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ENVIRONMENTAL CHEMISTRY, POLLUTION & WASTE MANAGEMENT | RESEARCH ARTICLE

Particulate matter pollution from open burning of sawdust in Southwestern Nigeria

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Abstract: The study investigated the annual atmospheric loadings of particulate matter (PM) from open burning of sawdust in southwestern Nigeria using emission factor approach. The estimated annual atmospheric loading of PM from the states ranged between 1.18–8.29 ton/annum while 23.4 ton/annum was obtained for the entire southwestern Nigeria. The maximum per capita and land distribution of the emission were estimated to be 0.844 g/capita and 304.592 g/km^2 and these were from Ondo and Lagos States, respectively. The dominant elemental emissions were potassium and sodium with annual atmospheric loadings of 10.4 ton/annum and 10.1 ton/annum, respectively. Heavy metals such as lead and mercury were present in small quantities. Given the possible impacts of the PM emissions on public health, the study suggested waste to energy as an option that could be explored in the region in order to achieve a win–win situation that addresses the solid waste problems and at the same time improving the regions energy mix.

Subjects: Renewable Energy; Chemical Engineering; Environmental Health; Pollution

Keywords: solid waste; air pollution; emission factor; AAS; per capita distribution; biomass energy

1. Introduction

Anthropogenic sources of air pollutants are ubiquitous and have become subjects of active investigation all over the world. This is largely due to various human health hazards that have been reported (Gauderman et al., 2007; Jaishankar, Tseten, Anbalagan, Mathew, & Beeregowda, 2015;

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PUBLIC INTEREST STATEMENT

Sawmills in southwestern Nigeria presently handle the enormous solid waste management challenge posed by huge heap of sawdust being generated on regular basis via open burning. Open burning as a method of disposal is worrisome as a result of the associated air pollutants and their effects on air quality and public health. This paper examined the atmospheric loading of particulates and heavy metals from open burning of sawdust in southwestern Nigeria. It also explored the possibilities of converting this waste to energy. The study concluded that a better management strategy that will create a “win-win” situation is to consider converting the sawdust to electricity via mini-grid systems. In this way energy is created; solid waste challenge is eliminated while air pollution will be better managed.

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Jomova & Valko, 2011; Valko, Jomova, Rhodes, Kuča, & Musílek, 2016; Wallenborn, Schladweiler, Richards, & Kodavanti, 2009). Animals, plants, soil, and climate have been reported to be affected by air-borne pollutants (Chameides et al., 1999; Olowoyo & Mugivhisa, 2015; Shahid et al., 2014; Turner, 2009). In Nigeria, consideration of anthropogenic sources have largely been tilted toward vehicular emissions (Fakinle, Sonibare, Akeredolu, Okedere, & Jimoda, 2013; Ojuri, Taiwo, & Oluwatuyi, 2016); thermal plants (Sonibare, 2010) and petroleum and oil industries (Oladimeji, Sonibare, & Oresegun, 2015; Sonibare, Akeredolu, Obanijesu, & Adebiyi, 2007) as major sources of anthropogenic air pollutants.

Nigeria is blessed with abundant forest reserves, most of which are located in the southwestern part of the country. There has been significant increase in the number of sawmills in this region of the country with Lagos, Oyo, Ogun, and Ondo States having the largest numbers. This is as a result of the need to satisfy the growing demands for wood for building and other construction purposes. There are several species of these forest products. Trees from the forests are processed at sawmills to produce construction, building, and furniture materials. After these perceived useful products have been taken, heap of sawdust produced is left behind (Figure 1). The Lumber recovery factor in most sawmills varies between 45 and 50% (Kehinde, Awoyemi, Omonona, & Akande, 2009). This implies that about 50–55% of log inputs into sawmills are left as wood residues.

Huge "mountain" of sawdust is created on regular basis at sawmills which consequently continues to create solid waste management problem at sawmills. The easiest way commonly adopted by most sawmill operators to get rid of the sawdust is open burning. Ogunbode, Fabunmi, Ibrahim, Jimoh, and Idowu (2013) reported that 96 per cent of the sawdust generated in Nigeria is usually disposed through open air burning. Burning of forest biomass has been known to be associated with emission of air pollutants such as PM (Ogunbode et al., 2013; Okedere, 2016; Wardoyo, Morawska, Ristovski, & Marsh, 2006).

In contrast to the sawdust resources that are in abundance in Nigeria, the country is still battling with the problem of insufficient energy required to meet the demands of the growing population and economy. Nigeria could invest in generation of energy from this perceived waste instead of indiscriminate burning of sawdust. Emission from open air burning of sawdust cannot be controlled. The argument for investment in waste incinerators as means to control air emission is weak against the backdrop of the need to generate more energy. While biomass power plants will also produce

Figure 1. Typical heap of sawdust at a sawmill in southwestern Nigeria

emissions, abatement technology in form of end of pipe treatment can easily be developed before emissions are released to the surrounding.

In the present work, the PM emission factor from open burning of sawdust found in southwestern Nigeria sawmills was determined. This was with a view to estimating the contribution of open burning of sawdust in this region of the country to the annual atmospheric loadings of some trace and heavy metals as well the total annual atmospheric loading of PM. The paper also suggested a possible alternative for the management of sawdust which is enormously in abundance in the region.

2. Methodology

2.1. Study area description

The study area is southwestern Nigeria which comprises Lagos, Oyo, Ogun, Osun, Ondo, and Ekiti States (Figure 2). The area lies between longitude 2^0 31^1 and 6^0 00^1 East and Latitude 6^0 21^1 and 8^0 37^1 N and has population of about 27,772,432 according to 2006 census figures which was the last official head count in the country (FRNOG, 2009). A breakdown of the population figure shows that 32.8, 20.1, 13.5, 12.3, 12.5, 8.7% of the populations belong to Lagos, Oyo, Ogun, Osun, Ondo, and Ekiti States, respectively (FRNOG, 2009). The study area is bounded on 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 Gulf of Guinea and has an approximate total land area of about 77,818 km^2 and 85 constituted forest reserves with a forest area cover of 842,499 hectare (Faleyimu, Akinyemi, & Agbeja, 2010). The climate of southwestern Nigeria is tropical in nature and it is characterized by wet and dry seasons. The temperature ranges between 21 and 34°C while the annual rainfall ranges between 1,500 and 3,000 mm. The wet season is associated with the southwest monsoon wind from the Atlantic Ocean while the dry season is associated with the northeast trade wind from the Sahara Desert. The vegetation in southwestern Nigeria is made up of fresh water swamp and mangrove forest at the belt, the low land in forest stretches inland to Ogun and part of Ondo State while secondary forest is toward the northern boundary where derived and southern Savannah exists.

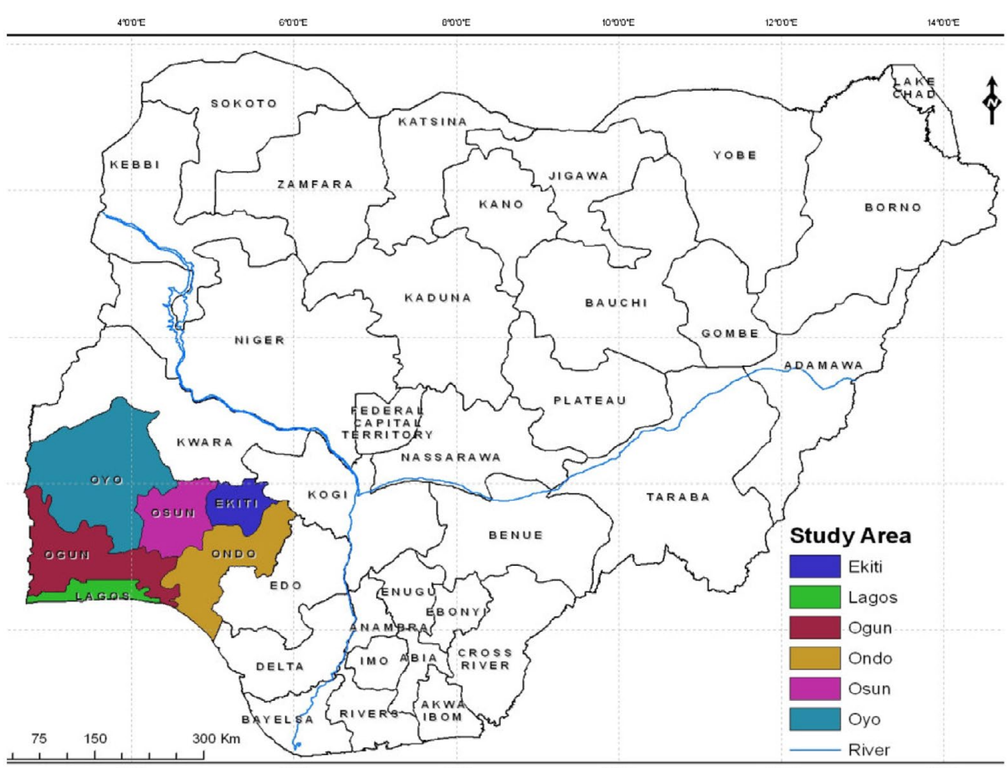

Figure 2. Map of Nigeria showing the study area.

Majority of the sawmills in Nigeria are located in the southern part of Nigeria to take advantage of timbers from several forest reserves (Oluoti, Megwai, Pettersson, & Richards, 2014).

2.2. Experimental procedures

The preliminary stage of the study involved collection and preparation of sawdust samples collected from selected sawmills in southwest region of Nigeria. Relevant information that will assist in estimation of the quantity of sawdust generated annually in the study area was obtained from sawmill operators and literatures. Other parameters investigated were the moisture content, particulate matter emissions, emission factors, and elemental compositions of the emitted particulates from burning of known mass of saw dust samples obtained from the study area. Particulate and elemental loadings from open burning of saw dusts were then estimated for the entire study area using the emission factor and elemental compositions obtained from laboratory investigation.

2.2.1. Collection and preparation of sawdust samples

The sawdust samples used in this study were collected at selected sawmills in southwest region of the country. Information from sawmill operators and literatures shows that virtually the same wood species are processed at all sawmills in this region of the country (Kehinde et al., 2009; Lasode & Balogun, 2010). The sawdust samples collected were properly dried so as to reduce moisture content and aid burning.

2.2.2. Estimation of annual quantity of saw dust generated in the study area

In order to estimate the annual quantity of sawdust generated in southwestern Nigeria, information on the number of sawmills in each state that make up southwestern Nigeria were obtained from Okedere (2016). Other information include number of logs of wood converted per sawmill per day; average conversion rate of log; log properties such as length, girth diameter, and density and 312 working days per annum (Kehinde et al., 2009; Lasode & Balogun, 2010; Ohimain, 2012). The annual tonnage of saw dust per state was calculated as:

$$T_A = \left(\frac{V_L \times \rho \times N_L \times C_A \times N_{SM} \times 312}{1000} \right) \quad (1)$$

where T_A = Annual tonnage of saw dust (ton/year); V_L = Volume of one log (m^3); ρ = Density of wood (kg/m^3); N_L = Average number of logs converted per saw mill per day; C_A = Conversion rate of log; N_{SM} = Number of sawmills per state.

The volume of one log was calculated as:

$$V_L = \pi \frac{D_g^2 L}{4} \quad (2)$$

where D_g (m) and L (m) are the girth diameter and length of one log, respectively.

2.2.3. Determination of moisture content

The SG91 Gallenkamp oven in the Department of Animal Sciences, Obafemi Awolowo University was used to determine the moisture contents of the saw dusts. The oven was set at a controlled temperature of 105°C and the pre-weighed sample was made to undergo drying for 10 min. The sample was removed and allowed to cool in a desiccator. The heating and cooling were repeated until constant weight was achieved. The procedure was repeated for each sample and the moisture content was calculated as:

$$\%\text{MC} = \left(\frac{M_i - M_f}{M_i} \right) \times 100\% \quad (3)$$

where M_i = weight of sample before oven drying M_f = weight of sample after drying

2.2.4. Determination of particulate matter (PM) concentration and emission factor from burning of saw dust

The sample of saw dust was divided into 2 portions of 100 g each. Each portion was subjected to open burning and the emitted particulate was determined gravimetrically. The gravimetric procedure involved sampling of emissions from the burning saw dust by means of Allegro Industry D-2 Mold-Lite Sampler P/N 9803–85 series. The entire sampling train consists of a 10 mm sampling probe mounted on the filter holder of the D-2 Mold-Lite sampler. The filter used was the Whatmann cellulose filter paper which had been pre-weighed with a Mettler Toledo AB54 balance. During each experimental run, the saw dust was allowed to burn out completely to ashes. The filter paper was carefully removed and kept in polythene envelope for final weight determination at the Environmental Engineering Laboratory, Department of Chemical Engineering, Obafemi Awolowo University, Nigeria using the same weighing balance. The duration of burning was noted as time. The concentration of PM emitted was determined using Equation (4) (Sippula, Hokkinen, Puustinen, Yli-Pirila, & Jokiniemi, 2007; U.S. Environmental Protection Agency (US EPA), 1999).

$$\mathrm{PM}\left(\frac{\mathrm{mg}}{\mathrm{m}^3}\right)=\left(\frac{W_2-W_1}{V_f}\right) \tag{4}$$

where W_2 = Final weight of filter paper W_1 = Initial weight of filter paper V_f = Volume of air sample (volumetric flow rate multiplied by sampling duration)

The PM concentrations obtained were used to calculate the emission factor of PM for the sawdust samples using Equation (5) (Okedere, Fakinle, & Sonibare, 2015; Sonibare, 2010; Sonibare et al., 2007).

$$\mathrm{EF}=\left(\frac{\mathrm{PM}\times V_F}{A}\right) \tag{5}$$

where EF = Emission factor of PM (g/kg) of saw dust burnt A = Activity or amount of saw dust burnt

2.2.5. Digestion of filters and atomic absorption spectrometric analysis

The determination of the elemental compositions of PM from burning of saw dust samples was achieved by subjecting the filter papers in Section 2.2 above to atomic absorption spectrometric (AAS) analysis. Prior to AAS analysis, each loaded filter paper was digested by adding 5 ml of concentrated HNO_3 to the filter inside a porcelain crucible and heated with heating mantle for 15 min. About 2.5 ml H_2O_2 was added and the whole mixture heated to dryness. About 1 ml HNO_3 was added and the resulting solution made up to 25 ml in a standard flask. AAS analysis was done with Buck 211VGP at the Institute of Agricultural Research and Training, Obafemi Awolowo University, Ibadan, Nigeria. The solution of digested sample was atomized in flame photometer burner preceded by a hollow cathode lamp which emitted the spectrum of the metal used as cathode. The beam was passed through the flame and focused on the entrance slit of a monochromator which read the intensity at certain wavelengths. The elemental concentration in mg/kg of the PM was determined for the samples.

2.2.6. PM and elemental loading

The particulate matter loadings (PM_L) as well as the elemental loadings (E_L) from open burning of sawdust in southwestern Nigeria were obtained by combining the mean PM emission factor (EF) of 0.0463 and grand mean elemental compositions, respectively, with the quantity of sawdust subjected to open burning in each of the six States that make up southwestern Nigeria. According to Ogunbode et al. (2013); about 96% of sawdust generated in Nigeria and disposed via open burning. This percentage was adopted in this study. The PM_L and E_L were determined as:

$$\mathrm{PM}_L(\text{tons/year})=\text{Mean EF}\times\text{Sawdust generated annually}\times 0.96 \tag{6}$$

$$E_L(\text{tons/year})=\text{Mean elemental composition}\times\text{Amount of sawdust burnt annually} \tag{7}$$

The per capita and land distributions of emissions were determined using Equations (8) and (9), respectively (Okedere, Sonibare, Ajala, Adesina, & Elehinafe, 2017; Sonibare, 2010).

$$\text{Per capital emission (g/capita)} = \text{Amount of PM emitted (g/annum)}/\text{Population of state} \quad (8)$$

$$\text{Land distribution of emission} = \text{Amount of PM emitted (g/annum)}/\text{Land mass of state (km}^2\text{)} \quad (9)$$

3. Results and discussion

The estimated annual quantities of sawdust from each of the states in southwestern Nigeria are as summarized in Table 1. The total number of registered sawmills in the region is about 1976; Lagos State which has the largest concentration of sawmills in the region generates the largest amount of sawdust while Ekiti generates the least annual quantity of sawdust. The total quantity of sawdust generated in the region is about 526, 650 metric tons on annual basis. These huge mountains of sawdust continue to pose solid waste management issues to the owners of sawmills who have settled for burning as the easiest way out and with about 96% of generated sawdust disposed via open burning (Ogunbode et al., 2013), up to 505,804 tons of sawdust are being burnt in the study area on annual basis without minding the environmental and air quality issues that may arise.

Results of experimental determination of PM concentrations and emission factor from open burning of sawdust samples are summarized in Table 2. The PM concentrations ranged between 1000.00 mg/m^3 and 10201.00 mg/m^3 with a mean value of 4793.91 mg/m^3 while the emission factors ranged between 0.010 g/kg and 0.097 g/kg with a mean value of 0.0463 g/kg. The moisture contents of the sawdust samples ranged between 11.02–12.25%. Since the moisture content did not vary markedly among the samples, its effects on particulate matter (PM) concentrations and the emission factors would also be marginal so that emissions factors are true reflections of the sawdust samples.

The results of atomic absorption spectrometric analysis for elemental composition of the emitted particulate matter are summarized in Table 3. The mean elemental compositions of Na, K, Ca, Mg, Mn, Fe, Zn, Cu, Ni, Pb, Cr, Hg were 20.01, 20.50, 0.027, 0.021, 0.029, 0.033, 0.027, 0.019, 0.022, 0.004, 0.021, and 0.0001 mg/kg, respectively, with the dominant elements emitted being potassium and sodium. Majority of the other element were emitted in low quantity especially mercury and lead.

The atmospheric loadings of particulate matter from burning of sawdust in the region had earlier been presented in Table 1. The estimated annual PM loading ranged between 1.18 and 8.29 ton/annum with the maximum and minimum loadings expected to be experienced in Lagos and Ekiti,

Table 1. Estimated annual quantity of sawdust generated and burnt in southwestern Nigeria

State	Number of sawmills[a]	Sawdust generated[a] (ton/year)	Sawdust burnt[b] (ton/year)	Estimated PM loading (ton/year)
Lagos	700	186.567	179104.32	8.2925
Ogun	300	79.957	76758.72	3.5539
Oyo	320	85.287	81875.52	3.7908
Ondo	311	82.889	79573.44	3.6843
Osun	245	65.298	62686.08	2.9024
Ekiti	100	26.652	25585.92	1.1846
Southwest	1976	526.650	505584.00	23.4085

[a]Okedere (2016).

[b]Based on 96% open burning of sawdust (Ogunbode et al., 2013).

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Table 2. Concentrations and emission factors of PM from the samples

Sample	$W_2 - W_1$ (g)	$W_2 - W_1$ (g)	Mean (g)	Time (s)	PM (mg/m³)	Emission factor (g/kg)
1	0.0009	0.0011	0.001	100	1000.0000	0.0100
2	0.0013	0.0017	0.0015	95	1578.9474	0.0150
3	0.001	0.0101	0.00555	105	5285.7143	0.0555
4	0.0001	0.0106	0.00535	110	4863.6364	0.0535
5	0.0001	0.0136	0.00685	110	6227.2727	0.0685
6	0.0001	0.0028	0.00145	95	1526.3158	0.0145
7	0.0002	0.0153	0.00775	94	8244.6809	0.0775
8	0.0025	0.0012	0.00185	105	1761.9048	0.0185
9	0.0008	0.0047	0.00275	85	3235.2941	0.0275
10	0.0008	0.0012	0.001	96	1041.6667	0.0100
11	0.0004	0.0101	0.00525	95	5526.3158	0.0525
12	0.0002	0.0105	0.00535	100	5350.0000	0.0535
13	0.0093	0.0101	0.0097	95	10210.5263	0.0970
14	0.0101	0.0061	0.0081	85	9529.4118	0.0810
15	0.0013	0.0012	0.00125	80	1562.5000	0.0125
16	0.0004	0.0104	0.0054	90	6000.0000	0.0540
17	0.0007	0.0101	0.0054	91	5934.0659	0.0540
18	0.0005	0.0106	0.00555	100	5550.0000	0.0555
19	0.0005	0.0108	0.00565	100	5650.0000	0.0565
20	0.0007	0.0109	0.0058	100	5800.0000	0.0580
Mean				96.55	4793.913	0.0463

Table 3. Mean elemental emissions obtained by AAS

Sample	Mean elemental composition of PM (mg/kg)											
	Na	K	Ca	Mg	Mn	Fe	Zn	Cu	Ni	Pb	Cr	Hg
1	30.125	25.241	0.009	0.013	0.007	0.018	0.042	0.008	0.010	0.000	0.007	0.000
2	30.214	35.322	0.035	0.009	0.016	0.036	0.030	0.011	0.019	0.002	0.002	0.000
3	20.341	40.241	0.041	0.022	0.027	0.046	0.003	0.022	0.003	0.008	0.013	0.001
4	10.245	20.422	0.025	0.018	0.039	0.022	0.022	0.016	0.007	0.004	0.017	0.000
5	35.125	30.912	0.017	0.026	0.014	0.024	0.020	0.007	0.027	0.002	0.009	0.004
6	20.217	20.272	0.013	0.017	0.027	0.028	0.006	0.019	0.024	0.002	0.005	0.002
7	15.321	10.123	0.022	0.031	0.034	0.042	0.049	0.023	0.008	0.002	0.002	0.010
8	30.243	20.712	0.031	0.022	0.029	0.03	0.015	0.015	0.03	0.009	0.019	0.005
9	12.422	10.134	0.033	0.015	0.032	0.033	0.024	0.032	0.023	0.005	0.025	0.000
10	20.134	20.124	0.005	0.011	0.025	0.014	0.013	0.009	0.029	0.002	0.022	0.000
11	15.412	25.151	0.012	0.025	0.036	0.011	0.007	0.025	0.032	0.004	0.028	0.000
12	14.391	30.333	0.029	0.007	0.021	0.050	0.016	0.012	0.036	0.004	0.034	0.003
13	25.124	10.342	0.032	0.033	0.033	0.047	0.044	0.017	0.025	0.000	0.03	0.001
14	20.323	10.426	0.024	0.029	0.012	0.044	0.033	0.029	0.006	0.006	0.036	0.006
15	12.427	20.512	0.037	0.005	0.023	0.048	0.041	0.034	0.021	0.008	0.029	0.000
16	10.114	10.125	0.039	0.012	0.037	0.035	0.017	0.018	0.034	0.003	0.033	0.002
17	20.235	20.812	0.043	0.035	0.042	0.043	0.039	0.021	0.038	0.004	0.024	0.000
18	25.125	12.613	0.038	0.037	0.039	0.029	0.032	0.013	0.02	0.007	0.037	0.004
19	18.404	15.823	0.027	0.019	0.045	0.032	0.047	0.016	0.028	0.003	0.013	0.000
20	14.235	20.347	0.036	0.024	0.048	0.036	0.045	0.022	0.026	0.006	0.026	0.002
Mean	20.0089	20.4994	0.0274	0.0205	0.0293	0.0334	0.0273	0.0185	0.0223	0.0041	0.0206	0.0020

Table 4. Estimated annual elemental loading from burning of sawdust

State	Ton/year												
	Sawdust burnt	Na	K	Ca	Mg	Mn	Fe	Zn	Cu	Ni	Pb	Cr	Hg
Lagos	179104.32	3.5837	3.6715	0.0049	0.0037	0.0052	0.0060	0.0049	0.0033	0.00399	0.00073	0.00369	0.0004
Ogun	76758.72	1.5359	1.5735	0.0021	0.0016	0.0022	0.0026	0.0021	0.0014	0.00171	0.00031	0.00158	0.0002
Oyo	81875.52	1.6382	1.6784	0.0022	0.0017	0.0024	0.0027	0.0022	0.0015	0.00183	0.00034	0.00169	0.0002
Ondo	79573.44	1.5922	1.6312	0.0022	0.0016	0.0023	0.0027	0.0022	0.0015	0.00177	0.00033	0.00164	0.0002
Osun	62686.08	1.2543	1.2850	0.0017	0.0013	0.0018	0.0021	0.0017	0.0012	0.0014	0.00026	0.00129	0.0001
Ekiti	25585.92	0.5119	0.5245	0.0007	0.0005	0.0007	0.0009	0.0007	0.0005	0.00057	0.0001	0.00053	0.0001
Southwest	505584	10.1162	10.3642	0.0139	0.0104	0.0148	0.0169	0.0138	0.0094	0.01127	0.00207	0.01042	0.0010

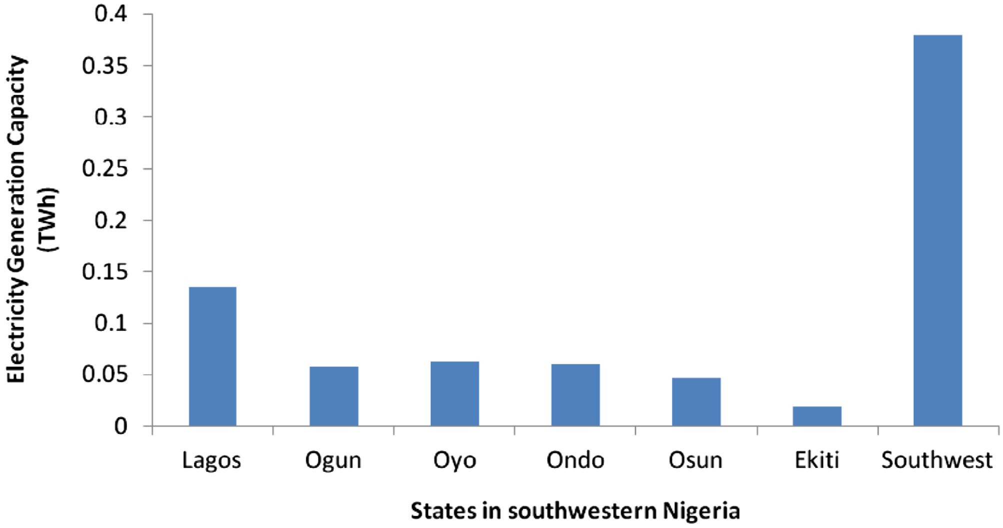
respectively. The annual total atmospheric loading of particulate matter for the entire southwestern Nigeria is estimated to be about 23.4 tons. Using the elemental emission per kilogram of sawdust burnt (Table 3) and the estimated quantity of sawdust subjected to open burning in each State (Table 1), the obtained estimated atmospheric loadings of the elements from burning of sawdust in southwestern Nigeria are as summarized in Table 4 with potassium and sodium being the predominant elements. As expected, the maximum and least elemental emissions were from Lagos and Ekiti States, respectively. Lagos where the largest quantity of sawdust is generated and burnt is expected to experience potassium and sodium loadings of 3.67 and 3.58 tons while Ekiti is estimated to experience 0.52 and 0.51 tons of the same elements on annual basis. The entire southwestern Nigeria is expected to receive 10.4 and 10.1 ton/annum of potassium and sodium, respectively, from burning of sawdust. Considering the huge annual tonnage of sawdust subjected to open burning in the region and the possibility of the same elements from other anthropogenic sources; the atmospheric loadings of other elements which were observed to be emitted in low quantities (Pb and Hg) could become significant.

The per capita and land distributions of pollutants are useful indications of impacts of pollutants in terms of public health and ecology. The per capita and land distribution of PM from sawdust burning in the region are summarized in Table 5. The per capita distribution which is an expression of population distribution of pollutant ranged between 0.494 and 1.065 g/capita among the states with Ekiti and Ogun States experiencing the least and greatest impacts of emissions, respectively. The estimated per capita distribution of PM emissions for the entire southwest region of the country is 0.844. The per capita emission exceeded the regional value in four of the states that make up the southwestern Nigeria. Given the same public health conditions in all the southwestern states, the public health impact of PM emissions from burning of sawdust is expected to be more felt in Ondo being the state with the largest emission per unit population ratio. Although, Lagos had the maximum annual atmospheric loading of PM from burning of sawdust, its population is huge and the amount of pollutant per unit population is therefore lower than what was obtained for Ogun and Ondo States.

Table 5. Per capita and land distributions of PM

State	Per capita	Land distribution
	g/capita	g/km^2
Lagos	0.910	2258.921
Ogun	0.947	216.701
Oyo	0.679	143.049
Ondo	1.065	232.889
Osun	0.849	321.560
Ekiti	0.494	217.958
Southwest	0.844	304.592

Figure 3. Electricity generation capacities of southwestern Nigeria States from sawdust.



The corresponding land distributions of PM emissions among southwestern Nigeria states ranged between 143.049 and 2258.921 g/km^2 with Oyo and Lagos States having the least and largest emission per unit land area, respectively. The extremely high value of land distribution of PM observed for Lagos was basically due to coincidence of large emission value and very small land area that is characteristic of the state. The estimated land distribution for the entire southwestern Nigeria was 304.592 g/km^2. With the exception of Lagos, the land distributions of PM emissions from burning of sawdust in other states were lower than the figure obtained for the entire region.

The presence of other anthropogenic sources of PM in the region which include vehicles, gasoline and diesel generators, agricultural bush burning, municipal waste burning etc. suggest that atmospheric loadings of these elements could occasionally reach a level that could endanger public health. Hence, the burning of sawdust as a means of escaping solid waste management problem is therefore considered a non-sustainable option. Oluoti et al. (2014) observed that up to 1.3 TWh of electricity can be generated from about 1.8 million tons of wood generated by the sawmills in Nigeria on annual basis and further suggested that waste to energy option be considered in the management of the waste. Considering about 526, 650 metric tons of sawdust that is available in southwestern Nigeria (Okedere, 2016) on annual basis; biomass electricity is suggested as an option that can be explored in the region for on-site power generation via mini-grid systems. Figure 3 shows the sawdust electricity generation capacities of states that make up southwestern Nigeria. As expected Lagos and Ekiti States have the largest and least capacities of 0.135 and 0.019 TWh, respectively, while the regional capacity is 0.38 TWh. This is expected to reduce absolute dependence on the fossil fuel thermal plants that are currently the backbone of energy supply in the country. Mini grids can be made to serve small holdings including the sawmill clusters. It will also help solve the problem of solid waste management.

4. Conclusion

The atmospheric loadings of PM and some elements from open burning of sawdust in southwestern Nigeria was investigated using emission factor approach. The estimated annual PM loading ranged between 1.18 and 8.29 ton/annum with the maximum and minimum loadings corresponding to Lagos and Ekiti, respectively. The annual total atmospheric loading of PM for the entire southwestern Nigeria was estimated to be about 23.4 tons. The study observed that the dominant elements present in the emissions were potassium and sodium though some other elements were also present in smaller quantities. The high value of per capita and land distribution of PM obtained for some states are indications that emissions from burning of sawdust may not really be a sustainable way out of the solid waste management problem posed by huge “mountain” of sawdust generated in the region. The study concluded that waste to energy options via mini-grid systems should be explored to solve the problems of solid waste management, air pollution, and energy in this region of the country.

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