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A Comparative Investigation of the Impact of Two Different Charcoal Stove Configurations on Polycyclic Aromatic Hydrocarbons and Particulate Matter Emissions

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Abstract

Due to dwindling income occasioned by inflation, vast numbers of Nigerians have reverted to charcoal stoves to meet or supplement their domestic energy need. Two brands of charcoal stoves (local and modernized) presently in use in Nigeria were investigated for their contributions to indoor level of polycyclic aromatic hydrocarbons (PAHs). The two stoves were loaded with equal quantity of wood charcoals and allowed to burn for 2-hours a day in separate rooms of equal sizes. Passive sampling involving the use of polyurethane foam (PUF) disks was adopted and the PUF disks were withdrawn after 3 and 7 days for laboratory analysis. Gas Chromatography – Mass Spectrometer (GC-MS) analytical procedures were used for the determination of the PAHs concentrated on the PUF disks. The total PAH concentrations after 3 days were 1.74 μg/m^3 and 0.61 μg/m^3 for local and modern charcoal stoves respectively while their corresponding total concentrations after 7 days were 2.91 μg/m^3 and 2.01 μg/m^3. The modern charcoal stove showed better performances over the two durations. However, the total PAHs concentrations from both stoves exceeded the ambient air recommended limits. Giving the carcinogenic tendencies of some of the PAHs, the study concluded that none of the two stoves is safe for indoor application.

Keywords**:** Charcoal, Charcoal stove, Coal pot, PAHs, Passive sampling, Indoor air pollution

1.0 INTRODUCTION

Domestic cooking is an essential aspect of everyday life all over the globe as food is essential for the survival of humanity. Closely associated with food is the energy source needed to get the cooking done. There has been a strong call globally for adoption of safe, clean and environmental friendly fuels and quite a number of efforts are currently on-going on development of clean fuels. This is largely due to the human and environmental health associated with some fuels.

In Nigeria, the popularity of liquefied petroleum gas (LPG) as a clean fuel has increased in the last years. The LPG consumption in the country grew from about 300, 000 metric tonnes in 2015 to around 470, 000 metric tonnes in 2018 with 2018 LPG penetration level being about 15.9% increase over the 2017 value [1]. Extracts from the summit held on LPG in Nigeria in 2019 revealed that the local consumption had reached 1 million metric tons and the projection for 2020 was 2 million metric tons [2]. Despite this growth, only a small fraction of the entire population is currently making use of LPG. Report showed that only 1.5 million households representing about 5% of the entire household in the country have been captured with the present growth in LPG consumption [3].

Upon this premise, it is safe to infer that the bulk of Nigerian populace still rely on less clean fuels. Business Day, a news medium in Nigeria had reported that up to 80 million rural dwellers have not been captured by the Nigeria LPG market [4]. These estimates were based on the fact that up to 70% of the Nigerian populace dwells in rural area according to Nigeria's National Population commission. The per capita LPG consumption in Nigeria is still very much lower than what is obtainable in some African countries despite the fact that Nigeria has huge gas reserve [5]. According

to International Center for Energy and Environmental Development (ICEED), fire wood, charcoal and kerosene presently constitute up to 72% percent of domestic energy source in the country and 90% among rural dwellers in Nigeria [4,6].

The drive towards increasing LPG penetration may have suffered a setback from mid 2021 because of the recent increase in LPG price and general inflation which have robbed increasing number of middle income class of their purchasing power. The price of 12.5 kg bottle of LPG increased from an average of N4000 to N8000 ($1= N 415 based on official rate); an increase of about 100%. Without corresponding increase in income, many Nigerians who had earlier adopted LPG have either totally or partially reverted to charcoal stoves to cater for their domestic cooking energy needs [7,8]. This is mostly true of middle and low income earners which form the bulk of Nigeria's population.

Charcoals, being of biomass origin are associated with emissions of polycyclic aromatic hydrocarbons (PAHs) when burnt because the combustion processes are largely incomplete [9,10]. PAHs are associated with serious human health hazards because of their carcinogenic, mutagenic and teratogenic tendencies [11-16]. Recent reports from toxicology and epidemiology studies have indicated an increase in the prevalence of cancer related diseases in Nigeria [17]. The recent hike in price of domestic cooking gas (LPG) in Nigeria has undoubtedly resulted in increase in usage of charcoal stoves (popularly called coal pot), thereby increasing the probability of exposure to carcinogens such as PAHs.

Quite a number of studies on measurement of PAHs have been undertaken recently in Nigeria. Ana et al. [18] studied the presence of PAHs in the ambient air of some oil producing communities of Niger Delta. Adesina et al. [15] studied the spatio- temporal occurrence of PAHs in the neighbourhood of medical wastes disposal facilities. The effects of PAHs emission from vehicular activities on ambient air were considered by Fakinle et al. [19]. Adesina et al. [16] also investigated the presence of PAHs in air and soil around municipal open dumpsite. Studies have also been conducted to investigate the presence of PAHs in Nigerian soils [20-23]. The studies have also been extended to various water bodies [24-27]. None of these studies considered the impact of charcoal stoves on indoor levels of PAHs.

Most charcoal stoves are used in the indoor environment (kitchen) just like the LPG stoves giving rise to serious indoor air pollution concern. There is no doubt that the price of LPG has increased and further increase is anticipated in the nearest future as the Federal Government has communicated its intention to withdraw subsidies it currently pays on imported refined petroleum products in the first quarter of 2022. The utilization of charcoal stoves is therefore likely to assume permanence in the face of dwindling disposable income. Owing to the reported increase in the incidence of cancer related diseases; the present study investigated the indoor concentrations of PAHs and particulate matter from two different charcoal stove configurations that are presently in use in the country by passive sampling of the emitted smoke. Passive samplers are affordable and easy to assemble. They consist of polyurethane foam and stainless steel plates arrangement erected at desirable heights. The sampling process involves diffusion of PAHs laden emissions to the surface of the PUF which is subsequently extracted and determined by appropriate laboratory and analytical procedures. The present study was carried out with a view to establishing if any of the stove configurations is safe for indoor application even over a short time period.

2.0 METHODOLOGY

2.1 Materials Used and Sample Collection

The materials used for the experiment include wood charcoals which were sourced from open local markets in Nigeria and two different configurations of charcoal stoves that are mostly used in the country. Figure 1 and Figure 2 show the two charcoal stoves. The first is a locally fabricated stove while the second is a modernized charcoal stove. Other materials include the polyurethane foam (PUF) passive samplers which were used for air sampling. Each passive sampler was made of two different sizes of stainless steel bowls of diameter (20 and 22 cm) and polyurethane foam having a surface area of 102 cm^2.

Figure 1. Flowchart of the study.

Figure 2: Modern charcoal stove (MS)

Pre-cleaning of the PUF disks was achieved by washing with distilled water followed by additional washing with acetone and petroleum ether in two separate 24 h processes. The PUFs were dried in a dessicator, enclosed in an aluminum foil and taken to the experimental rooms [15,16]. Equal masses of charcoals were fed into the two stoves and ignited in two indoor environments (rooms) of the same size. The window arrangement in most middle income owner's houses in Nigeria is the aluminum sliding window type. These were open half way in the two experimental rooms to match the real life cooking scenario in most houses. The burning processes in the two rooms were commenced simultaneously and stopped after 2 hours to ensure uniformity. Polyurethane foam (PUF) passive samplers positioned at equal distances from the stoves were used to collect air samples. The PUFs were withdrawn after 3 and 7 days. For passive sampling of particulate matter, equilibrated pre-weighed filter papers were placed inside petri dishes in the experimental rooms alongside the PUFs. The surfaces of the filters were completely left open. The filters were withdrawn after 24 – hours and re-weighed. The quantity of particulate matter deposited was determined by gravimetric procedure based on total air volume of 3 m^3/day [28, 29].

2.2 Sample Processing And Analysis For Determination of PAHs

Sohxlet extraction procedure using dichloromethane was conducted for 24 h to extract the PAHs from the PAH laden PUFs. Cleaning up and elution were done with 5 g of silica gel column and and 40 mL 1:1, DCM:Hexane followed by concentration in a rotary evaporator using a stream of nitrogen. Analysis of the samples was achieved with gas chromatography (Agilent 7890) with mass detector (Agilent 5975) that was done in selected ion monitoring mode and using electron impact ionization. The chromatographic column has a dimension of 30 m × 0.25 mm with internal diameter × 0.25 µm film thickness. The temperature program for the analytical procedure was set as: 90 °C (1.0 min), 30 °C/min, 250 °C, 4 °C/min, 330 °C (5 min).

PAHs were determined in laboratory and field blanks and external standard method was adopted to quantify PAHs. Pre-extraction procedure involved spiking of the samples with 25 mL of recovery standard (RS) which contained 20 ng of phenanthrene d10 recovery ranged between 80 and 90%. Field blanks were below detection limit for all compounds of interest; therefore, no blank correction was required. The concentrations of PAHs in air were obtained by dividing the amount deposited on the PUF (µg) by air volume (m^3). Global Atmospheric Passive Sampling (GAPS)

network template was used for the computation of the effective air volume. Duration of deployment, mean temperature, rate of sampling were the template input parameters [30, 31].

3.0 RESULTS AND DISCUSSION

3.1 PAHs from locally fabricated charcoal stove

Table 1 shows the 3-day and 7-day concentrations of PAHs obtained from the GCMS analysis of PUFs exposed to emissions from the deployment of the locally fabricated charcoal stove that is commonly used in Nigeria. Out of the sixteen priority PAHs, ten were detected in the two burning scenarios (3 and 7 days). The observed PAHs were naphthalene (Nap), acenaphthene (Ace), fluorine (Flu), phenanthrene (Phe), anthracene (Ant), fluoranthene (Flt), pyrene (Pyr), benzo[a]anthracene (BaA), chrysene (Chy) and benzo[k]fluoranthene (Bkf). In the two scenarios, one low molecular weight PAH (acenaphthylene (Ace)) was not detected while remaining undetected PAHs were of high molecular weight and these include benzo[b]fluroanthene (BbF), benzo[a]pyrene (BaP), indeno(1,2,3-cd)pyrene (IndP), dibenzo[a,h]anthracene (DahA) and benzo[g,h,i]perylene (BghiP).

Table 1: Concentrations of PAHs from local charcoal stove (μg/m^3)

	3-days			7-days		
PAHs	S_1	S_2	Mean	S1	S2	Mean
Naphthalene	0.37	0.389	0.3795	0.401	0.503	0.452
Acenaphthene	0.1	0.103	0.1015	0.22	0.241	0.2305
Acenaphthylene	NA	NA	NA	NA	NA	NA
Fluorene	0.271	0.29	0.2805	0.302	0.289	0.2955
Phenanthrene	0.298	0.292	0.295	0.402	0.335	0.3685
Anthracene	0.1	0.09	0.095	0.221	0.403	0.312
Fluroanthene	0.114	0.121	0.1175	0.313	0.41	0.3615
Pyrene	0.092	0.11	0.101	0.325	0.391	0.358
Benzo[a]anthracene	0.1	0.1	0.1	0.121	0.158	0.1395
Chrysene	0.277	0.255	0.266	0.401	0.375	0.388
Benzo[b]fluroanthene	NA	NA	NA	NA	NA	NA
Benzo[k]fluroanthene	0.003	0.002	0.0025	0.005	0.007	0.006
Benzo[a]pyrene	NA	NA	NA	NA	NA	NA
Indeno(1,2,3-cd)pyrene	NA	NA	NA	NA	NA	NA
Dibenzo(a,h)anthracene	NA	NA	NA	NA	NA	NA
Benzo[ghi]perylene	NA	NA	NA	NA	NA	NA

After 3-days of PUF exposure, the mean concentrations of the naphthalene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo[a]anthracene, chrysene and benzo[k]fluoranthene were 0.38, 0.10, 0.28, 0.30, 0.10, 0.12, 0.10, 0.10, 0.27 and 0.003 μg/m^3. Their corresponding concentrations after 7 days were 0.45, 0.23, 0.30, 0.37, 0.31, 0.36, 0.36, 0.14, 0.39 and 0.006 μg/m^3. These results indicated that the concentrations of PAHs increased with the duration of exposure of the PUF. The total concentrations of all the PAHs emitted after 3 and 7 days were 1.74 μg/m^3 and 2.91 μg/m^3 respectively. These concentrations are well above the permissible limit of 10 ng/m^3 set for concentration of total PAHs in air by China and European Union [16, 31]. Naphthalene was the highest contributor to the Σ PAH concentrations accounting for 21.8% and 15.5% after 3 and 7 days respectively.

The sources of polycyclic aromatic hydrocarbons in the environment are ubiquitous and several authors have reported varying concentrations of PAHs in air depending of the emitting sources. Adesina et al. [16] reported mean outdoor Σ PAH concentrations between 3.3 – 4.0 μg/m^3 in the vicinity of open burning sites for municipal wastes. In another ambient air study of PAH concentrations in the oil producing communities of Niger Delta, Nigeria, Σ PAH concentrations in the range of 0.000023 -0.074 μg/m^3 were obtained by Ana et al [18]. While the Σ PAH concentrations obtained in this study for indoor burning of charcoal were lower than those obtained by Adesina et al [16] for outdoor

burning of municipal wastes, they are clearly higher than those obtained by Ana et al. [18] for ambient environments of oil producing communities. It is instructive to state that the PUFs were exposed for 28 days by Adesina et al. [16].

The Σ PAH concentrations obtained in this study were also compared with indoor levels of PAHs from other parts of the world. For instance, Gevao et al. [28] obtained the mean Σ PAH concentrations for indoor air in Kuwait to range between 1.3 – 16 ng/m^3. Cristale et al. [33] reported indoor air total PAHs influenced by outdoor burning of sugarcane in Araraquara, Brazil as 22.9 ng/m^3 These concentrations are clearly lower when compared with Σ PAH concentrations obtained in this study.

Seven (benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeno[1, 2, 3-cd]pyrene, and Dibenzo(a,h)anthracene) of the sixteen priority PAHs have been identified as having carcinogenic tendencies. Out of the seven carcinogenic PAHs, only three were detected and these were benzo[a]anthracene, chrysene and benzo[k]fluoranthene. Their respective mean concentrations from the locally fabricated stove after 3 days of charcoal burning were 0.10, 0.27and 0.003 µg/m^3 while their corresponding concentrations after 7 days were and 0.14, 0.39 and 0.006 µg/m^3. The total concentrations of carcinogenic PAHs present after 3 and 7 days were 0.37 µg/m^3 and 0.53 µg/m^3 respectively. Although, benzo[a]pyrene, the reference PAH for carcinogenic PAHs was not detected, the presence of the three carcinogenic PAHs also poses a worrisome situation considering that it is an indoor environment with limited ventilation.

3.2 PAHs Modernized Charcoal Stove

Table 2 shows the concentrations of the emitted PAHs from modernized charcoal stove that is also in use in Nigeria. This stove was deployed simultaneously with the locally fabricated stove in a separate room but all other experimental conditions were similar. With the exception of benzo[k]fluroanthene which was not detected after 3 days of charcoal burning in the modernized charcoal stove, all other nine PAHs that were detected during the deployment of the locally fabricated stove were also detected after 7 days. Again, there was an increase in the concentrations of the emitted PAHs between 3 and 7 days of burning. Generally, the modernized stove showed slight reduction in the concentrations of the emitted PAHs over the locally fabricated stove.

Table 2: Concentrations of PAHs from modernized charcoal stove (µg/m^3)

	Modernized Stove			Modernized Stove		
PAHs	S_1	S_2	Mean	S1	S2	Mean
Naphthalene	0.285	0.273	0.279	0.38	0.401	0.3905
Acenaphthene	0.003	0.004	0.0035	0.181	0.207	0.194
Acenaphthylene	NA	NA	NA	NA	NA	NA
Fluorene	0.153	0.14	0.1465	0.279	0.29	0.2845
Phenanthrene	0.008	0.003	0.007	0.301	0.29	0.2955
Anthracene	0.005	0.002	0.005	0.205	0.248	0.2265
Fluroanthene	0.143	0.137	0.145	0.158	0.201	0.1795
Pyrene	0.036	0.03	0.033	0.108	0.09	0.099
Benz[a]anthracene	0.013	0.01	0.0115	0.105	0.122	0.1135
Chrysene	0.017	0.014	0.0155	0.22	0.31	0.265
Benzo[b]fluroanthene	NA	NA	NA	NA	NA	NA
Benzo[k]fluroanthene	NA	NA	NA	0.004	0.003	0.0035
Benzo[a]pyrene	NA	NA	NA	NA	NA	NA
Indeno(1,2,3-cd)pyrene	NA	NA	NA	NA	NA	NA
Dibenzo(a,h)anthracene	NA	NA	NA	NA	NA	NA
Benzo[ghi]perylene	NA	NA	NA	NA	NA	NA

After 3-days of PUF exposure, the mean concentrations of the naphthalene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo[a]anthracene and chrysene were 0.28, 0.004, 0.15, 0.007, 0.005, 0.15, 0.03, 0.01 and 0.02 µg/m^3 respectively while their corresponding concentrations after 7 days 0.39, 0.19, 0.28, 0.30, 0.23, 0.17, 0.10,

0.11, 0.27 μg/m^3. In addition to the nine PAHs, benzo[k]fluroanthene which was detected after 7 days had a concentration of 0.004 μg/m^3. The total PAH concentrations after 3 and 7 days were 0.61 μg/m^3 and 2.01 μg/m^3 respectively which also exceeded the permissible limit. Benzo[a]anthracene and chrysene with mean concentrations 0.01 μg/m^3 and 0.02 μg/m^3 were the only carcinogenic PAHs detected in the 3 day samples. The 7 days sample had Benzo[a]anthracene (0.11 μg/m^3), chrysene (0.27 μg/m^3) and benzo[k]fluroanthene (0.004 μg/m^3) as the present carcinogenic PAHs. The total carcinogenic PAHs after 3 and 7 days were 0.378 μg/m^3 and 0.3832 μg/m^3 respectively.

3.3 PAH Diagnostic Ratios

In the study of PAHs, it is customary to carry out source attributions which helps to identify the sources of PAHs observed in the environment under investigation. One of the methods commonly used to achieve this objective is the PAH diagnostic ratio. This is a binary ratio approach for identification of PAH source and it entails comparison of pairs of frequently found PAHs [18]. The determination of the source of PAHs with the use of specific isomeric ratios of PAHs was further buttressed by Kim et al. [34]. The ratio was described as comparison between low molecular weight PAHs to those having high molecular weight. These ratios have been reported in many published literature for different sources.

For example, the ratios Ind/[Ind +BghiP] = 0.56, Flt/[Flt +Pyr] > 0.50, Ant/[Ant +Phe] > 0.10 , BaP/BghiP = 0.90 ≤ 6.60 and BaA/[BaA +Chy] > 3.50 depict coal combustion as the source of the observed PAHs. For vehicular sources, the diagnostic ratios Ind/[Ind +BghiP] = 0.18 ≤ 0.40, Flt/[Flt +Pyr] = 0.40 ≤ 0.50, Ant/[Ant +Phe] < 0.10 , BaP/BghiP = 0.30 ≤ 0.44 and BaA/[BaA +Chy] = 0.40 ≤ 0.50. the reported diagnostic ratios that will confirm the PAHs as coming from combustion biomass materials (wood, charcoal etc) must comply with Ind/[Ind +BghiP] = 0.62, Flt/[Flt +Pyr] > 0.50, and BaA/[BaA +Chy] > 0.43 [18].

In the present study, the material that underwent combustion was wood charcoal and the marker PAHs for establishment of diagnostic ratios are indeno(1,2,3-cd)pyrene, benzo[ghi]perylene, fluroanthene, pyrene, benz[a]anthracene as well as chrysene. However, indeno(1,2,3-cd)pyrene, and benzo[ghi]perylene were not detected from wood combustion in either of the stoves investigated in this study. Alternative diagnostic ratios (Flt/[Flt +Pyr] > 0.50, and BaA/[BaA +Chy] > 0.43 thus employed. The ratio Flt/[Flt +Pyr] (Table 1) for the PUF disks exposed to emissions from the local charcoal stove and withdrawn after 3 and 7 days are 0.54 and 0.504 respectively. These ratios are clearly in agreement with the previous studies which put the ratio at any value greater than 0.5. The ratio Flt/[Flt +Pyr] for modernized charcoal stove yielded 0.81 and 0.64 after 3 and 7 days respectively. These values equally exceeded 0.5, thereby affirming that the observed PAHs were from biomass combustion sources. The application of diagnostic ratio BaA/[BaA +Chy] to PUFs exposed to emissions from the local stove for 3 days yielded BaA/[BaA +Chy] =0.425 ≈ 0.43, which also affirms that the observed PAHs were from biomass burning.

3.4 Toxicity Equivalence

The extent of toxicity of the individual PAH is usually expressed in terms of toxicity equivalence (TEQ) which is a product of toxicity equivalent factor (TEF) and the concentration of the PAH. The TEQs of the PAHs emitted by the two charcoal stove configurations are presented in Table 3. Clearly, the total TEQs (TTEQ) are in the order LS7 (0.024) > MS7 (0.018) > LS3 (0.015) > MS3 (0.002). The LS certainly emitted more emissions than the MS although both stoves are not suitable for indoor use based on observed total PAH concentrations that exceeded 10 ng/m^3 permissible limit. The present condition of use of the stoves is even more worrisome considering the fact that the PAHs are released directly into indoor environments with poor ventilation.

Table 3: Toxicity equivalent of PAHs (μg/m^3)

		Local Stove		Modernized Stove	
PAHs	TEF	3-days	7-days	3-days	7-days
Naphthalene	0.001	0.00038	0.000452	0.000279	0.000391
Acenaphthene	0.001	0.000102	0.000231	3.5E-06	0.000194
Acenaphthylene	0.001	NA	NA	NA	NA
Fluorene	0.001	0.000281	0.000296	0.000147	0.000285
Phenanthrene	0.001	0.000295	0.000369	0.000007	0.000296
Anthracene	0.01	0.00095	0.00312	0.00005	0.002265
Fluroanthene	0.001	0.000118	0.000362	0.000145	0.00018
Pyrene	0.001	0.000101	0.000358	0.000033	0.000099
Benzo[a]anthracene	0.1	0.01	0.01395	0.00115	0.01135

Chrysene	0.01	0.00266	0.00388	0.000155	0.00265
Benzo[b]fluroanthene	0.1	NA	NA	NA	NA
Benzo[k]fluroanthene	0.1	NA	0.0006	NA	0.00035
Benzo[a]pyrene	1	NA	NA	NA	NA
Indeno(1,2,3-cd)pyrene	0.1	NA	NA	NA	NA
Dibenzo(a,h)anthracene	0.1	NA	NA	NA	NA
Benzo[ghi]perylene	0.01	NA	NA	NA	NA
TTEQ		0.014885	0.023616	0.001969	0.018058

3.5 Suspended Particulate Matter Concentration

Gravimetric procedure was adopted for the determination of suspended particulate matter (SPM) in the two indoor environments. This entails the use of equilibrated filter papers whose pre and post experiment weights were taken. The levels of particulates were determined by dividing the weight difference by the volume of air sampled. The 24- hour concentrations of suspended particulate matter in the two experiment room are depicted in Table 4. The obtained values for SPM from the local and modernized stoves were 33,800 μg/m^3 and 10,000 μg/m^3 respectively. There is presently no set limit for indoor level of SPM in Nigeria, however, the permissible limit set for SPM in ambient air is 250 μg/m^3. Clearly, the indoor levels of SPM associated with the use of the two charcoal stoves markedly exceeded the outdoor permissible thresh-holds.

Table 4: Total suspended particulate matter

M1	M2	Mean	Concentration (μg/m^3)	M1	M2	Mean	Concentration (μg/m^3)
0.103	0.1	0.102	33,800	0.004	0.056	0.03	10,000

4.0 CONCLUSION

A comparative study on the PAHs emission characteristics of two different configurations of charcoal stoves that are commonly used in Nigeria was carried out. The two stove configurations were the locally fabricated and the modernized stoves. The study became imperative due to the rising cost of LPG which has forced most Nigerians to either revert wholly or partly to charcoal stoves to meet their domestic energy need in the face of dwindling income. The study found the modernized stove to emit lesser PAHs and SPM than the locally fabricated stove under identical deployment conditions. However, none of the two stoves is safe for indoor use considering the fact that the total PAH and SPM concentrations exceeded the permissible ambient air limits. The total PAH concentrations obtained in this are higher than PAHs concentrations reported for Brazil and Kuwait for indoor environments. Within the limit of experimental error, the PAH diagnostic ratio confirmed that the PAHs obtained in this study were actually attributable to wood charcoal burning. Awareness on the need to desist from usage of the charcoal stoves in an indoor environment has to be stepped up in order to safeguard the public health. The use of charcoal stoves must be restricted to outdoor environment.

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