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Estimation of Pollutants' Emission Rates and Associated Impact on Local Air Quality: A Case Study of Cottage Industry in Ibadan Metropolis

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Abstract

Major urban cities in the developing countries are faced with the peculiar problem of poor air quality, which has resulted into millions of untimely death as well as other adverse environmental impacts including climate change. To combat this negative trend, regular documentation of the emission rates and concentrations of the various air pollutants has been identified as a suitable means of designing a sound mitigation approach. Here, we estimated the emission rates of criteria air pollutants (CAPs) and greenhouse gases (GHGs) generated from an industrial setting; as well as the associated environmental impact on local air quality, using emission inventory methodology and air dispersion model. In the study area, the energy consumption pattern was reported and the emission rates of associated gaseous pollutants were observed to range from 0.22 to 85500 kg/day. Similarly, the concentrations of major pollutants were observed to be within the thresholds stipulated by the World Health Organization.

Keywords: emission rate, air quality, cottage industry, criteria air pollutants, greenhouse gases

1. INTRODUCTION

Clean air is considered to be a basic requirement of human health and well-being [1]. However, rapid population growth in cities, industrialization, development, and intensification of road traffic have continued to pose significant challenges on ambient air quality. Poor urban air quality is traceable to the release of toxic air pollutants into the environment; and according to the US Clean Air Act of 1970, six pollutants are designated as criteria air pollutants (CAPs), namely: sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), ozone (O_3), particulate matter (PM) with aerodynamic diameters under 10 and 2.5 μm, as well as lead (Pb). These are regarded as criteria pollutants because they are strongly suspected to be harmful to public health and the environment [2]; other toxic gaseous pollutants include: volatile organic compounds and ammonia. In most cities, the concentration of these pollutants, in excess of the stipulated threshold values, have critical negative impacts on air quality [3].

More than eight out of ten people in the world's urban areas live where the concentration of air pollutants – whether chemicals, soot or other damaging substances introduced into the atmosphere – exceeds the World Health Organization's air quality standard; this results in millions of premature deaths each year and huge costs to the global economy [4]. Ambient particulate matter, nitrogen dioxides, and other pollutants have also been associated with increased prevalence of respiratory and cardiovascular diseases, cancers and even appear to be correlated with neurodevelopmental disorders in children and neurodegenerative diseases in adults [5]. Aside the health impact of these toxic pollutants, there exist several direct and indirect impacts, notably: acidification, eutrophication, ground-level ozone, stratospheric ozone depletion and global warming [6]. Global warming is as a result of the emission of greenhouse gases (GHGs) with consequential negative impact.

The main cause of urban air pollution is the use of fossil fuels in transportation, power generation, industries, and domestic sectors. In addition, the burning of firewood, agricultural and animal wastes also contributes to these adverse environmental impacts [6]. Combustion of fossil fuels typically contributes over 90 percent of the CO_2 emissions and 75 percent of the total GHG emissions in developed countries. CO_2 accounts typically for 95 percent of energy sector emissions with methane and nitrous oxide responsible for the balance. Stationary combustion is usually responsi-

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ble for about 70 percent of the GHGs emissions from the energy sector and about half of these emissions are associated with combustion in energy industries mainly power plants and refineries. Similarly, mobile combustion (road and other traffic) causes about one-quarter of the emissions in this carbon-intensive sector [7].

The over-reliance on the combustion of these non-renewable fuels for industrial production has been identified as not only a potential source of CAPs and GHGs but also one with consequential impact on the depletion of natural resources [8]. Industrial pollution is by far a major problem in many developing countries, the extensiveness of these problems is detrimental to the economic growth of the region, and this has been largely attributed to the absence of reliable and comprehensive system of monitoring environmental data on industrial emissions as well as inadequate resources [9]. The situation in Sub – Saharan African (SSA) cities is even more disturbing and worrisome. Schwela [6], opined that SSA is facing substantial challenges as a result of poor urban air quality leading to several thousands of annual premature deaths. And, this can unarguably be traced to several factors such as: usage of old and uncontrolled industrial plants with obsolete technologies, lack of cleaner fuels, lack of emission inventories in several SSA countries, usage of old vehicles without emission control and many more.

The 2016 data on Nigeria's air quality put the nation's population exposed to high concentration of PM 2.5 at 94% which is well above the 72% SSA average [10]. This air quality is also among the poorest in the world with associated 150 deaths per 100,000 people; and according to the 2019 Health Effects Institutes (HEI) chart, the air in Nigeria is the deadliest in Africa and the fourth deadliest in the World [11]. Despite the huge awareness over the years, little is being done to salvage this situation. However, to abate this trend and reduce the potential future impacts, there is thus an urgent need to put mitigative measures in place. To achieve this, Schwela [6] affirmed the need to continuously obtain baseline data on ambient air pollution levels, source data on emission factors and annual/monthly emissions for point and area sources, as well as the trends in air quality. While there exist some studies, in some states of the country, on the estimation of the annual emission rates of CAPs and GHGs from major industries in general and cottage industry in particular [9, 12], such rarely exist for cottage industry in Ibadan metropolis.

World over, the contribution of cottage industry has been recognized as the main sustenance of any economy because of their capacity in enhancing the economic output as well as human welfare through the utilization of local raw materials and indigenous technology [13]. Currently in Nigeria, small scale industries represent about 90% of the industrial sector in terms of enterprise; they also amount to about 70% of the national industrial development if the threshold is set at 10-70 employee and contributed 10% of the manufacturing sector output [14]. In addition, they contribute significantly to economic development and gross domestic product (GDP) through employment, job creation and sustainable livelihood [14]. Although, the economic importance of cottage industry cannot be overemphasized. However, the consumption of fuels by the various operational units in the sector makes it a potential source of CAPs and GHGs. Hence, this study is set out to estimate the emission rates (ERs) of CAPs and GHGs, generated from cottage industry in Ibadan metropolis due to energy use; and also to estimate the annual per capita emission of GHGs. In addition, the environmental impact of the generated CAPs on the air quality within the study area is to be determined.

2. MATERIALS AND METHODS

In order to estimate the ERs of CAPs and GHGs as well as assess the associated environmental impact on local air quality, the predominant cottage industry categories in Ibadan metropolis were identified and selected through reconnaissance survey. Due to the observed energy consumption pattern, the selected industry categories were limited to: packaged water (PW), block making (BM), bakery (BA); welding (WL), and sawmill (SM). Both point and mobile sources of emission were assessed. ERs were estimated using emission inventory methodology and the following assumptions were made:

1. Emissions resulting from electricity consumption were not put into consideration, because the scope of research is limited to the local air quality in the research area which is far away from the various sources of electricity generation in Nigeria. Hence, the research area has zero net emission due to electricity consumption.

2. Fugitive emissions were considered to be insignificant.

2.1. Research Area

Ibadan city is a traditional urban centre founded in 1820's and it is the largest indigenous urban centre in Africa south of the Sahara [15]. It is the capital of Oyo State, located in South-Western Nigeria. The city lies mostly on lowlands which are punctuated by rocky outcrops and series of hills. Elevation ranges from 150m in the valley area to 275 meters above sea level. The climate is equatorial, notably with dry and wet seasons (with relatively high humidity). The dry season lasts from November to March while the wet season starts from April and ends in October [16]. Rainfall is about 1,150 mm per year on average and average daily temperature ranges between 25°C(77.0°F) and 35°C(95.0°F), almost throughout the year [16]. At Nigerian independence, Ibadan was the largest and most populous city in the country and the third in Africa after Cairo and Johannesburg [17].

Table 1: Details of selected study area and the local governments of interest.

LG	Study area 1 Name	Study area 1 Land size (km^2)	Study area 2 Name	Study area 2 Land size (km^2)	Study area 3 Name	Study area 3 Land size (km^2)	Land size of LG (km^2)
IBN	Sango	1.48	Mokola	1.87	Bodija	5.72	145.6
IBNE	Aremo	0.47	Olorunsogo	1.31	Agugu	0.99	81.5
IBNW	Eleyele	3.79	Adamasingba	0.20	Mapo	0.30	31.4
IBSE	Odinjo	1.11	Elekuro	1.15	Orita-Aperin	0.31	80.5
IBSW	Adeoyo	2.15	Challenge	0.90	Odo-Ona	0.37	124.6

LG = Local government

Administratively, Ibadan comprises eleven Local Government Areas (LGAs): Ibadan Metropolis consists of five LGAs which cover the 'inner city': Ibadan North (IBN), Ibadan North-East (IBNE), Ibadan North West (IBNW), Ibadan South West (IBSW) and Ibadan South-East (IBSE); the six remaining LGAs constitute the suburbs of the city. According to the 2006 census, the population of Ibadan is 2.6 million; with Ibadan metropolis having a population of approximately 1.35 million people. Also, the population of the city as at 2015 is estimated to be 3.4 million with an annual population growth rate of about 3.2% [16, 18]. Figure 1 depicts the map of Ibadan metropolis.

2.2. Data Collection and Processing

A multistage sampling technique was used for this research, in which three study areas were randomly selected as representative sample for each local government in Ibadan metropolis. Consequently, in each study area, three companies were randomly selected for each industry category. Primary data were collected in each company using structured questionnaire. Questions were asked about the number of operational days per year, number of company per study area, source type, fuel type and fuel consumption rates. The land sizes (in km^2) of the study areas and the Local governments of interest, as presented in Table 1, were obtained using Google Earth software and also from existing literature [16].

To estimate the ER and impact of CAPs and GHGs in the study area, the population size of the various industry categories is essential in determining the required input data. However, since industry statistics is rarely available nor accessible in this part of the world, the industry density method adopted by Hussaini et al. [12] was utilized to estimate the total number of companies and energy use pattern for all the cottage industry categories that were considered in each local government. Equation (1) – (8) were adopted for determining the industry density, industry population and annual energy consumption. However, the exact number of industry population is to be utilized where companies clustered in a location or the total number of companies is known with certainty. Excel spreadsheet and SPSS software were adopted for data processing and presentation.

2.2.1. Estimating the industry population

1. Industry density for a particular industry category in a local government, $E_{k.l}$:

$$E_{k.l} = \frac{\sum_{j=1}^{m} \frac{(\sum_{i=1}^{n} X_i)}{L_j}}{nm} \quad (1)$$

2. Estimated Industry population per local government, M_l:

$$M_l = T_l \times \sum_{k=1}^{y} E_{k.l} \quad (2)$$

3. Estimated Industry population for each industry category In Ibadan metropolis, P_k:

$$P_k = \sum_{l=1}^{z} E_{k.l} \times T_l \quad (3)$$

4. Estimated Industry population in Ibadan metropolis, N:

$$N = \sum_{l=1}^{z} M_l \quad (4)$$

where n is the total number of companies considered per study area, m is the number of area considered, y is the number of the considered industry categories, Z is the number of local government in Ibadan metropolis, X_i is the number of company in an area; as given by each respondent, L_j is the land size of each area (in km^2) and T_l is the land size of each local government (in km^2).

2.2.2. Estimating the energy consumption

1. Average energy consumption for each industry category in a local government, $B_{k.l}$:

$$B_{k.l} = \frac{\sum_{j=1}^{m} \sum_{i=1}^{n} A_i}{nm} \quad (5)$$

2. Estimated annual energy consumption per local government, C_l:

$$C_l = T_l \times \sum_{k=1}^{y} B_{k.l} \times E_{k.l} \quad (6)$$

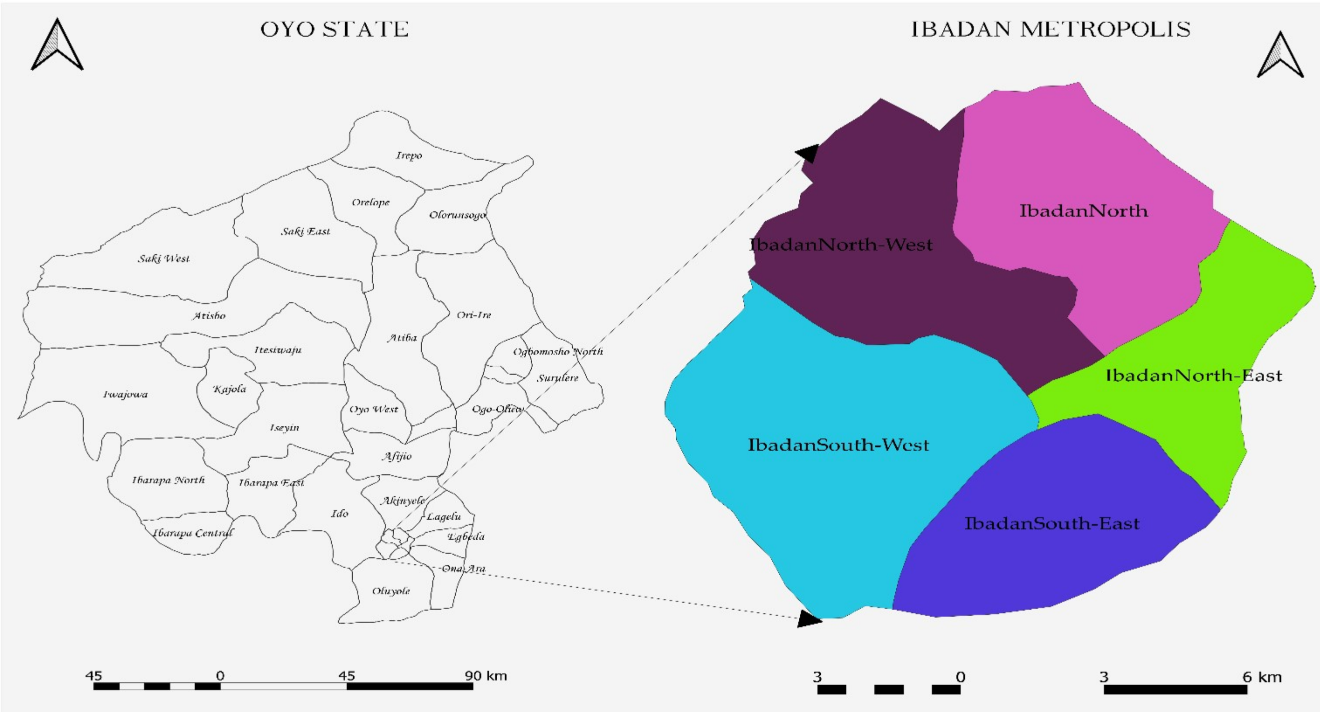

Figure 1: Map showing Ibadan metropolis.

3. Estimated annual energy consumption per industry category in Ibadan metropolis, D_k:

$$D_k = \sum_{l=1}^{z} B_{k.l} \times E_{k.l} \times T_l \tag{7}$$

4. Estimated annual energy consumption in Ibadan metropolis, M:

$$M = \sum_{l=1}^{z} C_l \tag{8}$$

Where A_i (in MJ) is the annual energy consumption by a company in an area as given by each respondent.

2.3. Emission Inventory

Emission inventory(EI) is an essential component for the understanding of air quality and climate change issues from local, regional to global scales [19]. EIs provide a description of the polluting activities that occur across a specific geographic domain and are widely used as input in air quality model for the assessment of compliance with environmental legislation [20].

In addition, Barn et al. [21] iterated the fact that EI, as a tool, is mostly effective when used to describe pollution trends over time scales that is not less than a year. For a fuel-based emission inventory, the annual emissions rates from all sources of combustion can be estimated on the basis of the quantities of fuel combusted and average emission factors (EFs) [7]. The emission inventory improvement program (EIIP) developed by United States Environmental Protection Agency (USEPA) and the 2006 IPCC (Intergovernmental Panel on Climate Change) guidelines for national greenhouse gas Inventories were adopted for the estimation of emission rates for CAPs and GHGs respectively.

As presented by Waldron et al. [22], total emission rate (ER) based on fuel combustion can be estimated using:

$$ER = \Sigma_a \text{fuel}_a \times EF_a \tag{9}$$

Where a = fuel type (diesel, gasoline, wood and charcoal).

EF is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, energy or duration of the activity emitting the pollutant. EFs for the various emissions were obtained from available literature [12, 22–26]; which are presented in Tables 2 and 3 for stationary and mobile sources respectively. Depending on the unit of EF, there is a need to convert the fuel consumption rate to the unit of mass per year or energy per year using various conversion factors. These factors are highlighted in Table 4 for the various fuels.

The annual per capita emission of GHGs was estimated by dividing the total annual GHGs emission with the current population size of the study area; to determine the total annual GHGs emission, global warming potentials of 1, 296, and 23 were adopted for CO_2, N_2O and CH_4 as specified in existing literature [8]. It must however

Table 2: Emission factors for stationary sources

Fuel Type	Pollutants (kg/GJ)						
	CO_2	**N_2O**	**CH_4**	**PM_{10}**	**CO**	**NO_x**	**SO_2**
Gasoline	69.3	6×10^{-4}	3×10^{-3}	4.4×10^{-5}	2.70×10^{-2}	6.99×10^{-4}	3.6×10^{-5}
Diesel	74.1	6×10^{-4}	3×10^{-3}	1.35×10^{-4}	4.10×10^{-4}	1.90×10^{-3}	1.26×10^{-4}
Charcoal	112.0	4×10^{-3}	2×10^{-1}	7.32×10^{-6}	2.58×10^{-4}	2.11×10^{-4}	1.08×10^{-5}
Wood	112.0	4×10^{-3}	3×10^{-2}	7.32×10^{-6}	2.58×10^{-4}	2.11×10^{-4}	1.08×10^{-5}

Table 3: Emission factors for mobile sources

Fuel Type	Pollutants (kg/GJ)						
	CO_2	**N_2O**	**CH_4**	**PM_{10}**	**CO**	**NO_x**	**SO_2**
Gasoline	69.3	5.7×10^{-3}	3.8×10^{-3}	6.8×10^{-4}	5.4	5.77×10^{-1}	3.6×10^{-5}
Diesel	74.1	3.9×10^{-3}	3.9×10^{-3}	6.57×10^{-2}	2.57×10^{-1}	4.05×10^{-1}	1.26×10^{-4}

Table 4: Conversion factors for different fuels.

S/N	Fuels	Conversion factor (density)	Conversion factor (net calorific value)
1	Gasoline	741 kg/m^3	32.7 MJ/L
2	Diesel	837 kg/m^3	45.5 MJ/kg
3	Charcoal	34 kg/bag	28 MJ/kg
4	Wood	9 kg/log	13.6 MJ/kg

Source [8, 12, 27]

be noted that CO_2 emission from the combustion of biomass (wood and charcoal) was assumed to be negligible, since the amount of CO_2 used up during photosynthesis is considered to be equal to the amount that is emitted during combustion process. The extrapolated population of Ibadan metropolis in 2020 was evaluated using Eq. (10).

$$P = P_0(1 + g_R)^T \tag{10}$$

Where P is the 2020 population, P_0 is the 2006 population, g_R is the population growth rate and T is the extrapolation time.

2.4. *Impact on Air quality*

The impact of CAPs emission on local air quality was approximated using air quality modelling techniques for the prediction of the maximum ground level concentrations of pollutants, which were then compared with standards set by relevant authorities. Air quality modelling was conducted using SCREEN3 model, version 3.0; which is a screening model developed by USEPA for determining the worst-case pollution concentration for different types of stationary source [28]. This study thus estimated the total impact of CAPs emission on local air quality by aggregating the maximum ground level concentration of pollutants from stationary sources – as predicted by SCREEN3 model in conjunction with baseline and metrological data that were obtained from the research works of other authors [2, 29]. The selected baseline data were adopted for this study because they accounted for the emissions that were completely free from local sources – residential, commercial and mobile – as well as other undesirable influences.

To obtain a reliable estimate, the airshed was modelled as a simple flat terrain area source with spatio-temporal characteristics of 10km by 10km domain size, averaging period of one-hour and spatial resolution of 100m; this gives the ground level concentrations of pollutants under the worst case scenario and as such aid in determining whether there is need to adopt a comprehensive airshed model for future study. ER per square meter, which is an input parameter for SCREEN3 model, was determined by dividing ER of each CAP (in g/s) by the total area of the pollution source (in m^2). Since the pollution source is a collection of multiple point sources, each point source was assumed to have an average dimension of 2 m by 5 m. The one-hour average result obtained from this model can be converted to a long term concentration using suitable averaging time factors; however, for all area sources, the model's 1-hour average concentration output is equivalent to the 3, 8, and 24-hour average concentrations [30].

3. RESULTS AND DISCUSSION

3.1. *Industry Population*

A total number of 4242 companies were estimated for the considered cottage industry categories in Ibadan metropolis. As depicted in Fig. 2, IBN has the largest industry size of approximately 1370 companies as compared to IBNE that has the least industry size of about 676 companies. The industry size in other LGs are: 814 companies for IBSW, 705 companies for IBNW and 677 companies for IBSE. Similarly, BA has the highest number of companies that stands at 1752 and it is followed closely by WL, which accounted for approximately 36% of the total industry size. BM, SW, and PW has a total number of 512, 268, and 183 companies respectively. BA and WL were observed to possess homogeneous spread across the study area and this phenomenon can be closely linked to the rationale behind their

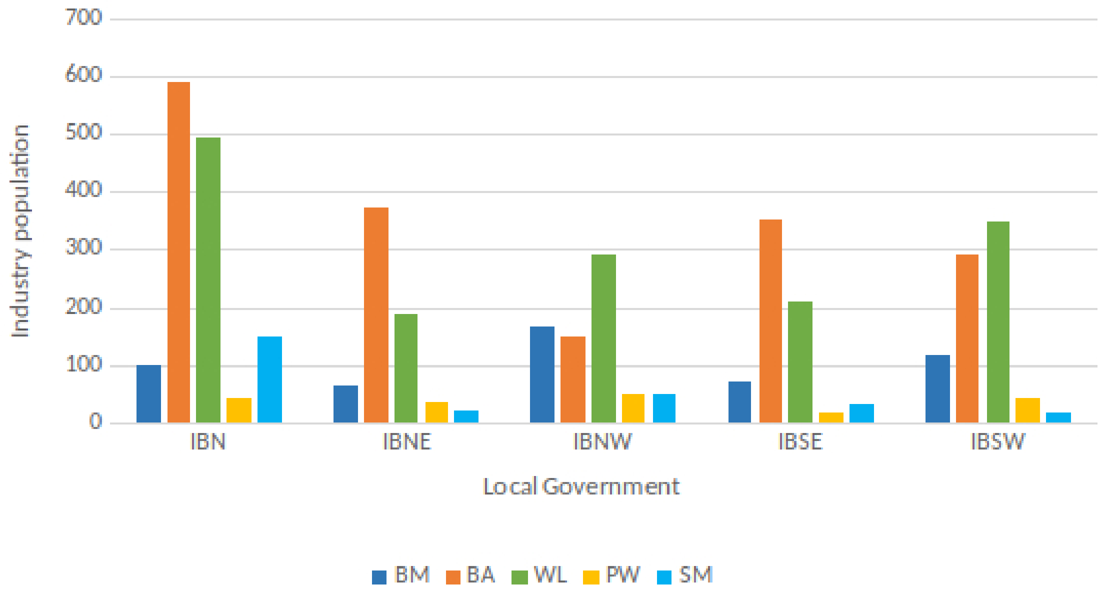

Figure 2: Population of selected industry categories in Ibadan metropolis.

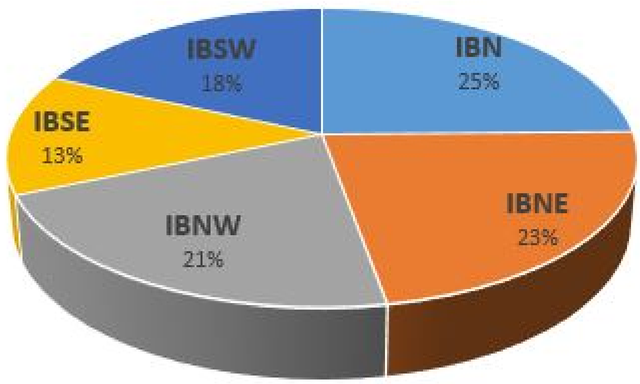

Figure 3: Percentage distribution of energy use.

high industry populations. On the other hand, other industry categories showed different types of spread: SW were mostly observed to be in cluster, usually in a designated area; while BM and PW were observed to possess uneven distribution across each LG. Average daily operational period was obtained as 8 hours.

3.2. Energy Use Pattern

The estimated total energy use in the study area is approximately 8716 GJ/day. Figure 3 shows the distribution of energy use in each LG, which ranged from approximately 1144 GJ/day in IBSE to about 2153 GJ/day in IBN. The bulk of the total energy use was as a result of the use of wood for energy generation and it accounted for about 87% of the total energy consumed as compared with diesel and gasoline that accounted for 12% and 1% respectively. Equally, the stationary source is the predominant energy source as it accounted for 99% of the total energy use in the study area; unlike the mobile source that has a partly 1% contribution. Majorly, the stationary sources in the study area are being powered with diesel, charcoal, and wood for energy generation; average daily use of diesel, across the study area, for the selected industry categories are: 2892 L/day for BM, 4301 L/day for BA, 13380 L/day for WL, 3650 L/day for PW and 3080 L/day for SW. The utilization of charcoal as fuel for energy production was not reported by any respondent.

In addition, the use of wood as an energy source is peculiar to BA; its average daily use for the considered LGs are: 14160 logs for IBN, 14920 logs for IBNE, 12665 logs for IBNW, 8400 logs for IBSE and 11600 logs for IBSW. For mobile sources, fossil fuels (diesel and gasoline) are used to power vehicles for products delivery. However, it was observed that most of the respondents relied on the use of third party vehicles for their day-to-day business activities. From the data obtained, about 272 L/day of gasoline is used by mobile sources in IBNE, 1490 L/day in IBNW and 315 L/day in IBSW. Similarly, diesel accounted for approximately 400 L/day of fuel used in IBN while the daily usage of diesel fuel is 750 and 170 liters for IBNW and IBSE respectively

3.3. Environmental Burden

CO_2 emission has the highest ER of approximately 85500 kg/day while the ERs for other gaseous emissions were obtained as follows: 31.44 kg/day for N_2O, 230.30 kg/day for CH_4, 3.54 kg/day for PM_{10}, 382.05 kg/day for CO, 63.12 kg/day for NO_x and 0.22 kg/day for SO_2. As evident from Fig. 4, the use of gasoline accounted for approximately 96% and 62% of CO and NO_x emission respectively. However, diesel is the major contributor to CO_2, PM_{10} and SO_2 emission having values that ranged from about 62 – 97%

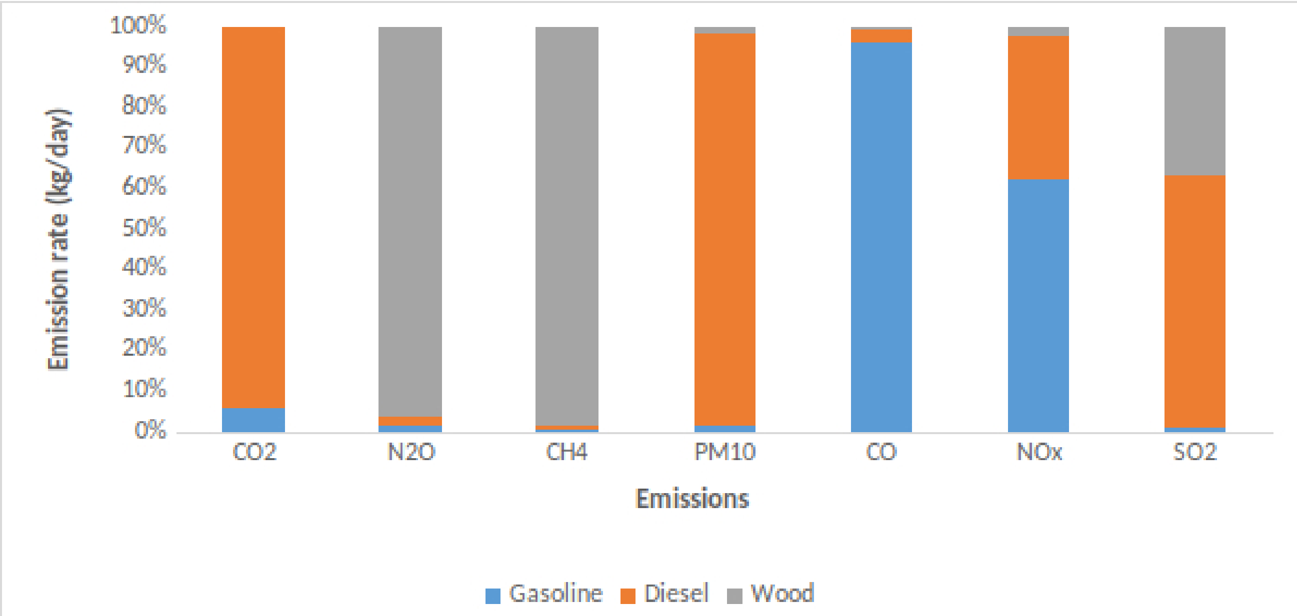

Figure 4: Emission rates of gaseous pollutants within the study area.

of the aggregate for each pollutant. Similarly, wood consumption accounted for more than 95% of N_2O and CH_4 emissions. Based on the SCREEN3 model result, the overall concentrations of 28.24 $\mu g/m^3$, 0.43 mg/m^3, 341 $\mu g/m^3$ and 22.22 $\mu g/m^3$ were obtained for PM_{10}, CO, NO_x, and SO_2 respectively. It was observed that all CAPs, except NO_x, were within the WHO acceptable 24-hour mean limits of 50 $\mu g/m^3$ for PM_{10}, 30 mg/m^3 for CO, 200 $\mu g/m^3$ for NO_x and 125 $\mu g/m^3$ for SO_2 [1, 2, 6, 29].

The annual GHG emission and total GHG emission per capital were estimated as 36530 tCO_{2e}/year and 0.02 tCO_2/cap respectively. Comparing these results with the National values reported by Hussaini et al. [12] as 48 $mtCO_{2e}$/year and 0.5 tCO_2/cap respectively for the manufacturing/construction sector. It can be deduced that the contribution of the selected industry categories to the total annual GHG emission in the country is partly 0.08%; which is an indication that the impact from these industry categories is negligible when compared with other energy-intensive industries in Nigeria.

4. CONCLUSION

The projected emission rates of CAPs and GHGs from cottage industry in Ibadan metropolis have been reported. For an estimated industry size of 4242 companies, the emission rates were observed to range from 0.22 to 85500 kg/day for the considered gaseous pollutants. Likewise, the impact on local air quality was assessed and it was observed that the concentrations of major pollutants were within the acceptable limits set by the World Health Organization. However, due to certain degree of subjectivity in the methods employed, the establishment of air quality monitoring stations that measure real-time data will surely provide cost-efficient and more objective data on the concentrations of CAPS and GHGs within the study area.

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