



Research article

Risk assessment of chromium and cadmium emissions from the consumption of premium motor spirit (PMS) and automotive gas oil (AGO) in Nigeria

F.B. Elehinafe^{a,*}, A.O. Mamudu^a, O.B. Okedere^b, A. Ibitioye^a^a Department of Chemical Engineering, College of Engineering, Covenant University, Ogun State, Ota, Nigeria^b Department of Chemical Engineering, Faculty of Engineering and Environmental Sciences, Osun State University, Osogbo, Nigeria

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ABSTRACT

This paper assessed the chromium and cadmium emissions from consumption of premium motor spirit (PMS) and automotive gas oil (AGO) across the states, regions and the nation, Nigeria as a whole. This was with a view to determining the levels of per capita and land exposures to the emissions and the associated risks to humans, plants and animals. Annual fuel consumption and toxic transition metals contents were combined to estimate the annual emission rates of chromium and cadmium emissions from combustion of the PMS and AGO for a period of ten years (2009–2018). Per capita and land distributions of emissions were then calculated by using population and land areas, respectively. The results showed that total emission rates from both PMS and AGO were lowest in 2012, with 1,102 million mg/yr of chromium and 3,253 million mg/yr of cadmium, and highest in 2018, with 14,454 million mg/yr of chromium and 39,580 million mg/yr of cadmium. Emission rates per capita were also lowest in 2012, with 7 mg/yr.person of chromium and 20 mg/yr.person of cadmium, and highest in 2018 with 74 mg/yr.person of chromium and 201 mg/yr.person of cadmium. Land distribution was lowest in 2012, with 1.19 mg/yr.km² of chromium and 3.52 mg/yr.km² of cadmium, and highest in 2018, with 15.63 mg/yr.km² of chromium and 42.81 mg/yr.km² of cadmium. Comparing to regulatory limits, the risks of humans, animals and plants be poisoned are very high. It is recommended that stiff regulations concerning the heavy metal contents of fuels imported and distributed in Nigeria should be created and implemented to mitigate the risks of poisoning to humans, animals and crops.

1. Introduction

The environment and its compartments have been severely polluted by transition metals. This has compromised the ability of the environment to foster life and render its intrinsic values. Heavy metals are known to be naturally occurring compounds, but anthropogenic activities, especially combustion of fossil fuels, introduce them in large quantities in different environmental compartments (Prüss-Üstün, 2016; Odunlami et al., 2018; Olukanni. and Adeoye, 2012). Transition metals can have deleterious, toxic and carcinogenic to humans when ingestion or inhaled in higher concentrations (Panne et al., 2001). More than 20 different transition metals toxins have negative impacts on human health and each toxin will produce different behavioural, physiological and cognitive changes in exposed individuals (Extreme health USA, 2005). The degree to which a system, an organ, a tissue or a cell is affected by a transition

metal toxin depends on the toxin itself and the individuals' degree of exposure to the toxin (Soleimani et al., 2018). Combustion of fuels contaminated with metals has been found to contribute toxic transition metals to the environment – air, water bodies and soil (Wong, 2013). Riley et al. (1992) and NJDEP (1996) have reported soil concentration ranges and regulatory guidelines for some toxic transition metals (Table 1). In Nigeria, in the interim period, whilst suitable parameters are being developed, the Department of Petroleum Resources recommended, in 2002, guidelines on remediation of contaminated land based on two parameters intervention values and target values (Table 2). Table 3 presents the WHO (2004) safe limits as regards the minimum and maximum limits for drinking water.

The largest sources of airborne cadmium (Cd) in the environment are the burning of fossil fuels such as coal or oil, and incineration of municipal waste materials. Cadmium may also be emitted into the air

* Corresponding author.

E-mail address: francis.elehinafe@covenantuniversity.edu.ng (F.B. Elehinafe).

from zinc, lead, or copper smelters (U.S. Department of Labor, 2004). Cadmium emitted into the environment pollutes water bodies and land and is eventually ingested by plants and animals which are then ingested by human beings (WHO, 2010; Molognoni et al., 2017). Humans are commonly exposed to cadmium by inhalation and ingestion. Cadmium enters in air from both natural and anthropogenic sources and bind to small particles where it can combine with water or soil causing contamination, in nano-form, of fish, plants and animals (Honey et al., 2015). Spills at hazardous waste sites and improper waste disposal can cause cadmium leakages in nearby habitats. Foodstuffs like liver, mushrooms, shellfish, mussel, cocoa powder and dried seaweed are cadmium rich increasing the concentration in human bodies (Honey et al., 2015). While it is necessary in small amounts for biological processes in human beings, larger amounts of the substance are toxic and can have devastating effects ranging from stomach irritation to kidney failure (Akhilesh et al., 2009). The Joint FAO/WHO has recommended the provisional tolerable daily intake (PTDI) as 0.007 mg/kg body weight for cadmium (JEFCA, 2004). The EPA maximum contaminant level for cadmium in drinking water is 0.005 mg/L whereas the WHO adopted the provisional guideline of 0.003 mg/L (WHO, 2004).

Chromium (Cr) is one of the major industrial wastes produced from many industries like textiles, tanneries, electroplating, metallurgical which causes health issues in humans and animals and also affects marine life (Ajmal et al., 1996; Moncur et al., 2005; Molognoni et al., 2016). Combustion of fossil fuels also release a certain amount of Cr into the environment (Wong, 2013). Cr exists as Cr(VI) and Cr(III) and Cr(III) get easily oxidized to Cr(VI) in air (Kirti et al., 2015). The oral intake of Cr for infants of 1 yr is 33–45 µg/day, for children of 11 yr is 123–171 µg/day and for adults it is 246–343 µg/day (Rowbotham et al., 2000). The maximum amount of Cr(VI) which gets inhaled by air is 0.02 µg/m³ (Kirti et al., 2015). It has been studied that Cr (III) has an essential role in protein and lipid metabolism but there is one study which has reported that Cr(III) cause oral toxicity in humans (Kusiak et al., 1993). Chromium deficiency has been described in both humans and animals, but a clear quantitative definition of the daily requirement of chromium in human nutrition has not been arrived at (MERTZ, 1967). WHO (1996) estimates that the daily minimum population mean intake likely to meet normal requirements for chromium might be approximately 33 µg/person. Ulcerations or perforations of the nasal septum were reported in two-thirds of subjects following inhalation exposure to chromium (VI) (as chromic acid) resulting from exposure at peak concentrations of more than 20 µg/m³ (Lindberg and Hedenstierna, 1983).

Various studies have been conducted, in the past, on the transition metal levels in PMS and AGO consumed in Nigeria. The heavy metal contents of various fossil-fuel samples were measured by Akpoveta and Osakwe in 2014. In the research petroleum products, were sampled in Delta State, Nigeria and analysed using an Atomic Absorption Spectrophotometer. The trace metals which were analysed include Cadmium, Chromium, Copper, Lead and Zinc. Jimoda et al. (2014) analysed gasoline and diesel samples from South Western Nigeria using Atomic Absorption Spectrometer for their Lead (Pb) levels. The Pb levels were then used to calculate the percentage Pb contributions from the consumption of gasoline and diesel. It was found that the Pb contributions from consumption were low due to various established fuel-level regulations. The

Table 1. Soil concentration ranges and regulatory guidelines for some heavy metals.

Metal	Soil concentration range (mg/kg)	Regulatory limits (mg/kg)
Pb	1.00–69000	600
Cd	0.10–345	100
Cr	0.05–3950	100
Hg	0.01–1800	270
Zn	150–5000	1500

Source: Riley et al. (1992) and NJDEP, 1996.

Table 2. Target and intervention values for some metals for a standard soil.

Metal	Target value ((mg/kg)	Intervention value (mg/kg)
Ni	140.00	720.00
Cu	0.3	10.00
Zn	-	-
Cd	100.00	380.00
Pb	35.00	210.00
As	200	625
Cr	20	240
Hg	85	530

Source: Department of Petroleum Resources (2002).

annual levels of sulphur dioxide from the consumption of gasoline and diesel in Nigeria were estimated by Okedere et al. (2017). The work also assessed the risks associated with the per capita and land distributions of emissions. It was found that Lagos and Ogun States had the highest sulphur dioxide emissions. This paper sought to estimate the chromium and cadmium emissions associated with the consumption of PMS and AGO in Nigeria in relation to population and land areas in the regions and states of Nigeria from 2009 to 2018.

2. Methodology

2.1. Study area

The area under consideration in this project is the entire nation of Nigeria (Figure 1). Nigeria is a country in West Africa. The Federal Republic of Nigeria, with an area of 923,769 square kilometers (made up of 909,890 square kilometres of land area and 13,879 square kilometres of water area), is situated between 3° and 14° East Longitude and 4° and 14° North Latitude. The longest distance from East to West is about 767 km, and from North to South 1,605 km. The country is bordered on the west by the Republics of Benin and Niger; on the east by the Republic of Cameroon; on the north by Niger and Chad Republics and on the south by the Gulf of Guinea. There are six geo-political zones in the country: The North-West (NW), North-Central (NC), North-East (NE), South-West (SW), South-East (SE) and the South-South (SS). Its capital territory is Abuja and it has 36 states: 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.

2.2. Sourcing for data

The annual consumption data for PMS and AGO for the years 2009–2014 were obtained from the Nigerian National Petroleum Corporation's (NNPC) annual statistical bulletins. For the years 2015–2018, consumption data was obtained from the National Bureau of Statistics

Table 3. WHO safe limits with minimum and maximum acceptable limits for drinking water.

Metal	Maximum limit (mg/L)	Minimum limit (mg/L)
Pb	0.05	-
Cu	1.5	0.05
Cr	0.05	-
Hg	0.001	-
Fe	0.3	0.1
Mn	0.5	0.005
Se	0.01	-
As	0.05	-

Source: Akhilesh et al. (2009)..

(NBS), Petroleum Products Consumption Statistics in Nigeria and Petroleum Products Import and Consumption (Truck In) Statistics reports. Tables 5 and 6 show the annual consumption data. The population data used in this project were extrapolated from the 2006 Census data (NPC, 2016) and are shown in Table 7. Areas of states in Nigeria were extracted from National Bureau of Statistics (2010) as shown in Table 8. So far, there are few studies 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 (2014) and is shown in Table 4.

2.3. Extrapolation of population data

The 2006 census data were extrapolated to the years (2009–2018) under consideration in this paper using the equation extracted from Anozie et al. (2007):

$$P = P_0 \times e^{rt} \tag{1}$$

Where.

- P = Population after time t,
- P₀ = Initial Population,
- e = Euler's number,
- r = annual growth rate,
- t = time in years.

Euler's number, used in this project, is 2.71828. The annual growth rate of Nigeria is 2.83% (Anozie et al., 2007).

2.4. Determination of annual emission rates

The annual rates were calculated from the consumption data (Tables 5 and 6) and transition metal content of fuel data (Table 4) using Eq. (2) obtained from Jimoda et al. (2014).

$$\text{Trace Metal content of Fuel} \left(\frac{mg}{L} \right) = \frac{\text{Annual Emission rate (mg/yr)}}{\text{Annual Fuel Consumption (L/yr)}} \tag{2}$$

2.5. Computation of the emission rates per capita

The emission rates per capita were computed using Eq. (3).

$$\text{Emission rate per capita} (mg / yr.person) = \frac{\text{Emission rate} (mg/yr)}{\text{Population (people)}} \tag{3}$$

The emission rates per capita can be seen as the amount of transition metals generated per person or, alternatively, the amount of heavy metal emissions a person was exposed to over the years considered.

2.6. Calculation of land distribution of the emissions

The emission rates per land areas (land distribution) were calculated using the following formula:

$$\text{Emission rate per land area} \left(\frac{mg}{yr.km^2} \right) = \frac{\text{Annual emission rate} \left(\frac{mg}{yr} \right)}{\text{Land area} (km^2)} \tag{4}$$

The land distribution of emissions can be seen as the amount of trace metals that every square kilometre of land is exposed to.

3. Results and discussion

3.1. Annual emission rates

The total chromium emission rates from both PMS and AGO for the years 2009–2018 were computed for each state, region and the nation and are summarized in Table 9. It can be seen, in Figure 2, that the overall emission rates dropped in most states and regions from 2009 to 2012. However, it increased greatly from 2012 to 2013 and kept rising till 2018 unabated following the consumption of PMS and AGO (Tables 4 and 5). This shows that the regulatory bodies in Nigeria are not proactive enough. It can be seen from Table 9 that the states with the highest overall emission rate were Abuja (FCT) 123 million mg/yr in 2012 and Lagos State at 3, 095 million mg/yr in 2015 due to high commercial and government administrative activities. The state with the lowest emission rates were Ebonyi State at 8 million mg/yr in 2012 and Yobe State at 29 million mg/yr in 2018. The regions with the highest rates of emission were NC with 275 million mg/yr in 2012 and SW with 5, 310 million mg/yr in 2016. The region with the lowest emission rates was SE with 87 million mg/yr in 2012 within the period in focus. At national level, Cr emission rates ranged between 1102 million mg/yr in 2012 to 14,454 million mg/yr in 2018. The threats of toxicity posed by this Cr emission rates would be the functions of the per capita and land distribution would depend on the population and surface areas of the nation, Nigeria and its federating units.



Figure 1. Map of Nigeria showing the geopolitical zones (Ekong et al., 2012).

Table 4. Average trace metal content of Premium Motor Spirit and Automotive Gas Oil consumed in Nigeria.

Petroleum Product	Chromium Content (mg/L)	Cadmium Content (mg/L)
Premium Motor Spirit	0.54	1.68
Automotive Gas Oil	0.86	1.50

Source: Akpoveta and Osakwe (2014).

The sum of cadmium emission rates from the consumption of PMS and AGO for the years 2009–2018 were calculated for each state, each region and the nation at large and are summarized below in Table 10. From Figure 3, it can be seen that the emission rates, again, dropped in most states and regions, and in the country overall, from 2009 to 2012. Then increased greatly from 2012 to 2013 and kept rising till 2018 the latest year under consideration. It is seen from Table 10 that the federating unit with the highest overall emission rates ranged between 372 million mg/yr in 2012 for Abuja (FCT) and 7, 917 million mg/yr in 2015 for Lagos State. The states with the lowest emission rates was Ebonyi and ranged between 22 million mg/yr in 2012 and 200 million mg/yr in 2018. The regions with the highest emission rates of Cd emission were NC and SW ranging from 816 million mg/yr in 2012 for NC to 13,674 million mg/yr in 2016 for SW, while SE had the least rate of the emission at 253 million mg/yr in 2012. The risks posed by this Cd emission rates would be the functions of the per capita and land distribution would depend on the population and surface areas at state, regional and national levels.

3.2. Emission rate per capita

Table 11.1 to 11.4 showed the extrapolated population of Nigeria for the years being considered in this research. Table 12 represent the estimated chromium emission rates per capita. Figure 4 showed that the same trends as seen in the previous figures with values dropping from 2009 to 2012 and then rise to spike in 2013 and continued to rise till 2018, the latest year, under consideration unchecked. The table showed that Abuja had the highest emission rate per capita ranging from 74 million mg/yr.person in 2012 to 494 million mg/yr.person in 2014 (due to its small population and high consumption of PMS and AGO as a result of commercial and administrative activities) and therefore, the populates in Abuja (FCT) are at the highest risk of chromium poisoning in Nigeria. Jigawa State had the least emission rate per capita at 3 million mg/yr.person in 2012. So, the populates in Jigawa State are least exposed to Cr emission. On regional basis, emission rate per capita ranged from 4 million mg/yr.person for NE in 2012 to 127 million mg/yr.person for SW in 2018. On a national basis, emission rates per capita ranged from 7 million mg/yr.person in 2012 to 73 million mg/yr.person in 2017. These results showed that populates are at the risk of Cr poisoning for WHO maximum safe limit for Cr which is 0.05 ppm (Akhilesh et al., 2009) for drinking water was likely to be breached at state, regional and national levels. Also, the amount of Cr inhalable through air by humans was likely to exceed the maximum limit of 0.02 µg/m³ as reported by Kirti et al. (2015). Exposure to peak concentrations of more than 20 µg/m³ leads to ulcerations or perforations of the nasal septum (Lindberg & Hedenstierna, 1983).

Table 13 represents the estimated cadmium emission rates per capita on state, regional and national bases. Figure 5 shows the trend of the

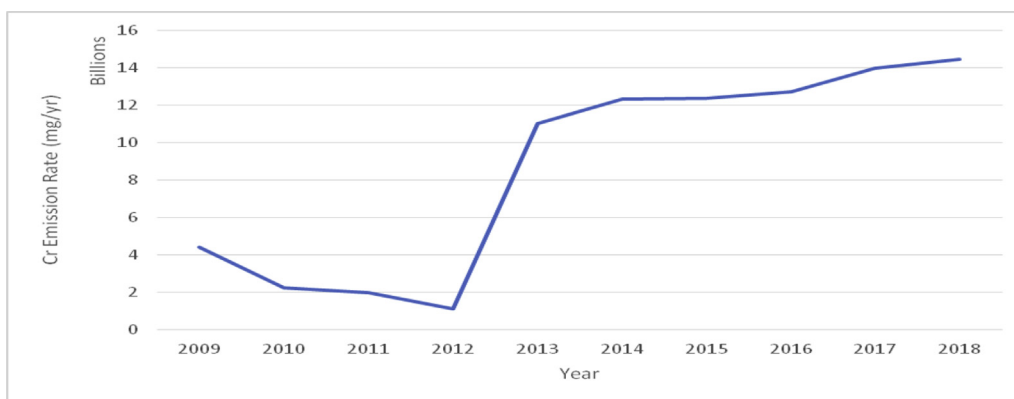


Figure 2. National chromium emission rates 2009–2018 (mg/yr).

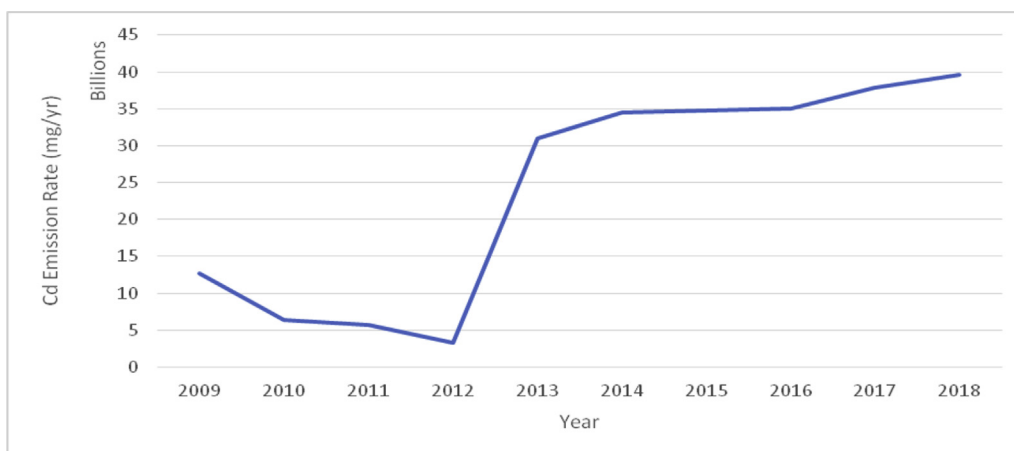


Figure 3. National cadmium emission rates 2009–2018 (mg/yr).

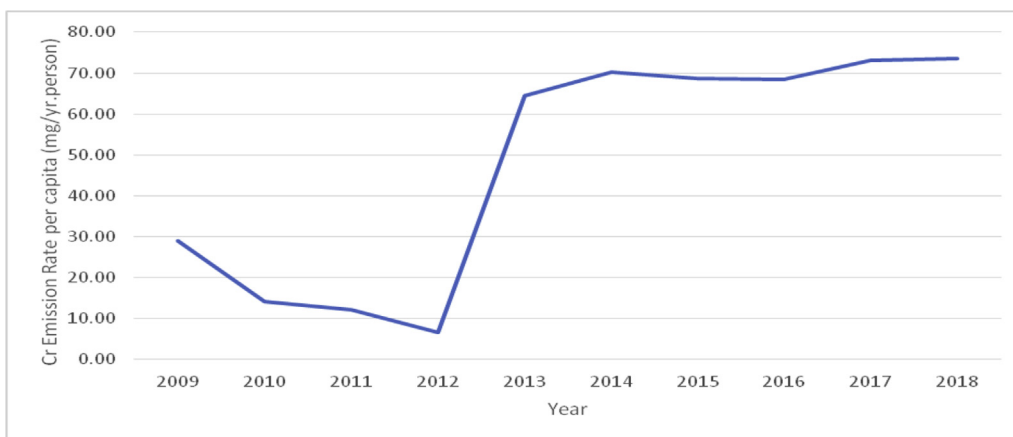


Figure 4. Total chromium emission rates per capita 2009–2018 (mg/yr.person).

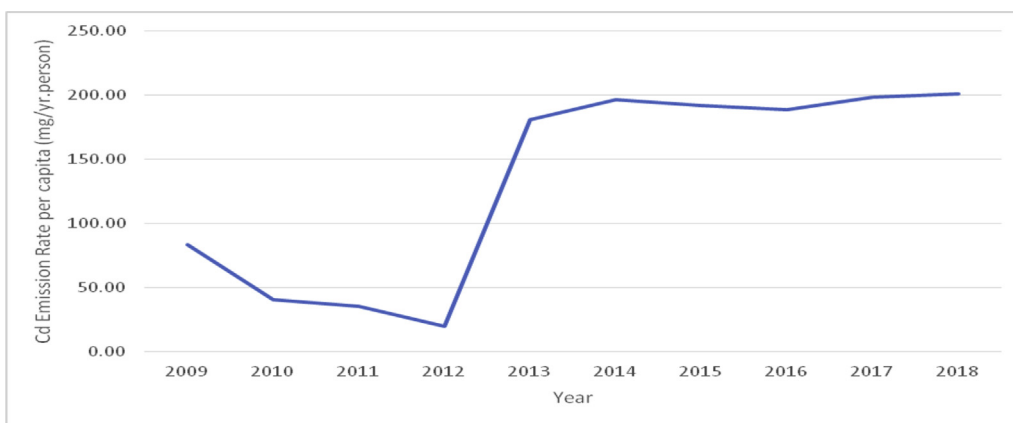


Figure 5. Total cadmium emission rates per capita 2009–2018 (mg/yr.person).

emission rates within the period under consideration with values dropping from 2009 to 2012 and the spiking in 2013 and continued to rise till 2018. The table show that Abuja had the highest emission rate per capita ranging from 224 mg/yr.person in 2012 to 1,504 mg/yr.person in 2014 making the dwellers to be at highest risk of Chromium poisoning in Nigeria for high consumption of the petroleum products (PMS and AGO) by few dwellers. Jigawa State had the least emission rate per capita ranging at 7 mg/yr.person in 2012 making Jigawans to be at least risk due to low consumption of the fuels. On regional basis, Cd emission rate per capita ranged from 13 mg/yr.person for SE in 2012 to 335 mg/yr.person for SW in 2018. Nationally, Cd emission rate per capita ranged from 20 mg/yr.person in 2012 to 201 mg/yr.person in 2018. Comparing

to standards and permissible limits, there is likelihood of having intake (by inhalation) of Cd above: the provisional tolerable daily intake (PTDI) of 0.007 mg/kg body weight reported by JEFCA (2004); the EPA maximum contaminant level for cadmium in drinking water of 0.005 mg/L; and WHO provisional guideline of 0.003 mg/L (WHO, 2004) for drinking water.

3.3. Land distribution

Table 14 summarized the Cr emission land distribution at state, regional and national levels. Figure 6 shows the trend of the distribution. At state level, the land distribution of Cr emission for Lagos State is vastly

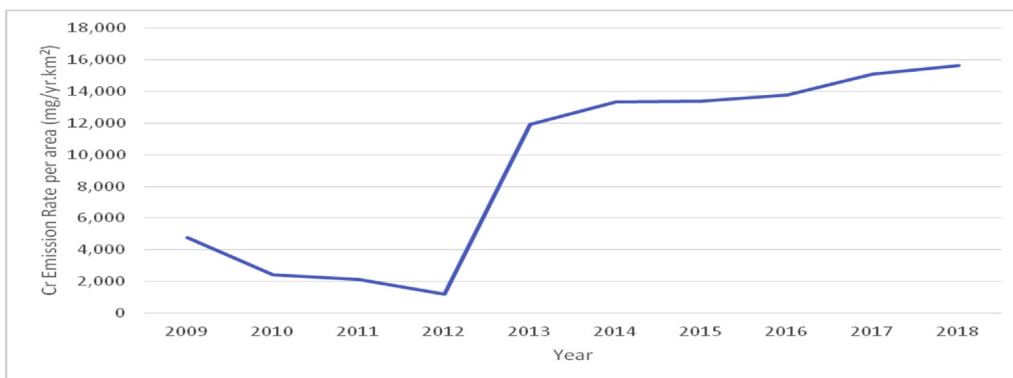


Figure 6. Total Chromium land distribution 2009–2018 (mg/yr.km²).

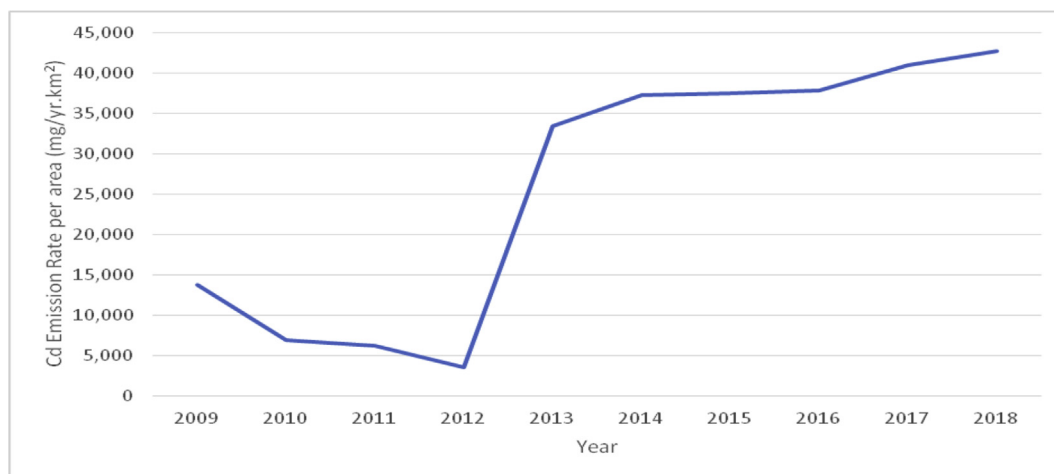


Figure 7. Total Cadmium land distribution 2009–2018 (mg/yr.km²).

greater than any other state, ranging from 20.40 mg/yr.km² in 2012 to 925.27 mg/yr.km² in 2015 due to its high consumption of PMS and AGO yearly. Taraba State had the lowest land distribution of 0.23 mg/yr.km² of Cr in 2010. The Southwest, going by the regions, had the highest land distribution of 2.3 mg/yr.km² and 66.65 mg/yr.km² of chromium in 2012 and 2016 respectively while NE had the least of Cr land distribution of 0.47 mg/yr.km² and 3.23 mg/yr.km² in 2012 and 2018 respectively. In country, Cr emission land distribution ranged from 1.19 mg/yr.km² in 2012 to 15.63 mg/yr.km² in 2018. The accumulation of these emissions over the years would lead to increased Cr concentrations in the soils in states and regions in Nigeria beyond the permissible limits. With continuous consumption and accumulation of Cr adulterated PMS and AGO, the risk of getting the Cr soil concentration above the regulatory limit of 100 mg/kg (Riley et al., 1992; NJDEP, 1996) is unavoidable and also corroborated in Tables 1, 2, and 3.

Table 15 summarized the Cd emission land distribution at state, regional and national levels. Figure 7 shows the cadmium land distribution trend within the period of years being considered in this work. At state level, the land distribution of Cd emission for Lagos State significantly exceed those of other states and ranged from 61.40 mg/yr.km² in 2012–2366.81 mg/yr.km² in 2015 due to its high consumption of PMS and AGO on yearly basis. After Lagos State are Abuja (FCT) and Rivers State. Taraba State had the lowest land distribution of 0.67 mg/yr.km² of Cr in 2010 and of 5.97 mg/yr.km² in 2014. The South West, going by the regions, had the highest land distribution of 6.81 mg/yr.km² and 171.64 mg/yr.km² of cadmium in 2012 and 2016 respectively while NE had the least of Cd land distribution of 1.36 mg/yr.km² and 11.51 mg/yr.km² in 2012 and 2014 respectively. In the country, Cd emission land distribution ranged from 3.52 mg/yr.km² in 2012 to 42.81 mg/yr.km² in 2018. The accumulation of these emissions over the years would lead to increase in cadmium concentrations in the water bodies and soils in states and regions in the nation beyond the permissible limits. With continuous consumption of adulterated PMS and AGO with Cd, the risk of getting the cadmium soil concentrations above the WHO 2008 maximum limit of 0.35 mg/kg is high and those of water bodies above the WHO permissible limit of 0.003 mg/l WHO (2008).

4. Conclusion

The emission rates of chromium and cadmium in Nigeria from the sum of consumption of PMS and AGO are clearly a health risk that should be looked into. With such high emission rates per capita in many states and such high land distribution of emissions, humans, animals and plant lives are at risk of chromium and cadmium poisoning. At most risk is Lagos and Abuja (FCT) because of their high emission rates per capita and

land distribution followed by states like Rivers State, Ogun State and Osun State. At lowest risk is Jigawa State in terms of emission rates per capita and Taraba State in terms of land distribution of the emissions. It is recommended that regulations be placed on the transition metal contents of fuels imported for distribution in the country. These regulations will help to reduce the amount of heavy metals emitted. It is also recommended that regulations which limit the chromium and cadmium emission rate per capita and per land area that are harmful to the populates and environment be established in Nigeria.

Declarations

Author contribution statement

Francis Boluwaji Elehinafe: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data.

Angela Mamudu: Analyzed and interpreted the data.

Tunji Okedere: Performed the experiments; Contributed reagents, materials, analysis tools or data.

Ayanfeoluwa Ibitoye: Analyzed and interpreted the data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

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