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Determinants of Household Air Pollution Exposure Among Pregnant Women in Zaria Metropolis, Kaduna State, Nigeria

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Abstract

Background: Household air pollution (HAP) from solid fuel combustion disproportionately affects pregnant women in low- and middle-income countries, yet data on their knowledge, perception, and exposure in Northern Nigeria remain scarce.

Aim: To assess knowledge and perception of HAP, determine the prevalence of household smoke exposure, and identify independent predictors of high exposure among pregnant women in Zaria Metropolis, Kaduna State.

Methodology: A descriptive cross-sectional study was conducted among 351 pregnant women attending antenatal care at eight selected primary health centres using multistage sampling. Data were collected with a structured interviewer-administered questionnaire and analysed using SPSS v25.0. Chi-square tests and binary logistic regression identified independent predictors of high HAP exposure at $p < 0.05$.

Results: Most respondents demonstrated good knowledge (82.1%) and positive perception (78.1%) of HAP health risks. Despite this, 68.1% experienced high exposure, predominantly from charcoal use (45.6%) and near-universal indoor cooking (92.9%). Knowledge was not associated with exposure ($p = 0.361$). Independent predictors of high exposure included lower respondent education (AOR up to 47.21; $p < 0.001$), lower spousal education (AOR = 3.020; 95% CI: 1.605–5.681; $p < 0.001$), household size ≥11 members (AOR = 13.503; 95% CI: 4.358–41.835; $p < 0.001$), and negative HAP perception (AOR = 1.960; 95% CI: 1.015–3.785; $p = 0.045$).

Conclusion: A significant knowledge-action gap exists, where awareness of HAP risks does not translate into reduced exposure. Structural determinants, particularly educational deprivation and large household size, are the primary drivers. Targeted antenatal counselling, male partner engagement, and clean fuel access programmes are urgently needed.

1. Introduction

Household air pollution (HAP), generated by the incomplete combustion of solid fuels including wood, charcoal, coal, crop residues, and animal dung, constitutes one of the most consequential yet underappreciated environmental health threats facing humanity today. The World Health Organization (WHO) estimates that HAP causes approximately 3.2 million premature deaths annually, with the overwhelming majority occurring in low- and middle-income countries (LMICs) of sub-Saharan Africa and South Asia. More than 2.6 billion people worldwide continue to depend on solid fuels for cooking and heating, and this number has declined only marginally despite decades of global clean energy initiatives [1].

Pregnant women occupy a position of heightened vulnerability in the HAP landscape. Epidemiological evidence has established associations between household smoke exposure and adverse maternal and perinatal outcomes, including hypertensive disorders of pregnancy, caesarean section [2–4], low birth weight, preterm birth, intrauterine growth restriction and stillbirth [3–7], spontaneous abortion, and neonatal mortality [3, 6]. The toxicological basis of these associations involves transplacental transfer of toxic smoke particles which have detrimental effects early in pregnancy by disrupting critical trophoblast functions needed for normal placenta development and function [8, 9].

In 2023, an estimated 21% of neonatal deaths in the first week of life were attributable to HAP, and over 500,000 deaths in children under five years were linked to household air pollution. Africa carries the largest burden: 19 of the 20 countries with the highest household air pollution exposure are in Africa, and in 24 African countries, over 90% of the population is exposed to smoke from solid fuels [1, 10]. The exposure levels in African homes often exceed the WHO safe limits for particulate matter by more than tenfold [11].

In Nigeria, over 77% of surveyed women from the 2018 Nigeria Demographic and Health Survey (NDHS) use unclean fuel for cooking [5]. As of 2023, 73.8% of the Nigerian population primarily relies on unclean fuels for cooking, whereas in the rural areas, only 9.7% of the population had access to clean fuels and technologies for cooking [12]. The North-East and North-West regions, where poverty is more prevalent and modern energy services are scarce, have less access to clean cooking technologies and more reliance on solid fuels than other regions of the country [13, 14].

Unclean cooking fuels contribute significantly to adverse birth outcomes in Nigeria, yet household-level interventions remain limited [5]. Despite this burden, published studies that specifically assess the knowledge, perception, and exposure patterns of pregnant women to household smoke in Nigeria are scarce, and those that exist are predominantly from Southern Nigeria [15]. This represents a critical evidence gap for Northern Nigeria, a region with distinct socio-cultural, economic, and environmental determinants that may substantially shape women's HAP knowledge, perceptions, and exposure behaviours. Addressing HAP exposure in this population requires understanding whether the barriers lie in knowledge deficits, attitudinal resistance, or the structural constraints that prevent even informed and motivated women from adopting safer cooking practices.

This study was therefore conducted to: (i) assess the level of knowledge of HAP and its associated health risks among pregnant women in Zaria Metropolis; (ii) determine their perception of those risks; (iii) investigate household smoke exposure patterns; and (iv) identify sociodemographic determinants and independent predictors of high HAP exposure.

2. Methodology

2.1 study area

This study was conducted in Zaria Metropolis, Kaduna State, Nigeria, the historic capital of the Zazzau Emirate Council, located in the northwestern part of Nigeria. The metropolis comprises Zaria and Sabon-Gari LGAs, and parts of Giwa. It covers an area of approximately 563 km² and has a population of over 1 million people [16, 17]. The predominant ethnic groups are Hausa and Fulani, and the major occupations include trading, farming, manual work, and civil

service. The city is served by one tertiary and several secondary health facilities, including private centres, as well as numerous primary health care centres that provide antenatal and delivery services [18].

2.2 Study Design

This was a descriptive cross-sectional study.

2.3 Study Population and Eligibility Criteria

The study population comprised pregnant women attending antenatal care (ANC) clinics at selected primary healthcare centres (PHCs) within Zaria Metropolis. Eligible participants were pregnant women attending ANC at the selected PHCs during the study period. Excluded were pregnant women who were severely ill or unable to respond to the questionnaire, those who attended ANC at the selected PHCs but did not reside in Zaria Metropolis, and those who had resided in Zaria Metropolis for fewer than six months prior to the study.

2.4 Sample Size Determination

The minimum sample size was determined using Cochran's formula for descriptive proportion studies:

$n = Z^2pq / d^2$

Where n = minimum sample size; Z = 1.96 (95% confidence level); p = estimated proportion of adequate knowledge of household smoke among pregnant women from a previous study = 0.741; q = 1 − p = 0.259; d = 0.05 (desired precision). By substitution: $n = (1.96)^2 \times 0.741 \times 0.259 / (0.05)^2 \approx 295$. Adjusting for an anticipated 10% non-response rate, the minimum sample size was 328. A total of 351 pregnant women were recruited using consecutive sampling; all completed questionnaires were included in the final analysis to improve statistical power and representativeness.

2.5 Sampling Technique

A multistage sampling technique was employed across four stages. In Stage 1, Zaria and Sabon-Gari LGAs were purposively selected from the three LGAs in Zaria Metropolis, based on high population density, facility distribution, and accessibility. In Stage 2, eight political wards were selected, four from each LGA using simple random sampling by balloting. In Stage 3, the model PHC from each selected ward was chosen (Table 1). In Stage 4, within each selected PHC, consecutive sampling was employed: all eligible pregnant women presenting for ANC on days of data collection were approached and recruited consecutively until the proportionately allocated sample size for that facility was attained.

Table 1
Proportionate Allocation of Sample Size Based on ANC Client Flow in Selected PHCs

PHC Facility	Average ANC Attendance	Proportion (%)	Sample Allocation
Zaria LGA			
PHC Ang. Alkali	30	8.6	28
PHC Babban Dodo	55	15.7	52
PHC Iyal	38	10.9	36
PHC Tudun Wada	60	17.1	56
Sabon Gari LGA			
PHC Basawa	55	15.7	52
PHC Chikaji	35	10.0	33
PHC Hanwa	45	12.9	42
PHC Samaru	32	9.1	30
Total	**350**	**100%**	**328**

2.6 Study Instrument

A structured interviewer-administered questionnaire adapted from similar studies and the NDHS was used for data collection [15]. The questionnaire was structured into three sections: Section A: Socio-demographic and household characteristics (age, education, ethnicity, occupation, household size, type of cooking fuel, and cooking location).

Section B: Knowledge of household smoke and associated health risks.

Section C: Perception regarding household smoke exposure and its consequences on pregnancy outcomes.

The questionnaire was pretested with 10% of the calculated sample size at the ANC clinic of Ahmadu Bello University Teaching Hospital (ABUTH), and adjustments were made based on findings.

2.7 Data Collection

Data were collected over two weeks in February 2026 by the researcher and five trained research assistants, all final year medical students. Training covered study objectives, ethical considerations, and proper questionnaire administration to ensure participant confidentiality and informed consent. The electronic questionnaire was administered using KoboToolbox on Android devices to 351 respondents recruited consecutively while waiting at the ANC section. All completed questionnaires were included in the final analysis.

2.8 Measurement of Variables

Knowledge

Assessed using 10 structured questions with 'Yes', 'No', and 'Not sure' options. Correct responses ('Yes') were scored 1; incorrect ('No' or 'Not sure') were scored 0. Respondents scoring ≥ 60% were classified as having good knowledge; those scoring < 60% were classified as having poor knowledge [19].

Perception

Measured using a three-point Likert scale (Agree/Disagree/Neutral). 'Agree' was scored 1; 'Disagree' or 'Neutral' were scored 0. Respondents scoring ≥ 4 of a maximum score of 6 were categorised as having positive perception; those scoring < 4 were classified as having negative perception [20].

Exposure: Assessed using two objective indicators; type of primary cooking fuel and location of cooking. Clean fuels (electricity, LPG, natural gas, biogas) were assigned a score of 1; unclean fuels (kerosene, coal, charcoal, wood, biomass, sawdust, animal dung) a score of 0. Outdoor cooking was scored 1; indoor cooking (in the house or a separate building) was scored 0. Four ordinal exposure categories were derived: very low (clean fuel + outdoor), low (clean fuel + indoor), medium (unclean fuel + outdoor), and high (unclean fuel + indoor). For analytical purposes, very low and low were grouped as 'low exposure'; medium and high were grouped as 'high exposure', yielding a binary outcome variable [21].

2.9 Data Analysis

Completed questionnaires were downloaded from KoboToolbox, imported into SPSS v25.0, and cleaned before analysis. Descriptive statistics; frequencies and proportions for categorical variables were generated. Bivariate analysis using chi-square tests (or Fisher's exact test where applicable) assessed associations between sociodemographic characteristics and knowledge, perception, and exposure at $p < 0.05$. Binary logistic regression identified independent predictors of high HAP exposure; adjusted odds ratios (AORs) and 95% confidence intervals (CIs) are reported.

2.10 Ethical Considerations

Ethical approval

was obtained from the Health Research Ethics Committee of Ahmadu Bello University Teaching Hospital, Zaria (Ref. No: ABUTH-NHREC/29/08/23). Verbal informed consent was obtained from all participants before administering the questionnaire.

3. Results

Table 2
Socio-demographic Characteristics of the respondents

Variable	Frequency	Percent (%)
Age Group (years)		
Early reproductive (15–24)	164	46.7
Mid-reproductive (25–34)	154	43.9
Late reproductive (35–49)	33	9.4
Respondents' Level of Education		
No formal education	29	8.3
Primary	37	10.5
Secondary	230	65.5
Tertiary	55	15.7
Tribe		
Hausa	286	81.5
Fulani	42	12.0
Yoruba	6	1.7
Other[+]	17	4.8
Respondents' Occupation		
Artisan	70	19.9
Civil servant	15	4.3
Self-employed	148	42.2
Professional	14	4.0
Unemployed	104	29.6
Husband's Age Group (years)		
Young age (< = 44)	278	79.2
Middle age (45–59)	65	18.5
Elderly (> = 60)	8	2.3
Husband's Level of Education		
No formal education	26	7.4
Primary	10	2.8
Secondary	130	37.0
Tertiary	185	52.7
Main Cooking Fuel		
Electricity	21	6.0
LPG/natural gas/biogas	91	25.9
Coal	32	9.1
Charcoal	160	45.6
Wood	42	12.0
Other*	5	1.4
>=11	83	23.6
Place of Cooking		
In the house	254	72.4
[+]Includes Nupe, Igbo, Kanuri, Ebira, Igala, Bajju, Zuru, Kamatan, Waja		
LFG = Liquefied petroleum gas. *Includes kerosene, sawdust, animal dung		

Variable	Frequency	Percent (%)
In a separate building	72	20.5
Outdoors	25	7.1
Household Population		
2–5	164	47.0
6–10	103	29.3
>=11	83	23.6
[+]Includes Nupe, Igbo, Kanuri, Ebira, Igala, Bajju, Zuru, Kamatan, Waja		
LFG = Liquefied petroleum gas. *Includes kerosene, sawdust, animal dung		

All 351 questionnaires were retrieved (response rate: 100%). Tables 2 present the sociodemographic characteristics. Almost half (164, 46.7%) of respondents were in the early reproductive age group (15–24 years), while 154 (43.9%) were aged 25–34 years, and 33 (9.4%) were aged 35–49 years. Secondary education was the highest level attained by the majority (230, 65.5%), followed by tertiary (55, 15.7%), while 29 (8.3%) had no formal education. Most respondents were Hausa (286, 81.5%), with Fulani constituting 12.0% (n = 42). The most common occupations were self-employment (148, 42.2%) and unemployment (104, 29.6%).

Regarding household characteristics, the majority of husbands were aged ≤ 44 years (278, 79.2%), and more than half had tertiary education (185, 52.7%). Charcoal was the most commonly used primary cooking fuel (160, 45.6%), followed by LPG/natural gas (91, 25.9%) and wood (42, 12.0%). Most respondents cooked inside the house (254, 72.4%), with 72 (20.5%) cooking in a separate building and 25 (7.1%) cooking outdoors. Nearly half lived in households with 2–5 members (164, 47.0%), 103 (29.3%) had 6–10 members, and 83 (23.6%) had ≥ 11 members.

A significant number of the respondents, 239 (68.1%) were classified as experiencing high HAP exposure and 112 (31.9%) as low exposure. 288 (82.1%) demonstrated good knowledge of HAP (score ≥ 60%) and 274 (78.1%) demonstrated positive perception of HAP health risks (score ≥ 4 of 6) (Fig. 1).

Table 3
Perception of HAP Among Pregnant Women in Zaria Metropolis, February 2026 (n = 351)

Perception Statement	Agree n (%)	Disagree n (%)	Neutral n (%)
Smoke from cooking in the house is a serious health problem	276 (78.6%)	54 (15.4%)	21 (6.0%)
I believe cooking smoke can harm my health	303 (86.3%)	34 (9.7%)	14 (4.0%)
I believe cooking smoke can harm my pregnancy	247 (70.4%)	75 (21.4%)	29 (8.3%)
Using clean fuels such as gas/electricity would improve my family's health	287 (81.8%)	40 (11.4%)	24 (6.8%)
Using firewood/charcoal/agricultural waste is unsafe during pregnancy	271 (77.2%)	51 (14.5%)	29 (8.3%)
Reducing exposure to cooking smoke during pregnancy is important for the unborn child	287 (81.8%)	38 (10.8%)	26 (7.4%)

High proportions agreed that cooking smoke can harm their health (303, 86.3%), that reducing exposure during pregnancy is important for the unborn child (287, 81.8%), and that clean fuels would improve family health (287, 81.8%). Agreement was lower for pregnancy-specific items: 271 (77.2%) believed firewood/charcoal is unsafe in pregnancy; 276 (78.6%) considered cooking smoke a serious health problem; and 247 (70.4%) believed cooking smoke can harm their pregnancy specifically (Table 3).

Table 4
Knowledge of HAP Among Pregnant Women in Zaria Metropolis, February 2026 (n = 351)

Knowledge Item	Yes n (%)	No n (%)	Not Sure n (%)
Do you know that smoke from cooking causes indoor air pollution?	282 (80.3%)	50 (14.2%)	19 (5.4%)
Smoke from cooking fuels such as firewood/charcoal/agricultural waste can be harmful to health	285 (81.2%)	48 (13.7%)	18 (5.1%)
Does smoke in the house cause more harm to babies and pregnant women?	232 (66.1%)	72 (20.5%)	47 (13.4%)
Cooking smoke can damage the lungs	268 (76.4%)	52 (14.8%)	31 (8.8%)
Do you know that smoke from cooking in the house can aggravate asthma?	295 (84.0%)	42 (12.0%)	14 (4.0%)
Can exposure to smoke in the house affect the health of the unborn child?	229 (65.2%)	82 (23.4%)	40 (11.4%)
Can exposure to smoke in the house cause miscarriage?	138 (39.3%)	136 (38.7%)	77 (21.9%)
Does cooking outdoors or in a kitchen with open windows reduce smoke exposure?	317 (90.3%)	20 (5.7%)	14 (4.0%)
Does using firewood/charcoal/agricultural waste produce more smoke than gas/electricity?	315 (89.7%)	26 (7.4%)	10 (2.8%)
Exposure to smoke in the house can cause breathing problems and eye irritation	306 (87.2%)	30 (8.5%)	15 (4.3%)

The majority correctly identified that cooking outdoors or with open windows reduces smoke exposure (317, 90.3%) and that solid fuels produce more smoke than gas or electricity (315, 89.7%). Cooking smoke was identified as a cause of breathing problems and eye irritation by 306 (87.2%), and asthma aggravation by 295 (84.0%). However, knowledge of pregnancy-specific consequences was substantially lower: 232 (66.1%) knew smoke causes more harm to babies and pregnant women; only 229 (65.2%) knew it can affect the health of the unborn child; and merely 138 (39.3%) correctly identified miscarriage as a potential consequence, the lowest correct response rate across all ten items (Table 4).

Table 5
Association Between socio-demographic Characteristics and HAP Exposure Among Pregnant Women in Zaria Metropolis, February 2026 (n = 351)

Variables	**Exposure Level**			
	High Exposure	**Low Exposure**	**Test Statistic**	**p-value**
Age Group (years)				
Early reproductive (15–24)	103	61		
Mid-reproductive (25–34)	107	47	$\chi^2 = 8.193$	0.017*
Late reproductive (35–49)	29	4		
Respondents' Level of Education				
No formal education	28	1		
Primary	31	6	$\chi^2 = 62.787$	< 0.001*
Secondary	166	64		
Tertiary	14	41		
Tribe				
Hausa	202	84		
Fulani	26	16	$\chi^2 = 5.935$	0.051
Other	11	12		
Respondents’ Occupation				
Employed	68	31		
Self-employed	100	48	$\chi^2 = 0.036$	0.982
Unemployed	71	33		
Husband’s Age Group				
Young age (< = 44)	182	96		
Middle age (45–59)	50	15	$\chi^2 = 4.601$	0.100
Elderly (> = 60)	7	1		
Husband’s Level of Education				
No formal education	22	4		
Primary	9	1	$\chi^2 = 35.691$	< 0.001*
Secondary	108	22		
Tertiary	100	85		
Household Population				
2–5	85	79		
6–10	74	29	$\chi^2 = 49.131$	< 0.001*
>=11	79	4		
**Statistically significant at p < 0.05*				

A statistically significant association was found between perception level and respondents' level of education (p = 0.012) and husband’s level of education (p = 0.016), as well as between knowledge level and husband’s level of education (p = 0.002) and respondent education approached significance (p = 0.052). Neither knowledge nor perception were significantly associated with HAP exposure. However, age group (p = 0.017), respondent's level of education (p < 0.001), husband's level of education (p < 0.001), and household population (p < 0.001) were significantly associated with high HAP exposure (Table 5).

Table 6
Binary Logistic Regression; Independent Predictors of High HAP Exposure Among Pregnant Women in Zaria Metropolis, February 2026 (n = 351)

Variables	Adjusted Odds Ratio (AOR)	95% Confidence Interval (CI)	p-value
Age Group (years)			
Mid-reproductive (25–34) (ref)	1.000		
Early reproductive (15–24)	0.631	0.330–1.204	0.162
Late reproductive (35–49)	3.368	0.815–13.913	0.093
Respondents' Level of Education			
Tertiary (ref)	1.000		
Secondary	5.672	2.563–12.551	< 0.001*
Primary	11.229	3.395–37.133	< 0.001*
No formal education	47.211	5.024–443.636	< 0.001*
Tribe			
Hausa (ref)	1.000		
Fulani	0.470	0.189–1.169	0.104
Other	0.691	0.222–2.147	0.523
Respondents' Occupation			
Employed (ref)	1.000		
Self-employed	1.570	0.573–4.297	0.380
Unemployed	1.719	0.583–5.071	0.326
Husband's Age Group			
Young age (< = 44) (ref)	1.000		
Middle age (45–59)	0.695	0.286–1.688	0.421
Elderly (> = 60)	1.462	0.135–15.894	0.755
Husband's Level of Education			
Tertiary (ref)	1.000		
Secondary	3.020	1.605–5.681	< 0.001*
Primary	4.852	0.479–49.183	0.181
No formal education	1.267	0.330–4.860	0.730
Household Population			
2–5 (ref)	1.000		
6–10	1.519	0.791–2.917	0.209
>=11	13.503	4.358–41.835	< 0.001*
Perception Level			
Positive (ref)	1.000		
Negative	1.960	1.015–3.785	0.045*
AOR = Adjusted Odds Ratio; CI = Confidence Interval; ref = reference category. *Statistically significant at p < 0.05			

After controlling for all significant bivariate predictors, four independent predictors of high HAP exposure were identified. Respondent's educational attainment demonstrated a striking dose-response gradient. Compared to those with tertiary education, respondents with secondary education (AOR = 5.672; 95% CI: 2.563–12.551; p < 0.001), primary education (AOR = 11.229; 95% CI: 3.395–37.133; p < 0.001), and no formal education (AOR = 47.211; 95% CI: 5.024–443.636; p < 0.001) had significantly higher odds of high HAP exposure. Regarding spousal education, respondents whose husbands had secondary education (vs. tertiary) had approximately three times higher odds of high exposure (AOR = 3.020; 95% CI: 1.605–5.681; p < 0.001). Household size of ≥ 11 members conferred more than 13-fold higher odds of high exposure versus households of 2–5 members (AOR = 13.503; 95% CI: 4.358–41.835; p < 0.001). Negative HAP perception was also an independent predictor of high exposure (AOR = 1.960; 95% CI: 1.015–3.785; p = 0.045) (Table 6).

4. Discussion

About 82% of pregnant women in Zaria Metropolis demonstrated good knowledge of household smoke hazards, and 78.1% held positive perceptions of its risks, yet 68.1% remained highly exposed. Knowing the danger and being protected from it are two entirely different things in this population.

Charcoal was the most commonly used primary cooking fuel (45.6%), and most women cooked inside the house (72.4%) with an additional 20.5% cooking in a separate building (indoor). The charcoal dominance is consistent with findings from a nine-LMIC study where African pregnant women reported higher use of charcoal (85.4–93.5%) [22], but differs from the 2023 NDHS report where wood (52.3%) was the most common fuel nationally, a discrepancy explained by marked regional and urban-rural differences in fuel availability and cooking culture [23]. Most households had 2–5 members (47.0%), consistent with the 2024 NDHS report of 69.5% of Nigerian households having five or fewer usual members [23].

The prevalence of good HAP knowledge (82.1%) found in this study is notably high and exceeds findings from the only available comparable Nigerian study, conducted among pregnant women in Osogbo, which reported 74.1% good knowledge [15]. The higher proportion observed in Zaria may reflect the urban character of the Metropolis and the experience from long term use of solid fuel.

However, a clinically critical knowledge gap was identified for pregnancy-specific HAP consequences. Only 65.2% knew that smoke in the house can affect the health of the unborn child, and merely 39.3% correctly identified miscarriage as a potential consequence, the lowest correct response rate across all knowledge items. This is particularly alarming given the well-established associations between prenatal HAP exposure and spontaneous abortion, preterm birth, and low birth weight [3, 4, 6]. It suggests that health messaging, while covering general respiratory effects adequately, systematically fails to communicate the specific vulnerabilities of the pregnant mother-foetal unit. Similar pregnancy-specific knowledge gaps have been documented in Ethiopia, Rwanda and Uganda, suggesting that this is a consistent deficit in antenatal HAP communication across LMICs [24–26].

The husband's educational level was significantly associated with respondent HAP knowledge ($p = 0.002$), suggesting that higher spousal education creates a domestic environment more conducive to health information uptake, an important finding in a setting where male household heads exercise considerable influence over household decision-making and resource allocation [27].

The positive perception prevalence (78.1%) compares favourably with comparable settings. Research in urban Rwanda found that most women perceived HAP to have only short-term health effects,[28] while the companion Nigerian study in Osogbo found similar positive attitudinal patterns among ANC-attending urban women [15]. The comparatively positive profile observed here may reflect the sensitising effect of ANC utilisation in PHC settings.

Despite this overall positive profile, residual negative perceptions are clinically important. Notably, 29.6% did not believe cooking smoke could harm their pregnancy, and 22.8% were unconvinced that firewood and charcoal are unsafe in pregnancy. These perceptions are particularly concerning given the documented transplacental toxicity of HAP combustion products [6, 9, 29]. Consistent with Health Belief Model theory [30], which posits that perceived susceptibility and perceived severity are necessary antecedents of protective health behaviour, negative perception emerged as an independent predictor of high HAP exposure in the multivariate analysis (AOR = 1.960; $p = 0.045$). This confirms that attitudinal barriers contribute independently to exposure behaviour, even in a population where the majority hold positive perceptions. Both respondent's education ($p = 0.012$) and spousal education ($p = 0.016$) were significantly associated with perception, reinforcing the dual role of individual and household educational capital in shaping risk appraisal.

The 68.1% prevalence of high HAP exposure is consistent with national estimates of unclean fuel use at 65.8% in 2024 [23], and with regional analyses showing Northern Nigeria's disproportionate HAP burden [21]. The near-universal prevalence of indoor cooking (92.9%) amplifies the health risk of solid fuel combustion by concentrating combustion byproducts in enclosed spaces where pregnant women spend prolonged hours.

The absence of a significant association between knowledge and HAP exposure at both bivariate ($p = 0.976$) and multivariate levels (AOR = 0.733; $p = 0.361$) constitutes the central epidemiological paradox of this study and demonstrates the knowledge-action gap documented across global HAP literature [15, 25, 31]. A woman who knows that charcoal smoke harms her foetus but cannot afford LPG, lives in a household where the fuel decision rests with her husband, or has no alternative cooking space, is navigating a structural constraint, not making a behavioural choice. Informational interventions alone will yield limited impact without simultaneously addressing these economic and infrastructural barriers.

The dose-response relationship between educational attainment and HAP exposure was the most striking finding of the regression analysis. Compared to those with tertiary education, the odds of high exposure were 5.7 times higher with secondary education, 11.2 times with primary education, and 47.2 times with no formal education. This profound relationship situates HAP exposure firmly within the social determinants of health framework: education confers income, health literacy, and social capital that collectively facilitate access to and sustained adoption of clean cooking alternatives. This is consistent with evidence from Tanzania, Ethiopia, and Northern Nigeria identifying educational attainment as the dominant predictor of household fuel choice [21, 32, 33].

Spousal secondary education (vs. tertiary) conferred 3.0-fold higher odds of high exposure (AOR = 3.020; $p < 0.001$), reflecting the socio-cultural reality of Northern Nigeria where male household heads typically control major domestic economic decisions, including fuel purchasing. Studies in Kaduna State have identified household head education and income as key determinants of fuel energy transition in the Zaria sub-region [27].

Household size ≥ 11 members were associated with more than 13-fold higher exposure odds versus households of 2–5 members (AOR = 13.503; $p < 0.001$). Notably, households of 6–10 members were not significantly different from 2–5 member households (AOR = 1.519; $p = 0.209$), suggesting a threshold effect where very large households (≥ 11 members) generate cooking demands and economic constraints that disproportionately elevate exposure risk. This finding is consistent with previous studies in Nigeria and Tanzania [21, 33, 34]. The high proportion (23.6%) of very large households in this study may reflects the prevalence of polygamous family structures and extended family living in Zaria Metropolis.

Several limitations should be considered when interpreting these findings. First, HAP exposure was assessed using a validated but proxy-based composite measure derived from self-report; objective environmental or biological measurements were not feasible. Self-reported data may be subject to social

desirability bias. We made considerable effort to address this by ensuring confidentiality and privacy. Third, recruitment from PHC-based ANC clinics may limit generalisability to pregnant women who do not attend ANC, who may systematically differ in education, knowledge, and exposure. Fourth, the study was restricted to Zaria Metropolis and may not fully represent the broader rural Northern Nigerian context, where solid fuel dependence may be considerably higher. Despite these limitations, the 100% response rate, validated instrument, systematic multistage sampling, and electronic data collection with real-time quality assurance strengthen the reliability of the findings.

5. Conclusion

Most pregnant women in Zaria Metropolis possessed good knowledge and positive perception of household air pollution; however, high HAP exposure remained prevalent, affecting 68.1% of respondents. A significant knowledge-action gap was demonstrated: knowledge was not a significant predictor of exposure. Instead, the key independent predictors were lower educational attainment, lower spousal education, large household size, and negative HAP perception; structural and attitudinal factors that cannot be addressed through information delivery alone. Effective and sustainable reduction of HAP exposure in this population requires integrated multi-level approaches that simultaneously address informational gaps, attitudinal barriers, and the structural inequalities constraining access to clean cooking energy.

6. Recommendations

To Antenatal Care Providers and PHC Staff

Structured HAP counselling specifically addressing pregnancy-related consequences such as miscarriage, preterm birth, and foetal growth restriction should be integrated into routine ANC visits. Practical interim exposure-reduction strategies should be offered to women unable to immediately transition to cleaner fuels.

To the Kaduna State Ministry of Health and Policymakers

Clean cooking fuel subsidies and improved cookstove distribution should prioritise large households (≥11 members) and women with low educational attainment. Girls' access to education should be promoted and HAP should be formally recognised as an antenatal risk factor in state maternal health policy, with clear counselling and referral protocols.

To Community Health Educators and NGOs

Behavioural change communication campaigns should actively engage male household heads, and campaigns should acknowledge financial barriers to clean fuel adoption and offer practical, culturally acceptable interim strategies.

To Future Researchers

Future studies should incorporate objective HAP exposure measures such as personal PM2.5 monitoring or biomarkers to contribute in mapping pregnancy related HAP exposomes.

Declarations

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Author contributions

MSA: Conceptualization, methodology, resources, data analysis, writing original and final draft, coordination of data collection and administration. ZSB: Supervision, methodology, writing, review and editing. AB: Institutional permission acquisition, data collection and review. HYH: writing, review and editing,

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Materials and data availability

The materials and datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethical approval and consent to participate

Ethical approval was obtained from the Health Research Ethics Committee of Ahmadu Bello University Teaching Hospital, Zaria (Ref. No: ABUTH-NHREC/29/08/23). Institutional permission was obtained from the Kaduna State primary healthcare board (zone 1) and the PHC departments of Zaria and Sabon Gari LGAs. Verbal informed consent was obtained from all participants before administering the questionnaire. Participation was voluntary and confidentiality was maintained by de-identifying all data. All methods were carried out in accordance with relevant guidelines and regulations.

Clinical trial number: not applicable

Competing interests

The authors declare no competing interests.

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Figures

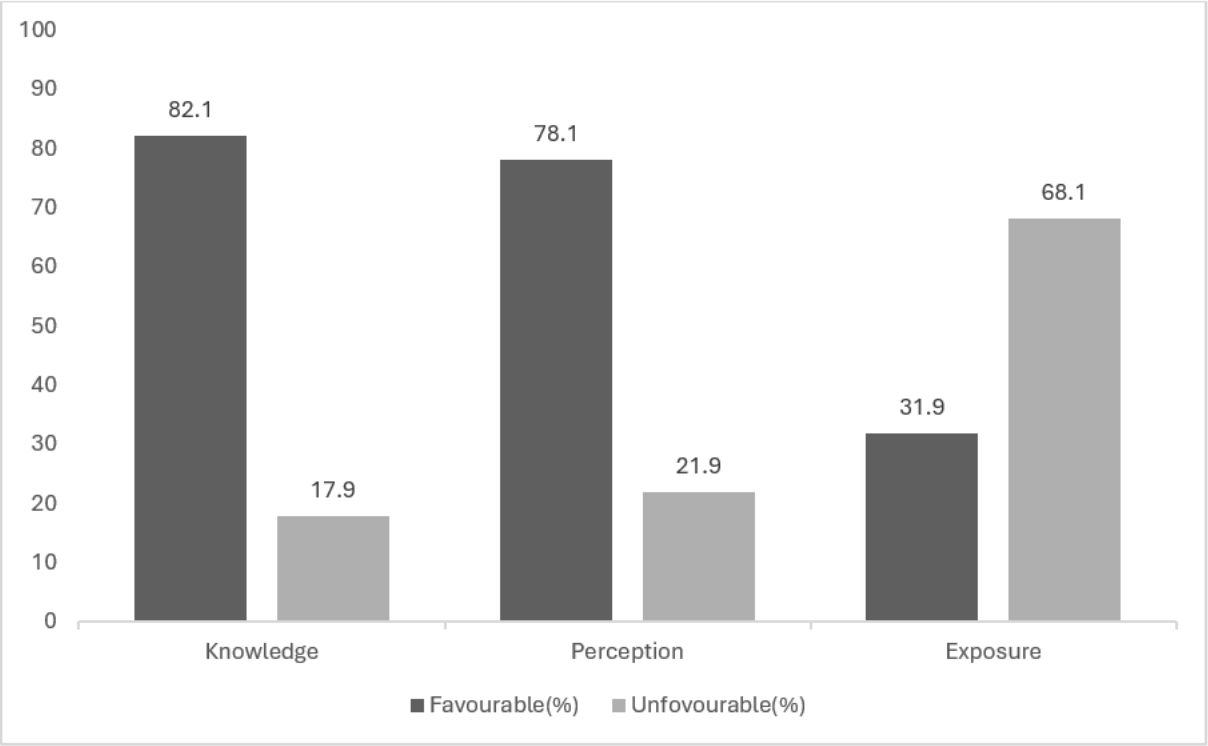


Figure 1

Distribution of HAP Knowledge, Perception and Exposure Among Pregnant Women in Zaria Metropolis, February 2026 (n=351)