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Investigating health impacts of household air pollution on woman's pregnancy and sterilization: Empirical evidence from Pakistan, India, and Bangladesh

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ABSTRACT

The health impacts of increasing household air pollution produced by inefficient cooking fuels on woman's health concerning pregnancy, fertility, and sterilization in the most populous South Asian countries have not got due attention previously. As these health issues are some of the most critical health indicators for women; therefore, the study investigates a robust statistical relationship between household air pollution produced by cooking fuels and above indicators of woman's health that are less focused. Because living in such an environment can increase more health risks unless effective strategies based on empirical research foundations are put in place to curb the rising health implications. The study uses cross-sectional data of the three most populous countries of South Asia (India, Pakistan, and Bangladesh) and employs the MANOVA and OLS regression methods to examine this empirical relationship. The results have revealed that the type of cooking fuel is the topmost concern for a woman's health, such as termination and duration of current pregnancy, years since and age at sterilization, residence, and education. Moreover, cooking places also adversely impact age at sterilization. Based on findings, the study proposes effective policy suggestions to the governments and policymakers to take necessary measures to prevent health risks.

1. Introduction

The combustion of solid cooking fuels, such as firewood, coal, charcoal, dung, crops, or straws in rural areas of the developing countries causes household air pollution that further leads to rampant indoor and then outdoor air pollution. The developing countries which already have undeveloped energy infrastructure, incomplete electrification, and a dilapidated network of gas pipelines, household air pollution specifically produced by cooking fuels has become one of the major issues that cause millions of lives to be lost every year. According to the World Health Organization (WHO) reports, around 7 million people die due to household air pollution each year; moreover, millions of people suffer from various respiratory and cardiovascular diseases, strokes, heart and lung diseases [1]. Besides, it also directly or indirectly leads to premature deaths of around 5 million people annually in developing countries [2], where cooking practices heavily depend on solid fuel consumption. This dependency on inefficient sources of energy for cooking poses a considerable threat to women's health, as women bear the sole responsibility of preparing a meal for the whole family. Also in rural South Asia, women spend most of their daily time collecting woods, crops, straws or collecting manure, making bread of it, and drying it under the sun to prepare it as cooking fuel. This practice widely affects the girls' education because they are not left with sufficient time to study [3].

Following the argument, most of the rural households of the three most populous developing countries of South Asia (Pakistan, India, and Bangladesh) also considerably depend on unclean and traditional sources of energy for cooking practices. These countries carry a significant economic, social, geographical, and

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environmental contribution to around 1.8 billion of the world's population. Almost 897 million (65%) people in India, 143 million in Pakistan (65%), and 100 million (60.6%) in Bangladesh live in rural areas that share a major portion of their total population [4]. Other countries have transformed and diversified their energy system for cleaner fuel consumption; however, despite being enriched with untapped affordable energy potential, these countries still heavily rely on imported non-renewable energy fuels (crude oil, gas, and coal) to power households as well as commercial and industrial activities [5–7]. These energy imports (Pakistan 13.14 billion, India 125 billion, and Bangladesh 8–9 billion in USD) consume a considerable chunk of their foreign reserves annually [8–10] that, otherwise, could be spent on social well-being and infrastructural development [11]. For decades, Pakistan has been facing a severe energy crisis, electricity shortage in summer, and gas shortage in winter; it has become a common trend, and households suffer a lot in extreme and dry seasons. According to statistics, more than 60% of fossil fuels are used in Pakistan for electricity and other purposes [12], and less than 2% of electricity is generated from renewable energy resources [13].

This situation is not different in India and Bangladesh as well. India, the most populous country in South Asia and the second-most in the world, shares the same problems with severe environmental and health implications of household air pollution: 70% of rural populations depend on solid fuel consumption [14]. Also, around 3% of renewable sources are used for electricity production and other purposes in Bangladesh [15]. Whereas traditional sources of energy for cooking purposes account for more than 85%, out of the total, around 45% from crops and 20% from dung [16]. Lack of electricity supply, dependency on solid fuels, and improper ventilation of cooking places produce severe health risks, particularly women suffer a lot from it [17].

Although an extensive literature has been published on the relationship of overall human wellbeing and renewable energy consumption for domestic or commercial/industrial purposes [18], electrification [19,20], indoor cold [21], and household living conditions [22,23]; while others have focused on the empirical association of energy poverty and health [24–26], however, the impact of increasing household air pollution produced by the combustion of cooking fuels on women's health concerning pregnancy and sterilization in the most populous South Asian countries (India, Pakistan and Bangladesh) have not got due attention previously. Issues of pregnancy, fertility, and sterilization are some of the most critical health indicators for women. If there is any statistical association between the variables, it must be investigated. The outcomes can have significant policy implications for the stakeholders. Also, to the best of our knowledge, these are the health issues which are not discussed widely and deeply in context of household air pollution, especially in South Asia. Therefore, the study aims to investigate a robust statistical relationship between household air pollution caused by cooking fuels and indicators of woman's health, specifically pregnancy, fertility, and sterilization that are less discussed. Because, the growing population in India, Pakistan, and Bangladesh raises major health and clean fuel challenges when most people cannot afford to have renewable, efficient, and eco-friendly cooking fuels. Besides, living in such an environment can increase more health risks unless effective strategies based on empirical research foundations are put in place to curb the rising health implications. In this context, the study also contributes to the literature that it analyzes the current situation of household air pollution due to cooking fuels in the three countries, provides a robust model to the countries overly dependent on solid fuel consumption for cooking practices, assesses its consequences on women's health, and subsequently, proposes practical policy measures to address the issue at the subnational, national, and regional level.

2. Literature review

Energy being the fundamental source for industrial and household activities, its availability and affordability strengthen economic development and makes domestic life more manageable. In this context, the availability, accessibility, and affordability of modern energy fuels become imperative for sustainable economic development [27–30], environmental sustainability [31–34], and healthy and safe cooking practices at the household level [35–37]. The consumption of efficient energy fuels improves air quality both at the household and outdoor level and social development and reduces health risks [38–40].

The use of solid fuels for cooking is considered riskier, which directly impacts health (Dherani et al.; [41,42]. Around 3.8 million people globally [43] and 0.5 million in Asia alone die due to household air pollution caused by the combustion of solid fuels for cooking [44], and thousands get affected by respiratory diseases such as lungs cancer, asthma and heart attack [45–50]. Solid fuels are used for both domestic (burnt for cooking purposes) and industrial purposes [51], which causes household and outdoor air pollution, respectively. Most people in low-income countries use these solid fuels and cook inside their homes without proper ventilation, which produces harmful pollutants that severely affects physical and mental human health [52,53], especially in developing countries that use non-renewable sources in excessive quantity [54].

Unfortunately, women and children suffer more from it. It affects not only the fertility and mortality of women but also women's ability to get pregnant, the physical development of a child, and increases the risks of birth defects [55,56]. A plethora of previous studies have discussed the health implications of solid fuel consumption at the household level, such as asthma, heart attack [57], and lung cancer [43]; physical and mental health [58], cardiovascular diseases [43], disability [59] and mental sickness of children [58,60]. However, the increasingly adverse impacts of household consumption of fossil fuels on woman's health particularly related to pregnancy and fertility have not gotten due attention in South Asia.

Therefore, this study aims to investigate an empirical relationship of consistent household air pollution due to the use of non-renewable cooking fuels on woman's health, especially woman's fertility, and pregnancy issues that need urgent attention as women are the primary group to cook food and stay at homes in Pakistan, India, and Bangladesh. Further, this study also statistically highlights the rampant trends of solid fuel consumption for cooking practices in the above-mentioned countries that have taken thousands of lives for the last two decades. Besides, the study also provides policy suggestions to the stakeholders to take necessary steps, so that, the detrimental impacts of this cooking trend on woman's health indicators could be avoided. For this purpose, this study uses two-way multivariate analysis of variance (MANOVA) and then employs ordinal least square (OLS) technique with STATA^{MP} 16.0 to examine approximation of a statistical association between household air pollution and selected indicators of women's health, such as pregnancy, fertility, and sterilization. Eventually, the study contributes to the existing literature in three ways that are discussed before.

3. Methods and data

3.1. Data

The data for this study was acquired from the United States

Agency for International Development (USAID). The USAID has been conducting different household surveys for decades in different regions of the world, such as economic surveys, education surveys, and health surveys with the collaboration of the concerned governments and representative institutions. The access to a dataset DHS-VII 2017−18 of Pakistan, India, and Bangladesh was granted after a formal request [61]. A unit of analysis of the input data is household. The data is very useful in policy perspectives, which provides the complete demographic and health profile of the households required for this study. Data of 14,325 households from Pakistan, 600,105 from India, and 17,205 from Bangladesh was used for the result analysis.

3.2. MANOVA

The two exogenous variables, the type of cooking fuels and places for cooking, are taken as the indicators of household air pollution. To measure the health of women, demographic indicators and health indicators related to pregnancy and sterilization were selected. First, this study used a two-way MANOVA technique to find out the statistical causal relationship among the dependent and independent variables. The two-way MANOVA is a multivariate analysis technique used for comparing one or more dependent variables across two or more than two independent variables. It allows us to look for differences across several dependent and independent variables. It creates a linear combination of the dependent and independent variables to test if there is any difference across the levels/categories of the independent variables on that linear combination of the dependent variables [62].

Other possibilities for using MANOVA could be assessing the relationship between independent variables or dependent variables and the relationship between independent and dependent variables. To run two-way MANOVA, there must be more than one dependent variable to better understand which variable or a reference category of the variable carries statistical significance across the several levels of the independent variables. Some cautions need to be considered while using MANOVA. The MANOVA is a more complicated design, and it requires subjective assumptions to remove the ambiguity of which independent variables impact dependent variables. We used MANOVA due to the following reasons. First, our group of dependent variables consists of binary and categorical variables. Second, for MANOVA, there must be different groups and different outcome variables; our research considers a large number of samples, particularly focusing on multiple indicators related to women's health. Third, this technique is suitable for the multivariate factor analysis and multi regression analysis of variance and simultaneously tests the explanatory variables' effects. Since multivariate variance can deal with numerous dependent variables at the same time, it provides some benefits in terms of statistical correctness and efficiency over other types of variance analysis. MANOVA is preferable if the researcher intends to minimize error probability and overcome the issue of dependent variable correlation. Compared to ANOVA and ANCOVA, MANOVA has the ability to test the differences of the linear combination of multiple response variables. Consequently, MANOVA is also a preferred method over structural equation modeling and partial least squares because it can work on very large data with binary and categorical types of variables. In contrast, multiple regression is commonly used in the association between independent variables and dependent variables and logistics regressions are preferable with binary types of variables. Thus, based on the type of variables, multiple constructs, differences between groups of the entities, and sample size, MANOVA is an appropriate technique for our model.

This study used two-way MANOVA for the analysis of the results, which can be expressed through the following equation (1).

$$Y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \varepsilon_{ijk} \tag{1}$$

Where, Y_{ijk} = dependent variables.

μ = vector of overall mean, τ_i = Vector of ith, the main effects of the independent variables (type of cooking fuel), β_j = Vector of jth, the main effects of the independent variables (food cooked in house/separate building/outdoor), and $(\tau\beta)_{ij}$ = vector interaction between independent variables.

For the independent variable, type of cooking fuel, we assume, H_0: $\tau_1 = \tau_2 = \tau_3 = \tau_4 = \tau_5, \tau_6, \tau_7 = \tau_8 = \tau_9 = \tau_{10} = \tau_{11}$, that is the vector means of the dependent variables. Otherwise, if H_1: H_0 is false, then the vector means of the dependent variable are not equal across the group. Similarly, for the second independent variable, food cooked in house/separate building/outdoor, we assume, H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4$, that is the vector means of dependent variables. Otherwise, if H_1: H_0 is false, then the vector means of the dependent variable are not equal across the group.

3.3. OLS

Second, to have more comprehensive and comparative results, the ordinary least square (OLS) technique using STATA^{MP}.16 was also run to examine the impacts of household air pollution on women's health. STATA ith command was used to investigate the approximation of causal association between the reference categories/levels of the explanatory variables. Table 1 shows the description of each variable used in this study. We firstly combined all the datasets of three countries to examine the overall impact on women's health. Similarly, we assessed each country's household air pollution impact on women's health.

4. Results and discussion

4.1. Results of household air pollution

Table 2 provides a statistical summary of the variables. Based on this data, the empirical results provide essential policy suggestions to policymakers and government personnel. The values of standard deviation, skewness, and kurtosis of the two variables, type of cooking fuels and respondent's occupation (grouped), are relatively higher, indicating a bit abnormal distribution of the data of the particular variables. It is because these are categorical variables with more than 11 reference levels for each. Similarly, skewness and kurtosis values of the variable, currently pregnant, are also a little higher due to its categorical nature. Keeping in the number of dependent variables in MANOVA, the number of dependent variables is more, but still, the statistical summary indicates the overall normal distribution of the data.

Fig. 1 shows the results of the type of cooking fuels used in each country. Firewood and natural gas are the two widely consumed cooking fuels, respectively. Almost 45% in Pakistan, 49% in India, and 48% of households in Bangladesh use firewood for cooking practices. Also, natural gas is the second common cooking fuel in Pakistan, India, and Bangladesh, with 48%, 35%, and 18%, respectively. Interestingly, dung and crops collectively make the second-highest percentage of usage in Bangladesh with 31%, and a considerable population also relies on animal manure and crops in India as well.

Fig. 2 describes the results of the places to cook food in the house which is another prime indicator of household air pollution. The figure shows that around 92% of households in Pakistan and 82% in India cook their foods in the house, indicating that it has potential risk for household air pollution. In contrast, around 75% of

Table 1
Description of the variables.

Variable		Items	Explanation
Independent	Household air pollution	HV226	Type of cooking fuel
		HV241	Food cooked in the house/separate building/outdoors
Dependent	Health indicators of women	HV219	Sex of head of household
		HV025	Type of place of residence
		V717	Respondent's occupation (grouped)
		V106	Highest educational level
		V213	Currently pregnant
		V228	Ever had a terminated pregnancy
		V319	Years since sterilization
		V320	Age at sterilization
		V214	Duration of current pregnancy

Note: Names and labels of the items/variables were taken from the acquired data and presented as it was. The authors did not change the names, instead, provided an explanation or definition of the variables.

Table 2
Statistical summary of each explanatory variable of the combined dataset.

Variables	Mean	S. D	Skewness	Kurtosis
Type of cooking fuel	6.22	5.598	11.386	179.183
Places of cooking	0.48	0.500	0.070	−1.995
Sex of head of household	1.13	0.340	2.160	2.665
Type of place of residence	1.69	0.463	−0.809	−1.345
Respondent's occupation	1.77	3.740	12.379	304.953
Highest educational level	1.07	0.988	0.314	−1.163
Currently pregnant	0.03	0.182	5.129	24.304
Ever had a terminated pregnancy	0.23	0.420	1.288	−0.342
Duration of current pregnancy	5.04	2.234	-.014	−1.202
Years since sterilization	5.59	1.146	−2.896	7.298
Age at sterilization	4.06	1.548	−1.179	−0.402

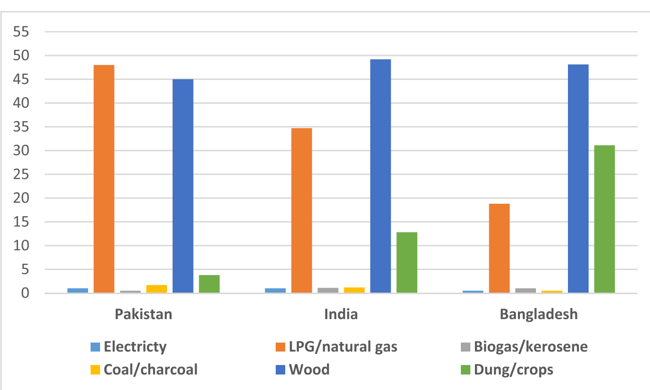

Fig. 1. Type of cooking fuel.

the population in Bangladesh uses a separate portion for cooking, whereas 22% of the population prefers outdoor cooking, making it relatively secure for household air pollution. But it produces massive outdoor air pollution because it is shown in Fig. 1 that a major portion of the population is dependent on solid fuel consumption. Taking into account the results of both graphs: 1) Fig. 1 demonstrates that firewood is the most widely used solid cooking fuel in the most populous countries of South Asia; 2) Fig. 2 shows that food is mostly cooked inside the house or in the dwelling area rather than in a separate properly ventilated place (kitchen). Thus, when firewood or any other inefficient cooking fuel is burnt for cooking inside the house with no proper ventilated system, it envisages household air pollution that can have health consequences for the person involved in cooking primarily and the other family as well.

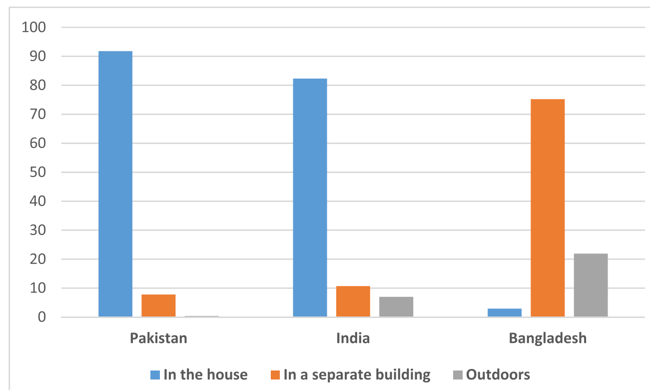

Fig. 2. Results of places for cooking practices.

4.2. MANOVA results

To run MANOVA, it is a prerequisite to fulfill all its assumptions. First, there should be at least two or more dependent variables, and they need to be measured in interval or ratio level. The model has nine dependent variables mixed up of categorical, binary, and continuous in nature. Interestingly, SPSS Statistics software refers to those levels collectively at scale. There is no choice of ratio or interval that means it is either interval or ratio. There is no way to distinguish between the dependent variables. They are treated the same. Second, there should be one or more independent variables and they must have two or more categories/levels. Table 3 shows that the model also meets this assumption. There are two independent variables, and both are categorical with more than three levels. The type of cooking has 11 and places of cooking have 4 levels. It is important to note that the levels of both independent variables are unequal in numbers (N), therefore, the study consults Scheffe instead of Tukey variance for the fulfillment of the post hoc test of this model. Tukey is normally used when the levels/categories of the factorial independent variable are equally distributed.

Third, the observations need to be independent with a sufficient sample size; specifically, it should have a minimum number of samples for each level of the independent variable. The survey data meet this assumption as well because the model has a sufficient sample size to run MANOVA. MANOVA assumes multivariate normality and is sensitive to outliers. Fourth, there needs to be a linear relationship between each pair of the dependent variables across each level of independent variables. Fifth, it also needs homogeneity of covariance matrices, and it is tested as part of MANOVA. Lastly, the dependent variables of MANOVA cannot be

Table 3
Results of between-subject factors of independent variables.

Between-Subjects Factors			
		Value Label	N
Type of cooking fuel	1	Electricity	6230
	2	LPG	217827
	3	Natural gas	3295
	4	Biogas	5980
	5	Kerosene	299
	6	Coal, lignite	6580
	7	Charcoal	3548
	8	Wood	289759
	9	Straw/shrubs/grass	9895
	10	Crops	13946
	11	Animal dung	42969
Places of cooking	1	In the house	495345
	2	In a separate building	63079
	3	Outdoors	41718
	4	In a kitchen	186

multicollinear. Following that, Table 4 describes Box's test results for the observed covariance matrices across the dependent variables of the MANOVA model. The results show that F-statistics is significant at the level $p < 0.01$, therefore, the model is unable to reject the null hypothesis that the covariance matrices of the dependent variables are equal across groups. The reasons could be, of course, the huge sample size with missing values, and the model also has a large sample of dependent variables, which are binary, categorical, and continuous.

The multivariate analysis examines the single and combined impact of the type of cooking fuel and the places of cooking (as the factors of household air pollution) on the women's health, such as pregnancy and sterility. Box's test of equality of covariance matrices with insignificant impact and Wilk's lambda significant impact determines the association of independent variable on the dependent variable. Table 5 presents the results of multivariate tests based on the combined dataset of Pakistan, India, and Bangladesh. If the model meets all assumptions, in other words, there is no violation of any assumption, Wilk's Lambda test is consulted to assess the robustness of the model. On the contrary, if the model does meet the assumptions, Pillai's Trace value is consulted. In this case, the results of Wilks' Lambda test were found at a significant level, $p < 0.01$ and $p < 0.05$ for both variables, respectively, which indicates no assumption of homogeneity and multicollinearity were violated. Even if any of the assumptions would have been violated, still, Pillai's Trace test is found significant at the levels 0.01 and 0.05. In addition, the study revealed significant results of Roy's Largest Root test at $p < 0.01$, which has also confirmed the robust results, free from any normality of data issue.

Since the study did not violate any assumptions, we then checked the cause-and-effect size between household air pollution (independent variables) and women's health (outcome variable). Results of tests of between-subject effects are presented in Table 6.

Table 4
Results of Box's test of equality of covariance.

Box's Test of Equality of Covariance Matrices[a]	
Box's M	2595.225
F	12.530
df1	196
df2	26081.887
Sig.	.000

Tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups.
[a] Design: Intercept + HV226 + HV241 + HV226 * HV241.

The results revealed that the type of cooking fuel has a significant cause and effect on the type of place of residence, respondent's educational level, ever had a terminated pregnancy, age at sterilization, and duration of current pregnancy. The empirical results further revealed a significant cause and effect of places of cooking practices with the age at sterilization only. However, there was no significant empirical relationship found between the places of cooking and occupation, education ever had terminated pregnancy, years since sterilization, ever had a terminated pregnancy, and duration of current pregnancy.

Table 7 presents the results of univariate tests between the factors of household air pollution and indicators of woman's health. It is, again, evident that the results of univariate analysis slightly differ but overall endorse the findings of the multivariate test. The types of cooking have a statistically significant association with all indicators, such as residence, occupation, education, pregnancy, and sterilization. However, cooking places do not have any significant empirical relationship with other indicators except for occupation and age at sterilization of women.

At last, Table 8 gives an overview of Post Hoc test results using Scheffe variance matrices (because the levels of independent factorial variables are unequal, as stated above). The results show a multiple comparative analysis of differences between each level of the independent variable of household air pollution to each dependent variable of woman's health. For a terminated pregnancy, the difference between cooking in the house, in a separate building, and the kitchen was significant, which indicates that there was a statistically significant difference between cooking in the house, in a separate building, and the kitchen one ever had terminated pregnancy dependent variable. Similarly, there was also a significant difference between cooking outdoors, in the kitchen, and a separate building in the years since sterilization and age at sterilization. On the contrary, none of them had any statistically significant difference on the duration of the current pregnancy dependent variable.

4.3. Results with OLS regression

To examine a more comprehensive and robust analysis of the empirical relationship between household air pollution and women's health variables, we applied the OLS regression. Table 9 provides the results of the relationship between the exogenous variables and endogenous variables using the *i*th command in STATA. The findings revealed that the type of cooking fuel had a significant positive link with residence (rural). The combined data

Table 5
Results of multivariate tests.

Multivariate Tests[a]					
Effect		Value	F	Hyp. df	Sig.
Type of fuels	Pillai's Trace	.221	9.585	77.000	.000
	Wilks' Lambda	.788	10.176	77.000	.000
	Hotelling's Trace	.257	10.763	77.000	.000
	Roy's Largest Root	.205	60.309[c]	11.000	.000
Places of cooking	Pillai's Trace	.013	2.009	21.000	.004
	Wilks' Lambda	.987	2.011	21.000	.004
	Hotelling's Trace	.013	2.013	21.000	.004
	Roy's Largest Root	.010	4.428[c]	7.000	.000

a. Design: Intercept + HV226 + HV241 + HV226 * HV241.
b. Exact statistic.
c. The statistic is an upper bound on F that yields a lower bound on the significance level.
d. Computed using alpha = .05.

Table 6
Results of effects of Between-Subjects.

Tests of Between-Subjects Effects					
Source	Dependent Variable	Sum of Sq.	Mean Sq.	F	Sig.
Type of fuels	Residence	98.071	8.916	55.322	.000
	Occupation	739.840	67.258	1.218	.269
	Educational	30.723	2.793	2.673	.002
	Ever had a terminated pregnancy	4.923	.448	2.916	.001
	Years since sterilization	14.500	1.318	.848	.592
	Age at sterilization	8.500	.773	6.882	.000
	Duration of current pregnancy	77.669	7.061	2.043	.021
Places of cooking	Residence	.501	.167	1.035	.376
	Occupation	322.465	107.488	1.947	.120
	Educational	4.699	1.566	1.499	.213
	Ever had a terminated pregnancy	.327	.109	.709	.547
	Years since sterilization	5.074	1.691	1.087	.353
	Age at sterilization	1.584	.528	4.701	.003
	Duration of current pregnancy	16.456	5.485	1.587	.190

Table 7
Univariate test results.

Univariate Test Results					
Source	Dependent Variable	Sum of Sq.	M. Sq.	F-value	Sig.
Type of fuels (contrast)	Residence	76.005	6.910	42.875	.000
	Occupation	4906.823	446.075	8.079	.000
	Educational	47.486	4.317	4.131	.000
	Ever had a terminated pregnancy	9.539	.867	5.649	.000
	Years since sterilization	164.508	14.955	9.615	.000
	Age at sterilization	189.968	17.270	153.802	.000
	Duration of current pregnancy	99.084	9.008	2.606	.003
Cooking place (contrast)	Residence	.339	.113	.701	.551
	Occupation	368.212	122.737	2.223	.083
	Educational	4.280	1.427	1.365	.252
	Ever had a terminated pregnancy	.217	.072	.471	.703
	Years since sterilization	4.163	1.388	.892	.444
	Age at sterilization	.864	.288	2.565	.053
	Duration of current pregnancy	13.529	4.510	1.305	.271

results also confirmed the type of fuel had a significant impact on the three reference categories of the variable years since sterilization and four levels of age at sterilization. Further, the results also show that the places of cooking were statistically linked with rural residence in rural areas and primary education as well. A significant relationship with currently pregnant, years since sterilization, and age at sterilization was also found. Overall, the combined results revealed the type of cooking fuel and cooking areas are the most concerning for the women years since sterilization and age at sterilization.

This study endorsed and advanced some empirical findings of the previous studies in other regions of the world focusing on the same issue. Some previous studies reported the impacts of household multidimensional energy poverty [63], solid fuel consumption, and household air pollution [17,64–68] on woman's health.

Besides household air pollution from the combustion of solid fuels, other studies also reported the influence of technological devices; for instance, the frequent use of humidifiers causes a headache; on the other hand, high humidity levels and unclean humidifiers can produce respiratory diseases [69]. These energy-efficient pieces of equipment can intervene to restrict the ventilation system and increase concentration levels of indoor pollutants

Table 8
Results of Post Hoc tests with Scheffe variance for the places of cooking.

Multiple Comparisons					
Scheffe Dependent variable		In the house	Separate building	Outdoors	Kitchen
Ever had a terminated pregnancy	In the house	–	.05*** .082	.06 .211	.07** .027
	In a separate building	-.05*** .082	–	.00 .999	.02 .888
	Outdoors	-.06 .211	.00 .999	–	.02 .962
	In a kitchen	-.07** .027	-.02 .888	-.02 .962	–
Years since sterilization	In the house	–	-.43* .000	-.44* .000	-.42* .000
	In a separate building	.43* .000	–	-.01 .999	.01 1.000
	Outdoors	.44* .000	.01 .999	–	.02 .998
	In a kitchen	.42* .000	-.01 1.000	-.02 .998	–
Age at sterilization	In the house	–	.37* .000	.37* .000	.36* .000
	In a separate building	-.37* .000	–	.00 1.000	.00 .999
	Outdoors	-.37* .000	.00 1.000	–	-.01 .997
	In a kitchen	-.36* .000	.00 .999	.01 .997	–
Duration of current pregnancy	In the house	–	-.06 .939	.08 .934	.02 .998
	In a separate building	.06 .939	–	.14 .814	.08 .947
	Outdoors	-.08 .934	-.14 .814	–	-.06 .988
	In a kitchen	-.02 .998	-.08 .947	.06 .988	–
Residence	In the house	–	-.04 .341	-.05 .334	-.06 .125
	In a separate building	.04 .341	–	-.01 .983	-.02 .896
	Outdoors	.05 .334	.01 .983	–	-.01 .993
	In a kitchen	.06 .125	.02 .896	.01 .993	–
Occupation	In the house	–	-.87 .131	.17 .990	.03 1.000
	In a separate building	.87 .131	–	1.04 .349	.90 .431
	Outdoors	-.17 .990	−1.04 .349	–	-.14 .997
	In a kitchen	-.03 1.000	-.90 .431	.14 .997	–
Education	In the house	–	-.12 .146	-.20* .035	-.03 .975
	In a separate building	.12 .146	–	-.08 .787	.09 .706
	Outdoors	.20** .035	.08 .787	–	.17 .287
	In a kitchen	.03 .975	-.09 .706	-.17 .287	–

Based on observed means. The error term is Mean Square (Error) = 1.045.
*, **, ***. The mean difference is significant at the 0.01, 0.05, 0.1 levels, respectively.

[70]. Similarly, other technologies such as televisions, refrigerators, computers, etc., emitting VOCs (Volatile organic compounds) can cause several health-related issues, from simple allergy-related symptoms to major diseases [71,72]. Furthermore, electronic wastages, comprised of discarded equipment, such as microwave ovens, computers, and refrigerators, have raised increasing concerns, particularly Asian countries are suffering from these wastages. The findings indicate, 1 million people in India are engaged in the manual recycling activities of electronic wastages, as a result, men, women, and children are at high risks [73].

Besides technology, households' job pollution also influences woman's health. Women perform multiple tasks in the house, and this routine work includes cooking, cleaning, and family care responsibilities [74]. The studies report [75,76] that more than 60% of women in India and 58% in Bangladesh mostly suffer back pain because of this. General cleaning like sweeping, cleaning the bathroom, and washing clothes directly impacts the lower back pain. Compared to men, women in India spent significant time on

Table 9
Health consequences of household air pollution for women using the combined dataset of Pakistan, India, and Bangladesh.

	Type of Cooking fuel	Cooking place
Sex		
Female	0.309 (1.02)	0.890 (−0.14)
Residence		
Rural	0.000*** (3.57)	0.000** (8.40)
Occupation		
Professional/technical/managerial	0.447 (0.76)	0.716 (0.36)
Sales	0.097* (−1.66)	0.862 (−0.17)
Agricultural - self employed	0.458 (−0.74)	0.000*** (30.24)
Household and domestic services	0.763 (0.30)	0.866 (0.17)
Skilled manual	0.400 (−0.84)	0.405 (−0.83)
Unskilled manual	0.133 (−1.50)	0.418 (−0.81)
Education		
Primary	0.192 (−1.30)	0.047** (1.98)
Secondary	0.036** (2.10)	0.278 (1.08)
Higher	0.845 (−0.19)	0.670 (0.43)
Currently pregnant		
Yes	0.680 (−0.41)	000*** (−10.87)
Ever had a terminated pregnancy		
Yes	0.148 (1.45)	0.670 (0.43)
Duration of current pregnancy		
2	0.664 (0.43)	0.797 (−0.26)
3	0.992 (−0.01)	0.512 (0.66)
4	0.458 (0.74)	0.471 (−0.72)
5	0.473 (0.72)	0.680 (0.651)
6	0.779 (0.28)	0.164 (0.45)
7	0.348 (0.94)	0.944 (−0.07)
8	0.222 (1.22)	0.799 (−0.25)
9	0.370 (−0.90)	0.130 (−1.51)
10	0.505 (0.67)	0.405 (−0.83)
Years since sterilization		
2-3	0.442 (0.77)	0.037** (2.09)
4-5	0.005*** (2.82)	0.182 (1.33)
6-7	0.029** (2.19)	0.796 (0.26)
8-9	0.048** (1.98)	0.000*** (−3.62)
10+	0.833 (0.21)	0.031** (−2.16)
Age at sterilization		
25-29	0.000*** (8.31)	0.000*** (4.46)
30-34	0.000*** (8.39)	0.000*** (4.63)
35-39	0.000*** (4.54)	0.304 (1.03)
40-44	0.753 (−0.31)	0.173 (1.36)
45-49	0.022** (−2.29)	0.830 (0.22)

***Significant at the level 0.01, **Significant at the level 0.05, *Significant at the level 0.1.

errands, completing chores, doing laundry, cleaning the house and cleaning the kitchen, and spending less time on physical and outdoor activities [77]. Moreover, the study suggests [76] that women living in rural areas do more work and are involved in agricultural activities, such as cattle farming and cleaning the house; therefore, these activities directly impact their health. Women and children are the main victims of pollution exposure due to spending more time i-e., 90% in an indoor rather than outdoor environment. A study reveals that girls below the age of 5 and females in 30–60 age groups (who are usually the chief cooks in a family) are at higher risks than males in the same age groups [78].

The use of biomass with traditional cooking technologies causes household air pollution and is responsible for 3.5 million deaths globally [79]. In developing countries, exposure to household wood smoke from cooking is a risk factor for chronic obstructive lung disease among women [80]. Chronic obstructive pulmonary disease (COPD) in developing countries [81,82] is responsible for 2% of the total global burden of disease. Moreover, COPD is projected to rank as the third-leading cause of death among women in the world by 2015 [83]. Furthermore, women who spend a large part of their day inside the kitchen can suffer from a variety of adverse health effects, including; middle ear infection, tuberculosis, perinatal mortality, low birth weight, eye irritation, cataract, asthma, and oral cancer [84]. Hence, more prone to aerosol, VOCs, fumes, and tobacco.

Solid fuels for cooking affect women's pregnancy, both as a fetus and as the youngster progresses through adolescence. Living in a poorly ventilated system is highly risky, which may be the major contributor to high mortality rates. If this is the situation, women who inhale the smoke for hours every day suffer from respiratory diseases [85]. A kitchen is a place where women often move to prepare meals and the biggest source of pollution (if there is no proper ventilation system), which is one of the reasons that housewives are prone to diseases [86]. The findings of the previous studies also confirmed the adverse consequences of household air pollution on health. For instance, empirical evidence shows cooking with dirty fuels is a health risk for women in China [87]. The findings of other studies show that the use of unclean fuel, like, charcoal, animal's dung, burning wood, and kerosene is a threat to women and children [88]. Similar to these findings, the results of [89] suggest that household air pollution from cooking increases the health risks and impacts women's pregnancy. Our results support these findings and further provide a more detailed analysis with a range of multiple indicators related to the type of cooking and place of cooking and its influence on pregnancy, duration of a pregnancy, and age at sterilization, which is a new insight in our findings. The results of this study provide important implications to the countries (Pakistan, India, and Bangladesh), where women are particularly affected by pregnancy losses [90] and are in line with the studies concerning pollution from burning animal dung, straws, and agricultural waste affects the woman's health [91].

5. Conclusion and policy suggestions

The present study aimed to understand the increasing household energy consumption specifically in cooking practices and, subsequently, analyze its impacts on women's health specifically pregnancy and sterilization in Pakistan, India, and Bangladesh. Overall, the MANOVA and the OLS results demonstrated that the type of cooking fuels and places of cooking had significant effects on the indicators of women's health, such as current pregnancy, duration of pregnancy, years at sterilization, and age at sterilization. Pakistan, India, and Bangladesh are the countries where women are the front liners who cook for their families; therefore, household air pollution produced by fossil fuel consumption for cooking is undoubtedly a high risk for women without efficient and health-friendly cookstoves.

The empirical evidence shows that place of cooking impacts women's health, particularly on ever had a terminated pregnancy, age at sterilization, and duration of current pregnancy. Women in the rural areas are responsible for collecting wood and agricultural wastages, and usually, females are the main cooks for preparing food. It is understood that woman's health is affected excessively due to the inefficient fuel consumption for the cooking practices, of which contaminated fuel is the main source. Type of fuel is one the main contributors to environmental impact in households. We must analyze whether coal, charcoal, natural gas, wood, biogas, dung/crops, etc., make up the majority of fuel consumption for the cooking practices in the households. In this regard, recent studies report the risk of diseases such as preeclampsia, lower gestation age, and gestational hypertension among contaminated fuel users [92,93].

Our study identified that the rates of consumption of unclean fuels for cooking are relatively high in these countries. It employs that these three Asian countries do not have adequate policies to curb the adverse impact of contaminated fuel consumption on woman's health. To reduce dirty fuel consumption, governments are required to invest in renewable energy technologies and promote an efficient energy system for the public, for example, solar or electric cookers in rural areas [94]. In contrast, a significant amount of household's income on buying cooking fuel accounts for spending a large proportion of income. Mostly, low-income people find it expensive and difficult to buy modern cooking stoves; therefore, the government should ease taxes and initiate programs of efficient cookstoves. On the other hand, the government should subsidize fuel prices to assist basic expenditures [63]. If people reduce the usage of firewood, animal dung, and crop, it will ultimately reduce environmental degradation. Accordingly, the need is to build a mechanism to transform the energy system into a clean energy option to protect the health and environment. Furthermore, the reliance on traditional cooking fuels can be minimized with a network of natural gas pipelines in remote and rural areas [11].

The empirical evidence also shows that a place of cooking impacts women's health, particularly on age at sterilization. There is a dire need to reduce contaminated pollutants through improved cookstoves and changing housing structure design [89,95]. For example, a separate kitchen, ventilation of the house, installing chimneys can prevent exposure to pollutants. Since poor ventilation is a health risk, the government should pay attention to rural areas and struggle to promote the rural economy. As these countries are also the most populous in South Asia, with around 25% of the population living in these countries, our results depict that residence is also an important factor. Large families with poor housing and congested living conditions can be vulnerable to household hazards. Women and children spend most of their time at home; therefore, healthy homes and better living conditions can promote good physical and mental health. The government should establish housing schemes and provide a better living environment. The governments should introduce housing schemes under a public-private partnership or joint ventures with the private sector to build affordable houses.

Growing population, dependency on fossil fuels, unawareness and lack of education, and lack of technological advancement are the other similar issues that further exacerbate the economic and political conditions to address the issue. On the other hand, most people are not educated or unaware of health consequences; therefore, there is a need to promote education and awareness against the harmful substances that affect woman's health. Such initiatives by the government can increase awareness among people, which can be beneficial to understanding the intensity of hazardous pollutants and their impacts on health.

Credit author statement

Mansoor Ahmed: Conceptualization, Data curation, Methodology, Software, Writing – original draft. Chuanmin Shuai: Formal analysis, Supervision, Writing – review & editing. Khizar Abbas: Methodology, Software, Writing – review & editing. Faheem Ur Rehman: Writing – review & editing, Visualization. Wali Muhammad Khoso: Writing – review & editing, Visualization.

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.energy.2022.123562.

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