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Hazardous Organic Pollutants from Open Burning of Municipal Wastes in Southwest Nigeria

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ABSTRACT

The Southwest Nigeria has witnessed tremendous increase in the output of municipal wastes in the recent years. Non availability of government policy on solid wastes management or its lack of effectiveness where it exists makes unabated open burning the predominant means of municipal solid waste disposal in the region. Open burning of municipal wastes being a major source of anthropogenic air emissions was investigated for atmospheric loading of some hazardous organic pollutants using the emission inventory method. The specific pollutants considered in this study were volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polychlorinated dibenzo –p- dioxin (PCDDs) and polychlorinated dibenzo furan (PCDF). The estimated release of VOCs, PAHs, PCBs, PCDD and PCDF from open burning of municipal wastes in the region over the 5-year period investigated were 64000 tonnes, 988 tonnes, 43 tonnes, 0.56 tonnes and 0.2 tonnes respectively. Given the serious human health implications associated with these hazardous organic pollutants, the study suggested conversion of wastes to energy as a possible solution since the region also faces energy challenges.

Keywords: VOCs, PAHs, PCBs, PCDDs, PCDF, municipal wastes, emission inventory.

INTRODUCTION

Increase in population and lifestyle changes are two vital factors influencing the output and compositions of municipal wastes worldwide. Municipal solid wastes constitute serious environmental challenges worldwide due to the huge volume of wastes being churned out on daily basis [1–3]. However, the environmental pollution concerns from municipal wastes are more worrisome in developing countries where the rates of generation far exceed the available capacity to manage such wastes [4–5, 2]. In many instances, such management capacities do not even exist. Nigeria is believed to be generating over 42 million metric tons of municipal wastes on annual basis [6] with little or no capacity and facilities on ground to manage them in almost all the cities.

Although, the composition of municipal wastes may vary slightly from one place to another depending on level education, civilization, income level, lifestyle and culture; generally, municipal wastes are usually composed of food residue, papers, wood residue, fabrics, metal scraps, sludge, cans, and plastic wastes etc. [1, 6]. However, the growing usage of plastic products as packaging materials across the world is seriously increasing the fractions of plastic wastes in the municipal wastes [7]. In the United States, the compositions of plastic wastes have increased to about 30% of MSW annually [8]. China and

Indian have also experienced increase in fractions of plastics in their municipal wastes despite a recent ban on plastic importation in China [9, 10]. Although, Nigeria used to be an agrarian society, there has been drastic shift in lifestyle and product consumptions. Plastic products are now featured more in the day to day activities of Nigerians. They are the choice materials for packaging of products from pharmaceutical, food, and water industries. Agricultural products such as pesticides and herbicides are also packaged in plastic bottles. Wholesale shopping malls and retail shops also used polythene bags to package the sold items. The menace of plastic wastes has recently been acknowledged by the federal government of Nigeria which is presently looking at the possibility of recycling [11].

Despite the recent acknowledgment of the enormity of the challenges posed by municipal wastes by the Nigerian government, the usual practice of open dumping and burning at government dumpsites, community dumpsites and residential backyards still continues unabated in all Nigerian cities and communities [12–14]. A typical scene of open burning of unsorted municipal wastes in Southwest Nigeria is shown in Figure 1. The paucity of fund is keeping the government at various levels away from tackling the problem following best available practices. Moreover, there is low level of awareness on the environmental and public health consequences and risks associated with open burning of these wastes.

In addition to the emission of criteria air pollutants and greenhouse gases, open burning of municipal wastes is also associated with the emissions of some highly hazardous organic air pollutants which include mercury, benzene, toluene, ethyl benzene, polycyclic aromatic hydrocarbons (PAHs) and persistent organic pollutants (POPs) [2, 5, 13]. There is reported evidence that these pollutants are toxic to human health even at very low dose of exposure [5, 15]. They are also reported in many publications to exhibit carcinogenic, mutagenic and teratogenic properties in human [15]. The Agency for Toxic Substances and Disease Registry (ATSDR) has specifically listed some of these as priority pollutants [16, 17]; hence, continuous open burning of municipal wastes is not a sustainable approach to their management.

The studies on the extent and compositions of municipal wastes in Nigeria have been reported by several authors [12, 14]. A few studies on anthropogenic air pollutants from combustion of municipal solid wastes in Nigeria also exist in the literature [2, 15, 18]. However, the studies by these authors were limited in scope based on the number of pollutants and study areas covered. There is presently no specific study on the contribution of open burning of municipal wastes to atmospheric loading of total volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polychlorinated dibenzo –p- dioxin (PCDDs) and polychlorinated dibenzo furan (PCDF) in Nigeria. Therefore, the present study examined the emission inventory of these organic air pollutants from open burning of municipal wastes in Southwest Nigeria. The study will provide the information that will further strengthen the present drive of Nigeria's Federal Government at municipal waste management.

Figure 1. Scene of open burning of unsorted wastes in southwest Nigeria

METHODOLOGY

Study area

The study area is the Southwest region of Nigeria (Figure 1) which lies between 2° 31' and 6° 00' East and Latitude 6° 21' and 8° 37' N. It comprises six States (Lagos, Ogun, Oyo, Ondo, Osun and Ekiti). The region is bounded on the East by Delta and Edo States, in the North by Kogi and Kwara States, in the West by Benin Republic and in the South by the Gulf of Guinea. It has an estimated total land area of about 77,818 km^2 with tropical climate that 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 wheras 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.

This region of Nigeria is indigenous to the Yoruba people who were predominantly farmers although modern civilization has reversed this trend. On the basis of the 2006 population census, the region had the second highest population of a little below 28 million people and accounted for 19.7% of Nigeria's total population. A breakdown of the population Figure 2 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 [19]. It is often regarded as the industrial hub and commercial nerve centre of the country. The heavy presence of manufacturing industries in Ogun and the deep sea ports in Lagos both of which are in the Southwest region have conferred on it a level of special status. Moreover, Lagos State served as Federal Capital for the country for several years until 1991 when the seat of government was moved to Abuja. Up to date, it is still the industrial and economic backbone of the country. Due to population and lifestyle changes, the quantity of plastic wastes generated in this region of Nigeria is enormous.

Estimation of annual municipal solid wastes output from Southwest Nigeria

The absence of accurate waste collection data among States in Nigeria is a major challenge in the estimation of annual quantity of municipal wastes at any given time. However, several authors have

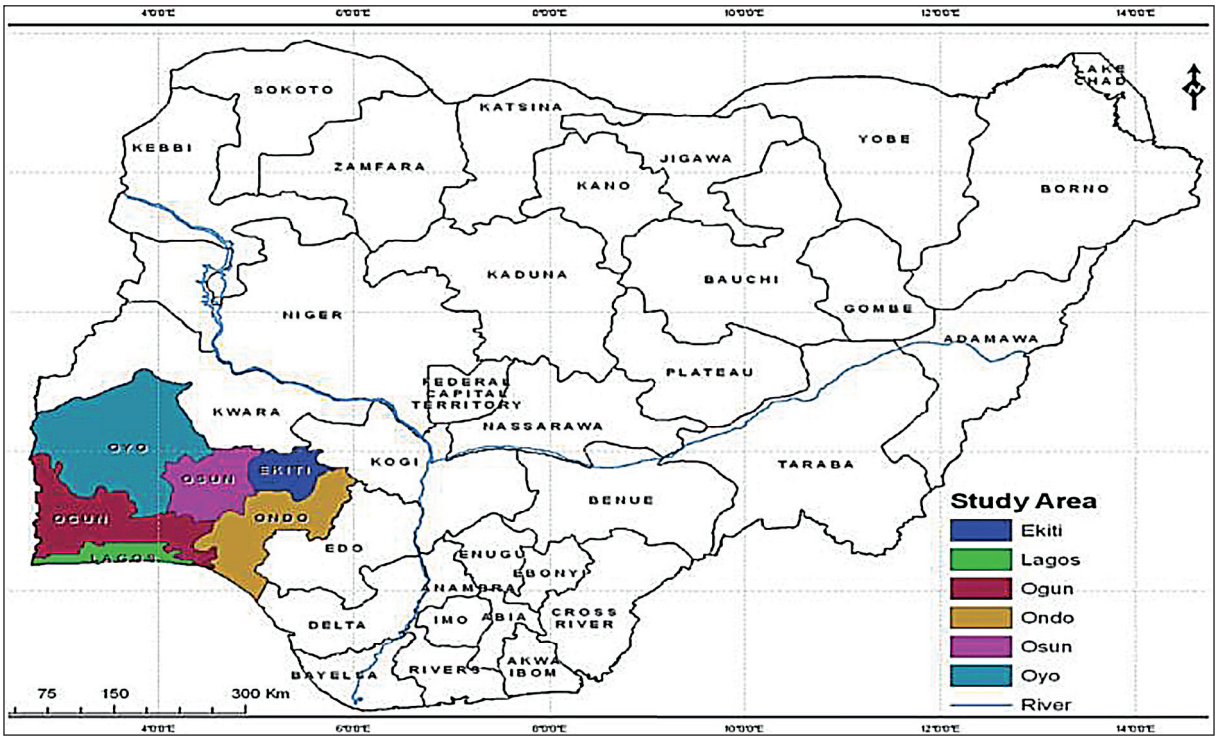

Figure 2. Map of Nigeria showing the location of southwest region

reported different per capita municipal waste based on the studies conducted in different parts of the country. According to a 2012 World Bank report, the per capita municipal waste rate in Nigeria was 0.56 kg/capita/day [20]. Abila and Kantola [21] gave a value between 0.44–0.66 kg/capita/day; Nnaji [22] reported a range of 0.49–0.95 kg/capita/day; per capita waste between 0.65–0.95 kg/capita/day was reported by Ike et al., Noiki et al. and Edet and Maduabuchi [6, 14, 23] while Sowunmi et al. [24] reported a per capita waste generation between 0.26 and 1.02 kg/capita/day for the country.

Going by the current trend in the literature, the present study has adopted a value of 0.6 kg/capita/day. This information was combined with the population data of the region to estimate the annual output of municipal solid wastes as represented by Eq. (1). According to a World Bank report on development indicators [25], the annual population growth rate of Nigeria oscillated between 2.6% and 2.7% since 2006 when the last official head count in the country was held. These population growth rates were used to generate the population data used in this study for years 2016–2020. The 2006 population census data were obtained from the Federal Republic of Nigeria's Official Gazette [19].

$$\mathrm{MSW}\left({}^{\text{tonnes}}/_{\text{year}}\right) = 0.6\left({}^{\text{kg}}\Big/_{\frac{\text{capita}}{\text{day}}}\right)\times \times \text{Population} \times 365 \text{ days} \times 0.001 \quad (1)$$

Estimation of emission rates of the pollutants

The pollutants of interest in this study are volatile organic compounds TVOCs, TPAHs, TPCBs, TPCDD and TPCDF. Emission inventory approach which requires the combination of pollutant emission factor and the activity associated with emission of the pollutant was adopted for the determination of the annual emission rate of each pollutant [26–34]. The emission rates of TVOCs, TPAHs, TPCBs, TPCDD and TPCDF were calculated for open burning of municipal wastes in Southwest Nigeria.

The exact quantity wastes burnt annually in the study area is not known but numerous evidences point to open burning as the predominant means of disposal of solid wastes in Nigeria [7, 13, 14, 18, 30, 35–37]. According to a study conducted in Benin City by Ezeudu and Ezeudu [38], about 68% of municipal wastes are indiscriminately dumped while 10.7% are burnt. A similar study in Sokoto State indicated that about 55%, 30.2% and 7.0% of wastes are disposed by open dumping; open burning and government collection respectively. In the study area, Achi et al. [1] investigated solid waste management practices in Abeokuta, the capital city of Ogun State in Southwest Nigeria. Their findings showed that 26.28%, 47.44%, 6.26%, 14.19% and 5.81% of respondents disposed of their wastes without sorting via open dumping, open burning, burying, use of cart pushers and local government trucks respectively. It is worth noting that a large fraction of the open dumped wastes is usually burnt at unapproved dumpsites while all those handed over to truck pushers and local government trucks would end up at designated open dumpsite and disposed by burning for volume reduction.

For instance, workers at the Osun State dumpsite located at the Egbedi village in the outskirt of the Osogbo, the State's capital admitted orally that the wastes at the approved dumpsite are burnt twice in a week. It is thus safe to conclude that at least 50% of the municipal wastes are disposed via open burning either at government approved site (waste collected) or unapproved dumpsites (residential backyards or community dumpsite). Again, a conservative figure of 40% was adopted for the determination of annual activities of municipal wastes associated with open burning. These activities were combined with the emission factors of the pollutants to establish their annual emission rates as captured in Eq. (2). The emission factors of the pollutants for open burning of municipal wastes that were used in this study are summarized in Table 1.

$$\text{Emission Rate}\left(\frac{\text{tonnes}}{\text{year}}\right) = 0.4 \times \times \text{Mass of Waste}\left(\frac{\text{tonnes}}{\text{year}}\right) \times \text{Emission Factor} \quad (2)$$

Table 1. Emission factors of some organic pollutants for open burning of wastes [27]

Pollutants	Emission factor (lb/tons)
TVOCs	8.556
TPAH	0.132
TPCB	0.00572
TPCDD	0.000076
TPCDF	0.0000122

RESULTS AND DISCUSSION

Estimated output of municipal wastes in Southwest Nigeria

The estimated annual output of municipal wastes for the entire Southwest Nigeria between 2016 and 2020 is summarized in Table 2. The annual quantity of wastes generated progressively increased for all States during the period under investigation. The principal factor responsible for the progressive increase in municipal wastes generation is the increase in population of the States. The estimated total quantity of waste generated in the study area increased from about 7.89 million tonnes in 2016 to approximately 9 million tonnes in 2020 with the Ekiti and Lagos States having the least and largest output of municipal wastes respectively. This volume of waste is about 14.5% of total wastes from Sub-Sahara Africa and about 80% greater than what is generated in Ghana on annual basis [39–41].

Over the 5 – year period investigated, the total amount of municipal wastes generated in the study area was estimated to be about 42 million tonnes. Among the States in the southwestern Nigeria, only Lagos has a semblance of solid wastes management and available evidences point to grossly inadequate capacity to manage the huge volume of wastes. In other States, there is practically absence of municipal wastes management. The wastes are principally disposed of via open burning in all States in the region without sorting. Due to life style changes, the percentage of plastics in the wastes has increased tremendously in the recent years. Open burning as a means of disposal is thus plagued with emissions of varieties of hazardous organic pollutants.

Emission rates of pollutants from municipal wastes

The estimated annual emission rates of total volatile organic compounds (TVOCs), total polycyclic aromatic hydrocarbons (TPAHs), total polychlorinated biphenyls (TPCBs), total polychlorinated dibenzo – p – dioxins (TPCDD) and total polychlorinated dibenzo furans (TPCDF) from open burning of municipal wastes in Southwest Nigeria over a 5-year period (2016–2020) are summarized in Table 3, Table 4, Table 5, Table 6 and Table 7 respectively.

From Table 3, the total VOCs emitted between 2016 and 2020 ranged between 1052 – 1166 tonnes/year, 1498–1660 tonnes/year, 1518–1682 tonnes/year, 1645–1823 tonnes/year, 2447–2712 tonnes/year and 3997–4429 tonnes/year for Ekiti, Osun, Ondo, Ogun, Oyo and Lagos respectively. The estimated 5– year (2016–2020) VOCs emitted in the region was about 64,000 tonnes, an average of about 13,000 tonnes on annual basis. A comparison of this annual average with the reported annual contributions of petroleum refineries to VOCs in Nigeria shows that open burning of municipal wastes in Southwest Nigeria alone exceeds the contributions of refineries by approximately 9,000 tonnes [42].

Between 2016 and 2020 (Table 4), the emission inventories of total polycyclic aromatic hydrocarbons (TPAHs) from open burning of municipal wastes for study area were in the range of 16.23–17.98 tonnes/year, 23.11–25.62 tonnes/year, 23.42–25.95 tonnes/year, 25.38–28.12 tonnes/year, 37.76–41.84 tonnes/year and 61.66–68.32 tonnes/year for Ekiti, Osun, Ondo, Ogun,

Table 2. Estimated municipal wastes output in Southwest Nigeria (tonnes/year)

Year	Ekiti	Osun	Ondo	Ogun	Oyo	Lagos
2016	683091.22	972962.25	985467.588	1068118.63	1589132.11	2595054.08
2017	700851.47	998259.16	1011089.931	1095889.80	1630449.53	2662525.57
2018	719073.80	1024213.94	1037378.253	1124382.79	1672841.14	2731751.25
2019	737769.61	1050843.47	1064350.074	1153616.88	1716334.97	2802776.67

Table 3. Estimated annual total VOC emissions (tonnes/annum)

Year	Ekiti	Osun	Ondo	Ogun	Oyo	Lagos
2016	1052.02	1498.44	1517.70	1644.99	2447.39	3996.59
2017	1079.37	1537.40	1557.16	1687.76	2511.02	4100.50
2018	1107.43	1577.37	1597.64	1731.64	2576.31	4207.12
2019	1136.22	1618.38	1639.18	1776.66	2643.29	4316.50
2020	1165.77	1660.46	1681.80	1822.86	2712.02	4428.73

Oyo and Lagos respectively. The estimated total PAHs emissions from this region of Nigeria for year 2020 was about 210 metric tonnes and this amounted to about 18.4% of PAHs emissions for the whole of Southeast Asia in 2015 [43] (Oanh et al. 2015). Over the 5–year period covered by the study, it is estimated that at least 988 tonnes of PAHs have been emitted from open burning of municipal wastes in Southwest Nigeria.

From Table 5, the emission inventories of total polychlorinated biphenyls (TPCBs) from open burning of municipal wastes for study area between 2016 and 2020 ranged between 0.70–0.78 tonnes/year, 1.00 –1.11 tonnes/year, 1.01–1.12 tonnes/year, 1.10–1.22 tonnes/year, 1.64–1.81 tonnes/year and 2.67–2.96 tonnes/year for Ekiti, Osun, Ondo, Ogun, Oyo and Lagos respectively. The estimated annual total PCB emitted in the study area in the year 2020 was 9.01 tonnes which is about 0.15 tonnes above the value reported for Southeast Asia by Oanh et al (2015). During the 5 – year period covered by the study, about 42.8 tonnes of PCBs were emitted from burning of municipal wastes in Southwest Nigeria.

From Table 6, the estimated levels of PCDD from open burning of municipal wastes between 2016 and 2020 ranged between 9.36–10.36 kg/year, 13.3–14.8 kg/year, 13.5–14.9 kg/year, 14.6–16.2 kg/year, 21.7–24.1 kg/year and 35.5–39.3 kg/year for Ekiti, Osun, Ondo, Ogun, Oyo and Lagos respectively. The average annual PCDD emission between 2016 and 2020 was 113.8 kg while the 5 – year atmospheric loading was 569 kg. As presented in Table 7, Ekiti, Osun, Ondo,

Table 4. Estimated annual total PAHs emissions (tonnes/annum)

Year	Ekiti	Osun	Ondo	Ogun	Oyo	Lagos
2016	16.23	23.11	23.42	25.38	37.76	61.66
2017	16.65	23.72	24.02	26.04	38.74	63.26
2018	17.08	24.34	24.65	26.72	39.75	64.91
2019	17.53	24.97	25.29	27.41	40.78	66.59
2020	17.98	25.62	25.95	28.12	41.84	68.32

Table 5. Estimated annual total PCB emissions (tonnes/annum)

Year	Ekiti	Osun	Ondo	Ogun	Oyo	Lagos
2016	0.70	1.00	1.01	1.10	1.64	2.67
2017	0.72	1.03	1.04	1.13	1.68	2.74
2018	0.74	1.05	1.07	1.16	1.72	2.81
2019	0.76	1.08	1.10	1.19	1.77	2.89
2020	0.78	1.11	1.12	1.22	1.81	2.96

Table 6. Estimated annual total PCDD emissions (tonnes/annum)

Year	Ekiti × 10^{-3}	Osun × 10^{-2}	Ondo × 10^{-2}	Ogun × 10^{-2}	Oyo × 10^{-2}	Lagos × 10^{-2}
2016	9.36	1.33	1.35	1.46	2.17	3.55
2017	9.60	1.36	1.38	1.50	2.23	3.64
2018	9.84	1.40	1.42	1.54	2.29	3.74
2019	10.08	1.44	1.46	1.58	2.35	3.84
2020	10.36	1.48	1.49	1.62	2.41	3.93

Table 7. Estimated annual total PCDF emissions (tonnes/annum)

Year	Ekiti × 10^{-3}	Osun × 10^{-3}	Ondo × 10^{-3}	Ogun × 10^{-3}	Oyo × 10^{-3}	Lagos × 10^{-3}
2016	1.50	2.14	2.16	2.36	3.48	5.68
2017	1.54	2.19	2.22	2.40	3.60	5.84
2018	1.58	2.25	2.28	2.48	3.68	6.00
2019	1.62	2.31	2.34	2.52	3.76	61.6
2020	1.66	2.37	2.40	2.60	3.88	63.2

Ogun, Oyo and Lagos had annual total PCDF ranging between 15.0–16.6 kg, 21.4–23.7 kg, 21.6–24.0 kg, 23.6–26.0 kg, 34.8–38.8 kg and 56.8 –63.2 kg respectively. The total atmospheric loading of PCDF from open burning of municipal wastes in the region was 203.6 kg with an annual average of 40.7 kg.

CONCLUSIONS

The quantity of municipal waste generated in Southwest Nigeria was estimated based on available per capita wastes generation and the atmospheric loading of some hazardous organic pollutants from open burning of the wastes was studied using the emission inventory approach. The results showed that the amount of wastes generated in this region of Nigeria is about 14.5% of total wastes from Sub-Sahara Africa and about 80% greater than what is generated in Ghana on annual basis. Open burning of wastes in Southwest Nigeria was observed to contribute to the atmospheric loading of VOCs more than petroleum refining activities in Nigeria. The annual PAHs level from this region of Nigeria was found to be around 18% of what was reported for Southeast Asian countries while annual PCB actually exceeded the Southeast Asian levels. Due to the serious health hazards associated with these pollutants, Nigeria's government at all levels cannot continue to avoid the implementation of policies that will address the huge volume of wastes being churned out on daily basis. A possible approach that could result in win-win situation in terms of environmental and human health protection is to consider energy recovery from the wastes.

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REFERENCES

1. Achi H.A., Adeofun C.O., Gbadebo A.M., Ufoegbune G.C., Oyedepo J.A. 2012. An assessment of solid waste management practices in Abeokuta, Southwest, Nigeria. J. Biol. Chem. Research, 29(2), 177–188.
2. Okedere O.B., Olalekan A.P., Fakinle B.S., Elehinafe F.B., Odunlami O.A., Sonibare J.A. 2019. Urban air pollution from the open burning of municipal solid waste. Environ Qual. Manage., 28, 67–74.
3. US EPA, 2021. National overview: facts and figures on materials, wastes and recycling. United States Environmental Protection Agency. https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials. Accessed: 13 January, 2022.
4. Permadi D.A., Oanh N.T.K. 2012. Assessment of biomass open burning emissions in Indonesia and potential climate forcing impact. Atmospheric Environment, 78, 250–258.
5. Kumari K., Kumar S., Vineel R., Khare A., Kumar R. 2019. Emission from open burning of municipal solid waste in India. Environmental Technology, 40(17), 2201–2214. http://dx.doi.org/10.1080/09593330.2017.1351489
6. Ike C.C., Ezeibe C.C., Anijiofor S.C., Nik-Daud N.K. 2018. Solid waste management in Nigeria: problems, prospects, and policies. The Journal of Solid Waste Technology and Management, 44(2), 163–172. https://doi.org/10.5276/JSWTM.2018.163
7. Kehinde O., Ramonu O.J., Babaremu K.O., Justin L.D. 2020. Plastic wastes: environmental hazard and instrument for wealth creation in Nigeria. Heliyon, 6, e05131. https://doi.org/10.1016/j.heliyon.2020.e05131
8. Seay J., Chen W.G., Ternes M.E. 2018. Waste Plastic: Challenges and opportunities for the chemical industry. Accessed 11 December, 2021. https://www.aiche.org/resources/publications/cep/2020/november/waste-plastic challenges -and-opportunities-chemical-industry
9. CSE. 2021. Plastic waste is India's and the world's most formidable environmental challenge today, and the COVID-19 pandemic has made matters worse: Centre for Science and Environment. Accessed 18 September, 2021. https://www.cseindia.org/plastic-waste-is-india-s-and-the-world-s-most-formidable-environmental-challenge-10375
10. Wen Z., Xie Y., Chen M., Dinga C.D. 2021. China's plastic import ban increases prospects of environmental impact mitigation of plastic waste trade flow worldwide. Nature Communication, 12, 425. https://doi.org/10.1038/s41467-020-20741-9
11. Bokani U.A. 2019. Current status of waste management and plastic management in Nigeria, policy & industry aspects. Federal Ministry of Environment, Abuja, Nigeria. Accessed 03 February, 2021. http://www.unido.or.jp/files/191007_UNIDO-Seminar_Nigeria.pdf
12. Kaoje A.U., Sabir A.A., Yusuf S., Jimoh A.O. Raji M.O. 2011. Residents' perception of solid waste disposal practices in Sokoto, Northwest

Nigeria. African Journal of Environmental Science and Technology, 11(2), 94–102. DOI: 10.5897/AJEST2014.1791

13. Minamata Convention, 2017. Nigeria's submission emission of mercury resulting from the open burning of waste. https://www.mercuryconvention.org/sites/default/files/documents/submission_from_government /NIGERIA-OPEN%20BURNING.pdf. Accessed 12 January 2022.
14. Noiki A.A., Afolalu S.A., Yusuf O.O., Emetere M.E., Ongbali S.O., Oloyede O.R., Joseph O.O., Banjo S.O. 2021. Impact assessment of the current waste management practices in Nigeria. IOP Conference Series: Materials Science and Engineering. DOI: 10.1088/1757-899X/1107/1/012172
15. Adesina O.A., Adesina A.O., Adeniran J.A. 2020. Level of polycyclic aromatic hydrocarbon emission in the ambient air and residual ash from a typical municipal solid waste open burning site in Nigeria Waste Disposal & Sustainable Energy, 2, 105–111. DOI: 10.1007/s42768-020-00035-y.
16. ATSDR, 1995. Toxicology profile for polycyclic aromatic hydrocarbons. Agency for Toxic Substances and Disease Registry Atlanta, GA: US Department of Health and Human Services, Public Health Service. Accessed: 5 February, 2022. www.atsdr,cdc.gov/phs/phs.asp?id=120&tid=25
17. ATSDR, 2007. Public health statement for benzene. Agency for Toxic Substances and Disease Registry.US Department of Health and Human Services, Public Health Service. Accessed: 19 January. 2022. www.atsdr,cdc.gov/phs/phs.asp?id=37&tid=214
18. Daffi R.E., Chaimang A.N., Alfa M.I. 2020. Environmental impact of open burning of municipal solid waste dumps in parts of Jos Metropolis, Nigeria. Journal of Engineering Research and Reports, 12(3), 30–43. DOI: 10.9734/JERR/2020/v12i317083
19. FRNOG, 2009. Legal notice on publication of 2006 census final results. Federal Republic of Nigeria Official Gazette, 96, B1–42. Accessed 30 January, 2022. https://gazettes.africa/archive/ng/2009/ng-government-gazette-dated-2009-02-02-no-2.pdf
20. World Bank, 2012. Urban development series: What is waste; a global review of solid waste management, 15. Accessed 14 November, 2021. https://datatopics.worldbank.org/what-a-waste/
21. Abila B., Kantola J. 2013. Municipal solid waste management problems in Nigeria: evolving knowledge management solution. in proceedings of World Academy of Science, Engineering and Technology, 78, 292. Accessed 17 March, 2022. http://waset.org/publications/4713
22. Nnaji C.C. 2015. Status of municipal solid waste generation and disposal in Nigeria. Manag. Environ Qual. Int. J., 26(1), 53–71. DOI: 10.1108/MEQ-08-2013-0092
23. Edet H.U., Maduabuchi M.N. 2019. Waste recycling as a key to conservation of natural resources in Nigeria: An Overview. Adv. Environ. Waste Manag. Recycle, 2(2), 2–5. DOI: 10.33140/aewmr.02.02.5
24. Sowunmi A.A. 2019. Municipal solid waste management and the inland water bodies: Nigerian perspectives, municipal solid waste management, Hosam El-D in Mostafa Saleh, IntechOpen. DOI: 10.5772/intechopen.84921
25. World Bank, 2020. World development indicators. https://datatopics.worldbank.org/world-development-indicators/. Accessed 07 February, 2022.
26. USEPA, 1995. AP 42, fifth edition, compilation of air pollutant emission factors, volume 1: stationary point and area sources, section 2.5: open burning. United States Environmental Protection Agency. Accessed 30 July 2021. http://www.epa.gov/ttn/chief/ap42/.
27. US EPA, 1997. Evaluation of emissions from the open burning of household waste in barrels. EPA-600/R-97-134a. U.S. Environmental Protection Agency, Control Technologies Center. Research Triangle Park, North Carolina. Accessed 16 November, 2021. https://www.epa.gov/sites/default/files/2015-08/documents/iii16_apr2001.pdf
28. Sonibare J.A., Akeredolu F.A., Obanijesu E.O.O., Adebiyi F.M. 2007. Contribution of volatile organic compounds to Nigeria's airshed by petroleum refineries. Petroleum Science and Technology, 25(4), 503–516. DOI: 10.1080/10916460500295397.
29. Sonibare J.A. 2010. Air pollution implications of Nigeria's present strategy on improved electricity generation. Energy Pol., 38, 5783–5789. DOI: 10.1016/j.enpol.2010.05.029
30. Okedere O.B., Fakinle B.S., Sonibare J.A. 2015. Ground level concentrations of hydrocarbon emissions from diesel fueled electric power generators. Glob. NEST J. 17(4), 673–681. DOI: 10.30955/gnj.001373
31. Okedere O.B., Fakinle B.S., Sonibare J.A., Elehinafe F.B., Adesina O.A. 2017. Particulate matter pollution from open burning of sawdust in Southwestern Nigeria. Cogent Environ. Sci., 3, 1367112. https://doi.org/10.1080/23311843.2017.1367112
32. Okedere O.B., Fakinle B.S., Sonibare J.A. 2018. Annual estimates of air pollutants from utilization of diesel as energy source at base transceiver stations. Environ. Qual. Manag., 28(2), 129–135. DOI: 10.1002/tqem.21600
33. Okedere O.B., Elehinafe F.B., Oyelami S., Ayeni A.O. 2021. Drivers of anthropogenic air emissions in Nigeria - a review. Heliyon, 7, e06398. https://doi.org/10.1016/j.heliyon.2021.e06398
34. Okedere O.B., Oyelami S. 2021. Emission inventory of greenhouse gases and sustainable energy for mobile telecommunication facilities in Nigeria.

Environmental Challenges, 4, 100203. https://doi.org/10.1016/j.envc.2021.100203

35. Yekeen A. 2019. Plastic Wastes: The silent killer Nigerians love. International Centre for Investigative reporting. Accessed 29 October, 2021. https://www.icirnigeria.org/plastic-wastes-the-silent-killer-nigerians-love/
36. HBS, 2020. Consumption and trends. Heinrich Boll Stiftung. Accessed 28 January, 2022. https://ng.boell.org/en/2020/08/14/nigeria-consumption-and-trends
37. Bakare W. 2020. Solid waste management in Nigeria. BioEnergy Consult. Accessed 23 February, 2022. https://www.bioenergyconsult.com/solid-waste-nigeria/
38. Ezeudu O.B., Ezeudu T.S. 2019. Implementation of circular economy principles in industrial solid waste management: case studies from a developing economy (Nigeria). Recycling, 4(4), 42. DOI: 10.3390/recycling4040042
39. Hoornweg D., Bhada-Tata P. 2012. What a Waste: A Global Review of Solid Waste Management. Urban development series. World Bank. 2012. Accessed 31 January, 2022. https://openknowledge.worldbank.org/handle/10986/17388
40. Miezah K., Obiri-Danso K., Kádár Z., Fei-Baffoe B., Mensah M.Y. 2015. Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana. Waste Manag., 46, 15–27. DOI: 10.1016/j.wasman.2015.09.009
41. Lissah S.Y., Ayanore M.A., Krugu J.K., Aberese-Ako M., Ruiter R.A.C. 2021. Managing urban solid waste in Ghana: Perspectives and experiences of municipal waste company managers and supervisors in an urban municipality. PLoS ONE, 16(3), e0248392. DOI: 10.1371/journal.pone.0248392
42. Oladimeji T.E., Sonibare J.A., Odunfa K.M., Oresegun O.R. 2015. Environmental impact analysis of the emission from petroleum refineries in Nigeria. Energy and Environment Research, 5(1), 33–41. DOI: 10.5539/eer.v5n1p33
43. Oanh N.T.K., Chirasuda T., Permadi D.A., Pannawee M., Hang N.T. 2017. Monitoring and inventory of hazardous pollutants emitted from solid waste open burning in Southeast Asia. Accessed 14 December 2022. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjZxo3Y8sHyAhWl0eAKHU_yBNYQFnoECAYQAQ&url=https%3A%2F%2Fagu.confex.com%2Fagu%2Ffm17%2Fmediafile%2FHandout%2FPaper236766%2FPoster_AGU_2017-SWOB-SEA-send-KO.pdf&usg=AOvVaw0SzSiJ6EfACqu8A5P1Dkpu