The plausible reason for this could be that younger children, due to their age, are more likely to be more attached to their mothers, as some may still be breastfeeding and, therefore, likely to be more exposed to HAP from cooking fuel.

In this study, the type of fuel used for cooking in households was also significantly associated with ARI. Children whose households used higher polluting fuels had higher odds of ARI than those from other households using clean fuel for cooking. This finding is not new and has been reported in many studies[14,19,34,35,43,50,53,55].

Households using polluting fuel are usually on the lower end of the energy ranking. Polluting fuels are typically made of wood/straw, animal dung and charcoal. Therefore, it is not surprising that most people using polluting fuels are residing in rural areas where most are peasant farmers and are poor[53,56]. Also, sometimes, it is possible for a household to use more than one form of fuel by switching from clean fuel to polluting one, especially when in financial difficulties. Studies conducted in Bangladesh indicated that households reporting gas as their primary fuel frequently changed to cooking with biomass fuels during shortages of gas supply, which may result in higher concentrations of HAP and weaken associations between HAP and ARI incidence[5,33].

Access to mass media, such as radio or television, has been shown to aid in better assimilation of preventive health through advertisement of health promotion initiatives.[57,58]. In addition, the fact that preventative health information is usually carried out and disseminated using social marketing strategies on television, newspapers and radio stations may have lent support to the association observed in this study. Therefore, this may be why the findings that children whose mothers had access to all three forms of mass media are less likely to develop ARI compared to those whose mothers do not is in the right direction. Evidence from previous research conducted in several low-income countries has documented this[7,15,22,41,52,59,60].

Unlike what has been reported elsewhere[47], this study found an association between gender differences in the likelihood of developing ARI among children. The result shows that female children were less likely to develop ARI compared to their male counterparts. Hence, the findings were in the same direction as reported among children in India[22,49].

Also, the result of the present research indicates that children born to younger mothers are more likely to develop ARI compared to children whose mothers are much older. This finding is expected and echoes what has been reported elsewhere[6,14,53]This could be due to older mothers' experience of caregiving and a better understanding of how to protect their children from predisposing factors of ARI. However, a lack of knowledge and education about childcare may be responsible for the observed pattern for young mothers.

Furthermore, the results show a wide variation in the likelihood of developing ARI based on a woman's number of live births. Specifically, the results show that despite the reported higher birth rate in Chad, which is higher than the average for the region, children born to women with at least four live births were less likely to develop ARI than mothers with between one to three live births. The observed finding may be due to the fact that older children might have developed immunity over time compared to their younger siblings. This finding negates what was reported in other settings[6,12,61].

In sum, the results corroborate the evidence that polluting biomass fuels alongside other factors such as household wealth, place of residence, educational status of mothers, level of economic development of the neighbourhood and access to educational information through mass media are associated with an increased likelihood of ARI risk in children in Chad. Therefore, policy-oriented interventions are needed to specifically help reduce women's use of polluting fuels alongside targeted educational interventions about the deleterious health effects of HAP from cooking fuel in Chad.

Policy Implications

Four major intervention categories have been highlighted to mitigate the impact of indoor air pollution on child ARI: cleaner-burning fuels, improved cook stoves, housing design and behavioural change. Efforts are required to implement these interventions to achieve the desired result.

Study Strengths & Limitations

The findings from this study have many limitations and should be noted when interpreting the results. The research used secondary data based on a nationally representative survey. However, there are a few potential sources of bias, which may be attributed to the selection of participants, misclassification of cooking fuel and recall bias on the part of the respondents. First, the classification of cooking fuel may be a source of misclassification bias, as some households use a combination of polluting and clean fuels[12,34]. The incidence of ARI/ symptoms is self-reported by the mothers, who are prone to recall bias. However, evidence has shown that recall can be accurate depending on the duration of events and what it entails[61].

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5. Conclusions

The results revealed that household wealth status, HAP through the use of highly polluting cooking fuel, maternal age, never being breastfed, lack of education, residing in rural areas and living in most socioeconomically disadvantaged communities are significant risk factors for ARI among Chadian children. There are a lot of significant findings from this study, which, with targeted interventions, have the potential to help reduce the ARI burden among children in Chad. First, the fact that HAP from cooking fuel alongside socioeconomic status at individual and neighbourhood levels featuring other variables amenable to changes such as maternal education as risk factors for ARI points towards the need for empowerment initiatives in different forms. Although resources are limited in low-income countries where several health and developmental priorities are competing, but tackling each of the drivers of ARI among children is possible. First, exposure to HAP is preventable with clean cooking fuel and technology. However, this can only be achieved by improving households' socioeconomic status. For example, the government can provide those who are poor with a means of livelihood through a poverty alleviation program to help them out of poverty so that they can get a befitting living environment that is well-ventilated to live in. Being economically able would provide them with money to purchase clean cooking fuel. Second, educational awareness and sensitisation using local languages to spread information about the deleterious effects of HAP is another thing that can be used to bridge the lack of education, which is another risk factor for ARI.

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Institutional Review Board Statement: We analysed existing population-based survey data where all personal information was encoded. The Ethics Committee approved this study of the ICF Macro (Fairfax, VA, USA) and the National Ethics Committees in individual countries, in this case, Chad. Respondents gave their informed consent, and all information was collected confidentially. Relevant guidelines and regulations were carried out in all methods, and data were sourced from the link below. https://dhsprogram.com/data/available-datasets.cfm((accessed on 11 November 2024).

Informed Consent Statement: The data collection in the original survey received fully approved ethical clearanc**e.** All participants in the original survey conducted by ICF Macro gave their consent to participate in the survey.

Data Availability Statement: Relevant guidelines and regulations carried out all procedures, and data were sourced from this link: https://dhsprogram.com/data/available-datasets.cfm (accessed on 11 November 2024)

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