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Appraisal of lead (Pb) contamination and potential exposure risk associated with agricultural soils and some cultivated plants in gold mines

Aminu Darma[1,2], Sani Ibrahim[2], Ali Sani[2,3*], Peiman Zandi[1,4] and Jianjun Yang[1]

Abstract

Background: Artisanal gold mining has been one of the major contributors to soil pollution. These types of soil have potential environmental implications and varying degrees of health risk due to agricultural product cultivation. The contamination level of Pb in soils under cultivation by maize and spinach from gold mines in Abare, Dareta and Bagega mines of Anka local government Zamfara state was examined. Three levels of soil depths (0–21, 21–40 and 41–60 cm) from study sites were considered for vertical distributions of the Pb. The samples were digested and analyzed using flame atomic absorption spectrophotometry (Varian model-AA240FS).

Results: The total Pb concentration ranges from 326.2 to 383.43 (Abare), 67.74–76.44 (Bagega) and 17.88–42.00 mg/kg (Dareta), which are all within the environmental protection agency (EPA) 400 mg/kg permissible limits, while only those analyzed from Abare were above the 85 mg/kg department of petroleum resources of Nigeria (DPR) threshold. From the result, the spinach grown in those areas exceeded the FAO/WHO 0.3 mg/kg threshold.

Conclusion: Additionally, all study sites from all areas revealed the highest Pb concentrations at a 0–20 cm soil depth. This study further indicates all the soils from these areas are within safety limits based on the single pollution index (SPI) and Nemerow composite pollution index (NCPI). This information will significantly help provide greater insight into developing more effective remediation strategies for the affected localities. More research is needed into the speciation, chemical forms, bioavailability, and biogeochemical mechanisms that influence Pb mobility in those areas.

Highlights

- pH and CEC influence lead (Pb) concentration in contaminated areas
- Pb concentration from all the areas is within the EPA 400 mg/kg threshold
- The concentration of Pb is high at the depth between 0 and 20 cm in all the sites
- The overall status of all the soil studied is within the safety limit
- All the maize grown on the cultivated soil from the studied sites are safe for consumption

*Correspondence: asani.bio@buk.edu.ng

[2] Department of Biological Sciences, Bayero University, Kano, Nigeria
Full list of author information is available at the end of the article

Keywords: Biomonitoring, Lead contamination, Mining activity, Remediation

Introduction

The problems associated with heavy metal accumulation and environmental pollution are substantial and draw increasing attention due to their adverse effects on human health and the ecosystem in general (Rotkittikhun et al. 2006; Hu et al. 2017). Natural processes, rapid industrialization, fossil burning, iron smelting, and/or intensive mining activities, among others, are frequently responsible for global heavy metals contamination in the environment. For decades, it has been established that mining activities are a significant contributor to the increased concentration of many heavy metals in various environmental components (Cai et al. 2015; Cheng et al. 2018). Among these heavy metals include, but are not limited to zinc (Zn), arsenic (As), and lead (Pb). Potential ecological risk index (PERI) revealed greatest concentration of Hg and Cd in sediments and soils among other metals (Kumar et al. 2022). Similarly, the levels of potentially toxic elements in industrial soils were greatest then followed by agricultural and non-agricultural soils (Verma et al. 2021).

Mining for Zn-Pb, gold (Au), and galena (PbS), in particular, is an unsafe practice that not only pollutes the environment but also poses a greater risk to human health and agricultural products due to the high degree of Pb toxicity (Cheng et al. 2018).

Intense and unauthorized gold mining was the primary source of a terrible outbreak of Pb poisoning crisis in gold mines communities, particularly in Anka local government of Zamfara state Nigeria (UNEP/OCHA 2010; Anka et al. 2020). The operation involves physically grinding, washing, processing, and storing the gold extracted from the Pb-rich ore. As a result, these aggressive procedures generate Pb dust, tailing and varying forms of waste, resulting in multiple health issues and widespread environmental concern, particularly to the communities in and around the mining sites (UNEP/OCHA 2010; WHO 2011; Mohammed and Abdu 2014; Abdulkareem et al. 2015; Njinga and Tshivhase 2019). Preliminary investigations have confirmed the presence of elevated Pb concentrations in blood, sediment, soil, and agricultural products from these areas (Nuhu et al. 2014). These draw the attention of local stakeholders and international experts, who collaborated to determine the actual Pb concentration in the affected communities, an initiative that resulted in the areas receiving recommendations for various control measures and remediation strategies (Abdu 2010; UNEP/OCHA 2010; Abdulkareem et al. 2015; Tirima et al. 2018; Adewumi 2020).

Despite these incidents and proposed mitigation measures, farming activities continue within and around the affected villages (Abdu and Yusuf 2013; Abdulkareem et al. 2015).

This is because the soil as a definitive part of the biosphere is exposed to a vast array of pollutants which include heavy metals. Consequently, the heavy metals upsurge affects all organisms via biomagnifications (Kumar et al. 2019).

Hence, a need for further evaluation and review of the soil pollution status and potential exposure risk associated with agricultural products grown in those communities, for there is a dearth of information on the exposure risk and potential Pb pollution in such communities, particularly during post-remediation exercises. Therefore, the focus of this research was to evaluate the level of Pb contamination, potential exposure risk on some cultivated agricultural products and how some basic soil parameters influence the Pb availability in the affected communities around Anka mining sites. The study's findings will contribute to a better understanding of Pb pollution and potential exposure risk to vulnerable communities.

Materials and methods

Study sites and sampling

The study was conducted from selected study sites from three selected mining areas, i.e. Abare, Bagega, and Dareta of Anka local government, Zamfara state (Fig. 1). The area has a total population of 142,280 and total land under cultivation of approximately 2,746km^2 (Johnbull et al. 2019), with a location coordinate of latitudes 11° 40′ 0″ and 12° 20′ 0″ North and longitudes 5° 50′ 0″ and 6° 20′ 0″ East. The three sites were identified as having the most risk from lead poisoning due to ore processing and conspicuous mining activities (UNEP/OCHA 2010). Abare is a confirmed Pb contaminated area with an estimated population of 5000 people (UNEP/OCHA 2010). Most of the inhabitants are farmers, while many youths earned their living by engaging in illegal gold ore mining. On the other hand, Baggage, another Pb contaminated area, has an estimated population of 8500 people (Tirima et al. 2018), with the majority of its inhabitants relying on farming while a significant proportion of its youth earned their living by engaging in trading and illegal mining of gold ore, while Dareta is a remediated contaminated area in June-July 2010. The community has an estimated population of 2000 people (Udiba et al. 2020). The majority of the inhabitants are farmers, while a significant

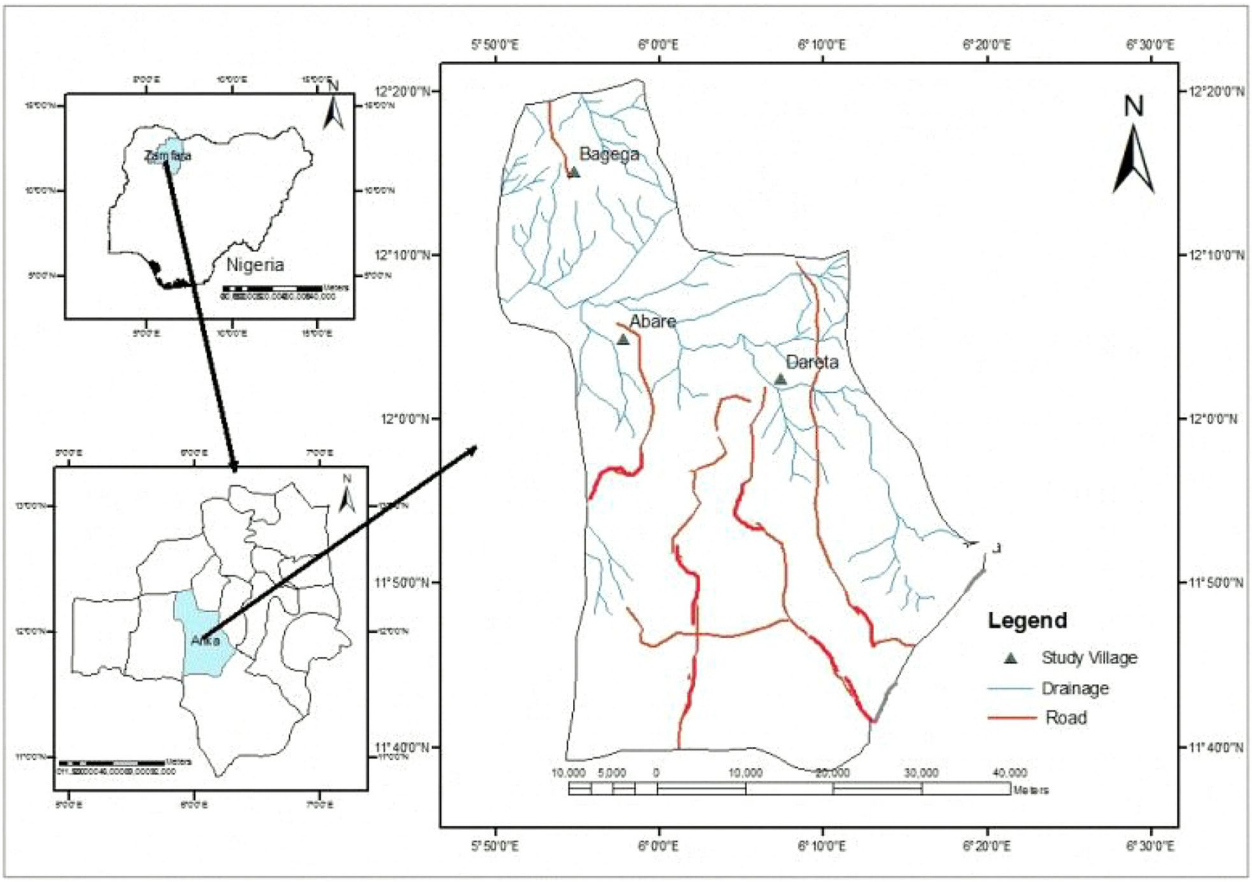

Fig. 1 Location of the study sites from Anka local government, Zamfara state, Nigeria

proportion of youth in the area earned their living by trading and illegally mining gold ore. Mining processes in these areas include crushing, washing, drying, aggregating mercury (Hg), and melting the aggregates to remove gold (Adewumi 2020). In all these study areas, maize (*Zea mays* L.) is the major crop and is consumed as a staple food along with spinach (*Spinacia oleracea*) by the residents at every meal.

Soil sample collection and preparation

Soil samples were collected from the agricultural field very close to the active mining sites using a standard soil auger at three depths 0–20 cm, 21–40 cm and 41–60 cm. Four different agricultural fields were selected for sampling at each study area (Fig. 1). Three replicates of the samples were collected from each profile pits at a different depth. This gave a total of twelve (12) sample pits from each of the study areas. The soil samples collected were placed inside a polythene bag and taken to a laboratory, air-dried and sieved through a 2 mm sieve for further physical and chemical analysis (Chaudhry et al. 2012; Abdulkareem et al. 2015).

Crop and vegetable sampling

Fresh spinach and maize, which represent the crop and vegetable samples in the study sites, were collected from the same study area as the soil samples (Fig. 1). These samples were all collected from four farmlands from each of the three study sites; during the growing season. All the collected samples were washed with double deionized water to eliminate dust and dirt particles, and the inedible parts were removed. For the maize, the edible parts were removed and dried separately on a sheet of filter paper. All the samples were then separately dried in an oven at 65 °C for 72 h until constant weight. The dried samples were powdered using an electric grinder and stored in labelled plastic bags for further analyses (Rehman et al. 2017).

Basic soil properties

The dried soil samples were sieved through a 2.0 mm sieve and were analysed for basic properties. With the aid of a well-calibrated electrical conductivity meter and pH meter, the soil pH and electrical conductivity were measured at a 1: 2.5 ratio (w: v; at a soil–water ratio). Organic carbon

(OC) was analysed by Walkley and Black (Nelson and Sommers 1983). Available phosphorus was analysed using Bray 1 extraction method (Bray and Kurtz 1945), whereas available nitrogen was determined using the Kjeldahl method (Amusan et al. 2005; Zhao et al. 2010) and exchangeable cations extraction using 1 N NH_4OAc solution (Chaudhry et al. 2012).

Determination of soil total Pb concentration

The air-dried soil samples were digested according to Nwajei (2000) and Cao et al. (2010) with a slight modification. Approximately 0.3 g dried soil samples were treated with 3 mL HNO_3 in digestion tubes and left overnight. Subsequently, 1 mL of $HClO_4$ and 3 mL HF were added to the mixture. The mixture was heated to 80 °C for 3 h and allowed to be digested and then filtered. The filtered solution was made up to 100 ml in a standard plastic bottle with distilled water and analyzed for total Pb concentration using flame atomic absorption spectrophotometry (Varian model-AA240FS).

The Rotkittikhun et al. (2006) method was adapted with little modifications for grounded maize and spinach. In the process, 0.5 g of the sample was digested using HNO_3 and $HClO_4$ (4:1, V/V). The mixtures were allowed to digest and later filtered completely. Subsequently, Pb concentration in the plant samples was analysed using flame atomic absorption spectrophotometry (Varian model-AA240FS) in the Ahmadu Bello University multi-user laboratory.

Indices of pollution

Bioaccumulation factor (BCF)

The bio-concentration factor (BCF) indicates the plant (spinach and maize) sample's potential to accumulate a Pb relative to the concentration in the soil. It was computed using the following equation (Cui et al. 2004; Ghosh and Singh 2005).

$$\mathrm{BCF} = \frac{\mathrm{Conc.(Plant\ sample)}}{\mathrm{Conc.(Soil)}} \quad (1)$$

Single pollution index (SPI)

Appraisal of the Pb contamination in all the study sites was carried out using a single pollution index (SPI). The SPI was determined as a ratio of Pb concentration in the soil to that of regulatory standard using equation (ii) (Hu et al. 2017).

$$SPI = \frac{Conc.(in\ the\ soil)}{pollution\ threshold} \quad (2)$$

Nemerow composite pollution index (NCPI)

The degree and the classification of the Pb pollution load were done using Nemerow composite pollution index (NCPI). The index is useful in classifying the soils in terms of HM pollution. It was computed based on equation (iii) (Hu et al. 2017). The grade of the pollution based on this index is represented in Table 1.

$$\mathrm{NCPI} = \frac{\sqrt{(P\max)^2 + (Pi)^2}}{2} \quad (3)$$

Statistical analysis

The data collected were analysed using SPSS 25 software (US, Chicago, IBM Company) and Microsoft Excel (Version 2016). Means between the study sites for each study area were analyzed using one-way ANOVA, and statistically significant differences were computed using Duncan multiple range techniques (DMRT) at $p < 0.05$. Pearson's correlation analysis was employed to compare relationships between total Pb concentrations and the basic soil properties using Origin lab pro version 2021b.

Results and discussion

Physical and chemical parameters of the studied soil

The average pH of all the studied areas ranges from 6.9 to 7.4. These values indicate the pH of all the studied sites falls within acidic to neutral conditions (Table 2). According to Shu et al. (2001), normal plant growth is promising within the pH range of 5–7; therefore, the studied areas are within the pH range to support optimal plant growth. The observed values also match up with the average values in the region for plants' normal growth and development (Raji et al. 2015). The studied sites' average electrical conductivity (EC) ranges from 0.1 to 0.17 (ds/m), signifying low EC from all three study areas. These low EC values indicate no apparent salinity-associated problems in all the studied sites, as EC is a significant index for assessing soil salinity in a particular area (Shahid et al. 2018; Bañón et al. 2021). The organic carbon (OC) values of all study sites across all study areas ranged from 0.37 to 0.60 (g/kg). These values indicate very low carbon content in all study sites, implying

Table 1 Classes of the single pollution index (SPI) and Nemerow composite pollution index (NCPI)

Class	SPI	Grade	NCPI	Grade
1	≤ 1.0	Safety	≤ 0.7	Safety
2	$1.0 < SPI \leq 2.0$	Slight pollution	$1.0 < SPI \leq 2.0$	Alert
3	$2.0 < SPI \leq 3.0$	Mild pollution	$2.0 < SPI \leq 3.0$	Slight pollution
4	$3.0 < SPI \leq 5.0$	Moderate pollution	$3.0 < SPI \leq 5.0$	Moderate pollution
5	$SPI > 5.0$	Severe pollution	$SPI > 5.0$	Severe pollution

Classifications are based on Chen et al. (2015) and Hu et al. (2017)

Table 2 Basic physical and chemical parameters of the soil of the farmland across the three study areas

Soil parameters	Abare	Bagega	Dareta
pH	7.491667	7.096667	6.9
EC (ds/m)	0.176667	0.110833	0.1
OC(g/kg)	0.374167	0.603333	0.57
Available P (mg/kg)	4.296667	2.561667	2.45
Total N (g/kg)	1.256667	1.416667	1.4
K cmol (+)/kg	0.23	0.22	0.2
Na cmol (+)/kg	0.12	0.248333	0.18
Ca cmol (+)/kg	10.875	6.716667	6
Mg cmol (+)/kg	0.844167	1.079167	1

OC: organic carbon; EC: electric conductivitiy, pH, soil acodity

that the soil has a shallow carbon content (≤2%) based on Sigari et al. (2003) classifications. The low OC can be attributed to the study sites' lack of vegetation cover, which also agrees with OC values obtained from the findings of Raji et al. (2015).

The cation exchange capacity (CEC) of soil is an index that indicates the soil's ability to retain ions in a form that is available and potentially leachable in the soil profile (Solly et al. 2020). The higher the CEC values, the more soil potential to retain ions (Hazelton and Murphy 2016). The CEC of the soils from all the study sites ranges from 0.12 to 10.87 (cmol(+)/kg). These values implied variability in the nutrient retention across the study areas. However, it can be inferred that all study areas have a moderate CEC potential, which is beneficial to overall plant growth potential. The available phosphorus of all the studied sites ranges from 2.45 to 4.29 (mg/kg). These results indicate low P content in the area based on the Sigari et al (2003) classifications and correspond to low to medium P rating by the Federal Ministry of Agriculture and Natural Resources of Nigeria (Yahaya et al. 2021). Likewise, the total nitrogen (TN) from all the study sites ranges from 1.25 to 1.4 (g/kg), which can also be regarded as low based on Sigari et al (2003) classifications. Therefore, the relatively low available P and TN content in all the study area's agricultural land can be related to the low organic matter content and perhaps the considerable distance between the study sites with the municipal sewage system and few or no biosolid deposition in the area. This is because municipal sewage systems and biosolid applications have a strong relationship with high P and TN availability in particular settings (Bunce et al. 2018).

Total Pb concentration in the soil from all the study sites

The total Pb concentrations in all the soil samples collected from the farmland in all the study areas are presented in Table 3. The Pb concentrations vary significantly from 17.88 to 383.48 mg/kg across all the study areas. The trend of Pb concentrations in the soil from the three study sites was Abare > Begaga > Dareta. The average total Pb concentration in all the sites was below the EPA current allowable limits of 400 mg/kg in soil (US-EPA 2004; Widener 2018; Haque et al. 2021). Furthermore, the results revealed Pb level in all of the study areas was very low-low grade, as per USEPA standard (US-EPA 2004; Anka et al. 2020). However, when compared to the local threshold level of Pb 85 mg/kg, in the soil as set by the Nigerian Department of Petroleum Resources (DPR 2002), the Pb concentration in all the other two sites, i.e. Bagega and Dareta, are all below the standard limits whereas all the sites in Abare are above the DPR standard. However, the total Pb concentration in the soils has exceeded the permissible limits in Ludhiana district of Punjab, India (Dhaliwal et al. 2021). Moreover, Pb in agricultural soils has exceeded the China and Canadian soil guidelines limits (Kumar et al. 2021).

Table 3 Pb concentration (mg/kg), in soil, spinach and maize from the cultivated land across the study sites

Sites	Farm	Pb concentrations (mg/kg)		
		Soil	Spinach	Maize
Abare	1	383.48 ± 0.21a	9.815 ± 0.0567a	3.6 ± 0.0769b
	2	326.28 ± 0.22c	8.32 ± 1.7363a	4.2 ± 0.351a
	3	366.62 ± 0.25b	6.1 ± 0.1732b	3.76 ± 0.0312b
	4	383.60 ± 0.18a	6.78 ± 0.1519b	3.64 ± 0.0779b
Bagega	1	68.40 ± 0.18a	3.575 ± 0.0082	1.91 ± 0.0173b
	2	69.18 ± 8.37a	2.88 ± 0.0779	2.51 ± 0.0229a
	3	76.44 ± 2.13b	3.055 ± 0.0952	2.34 ± 0.0150a
	4	67.74 ± 0.10a	2.755 ± 0.0173	1.85 ± 0.0029b
Dareta	1	18.24 ± 0.27c	0.47 ± 0.0173	1.265 ± 0.0086a
	2	42.00 ± 0.10a	0.53 ± 0.1723	0.35 ± 0.0229c
	3	23.4 ± 0.18b	0.325 ± 0.0173	0.365 ± 0.0173c
	4	17.88 ± 0.10c	0.285 ± 0.150	0.44 ± 0.01730b

DPR, (2002) for soil: 85 mg/kg, EPA, (2004) for soil: 400 mg/kg, FAO/WHO (mg/kg) for crop: 35, FAO/WHO (mg/kg) for vegetable: 0.3; values are means ± standard errors (n = 3); means with the same superscript letter within each column are not significantly different at $p < 0.05$

Generally, the high Pb concentration in Abare can be linked to the fact that it is one of the prominent Pb contaminated areas associated with intensive artisanal mining of gold and PbS mining and grinding (UNEP/OCHA 2010; Adewumi 2020). Most notably, the majority of the agricultural land in the villages of that area is within the vicinity of the prohibited artisanal ore mining zone. This elevated total Pb concentration is similar to those obtained by Anka et al. (2020), where a total Pb concentration of about 385–688 mg/kg was obtained in the agricultural land of Abare village. The findings of this study are similar to the results of UNEP/OCHA (2010) and Adewumi (2020), where a significant level of Pb concentration was found in the soil of this study area. Furthermore, our findings agree with the elevated Pb levels found in some contaminated agricultural soils near Pb/Zinc smelting and mining areas in Hunan Province of China (Khan et al. 2016). Additionally, the higher Pb concentrations in Abare are similar to that obtained in some Pb-contaminated agricultural soil in Pakistan (Rehman et al. 2017). Prolonged accumulation of Pb in the agricultural soils of these sites may result in higher Pb uptake by food crops, which could be risky and increase the risks of food contamination in the affected areas. On the other hand, the relatively low Pb concentration in Bagega and Dareta could be attributed to massive remediation exercise employed by the joint action of state and UNEP/OCHA and to the fact that most of the artisanal mining activities in these areas are practiced far away from the agricultural area as opposed to those in Abare (UNEP/OCHA 2010; Udiba et al. 2020).

The vertical distribution of total Pb concentration in all the studied areas, as presented in Table 3 and Fig. 2, varies with an increase in soil depth. The total Pb concentration trend was 0–20 cm > 21–40 cm > 41–60 cm in all the study areas, indicating a decrease in the total Pb concentration with increased depth. Based on this trend, it can be inferred that the sources of Pb contaminations in those agricultural land are more of artificial supplementations by human activities like mining and deposition of metal ores from streams and households as opposed to geological sources. Also, these trends could reflect the high affinity of the Pb to the organic matter that is more condensed at the upper soil surface compared to the lower profile (Abdulkareem et al. 2015; Tomczyk et al. 2020). Furthermore, the high Pb concentration in the upper profile may be connected to the purity of the water saturating these areas. If the saturating water is already polluted with high Pb, it possibly remains that high Pb will be deposited at the surface, and its level will decrease with depth. These findings can be related to the results obtained by Mohammed and Abdu (2014) while examining the relative vertical distribution of Pb at some agricultural soils in Dareta village. Besides that, the accessible Pb concentrations in the lower depth may result from Pb downward leaching to the lower profile (Adewumi 2020).

Total Pb concentration in maize and spinach from all the study sites

Maize and spinach samples were collected from the agricultural land of all the study sites. They were analysed for total Pb concentrations as presented in Fig. 3, while the details are given in Table 4. The trend in the Pb accumulation across the studies site shows Spinach > Maize, which suggests more Pb accumulation in leafy vegetables than crops. The mean Pb concentrations of the maize range from 3.6 to 4.2, 1.9.1–2.5, and 0.35–1.26 mg/kg in Abare, Bagega and Dareta, respectively. These values from all the study sites are below 5 mg/kg FAO/WHO maximum allowable Pb limits in crops (FAO/WHO 2007; Chauhan and Chauhan 2014; Chaoua et al. 2019). Investigation of crops grown in these areas by Abdu and Yusuf (2013) demonstrated the concentration of Pb from some of these contaminated areas high above the FAO/WHO threshold. Even though the values obtained from Abdu and Yusuf's findings are higher than those obtained in our study, it can be generally understood that

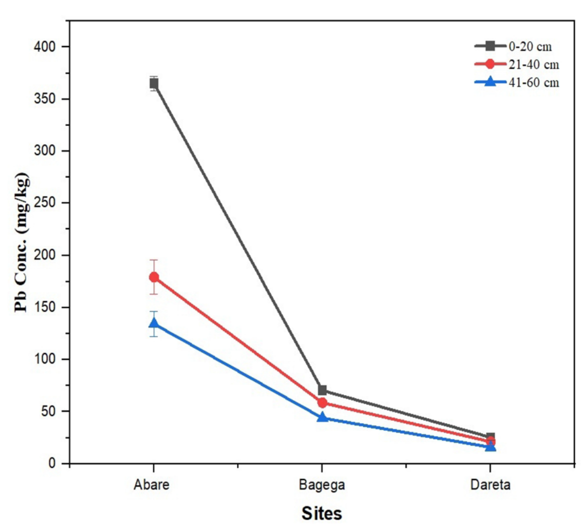

Fig. 2 Pattern of lead (Pb) concentration (mg/kg) across the three (3) soil depths in the cultivated farmland of Abare, Bagega and Dareta

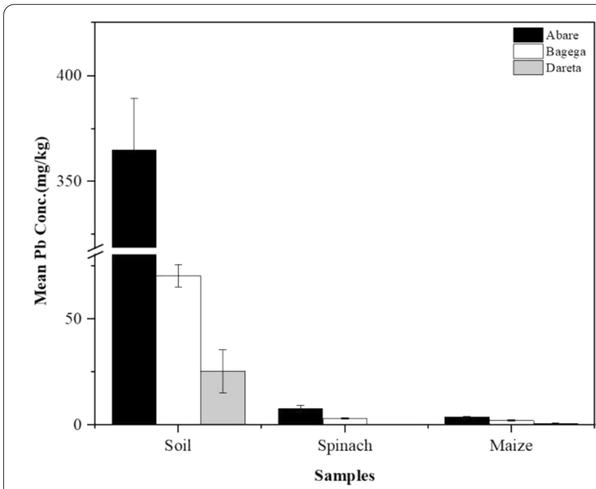

Fig. 3 Mean Pb Conc. (mg/kg) of soil, spinach and maize in the cultivated farmland of Anka local government, Zamfara state, Nigeria

Table 4 Pb concentration (mg/kg), and single pollution index (SPI) and Nemerow composite pollution index (NCPI) of the farmland across the study sites

Soil depth (cm)	Pb concentrations in soil (mg/kg) samples			SPI		
	Abare	Bagega	Dareta	Abare	Bagega	Dareta
0–20	364.995 ± 24.43a	70.44 ± 5.19a	25.38 ± 10.27a	0.91	0.18	0.06
21–40	179.1625 ± 56.24b	58.7 ± 4.32b	21.15 ± 8.56b	0.45	0.15	0.05
41–60	134.371875 ± 42.18c	44.025 ± 3.24c	15.8625 ± 6.42c	0.34	0.11	0.04
p-value	0.025	0.045	0.035			
NCPI				0.52	0.36	0.27

Pb (Lead), SPI (Single pollution index), NCPI (Nemerow composite pollution index); DPR 2002 for soil: 85 mg/kg, USEPA 2001for soil: 400 mg/kg; SPI and NCPI < 1 = Safe, SPI and NCPI > 1 = Pollution critical limit thus, unsafe; values are means ± standard errors (n = 3);means with the same superscript letter within each column are not significantly different at p < 0.05

contamination of farmland by Pb as a result of artisanal gold and Pb mining has significantly contributed to the elevated Pb concentration in the crops grown in these study areas. These variation may also ascribe to the remediation efforts and raising awareness about Pb pollution in the areas, which encourages residents to develop safer ore processing practices. In addition, the mean Pb concentration in other grains which include wheat and rice has exceeded the permissible limits in Ludhiana district of Punjab, India (Dhaliwal et al. 2021).

The finding of our study revealed the range of Pb concentration in vegetable samples as 6.1–9.8, 2.7–3.5, and 0.3–4.7 mg/kg in Abare, Bagega and Dareta, respectively. The results from our study indicate that, out of all the study areas, only one site in Dareta (Site 4) has its spinach samples below the 0.3 mg/kg FAO/WHO maximum allowable limits in vegetables (FAO/WHO 2001, 2007; Aderinola and Kusemiju 2012). Findings from Adewumi (2020) reveal some vegetable samples from farmland in Anka have their Pb concentrations above the maximum allowable limits of FAO. The investigation of vegetable samples grown in Pb mining areas in Pakistan by Rehman et al. (2017) revealed high Pb concentration in the studied vegetables, which agrees with our study findings. The variation in Pb accumulation in maize and spinach in this study may be connected to the fact that most leafy vegetables have higher metal accumulation than crops (Rehman et al. 2017). Furthermore, it can be attributed to the established findings that most leafy vegetables absorb significant amounts of Pb from atmospheric dust (Cao et al. 2010; Udiba et al. 2020). According to Abdu and Yusuf (2013), farming activities are still ongoing in the agricultural land affected by Pb poisoning in these areas; therefore, the Pb concentrations in the maize and spinach can be assumed to be derived from the already accumulated Pb in these contaminated areas. Moreover, the Pb content in the surrounding might be in bioavailable/mobile form that can be assimilated easily by the plants. With reference to the recent reports of Udiba et al. (2020), elevated Pb concentration in plants is directly associated with an increased Pb concentration in the soil; therefore, this could be the primary reason for the variation in the Pb concentration in the three different study areas. An additional finding by Adewumi (2020) shows a relative bioavailability of Pb in maize samples analyzed from farmlands near Anka mines. These elevated concentrations were assumed to be due to the mobilization of Pb from soil to the maize plants. From the study of Chibuike and Obiora (2014) and Adewumi (2020) it has been established that plants grown in farmlands contaminated with mining deposits or near mines have a high potential for heavy metal accumulation, and their consumption has a significant impact on agricultural products and poses a serious risk to human health.

Transfer of Pb from soil to maize and spinach

The bioaccumulation factor (BCF) of the Pb in maize and spinach was calculated from all the study sites and presented in Table 5. The BCF reflects the potential Pb uptake by maize and spinach from the agricultural land grown. The BCF of Pb in maize from all the study sites ranges from 0.01 to 0.07, while spinach ranges from 0.01 to 0.05. Although in some locations, the BCF values of maize are slightly higher than the spinach, but generally, it can be understood that the mobility or transfer of Pb from all the soils in the study areas to the plant's samples is low. The findings of this study reveal no apparent significant mobility of Pb from soil to the analyzed plant samples, as confirmed in some of these areas by Adewumi (2020). Therefore, the accumulation of the Pb in the maize and spinach can be ascribed to the significant deposition of Pb particles from dust during the intensive ore processing as opposed to the uptake from the soil during plant development. These findings are supported by several studies from these areas, which show that Pb uptake from some of these contaminated

Table 5 Transfer factor and pollution indices from the agricultural farm across the study sites

Sites/Subsites	Samples		Soil		
	BCF		Depth(cm)	Indexes	
Abare	Spinach	Maize		SPI	NCPI
1	0.03	0.01	0–20	0.91	
2	0.03	0.01	21–40	0.45	
3	0.02	0.01	61–60	0.34	
4	0.02	0.01			0.52
Bagega					
1	0.05	0.03	0–20	0.18	
2	0.04	0.04	21–40	0.15	
3	0.04	0.03	61–60	0.11	
4	0.04	0.03			0.36
Dareta					
1	0.03	0.07	0–20	0.06	
2	0.01	0.01	21–40	0.05	
3	0.01	0.02	61–60	0.04	
4	0.02	0.02			0.27

SPI-Single pollution index, NCPI-Nemerow composite pollution index; data are mean ±SD (n = 3); SPI and NCPI < 1 = Safe, SPI and NCPI > 1 = Pollution critical limit thus, unsafe; BCF = Transfer factor

soil is low and that the majority of the associated agricultural produce contamination is due to contaminated dust adhesion caused by intense mining and PbS processing (Lee et al. 2013; Roy and McDonald 2015; Tirima et al. 2018). Li et al. (2018) explained that accumulations of heavy metals in plants could be attributed to root uptake and or atmospheric deposition. This statement, therefore, validates the relatively low BCF and high Pb concentrations in the analyzed maize and spinach samples from these sites. It should be noted that some studies like Garg et al. (2014) linked to Pb contamination in other mining areas reported BCF value higher than that of our research. However, these variations may be interconnected to the nature and content of the organic matter, the chemical forms of the Pb in the soil, and the soil pH of the environment (Khan et al. 2015; Rehman et al. 2017; Udiba et al. 2020).

Pollution load indices and contamination assessment of heavy metals in the soils

The values of the SPI were computed using 400 mg/kg US EPA Pb allowable limits (Table 5). Whereas the results of the SPI in Abare range from 0.34 to 0.91, Bagega 0.11–0.18 and Dareta 0.04–0.06, the NCPI values are 0.52, 0.36 and 0.27 in Abare, Bagega and Dareta, respectively. The SPI and NCPI values of Pb from these agricultural sites indicated safety level (< 1) based on Chen et al. (2015) and Hu et al. (2017) classifications. These findings are consistent with pollution index values (PLI) reported by Yahaya et al. (2021) from some of these agricultural lands, where PLI was described as an indicator of low pollution load. However, investigation of the degree of pollution indices by Adewumi (2020) indicates a high degree of pollution in some agricultural land around Anka which is contrary to our findings. The variations could be attributed to variations in sampling locations, as different locations have varying degrees of contamination, as well as the fact that some remediation measures have been implemented in some of these areas (UNEP/OCHA 2010; Tirima et al. 2018; Anka et al. 2020; Udiba et al. 2020). For instance, PI showed low contamination of some heavy metals in Iranian agricultural soil samples (Keshavarzi & Kumar 2019). So also, there was a report of great heavy metals enrichment in agricultural soil samples with less ecological risk (Heidari et al. 2021).

Consequently, other results have suggested that heavy metals led to potential health risks to urban residents and environment (Dhaliwal et al. 2021). Contamination factor has equally revealed Pb among the key pollution contaminants and responsible for causing human health risks (Kumar et al. 2021).

Relationship of Pb with basic physicochemical parameters

Pearson correlation matrix was performed to elucidate the possible relationship between total Pb concentration and the basic soil physiochemical parameters in each study area (Fig. 4a–c). The correlation coefficient indicates a significant positive relationship between Pb with pH in Abare, Pb with K in Bagega and Pb with Ca in Dareta. The relationship between total Pb concentration and average soil pH in Abare (Table 2) can be related to the previous studies by Harter (1983), Bravo et al. (2017) and Obeng-Gyasi et al. (2021), which demonstrated a dependency of Pb retention in a soil with an increase in pH above 7.0. These findings indicate that Pb retention is high at a neutral to an alkaline condition. Correspondingly, the relationship between Pb and K in Bagega and Pb and Ca in Dareta can be described as Pb and CEC association. This relationship is interrelated to the finding of Zheng et al. (2020), who illustrated the significant contribution of CEC as an essential soil parameter influencing the availability of Pb in contaminated soil. As a result of these important findings, it is crucial to consider soil pH and CEC when assessing the risk of Pb exposure in a polluted environment. This is significant because Pb content in an environment fluctuates with changes in basic environmental conditions (Wani et al. 2015; Xiao et al. 2017; Zheng et al. 2020).

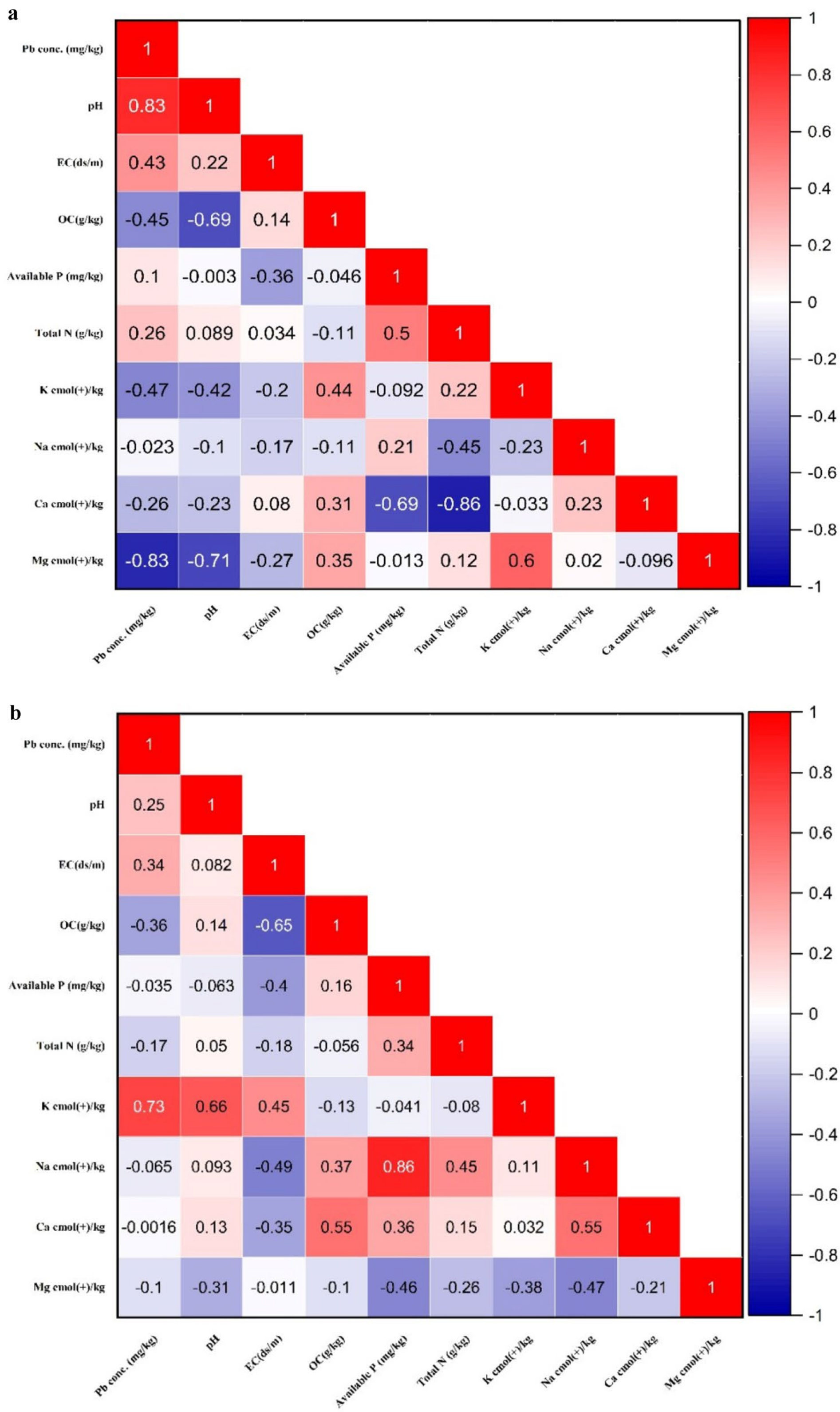

Fig. 4 Pearson's correlation matrix between average Pb concentrations (mg/kg) of soil and basic physicochemical parameters in the farmland across the Abare sites, Anka Local (**a**), Bagega sites, Anka local (**b**), and Dareta sites, Anka local (**c**) Governments, Zamfara State, Nigeria

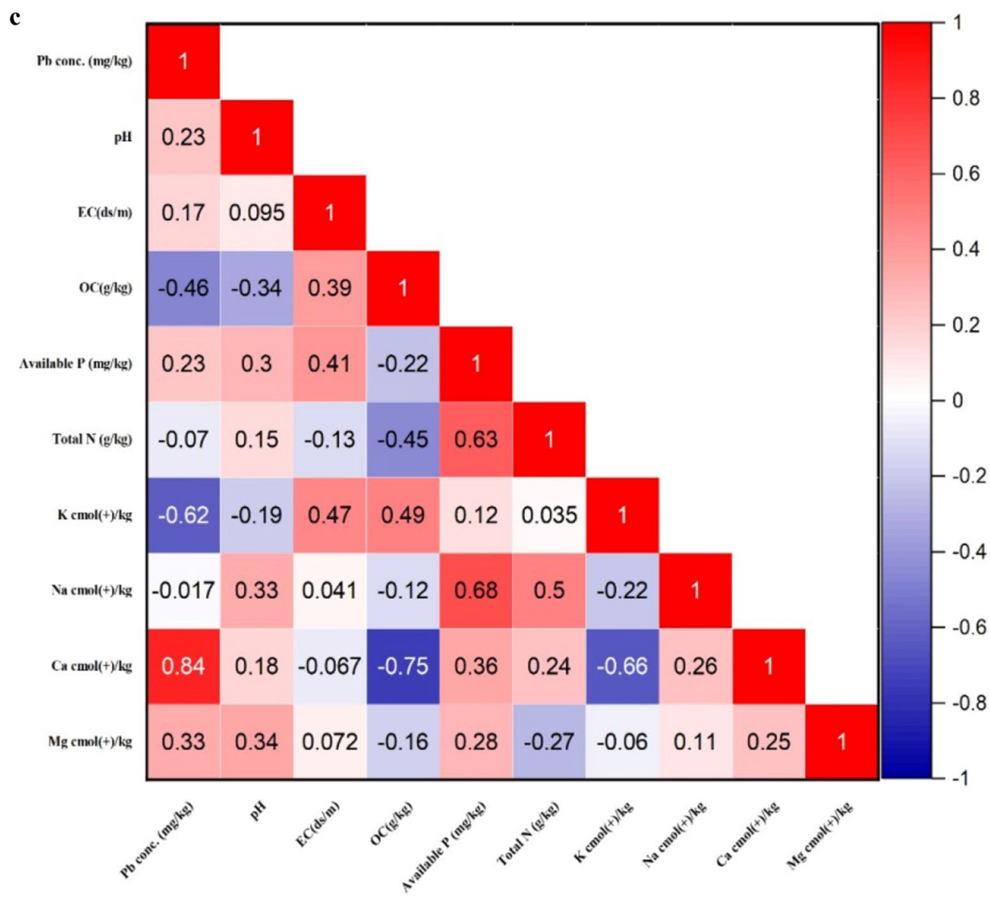

Fig. 4 continued

Conclusion and future directions

The purpose of this study was to determine the concentrations, contamination, and exposure risk associated with Pb contamination in some agricultural land in and around Anka mines. In summary, the total Pb concentrations from all the soil in the cultivated lands analysed in the study sites were found to be below the EPA 400 mg/kg permissible limits while those analysed in Abare demonstrate elevated Pb concentrations above the DPR 85 mg/kg threshold. The study further revealed a decrease in total Pb concentration with increasing depth at all agricultural land studied, which is an indicator of possible soil contamination by Pb particles from dust deposition and anthropogenic sources instead of geogenic origin. Based on the SPI and NCPI indices, all the studied areas can be regarded as safe for agricultural activity. Unlike the maize grown from all these areas, which can be safe for consumption, the spinach grown is unsafe for consumption. Importantly, pH and CEC show a significant relationship with total Pb concentrations, thus determining these areas' Pb fate. To effectively manage and regulate Pb pollution and toxicity in those areas, it is recommended to devote additional attention to studying the chemical forms, speciation, bioavailability, and biogeochemical mechanisms influencing Pb mobility in those areas. Overall, that information will provide greater insight into developing more effective remediation strategies for the affected localities.

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Author contributions
AID and SI conceptualized and designed the research. AID conducted the experiments. AID, AS, PZ and JY drafted the manuscript. All authors read and approved the final manuscript.

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Data sharing will be made available as per request to the corresponding author.

Declarations

Ethics approval and consent to participate
Ethical approval was obtained from the Ministry of Health, Zamfara state and consent was not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences, Beijing 100081, People's Republic of China. [2]Department of Biological Sciences, Bayero University, Kano, Nigeria. [3]Department of Instrument Science and Engineering, School of Electronics, Information and Electrical Engineering, Shanghai Jiao Tong University, Shanghai, People's Republic of China. [4]International Faculty of Applied Technology, Yibin University, Yibin 644000, People's Republic of China.

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