Periodica Polytechnica Chemical Engineering, 68(3), pp. 364–381, 2024

Mathematical-model Analysis of the Potential Exposure to Lead, Zinc and Iron Emissions from Consumption of Premium Motor Spirit in Nigeria

Francis B. Elehinafe[1*], Orirome O. Orupete[1], Hassan A. Adisa[1], Oluseye L. Lasebikan[2]

[1] Environmental Research Laboratory, Department of Chemical Engineering, College of Engineering, Covenant University, Km 10 Idiroko Road, 112104 Ota, Ogun State, Nigeria
[2] Department of Chemical Engineering Technology, School of Engineering Technology, Federal Polytechnic of Oil and Gas, 503101 Bonny, Rivers State, Nigeria
[*] Corresponding author, e-mail: fancis.elehinafe@covenantuniversity.edu.ng

Received: 11 December 2023, Accepted: 10 June 2024, Published online: 10 July 2024

Abstract

Environmental pollution has been on the increase due to emission from vehicles using fossil fuels. This research investigated the exposure of air, soil and water bodies to trace metal emissions: Pb, Zn and Fe, as a result of the consumption of premium motor spirit (PMS) in Nigeria. The exposure of air, soil, and water bodies to these emissions also lead to exposure of humans, food and animals to the emissions. This was done to estimate the emission rates, emission rate per capita, and emission rates per land areas (or land distribution). The results showed that: the annual emission rates ranged between 4.66 kg/y for Pb in 2012 in Jigawa State and $5.050 \cdot 10^3$ kg/y for Fe in 2015 in Lagos State; the emission rates per capita ranged between $0.52 \cdot 10^{-6}$ kg/(y·person) for Pb in 2012 in Kwara State and $2.33 \cdot 10^{-3}$ kg/(y·person) and this was recorded in Lagos State in the year 2015; while the rate per land area ranged between $0.093 \cdot 10^{-3}$ kg/(y·km^2) for Pb in 2012 in Taraba State and 1.38 kg/(y·km^2) for Fe in 2015 in Lagos State. Results showed that residents of Lagos are at the highest risk of trace metal poisoning because they had the highest emission rates per capita, followed by Abuja, Osun, and Ogun. The states at the lowest risk are Yobe and Taraba, with Yobe as the lowest. It is recommended that regulations concerning the trace metal contents of fuels imported and distributed in Nigeria should be created and implemented to curb these risks.

Keywords

analysis, exposure, trace metal, emissions, consumption, PMS

1 Introduction

Environmental pollution has been on the increasing trend due to many anthropogenic activities such as emission from vehicles using either premium motor spirit (PMS) or automotive gas oil (AGO) [1], the pollutants being released into the atmosphere are naturally occurring in compounds but the increased activities of man (combustion, open source burning etc.) has introduced them in enormous quantities to the environment [2, 3]. While mentioning the effect of combustion of fossil fuels to the environment, it is equally important to note that non-exhaust emission also contribute to the increased environmental pollution especially in the aspect of wear and tear of brake, clutches, road surfaces and tires [4].

Environmental pollution is one of the major causes of untimely death and disease and it has different types such as water, soil, noise, air and plastic [5, 6]. Environmental pollution is quite multifaceted and can be linked to many factors such as poverty, coal burning from thermal power plants, unplanned urbanization, urbanization, industrial development, agricultural development, deforestation, nature of modern technology, increased general affluence and economic growth and population growth [6–9], further posited that the different sources of air pollution include the natural sources and artificial sources (mobile and stationary sources).

It has been established that atmospheric pollutants are mostly in particulate or gaseous form. There are points and diffuse sources of these pollutants with periods that they remain in the atmosphere [10]. In addition to this, the degrees of effects caused by the air pollutants are largely a function of their chemical composition like solubility,

Cite this article as: Elehinafe, F. B., Orupete, O. O., Adisa, H. A., Lasebikan, O. L. "Mathematical-model Analysis of the Potential Exposure to Lead, Zinc and Iron Emissions from Consumption of Premium Motor Spirit in Nigeria", Periodica Polytechnica Chemical Engineering, 68(3), pp. 364–381, 2024. https://doi.org/10.3311/PPch.24036

oxidation, concentration and susceptibility of the individual affected [11, 12]. The continued demand for energy worldwide, due to urbanization and increased population, has birthed the rapid development of transportation system which now claim about 60% consumption of produced petroleum products and has emerged as the chief source of air emission and contributor to the greenhouse gases [13]. Nigeria as a country with an estimated population of over 200 million people has solely relied on the use of PMS and automotive gas oil (AGO) due to inadequate supply of electricity, therefore increasing the possibility of higher emission from generator sets from business centers and household, and vehicular emissions [14, 15].

At combustion of fuels, carbon dioxide and water should be produced. However, the internal combustion engines do not ensure complete combustion of fuels, hence the release of particulate matters, unburned hydrocarbons, carbon monoxide, particulates, oxides of nitrogen and sulfur [16]. As reported by Zhu et al. [17], the combustion of fuels by the internal combustion engines is characterized with the emission of particulate matters that contains trace metals like vanadium and nickel, mercury, lead, cadmium, chromium, antimony, manganese, cobalt, copper and zinc, having an atomic density greater than 4.5 g/cm^3 (the value in amu was converted to g/cm^3). These metals adversely affect the environment and living organisms at high concentrations [18]. They, without doubt, are important constituents for plants and humans, when present only in small amount. Contrary this, the work of Dumat et al. [19] has proven that some trace metals such as arsenic, cadmium, mercury and lead are toxic even at small concentrations.

Trace metals, being persistent and non-biodegradable, can neither be removed by normal cropping nor easily leached by rainwater [20]. They might be transported from soil to ground waters or may be taken up by plants, including agricultural crops. For this reason, the knowledge of metal plant interactions is also important for the safety of the environment [21]. There has been increasing interest in determining trace metal levels in public food supplied. However, their concentration in bio-available form is not necessarily proportional to the total concentration of the metal [22]. The quality of ecosystem becomes altered, when trace metals find their way, somehow, into it through human and natural activities. These activities are one of the most pressing concerns of urbanization in developing countries like Nigeria, which result in the problem of solid, liquid, and toxic waste management. Such waste may be toxic or radioactive [23]. Such waste management problems include heaps of uncontrolled garbage, roadsides littered with refuse, streams blocked with rubbish, prevalence of automobile workshops and service stations, inappropriately disposed toxic waste and disposal sites that constitute a health hazard to residential areas [24].

Trace metals polluting the atmospheric air space has been a universal concern as efforts are ongoing to reduce emission levels of the trace metals [21]. Emission of trace metals from internal combustion engines has posed a major health and environmental problems and researchers have studied the concentration of the trace metals from the engine [25]. In a separate research, Wang et al. [26] carried out a chemical characterization and toxicity assessment of fine particulate matters emitted from the combustion of petrol and diesel fuels. The results showed that fuel exhaust posed a potentially harmful health risks to the environment. Akpoveta and Osakwe [27] assessed the trace metal levels of several fuel samples using an atomic absorption spectrophotometer. Cadmium, chromium, copper, lead, and zinc were among the trace metals determined.

This research project aimed to investigate the exposure humans, animal and plants to trace metal emissions as a result of the consumption of premium motor spirit in Nigeria. The research focused on emission estimation of the release of the following trace metals: lead, zinc and iron from the consumption of petroleum motor spirit from years 2011 to 2020 in order to ascertain the levels of the release of the aforementioned trace metal pollutants into the environment, Mathematical model analysis was deployed to determine the emission rates, emission per capita and land distributions, and their implications.

2 Methodology

2.1 Study area

The area under study in this research project is the entire country of Nigeria. Nigeria is a country in West Africa with over 250 ethnic nationalities and has a land mass of 923,768 km^2. The country is bounded to the west by Benin Republic, to the east by Cameroon, to the south by the Atlantic Ocean and Niger Republic to the North. Nigeria lies between longitudes 2°–15° E and latitudes 4°–14° N. The country has six geo-political divides namely, the North-West (NW), North-Central (NC), North-East (NE), South-West (SW), South-East (SE) and the South-South (SS). There are thirty-six states and the Federal Capital Territory (FCT - Abuja); namely Abia, Adamawa, Akwa Ibom, Anambra, Bauchi, Bayelsa, Benue, Borno, Cross River, Delta, Ebonyi, Edo, Ekiti, Enugu, Gombe, Imo, Jigawa, Kaduna, Kano, Katsina, Kebbi, Kogi, Kwara, Lagos, Nasarawa, Niger, Ogun, Ondo, Osun, Oyo, Plateau, Rivers, Sokoto, Taraba, Yobe and Zamfara. Fig. 1 shows the maps of Nigeria illustrating the states, geo-political divisions and oil producing states as found by Ite et al. [28].

2.2 Sourcing for data

The annual consumption data for PMS for the year 2011–2020 by states (Tables 1 and 2) and regions (Tables 3 and 4) were obtained from the Nigerian National Petroleum Corporation's (NNPC) Annual Statistical Bulletins. For the years 2015–2018, the consumption data was obtained from the National Bureau of Statistics (NBS) [29], and Petroleum Products Consumption Statistics in Nigeria and Petroleum Products Import and Consumption (Truck In) Statistics reports [30]. The population data used in this research work were generated from the 2006 National Census data [31] and shown in Table 5. Areas of states in Nigeria were extracted from NBS [32], as shown in Table 6. There are few studies, so far, which determined the heavy metal contents of Nigerian petroleum products and the only one which measured the elements under consideration in this research is the work done by Akpoveta and Osakwe [27] and is shown in Table 7.

2.3 Extrapolation of population data

The 2006 census data were extrapolated to the years (2011–2020) under consideration in this paper using the equation extracted from Elehinafe et al. [3] as shown in Eq. (1):

$$P = P_0 \cdot e^{rt} \quad (1)$$

where:

- P = population after time t,
- P_0 = initial population,
- r = annual growth rate,
- t = time in years.

The annual growth rate of Nigeria used varied with each state of the federation as presented in the document by the National Population Commission.

2.4 Computation of annual emission rates

The annual rates were computed from the consumption data (Tables 1 and 2) and transition metal contents of fuel data (Table 7) using Eq. (2) obtained from Akpoveta and Osakwe [27].

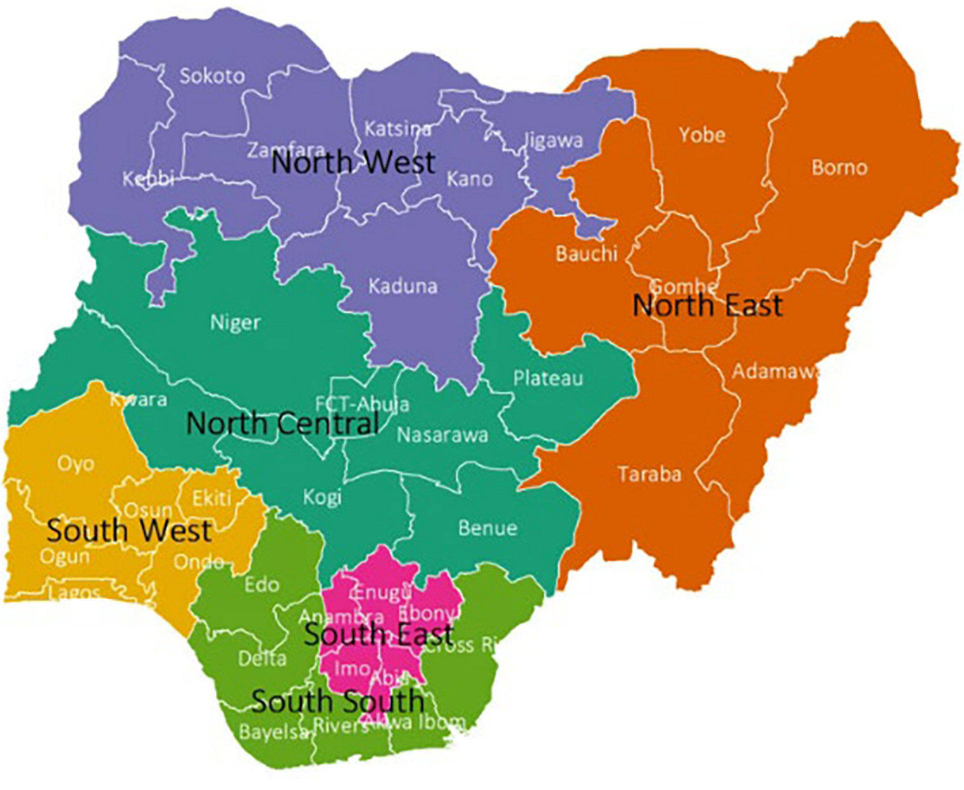

Fig. 1 Map of Nigeria depicting the geopolitical zones and states [28]

Table 1 PMS consumption by states from the year 2011 to the year 2015 (in L)

States	Year				
	2011	2012	2013	2014	2015
Abia	39,138,500	26,355,630	215,227,720	244,840,283	356,635,969
Adamawa	57,045,630	38,680,380	335,528,160	378,713,570	328,176,168
Akwa Ibom	32,035,020	36,993,680	236,570,970	418,663,938	418,680,155
Anambra	40,597,570	28,773,520	369,496,810	477,152,307	579,027,394
Bauchi	85,472,010	49,055,310	424,167,830	462,001,914	477,009,920
Bayelsa	25,994,380	29,694,840	101,754,910	127,189,127	169,164,491
Benue	41,331,670	31,334,070	169,190,230	168,458,683	179,991,811
Borno	61,157,830	35,762,920	392,151,880	417,434,771	182,154,804
Cross River	45,110,440	36,907,580	190,687,020	287,565,966	351,756,799
Delta	84,629,030	78,691,090	483,898,630	676,216,157	684,146,074
Ebonyi	10,802,590	11,492,810	51,984,450	81,319,780	108,794,612
Edo	68,061,670	49,971,810	364,486,100	634,172,375	678,839,286
Ekiti	32,870,380	23,936,630	259,959,830	105,496,843	129,424,255
Enugu	42,105,860	35,841,800	143,426,350	329,649,357	398,807,976
FCT	336,975,670	213,262,090	1,270,552,460	1,533,875,284	1,559,866,995
Gombe	48,567,790	36,675,190	212,271,640	153,621,748	127,129,299
Imo	41,901,440	36,215,960	236,052,340	287,914,016	381,421,574
Jigawa	34,528,950	19,423,690	180,276,340	182,629,128	172,732,765
Kaduna	176,190,650	125,691,710	577,112,990	491,281,892	500,420,857
Kano	168,440,020	77,176,550	627,498,180	585,283,119	472,764,344
Katsina	94,771,780	50,467,930	462,649,190	414,755,143	398,741,999
Kebbi	69,884,260	39,780,080	431,943,930	407,748,838	424,561,591
Kogi	53,107,680	45,784,460	218,029,310	206,016,650	219,237,839
Kwara	51,577,190	23,825,930	326,499,590	329,702,811	293,623,978
Lagos	486,591,090	116,970,730	2,500,803,750	3,206,398,314	3,412,199,252
Nasarawa	69,790,880	55,072,740	309,692,360	152,345,177	158,091,667
Niger	83,962,400	43,650,550	374,408,770	358,604,155	393,806,016
Ogun	82,322,750	47,932,210	867,617,520	944,161,723	1,042,239,552
Ondo	72,166,760	41,957,110	332,527,760	297,293,451	312,577,730
Osun	52,643,360	29,920,920	509,706,620	278,444,816	287,888,154
Oyo	150,086,430	41,208,040	846,195,180	977,202,398	770,667,967
Plateau	55,307,320	43,681,410	281,464,300	264,757,769	247,976,920
Rivers	156,984,470	101,561,210	770,437,550	932,238,422	750,036,513
Sokoto	44,139,850	32,320,570	267,825,130	191,719,980	189,181,089
Taraba	28,855,040	21,916,240	178,319,200	188,612,167	168,890,460
Yobe	50,135,580	19,781,150	245,689,380	225,792,800	274,807,851
Zamfara	48,401,000	24,788,950	128,366,980	171,746,756	178,371,931

Source: [29, 30, 32]

$$\text{Annual emission rate}\left(\frac{\text{kg}}{\text{y}}\right) = \text{Annual fuel consumption}\left(\frac{\text{L}}{\text{y}}\right) \cdot \text{Trace metal content of fuel}\left(\frac{\text{kg}}{\text{L}}\right) \quad (2)$$

2.5 Calculation of the emission rates per capita

The emission rates per capita were computed using Eq. (3). Obtained from Elehinafe et al. [3]. The emission rate per capita here is referred to the amount of trace metal emission a person is exposed to.

Table 2 PMS consumption by states from the year 2016 to the year 2020 (in L)

States	Year				
	2016	2017	2018	2019	2020
Abia	324,670,023	420,580,825	394,366,446	368,152,067	341,937,688
Adamawa	330,401,266	619,337,383	557,557,131	495,776,879	433,996,627
Akwa Ibom	341,176,787	375,577,635	383,408,126	391,238,617	399,069,108
Anambra	538,619,776	537,260,530	504,638,819	472,017,108	439,395,397
Bauchi	431,922,661	72,470,506	66,268,906	60,067,306	53,865,706
Bayelsa	97,586,723	90,695,623	96,376,863	102,058,103	107,739,343
Benue	292,065,914	486,127,673	460,860,651	435,593,629	410,326,607
Borno	182,198,282	233,218,987	241,672,809	250,126,631	258,580,453
Cross River	257,861,261	344,917,862	309,113,418	273,308,974	237,504,530
Delta	692,349,862	695,462,902	746,034,120	796,605,338	847,176,556
Ebonyi	94,054,908	76,498,343	92,187,063	107,875,783	123,564,503
Edo	490,367,992	521,078,255	519,415,828	517,753,401	516,090,974
Ekiti	132,294,905	84,974,421	78,682,631	72,390,841	66,099,051
Enugu	351,848,696	640,199,681	684,288,434	728,377,187	772,465,940
FCT	1,569,355,273	933,783,428	858,494,808	783,206,188	707,917,568
Gombe	131,093,788	229,422,757	278,799,262	328,175,767	377,552,272
Imo	318,230,543	395,495,722	399,471,445	403,447,168	407,422,891
Jigawa	157,458,137	35,047,485	47,039,260	59,031,035	71,022,810
Kaduna	557,480,264	722,485,254	662,924,964	603,364,674	543,804,384
Kano	532,672,044	1,365,296,571	1,565,227,374	1,765,158,177	1,965,088,980
Katsina	403,581,317	124,237,329	97,103,849	69,970,369	42,836,889
Kebbi	377,937,460	92,943,453	84,631,621	76,319,789	68,007,957
Kogi	256,936,587	145,415,412	121,218,392	97,021,372	72,824,352
Kwara	505,158,784	503,847,905	450,877,958	397,908,011	344,938,064
Lagos	3,114,958,106	3,025,853,567	2,995,872,829	2,965,892,091	2,935,911,353
Nasarawa	197,776,846	125,381,149	91,213,946	57,046,743	22,879,540
Niger	348,916,589	1,112,469,388	953,935,749	795,402,110	636,868,471
Ogun	952,933,330	985,211,612	886,300,404	787,389,196	688,477,988
Ondo	421,075,778	479,494,694	457,797,807	436,100,920	414,404,033
Osun	272,075,365	221,210,781	257,300,606	293,390,431	329,480,256
Oyo	1,085,343,654	798,541,525	847,177,010	895,812,495	944,447,980
Plateau	250,120,889	379,089,095	421,177,919	463,266,743	505,355,567
Rivers	587,699,990	709,400,579	675,199,566	640,998,553	606,797,540
Sokoto	179,989,965	65,145,804	70,489,101	75,832,398	81,175,695
Taraba	164,301,171	93,886,658	89,917,726	85,948,794	81,979,862
Yobe	281,476,105	28,982,869	40,049,008	51,115,147	62,181,286
Zamfara	158,016,433	564,696,226	584,622,399	604,548,572	624,474,745

Source: [29, 30, 32]

$$\text{Emission rate per capita}\left(\text{kg}/\left(\text{y}\cdot\text{person}\right)\right) = \text{Emission rate}\left(\frac{\text{kg}}{\text{y}}\right) \div \text{Population}\left(\text{people}\right) \quad (3)$$

2.6 Calculation of land distribution of emissions

The emission rate per land area (land distribution) was calculated using the following expression (Eq. (4)). The land distribution of emissions can be seen as the amount of trace metals that every square kilometer of land is exposed to.

Table 3 PMS consumption by region from the year 2011 to the year 2015 (in L)

Region	Year				
	2011	2012	2013	2014	2015
North-East	331,233,880	201,871,190	1,788,128,090	1,826,176,970	1,558,168,502
North-West	636,356,510	369,649,480	2,675,672,740	2,445,164,856	2,336,774,576
South-East	174,545,960	138,679,720	1,016,187,670	1,420,875,743	1,824,687,525
South-West	876,680,770	301,925,640	5,316,810,660	5,808,997,545	5,954,996,910
North-Central	692,052,810	456,611,250	2,949,837,020	3,013,760,529	3,052,595,226
South-South	412,815,010	333,820,210	2,147,835,180	3,076,045,985	3,052,623,318
Total	3,123,684,940	1,802,557,490	15,894,471,360	17,591,021,628	17,779,846,057

Source: [29, 30, 32]

Table 4 PMS consumption by regions from the year 2016 to the year 2020 (in L)

Region	Year				
	2016	2017	2018	2019	2020
North-East	1,521,393,273	1,277,319,160	1,274,264,842	1,400,981,849	1,268,156,206
North-West	2,367,135,620	2,969,852,122	3,112,038,568	3,657,426,578	3,396,411,460
South-East	1,627,423,946	2,070,035,101	2,074,952,207	2,304,126,397	2,084,786,419
South-West	5,978,681,138	5,595,286,600	5,523,131,287	6,248,298,823	5,378,820,661
North-Central	3,420,330,882	3,686,114,050	3,357,779,423	3,679,186,315	2,701,110,169
South-South	2,467,042,615	2,737,132,856	2,729,547,921	3,294,944,574	2,714,378,051
Total	17,382,007,474	18,335,739,889	18,071,714,248	17,807,688,607	17,543,662,966

Source: [29, 30, 32]

$$\text{Emission rate per land area}\left(\text{kg}/\left(\text{y}\cdot\text{km}^2\right)\right) = \text{Annual emission rate}\left(\frac{\text{kg}}{\text{y}}\right) \div \text{Land area}\left(\text{km}^2\right) \quad (4)$$

3 Results and discussion

3.1 Annual emission rates

The total emission rates of Pb emissions from the consumption of PMS in Nigeria for years 2011–2020 for each state, region and the nation are summarized in Fig. 2. The minimum estimated annual Pb emission rate of 4.66 kg/y was obtained in 2012 in Jigawa State while the maximum estimated annual Pb emission of 726.20 kg/y was obtained in 2015 from the consumption in Lagos State. The regions with the highest rates of emission were SW with $1.43 \cdot 10^3$ kg/y in 2015 and $1.50 \cdot 10^3$ kg/y in 2019. The region with the lowest emission rates was NE with 304.36 kg/y in 2020 within the period in focus. The pronounced variations in the annual Pb emission rates from the consumption of PMS across the 36 states and the FCT in Nigeria is due to various reasons ranging from overpopulation and under-population in some states, and high consumption in urban areas. In comparison with the estimated annual Pb emissions of $2.53 \cdot 10^6$ kg/y in Nigeria reported by Obioh et al. [33] as the standard national Pb emission rate level. It was estimated that the lowest national annual Pb emission rate of 432.62 kg/y was recorded in 2012 while the highest national annual Pb emission rates of $4.40 \cdot 10^3$ kg/y was obtained in 2017.

The percentage contribution of lead emissions from PMS consumption estimated in this study to national lead emissions rates is very low (0.00174%) because different regulations on lead levels in fuel have been established over the years to gradually eliminate the consumption of leaded fuel and the introduction of unleaded fuel. It was therefore expected that current national lead emissions have fallen significantly from those reported by Obioh et al. [33]. It is however worthy to note that exposure to Pb is not safe at any level [34, 35]. Lead contamination disrupts soil health, diminishes crop productivity, endangers human health, and disrupts ecological systems. Unlike other elements such as chromium, manganese, molybdenum, nickel, and selenium, which have both toxic and essential properties depending on their concentration, lead does not fall into the category of being a required nutrient at any level. While these aforementioned elements can be beneficial in smaller amounts, lead lacks any essentiality and is consistently toxic, even at low levels of exposure [36, 37].

Table 5 Nigerian population in the year 2006 by states

State	Population
Abia	2,845,380
Adamawa	3,178,950
Akwa Ibom	3,902,051
Anambra	4,177,828
Bauchi	4,653,066
Bayelsa	1,704,515
Benue	4,253,641
Borno	4,171,104
Cross River	2,892,988
Delta	4,112,445
Ebonyi	2,176,947
Edo	3,233,366
Ekiti	2,398,957
Enugu	3,267,837
FCT	2,365,040
Gombe	3,927,563
Imo	4,361,002
Jigawa	6,113,503
Kaduna	9,401,288
Kano	5,801,584
Katsina	3,256,541
Kebbi	3,314,043
Kogi	2,365,353
Kwara	9,113,605
Lagos	1,869,377
Nasarawa	3,954,772
Niger	3,751,140
Ogun	3,460,877
Ondo	3,416,959
Osun	5,580,894
Oyo	3,206,531
Plateau	5,198,716
Rivers	3,702,676
Sokoto	2,294,800
Taraba	2,321,339
Yobe	3,278,873
Zamfara	1,406,239
Total	140,431,790

Source: [31]

Table 6 Land areas of Nigeria by states

State	Area (km^2)
Abia	4,900
Adamawa	38,700
Akwa Ibom	6,900
Anambra	4,865
Bauchi	49,119
Bayelsa	9,059
Benue	30,800
Borno	72,609
Cross River	21,787
Delta	17,108
Ebonyi	6,400
Edo	19,187
Ekiti	5,435
Enugu	7,534
FCT	17,100
Gombe	5,288
Imo	23,287
Jigawa	42,481
Kaduna	20,280
Kano	23,561
Katsina	36,985
Kebbi	27,747
Kogi	35,705
Kwara	3,671
Lagos	28,735
Nasarawa	68,925
Niger	16,400
Ogun	15,820
Ondo	9,026
Osun	26,500
Oyo	27,147
Plateau	10,575
Rivers	27,825
Sokoto	56,282
Taraba	46,609
Yobe	37,931
Zamfara	7,607
Total	909,890

Source: [32]

Fig. 3 summarizes the total annual of Zn emission rates from the consumption of PMS in Nigeria and by states, regions and nation. During the period 2011–2020, the recorded emission rates varied between 15.45 kg/y and $4.88 \cdot 10^3$ kg/y. The maximum estimated annual Zn emission rate of $4.88 \cdot 10^3$ kg/y was recorded in 2017 in Lagos State. In contrast, for the period under review, the minimum annual Zn emission rate was 15.45 kg/y in the year 2011 in Ebonyi State. Across the 36 states and the FCT, a noticeable variation is observed, and this can be attributed to several factors such as the rate of commercial activities and population density to mention but a few. From the estimation

Table 7 Determined trace metal content in PMS

Trace metal	Content (mg/L)
Lead	0.24
Zinc	1.43
Iron	1.48
Cobalt	0.12
Nickel	0.15

Source: Akpoveta and Osakwe [27]

of regional distribution for Zn emission rates in PMS, the least annual Zn emission rate recorded, was 198.31 kg/y in 2012 in the southeastern region while the greatest annual Zn emission rate of $8.94 \cdot 10^3$ kg/y was obtained in 2019 in the southwest. Nationally, Zn emission rates ranged between $2.58 \cdot 10^3$ kg/y in 2012 and $26.22 \cdot 10^3$ kg/y in 2017. Going by the research conducted by Sandstead [38] and Wang et al. [39], the rate of Zn emission is on the high side and would zinc particle in the air and increase the natural zinc content of the soil and water bodies. Inhalation of Zn particles can cause inflammation of the airways and metal fume fever as reported by Fine et al. [40].

The results of Fe emissions rate from the consumption of PMS in Nigeria are summarized in Fig. 4 by states. The Fe emission rates from the consumption of PMS ranged between 15.99 kg/y and $5.05 \cdot 10^3$ kg/y. The minimum estimated annual Fe emission rate of 15.99 kg/y was obtained in 2011 in Ebonyi State while the maximum estimated annual Fe emission rate of $5.05 \cdot 10^3$ kg/y was obtained in 2015 in Lagos State. The pronounced variations in the annual Fe emission from the consumption of PMS across the 36 states and the Federal Capital Territory in Nigeria can be attributed to various reasons such as high-rate consumption of PMS and uneven distribution of population in some areas. It was estimated that the lowest national annual Fe emission rate of $2.05 \cdot 10^3$ kg/y was recorded in 2012 in the Southeast while the highest annual regional Fe emission rate of $9.25 \cdot 10^3$ kg/y was obtained in 2019 in the Southwest. During the period 2011–2020, a 461% increase was observed nationwide when total annual emission rates increased from $2.67 \cdot 10^3$ kg/y in 2012 to 27.14 kg/y in 2017 as shown in Fig. 5. As reported by Mitra et al. [41] and Azeh Engwa et al. [42], the Fe emission is huge to have negative impacts on the components of environment, thereby posing threats to plants, animals and human health.

3.2 Annual emission rates per capita

Fig. 6 shows the annual emission rates per capita for Pb from the year 2011–2020. The amount of Pb each person was to be exposed on a yearly basis. The least emission rate per capita for Pb was $0.52 \cdot 10^{-6}$ kg/(y·person) in

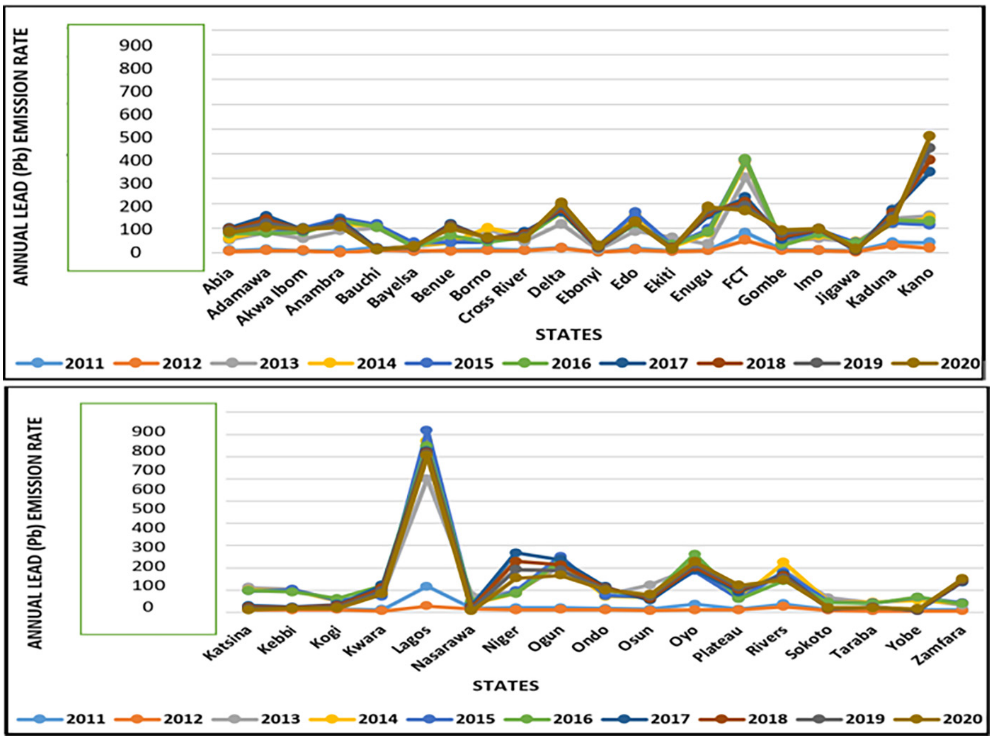

Fig. 2 Lead emission rates from the consumption of PMS by states 2011–2020 (kg/y)

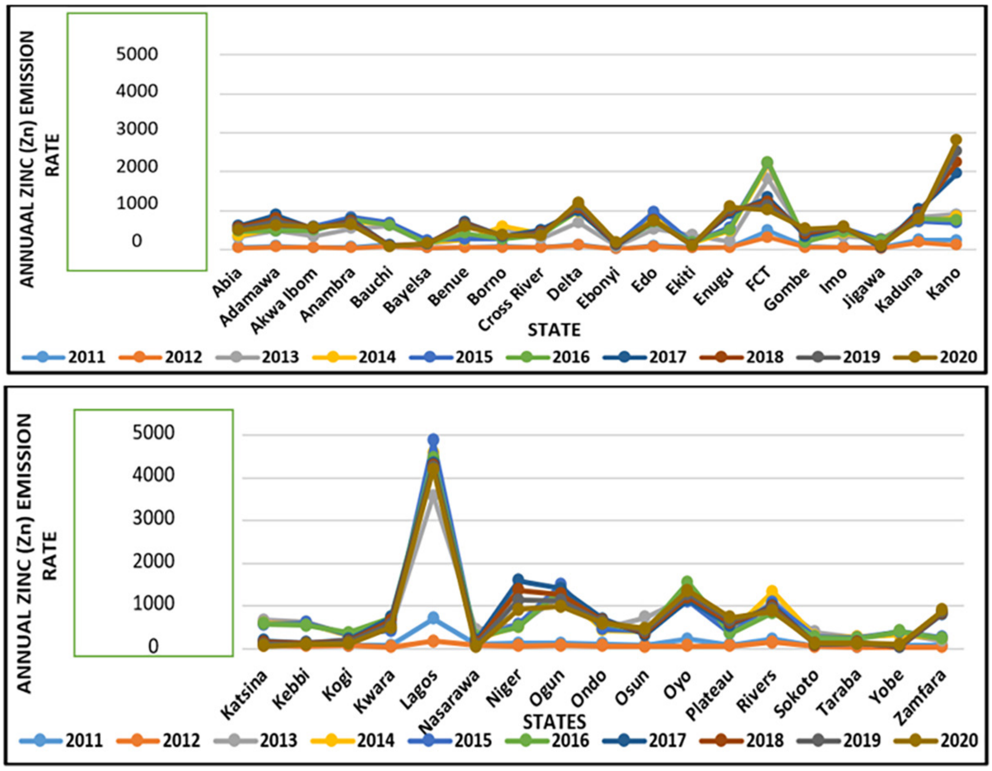

Fig. 3 Zinc emission rates from the consumption of PMS by states 2011–2020 (kg/y)

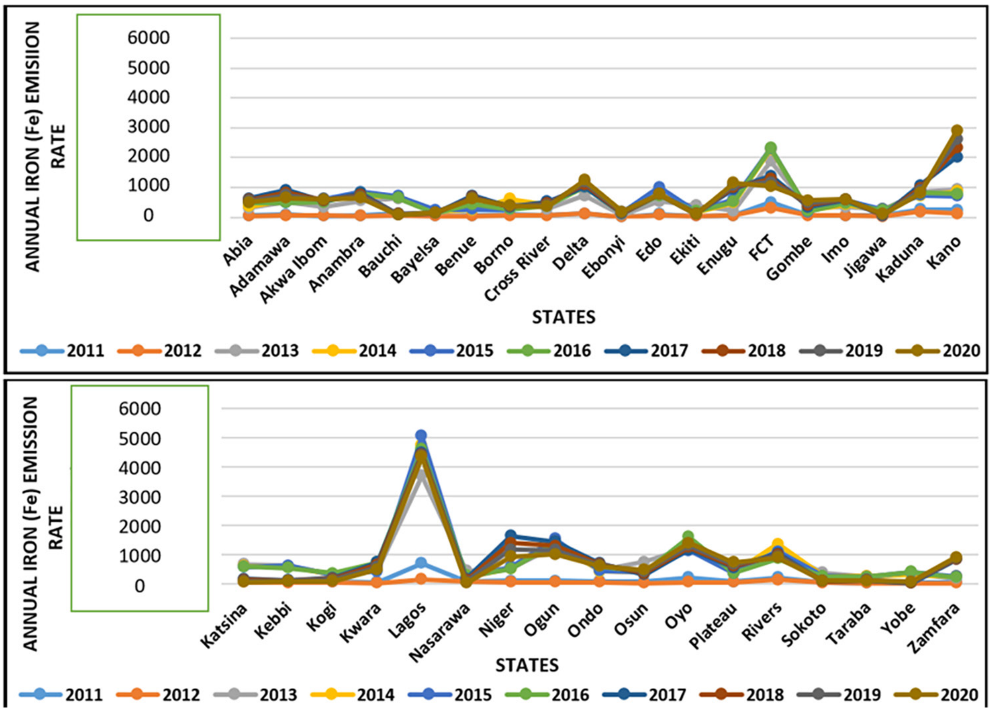

Fig. 4 Iron emission rates from the consumption of PMS by states, 2011–2020 (kg/y)

Kwara State in the year 2012. On the other hand, the highest Pb emission rate per capita was $2.33 \cdot 10^{-3}$ kg/(y·person) and this was recorded in Lagos State in the year 2015. However, from 2017 to 2020, Kano State maintained the second highest Pb emission rates per capita and this can be closely related to the large population and commercial activities in the state. The values from the Fig. 6 are considerably to engender Lead poisoning through inhalation, dinking and eating food crops contaminated with lead. Gilani et al. [43] showed that lead toxicity deteriorate

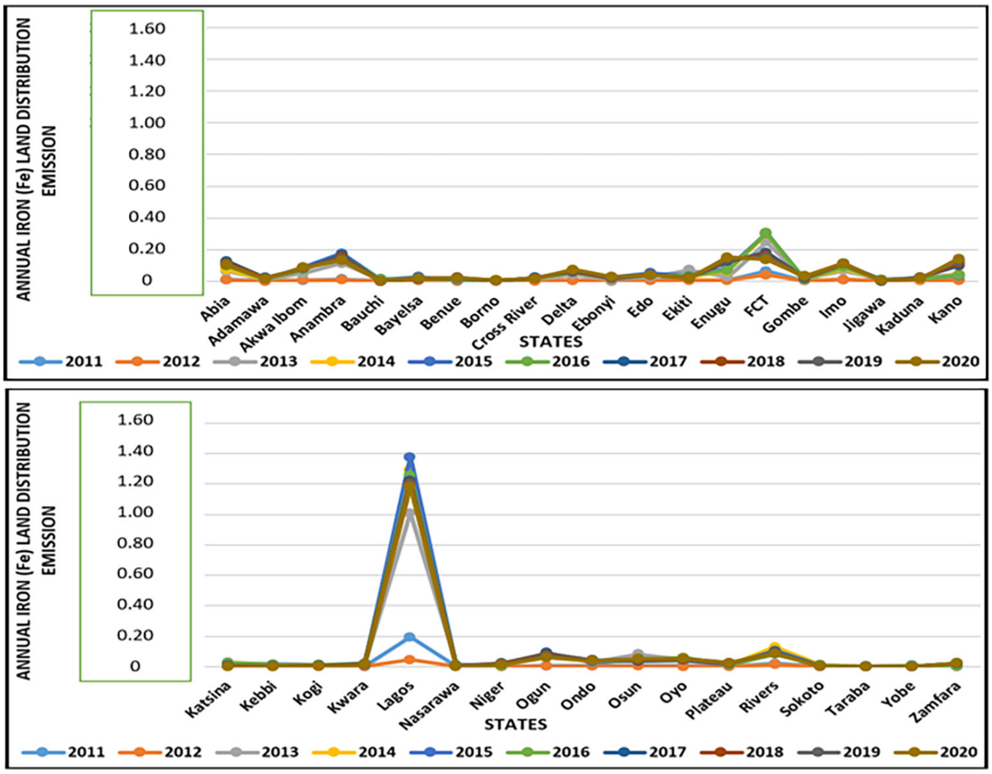

Fig. 5 Iron emission rates per land area from PMS consumption by state for 2011–2020 (kg/(y·km^2))

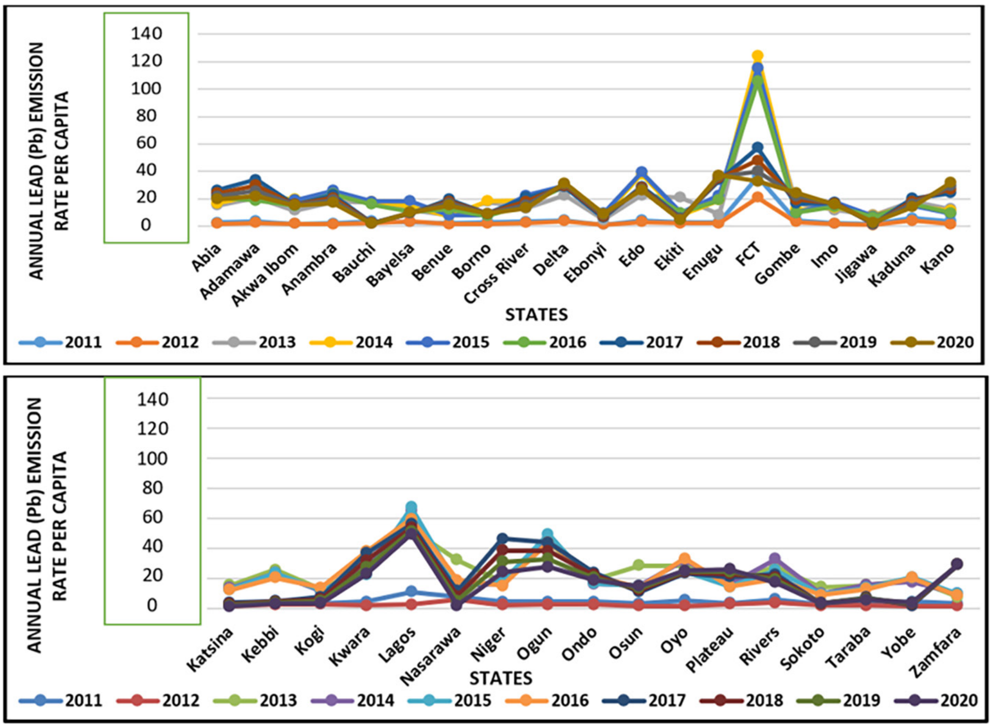

Fig. 6 Lead emission rates per capita from PMS consumption by states, 2011–2020 (·10^{-6} kg/(y·person))

the nervous system in the human body when compared with other human parts. Symptoms worsen and give rise to paralysis, coma, or even death. Lead is e a neurotoxin in the human body. The half-life of lead in the brain ranged between 2 and 3 years whereas it lingers to 30 days in the blood. A progressive deterioration in the parts of the human brain (encephalopathy condition) results and give obvious manifestations of poor attention span, memory loss, headache, dullness and hallucinations within days of exposure [44, 45]. The standard increased blood lead level has been set by the Centers for Disease Control and Prevention in the United State of America at 0.1 mg/L for adults and 0.05 mg/L for children as reported by Centers for Diseases Control and Prevention in 2012 [34].

The annual zinc emission rates per capita from PMS consumption are summarized in Fig. 7. A significant increase in also observed in the emission rates per capita from $9.28 \cdot 10^{-5}$ kg/(y·person) in 2012 to $0.82 \cdot 10^{-3}$ kg/(y·person) in 2013 across all states of Nigeria. From the Fig. 7, the North-Central region, a constant decline in emission rate per capita is observed from $0.13 \cdot 10^{-3}$ kg/(y·person) in 2017 to $0.87 \cdot 10^{-4}$ kg/(y·person) in 2020. In contrast, the emission rates per capita for the North-West region increased slightly from 2017 to 2020. Nationwide, the emission rate per capita for zinc increased by almost 340% between 2011 and 2020, which is alarming (Fig. 7). The values are high to make every resident in Nigeria to be at risk of zinc poisoning through inhalation, dinking and eating food crops contaminated with zinc. Although, zinc is a significant micronutrient that holds great importance in the physiological and metabolic functions of various living beings, excessive amounts of zinc can have a harmful impact on the organism, leading to toxicity (Singh and Kalamdhad [48]). The highest limit dose of zinc for adults is 40 mg per day, while the highest limit dose for babies less than 6 months is 4 mg/day, according to the National Institutes of Health [46]. High zinc emissions can contaminate soil and water; the permissible limit of zinc in water according to WHO standards is 5 mg/l [47]. Such contamination poses risks to the health of plants, animals, and microorganisms. It can lead to reduced biodiversity and ecological imbalances. Aquatic organisms, in particular, are vulnerable to the toxic effects of zinc. Increased levels of zinc in water bodies can harm fish, invertebrates, and other aquatic life, negatively impacting their growth, reproduction, and overall ecosystem health [48]. When it comes to human health, excessive zinc intake or exposure can lead to various problems. The gastrointestinal system may be affected, resulting in stomach cramps, nausea, vomiting, and diarrhea [17].

Fig. 8 shows the emission rate per capita for iron across the 36 states of the federation and the FCT – Abuja, between 2011–2020. The data presented indicates that the year 2015 witnessed the highest emission rate per capita of $2.06 \cdot 10^{-3}$ kg/(y·person) and this was recorded in Lagos State while the least emission rate per capita of $3.20 \cdot 10^{-6}$ kg/(y·person) was observed in 2012 in Kwara State. This can be attributed to the variation in population density in both states. On a regional level, it was estimated that the Southwest region accounted for the highest Fe emission per capita with a total of $0.34 \cdot 10^{-3}$ kg/(y·person) in 2014. According to the Fig. 8, the lowest nationwide Fe emission rate per capita for the period 2011–2020 was $0.18 \cdot 10^{-3}$ kg/(y·person) and this was recorded in Jigawa

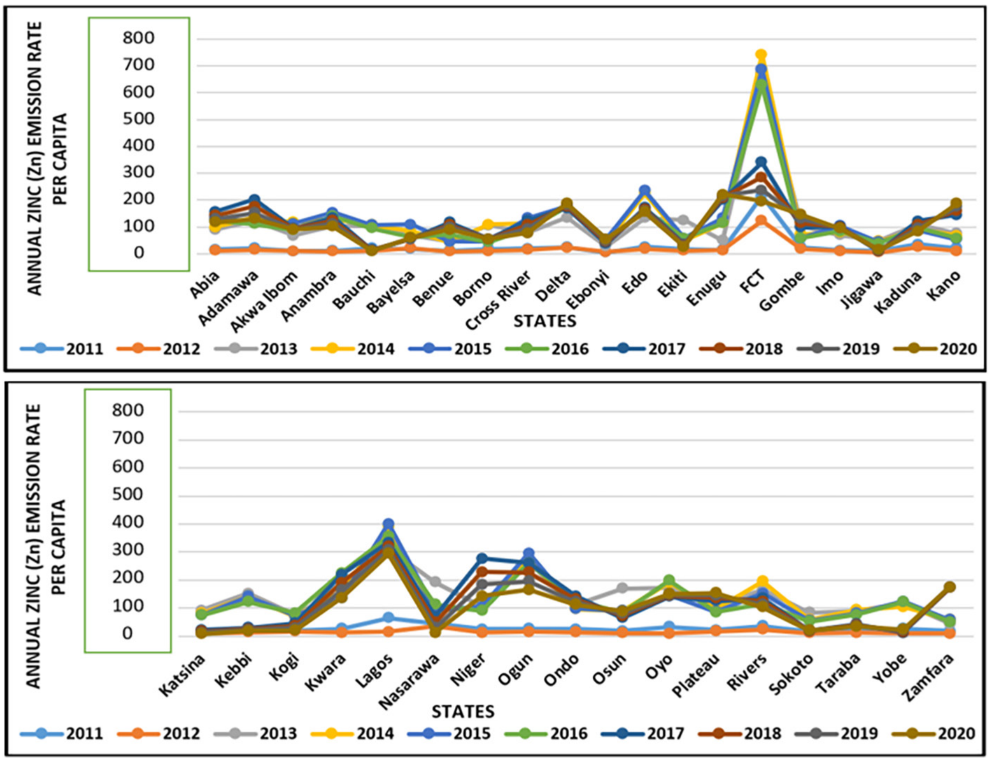

Fig. 7 Zinc emission rates per capita from PMS consumption by states, 2011–2020 ($\cdot 10^{-6}$ kg/(y·person))

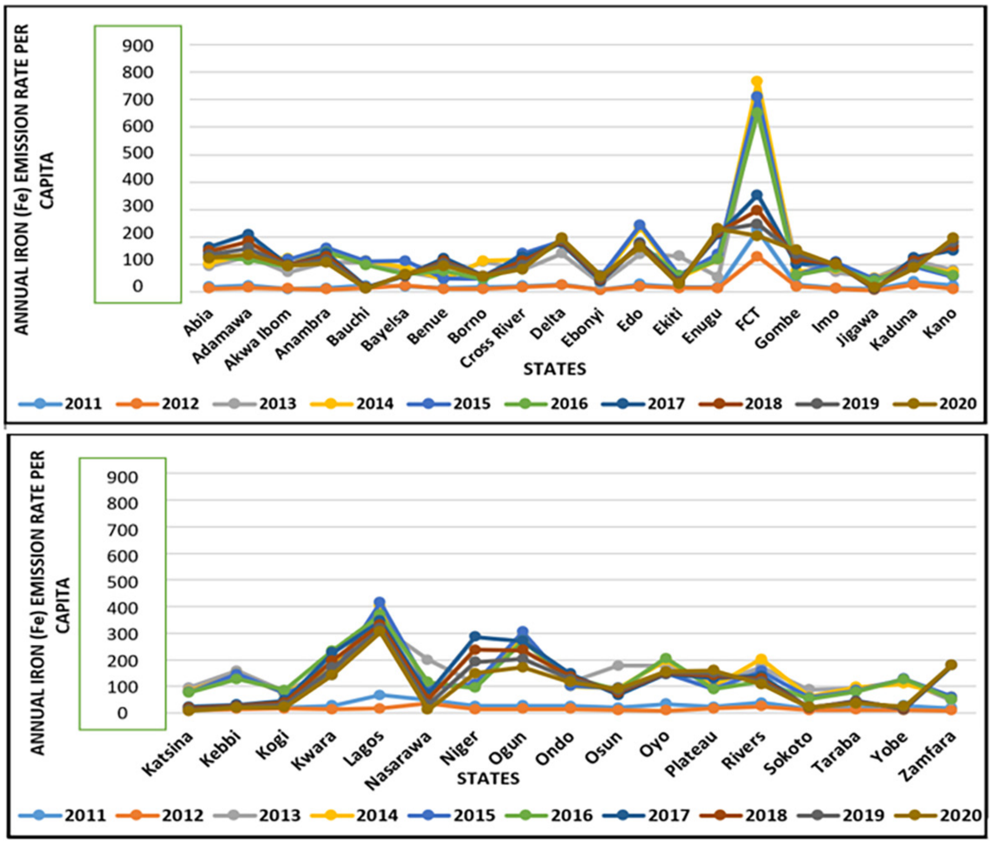

Fig. 8 Iron emission rates per capita from PMS consumption by states, 2011–2020 ($\cdot 10^{-6}$ kg/(y·person))

State. Iron is essential, but too much of it can be harmful and harm your heart, liver, and other key organs [49]. When iron is obtained only from diet, iron excess is not a problem; unless exposure to iron from unmerited means – through inhalation, drinking and food intake. Keeping in mind that, the tolerable upper intake level (UL) for iron is between 40 and 45 mg/day which is well below the upper-level Intake exposed to the population in Nigeria [50]. The cumulative dose per individual over period of years would exceed UL intake of Fe thereby leading ill-health. In terms of health, breathing in iron oxide particles might cause respiratory problems. Coughing, wheezing, shortness of breath, and inflammation of the nose, throat, and lungs are a few examples of these symptoms. Long-term exposure to excessive iron emission levels may lead to the onset or exacerbation of respiratory diseases like bronchitis or asthma [49].

3.3 Annual emission rates per land area

Lead is naturally present in all types of soil. It generally occurs in the range of 15 to 40 ppm lead in soil, or 15,000 to 40,000 mg/km^2. Pollution can increase soil Pb levels to several thousand ppm [51]. Fig. 9 shows the results of Pb emissions rate per land area from the consumption of PMS in Nigeria, by States, regions and nation respectively. For the period 2011–2020, the Pb emission rate per land area emission varied between $9.30 \cdot 10^{-5}$ kg/(y·km^2) and $2.33 \cdot 10^{-1}$ kg/(y·km^2) with the maximum estimated annual Pb emission rate per land area recorded in 2015 in Lagos State, which way higher than the standards published by United State Environmental Protection Agency (US EPA). In contrast, for the period under review, the minimum annual Pb emission rate per land area from the consumption of PMS was in the year 2012 in Taraba State. Across the 36 states and the Federal Capital Territory in Nigeria, a noticeable variation is observed, and this could be attributed to several factors such as the rate of commercial and industrial activities as well as population density. From the regional distribution for Pb emission rates per land area in PMS as computed, the least annual Pb emission rate per land area was $0.17 \cdot 10^{-3}$ kg/(y·km^2) in 2012 in the North-Eastern region of Nigeria while the greatest annual Pb emission of $19.51 \cdot 10^{-3}$ kg/(y·km^2) was obtained in 2019 in the Southwest.

The Environmental Protection Agency's residential soil screening level for Pb is 400 ppm, while the industrial soil screening level is set at 1,200 ppm [52]. The cumulative effect would cause the Pb screening to be above the set standards. High levels of lead in soil can lead to soil

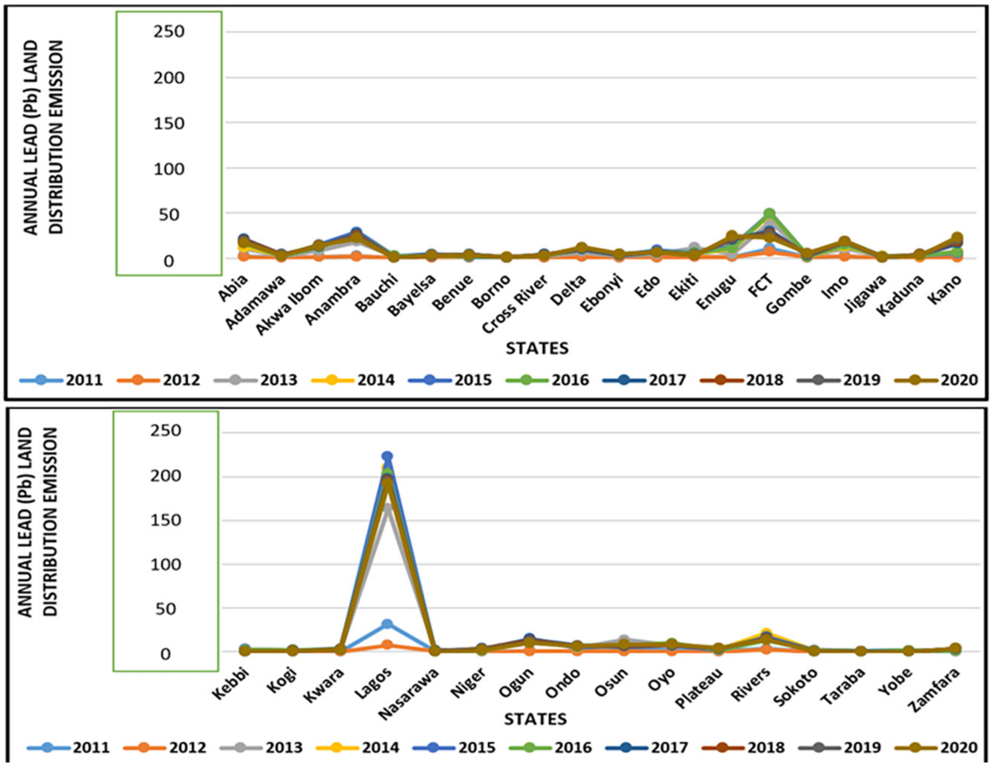

Fig. 9 Lead emission rates per land area from PMS consumption by states, 2011–2020 ($\cdot 10^{-3}$ kg/(y·km^2))

degradation. It affects the soil's physical and chemical properties, resulting in reduced soil fertility and diminished agricultural productivity. Lead can alter soil pH and interfere with nutrient availability, which hampers the growth and development of plants. Plants can absorb lead from the soil through their roots, subsequently transporting it to various parts of the plant, including edible portions. This poses risks to human health through the consumption of lead-contaminated crops [53, 54]. Additionally, Lead accumulation in plants can impede their growth, disrupt photosynthesis, and overall compromise plant health [55]. Lead contamination in soil can have adverse effects on soil-dwelling organisms such as microorganisms, earthworms, and other invertebrates. These organisms play crucial roles in maintaining soil fertility, nutrient cycling, and overall soil ecosystem health. High levels of lead can disturb their populations and disrupt the ecological balance within the soil ecosystem.

Furthermore, lead from contaminated soil can leach into groundwater or nearby water bodies, resulting in water contamination [56]. This affects human and environmental health, as lead-contaminated water can be hazardous when consumed and can harm aquatic organisms. WHO recommends a maximum allowable concentration of 10 ppb for lead in drinking water [57].

The results of Zn emission rate per land area from the consumption of PMS in Nigeria are presented in Fig. 10 by states. The emission ranged between $0.56 \cdot 10^{-3}$ kg/(y·km^2) and 1.33 kg/(y·km^2). The minimum estimated annual Zn emission per land area of $0.56 \cdot 10^{-3}$ kg/(y·km^2) was recorded in 2012 in Taraba State while the maximum estimated annual Zn emission per land area of 1.33 kg/(y·km^2) was observed in 2015 from the consumption of PMS in Lagos State. The remarkable variations in the annual Zn emission per land area from the consumption of PMS across the 36 states and the FCT in Nigeria can be attributed to various reasons such as differing consumption of PMS, uneven population and land mass distribution. It is shown that between the lowest national annual Zn emission rate per land rate of $2.45 \cdot 10^{-2}$ kg/(y·km^2) was recorded in while the highest national annual Zn emission rate per land area of $3.41 \cdot 10^{-1}$ kg/(y·km^2) was obtained in 2019. During the period 2011–2020, the total Zn emission rate per land area increased massively from $4.22 \cdot 10^{-2}$ kg/(y·km^2) to $2.95 \cdot 10^{-1}$ kg/(y·km^2).

Most organization do not provide specific permissible levels or standards for zinc in soil, however, Dohare et al. [58] stated that the zinc present in the soil is approximately 0.05 g/kg in the earth crust. The health and growth of plants may be harmed by excessive zinc levels

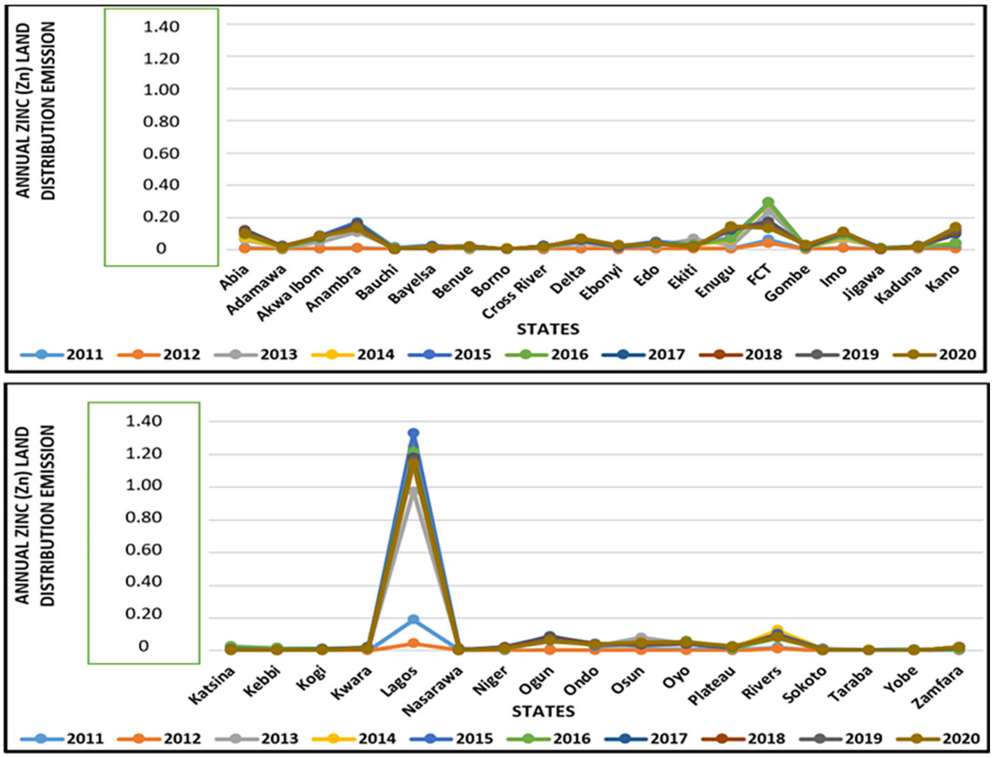

Fig. 10 Zinc emission rates per land area from PMS consumption by states, 2011–2020 (kg/(y·km^2))

in the soil brought on by emissions. Plant phytotoxicity can result from zinc concentrations that are too high [59]. Chlorosis, stunted development, and decreased agricultural output are some examples of how this might show up. The equilibrium of nutrients can be disturbed by high zinc levels in soil. The availability and absorption of other crucial minerals, like iron, copper, and manganese, which plants need, can be hampered by excessive zinc. Plant development and general soil fertility may be negatively impacted by this imbalance in the availability of nutrients. Zinc emissions can also have an impact on beneficial bacteria and fungus in the soil [60]. High zinc concentrations have the potential to damage or even kill certain bacteria. Critical soil processes like nutrient cycling and organic matter breakdown may be impacted by this disturbance to soil microbes [61, 62].

The typical iron concentrations in soils range from 0.2% to 55% (20,000 to 550,000 mg/kg). Fig. 5 shows the emission rate per land area for Iron across the 36 states of Nigeria between 2011–2020. The data presented indicates that the year 2015 witnessed the highest emission rate per land area of 1.38 kg/(y·km^2) and this was recorded in Lagos State while the least emission rate per land area of $0.58 \cdot 10^{-3}$ kg/(y·km^2) was observed in 2012 in Taraba State. This can be attributed to the variation in population and land area covered by both states. On a regional level, it was computed that the Southwest region accounted for the highest Fe emission per land area with a total of $9.05 \cdot 10^{-1}$ kg/(y·km^2). As estimated, the lowest nationwide Fe emission rate per land area for the period 2011–2020 was $1.07 \cdot 10^{-3}$ kg/(y·km^2) and this was recorded in the North-East in 2012. These values are high in all states to cause a significant Fe accumulation in food crop and aquatic life contaminated, hence human poisoning. Trace metals such as Fe, Cr, Hg etc. at excessive levels are detrimental to plant growth [63]. Plant height and biomass yield decreased in soils with elevated metal concentrations, as compared to the control [64]. The life cycle of soil macro-organisms is affected by Cd, Zn, and Pb, and Cu contamination and earthworm activity modified the availability of heavy metals in soils [65]. Bamgbose et al. [66] reported that earthworm activity can serve as a bioindicator in the trace metal polluted environments and the ratio of trace metal concentration in earthworms to that in the polluted soil was determined to be less than unity for Pb, Zn and Cu.

4 Conclusion

It is evident from the mathematical analysis, that the rates of emission of lead, zinc and iron, in trace quantities, in Nigeria from the sum of consumption of PMS into the environment are of great concern. With such high emission rates per capita and high land distribution of emissions, humans, terrestrial and aquatic plant and animal lives are exposed to, and at risks of Lead, Zinc and Iron poisoning. It is recommended that regulations be placed on the trace metal contents of fuels, imported or locally produced, for distribution in the country. These regulations will help to reduce the amount of trace metals emitted into the three components of the environment – air, water bodies and soil. It is also recommended that statutory limit for each of Lead, Zinc and Iron emission rate per capita and per land area be established and promulgated in Nigeria.

5 Author contribution statement

Francis B. Elehinafe: Conceived and designed the modelling process; Oluseye L. Lasebikan gathered the primary data from various data bases and Orirome O. Orupete wrote the paper, Hassan A. Adisa reviewed and edited the paper.

6 Competing interest statement

The authors declare no conflict of interest.

7 Data availability

The authors declare that the data can be made available at request.

References

[1] Akintunde, A. A., Salawu, A. A., Opadijo, O. G. "Prevalence of Traditional Cardiovascular Risk Factors among Staff of Ladoke Akintola University of Technology, Ogbomoso, Nigeria", Nigerian Journal of Clinical Practice, 17(6), pp. 750–755, 2014. https://doi.org/10.4103/1119-3077.144390

[2] Olukanni, D. O., Adeoye, D. O. "Heavy metal concentrations in road side soils from selected locations in the Lagos metropolis, Nigeria", International Journal of Engineering and Technology, 2(10), pp. 1743–1752, 2012.

[3] Elehinafe, F. B., Mamudu, A. O., Okedere, O. B., Ibitioye, A. "Risk assessment of chromium and cadmium emissions from the consumption of premium motor spirit (PMS) and automotive gas oil (AGO) in Nigeria", Heliyon, 6(11), e05301, 2020. https://doi.org/10.1016/j.heliyon.2020.e05301

[4] Talebzadeh, F., Valeo, C., Gupta, R. "Cadmium Water Pollution Associated with Motor Vehicle Brake Parts", IOP Conference Series: Earth and Environmental Science, 691, 012001, 2021. https://doi.org/10.1088/1755-1315/691/1/012001

[5] Odunlami, O. A., Elehinafe, F. B., Oladimeji, T. E., Fajobi, M. A., Akeredolu, F. A., Okedere, O. B., Fakinle, B. S. "Implications of lack of maintenance of vehicles on ambient air quality", International Journal of Mechanical Engineering and Technology, 9(9), pp. 647–654, 2018.

[6] Ajibade, F. O., Adelodun, B., Lasisi, K. H., Fadare, O. O., Ajibade, T. F., Nwogwu, N. A., Sulaymon, I. D., Ugya, A. Y., Wang, H. C., Wang, A. "Chapter 25 - Environmental pollution and their socioeconomic impacts", In: Microbe Mediated Remediation of Environmental Contaminants, Woodhead Publishing, 2021, pp. 321–354. ISBN 978-0-12-821199-1 https://doi.org/10.1016/B978-0-12-821199-1.00025-0

[7] Appannagari, R. R. "Environmental pollution causes and consequences: A study", North Asian International Research Journal of Social Science & Humanities, 3(8), pp. 151–161, 2017.

[8] Takano, H., Inoue, K. "Environmental pollution and allergies", Journal of Toxicologic Pathology, 30(3), pp. 193–199, 2017. https://doi.org/10.1293/tox.2017-0028

[9] Ali, M. U., Liu, G., Yousaf, B., Ullah, H., Abbas, Q., Munir, M. A. M. "A systematic review on global pollution status of particulate matter-associated potential toxic elements and health perspectives in urban environment", Environmental Geochemistry and Health, 41(3), pp. 1131–1162, 2019. https://doi.org/10.1007/s10653-018-0203-z

[10] Fakinle, B. S., Odekanle, E. L., Olalekan, A. P., Ije, H. E., Oke D. O., Sonibare, J. A. "Air pollutant emissions by anthropogenic combustion processes in Lagos, Nigeria", Cogent Engineering, 7(1), 1808285, 2020. https://doi.org/10.1080/23311916.2020.1808285

[11] Ukaogo, P. O., Ewuzie, U., Onwuka, C. V. "21 - Environmental pollution: causes, effects, and the remedies", In: Microorganisms for Sustainable Environment and Health, Elsevier, 2020, pp. 419–429. ISBN 978-0-12-819001-2 https://doi.org/10.1016/B978-0-12-819001-2.00021-8

[12] Saleh, M. Q., Hamad, Z. A., Hama, J. R. "Assessment of some heavy metals in crude oil workers from Kurdistan Region, northern Iraq", Environmental Monitoring and Assessment, 193(1), 49, 2021. https://doi.org/10.1007/s10661-020-08818-w

[13] Maijama, R., Musa, K. S. "Liquified petroleum gas as an alternative to transportation fuels in Nigeria", International Journal of Multidisciplinary Research and rowth Evaluation, 1(1), pp. 1–7, 2020.

[14] Okedere, O. B., Sonibare, J. A., Ajala, O. E., Adesina, O. A., Elehinafe, F. "Estimation of sulphur dioxide emission from consumption of premium motor spirit and automotive gas oil in Nigeria", Cogent Environmental Science, 3(1), 1330456, 2017. https://doi.org/10.1080/23311843.2017.1330456

[15] Okedere, O. B., Fakinle, B. S., Sonibare, J. A. "Consumption of Premium Motor Spirit and Automotive Gas Oil in Nigeria: Implication for a Greenhouse Gas Emission", Ife Journal of Science and Technology, 1(2), pp. 276–295, 2018.

[16] Idris, A. M., Mustapha, A., Abdulkadir, M., Ekhalia, B. J. "Alternative Source of Fuels Used in Automobile towards Zero Carbon Emission", In: Proceedings of the 31th Annual National Conference of Technology Education Practitioners Association of Nigeria (TEPAN) (Formally Nigerian Association of Teachers of Technology (NATT)), Kano, Kano State, Nigeria, 2018, pp. 222–227. ISBN 978-978-967-443-5

[17] Zhu, C., Tian, H., Hao, J. "Global anthropogenic atmospheric emission inventory of twelve typical hazardous trace elements, 1995–2012", Atmospheric Environment, 220, 117061, 2020. https://doi.org/10.1016/j.atmosenv.2019.117061

[18] Duruibe, J. O., Ogwuegbu, M. O. C, Egwurugwu, J. N. "Heavy metal pollution and human biotoxic effects", International Journal of Physical Sciences, 2(5), pp. 112–118, 2007.

[19] Dumat, C., Quenea, K., Bermond, A., Toinen, S., Benedetti, M. F. "Study of the trace metal ion influence on the turnover of soil organic matter in cultivated contaminated soils", Environmental Pollution, 142(3), pp. 521–529, 2006. https://doi.org/10.1016/j.envpol.2005.10.027

[20] Cui, H., Ma, K., Fan, Y., Peng, X., Mao, J., Zhou, D., Zhang, Z., Zhou, J. "Stability and heavy metal distribution of soil aggregates affected by application of apatite, lime, and charcoal", Environmental Science and Pollution Research, 23(11), pp. 10808–10817, 2016. https://doi.org/10.1007/s11356-016-6271-7

[21] Rosca, C., Schoenberg, R., Tomlinson, E. L., Kamber, B. S. "Combined zinc-lead isotope and trace-metal assessment of recent atmospheric pollution sources recorded in Irish peatlands", Science of The Total Environment, 658, pp. 234–249, 2019. https://doi.org/10.1016/j.scitotenv.2018.12.049

[22] Nwaedozie, G., Nyan, S. E. "Determination of heavy metals in soots from petroleum vehicles exhaust tailpipes", International Journal of Environment, Agriculture and Biotechnology, 3(6), pp. 2233–2243, 2018. https://doi.org/10.22161/ijeab/3.6.39

[23] Pulles, T., Denier van der Gon, H., Appelman, W., Verheul, M. "Emission factors for heavy metals from diesel and petrol used in European vehicles", Atmospheric Environment, 61, pp. 641–651, 2012. https://doi.org/10.1016/j.atmosenv.2012.07.022

[24] Cheng, K., Wang, Y., Tian, H., Gao, X., Zhang, Y., Wu, X., Zhu, C., Gao, J. "Atmospheric emission characteristics and control policies of five precedent-controlled toxic heavy metals from anthropogenic sources in China", Environmental Science & Technology, 49(2), pp. 1206–1214, 2015. https://doi.org/10.1021/es5037332

[25] Patel, C., Chandra, K., Hwang, J., Agarwal, R. A., Gupta, N., Bae, C., Gupta, T., Agarwal, A. K. "Comparative compression ignition engine performance, combustion, and emission characteristics, and trace metals in particulates from Waste cooking oil, Jatropha and Karanja oil derived biodiesels", Fuel, 236, pp. 1366–1376, 2019. https://doi.org/10.1016/j.fuel.2018.08.137

[26] Wang, J. M., Jeong, C.-H., Hilker, N., Healy, R. M., Sofowote, U., Debosz, J., Su, Y., Munoz, A., Evans, G. J. "Quantifying metal emissions from vehicular traffic using real world emission factors", Environmental Pollution, 268, 115805, 2021. https://doi.org/10.1016/j.envpol.2020.115805

[27] Akpoveta, O. V., Osakwe, S. A. "Determination of Heavy Metal Contents in Refined Peroleum Products", IOSR Journal of Applied Chemistry, 7(6), pp. 1–2, 2014. https://doi.org/10.9790/5736-07610102

[28] Ite, A. E., Ibok, U. J., Ite, M. U., Petters, S. W. "Petroleum exploration and production: Past and present environmental issues in the Nigeria's Niger Delta", American Journal of Environmental Protection, 1(4), pp. 78–90, 2013. https://doi.org/10.12691/env-1-4-2

[29] National Bureau of Statistics (NBS) "Annual Abstract of Statistics", Federal Republic of Nigeria, 2021. [online] Available at: www.nigerianstat.gov.ng [Accessed: 27 August 2023]

[30] Nigeria National Petroleum Corporation (NNPC) "Annual Statistical Bulletin", National Petroleum Corporation, Abuja, Nigeria, 2021. [online] Available at: https://nnpcgroup.com [Accessed: 27 August 2023]

[31] NPC "Report of Nigeria's National Population Commission on the 2006 Census", Population and Development Review, 33(1), pp. 206–210, 2007. [online] Available at: http://www.jstor.org/stable/25434601 [Accessed: 27 August 2023]

[32] National Bureau of Statistics (NBS) "Annual Abstract of Statistics", Federal Republic of Nigeria, pp. 3–4, 2010. [online] Available at: www.nigerianstat.gov.ng [Accessed: 22 August 2023]

[33] Obioh, I. B., Ezeh, G. C., Abiye, O. E., Alpha, A., Ojo, E. O., Ganiyu, A. K. "Atmospheric particulate matter in Nigerian megacities", Toxicological & Environmental Chemistry, 95(3), pp. 379–385, 2013. https://doi.org/10.1080/02772248.2013.790970

[34] WHO Study Group "Recommended health-based limits in occupational exposure to heavy metals", [pdf] World Health Organization, Geneva, Switzerland, Technical Report Series 647, 1980. ISBN 9241206470 Avaialable at: https://apps.who.int/iris/bitstream/handle/10665/41401/WHO_TRS_647.pdf;jsessionid=70B382623365E84AE8F8CB6E0DF53AE0?sequence=1 [Accessed: 27 August 2023]

[35] Collin, M. S., Venkatraman, S. K., Vijayakumar, N., Kanimozhi, V., Arbaaz, S. M., Stacey, R. G. S., Anusha, J., Choudhary, R., Lvov, V., Tovar, G. I., Senatov, F., Koppala, S., Swamiappan, S. "Bioaccumulation of lead (Pb) and its effects on human: A review", Journal of Hazardous Materials Advances, 7, 100094, 2022. https://doi.org/10.1016/j.hazadv.2022.100094

[36] Shilpa, O., Anupama, K. P., Antony, A., Gurushankara, H. P. "Lead (Pb) induced Oxidative Stress as a Mechanism to Cause Neurotoxicity in *Drosophila melanogaster*", Toxicology, 462, 152959, 2021. https://doi.org/10.1016/j.tox.2021.152959

[37] Tiwari, S., Tripathi, I. P., Tiwari, H. I. "Effects of lead on Environment", International Journal of Emerging Research in Management & Technology, 2(6), pp. 1–5, 2013. [online] Available at: https://www.academia.edu/33089601/Effects_of_Lead_on_Environment [Accessed: 27 August 2023]

[38] Sandstead, H. H. "Chapter 61 - Zinc", In: Nordberg, G. F., Fowler, B. A., Nordberg, M. (eds.) Handbook on the Toxicology of Metals, 2, Academic Press, 2015, pp. 1369–1385. ISBN 978-0-444-59453-2 https://doi.org/10.1016/B978-0-444-59453-2.00061-5

[39] Wang, Z., Wen, Y., Gou, W., Ji, J., Li, W. "Zn isotope signatures in soil Fe-Mn nodules with karst high geochemical background", Science of The Total Environment, 882, 163365, 2023. https://doi.org/10.1016/j.scitotenv.2023.163365

[40] Fine, J. M., Gordon, T., Chen, L. C., Kinney, P., Falcone, G., Beckett, W. S. "Metal fume fever: characterization of clinical and plasma IL-6 responses in controlled human exposures to zinc oxide fume at and below the threshold limit value", Journal of Occupational & Environmental Medicine, 39(8), pp. 722–726, 1997.
https://doi.org/10.1097/00043764-199708000-00006

[41] Mitra, S., Chakraborty, A. J., Tareq, A. M., Emran, T. B., Nainu, F., Khusro, A., Idris, A. M., Khandaker, M. U., Osman, H., Alhumaydhi, F. A., Simal-Gandara, J. "Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity", Journal of King Saud University - Science, 34(3), 101865, 2022.
https://doi.org/10.1016/j.jksus.2022.101865

[42] Azeh Engwa, G., Udoka Ferdinand, P., Nweke Nwalo, F., Unachukwu, M. N. "Mechanism and Health Effects of Heavy Metal Toxicity in Humans", In: Karcioglu, O., Arslan, B. (eds.) Poisoning in the Modern World – New Tricks for an Old Dog?, IntechOpen, 2019. ISBN 978-1-83880-785-6
https://doi.org/10.5772/intechopen.82511

[43] Gilani, S. R., Zaidi, S. R. A., Batool, M., Bhatti, A. A., Durrani, A. I., Mahmood, Z. "Report: Central nervous system (CNS) toxicity caused by metal poisoning: Brain as a target organ", Pakistan Journal of Pharmaceutical Sciences, 28(4), pp. 1417–1423, 2015. [online] Available at: https://pubmed.ncbi.nlm.nih.gov/26142507/ [Accessed: 27 August 2023]

[44] Karri, S. K., Saper, R. B., Kales, S. N. "Lead encephalopathy due to traditional medicines", Current Drug Safety, 3(1), pp. 54–59, 2008.
https://doi.org/10.2174/157488608783333907

[45] Adedayo, O. O., Abidemi, O. M., Leke, O. E., Ademola, S. J., Ayodele, I. O., Oyeleke, O. B., Ayodele, O. S. "Gaseous Emission from the Combustion of Premium Motor Spirit (PMS) from the Kaduna Refinery and Petrochemical Company (KRPC) in Nigeria", Journal of Korean Society of Environmental Engineers, 43(5), pp. 319–324, 2021.
https://doi.org/10.4491/KSEE.2021.43.5.319

[46] National Institutes of Health "Zinc: Fact Sheet for Consumers", National Institutes of Health, 08 December 2021. [online] Available at: https://ods.od.nih.gov/factsheets/Zinc-Consumer/ [Accessed: 04 September 2022]

[47] Nazir, R., Khan, M., Masab, M., Rehman, H. U., Rauf, N. U., Shahab, S., …, Shaheen, Z. "Accumulation of heavy metals (Ni, Cu, Cd, Cr, Pb, Zn, Fe) in the soil, water and plants and analysis of physico-chemical parameters of soil and water collected from Tanda Dam kohat", [pdf] Journal of Pharmaceutical Sciences and Research, 7(3), pp. 89–97, 2015. Available at: https://www.jpsr.pharmainfo.in/Documents/Volumes/vol7issue03/jpsr07031501.pdf [Accessed: 27 Auguss t 2023]

[48] Singh, J., Kalamdhad, A. S. "Effects of heavy metals on soil, plants, human health and aquatic life", International Journal of Research in Chemistry and Environment, 1(2), pp. 15–21, 2011. [online] Available at: https://www.researchgate.net/publication/265849316_Effects_of_Heavy_Metals_on_Soil_Plants_Human_Health_and_Aquatic_Life [Accessed: 27 August 2023]

[49] Andersson, L., Bryngelsson, I.-L., Hedbrant, A., Persson, A., Johansson, A., Ericsson, A., Lindell, I., Stockfelt, L., Särndahl, E., Westberg, H. "Respiratory health and inflammatory markers - Exposure to respirable dust and quartz and chemical binders in Swedish iron foundries", PLoS ONE, 14(11), e0224668, 2019.
https://doi.org/10.1371/journal.pone.0224668

[50] Griffin, R. M. "Dietary Iron and Iron Supplements", Nourish by WebMD, 06 November 2021. [online] Available at: https://www.webmd.com/diet/supplement-guide-iron#:~:text=At%20high%20doses%2C%20iron%20is,than%2040%20mg%20a%20day [Accessed: 27 August 2023]

[51] U.S. Environmental Protection Agency "Lead in Soil", [pdf] U.S. Environmental Protection Agency, Region III, USA, 2020. Available at: https://www.epa.gov/sites/default/files/2020-10/documents/lead-in-soil-aug2020.pdf [Accessed: 27 August 2023]

[52] Caravanos, J., Clark, E., Fuller, R., Lambertson, C. "Assessing worker and environmental chemical exposure risks at an e-waste recycling and disposal site in Accra, Ghana", Journal of Health and Pollution, 1(1), pp. 16–25, 2011.
https://doi.org/10.5696/jhp.v1i1.22

[53] Ashraf, U., Kanu, A. S., Mo, Z., Hussain, S., Anjum, S. A., Khan, I., Abbas, R. N., Tang, X. "Lead toxicity in rice: effects, mechanisms, and mitigation strategies—a mini review", Environmental Science and Pollution Research, 22(23), pp. 18318–18332, 2015.
https://doi.org/10.1007/s11356-015-5463-x

[54] Jamla, M., Khare, T., Joshi, S., Patil, S., Penna, S., Kumar, V. "Omics approaches for understanding heavy metal responses and tolerance in plants", Current Plant Biology, 27, 100213, 2021.
https://doi.org/10.1016/j.cpb.2021.100213

[55] Ackova, D. G. "Heavy metals and their general toxicity on plants", Plant Science Today, 5(1), pp. 14–18, 2018.
https://doi.org/10.14719/pst.2018.5.1.355

[56] Park, J. H., Bolan, N., Megharaj, M., Naidu, R. "Comparative value of phosphate sources on the immobilization of lead, and leaching of lead and phosphorus in lead contaminated soils", Science of the Total Environment, 409(4), pp. 853–860, 2011.
https://doi.org/10.1016/j.scitotenv.2010.11.003

[57] Ul-Haq, N., Arain, M. A., Badar, N., Rasheed, M., Haque, Z. "Drinking water: a major source of lead exposure in Karachi, Pakistan", Eastern Mediterranean Health Journal, 17(11), pp. 882–886, 2011.
https://doi.org/10.26719/2011.17.11.882

[58] Dohare, D., Deshpande, S., Kotiya, A. "Analysis of ground water quality parameters: A Review", [pdf] Research Journal of Engineering Sciences, 3(5), pp. 26–31, 2014. Available at: http://www.isca.in/IJES/Archive/v3/i5/3.ISCA-RJEngS-2014-24.pdf [Accessed: 27 August 2023]

[59] Chaney, R. L. "Zinc phytotoxicity", In: Robson, A. D. (ed.) Zinc in Soils and Plants, Springer, 1993, pp. 135–150. ISBN 978-94-010-4380-9
https://doi.org/10.1007/978-94-011-0878-2_10

[60] Kelly, J. J., Häggblom, M. M., Tate, R. L. "Effects of heavy metal contamination and remediation on soil microbial communities in the vicinity of a zinc smelter as indicated by analysis of microbial community phospholipid fatty acid profiles", Biology and Fertility of Soils, 38(2), pp. 65–71, 2003.
https://doi.org/10.1007/s00374-003-0642-1

[61] Guarino, F., Improta, G., Triassi, M., Cicatelli, A., Castiglione, S. "Effects of zinc pollution and compost amendment on the root microbiome of a metal tolerant poplar clone", Frontiers in Microbiology, 11, 1677, 2020.
https://doi.org/10.3389/fmicb.2020.01677

[62] Tang, Q., Xia, L., Ti, C., Zhou, W., Fountain, L., Shan, J., Yan, X. "Oxytetracycline, copper, and zinc effects on nitrification processes and microbial activity in two soil types", Food and Energy Security, 9(4), e248, 2020.
https://doi.org/10.1002/fes3.248

[63] Ghani, A. "Toxic effects of heavy metals on plant growth and metal accumulation in maize (*Zea mays* L.)", Iranian Journal of Toxicology, 3(3), pp. 325–334, 2010.

[64] Moustakas, M., Lanaras, T., Symeonidis, L., Karataglis, S. "Growth and some Photosynthetic characteristics of field grown *Avena sativa* under copper and lead stress", Photosynthetica, 30(3), pp. 389–396, 1994.

[65] Lemtiri, A. "Effects of agricultural practices and heavy metal contamination on the community dynamics of earthworms in relation to soil physical and chemical factors in agricultural fields (Belgium)", PhD Thesis, Université de Liège, Gembloux, Belgium, 2015.

[66] Bamgbose, O., Odukoya, O., Arowolo, T. O. A. "Earthworms as bio-indicators of metal pollution in dump sites of Abeokuta City, Nigeria", Revista de Biología Tropical, 48(1), pp. 229–234, 2000.
https://doi.org/10.15517/rbt.v48i1.18702