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Original Research Article

Soil Potentially Toxic Elements Contamination in different Rural - Urban Fringe Land Uses in Edo State, Nigeria

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ABSTRACT
The study investigated soil potentially toxic elements contamination in different rural - urban fringe land uses in Edo State, Nigeria. The objectives were to determine the level of PTEs in the soils, their contamination status and implications. Nine soil samples were collected from mechanic workshop, secondary forest, block molding site, oil palm production site, fire wood processing site, cassava farm, back yard farm, cooking gas plant site and oil palm plantation respectively at 0-15cm soil depth. Each soil sample was analyzed for lead, chromium, cobalt, arsenic, cadmium, vanadium and nickel using USEPA method 3050B. Data obtained was analyzed using index of geoaccumulation, contamination factor and single element pollution indices. The results revealed that the status of Lead (Pb), Chromium (Cr), Cobalt (Co), Arsenic (As), Cadmium (Cd), Vanadium (V) and Nickel (Ni) in the soils were low. Backyard farm had higher Co, As, V and Ni levels compared to the other examined land uses. Contamination factor showed very slight contamination (< 0.1) while Single Element Pollution Indices indicated low contamination (> 1). Index of Geoaccumulation demonstrated that the soils' were unpolluted (0 < Igeo ≤ 1). The findings also indicated that backyard farm had higher levels of PTEs (Co, As, V and Ni), followed by oil palm plantation (Cr and Cd), firewood processing site (Pb) and secondary forest (V) respectively. The study concluded that the PTEs status of the soils was not toxic and that the soils in the investigated land uses were not severely contaminated. It recommended intervallic monitoring in the existing land uses while further researches should focus on the evolving ones.

Keywords: Pollution indices, Outskirts, Soil quality and sustainability, Soil management, Toxicity

INTRODUCTION

Ecological contamination is a severe problem in developing countries as a result of rapidly increasing population growth, industrial and commercial development, and accelerated urbanization (Qadir *et al*. 2010). Soil contamination indicates the incidence of a chemical or foreign substance in concentrations beyond the normal threshold, which may be harmful to an organism or human (Agyeman *et al*. 2022). Heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn) are considered potentially toxic elements (PTEs) due to their high toxicity, lengthy period of time and persistent bioavailability (Alloway *et al*. 2013). PTEs are a significant type of contaminant that can accrue in the soils from varied sources. Following the prevalence of industrial activities, mining, fossil fuel consumption, transportation, use of agricultural inputs, etc, PTEs contamination has arisen as a grave global concern during the recent past and its contents have been detected in soils at varying scales (Natasha *et al*. 2022; Lima *et al*. 2024).

PTEs that are generally present in soils include aluminum (Al), arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni), and zinc (Zn). Amongst these PTEs, As, Cd, Hg, and Pb are also reported in the top 20 Hazardous Substances of the Agency for Toxic Substances and Disease Registry (ATSDR) and the United States Environmental Protection Agency (USEPA) (Goren *et al*. 2022). The incidence of extreme quantities of PTEs over allowable limit in soil instigates toxicity to all living organisms (El-Naggar *et al*. 2021). Soil PTEs contamination has adverse effects, such as contamination of ground water and soil, phytotoxicity, biotoxicity, accumulative behavior and potential human health risk (Qin *et al*. 2020). Consumption of plants from the contaminated area or inhalation of polluted particles is the prime factors instrumental to PTEs exposure for the human population (Loutfy *et al*. 2006). When high levels of PTEs go into the soil biota, they damage the structure and function of the ecosystem and

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progressively depreciate the soil quality, and diminish the soil productivity and subsequently alter human health through the food chain (Taghavi *et al*. 2023). Soil contamination by PTEs of adjoining biomes and inhabited areas is often unavoidable due to leaching and wash-off (Patinha *et al*. 2018).

Globally, researchers have undertaken a series of studies on soil PTEs contamination. Notable amongst them are; Simic *et al*. (2023); Kamanina *et al*. (2023); Albanese and Guarino *et al*. (2022); Chen *et al*. (2022); Gan *et al*. (2022); Goh *et al*. (2022); Zhang *et al*. (2022); He *et al*. (2015) etc. In Nigeria, researchers (Elemile *et al*. 2023; Olatunji and Adeyemi 2021; Edogbo *et al*. 2020; Ezeofor *et al*. 2019; Orobator *et al.* 2019; Odukoya *et al*. 2018; Orobator *et al*. 2017; etc.) have also carried out inquiries on PTEs contamination in soils. These prior studies revealed that there is dearth of empirical investigations on PTEs contamination in rural - urban fringe soils especially in the study area. Rural-urban fringe soils serve as a spatial transition zone between urban and rural areas, keeping the local milieu and biome in balance (Olatunji and Adeyemi 2021). Nevertheless, due to increasing urbanization, PTEs concentration in soils of rural - urban fringe land uses may develop more rapidly than in rural soils.

In addition to filling the gap in research, examining the concentrations and degree of PTEs contamination in rural-urban fringe soils can allow for the identification of contamination hotspots within rural - urban fringe land uses as well as potentially show their concentration levels. Orobator *et al.* (2019) noted that the buildup of heavy metals (PTEs) on anthropic soil obliges exigent reaction from biogeographers, soil geographers, ecotoxicologists, urban planners and soil scientists. Consequently, the present study examined soil PTEs contamination in different rural-urban fringe land uses in Edo State, Nigeria. The objectives of the research were to (i) determine PTEs concentrations in the soils (ii) examine the status of soil PTEs in the rural-urban fringe (iii) analyze the degree of PTEs contamination, and (iv) examine implications of the investigated PTEs on soils. The novel evidence on PTEs contamination from this investigation can act as significant baseline data supporting soil management for soil quality and sustainability in the rural-urban fringe as well as immensely aid local environmental monitoring.

MATERIALS AND METHODS

Study area

In order to achieve the objectives of the investigation and to find a suitable site for the study, an all - inclusive reconnaissance survey was conducted by the authors. A distinctive rural – urban fringe comprising of Egbean - Iguadolor - Uhogua communities situated in Ovia North East Local Government Area, Edo State, Nigeria was adopted for the research. However, the study area (Figure 1) of the present study had earlier been extensively described in the prior contemporary work of the authors (Orobator and Daniel 2023).

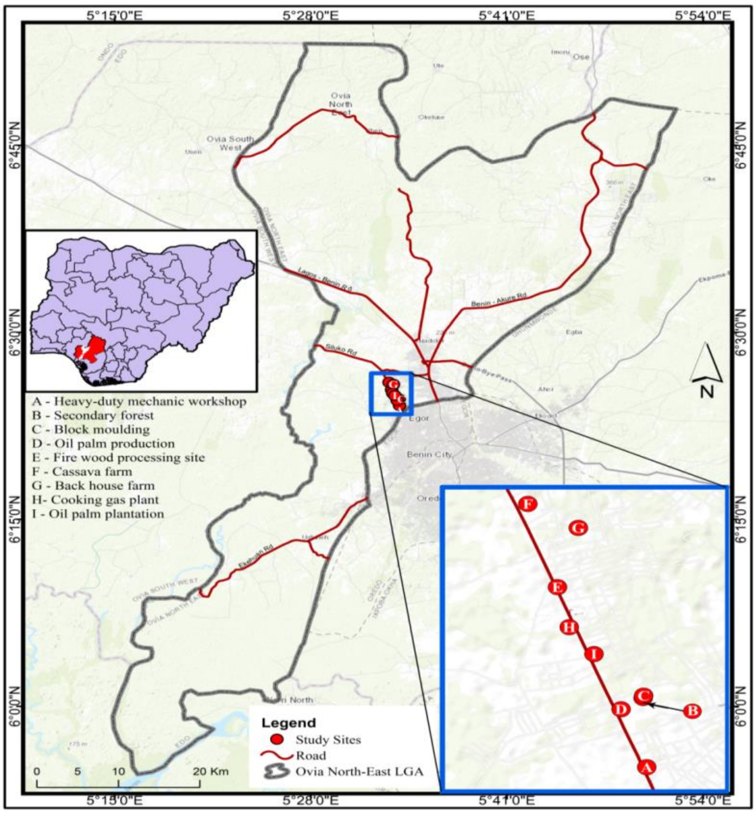


Figure 1 Location of rural-urban land uses

Soil sampling

Nine soil samples were collected for the purpose of this study. One soil sample was collected using a soil auger from each of the nine examined rural-urban fringe land uses (Mechanic workshop, secondary forest, block molding site, oil palm production site, firewood processing site, cassava farm, back yard farm, cooking gas plant and oil palm plantation) at 0 -15cm (top soil). The land uses were chosen because they are the dominant ones in the rural-urban fringe. The simple random sampling technique was utilized for the investigation.

Laboratory analysis

The air-dried soil sample was finely ground in stainless steel, 1 g of each sample was placed in a conical flask, and a mixture of concentrated HNO3:HClO4:HF in the ratio 3:1:3 was added (Yahaya *et al*. 2021). The mixtures were then heated to 800 oC for 3 hrs. The digests were filtered into a 100-ml standard plastic bottle and made to 100 mL with deionized water (Lu *et al*. 2009). The PTEs concentrations in the soil samples were measured using fame atomic absorption spectrophotometry (Varian model-AA240FS). AAS is an extensively used analytical method for determining the concentrations of elements in soil samples (Kamanina *et al*. 2023). The PTEs determined include: Lead (Pb), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Nickel (Ni), Arsenic (As) and Vanadium (V). Goren *et al*. (2022) stated that these PTEs are reported as hazardous substances by the Agency for Toxic Substances and Disease Registry (ATSDR) and the United States Environmental Protection Agency (USEPA).

Data analysis

Pollution indices are valuable in processing, analyzing, and transmitting raw environmental data to the public and decision-makers (Yahaya *et al*. 2021). This study adopted the Index of Geoaccumulation (Igeo), Contamination Factor (Cf) and Single Element Pollution Index (SEPI) pollution indices to determine the degree of PTEs contamination in soils of the examined rural-urban fringe land uses. Department of Petroleum

Resources (2002) permissible limits were used to determine the status of PTEs in the rural-urban fringe land uses soils.

Index of Geoaccumulation (Igeo)

The Index of geoaccumulation (Igeo) essentially permits the assessment of contamination by comparing the current and pre-industrial concentrations originally utilized with bottom sediments (Weissmannová and Pavlovský 2017). It can also be applied to the assessment of soil contamination. The method evaluates the degree of heavy metal pollution in terms of seven enrichment classes (Table 1) based on the increasing numerical values of the index Aigbogun (2018). It was computed using the Equation (1) below. This contamination assessment index has been adopted by many researchers in environmental studies (Loska *et al*. 2003; Abrahim and Parker 2008; Lu *et al*. 2009; Aigbogun 2018) and is defined by the equation:

$$I_{geo} = \log_2 \frac{\mathrm{C_n}}{1.5 * \mathrm{B_n}} \quad (1)$$

Where:
C_n = is the measured concentration of element n in the soil,
B_n = is the geochemical background value for the element n,
1.5 = constant introduced to minimize the effect of possible variations in the background.
Values X which may be attributed to lithologic variations in the soils.

Table 1: Classes of index geoaccumulation

I_{geo} value	I_{geo} Class	Status of Soils
< 0	0	Unpolluted
0-1	1	From unpolluted to moderately polluted
1-2	2	Moderately polluted
2-3	3	From moderately to strongly polluted
3-4	4	Strongly polluted
4-5	5	From strongly to extremely polluted
> 5	6	Extremely polluted

Source: Aigbogun (2018)

Contamination Factor (Cf)

The geochemical background values in continental crust averages of the PTEs under consideration reported by Taylor and McLennan (1985) were used as background values for the PTMs (Equation 2).

$$Contamination\ Factor\ (Cf) = \frac{C_{metal}}{C_{background}} \quad (2)$$

Where:
C*F* = is the contamination factor,
C metal = is the concentration of pollutant in soil,
C background = is the background value for the metal.

Cf was classified into four groups as expressed in Table 2 below:

Table 2: Categories on basis of contamination factor

CF value	CF category	Contamination extent
<1	0	Low contamination
1≤CF<3	1	Moderate contamination
3≤CF≤6	2	Considerable contamination
>6	3	Very high contamination

(Hakanson, 1980; Nasr et al., 2006 & Mmolawa et al., 2011)

Single Element Pollution Index (SEPI)

Single Element Pollution Index (SEPI) was adopted to identify single-element pollution consequent on heavy metal toxicity. The formula used to calculate SEPI is as follows (Equation 3):

$$SEPI = \frac{metal\ content\ in\ soils}{permissible\ level\ of\ metal} \quad (3)$$

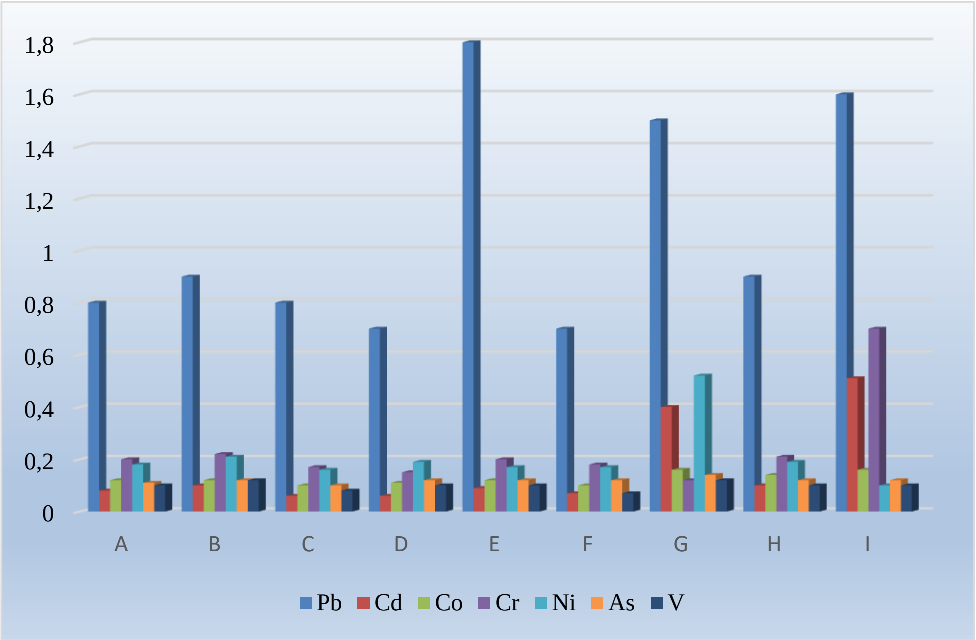
SEPI ≤ 1 = low contamination, 1 < SEPI ≤ 3 = moderate contamination and SEPI > 3 = high contamination (Chen *et al*. 2005).

RESULTS AND DISCUSSION

Lead (Pb)

Pb is a highly prevalent toxic metal that is released in air from varied anthropogenic activities such industries using Pb composites, fossil fuels combustion, alloys, Pb mining, automobile exhaust etc. (Collin *et al*., 2022). The values of Pb in the examined land uses ranged from 0.70 - 1.80 mg/kg (Figure 2). The order of occurrences follow this pattern; oil palm production site/cassava farm < mechanic workshop/block molding < secondary forest/cooking gas plant site < back yard farm < oil palm plantation< firewood processing. The higher level of Pb observed in firewood processing site may be due to the effects of traffic pollution from the road-side. The firewood processing site was situated near a paved road in the study area. The combustion process from vehicles, the layer of road degradation and the particles from the road surface contributed to release pollutants into the environment (Olafisoye *et al*. 2016). Orobator *et al*. (2019) reported higher values of Pb (10.27 mg/kg) in motor mechanic workshop located in the Benin metropolis. The levels of Pb reported in this study are relatively low compared to that observed by Onianwa and Umoren (2005).

High concentrations of Pb can be damaging, resulting to blood and nervous system maladies, kidney impairment, diarrhea, infertility, miscarriages, and exhaustion (Staudinger and Roth 1998). Nevertheless, comparing the values obtained for Pb with Department of Petroleum Resources (DPR) permissible limits, the status of Pb is low (< 85). To assess the degree contamination in all the land uses, Igeo values (Figure 3) indicated that Pb was unpolluted in the soils (Class 1; 0 < Igeo ≤ 1). Cf values (Figure 4) revealed very slight contamination (< 0.1) while SEPI values (Figure 5) indicated low contamination (> 1). The findings of this study do not agree with Yahaya *et al.* (2021) who reported that the degree of Pb contamination was strongly to extremely polluted (Igeo).



NB: A- Mechanic workshop**, B**- Secondary forest**, C** -Block molding site**, D**- Oil palm production site**,**
E- Firewood processing site**, F**- Cassava farm**, G**- Back yard farm**, H**- Cooking gas plant**, I**- Oil palm plantation.

Figure 2. PTES values in the different rural-urban fringe land use

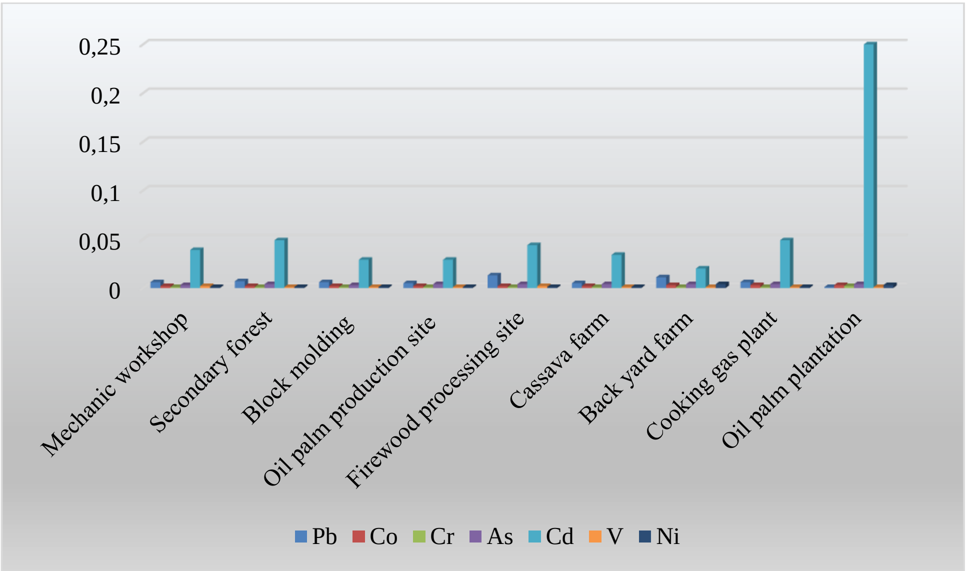


Figure 3. Index of Geoaccumulation values of PTEs

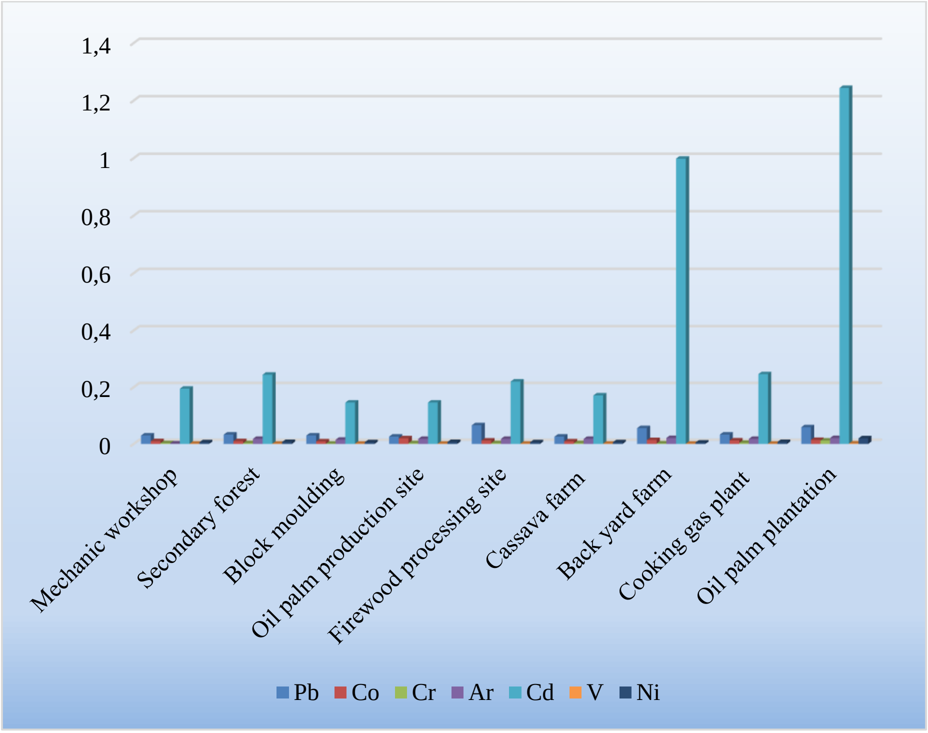


Figure 4. Contamination index values of PTEs

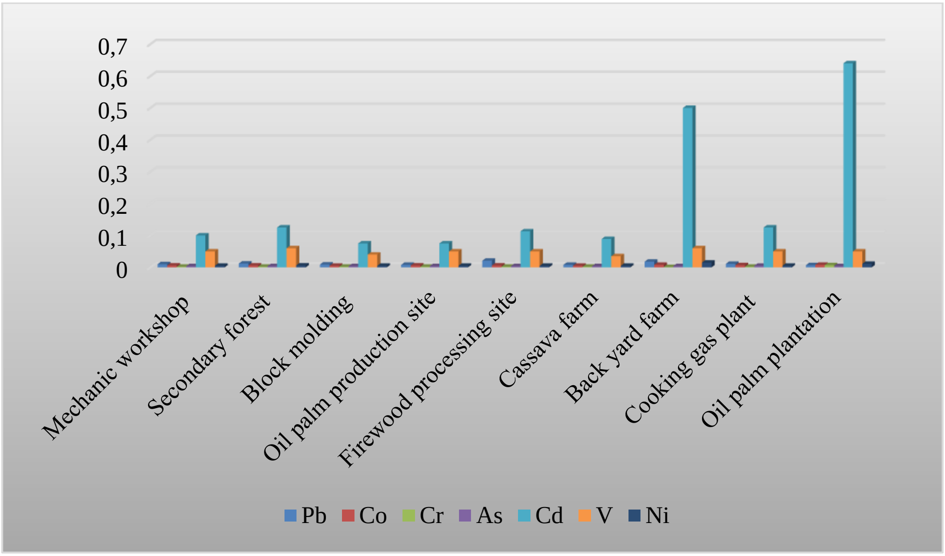


Figure 5. Single element pollution index (SEPI) values of PTEs

Cobalt (Co)

Co is found in the environment along with Fe, Ni, Ag, Pb, Cu, Mn and is likewise found to be existent as carbonates (Mahey *et al*. 2020). Besides, factories that produce cement, carbide tool grinding, e-waste, polishing disc, pigment and paint; incinerators, mining activities as well as televisions (TVs), mobile batteries, computer monitors, and liquid crystal display TVs are also potential human sources of Co (Graedel *et al*. 2014). Comparative values of Co in all investigated land uses ranged from 0.10 - 0.16 mg/kg (Figure 2). The order of Co concentrations as indicated in Table 2 follow this trend; block molding site /cassava farm < oil palm production site < mechanic workshop/secondary forest/ firewood processing site < cooking gas plant < back yard farm/oil palm plantation. The higher level of Co in back yard farm can be ascribed to the prevalence of organic manure from the droppings of poultry birds and livestock on the soils.

Akhter *et al*. (2022) reported that due to poultry waste, press mud, and farmyard manure, Co showed more concentration in the soil. Excessive use of herbicides and fertilizers may account for the higher level of Co detected in oil palm plantation (Adedeji *et al*. 2019). The disproportionate use of pesticides and fertilizers will lead to the higher levels of PTEs in the soil (Huo *et al*. 2022). High concentrations of Co can provoke cardiotoxicity in humans when exposed heavily (Linna *et al*. 2020). However, comparing the values of Co with DPR permissible limits, Co status is low (< 20). To ascertain the degree of Co contamination in the land uses, Igeo values (Figure 3) indicated unpolluted (Class 1; $0 < \text{Igeo} \leq 1$) while Cf values (Figure 4) revealed very slight contamination (< 0.1). SEPI (Figure 5) showed low contamination (>1). The values of contamination factor observed in this study were lower than those reported by Akintola (2014), Akintola and Bodede (2019).

Chromium (Cr)

Cr is released into the environment via both natural practices and anthropogenic undertakings such as agricultural activities, metal processing, smelting, manufacturing, and, mining causing pollution and the damage of ecologies (López-Bucio *et al*. 2022). Cr concentration values across the investigated land uses ranged from 0.12 to 0.70 mg/kg (Figure 2). Cr concentrations followed the order; backyard farm < oil palm production site < block molding site < cassava farm < firewood processing site/ mechanic workshop < cooking gas plant < secondary forest < oil palm plantation. The higher value of Cr in oil palm plantation may be due to inappropriate use of agrochemicals and fertilizers (Kalpakjian *et al*. 2011, Olafisoye *et al*. 2020, Thompson-Morrison *et al*. 2022). The finding of study was consistent with Olafisoye *et al.* (2020), who reported higher level of Cr in soils of all the fifteen sampled oil palm plantations. The levels of Cr found in this study were relatively low compared to that reported for soil of automobile workshops (Oguntimehin and Ipimoroti 2008). Comparing the results with DPR permissible limits for Cr, Cr content is low (< 100). To determine the degree of Cr contamination in soils of the examined land uses, Igeo values (Figure 3) indicated that Cr concentrations was unpolluted (Class 1; $0 < \text{Igeo} \leq 1$); Cf values (Figure 4) revealed very slight contamination (< 0.1). SEPI (Figure 5) indicated that contamination Cr was low (> 1). This present study contradicts (Ololade 2014), reported contamination of Cr in soils investigated (Igeo).

Arsenic (As)

As is a naturally prevailing potential toxic metal whose place in pollution are global due to both natural processes and anthropogenic happenings (Hettick *et al.* 2015). As values in soils under the examined land uses are indicated in Figure 2. The level of concentrations of As in the soils under the examined land uses ranged from 0.10 - 0.14 mg/kg. The order of incidence of As in soils under different land uses are as follows; block molding site < mechanic workshop/secondary forest/oil palm production site/firewood processing site /cassava farm/cooking gas plant/oil palm plantation < back yard farm. The occurrence of higher level of As in back yard farm may be due to the influence of domestic wastes and livestock droppings. (Kayode *et al*. 2021). As levels observed in this study were lower than a study carried out within the vicinity of the mechanical workshop by Oloye *et al*. (2014). As toxicity can cause developmental effects, neurotoxicity and diabetes in humans (Singh *et al*. 2007). However, comparing the results of As with DPR permissible limits for As, the status is low. To determine the degree of As contamination in the investigated land uses; Igeo values (Figure 3) indicated that As concentrations in soils were unpolluted (Class 1; $0 < \text{Igeo} \leq 1$); Cf values (Figure 4) revealed that As contamination was very slight (< 0.1). SEPI (Figure 5) indicated that contamination was low in all the land uses (> 1).

Cadmium (Cd)

Cd is a heavy metal whose continuous sources of contamination are linked to its use in industry as a corrosive reagent, as well as its usage as color pigments, a stabilizer in PVC products, and Ni-Cd batteries (Genchi *et al*. 2020). The values of Cd in soils under the different land use ranged from 0.06 - 0.51 mg/kg (Figure 2).

They are in the following order; block molding site/oil palm production site < cassava farm < mechanic workshop < firewood processing site < secondary forest / cooking gas plant < back yard farm < oil palm plantation. The higher value of Cd in oil palm plantation may be credited to the application of phosphate rock fertilizer on the soils (Orobator *et al*. 2017). This study contradicts that of Bamgbose *et al*. (2000), who reported higher levels of Cd. In humans, Cd toxicity can lead to a range of severe effects, such as renal and hepatic dysfunction, pulmonary edema and testicular damage (Gencihi *et al*. 2020). Conversely, comparing the Cd results obtained for the investigation with DPR permissible limits for Cd, Cd status is low (<0.8). To assess the degree of Cd contamination, Igeo values (Figure 3) indicated that Cd concentrations in soils were unpolluted (Class 1; 0 < Igeo ≤ 1); Cf values (Figure 4) revealed was very slight Cd contamination in all the land uses (< 0.1). SEPI (Figure 5) indicated that contamination was low in all the land uses (> 1).

Vanadium (V)

V is an abundant heavy metal on earth whose main anthropogenic sources of release into the environment includes burning of fossil fuels, industries, mining, pesticide and fertilizer application and recycling of domestic waste (Imtiaz *et al*. 2015). The pattern of V incidences under the different land uses are shown in Figure 2. The level of V contents in the soil ranged from 0.07 to 0.12mg/kg. The trend of abundance of V is as follows; cassava farm < block molding site < mechanic workshop/oil palm production site /firewood processing site /cooking gas plant/oil palm plantation < secondary forest/back yard farm. The higher level of V in back yard farm may be due to the prevalence of household wastes in the soils (Liu *et al*. 2022). In addition, incidences of V in secondary forest may be accredited to the parent material of the soils. The parent materials of soils can indicate V concentrations in soils, even in those unaffected by contamination (Guagliardi *et al*. 2018). The result of this study agreed with Han and Xu (2022), who reported that higher concentrations of heavy metals were detected in the secondary forest. V toxicity can prompt oxidative impairment in the brain and develop blood brain barrier disorder and neuropathology (Rojas-Lemus *et al*. 2020). Yet, comparing the findings of V with DPR permissible limits, V status is low. To evaluate degree of V contamination, Igeo values (Figure 3) indicated that V concentrations in soils were unpolluted (Class 1; 0 < Igeo ≤ 1), Cf values (Figure 4) revealed that V contamination was very slight in all the land uses (< 0.1) whereas SEPI (Figure 5) indicated that contamination was low in all the land uses (> 1).

Nickel (Ni)

Ni is a potentially toxic element extensively released into the ecosystem from various anthropogenic and natural sources such as pigment manufacturing processes, wastes, alloy industries, industry wastewater, aerial deposition of pollutants, mafic and ultramafic rocks (El-Naggar *et al*. 2021). The contents of Ni in soils under the different land use ranged from 0.10 - 0.52 mg/kg (Figure 2). The order of Ni concentration in soils follow this pattern; oil palm plantation < block molding site < firewood processing site/cassava farm < mechanic workshop < oil palm production site < cooking gas plant < secondary forest < back yard farm (Figure 2). The higher level of Ni in the back yard farm may be ascribed to the effects of farming activities. Anthropogenic activities such as farming activities, smelting and mining development etc. can directly influence soil (Wang and Zhang 2007). In addition, Ni levels observed in backyard farm could be as a result of organic manure coupled with leaching from household wastes (Oladeji 2017). PTEs infiltrate the soils of farmland as well as the crops (Leng *et al*. 2023). The levels of Ni observed in the present study were lower than that found in urban soils in Nigeria (Umoren and Onianwa 2005). Ni toxicity can instigate a multiplicity of side effects on anthropoid health, such as allergy, cardiovascular and kidney diseases, lung fibrosis, lung and nasal cancer (Genchi *et al*. 2020). However, matching the results obtained for Ni with DPR permissible limits for Ni, the status of Ni was low (< 35). To ascertain the degree of Ni contamination, Igeo values (Figure 3) indicated that Ni concentrations in soils of the examined land uses were unpolluted (Class 1; 0 < Igeo ≤ 1), Cf values (Figure 4) revealed that Ni contamination was very slight in all the land uses (< 0.1) while SEPI (Figure 5) indicated that contamination was low in all the land uses (> 1). This finding of this study do not agree with Iyama *et al*. (2021), who reported that Ni (0.028 – 2.197) showed very slight contamination to moderate pollution (contamination factor).

CONCLUSIONS

We examined soil potentially toxic elements contamination in different rural-urban fringe (R-U fringe) land uses in Edo state. The findings indicated that the status of Pb, Co, Cr, As, Cd, V and Ni were low in all the investigated land uses. The results also revealed that backyard farm had higher levels of majority of the investigated PTEs (Co, As, V and Ni), followed by oil palm plantation (Cr and Cd), firewood processing site (Pb) and secondary forest (V). Furthermore, results obtained showed that the degree of soil PTEs contamination were very slight (Cf), low contamination (SEPI) and unpolluted (Igeo). The research concluded that the status of the examined PTEs in the soils were not toxic, hence, not detrimental to humans when transferred to consumable parts of plants. It also concluded that anthropogenic undertakings have not yet intensified in the rural-urban fringe land uses to severely contaminate the soils. The study recommended regular monitoring of soils in the existing land uses by biogeographers, soil geographers and soil scientists, to promptly detect any incidence of high PTEs status and contamination. Further studies should focus on the evaluation of PTEs in emerging land uses in the rural – urban fringe to determine possible contamination.

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