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Impacts of heavy duty truck emissions on the vertical distributions of soil polycyclic aromatic hydrocarbons at a big haulage vehicle park

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ABSTRACT

Nigeria relies heavily on heavy duty haulage vehicles to convey commodities from one end of the nation to the other, owing to the decades-long collapse of the rail transportation infrastructure. This is resulting in settings with very high concentrations of the trucks on the country's key roads. Diesel engine exhausts have long been recognized to be detrimental to human health. The concentrations of polycyclic aromatic hydrocarbons (PAHs) in the top and bottom soil samples from an extensive haulage vehicle stop located at Ogere, a roadside town along the ever busy Lagos-Ibadan highway were investigated. Soil samples taken at depths of 0–15 cm and 15–30 cm were subjected gas-chromatographic/mass spectrometer analysis. The Σ priority PAHs in the top and bottom soils at four sampling locations ranged between 16.4 and 32.0 mg/kg and 18.6–26.6 mg/kg respectively. The corresponding Σ carcinogenic PAHs for top and bottom soils ranged between 9.2 and 17.4 mg/kg and 8.7–12.0 mg/kg respectively. The concentrations of PAHs obtained in this study clearly exceeded the permissible limits set for soil PAHs in most developed nations of the world. The diagnostic ratio attributed the observed PAHs to diesel emissions. The study concluded that the emissions from the trucks at the haulage vehicle stop have tremendous impact on the soil PAH concentrations.

1. Introduction

The complete collapse of the rail means of transportation in Nigeria a few decades ago necessitated the use of heavy duty haulage vehicles for movement of goods and commodities across the nook and crannies of the country [1]. Although efforts are being made of recent to revive the sector through reconstruction of damage sections of the rail, several freights of heavy duty trucks still presently serve as the only means of transporting the goods (see Fig. 1).

Pools of heavy duty haulage trucks can be seen along most inter-city highways in Nigeria. A predominantly heavy duty truck laden highway in Nigeria is the Lagos- Ibadan expressway which is by far the busiest road in Nigeria [2,3]. The highway links the rest of the country to Lagos which houses the major and active seaports. Also, Lagos-Ogun axis of the country which has the largest cluster of industry and manufacturing companies is majorly serviced by this highway. It is therefore not unexpected to see several haulage vehicle parks along this highway either waiting to deliver raw materials to the region or take consignments of manufactured goods to other parts of the country. In addition, the country presently meets almost all her daily needs of refined petroleum products through importation due to the non-functional states of the local petroleum refineries which have become obsolete over the years. These products are delivered via the seaports in Lagos and transported to different filling stations across the country via haulage trucks.

The presence of the large volume of haulage trucks along the highway has led to some unregulated haulage vehicle parks and serious commercial activities have also sprung up around the parks. One of such parks is at Ogere town in Ogun State which is located along the Lagos –Ibadan Express Highway. This park appears to have the largest concentrations of heavy duty trucks in the country. Activities of the haulage vehicles within and around this park have been reported to have serious impacts on environment health. Worried by the presence of commercial activities of trading as well as residential apartment in the area, Fakinle et al. [1] investigated the toxicity potentials of ambient total suspended particles (TSP) within the park using an in-situ particulate monitor from Metone instruments and reported worrisome levels of ambient TSP and

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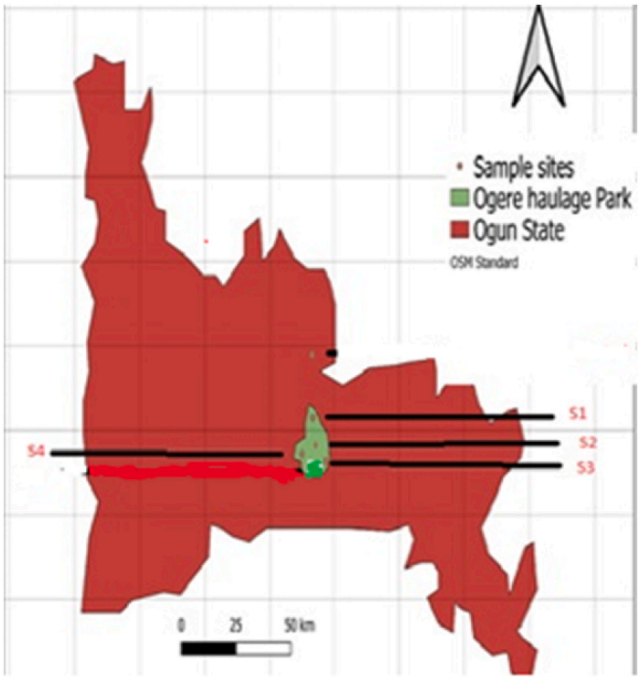

Fig. 1. Map of Ogun State Showing Ogere and sampling points.

toxicity potentials. The exact chemical compositions of the TSP were not investigated. Lala et al. [4] also investigated the ambient levels of some gaseous criteria air pollutants including carbon monoxide (CO) and nitrogen dioxides (NO_2) using ToxiRae II gas monitors. The levels of NO_2 were reported to assume dangerous dimensions during the dry season.

In pollution parlance, the ground is often reported to be the sink for most of the pollutants [5–8]. The atmosphere has a self-cleansing process by which the pollutants emitted into it are washed down to the surface of the earth. Hence, either by wet or dry deposition processes, the soil within the park is likely to be the final recipient (sink) of the emitted pollutants [9,10]. Apart from the pollutants earlier investigated in the air compartment of Ogere Park, several other hazardous pollutants are associated with vehicular emissions and most importantly, heavy duty trucks running on diesel. Such pollutants include are the polycyclic aromatic hydrocarbons (PAHs) [11–13].

PAHs are the groups of organic compounds with two or more benzene rings [14]. They are usually classified either as light or heavy PAHs depending on the number of benzene rings [15]. These groups of pollutants are known for their carcinogenic, mutagenic and teratogenic properties [16–20]. The World Health Organization (WHO) and the United States Environmental Protection Agency presently regulate sixteen (16) of the PAHs which are termed priority PAHs [17,21]. Still among the priority PAHs, the Agency for Toxic Substances and Diseases Registry (ATSDR) of the United States treats seven of the PAHs as carcinogenic [17,22]. Continuous studies on the sources and presence of PAHs in the environment are essentially premised on their carcinogenic nature [23]. In Nigeria, the prevalence of cancer related diseases in recent studies necessitates further studies on the presence of PAHs in the environment [24].

In the present study, the authors focused on the levels of PAHs in the soil of a haulage vehicle park in Ogere, Ogun State, Nigeria which is expected to be final sink for all pollutants released into the air by trucks activities within and around the park. Due to heavy presence of human activities at the park during the day and night periods, the study assessed the toxicity equivalence TEQ for the individual priority PAH and the total toxicity equivalence (TTEQ) for soil samples at some locations within the park. Diagnostic ratio was also used to affirm the source attribution.

2. Methodology

2.1. Study area and sample collection

The study area is the haulage truck park located at Ogere town in Ogun State, Nigeria. It arguably houses the largest pool of haulage trucks in the country. The full description of the park had been discussed in the author's previous study and studies by other authors [1,4]. The specific sampling locations (S1, S2, S3, S4 and Control) where soil samples were taken are shown in Table 1. The locations S1 – S4 are in the active areas of the park while the control is outside the park. Soil samples were taken at depths of 0–15 cm and 15–30 cm to represent the top and bottom soil respectively. The samples were taken during the Rainy Season and specifically in the month of July in 2021. The soil samples were stored in polythene bags and transported to the laboratory for analysis.

2.2. Sample preparation and analysis

The soil samples were air dried and homogenized. Unwanted materials such as stones and plant residues were removed and the samples were sieved through a 2 mm sieve to obtain the fine dust needed for analysis. A 24- h procedure involving the use of dichloromethane in a soxhlet extractor was used to extract the PAHs from the samples. This was followed by cleaning procedure using 5 g silica gel column and eluted with 40 mL 1:1 DCM: Hexane. The extracts were concentrated in rotary evaporator under mild stream of nitrogen. Analysis of samples was achieved with gas chromatography (Agilent 7890) with a mass detector (Agilent 5975) which was conducted in selected ion monitoring mode with electron impact ionization. A chromatographic column dimension of 30 m × 25 mm with internal diameter × 0.25 μm film thickness was used. The temperature program for the analysis was set at 90 °C (1 min), 0 °C/min, 250 °C, 4 °C/min and 330 °C (5 min). Determination of PAHs in both laboratory and field blanks was carried out and the external standard method was adopted for quantification of the PAHs. Prior to extraction, the samples were spiked with 25 mL of recovery standard which contained 20 ng of phenanthrene d10 recovery ranged between 80 and 90%. Field blanks were below detection limit for all targeted compounds and there was no need for blank correction [17,25].

3. Results and discussion

3.1. Concentrations of PAHs in the top soil (0–15 cm)

Table 2 shows the concentrations of priority PAHs in the top soil samples taken from the haulage park. With the exception of benzo[k] Fluoranthene which was below detectable limit in all the sampling locations, the remaining fifteen (15) priority PAHs were detected in all the samples. The range of concentrations of naphthalene, acenaphthene, acenaphthylene and fluorene from the four sampling locations (S1–S4) were 0.14–0.57 mg/kg, 0.13–0.88 mg/kg, 0.31–0.85 mg/kg and 0.49–4.79 mg/kg with mean values of 0.43 mg/kg, 0.43 mg/kg, 0.55 mg/kg and 3.58 mg/kg respectively. Phenanthrene, anthracene, fluoranthene and pyrene had concentrations in the range of 0.40–3.85 mg/kg, 0.28–0.89 mg/kg, 0.16–0.62 mg/kg and 0.28–5.64 mg/kg with the corresponding mean values of 2.58 mg/kg, 0.58 mg/kg, 0.41 mg/kg and

Table 1
Description and geographic positions of sampling points.

Sampling points	Description	Location
Control	Outside the park	7° 34′ 0″ N and 3° 57′ 0″ E
S1	Within the park	6° 52′ 0″ N and 3° 33′ 0″ E
S2	Within the park	6° 52′ 0″ N and 3° 25′ 0″ E
S3	Within the park	6° 57′ 0″ N and 3° 43′ 0″ E
S4	Within the park	6° 53′ 0″ N and 3° 30′ 0″ E

Table 2
Concentrations of PAHs in top soil.

PAH detected	S1 (mg/kg)	S2 (mg/kg)	S3 (mg/kg)	S4 (mg/kg)	Control
Naphthalene	0.433	0.136	0.573	0.57	0.044
Acenaphthene	0.128	0.317	0.877	0.41	0.047
Acenaphthylene	0.31	0.32	0.721	0.845	0.064
Fluorene	4.972	4.628	0.494	4.228	0.037
Phenanthrene	2.388	3.85	0.398	3.69	0.030
Anthracene	0.644	0.276	0.878	0.53	0.073
Fluoranthene	0.37	0.501	0.615	0.164	0.010
Pyrene	4.932	5.635	0.277	2.287	0.023
Benzo[a]anthracene	5.371	4.725	4.563	3.856	0.038
Chrysene	3.928	0.71	0.83	0.833	0.073
Benzo[b] fluoranthene	3.751	3.106	2.074	1.42	0.012
Benzo[k] Fluoranthene	N/A	N/A	N/A	N/A	N/A
Benzo[a]pyrene	2.803	2.939	2.625	2.109	0.015
Indeno [1,2,3-cd] pyrene	0.803	0.705	0.436	0.217	0.062
Dibenzo[a,h] anthracene	0.773	1.055	0.907	0.718	0.082
Benzo[ghi]perylene	0.354	0.338	0.178	0.275	0.045
Total					0.655

3.28 mg/kg respectively. The concentrations of Benzo[a]anthracene, Chrysene, Benzo[b]fluoranthene and Benzo[a]pyrene ranged between 3.86 and 5.37 mg/kg, 0.71–3.93 mg/kg, 1.42–3.75 mg/kg and 2.11–2.94 mg/kg respectively while their corresponding means were 4.63 mg/kg, 1.58 mg/kg, 2.59 mg/kg and 2.62 mg/kg. The remaining three priority PAHs (indeno [1,2,3-cd] pyrene, dibenzo[a,h]anthracene and benzo[ghi]perylene) had mean concentrations of 0.54 mg/kg, 0.86 mg/kg and 0.29 mg/kg respectively with their corresponding ranges being 0.22–0.80 mg/kg, 0.72–1.06 mg/kg and 0.18–0.35 mg/kg.

The total PAH concentration (Σ priority PAHs) at the sampling locations were 32.0 mg/kg, 29.2 mg/kg 16.4 mg/kg and 22.2 mg/kg for S1, S2, S3 and S4 respectively. Based on research findings, seven of the sixteen priority PAHs are usually regarded as carcinogenic and these are benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]Fluoranthene, benzo[a]pyrene, Indeno [1,2,3-cd] pyrene and dibenzo[a,h] anthracene. Benzo[k]Fluoranthene was however below detectable limit at all locations. The Σ carcinogenic PAHs at S1, S2, S3 and S4 were 17.4 mg/kg, 13.2 mg/kg, 11.4 mg/kg and 9.2 mg/kg respectively. In the absence of regulatory standard for soil PAHs in Nigeria, the obtained Σ carcinogenic PAHs were compared with permissible limits set by other countries. This standard is usually indicated as the concentration of benzo[a]pyrene. The permissible limits set for benzo[a]pyrene in Netherlands, Sweden and Canada are 0.12 mg/kg, 0.30 mg/kg and 0.5 mg/kg respectively [17,26–28]. Clearly, the concentrations of benzo[a] pyrene obtained in this study (2.11–2.94 mg/kg) far exceeded the permissible limits indicating extreme pollution of Ogere haulage stop by PAHs.

Source attribution of PAHs may be explained in terms of diagnostic ratios (D_R) [29]. Several diagnostic ratios have been established that help to associate the PAHs concentrations observed in environmental samples with the sources responsible for them. These ratios are explained in details by previous authors [30]. One of such D_R diagnostic ratios (D_{Rs}) which attributes PAHs observed in the environment to diesel emission is the ratio of the concentration of indeno [1,2,3-cd]pyrene to the sum of the concentrations of indeno [1,2,3-cd]pyrene and benzo [ghi]perylene as shown in Eq. (1).

$$D_R = \left[\frac{indeno[1,2,3-cd]pyrene}{indeno[1,2,3-cd]pyrene + benzo[ghi]perylene}\right] \quad (1)$$

According to Ravindra et al. [30], values of D_R between 0.35 and 0.7 are indications that the PAHs in a particular environmental sample is attributable to diesel emissions. In the present study, the values of D_R for locations S1, S2, S3 and S4 are 0.69, 0.67, 0.71 and 0.44 respectively. These D_R values clearly confirm that the predominant source of PAHs observed in the soil samples taken from the study area is attributable to the haulage trucks in the area.

It is often necessary to describe the toxicity of the individual PAH and this is usually expressed as toxicity equivalence (TEQ). The TEQ is commonly obtained as a product of the toxicity equivalent factor (TEF) and the PAH concentration [17]. Table 3 shows the TEF and TEQ of the individual PAH as well as the total toxicity equivalence (TTEQ) obtained for the sampling locations S1, S2, S3 and S4. In all the samples, benzo[a] pyrene had the highest TEQ and therefore the largest contributor to the TTEQ with TEQs of 2.80, 2.93, 2.63 and 2.11 at S1, S2, S3 and S4 respectively. The TEQ values obtained in this study exceeded the thresh-hold limit recommended the United State Environmental Protection Agency. The implication of these results is that public health is at risk in the study area due to the possibility of body contact with soils having extreme levels of carcinogenic PAHs. Generally, substantial contributors to the obtained TTEQs are in the order benzo[a]pyrene > benzo[a]anthracene > benzo[b]fluoranthene.

3.2. Concentrations of PAHs in the bottom soil (15–30 cm)

Table 4 shows the concentrations of priority PAHs in the bottom soil samples obtained from Ogere haulage truck park. Similar to what was observed in the top soil, benzo[k]fluoranthene was not detected in the bottom soil while the rest of the priority PAHs was detected. The mean concentrations of naphthalene, acenaphthene, acenaphthylene and fluorene in the bottom soil at the four sampling locations (S1–S4) were 0.44, 0.39, 0.56 and 2.43 mg/kg respectively. Phenanthrene, anthracene, fluoranthene and pyrene had mean concentrations of 3.01, 0.55, 0.77 and 3.63 mg/kg while 4.35, 0.67, 2.20 and 1.81 mg/kg were the observed concentrations for benzo[a]anthracene, chrysene, benzo[b] fluoranthene and benzo[a]pyrene in the same sampling locations. The mean concentrations of the rest of the priority PAHs (Indeno [1,2,3-cd] pyrene, dibenzo[a,h]anthracene and benzo[ghi]perylene) in the bottom soil were 0.55, 0.81 and 0.31 mg/kg at S1, S2, S3 and S4 respectively.

On the general note, the concentrations of PAHs in the top soil samples were higher than their concentrations at depths between 15 and 30 cm. The Σ carcinogenic PAHs at S1, S2, S3 and S4 were 10.48, 11.97, 10.46 and 8.67 mg/kg respectively. The concentration of Σ carcinogenic PAHs were also higher in the top soil than in the bottom layers of the soil. Nevertheless, the obtained bottom soil concentrations of Σ carcinogenic PAHs in this study still exceed the permissible limits in

Table 3
TEQs of PAHs in top soil.

PAH detected	TEF	S1	S2	S3	S4
Naphthalene	0.001	0.000433	0.000136	0.000573	0.00057
Acenaphthene	0.001	0.000128	0.000317	0.000877	0.00041
Acenaphthylene	0.001	0.00031	0.00032	0.000721	0.000845
Fluorene	0.001	0.004972	0.004628	0.000494	0.004228
Phenanthrene	0.001	0.002388	0.00385	0.000398	0.00369
Anthracene	0.01	0.00644	0.00276	0.00878	0.0053
Fluoranthene	0.001	0.00037	0.000501	0.000615	0.000164
Pyrene	0.001	0.004932	0.005635	0.000277	0.002287
Benzo[a]anthracene	0.1	0.5371	0.4725	0.4563	0.3856
Chrysene	0.01	0.03928	0.0071	0.0083	0.00833
Benzo[b] fluoranthene	0.1	0.3751	0.3106	0.2074	0.142
Benzo[k] Fluoranthene	0.1				
Benzo[a]pyrene	1	2.803	2.939	2.625	2.109
Indeno [1,2,3-cd] pyrene	0.1	0.0803	0.0705	0.0436	0.0217
Dibenzo[a,h] anthracene	0.1	0.0773	0.1055	0.0907	0.0718
Benzo[ghi]perylene	0.01	0.00354	0.00338	0.00178	0.00275
		3.935593	3.926727	3.445815	2.758674

Table 4
Concentration of priority PAHs in the bottom soil.

PAH detected	S1 (mg/kg)	S2 (mg/kg)	S3 (mg/kg)	S4 (mg/kg)	Control (mg/kg)
Naphthalene	0.409	0.125	0.623	0.593	0.003
Acenaphthene	0.137	0.339	0.857	0.231	0.008
Acenaphthylene	0.382	0.301	0.748	0.817	0.004
Fluorene	0.498	4.382	4.482	0.389	0.003
Phenanthrene	2.392	3.007	3.21	3.421	0.001
Anthracene	0.572	0.315	0.796	0.509	0.003
Fluoranthene	0.465	0.472	0.708	1.43	0.002
Pyrene	4.953	5.142	2.35	2.09	0.003
Benzo[a] anthracene	5.21	4.447	4.000	3.754	0.008
Chrysene	0.52	0.644	0.813	0.719	0.007
Benzo[b] fluoranthene	3.047	2.359	2.118	1.263	0.001
Benzo[k] Fluoranthene	N/A	N/A	N/A	N/A	N/A
Benzo[a]pyrene	0.271	2.645	2.327	2.003	0.002
Indeno [1,2,3-cd] pyrene	0.743	0.783	0.402	0.287	0.005
Dibenzo[a,h] anthracene	0.684	1.095	0.798	0.648	0.007
Benzo[ghi] perylene	0.405	0.322	0.205	0.318	0.005
Total	20.688	26.378	24.437	18.472	0.062

Netherland, Sweden and Canada. The application of diagnostic ratio (Eq. (1)) for source attribution of the PAHs found in the bottom soil samples also pointed to diesel emission as the primary culprit. The diagnostic ratio returned 0.65, 0.71, 0.66 and 0.47 for locations S1, S2, S3 and S4 respectively. Table 5 shows the TEQs and TTEQs of the PAHs observed in the bottom soil. The extent of contribution to toxicity of the bottom soil by the three major contributors to TTEQ is in the order benzo [a]pyrene > benzo[a]anthracene > benzo[b]fluoranthene.

4. Conclusion

The impacts of diesel exhaust emissions from haulage trucks on the top and bottom soil concentrations of PAHs were investigated at the popular haulage stop located at Ogere, a roadside town along the Lagos-Ibadan highway, Nigeria. A total of fifteen priority PAHs were observed in the top and bottom soils. The concentrations of the PAHs were generally higher in the top than in the bottom soils. The obtained concentrations of PAHs exceeded the recommended soil limits in some developed nations of the world. It was also observed that the soil samples taken at the control point had lower PAHs concentrations than those taken from the park. The diagnostic ratio confirmed the observed PAHs as emanating from diesel emissions which must have come from the trucks at the haulage stop. Considering the levels of PAHs obtained in this study and the high volume of commercial activities at the park, the possibility of human exposure to soils that are heavily contaminated by PAHs exist. The study concluded that activities at the park need intervention of the policy makers.

Credit author statement

The authors did not receive funding for the research.

Data availability statement

The data in Tables 1–3 were generated from the specifications written on the soil samples collected at sampling points in the location of study.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Table 5
TEQs of PAHs in bottom soil.

PAH detected	TEF	S1	S2	S3	S4
Naphthalene	0.001	0.000409	0.000125	0.000623	0.000593
Acenaphthene	0.001	0.000137	0.000339	0.000857	0.000231
Acenaphthylene	0.001	0.000382	0.000301	0.000748	0.000817
Fluorene	0.001	0.000498	0.004382	0.004482	0.000389
Phenanthrene	0.001	0.002392	0.003007	0.00321	0.003421
Anthracene	0.01	0.00572	0.00315	0.00796	0.00509
Fluoranthene	0.001	0.000465	0.000472	0.000708	0.00143
Pyrene	0.001	0.004953	0.005142	0.00235	0.00209
Benzo[a]anthracene	0.1	0.521	0.4447	0.4	0.3754
Chrysene	0.01	0.0052	0.00644	0.00813	0.00719
Benzo[b] fluoranthene	0.1	0.3047	0.2359	0.2118	0.1263
Benzo[k] Fluoranthene	0.1	0	0	0	0
Benzo[a]pyrene	1	0.271	2.645	2.327	2.003
Indeno [1,2,3-cd] pyrene	0.1	0.0743	0.0783	0.0402	0.0287
Dibenzo[a,h] anthracene	0.1	0.0684	0.1095	0.0798	0.0648
Benzo[ghi]perylene	0.01	0.00405	0.00322	0.00205	0.00318
		1.263606	3.539978	3.089918	2.622631

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References

[1] B.S. Fakinle, J.A. Sonibare, F.A. Akeredolu, O.B. Okedere, L.A. Jimoda, Toxicity potential of particulates in the airshed of haulage vehicle park, Global Nest J. 15 (4) (2013) 466–473.
[2] U.O. Salisu, O.O. Oyesiku, B.O. Odufuwa, Highway development and capacity utilization in Ogun State, Nigeria, Sci. J. Transport Logist. 2 (1) (2020) 66–77, https://doi.org/10.2478/logi-2020-0007.
[3] U.O. Salisu, O.O. Oyesiku, Traffic survey analysis: implications for road transport planning in Nigeria, Sci. J. Transport Logist. 2 (2) (2020) 12–22, https://doi.org/10.2478/logi-2020-0011.
[4] M.A. Lala, O.A. Adesina, L.T. Popoola, J.O. Owolabi, B.O. Oyewale, Spatial distribution and toxicity potential of gaseous criteria air pollutants in the ambient air around a typical haulage truck stop, SN Appl. Sci. 1 (2019) 369, https://doi.org/10.1007/s4245 2-019-0373-z.
[5] N. Rodriguez- Eugenio, M. McLaughlin, D. Penncock, Soil Pollution: a Hidden Reality, Food and Agriculture Organization of the United Nation (FAO), Rome, 2018, p. 142.
[6] J. Ren, X. Wang, P. Gong, C. Wang, Characterization of Tibetan soil as a source or sink off atmospheric persistent organic pollutant: seasonal shift and impact of global warming, Environ. Sci. Technol. 53 (7) (2019) 3589–3598, https://doi.org/10.1021/acs.est9b00698.
[7] V.E. Molnar, E. Simon, S. Ninsawat, B. Tothmeresz, S. Szabbo, Pollution assessment based on element concentration of tree leaves and top soil in Ayutthaya Province, Thailand, Int. J. Environ. Res. Publ. Health 17 (2020) 5165, https://doi.org/10.3390/ijerph17145165.
[8] D. Giltrap, J. Cavanagh, B. Stevenson, A. Ausseil, The role of soils in the regulation of air quality, Philos. Trans. R. Soc. Lond. B Biol. Sci. 376 (1834) (2021) 20200172, https://doi.org/10.1098/rstb.2020.0172.
[9] M. Amodio, S. Catino, P.R. Dambruoso, G. de Gennaro, E. Di Gilio, P. Giungato, E. Laiola, A. Marzocca, A. Mazzone, A. Sardaro, M. Tutino, Atmospheric deposition: sampling procedures, analytical methods, and main recent findings from scientific literature, Adv. Meteorol. 2014 (2014), https://doi.org/10.1155/2014/161730.
[10] Y.P. Pan, X.Y. Zhu, S.L. Tian, L.L. Wang, G.Z. Zhang, Y.B. Zhou, P. Xu, B. Hu, Y. S. Wang, Wet deposition and scavenging ratio of air pollutants during an extreme rainstorm in the North China Plain, Atmos. Oceanic Sci. Lett. 10 (5) (2017) 348–353, https://doi.org/10.1080/16742834.2017.1343084.
[11] S. Hu, J.D. Herner, W. Robertson, R. Kobayashi, M.C.O. Chang, S.M. Huang, B. Zielinska, P. Rieger, T. Huai, A. Ayala, Emissions of polycyclic aromatic hydrocarbons (PAHs) and nitro-PAHs from heavy –duty diesel vehicles with DPF and SCR, J. Air Waste Manag. Assoc. 63 (3) (2013) 984–996, https://doi.org/10.1080/10962247.2013.795202.

[12] C.V. De Souza, S.M. Correa, Polcyclic aromatic hydrocarbons in diesel emission, Diesel Fuel Lubr. Oil 185 (2016) 925–931, https://doi.org/10.1016/j.fuel.2016.08.054.
[13] M. Szewczynska, J. Dabroska, K. Pyrzynska, Polycyclic aromatic hydrocarbons in the particle emitted from the diesel and gasoline engines, Pol. J. Environ. Stud. 26 (2) (2017) 801–807, https://doi.org/10.15244/pjoes/64914.
[14] C.M.A. Iwegbue, G.O. Tesi, G. Obi, G.E. Obi-Iyeke, U.A. Igbuku, S. Bice, B. S. Martincigh, Concentrations, health risks and sources of polycyclic aromatic hydrocarbons in Nigerian honey, Toxicol. Environ. Health. Sci. 8 (1) (2016) 28–42.
[15] H.I. Abdel-Shafy, M.S.M. Mansour, A review on polycyclic aromatic hydrocarbons: source, environmental impact, effect on human health and remediation, Egypt. J. Petrol. 25 (2016) 107–123.
[16] O.B. Okedere, A.P. Olalekan, B.S. Fakinle, F.B. Elehinafe, O.A. Odunlami, J. A. Sonibare, Urban air pollution from the open burning of municipal solid waste, Environ. Qual. Manag. 28 (2019) 67–74.
[17] O.A. Adesina, A.O. Adesina, J.A. Adeniran, 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 Sustain. Energy 2 (2) (2020) 105–111.
[18] O.B. Okedere, F.B. Elehinafe, S. Oyelami, A.O. Ayeni, Drivers of anthropogenic air emissions in Nigeria- a review, Heliyon 7 (2021), e06398, https://doi.org/10.1016/j.heliyon.2021.e06398, 2021.
[19] B. Ambade, S.S. Sethi, B. Giri, J.K. Biswas, K. Bauddh, Characterization, behaviour, and risk assessment of polycyclic aromatic hydrocarbons (PAHs) in the Estuary sediments, Bull. Environ. Contam. Toxicol. 108 (2022) 243–252, https://doi.org/10.1007/s00128-021-03393-3.
[20] S. Kurwadkar, J. Dane, S.R. Kanel, M.N. Nadagouda, R.W. Cawdrey, B. Ambade, G. C. Struckhoff, W. Richard, Per- and Polyfluoroalkyl Substances in water and wastewater: a critical review of their global occurrence and distribution, Sci. Total Environ. 809 (2022) 151003, https://doi.org/10.1016/j.scitotenv.2021.151.
[21] B. Ambade, A. Kumar, A. Kumar, L.K. Sahu, Temporary variability of atmospheric particulate bound polycyclic aromatic hydrocarbons (PAHs) over Central East India: sources and carcinogenic risk assessment, Air Qual. Atmos. Health 15 (2022) 115–130, https://doi.org/10.1007/s11869-021-01089-5.
[22] ATSDR, Toxicological Profile for Naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene, Agency for Toxic Substances and Disease Registry, 2005, pp. 1–347. https://www.atsdr%20.cdc.gov/subst%20ances%20/toxsu%20bstan%20ce.asp?toxid%20=43. (Accessed 26 January 2022).
[23] B. Ambade, T.K. Sanka, A. Kumar, A.S. Gautam, S. Gautam, COVID-19 lockdowns reduce the black carbon and polycyclic aromatic hydrocarbons of the Asian atmosphere: source apportionment and health hazards evaluation, Environ. Dev. Sustain. 23 (2021) 12252–12271, https://doi.org/10.1007/s10668-020-01167-1.
[24] O.A. Fatiregun, O. Bakare, S. Ayeni, A. Oyerinde, A.C. Sowunmi, A. Popoola, O. Salako, A. Alabi, A. Joseph, 10-Year mortality pattern among cancer patients in Lagos state University teaching hospital, Ikeja, Lagos, Front. Oncol. (2020), https://doi.org/10.3389/fonc.2020.573036.
[25] O.A. Adesina, J.A. Sonibare, P.N. Diagboya, J.A. Adeniran, R.O. Yusuf, Spatio-temporal distribution of polycyclic aromatic hydrocarbons close to a typical medical waste incinerator, Environ. Sci. Pollut. Control Ser. 25 (1) (2018) 274–282.
[26] I. Johansson, B. van Bavel, Levels of polycyclic aromatic hydrocarbons in incineration ashes, Sci. Total Environ. 311 (2) (2003) 21–31.
[27] Environment Canada, Canadian Soil Quality Guidelines, 2003 (Ottawa.
[28] C.H. Vane, I. Harrison, A.W. Kim, Polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) in sediments from the Mersery Estuary, UK, Sci. Total Environ. 374 (2007) 112–126.
[29] L. Maharjan, L. Tripathee, S. Kang, B. Ambade, P. Chen, H. Zheng, . Li, K. L. Shrestha, C.M. Sharma, Characteristics of atmospheric particle bound polycyclic aromatic compounds over the Himalayan Middle hills: implications for sources and health risk assessment, Asian J. Atmos. Environ. 15 (4) (2021) 2021101, https://doi.org/10.5572/ajae.2021.101.
[30] K. Ravindra, R. Sokhi, R.V. Grieken, Atmospheric polycyclic aromatic hydrocarbons: source attribution, emission factors and regulation, Atmos. Environ. 42 (2008) 2895–2921.