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An Estimation of a trace gaseous emission factor from combustion of common fuelwood species in South-western Nigeria

B. S. Fakinle [a], O. B. Okedere [b], O. Seriki [c], A. J. Adesanmi [d], and J. A. Sonibare [d]

[a]Department of Chemical Engineering, Landmark University, Omu-Aran, Kwara State, Nigeria; [b]Faculty of Engineering, Osun State University, Osogbo, Nigeria; [c]Global Environmental Technology Limited, Lagos, Nigeria; [d]Environmental Engineering Research Laboratory, Department of Chemical Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria

ABSTRACT
The current electricity shortage from Nigeria's national grid and the scarcity of refined petroleum products including kerosene which is used for domestic purposes make the use of fuelwoods more dominant in the country; especially in the rural areas. Air emissions from open burning of pre-determined quantity of some common fuelwoods identified in regions were characterized for gaseous air pollutants using the E8500 combustion analyzer. The measured concentrations were used to calculate emission factors of the air pollutants. The emission factors for the gaseous emission from the fuelwoods were 181.84–6547.57 g/kg for CO, 44.07–2986.40 g/kg for HC, 2.24–267.36 g/kg for NOx while SO_2 had 0.0–9.87 g/kg. This study establishes that *Gliricidia sepium* had the minimum emission factor for all the considered gaseous pollutants except for SO_2, thus all stakeholders considering the adoption of fuelwood in the country's quest for increased energy mix can be properly guided on the pollutants associated with the investigated fuelwoods. This may help in the choice of appropriate air pollution control.

KEYWORDS
Air pollution; emission factor; energy mix; fuelwood

1. Introduction

Air emissions from biomass burning due to anthropogenic activities are one of the major sources of criteria air pollutants (Evtyugina et al., 2014). According to Singh et al. (2014), about half of the world population is using woody biomass as an energy source for cooking and heating. Fuelwood biomass, derived from natural and planted forests, has been of concern in most developing countries due to its consumption level (IEA, 2013). It has been estimated that fuelwood accounts for about 90% of the Timber harvested in Africa annually (IEA, 2002; FAO, 2007). According to Temu (2002), about 90% of people in rural area in Africa depend on either firewood or charcoal for cooking and heating. This trend appears not to have a likelihood of reversing in many decades to come (FAO, 2001; Kituyi, 2002). Apart from the prevailing use of biomass as energy source in developed and developing countries such as Austria, Finland, Germany, Sweden, and many others tend to increase the available stock of these resources for the development of biomass-based energy sources (Singh et al., 2014).

Nigeria with a population of 144 million and an annual growth rate of about 3.2% (UN, 2008) has significant biomass resources to meet both traditional and modern energy uses (Ighodaro, 2010). The situation in the rural areas of the country is such that most end users depend on fuelwood.

CONTACT B. S. Fakinle fakinle.bamidele@lmu.edu.ng Department of Chemical Engineering, Landmark University, Omu-Aran, Kwara State, Nigeria.

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Owing to population growth, electricity shortage in the national grid and refined petroleum product shortage in the country, the use of wood fuels hasbeen on the increase. These biomass fuels are burnt without knowing their air quality impacts both on the users and its immediate environment. Residential wood burning is one of the sources that contribute to the atmospheric burden of air pollutants (Nazir et al., 2011). Air pollutants from woody biomass fuels consist of a mixture of gases including carbon monoxide (CO), sulfur dioxide (SO_2), oxides of nitrogen (NOx), particulate matter (PM), and gaseous hydrocarbons (HC) which contribute to the deleterious air quality and poor visibility.

This study investigated the emission factors of some gaseous emissions from different fuelwood species in southwestern Nigeria by performing real-time emission measurement of the gaseous emissions from open burning of the fuelwoods.

2. Methodology

2.1. *Study area – southwest Nigeria*

The fuelwoods used for this study were obtained from southwestern Nigeria. Southwestern Nigeria Consists of Lagos, Ogun, Oyo, Osun, Ondo, and Ekiti States in the south west geographical zone of the country (Figure 1). The area lies between latitude 6° 21′ and 8° 37′ North and longitude 2° 31′ and 6° 00′ East (Faleyimu et al., 2013) with a total land area of 76,852 km^2 and a population of 27,722,432 as in the 2006 population census (NBS, 2010). This region is bound in the east by Edo and Delta States, in the North by Kwara and Kogi States, in the west by the Republic of Benin, and in the south by the Atlantic Ocean. It has forest reserves with forest area cover of about 842,499 hectares (Faleyimu and Oyebade, 2012).

2.2. *Fuelwood species, sampling, and analyses*

The common fuelwoods from southwestern Nigeria were collected from the living plants and were properly identify. Upon identification, the fuelwoods were allowed to dry up naturally to a moisture content of 15% and eventually prepared into chips for open burning.

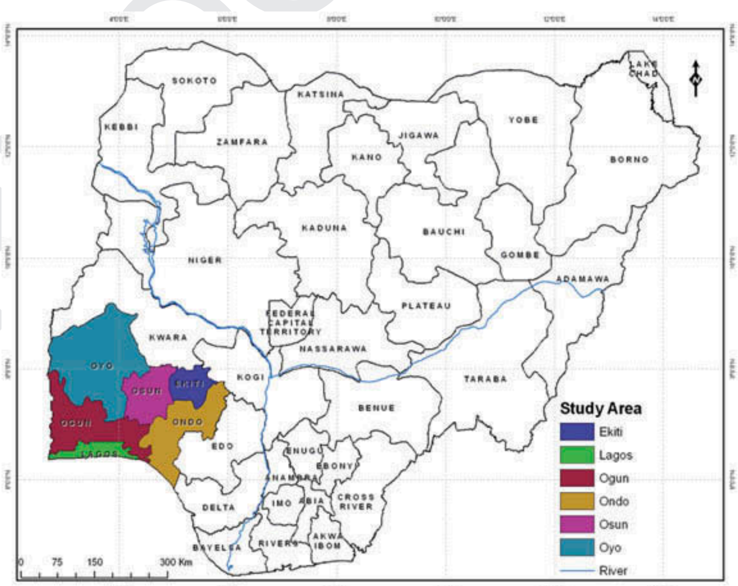

Figure 1. Map of the study area showing Southwestern Nigeria.

About 100 g of each of the identified fuelwoods used as the source of energy in the southwestern Nigeria were subjected to open burning. The fuelwoods were allowed to burn out completely, time taken for complete combustion of these fuelwoods into ashes was noted. Gaseous emissions from open burning of the identified fuelwoods were measured using a combustion analyzer model E8500 by E-instruments. This analyzer used has the capability to measure gaseous emission including: oxygen (O_2), hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NO, NO_2, and NOx), sulfur dioxide (SO_2), and hydrogen sulfide (H_2S). Its CO detection range is 0–20,000 ppm with 1 ppm resolution while it's NO and NO_2 detection range is 0–4,000 ppm with 1 ppm resolution. It can also combine both NO and NO_2 to form the all-important air quality parameter NO_X. The detection range of its H_2S is 0–500 ppm with 1 ppm resolution. The analyzer employs electrochemical sensors to measure O_2, NO, NO_2, NOx, SO_2, and H_2S while it employs the principle of nondispersive infrared (NDIR) for CO and HC measurement. Also meteorological parameters such as ambient temperature, relative humidity, and wind speed were monitored during the entire study period using the Kestrel 4,000 pocket weather tracker.

To determine the emission factor of the air pollutants from the open burning of the identified fuelwoods, parameters such as the concentration of the air pollutants, flow rate of the measured pollutants, mass of the fuelwood burnt, and time taken for complete burn out of the fuelwood were considered using Eqs. (1) and (2) (USEPA, 2010).

$$n = C_p \,.\, F \,.\, t \quad (1)$$

$$EF = \frac{n}{M} \quad (2)$$

where n is the mass of pollutants emitted (mg), C_p is the concentration of pollutant measure (mg/m^3), F is the flow rate in (m^3/s), t is the time taken for complete burning of the fuelwood (s), M is the mass of fuelwood burnt (kg), and EF is the emission factor of the pollutant (mg/kg).

3. Results and discussion

A total of 100 species of common fuelwoods found in the study area belonging to 37 families were obtained.

The gaseous air pollutants obtained from the air emission characterization during the study from the identified fuelwoods were carbon monoxide (CO), oxides of nitrogen (NOx), sulfur dioxide (SO_2), and hydrocarbons (HC). These are the common air pollutants that are of interest to well-being of man and the environmental protection. The measured pollutants were 972.30–10422.00 mg/m^3 with a mean value of 6077.80 mg/m^3 for CO, 235.60–12780.40 mg/m^3 for HC with a mean of 2178.90 mg/m^3, 12.00–330.00 mg/m^3 for NOx with an average concentration of 136.60 mg/m^3, while SO_2 was measured to be 0.00–23.70 mg/m^3 with a mean concentration of 8.40 mg/m^3. The fuelwood with the minimum emissions of CO, HC, and NOx concentrations was *Gliricidia sepium*.

The calculated emission factor which is the unit mass of the gaseous air pollutants per unit activity of the open burning of the identified common fuelwoods in study area were 181.84–6547.57 g/kg with a mean of 1787.20 g/kg for CO, 44.07–2986.40 g/kg with a mean of 615.70 g/kg for HC, 2.24–267.36 g/kg with a mean of 39.90 g/kg for NOx and 0.0–9.87 g/kg with a mean of 2.50 g/kg for SO_2 (Table 1). *Gliricidia sepium* has the minimum emission factor of all the gaseous pollutants except for SO_2 which has it minimum *Bombax buonopozense, Hura crepitans, Tectona grandis, Lagerstroemia speciosa, Trichilia prieureana, Musanga cecropioides, Erythrina sigmoidea*, and *Gmelina arborea. Milletia thonningii* has the maximum emission factor for CO and NOx while maximum emission factors of HC and SO_2 are from *Elaeis guineensis* and *Bridelia ferruginea* respectively.

On a family basis (Table 1), the investigated gaseous pollutants from the Anacardiaceae's family were 954.60–2815.80 g/kg with a mean of 2178.07 ± 1059.87 g/kg for CO, 462.30–800.60 g/kg with a mean of 658.73 ± 175.63 g/kg for HC, 17.50–45.40 g/kg with a mean of 33.23 ± 14.29 g/kg for NOx

Table 1. Emission factors of gaseous emissions from identified fuelwoods in g/kg.

S/N	SCIENTIFIC NAME	CO	HC	NOx	SO_2
	Anacardiacea's family				
1	*Spondias mombin*	954.60	462.30	17.50	2.40
2	*Mangifera indica*	2815.80	800.60	45.40	2.90
3	*Anacardium occidentale*	2763.80	713.30	36.80	3.80
	Annonaceae's family				
4	*Polyathia langifolia*	688.60	147.90	26.00	1.10
5	*Monodora tenuifolia*	1124.00	403.30	22.60	2.50
6	*Annona reticulata*	749.80	210.40	23.10	1.50
7	*Cleistopholis patens*	1749.10	444.70	28.50	0.50
	Apocynaceae's family				
8	*Funtumia africana*	2233.40	781.20	87.40	3.50
9	*Funtumia elastic*	1965.90	1325.90	45.90	1.10
10	*Holarrhena floribunda*	636.80	133.20	18.00	0.70
11	*Alstonia boonei*	1147.00	782.90	46.30	2.10
12	*Plumeria rubra*	1279.50	604.30	27.80	2.10
13	*Voacanga africana*	1858.60	548.50	54.10	0.90
14	*Rauvolfia vomitoria*	1509.20	640.60	30.80	2.90
	Arecaceae's family				
15	*Elaeis guineensis*	2004.50	2986.40	77.10	3.00
	Bignonaceae's family				
16	*Markhamia tomentosa*	2120.90	687.90	51.90	2.00
17	*Tabebuia rosea*	1054.50	203.50	23.80	5.80
	Bombacaceae's family				
18	*Bombax buonopozense*	790.60	243.60	10.30	0.00
	Boraginaceae's family				
19	*Cordia millenii*	866.90	210.20	26.10	1.50
	Caesalpiniaceae's family				
20	*Senna siamea*	1900.60	460.40	49.80	1.80
21	*Cassia fistula*	1208.10	827.40	18.40	2.70
22	*Bauhinia monandra*	1944.00	444.40	52.90	1.80
	Calophyllaceae's family				
23	*Calophylum inophyllum*	1008.30	340.00	17.20	2.30
	Combretaceae's family				
24	*Terminalia avicennoide*	1203.80	230.40	26.20	5.20
	Convovulaceae's family				
25	*Ipomoea intrapilosa*	2089.10	647.00	50.10	2.60
	Dilleniaceae's family				
26	*Dillenia indica*	566.00	308.80	17.00	2.60
	Ebenaceae's family				
27	*Diospyros barteri*	1037.30	249.10	18.80	3.70
	Euphorbiaceae's family				
28	*Bridelia micrantha*	3922.30	981.30	89.10	3.90
29	*Codiaeum variegatum*	1434.60	529.00	36.90	2.40
30	*Flueggea virosa*	2596.50	616.40	48.10	1.40
31	*Ricinodendron heudelotii*	1183.10	442.20	24.80	2.00
32	*Alchornea cordifolia*	3505.40	1209.50	71.10	3.80
33	*Bridelia ferruginea*	4977.40	2445.40	81.50	9.87
34	*Manihot glaziovii*	1631.10	448.10	25.60	0.70
35	*Hura crepitans*	357.10	141.10	5.50	0.00
	Fabaceae's family				
36	*Peltophorum pterocarpum*	981.40	379.60	31.50	3.50
37	*Delonix regia*	1488.90	694.40	27.00	2.50
38	*Dialium guineense*	3392.70	864.10	51.90	7.20
39	*Hylodendron gabunense*	1450.30	303.40	27.30	3.60
	Lamiaceae's family				
40	*Tectona grandis*	1383.24	655.40	45.55	0.00
41	*Clerodendrum polycephalum*	3092.51	566.78	59.16	6.61
	Lecythidaceae's family				
42	*Najooleona vogelii*	2692.91	810.99	53.36	1.71
	Loganiaceae's family				
43	*Anthocleista djalonensis*	1420.30	272.93	48.04	1.08
	Lythraceae's family				
44	*Lagerstroemia speciosa*	2281.86	1170.91	56.12	0.00

(*Continued*)

Table 1. (Continued).

S/N	SCIENTIFIC NAME	CO	HC	NOx	SO_2
	Malvaceae's family				
45	*Theobroma cacao*	831.76	197.62	17.40	1.07
46	*Triplochiton scleroxylon*	678.76	175.15	21.09	0.62
47	*Gossypium barbadense*	2330.22	762.63	32.11	2.72
	Meliaceae's family				
48	*Trichilia prieureana*	2191.22	1146.67	97.31	0.00
49	*Azadirachta indica*	1751.91	618.26	46.21	3.58
50	*Trichilia heudelotti*	2186.87	605.97	33.51	3.49
	Mimosaceae's family				
51	*Leucaena leucocephala*	2322.16	555.66	52.11	1.67
52	*Acacia auriculaeformis*	1504.72	676.48	42.52	2.07
53	*Albizia zygia*	2360.13	1010.45	42.28	2.55
54	*Tetrapleura tetraptera*	2739.29	672.04	42.06	4.03
55	*Entrerolobium cyclocarpum*	2386.5	650.87	45.8	3.35
56	*Adenanthera pavonina*	1421.79	278.05	16.8	2.61
57	*Calliandra portoricensis*	1197.76	400.56	18.66	5.03
	Moraceae's family				
58	*Ficus asperifolia*	957.34	225.73	25.65	0.54
59	*Myrianthus arborenus*	1439.43	389.45	60.43	1.58
60	*Musanga cecropioides*	611.42	159.09	36.13	0.00
61	*Bosqueia angolensis*	1036.57	841.74	35.49	1.35
62	*Ficus thonningii*	840.85	192.06	15.34	2.07
63	*Ficus sur*	903.15	366.66	16.52	1.09
64	*Millecia excels*	2455.59	450.34	54.74	4.37
65	*Ficus elasticoides*	360.71	111.56	7.68	0.55
66	*Ficus exasperate*	1682.87	448.2	39.55	2.65
67	*Artocarpus communis*	2411.03	602.61	36.52	3.10
68	*Ficus abutifolia*	638.93	144.15	13.11	1.37
69	*Ficus erionotryoides*	533.09	147.76	8.85	0.46
70	*Ficus mucosu*	428.59	101.4	14.7	1.20
71	*Antiaris africana*	953.56	218.12	9.06	0.71
	Myristicaceae's family				
72	*Pychanthus angolensis*	1113.45	245.02	14.04	1.58
	Myrtaceae's family				
73	*Eucalyptus camuldulensis*	4349.97	1263.79	45.48	4.39
74	*Psidium guajava*	1258.30	544.75	18.60	1.79
	Papilionaceae's family				
75	*Lonchocarpus sericeus*	1394.24	237.12	27.02	2.09
76	*Baphia nitida*	2033.98	755.24	48.48	1.92
77	*Milletia thonningii*	6547.57	1341.26	267.36	8.80
78	*Erythrina sigmoidea*	774.33	130.37	15.73	0.00
79	*Gliricidia sepium*	181.84	44.07	2.24	1.12
80	*Leptoderris micrantha*	2533.3	599.76	40.02	1.63
81	*Pterocarpus santalinoides*	2343.52	499.61	38.13	3.69
	Phyllanthaceae's family				
82	*Margaritaria discoidea*	5355.02	2365.67	135.85	5.05
	Pinaceae's family				
83	*Pinus caribea*	1950.89	675.08	24.07	4.28
	Poaceae's family				
84	*Phyllostachys aurea*	1077.39	621.03	18.7	2.15
	Rosaceae's family				
85	*Prunus dulcis*	1749.47	687.96	21.85	2.68
	Rubiaceae's family				
86	*Canthium vulgare*	2772.05	1052.39	50.74	6.41
87	*Gardenia jasmmoides*	1015.31	214.48	10.73	1.91
88	*Keetia vernosa*	1440.51	631.36	22.99	1.88
	Rutaceae's family				
89	*Citrus sinensis*	3006.47	1291.28	45.95	3.13
90	*Citrus paradisi*	1333.81	423.33	19.07	1.31
	Sapindaceae's family				
91	Blighia sapida	1936.64	889.29	48.04	1.15
92	Allophyllus africanus	3061.47	1221.23	57.28	2.43
93	Lecaniodiscus cupanioides	2707.74	695.44	49.58	5.62

(*Continued*)

Table 1. (Continued).

S/N	SCIENTIFIC NAME	CO	HC	NOx	SO_2
	Sapotaceae's family				
94	Chrysophyllum albidum	2160.27	969.47	56.78	1.92
	Sterculiaceae's family				
95	Sterculia tragacantha	2330.63	628.40	53.20	0.51
96	Cola millenii	1078.78	516.39	13.73	0.48
97	Cola hispida	823.70	142.98	18.04	1.13
98	Cola nitida	846.26	198.94	23.05	1.79
	Ulmaceae's family				
99	Celtis mildbraedii	2427.81	1330.27	88.77	5.22
	Verbenaceae's family				
100	Gmelina arborea	2893.16	839.41	109.98	0.00

and 2.40–3.80 g/kg with a mean of 3.03 ± 0.71 g/kg for SO_2. For Annonaceae's family the emission factors of these pollutants are 688.60–1749.10 g/kg with a mean of 1077.88 ± 487.11 g/kg for CO, 147.9–444.7 g/kg with a mean of 352.80 ± 125.05 g/kg for HC, while NOx and SO_2 are 22.60–28.50 g/kg with a mean of 25.05 ± 2.75 g/kg and 0.50–2.50 g/kg with a mean of 1.40 ± 0.84 g/kg, respectively. From Apocynaceae's family, the EFs are 636.80–2233.40 g/kg with a mean of 1518.63 ± 547.65 g/kg, 133.20–1325.90 g/kg with a mean of 688.09 ± 356.17 g/kg, 18.00–87.40 g/kg with a mean of 44.33 ± 22.75 g/kg, 0.70–3.50 g/kg with a mean of 1.90 ± 1.06 g/kg for CO, HC, NOx, and $SO_{2,}$ respectively. For Arecaceae's family the EFs are 2004.50 g/kg for CO, 2986.40 g/kg for HC, 77.10 g/kg for NOx and 3.00 g/kg for SO_2 while for Bignonaceae's family they are 1054.50–2120.90 g/kg with a mean of 1587.70 ± 754.06 g/kg for CO, 203.50–687.90 g/kg with a mean of 445.70 ± 342.52 g/kg for HC, 23.80–51.90 g/kg with a mean of 37.85 ± 19.87 g/kg for NOx and 2.00–5.80 g/kg with a mean of 3.9 ± 2.69 g/kg for SO_2.

The EFs of CO, HC, and NOx for Bombacaceae's Family are 790.56 g/kg, 243.60 g/kg and 10.30 g/kg respectively while Boraginaceae's family these air pollutants are 866.90 g/kg CO, 210.20 g/kg HC, 26.10 g/kg NOx and 1.50 g/kg SO_2. The EFs of the emissions from Caesalpiniaceae's family are 1208.10–1944.00 g/kg with a mean of 1684.23 ± 412.91 g/kg CO, 444.40–827.40 g/kg with a mean of 577.40 ± 216.65 g/kg HC, NOx, and SO_2 for the family were 18.40–52.90 g/kg with a mean of 40.37 ± 19.09 g/kg and 1.80–2.70 g/kg with a mean of 2.10 ± 0.52 g/kg respectively. From Calophyllacea's family they are 1008.30 g/kg CO, 340.00 g/kg HC, 17.20 g/kg NOx and 2.30 g/kg SO_2 while for Combretaceae's family the EFs are 1203.80 g/kg, 230.40 g/kg, 26.20 g/kg and 5.20 g/kg respectively for CO, HC, NOx and SO_2. From Convovulaceae's family, the pollutants EFs are 2089.10 g/kg for CO, 647.00 g/kg for HC, 50.10 g/kg for NOx and 2.60 g/kg for SO_2. For Dilleniaceae's family the EFs are 566.00 g/kg CO, 308.80 g/kg HC, 17.00 g/kg NOx and 2.60 g/kg SO_2 while for the Ebenaceae's family the CO emitted was 1037.30 g/kg, HC was 249.10 g/kg, NOx was 18.80 g/kg and SO_2 was 3.70 g/kg. From Euphorbiaceae's family, CO, HC, NOx, and SO_2 EFs are 357.10–4977.40 g/kg with a mean of 2450.94 ± 1575.60 g/kg, 141.10–2445.40 g/kg with a mean of 851.63 ± 725.04 g/kg, 5.50–89.10 g/kg with a mean of 47.83 ± 30.03 g/kg and 0.00–9.87 g/kg with a mean of 3.01 ± 3.09 g/kg ., respectively. For Fabaceae's family its CO were 981.40–3392.70 g/kg with mean of 1828.33 ± 1068.12 g/kg, HC were 303.40–864.10 g/kg with a mean of 560.38 ± 263.90 g/kg, NOx were 27.00–51.90 g/kg with a mean of 34.42 ± 11.83 and SO_2 were 2.50–7.20 g/kg with a mean 4.20 ± 2.06 g/kg.

The EFs of emissions from Lamiaceae's family were of the range 1383.24–3092.51 g/kg with a mean of 2237.88 ± 1208.64 g/kg for CO, 566.78–655.40 g/kg with a mean of 611.09 ± 62.66 g/kg for HC, 45.55–59.16 g/kg with a mean value of 52.36 ± 9.62 g/kg for NOx and 0.00–6.61 g/kg with a mean of 3.31 ± 4.67 g/kg for SO_2. Lecythidaceae's family EFs for it emissions had 2692.91 g/kg of CO, 810.99 g/kg of HC, 53.36 g/kg of NOx and 1.71 g/kg of SO_2 while Loganiaceae's family had 1420.30 g/kg CO, 272.93 g/kg HC, 48.04 g/kg NOx and 1.08 g/kg SO_2. The emissions from Lythraceae's family were 2281.86 g/kg of CO, 1170.91 g/kg of HC and 57.12 g/kg of NOx, the Malvaceae's family emissions were of the range 678.76–2330.22 g/kg with a mean of 1280.25 ± 912.52 g/kg for CO, 175.15–762.63 g/kg with a mean of 378.46 ± 332.88 g/kg for HC, 17.40–32.11 g/kg with a mean of 23.53 ± 7.65 g/kg for NOx and 0.62–2.72 g/kg with a mean of 1.47 ± 1.11 g/kg for SO_2. The CO, HC, NOx, and SO_2 emissions from the Meliaceae's family were 1751.91–2191.22 g/kg with a mean of 2043.33 ± 252.39 g/kg, 605.97–1146.67 g/kg with a mean of 790.30 ± 308.69 g/kg, 33.51–97.31 g/kg with a mean of 59.01 ± 33.77 g/kg, 0.00–3.58 g/kg with a mean of 2.36 ± 2.04 g/kg, respectively. Emissions from Mimosaceae's family were 1197.76–2739.29 g/kg with a mean of 1990.34 ± 598.88 g/kg CO, 278.05–1010.45 g/kg with a mean of 606.30 ± 233.53 g/kg HC, 16.80–52.11 g/kg with a mean of 37.18 ± 13.75 g/kg NOx and 1.67–5.03 g/kg with a mean of 3.04 ± 1.17 g/kg SO_2. Moraceae's family emissions EFs were 360.71–2455.59 g/kg with a mean of 1089.51 ± 675.48 g/kg for CO, 101.40–841.74 g/kg with a mean of 314.21 ± 215.80 g/kg for HC, 7.68–60.43 g/kg with a mean of 26.7 ± 17.33 g/kg for NOx and 0.00–4.37 g/kg with a mean of 1.50 ± 1.19 g/kg for SO_2. The emissions from Myristiacaceae's family were 1113.45 g/kg CO, 245.02 g/kg HC, 14.04 g/kg NOx and 1.58 g/kg SO_2 while for Myrtaceae's family the emissions were 1258.30–4349.97 g/kg with a mean of 2804.14 ± 2186.14 g/kg for CO, 544.75–1263.79 g/kg with a mean of 904.27 ± 508.44 g/kg for HC, 18.60–45.48 g/kg with a mean of 32.04 ± 19.01 g/kg for NOx and 1.79–4.39 g/kg with a mean of 3.09 ± 1.84 g/kg SO_2.

For Papilionaceae's family, the measure emissions were 181.84–6547.57 g/kg with a mean of 2258.39 ± 2073.30 g/kg for CO, 44.07–1341.26 g/kg with a mean of 515.35 ± 446.24 g/kg for HC, 2.24–267.36 g/kg with a mean of 62.71 ± 91.60 g/kg for NOx and 0.00–8.80 g/kg with a mean of 2.75 ± 289 g/kg for SO_2. For Phyllanthaceae's, Pinaceae's, Poaceae's, and Rosaceae's families their measured CO emissions were 5355.02, 1950.89, 1077.39, and 1749.47 g/kg, respectively; their HC emissions were 2365.67, 675.08, 621.03 and 687.96 g/kg, respectively; for NOx they were measured as 135.89, 24.07, 18.70, and 21.85 g/kg, respectively; their SO_2 were 5.05, 4.28, 2.15, and 2.68 g/kg, respectively. For the Rubiaceae's family, EF of the measured pollutants were of the range 1015.31–2772.05 g/kg with a mean of 1742.62 ± 916.51 g/kg for CO, 214.48–1052.39 g/kg with a mean of 632.74 ± 418.96 g/kg for HC, 10.73–50.74 g/kg with a mean of 28.15 ± 20.50 g/kg for NOx and 1.88–6.41 g/kg with a mean of 3.40 ± 2.61 g/kg for SO_2. For Rutaceae's family, the EFs were 1333.81–3006.47 g/kg with a mean of 2170.14 ± 1182.75 g/kg for CO, 423.33–1291.28 g/kg with a mean of 857.31 ± 613.73 g/kg for HC, NOx and SO_2 were 19.07–45.95 g/kg with a mean of 32.51 ± 19.01 g/kg and 1.31–3.13 g/kg with a mean of 2.22 ± 1.29 g/kg respectively. For Sapindaceae's family, CO emission were 1936.64–3061.47 g/kg with a mean of 2568.62 ± 575.18 g/kg, HC EFs were 695.44–1221.23 g/kg with a mean of 935.32 ± 265.9 g/kg, NOx and SO_2 EFs were 48.00–57.30 g/kg with a mean of 51.63 ± 4.95 g/kg and 1.15–5.62 g/kg with a mean of 3.07 ± 2.30 g/kg respectively. EFs of emissions from Sapotaceae's family were 2160.27 g/kg for CO, 969.47 g/kg for HC, 56.78 g/kg for NOx and 1.92 g/kg for SO_2 while that of Sterculiaceae's family were of the range 823.70–2330.63 g/kg with a mean of 1269.84 ± 716.53 g/kg for CO, 142.98–628.40 g/kg with a mean of 371.68 ± 237.34 g/kg for HC, 13.73–53.20 g/kg with a mean of 27.01 ± 17.87 g/kg for NOx, SO_2 emission were of the range 0.51–1.79 g/kg with a mean of 0.98 ± 0.62 g/kg. While for the Ulmaceae's and Verbenaceae's families their emissions were 2427.81 and 2893.16 g/kg for CO respectively, 1330.27 and 839.41 g/kg for HC, respectively, 88.77 and 109.98 g/kg for NOx, respectively, and 5.22 and 0.00 g/kg for SO_2, respectively.

The overall prevailing meteorological conditions during the study were 30.5–35.7 with a mean of 33.6°C, 51.30–55.7% with a mean of 53.6% and 0.5–1.2 m/s with a mean of 0.8 m/s for temperature, relative humidity and wind speed respectively.

In this study, the emission of CO from combustion might result from low combustion temperature, moisture content, insufficient oxygen, poor mixing of fuel with the combustion air and/or too short a resident time combustion gas in the combustion zone (Eskilsson et al., 2004; Tissari et al., 2009). Emissions of NOx varied between the different fuelwoods. The three main NOx formation

Table 2. Guidelines to standards for environmental pollution control in Nigeria.

Pollutant	Limits (mg/m^3)
Carbon monoxide	10
Hydrocarbon	50
Oxides of Nitrogen	350–1000
Sulfur dioxide	30–3000

Source: FEPA (1991)

during biomass combustions are: thermal NOx (formed from atmospheric nitrogen above 1300°C), prompt NOx formed at the flame front and fuel – NOx formed from elemental nitrogen contents of the fuel (Habi et al., 2008), also the emission of SO_2 varied insignificantly between the different fuelwoods. It emissions varies as a function of fuel bound sulfur while HC emissions are thermal decomposition products of lignin and cellulose which are released at inefficient burning of fuelwoods at combustion temperature below 700°C (Kjallstrand, 2002). More efficient burning leads to a reduced total amount of organic compounds in the emission.

When the emissions are compared with FEPA (1991) limits for gaseous emissions from stationary sources presented in Table 2, CO from the fuelwoods breach the permitted emission limit for stationary sources. HC emitted from the fuelwoods breached the permitted emission limit. For NOx (NO and NO_2) it was observed that it emission from the combustion of the fuelwoods were below the permitted limits for stationary sources. Also, it was observed that the emissions of SO_2 were below both the lower and the upper set limits. Deduced from the comparison, emissions from fuelwoods were below the set standard permitted for stationary source except for their carbon monoxide and hydrocarbon emissions. Hence fuelwood could serve as a source of energy with sustainable environmental effects.

4. Conclusion

Fuelwoods in southwestern Nigeria are readily available. A total of 100 different species of woody plant belonging to 37 families were obtained from the study area. Two of these fuelwoods were gymnosperms while the remaining were angiosperms.

The source concentrations of CO and HC from the fuelwoods when compared with FEPA (1991) breached the limit set for stationary source. For NOx (NO and NO_2) and SO_2 it was observed that their emissions were below the set standard for stationary source.

Gliricidia sepium fuelwood had the minimum emission factor of all gaseous emission except for SO_2. *Milletia thonningii* had the maximum emission factor for CO and NOx while maximum emission factors of HC and SO_2 were at *Elaeis guineensis* and *Bridelia ferruginea*, respectively. Hence *Gliricidia sepium* fuelwood could serve as a source of energy with maximum sustainable environmental effects in terms of air pollutants.

ORCID

B. S. Fakinle http://orcid.org/0000-0002-1465-7850

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