FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 10 No. 21, November, 2026, pp 297 – 302
DOI: https://doi.org/10.33003/fjs-2026-1021-6254

Spatial Distribution of Potentially Toxic Elements and Physicochemical Properties of Soils at a Military Shooting Range in Buni Yadi, Yobe State, Nigeria

***Muhammad Modu, Yakubu Magaji, Bashir Muhammad Sanda**

Department of Biotechnology, Faculty of Science, Nigerian Defence Academy, Kaduna, Nigeria.

*Corresponding authors' email: muhammadmodu36@gmail.com
ORCID: https://orcid.org/0009-0003-9928-1366

Received: 17 Aug. 2026
Accepted: 30 Oct. 2026
Published: 04 Nov. 2026

ABSTRACT
Military shooting ranges may receive inputs of metal containing ammunition, which can contribute to the localized accumulation of trace elements in soil. This study evaluated selected physicochemical properties and concentrations of lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As) and copper (Cu) in soils from the 27 Task Force Military Brigade Shooting Range in Buni Yadi, Yobe State, Nigeria. Twelve independent soil samples were collected, comprising three samples from each of three distances from the main shooting point (200 m, 100 m and 50 m) and three samples from a control location approximately 1 km away from the main shorting range. Soil pH, electrical conductivity (EC), bulk density, water-holding capacity, total nitrogen and temperature were assessed, while trace element concentrations were determined using atomic absorption spectrophotometry (AAS). Soil pH ranged from 5.7 to 6.4, and EC ranged from 1.975 to 1.997 mS/cm. Point C (50 m) had the highest mean concentrations of all five elements. Lead concentrations ranged from 24.45 ± 0.07 mg/kg in the control soil to 205.53 ± 0.03 mg/kg at Point C, while cadmium concentrations ranged from 0.30 ± 0.01 to 3.01 ± 0.03 mg/kg. Relative enrichment at Point C compared with the control was 8.41-fold for Pb, 10.03-fold for Cd, 1.36-fold for Cr, 3.46-fold for As and 1.64-fold for Cu. These findings indicate localized enrichment, particularly of Pb and Cd, and highlight the need for continued monitoring and further investigation of element mobility and bioavailability.

Keywords: Potentially Toxic Elements, Military Shooting Range, Soil Properties, Lead, Cadmium

INTRODUCTION

Soils can accumulate potentially toxic elements through natural processes and anthropogenic activities. Unlike many organic pollutants, elements such as metals cannot be broken down by natural processes and may remain in the soil for long periods. Their retention, mobility and potential effects on the environment are influenced by several soil properties, including pH, organic matter content, texture and ionic composition (Alloway, 2013; Kabata-Pendias, 2011; Tchounwou *et al.,* 2012). Anthropogenic activities can contribute to the accumulation of potentially toxic elements in soils, making the assessment of contaminated areas important for environmental protection. For example, Oteno et al. (2023) assessed heavy metal concentrations in soils around the Ajaokuta Steel Company and demonstrated the importance of evaluating metal contamination in soils affected by human activities.

Military shooting ranges are potential sources of localized soil contamination because ammunition fragments and particulate residues may introduce heavy metals and other toxic elements into the surrounding environment. Depending on the composition of the ammunition and local environmental conditions, these residues may contain lead (Pb), copper (Cu) and other toxic elements. Over time, weathering can alter the chemical forms of deposited residues and influence their mobility in soil (Cao *et al.,* 2003). Previous research have reported differences in heavy metal concentrations and bioaccessibility in shooting range soils, with lead identified as a major pollutant of concern (Sanderson et al., 2012; Sanderson et al., 2018).

Studies conducted in Nigeria similarly demonstrate the importance of investigating pollution at individual shooting ranges. Etim and Onianwa (2012) reported lead contamination in soil around a military shooting range in Ibadan, while Lawal et al. (2019) investigated Pb, Cd and Cu in soils from a shooting range in Katsina State. Although these studies provide useful information on potential pollution associated with military shooting ranges in Nigeria, their findings cannot be assumed to represent conditions at other locations. Differences in site characteristics, activities and environmental conditions may influence the concentrations and distribution of potentially toxic elements in soil.

Soil physicochemical properties play a vital role in determining how elements are retained and transported within the soil environment. Soil pH influences processes such as dissolution and adsorption, while electrical conductivity (EC) provides information about the concentration of soluble ions. Bulk density and water-holding capacity describe physical characteristics related to soil pore space and water retention. Previous research of shooting range soils have shown that soil properties can influence the distribution and mobility of ammunition associated elements (Cao et al., 2003; Sanderson et al., 2012; Mariussen et al., 2017). Examining these properties alongside element concentrations can therefore help explain the conditions under which potentially toxic elements occur in soil. Also, research on contaminated shooting ranges has emphasized the significance of understanding element flexibility and site specific environmental conditions when considering appropriate management measures (Okkenhaug et al., 2016; Zhu et al., 2024).

Despite existing research on soil pollution, information on potentially toxic elements at the 27 Task Force Military Brigade Shooting Range in Buni Yadi, Gujba Local Government Area, Yobe State, Nigeria, remains limited. In particular, site specific data are needed on the concentrations

of lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As) and copper (Cu) at different distances from the main shooting point and in comparison with a control location. Assessing these toxic elements together with selected soil physicochemical properties can provide baseline information for environmental monitoring and help identify areas that may require further investigation.

MATERIALS AND METHODS

Study Area

The study was conducted at the 27 Task Force Military Brigade Shooting Range in Buni Yadi, Gujba Local Government Area, Yobe State, Nigeria. Buni Yadi is located in northeastern Nigeria, the region characterized by distinct wet and dry seasons and generally high temperatures.

The shooting range is used for military firearms training. The site was selected because repeated shooting activities may contribute to the localized deposition of ammunition derived materials in surface soils. The sampling design was established to examine differences in the concentrations of selected potentially toxic elements at different distances from the main shooting point.

Field observations indicated that firing was directed towards the target area. The soil near the sampling location closest to the target area was comparatively soft and supported less vegetation, whereas the locations farther from the target area generally had harder soil and greater grass cover. These observations describe the conditions at the site during sampling but do not establish the causes of the observed differences in soil characteristics or element concentrations.

Soil Sampling

Soil samples were collected on 7 November 2025 from three sampling locations at different distances from the main shooting point. At each distance, three separate soil samples were collected randomly. The sampling points were designated A1–A3 at approximately 200 m (Point A), B1–B3 at approximately 100 m (Point B), and C1–C3 at approximately 50 m (Point C). Three additional samples, designated D1–D3, were collected from a control location approximately 1km away from the main shooting point.

The soil Samples were collected from the deep of 15cm using a soil auger. Each sample was placed in a clean, labelled container and transported to the biological science laboratory of yobe state university for preparation and analysis. All samples were prepared and analyzed independently.

The control location was situated about 1km from the main shooting point, outside the immediate shooting area. Field observations showed that the control site had greater vegetation cover and harder soil, conditions broadly similar to those observed at Points A and B. The control site was therefore used as a comparison location, and this limitation was considered when interpreting differences in element concentrations.

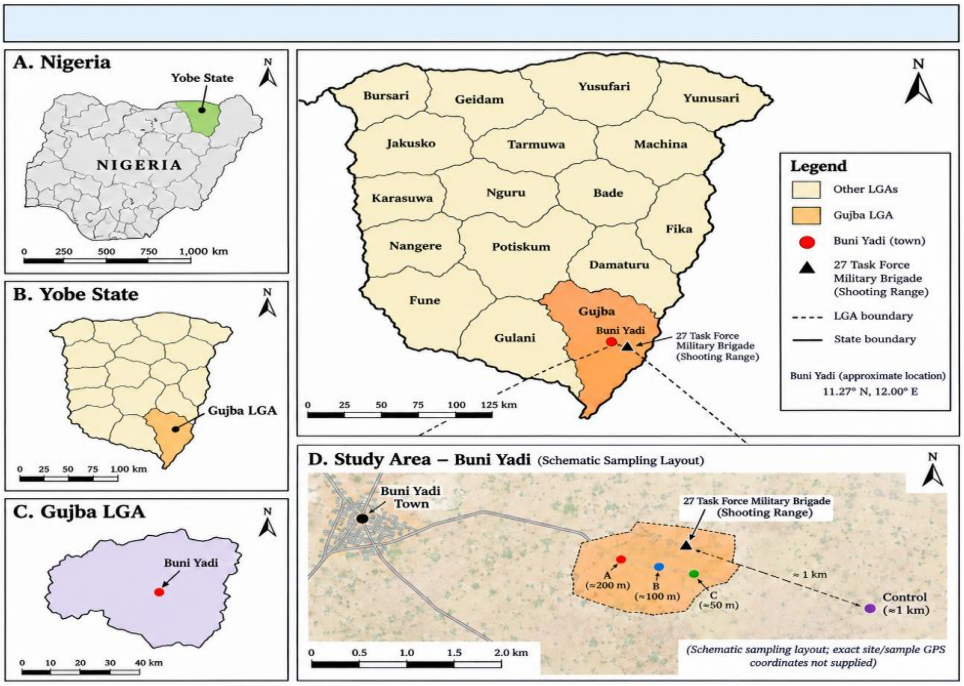


Figure 1: Location of the Study Area in Buni Yadi, Gujba Local Government Area, Yobe State, Nigeria

Note. The figure shows the location of Buni Yadi within Gujba Local Government Area, Yobe State, Nigeria, and the schematic arrangement of the sampling locations at approximately 200 m (Point A), 100 m (Point B), and 50 m (Point C) from the main shooting point, together with the control site located approximately 1 km from the main shooting point.

Sample Preparation

The soil samples were air-dried for approximately 2–3 weeks. After drying, the samples were gently disaggregated and passed through a 250 µm sieve to remove coarse debris and obtain a more uniform soil fraction for analysis. The prepared samples were stored in clean containers until physicochemical characterization and trace element analysis were carried out.

Determination of Physicochemical Properties

Soil pH was measured using the glass-electrode method described by McLean (1982). Electrical conductivity (EC) was determined using procedures for assessing soluble salts in soil extracts, as described by Rhoades (1982). Bulk density was determined using the soil-core method, while water-holding capacity was assessed by measuring the amount of water retained by the soil after saturation and drainage. Total

nitrogen was determined using established soil analytical procedures described by Anderson and Ingram (1989). Soil temperature was measured in situ at the sampling locations during sample collection using a soil thermometer, adapting the method described by Brady and Weil (2008). The thermometer was inserted into the soil at the root zone depth, and readings were taken after stabilization to ensure accurate measurement of soil temperature at the time of sampling.

Acid Digestion of Soil Samples

For trace element analysis, 1 g of each processed soil sample was weighed into a digestion vessel. A mixture of nitric acid and perchloric acid was added in a 5:2 volume ratio, comprising 5 mL of nitric acid and 2 mL of perchloric acid. The samples were heated in a fume hood until digestion was complete. After digestion, the samples were allowed to cool, and the resulting solutions were filtered through Whatman No. 42 filter paper. Each filtrate was transferred into a 50 mL volumetric flask and diluted to the mark with distilled water.

Determination of Potentially Toxic Elements by Atomic Absorption Spectrophotometry

The concentrations of lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As) and copper (Cu) in the prepared soil digests were determined using atomic absorption spectrophotometry (AAS). Calibration standards were used for instrumental analysis, and the concentrations of the elements in the samples were obtained from the corresponding analytical responses. The results were expressed as milligrams per kilogram of soil (mg/kg).

Data Analysis

The analytical results were organized according to sampling location. For each investigated element, the concentrations measured in the three independently collected soil samples at each location were summarized as the mean ± standard deviation (SD) using Microsoft Excel.

Differences in element concentrations among Points A, B and C and the control location were examined descriptively. Relative enrichment at Point C was calculated by dividing the mean concentration of each element at Point C by its corresponding mean concentration at the control location, using the following equation:

Relative enrichment = Mean concentration at Point C / Mean concentration at the control location

RESULTS AND DISCUSSION

Physicochemical Properties of the Soil

The physicochemical properties of soils collected from the 27 Task Force Military Brigade Shooting Range in Buni Yadi, Yobe State, Nigeria, are presented in Table 1. The parameters assessed included pH, electrical conductivity (EC), bulk density, water-holding capacity, total nitrogen and soil temperature.

Table 1: Physicochemical Properties of Soils from the Buni Yadi Military Shooting Range

Parameter	Point A (200m)	Point B (100m)	Point C (50m)	Control D (1km)
pH	6.4	6.1	5.8	5.7
EC (mS/cm)	1.975	1.982	1.997	1.984
Bulk density (g/cm³)	1.43	1.38	1.51	1.46
Water holding capacity (%)	35.2	35.8	31.5	43.7
Total nitrogen (%)	0.12	0.10	0.19	0.18
Soil temperature (°C)	31.2	30.8	31.5	28.9

Note: Points A, B and C represent sampling locations 200m, 100m and 50m from the main shooting point, respectively. D represents the control location around 1km away from the main shooting point.

Soil pH ranged from 5.7 in the control soil to 6.4 at Point A, indicating acidic conditions across all sampled locations. The pH at Point C was 5.8, lower than the values recorded at Points A and B but slightly higher than that of the control. Soil acidity is relevant to the behavior of potentially toxic elements because pH can influence their adsorption, dissolution and chemical transformations in soil (Alloway, 2013; Kabata-Pendias, 2011). Previous studies have also highlighted the influence of pH on lead behavior in shooting range soils (Cao et al., 2003; Sanderson et al., 2012).

Electrical conductivity ranged from 1.975 mS/cm at Point A to 1.997 mS/cm at Point C, while the control recorded 1.984 mS/cm. The relatively narrow range indicates that EC values were similar across the sampled locations. Electrical conductivity reflects the concentration of soluble ions in soil extracts and may vary with the amount of dissolved salts and other ionic constituents present (Rhoades, 1982). A higher value was noticed at Point C and this observation alone does not explain the higher concentrations of the investigated elements at that location.

Bulk density varied from 1.38 g/cm³ at Point B to 1.51 g/cm³ at Point C. The value at Point C was higher than those recorded at the other sampling locations, indicating greater soil mass per unit volume under the conditions measured. Bulk density is related to soil pore space and can influence water movement through the soil.

Water-holding capacity ranged from 31.5% at Point C to 43.7% in the control soil. Point C therefore had the lowest water-holding capacity among the sampled locations, whereas the control had the highest. Differences in water retention may influence soil-water movement and the transport of dissolved constituents. However, these processes also depend on other factors, including soil texture, organic matter content and the chemical forms of the elements present (Kabata-Pendias, 2011).

Total nitrogen concentrations ranged from 0.10% at Point B to 0.19% at Point C. The control recorded 0.18%, while Point A had a concentration of 0.12%. Although Point C had the highest measured total nitrogen concentration, its value was close to that of the control. The results did not show a consistent change in total nitrogen with increasing distance from the main shooting point. The observed variation therefore describes differences among the sampled locations rather than an established spatial relationship.

Soil temperature ranged from 28.9°C in the control to 31.5°C at Point C. The temperatures recorded at Points A and B were 31.2°C and 30.8°C, respectively. The higher temperature measured at Point C may reflect differences in surface conditions and exposure at the time of sampling. Since temperature was measured during field collection, the results represent conditions at that particular time and should not be interpreted as evidence of long-term temperature differences among the locations.

The physicochemical properties varied among the sampled locations. Point C had the highest EC, bulk density, total nitrogen and soil temperature, but the lowest water-holding capacity among the three point at the shooting-range. These measurements provide useful environmental context for interpreting the distribution of potentially toxic elements.

Concentrations of Selected Potentially Toxic Elements

The concentrations of lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As) and copper (Cu) in the soil samples, determined using atomic absorption spectrophotometry (AAS), are presented in Table 2. The results are expressed as mean ± standard deviation (SD), in milligrams per kilogram of soil (mg/kg).

Table 2: Concentrations of Selected Potentially Toxic Elements in Soils from the Buni Yadi Military Shooting Range

Element	Point A (200 m), mg/kg	Point B (100 m), mg/kg	Point C (50 m), mg/kg	Control D (1 km), mg/kg
Lead (Pb)	28.85 ± 0.05	53.22 ± 0.03	205.53 ± 0.03	24.45 ± 0.07
Cadmium (Cd)	0.54 ± 0.01	1.44 ± 0.01	3.01 ± 0.03	0.30 ± 0.01
Chromium (Cr)	12.02 ± 0.01	12.25 ± 0.02	14.25 ± 0.01	10.48 ± 0.03
Arsenic (As)	11.74 ± 0.01	14.75 ± 0.01	31.10 ± 0.02	8.99 ± 0.01
Copper (Cu)	38.48 ± 0.03	39.98 ± 0.03	52.50 ± 0.02	31.98 ± 0.03

Note: Values are presented as mean ± standard deviation based on three independent soil samples per location. Points A, B and C represent locations approximately 200 m, 100 m and 50 m from the main shooting point, respectively. Control D represents the control location approximately 1 km from the main shooting point

Point C, located nearly 50m from the main shooting point, recorded the highest mean concentration of each of the five investigated elements. In general, concentrations at Point A were lower than those at Points B and C, although the magnitude of the differences varied among elements. This pattern describes the observed distribution of the elements across the sampled locations.

Lead showed the largest difference among the sampling locations. Its concentration increased from 24.45 ± 0.07 mg/kg in the control to 28.85 ± 0.05 mg/kg at Point A, 53.22 ± 0.03 mg/kg at Point B and 205.53 ± 0.03 mg/kg at Point C. The pronounced increase at Point C is consistent with the well-established occurrence of Pb in soils affected by shooting activities. (Etim & Onianwa, 2012) reported substantial Pb accumulation around the berm of a military shooting range in Ibadan, Nigeria. Similar concentration patterns have been reported in shooting ranges elsewhere, where Pb residues are commonly concentrated around firing and impact areas (Cao *et al.,* 2003; Sanderson *et al.,* 2012; Sanderson *et al.,* 2018).

The relatively sharp increase between Points B and C is particularly noteworthy. Point B was 100 m from the shooting point, whereas Point C was 50 m away. This pattern suggests that the accumulation of Pb was concentrated near the shooting area rather than being evenly distributed throughout the range.

Cadmium (Cd) concentrations increased from 0.30 ± 0.01 mg/kg in the control to 0.54 ± 0.01 mg/kg at Point A, 1.44 ± 0.01 mg/kg at Point B and 3.01 ± 0.03 mg/kg at Point C. The highest mean concentration was therefore recorded at Point C, indicating enrichment relative to the control. Cadmium has also been investigated in soils associated with shooting ranges and other human activities (Etim & Onianwa, 2012; Lawal et al., 2019).

Chromium (Cr) concentrations ranged from 10.48 ± 0.03 mg/kg in the control to 12.02 ± 0.01 mg/kg at Point A, 12.25 ± 0.02 mg/kg at Point B and 14.25 ± 0.01 mg/kg at Point C. While Point C had the highest mean concentration, the difference between Point C and the control was smaller than the corresponding differences observed for Pb and Cd. The increase Cd Possible as a results of ammunition related inputs, natural soil composition or other sources.

Arsenic (As) concentrations were 8.99 ± 0.01 mg/kg in the control, 11.74 ± 0.01 mg/kg at Point A, 14.75 ± 0.01 mg/kg at Point B and 31.10 ± 0.02 mg/kg at Point C. The concentration at Point C was approximately 3.46 times that of the control, this show the arsenic occur in the study as a result of the human activities, such as military shorting range. Although in many case arsenic can occur naturally in the environment.

Copper (Cu) concentrations ranged from 31.98 ± 0.03 mg/kg in the control to 38.48 ± 0.03 mg/kg at Point A, 39.98 ± 0.03 mg/kg at Point B and 52.50 ± 0.02 mg/kg at Point C. The highest mean concentration was recorded at Point C. Copper has also been investigated in studies of shooting range soils and other potentially contaminated environments (Mariussen et al., 2017).

Therefore, all the five investigated elements recorded their highest mean concentrations at Point C. This pattern indicates localized enrichment in the sampled soil closest to the main shooting point, particularly for Pb and Cd. Though, the relative magnitude of enrichment differs among the elements, as shown by the enrichment ratios presented in Section 3.3.

Relative Enrichment of Potentially Toxic Elements

Relative enrichment at Point C was assessed by comparing the mean concentration of each potentially toxic element at Point C with its corresponding mean concentration in the control soil (Point D). The enrichment ratio was calculated by dividing the mean concentration at Point C by the mean concentration in the control. The results are presented in Table 3.

Table 3: Relative Enrichment of Selected Potentially Toxic Elements at Point C Compared with the Control

Element	Control D (mg/kg)	Point C (mg/kg)	Relative enrichment (fold)
Lead (Pb)	24.45	205.53	8.41
Cadmium (Cd)	0.30	3.01	10.03
Chromium (Cr)	10.48	14.25	1.36
Arsenic (As)	8.99	31.10	3.46
Copper (Cu)	31.98	52.50	1.64

Note: Relative enrichment = mean concentration at Point C ÷ mean concentration at control location D. Enrichment ratios are dimensionless and are expressed as fold differences rather than in mg/kg.

Cadmium showed the highest relative enrichment, with a concentration about 10.03 times that of the control soil. Lead had the second highest enrichment ratio at 8.41-fold, followed by arsenic (3.46-fold), copper (1.64-fold) and chromium (1.36-fold). These results show that the degree of enrichment differed among the five elements.

The high enrichment ratio for Cd should be interpreted in relation to its relatively low concentration in the control soil. A high ratio does not mean that Cd had the highest absolute concentration. In contrast, Pb had the highest absolute concentration at Point C and also showed substantial relative enrichment.

Point C was used for this calculation because it was the closest sampling location to the main shooting point and recorded the highest mean concentration for each of the five investigated elements. The calculation therefore represents the maximum observed enrichment relative to the control. It does not replace the broader spatial comparison provided in Table 2.

The enrichment pattern supports the interpretation that the soils closest to the shooting point received greater accumulation of the investigated elements. Previous studies have similarly reported higher concentrations of ammunition associated metals in areas receiving greater amounts of firing residues (Cao *et al.,* 2003; Mariussen *et al.,* 2017).

Relationship Between Physicochemical Conditions and Element Distribution

Point C had the highest measured mean concentrations of all five investigated elements. It also recorded the lowest pH among Points A, B and C, the highest electrical conductivity (EC), the highest bulk density, the lowest water-holding capacity and the highest soil temperature among the sampled locations. These findings show that differences in soil properties and element concentrations occurred together at Point C.

Soil pH can influence the solubility, adsorption and mobility of potentially toxic elements. Previous studies of shooting-range soils have shown that pH can affect the behavior of lead (Pb), including the formation and dissolution of secondary lead minerals (Cao et al., 2003; Sanderson et al., 2012). The relatively low pH recorded at Point C may be relevant to understanding the potential conduct of the elements at the site.

Electrical conductivity varied only slightly among the sampling locations, ranging from 1.975 to 1.997 mS/cm. Though Point C recorded the highest value, this small difference cannot, by itself, explain the higher concentrations of Pb and cadmium (Cd) observed at that location. Similarly, variations in bulk density and water-holding capacity indicate differences in the physical characteristics of the soils.

Further investigation of soil texture, organic matter content, element speciation and mobility would help clarify how soil properties influence the performance of the investigated elements at the study site. The present findings should therefore be interpreted as evidence of co-occurring differences in soil characteristics and element concentrations.

Environmental Significance

The concentrations of Pb, Cd, chromium (Cr), arsenic (As) and copper (Cu) varied among the sampled locations, with the highest measured mean concentration of each element recorded at Point C, closest to the main shooting point. This pattern indicates localized differences in element concentrations within the sampled area. Although ammunition residues are a possible source of those toxic elements in the shooting range soils (Sanderson *et al.,* 2018; Zhu *et al.,* 2024)

Lead and cadmium warrant particular attention because of their measured concentrations and relative enrichment patterns. Lead had the highest absolute concentration at Point C, whereas cadmium showed the highest relative enrichment compared with the control. These findings identify the two elements as priorities for further investigation and monitoring. However, the study measured concentrations in acid-digested soil samples and did not assess element speciation, bioavailability, leaching potential or ecological and human health risk indices.

Previous studies have shown that ammunition associated elements can persist in shooting range soils and that weathering processes may influence the mobility of deposited residues (Mariussen et al., 2017; Okkenhaug et al., 2016). Continued monitoring of the Buni Yadi site is therefore appropriate, particularly in areas close to the shooting and impact zones. Repeated sampling over time would help establish whether the observed concentrations remain relatively stable or change under local environmental conditions.

Future studies should include broader spatial and temporal sampling and direct assessments of element mobility, bioavailability and potential exposure pathways. Investigating additional ammunition-associated elements and applying suitable source characterisation methods could also help clarify the origins of the measured concentrations. These investigations would offer a stronger indication base for environmental assessment and the development of appropriate management measures at the Buni Yadi shooting range.

CONCLUSION

This study evaluated selected physicochemical properties and concentrations of lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As) and copper (Cu) in soils from the 27 Task Force Military Brigade Shooting Range in Buni Yadi, Yobe State, Nigeria. The highest measured mean concentration of each element was recorded at Point C, approximately 50 m from the main shooting point. Lead had the highest absolute concentration at this location (205.53 ± 0.03 mg/kg), whereas cadmium showed the greatest relative enrichment compared with the control, at approximately 10.03-fold. The enrichment ratios for Pb, Cr, As and Cu were 8.41, 1.36, 3.46 and 1.64, respectively. These findings indicate localized differences in the concentrations of the investigated elements, particularly Pb and Cd.This study provides baseline information to support continued environmental monitoring of the shooting range. Further research on element sources, mobility, bioavailability and potential exposure pathways is needed to better understand the environmental implications of the observed concentrations.

STUDY LIMITATIONS

Several limitations should be considered when interpreting the findings. First, sampling was restricted to three locations at different distances from the main shooting point and one control location approximately 1 km away, with three independent soil samples collected at each location. Although this approach allowed comparisons among the sampled locations, it may not adequately represent element distribution across the entire shooting range. Second, the geological equivalence of the control soil and the shooting range soils was not established. Consequently, differences between the control and sampling locations may reflect both

site related influences and natural variations in soil characteristics. Third, the sources of the investigated elements could not be conclusively identified because source characterisation analyses were not performed. Natural soil composition and other human activities may also have contributed to the measured concentrations. Fourth, the study did not directly assess element speciation, mobility, bioavailability, leaching potential or human and ecological exposure pathways. The measured concentrations alone are therefore insufficient to establish the extent of biological exposure or demonstrate a specific health risk.

RECOMMENDATIONS

Future studies should expand the spatial coverage of sampling to include additional locations within and around the shooting range and incorporate repeated sampling over time. The suitability of the control location should also be examined through comparisons of relevant soil and geological characteristics. Further analyses should investigate the speciation, mobility, bioavailability and leaching potential of the elements to improve understanding of their behavior under local environmental conditions. Source characterisation methods should be considered to help distinguish possible ammunition related inputs from natural or other anthropogenic sources. Investigating additional ammunition associated elements not included in the present study would also provide a more comprehensive assessment. Where appropriate, assessments of potential exposure pathways and ecological receptors should be conducted to determine whether the measured concentrations present a meaningful environmental concern. These investigations would strengthen the evidence available for long term monitoring and informed environmental management of the Buni Yadi military shooting range.

ACKNOWLEDGEMENTS

The authors acknowledge the Nigerian Defence Academy, Kaduna, and the Yobe State University Microbiology Laboratory for the institutional and laboratory support provided during this study and 27 task force military brigade commandant.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest associated with this study.

FUNDING

No external funding was received for this study.

REFERENCES

Alloway, B. J. (2013). *Heavy metals in soils: Trace metals and metalloids in soils and their bioavailability* (3rd ed.). Springer.

Anderson, J. M., & Ingram, J. S. I. (1989). *Tropical soil biology and fertility: A handbook of methods*. CAB International.

Cao, X., Ma, L. Q., Chen, M., Hardison, D. W., & Harris, W. G. (2003). Lead transformation and distribution in the soils of shooting ranges in Florida, USA. *Science of the Total Environment, 307*(1–3), 179–189. https://doi.org/10.1016/S0048-9697(02)00543-0

Etim, E. U., & Onianwa, P. C. (2012). Lead contamination of soil in the vicinity of a military shooting range in Ibadan, Nigeria. *Toxicological & Environmental Chemistry, 94*(5), 895–905. https://doi.org/10.1080/02772248.2012.678997

Kabata-Pendias, A. (2011). *Trace elements in soils and plants* (4th ed.). CRC Press.

Lawal, I. A., Uba, S., & Ekwumemgbo, P. A. (2019). Concentrations of lead, cadmium and copper in soil samples at a shooting range in Nasinta, Katsina, Nigeria. *Nigerian Research Journal of Chemical Sciences, 7*(2), 133–142.

Mariussen, E., Johnsen, I. V., & Strømseng, A. E. (2017). Distribution and mobility of lead (Pb), copper (Cu), zinc (Zn), and antimony (Sb) from ammunition residues on shooting ranges for small arms located on mires. *Environmental Science and Pollution Research, 24*(11), 10182–10196. https://doi.org/10.1007/s11356-017-8647-8

McLean, E. O. (1982). Soil pH and lime requirement. In A. L. Page, R. H. Miller, & D. R. Keeney (Eds.), *Methods of soil analysis: Part 2. Chemical and microbiological properties* (2nd ed., pp. 199–224). American Society of Agronomy and Soil Science Society of America.

Okkenhaug, G., Grasshorn Gebhardt, K.-A., Amstaetter, K., Bue, H. L., Herzel, H., Mariussen, E., Almås, Å. R., Cornelissen, G., Breedveld, G. D., Rasmussen, G., & Mulder, J. (2016). Antimony (Sb) and lead (Pb) in contaminated shooting range soils: Sb and Pb mobility and immobilization by iron based sorbents, a field study. *Journal of Hazardous Materials, 307*, 336–343. https://doi.org/10.1016/j.jhazmat.2016.01.005

Oteno, F., Musa, Q., Ilabija, J., Adaji, M. U., Usman, A. O., Ekwoba, L., & Omale, S. (2023). Assessment of the heavy metal pollution of the soil of Ajaokuta Steel Company, Ajaokuta, Kogi State, Nigeria. *FUDMA Journal of Sciences, 7*(5), 356–358. https://doi.org/10.33003/fjs-2023-0705-2029

Rhoades, J. D. (1982). Soluble salts. In A. L. Page, R. H. Miller, & D. R. Keeney (Eds.), *Methods of soil analysis: Part 2. Chemical and microbiological properties* (2nd ed., pp. 167–179). American Society of Agronomy and Soil Science Society of America.

Sanderson, P., Naidu, R., Bolan, N., Bowman, M., & McLure, S. (2012). Effect of soil type on distribution and bioaccessibility of metal contaminants in shooting range soils. *Science of the Total Environment, 438*, 452–462. https://doi.org/10.1016/j.scitotenv.2012.08.014

Sanderson, P., Qi, F., Seshadri, B., Wijayawardena, A., & Naidu, R. (2018). Contamination, fate and management of metals in shooting range soils: A review. *Current Pollution Reports, 4*(2), 175–187. https://doi.org/10.1007/s40726-018-0089-5

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., & Sutton, D. J. (2012). Heavy metal toxicity and the environment. In A. Luch (Ed.), *Molecular, clinical and environmental toxicology* (Vol. 101, pp. 133–164). Springer. https://doi.org/10.1007/978-3-7643-8340-4_6

Zhu, Y., Che, R., Tu, B., Miao, J., Lu, X., Li, J., Zhu, Y., & Wang, F. (2024). Contamination and remediation of contaminated firing ranges—An overview. *Frontiers in Environmental Science, 12*, Article 1352603. https://doi.org/10.3389/fenvs.2024.1352603

©2026 This is an Open Access article distributed under the terms of the Creative Commons Attribution 4.0 International license viewed via https://creativecommons.org/licenses/by/4.0/ which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is cited appropriately.