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Assessment of spatial distribution of lead in soils around an active military shooting range

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Abstract. In this study, the extent of Pb contamination around an active military shooting range is re-assessed to ascertain current contamination status comparatively to data's reported 20 years ago. This is because lead bullet disintegration and mobility takes several years and extensively affects levels of soil-Pb contamination. A total of 120 topsoil samples were collected within the impact area (front) and non-impact area (back) for Pb determination. High concentrations of Pb were found at impact berm both front (28940±2996 µg/g) and back (775±128 µg/g). Spatial distribution of contamination reflects the distances from berm. Soil-Pb contamination around non-impact area was notable at back berm through to 100 m distance with significant difference in Pb, Cr, Ni and Zn levels. Concentration of Pb at berm was observed to have increase five-fold over a period of about twenty years from previous study with accumulation factor of about 1000. Principal component analysis PCA indicated 67 % of total metal load of range soil was majorly from impact areas of the berm. The correspondence analysis relay plot shows pollution order of Pb > Ni > Cd > Cr > Zn > Cu. This confirms soil contamination especially around the impact area, i.e. impact berm and firing lines and non-impact area at 0 m, 10 m, 50 m and 100 m. Environmental consequence of high soil-Pb levels within the range especially non-impact areas utilized for farming activities will leave much to desire. Hence, extensive and continuous monitoring is needed. However, remediation through appropriate soil washing technique could reduce Pb levels and improve soil condition regardless of age.

***Keywords*:** lead; soil contamination; bullet; shooting range; principal component analysis.

1. Introduction

Soil is an essential natural resource that plays fundamental role in human development by supporting life forms in the ecosystem [1]. Passing years, soil contamination associated with various human activities such as shooting range, industrial, agricultural, mining, and waste disposal has been on the increase [2]. Among these sources of contamination, shooting range activity impacts negatively on the range surrounding environment especially soil contamination [3-6]. Some major contaminant associated with this activity is trace metals particularly lead [7-9]. Lead contamination from spent bullet fragments, among other pollutants have been known for its persistence in soil [10], and high concentrations usually reported at impact berm and firing lines [11, 12]. Mobility of Pb in range soil is always enhanced by natural weathering processes and soil conditions like pH, redox potential, moisture content, organic carbon [13, 14]. Particulate Pb from weathering process of bullet fragments and deposit are readily bioavailable in soil ecosystem, while Pb-dust can be absorbed by human body through skin contact, inhalation and assimilation [15-17]. Bioavailability of lead in shooting range soil can be a burden to the immediate and surrounding environment through bioaccumulation in food chain posing serious threat to humans and living organism [5, 18-20]. Lead is highly toxic even at low concentration in adults and children, small amount as low as 10 µg/L in human blood can affect the brain and nervous damage causing visual impairment even death [21-24].

There are several military and non-military shooting range across Nigeria with different degree of soil-Pb contamination [25-27]. Several of them are found in different regions of the country, however, in the southwestern region, the Second Mechanized Division Military Shooting Range is considered one of the oldest presently, and has been in existence for well over 70 years. Within the range is the impact berm, target basement and 100 to 500 m firing lines. The surrounding vegetation both in front and behind impact berm are farmlands for locally cultivated agricultural produce. From previous study conducted in 2004 [15], the range has continuously witness increased activities due to current security challenges of the country. Average lead concentration of about 5680±2700 µg/g in topsoil and 6370±2800 µg/g in sub soil was reported then at the impact berm [28].

Therefore, there is urgent need for reassessment of soil-Pb contamination within the range environment because of increase activities within the military shooting range. This reassessment is highly critical in view of the fact that spent bullets and other shots from firing activities have the ability to accumulate in soil for a long period of time. Secondly, tropical climate of the range environment will aid weathering process which may further increase Pb concentration in shooting range soil. Thirdly, particulate Pb can easily be washed by

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surface runoff water to pollute nearby waterways, underground water supply and surrounding agricultural farmlands. In light of these, this study carried out in 2023 aims at reassessing concentrations of Pb within the Ibadan Military shooting range soil environment after a period of about twenty years to ascertain current contamination status. Furthermore, to provide data on degree of contamination of impact berm soil over the years and established spatial variation of Pb both in front and behind impact berm of the range as it affects the environment.

2. Experimental

2.1. Sampling design and sample preparation

This study was conducted within the Ibadan military shooting range located in Ibadan, Oyo State, Nigeria. The range is very active and one of the oldest presently. The shooting range area has the impact berm, target basement - 10 m, 100 m, 200 m, 300 m, 400 m and 500 m firing lines. Behind the impact berm lies cultivated farmlands at various distances from the berm. Topsoil samples were collected at various distances from the berm: 0 m, 10 m 50 m, 100 m, 150 m, 200 m, 250 m, 300 m, 350 m, 400 m, 450 m and 500 m. Similarly, samples were also collected at this distances from behind the berm giving a total of twenty-four sampling locations. Control samples were collected about 1 km from the range. Five topsoil samples were collected from each of the locations giving a total of one hundred and twenty samples. Plastic hand trowel was used in collecting samples into plastic bags. The soils samples were transported to laboratory, air-dried, ground and sieved through 2 mm mesh sieve. Sample implements were decontaminated between sampling and sample preparation.

2.2. Materials and reagents

The reagents used for chemical analysis include the following: potassium hydrogen phthalate, $HOOCC_6H_4COOK$ (pH buffer 4.02); sodium tetraborate, $Na_2[B_4O_5(OH)_4]\cdot 8H_2O$ (pH buffer 9.22); sodium hexametaphosphate, ($Na_6[(PO_3)_6]$); potassium dichromate, $K_2Cr_2O_7$; ferrous ammonium sulfate, $(NH_4)_2Fe(SO_4)_2\cdot 6H_2O$; 1,10-phenanthroline, $C_{12}H_8N_2$ (ferroin indicator); magnesium chloride, $MgCl_2\cdot 6H_2O$; sodium acetate, $CH_3COONa\cdot 3H_2O$; ammonium acetate, $CH_3COONH_4\cdot 3H_2O$; nitric acid, HNO_3; hydroxylamine hydrochloride, $NH_2OH\cdot HCl$; acetic acid, CH_3COOH; 30% hydrogen peroxide, H_2O_2; sulfuric acid, H_2SO_4; hydrochloric acid, HCl; perchloric acid, $HClO_4$; hydrofluoric acid, HF.

The reagents were purchased from BDH, Poole, England and used as received.

2.3. Soil chemical analysis

The glass electrode method using Hanna pH meter (Hanna Instruments, Kehl, Germany) was used for soil pH determined in 1:1 soil-water mixture [29]. The Bouyoucos [30] hydrometer method was used for soil mechanical property determination, while soil organic matter determined using modified Walkley and Black method [31]. Wet digestion using aqua-regia acid mixture was used to determine total-pseudo metals in soils [32]. Soil speciation was carried out by fractionation method described by Tessier [33]. Different fractions determined included: exchangeable, carbonate-bound, reducible, oxidizable and residual fractions. The mineralized samples were analyzed for Pb, Ni, Cd, Cu, Cr and Zn by flame atomic absorption spectrophotometry (Buck Scientific, East Norwalk, USA, model 200A). Analar grade reagents were used for all analysis. Reagent blanks, duplicate reading and calibration standards were incorporated in the analysis. Recovery study of the metals were carried out by spiking four randomly selected soil samples with metal standards, homogenizing and metals determined by extraction and analytical steps stated above. Average levels obtained are Pb - 99.3±3.2 %, Ni - 93.6±5.2 %, Cd - 99.1±8.0 %, Cr - 97.9±3.0 %, Zn - 98.9±6.3 % and Cu - 93.8±7.1 %.

2.4. Statistical evaluation

Descriptive statistics of geometric mean and standard deviation, analysis of variance (p = 0.05), correlation coefficient (p = 0.05) and statistical T-testing were carried out using Microsoft Excel (version 2010). Similarly, Paleontological Statistics software (version 1.38) was used for principal component analysis (PCA), corresponding analysis (CA) and hierarchical cluster analysis (HCA) to established metal loading variability and categorization in soil. Accumulation factor (AF) was applied in this study to assess the degree of soil contamination. The AF was computed as the ratio of heavy metal concentrations at the different sample locations to the geometric mean of the control concentration of the corresponding metals.

3. Results and discussion

3.1. Soil physicochemical characteristics

The general soil physicochemical characteristics at the shooting range is provided in Table 1, with data necessary to understand likely behavior of metals in the soils.

Table 1. Physicochemical characteristics of range soil

Parameter	Impact berm (front)	Non-impact berm (back)	Impact area (front) 10 to 500 m	Non-impact area (back) 10 to 500m
pH	5.18±0.47	5.66±0.93	6.49±0.42	6.85±0.73
% Organic carbon	3.23±0.67	3.83±0.62	9.94±0.37	8.47±0.22
% Organic matter	5.58±0.36	6.62±0.41	9.65±0.34	14.6±0.37
% Sand	68.2±2.69	67.2±2.65	79.8±4.66	79.9±4.86
% Clay	10.6±3.34	13.7±2.37	8.79±3.30	8.44±4.31
% Silt	21.2±1.64	19.1±2.48	11.4±4.47	11.7±5.85

Soil pH values particularly at the impact berm of the range both in front (5.18±0.47) and behind (5.66±0.93) were generally acidic indicating oxidizable soil condition. This soil condition is known to aid in the dissolution and mobility of metals in soil, which therefore suggest that bullet fragments found within the impact berm soil are likely to disintegrate at a much faster rate thereby aiding its mobility. The berm soil though artificially constructed can be classified as silty-loamy with relatively high silt, clay content and low organic matter. This soil type is probably unfertile with low vegetation cover, and therefore of high risk to the migration and solubilization of metals particularly Pb from spent bullet fragments deposited in soil. A reducing soil pH value of 6.49±0.42 and 6.85±0.73 were mostly present within the surrounding vicinity of the range both in front and behind the berm. Soil conditions within the surrounding range vicinity (impact and non-impact areas: 10-500 m) showed loamy-sandy soil characterized by high organic matter content. With relative low silt and clay content, this reducible soils may not significantly aid in the bioavailability and mobility of metals. The present soil physicochemical properties of the range are not significantly different ($p = 0.05$) as previously report [28].

3.2. Metal concentration in range soil

Metals are found in soils in natural trace levels as a result of weathering of bed rock formations except there is human induced activity which may lead to elevated levels. Shooting activities within the Ibadan military shooting range over the years have significantly elevated the metal concentrations in soils especially at the impact berm (Table 2).

Table 2. Average metal levels (μg/g) in range soils at varying distance from impact berm

Distance (m)	Direction	Pb	Cd	Cr	Cu	Ni	Zn
0	*Front	28,940±2996	8.43±0.21	58.1±1.25	896±149	24.4±1.32	393±21
10		1653±152	3.62±0.64	46.5±2.19	221±113	12.9±0.83	193±11
50		82.6±5.64	1.44±0.27	21.9±1.94	53.9±10.3	4.24±0.37	32.9±4.49
100		1346±46	1.49±0.78	31.5±3.21	621±23	21.9±1.37	114±12
150		76.4±31.7	1.35±0.14	23.3±1.74	34.2±3.24	10.4±2.19	43.6±8.94
200		988±48	2.84±1.32	34.0±2.17	49.3±10.1	19.4±1.62	98.3±13.2
250		78.9±10.7	0.74±0.93	32.3±1.31	23.8±2.84	16.4±3.21	60.0±6.84
300		542±23	0.58±0.43	39.5±2.10	40.3±3.85	16.9±3.96	67.8±6.66
350		56.3±9.67	0.73±1.32	28.5±2.11	34.4±4.18	12.4±2.10	54.6±3.98
400		318±42	1.03±1.93	28.4±1.05	43.4±5.12	18.4±4.31	56.9±3.49
450		49.7±11.3	0.44±0.38	29.2±1.95	40.0±4.51	19.4±3.02	40.3±8.43
500		128±29	0.62±0.41	28.4±2.06	32.2±4.99	11.8±2.04	41.2±5.45
0	**Back	775±128	3.94±0.33	45.0±2.95	60.9±3.95	17.0±0.45	43.6±5.49
10		344±87	2.83±0.83	35.3±1.93	56.3±8.44	10.3±0.33	49.5±9.43
50		238±34	2.94±0.73	21.8±1.04	20.4±2.44	7.36±0.31	21.8±4.39
100		153±29	1.63±0.97	23.5±2.18	40.3±4.39	16.3±0.44	28.4±4.39
150		64.8±5.43	0.37±0.43	24.8±1.47	32.3±4.10	5.25±0.39	27.3±3.48
200		68.5±5.98	0.86±0.28	22.6±1.03	34.3±9.04	14.3±1.43	21.7±5.55
250		57.9±6.8	0.37±0.17	24.8±3.21	21.5±2.23	4.32±0.18	19.5±3.93
300		56.8±9.4	0.47±0.36	25.2±1.24	30.6±6.21	4.84±4.33	25.4±4.98
350		45.9±8.9	0.43±0.74	20.0±1.01	21.1±1.94	6.21±3.90	28.3±4.30
400		45.3±7.5	0.39±0.37	23.3±3.95	28.4±3.22	5.47±2.19	20.3±4.31
450		43.9±7.6	0.38±0.43	21.8±1.94	23.2±3.21	6.11±2.05	20.8±4.87
500		44.0±5.8	0.37±0.21	23.9±2.75	25.7±6.33	5.92±3.11	21.2±7.73
CTR		28.7±3.16	0.48±0.22	17.2±2.10	18.3±4.41	7.78±0.52	28.7±9.31

CTR-Control; *Front-Impact berm; **Back-Non-impact berm area

In particular, lead levels at the front (28,940±2996 μg/g) and back (775±128 μg/g) of the impact berm were significantly higher than other metals: Cd, Cr, Cu, Ni and Zn. This is basically due to the presence of large numbers of small bullet fragments derived from shooting activities in the soils of which the bullet fragments are largely made-up of about 90% Pb [34, 35]. Many other studies have also shown extensive soil-Pb contamination around impact berm of shooting range [6, 36]. Several environmental factors, such as soil pH condition, soil type and relative humidity could aid in corrosion and dissolution of bullet fragments thereby increasing soil-Pb concentrations in range soils. At the Ibadan Military shooting range the presence of corroding bullet fragments at the impact area of the berm occasioned by the humid oxidizable soil condition (low pH value - 5.18 to 5.66) and soil type (silty-loamy) could influence dissolution and mobility of Pb within the berm soils. This may explain the relative high Pb concentrations (775±128 μg/g) found around the non-impact area of the berm and surroundings which is not under any direct bullet impact from shooting activities. Assessing the impact areas (front of the berm) where major shooting activities are carried out, soil-Pb contamination was found to be extensive around the target basement (1653±152 μg/g) and at all the firing lines 500 to 100 m (128±29 to 1346±46 μg/g). However, contamination levels were substantially lower between firing lines of 450 to 150 m (49.7±11.3 to 82.6±5.64 μg/g). This may be due to deposition of Pb dust arising from shooting activities and corroding bullet jackets found within the firing lines and between firing lines. Considering the non-impact areas (back of the berm) where there's no direct shooting activities and where many farmlands are situated, soil-Pb concentrations were observed to decrease with increasing distance from the back berm (Table 2). Major soil-Pb contamination was notably at 10 m, 50 m and 100 m where concentrations were in excess of 100 µg/g while Pb levels in other locations within this area where about that obtained in control soils.

The graphical display of the soil metal data (Figure 1) which is a representation of the overall metal (Pb, Cd, Cr, Cu, Ni and Zn) load of the range soils at different locations shows that metal concentrations was significantly higher at the impact areas (front of berm F-0 to F-500) where there are active shooting activities with concentrations decreasing consistently with increasing distances away from the berm.

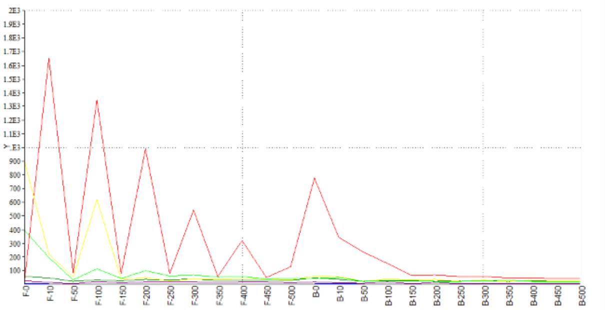

Figure 1. Graphical display of soil metal data

Similar observations were also found for the non-impact areas (back of berm B-0 to B-500) with high metal levels at the back berm and decreasing concentrations from the back berm. These locations are mostly associated with farming activities which raises concern on possible bioaccumulation of lead in farm produces. Average concentrations of Cu (986±149 µg/g) and Zn (393±21 µg/g) were higher around the front berm comparatively to the back berm. These Cu and Zn metals are often associated with most bullet types which could explain their presence in high concentrations. Other location within the study areas had concentrations of Cd, Cr, Cu, Ni and Zn about background levels. The statistical analysis of variance (p = 0.05) of the six metals (Pb, Cd, Cr, Cu, Ni and Zn) for the twenty-four sampling locations within the shooting range, showed that concentrations were significantly different which is expected bearing in mind that contamination is mostly concentrated at areas with shooting activities. Similarly, statistical T-testing (p = 0.05) further confirms significant differences mostly for Pb, Cr, Ni and Zn concentration between soil samples obtained at front berm (impact area) and back berm (non-impact area) of the range. This suggest that shooting activities within the range has extensive impact on soil-metal contamination.

From Table 3, a positive inter-element correlation (0.506 to 0.904) was generally observed, except for Pb and Ni (0.455), meaning that these metals could possibly originate from similar source of contamination.

Table 3. Person's inter-element correlation coefficient (p = 0.05)

	Pb	***Cd***	***Cr***	***Cu***	***Ni***	***Zn***
Pb	1					
Cd	0.824	1				
Cr	0.683	0.802	1			
Cu	0.835	0.721	0.651	1		
Ni	0.455	0.506	0.654	0.568	1	
Zn	0.905	0.849	0.832	0.878	0.588	1

The accumulation factor (AF) of lead in the soils was significantly high comparatively to other metals especially at the shooting range impact areas in order of 0 m -1008, 10 m - 57.6, 100 m - 46.9, 200 m - 34.4 and 300 m - 18.9 (Table 4).

Table 4. Accumulation factors# of heavy metals in range soils

Distances (m)	**Direction**	**Pb**	**Cd**	**Cr**	**Cu**	**Ni**	**Zn**
0	*Front	1008	17.6	3.38	49.0	3.14	13.7
10		57.6	7.74	2.70	12.1	1.66	6.72
50		2.88	3.00	1.27	2.95	0.54	1.15
100		46.9	3.10	1.83	33.9	2.81	3.97
150		2.66	2.81	1.35	1.87	1.34	1.52
200		34.4	5.92	1.98	2.69	2.49	3.43
250		2.75	1.54	1.88	1.30	2.11	2.09
300		18.9	1.21	2.30	2.20	2.17	2.36
350		1.96	1.52	1.66	1.88	1.59	1.89
400		11.1	2.15	1.65	2.37	2.37	1.98
450		1.73	0.92	1.70	2.19	2.49	1.40
500		4.46	1.29	1.65	1.76	1.52	1.44
0	**Back	27.0	8.21	2.62	3.33	2.19	1.52
10		11.9	5.90	2.05	3.08	1.32	1.72
50		8.29	6.13	1.27	1.11	0.95	0.76
100		5.33	3.40	1.37	2.20	2.10	0.99
150		2.26	0.77	1.44	1.77	0.67	0.95
200		2.39	1.79	1.31	1.87	1.84	0.76
250		2.02	0.77	1.44	1.17	0.56	0.68
300		1.98	0.98	1.47	1.67	0.62	0.89
350		1.60	0.90	1.16	1.15	0.80	0.99
400		1.58	0.81	1.35	1.55	0.70	0.71
450		1.53	0.79	1.27	1.27	0.79	0.72

Distances (m)	Direction	Pb	Cd	Cr	Cu	Ni	Zn
500		1.53	0.77	1.39	1.40	0.76	0.74

[#]Calculated as ratio of average concentration at given sample location, to average concentration at control site.

About the same order of magnitude also seen for non-impact areas 0 m - 27.0 and 10 m - 11.9. This reflects the nature of activity within the catchment areas.

From the speciation study in Table 5, the bioavailable fractions of the metals within the range vicinity were Pb - 66.9 %, Cu - 63.2 %, Cr - 53.7 %, Cd - 62.0 %, Ni - 49.9 % and Zn - 60.4 %. The most mobile of the bioavailable fractions where generally below 4% which is consistent with previous study carried out in 2004 [28].

Table 5. Average speciation (% in geochemical phases) of the metals

Phases	Pb	Cu	Cr	Cd	Ni	Zn
Exchangeable	3.32	2.63	0.95	2.76	1.34	3.66
Carbonate-bound	31.6	19.9	10.4	14.8	8.69	13.7
Reducible	20.2	8.67	11.1	33.0	15.3	23.6
Oxidizable	11.8	32.0	31.2	11.4	24.6	19.4
Residual	33.1	36.8	46.4	38.0	50.1	39.6

Lead exists more in the carbonate and reducible forms with 33.1 % in residual fractions which suggest potentially high bioavailability of Pb to vegetation's and possibly agricultural crops. The residual fractions of Cu, Cr, Cd, Ni and Zn were relatively higher than Pb indicating their possible origin from the geological bed rock formation.

Temporal variations in Pb concentration over a period of about twenty years at the impact berm (where bullet fragments are deposited) of the shooting range is illustrated in Figure 2. The accumulation of bullet fragments resulting from continuous usage of the range for shooting activities coupled with weathering and prevalent soil conditions at the berm has resulted in exponential five-fold increase in Pb concentrations [26, 28, 37-39]. As observed in Figure 2, there's constant rise in soil-Pb levels from 2004 although to 2017 with slight drop in 2018. However, 2023 recorded the highest soil-Pb levels of 28940 µg/g which is a five-fold increase. This continuous increase in Pb concentration may pose serious environmental concern owning to the farming activities within the surrounding range environment.

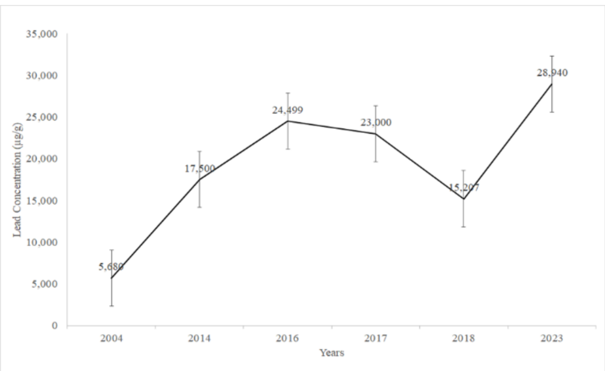

Figure 2. Variation of lead levels with time

Soil lead levels from this current study around impact area were compared with the Australian guideline for shooting range while non-impact area was compared with the Canadian guide value for agricultural soil since farming activities is extensive at these locations. Soil-Pb concentrations at impact berm, 10 m, 100 m, 200 m, 300 m, 400 m firing lines were higher than the Australian guide value of 300 mg/kg [40]. Similarly, Pb levels at surrounding non-impact area of the berm, 10 m, 50 m, and 100 m locations were also higher than the Canadian guide values [41] of 70 mg/kg for agricultural soils. Cultivation of agricultural crops at these locations could be at high risk of Pb contamination. Concentration of Pb at berm of the Ibadan Military shooting range soil was significantly higher than reported for Nigerian Air Force Base shooting range-526 mg/kg, Nigerian Army Depot, Zaria-216 mg/kg and Armed Forces Command and Staff College, Jaji-54.4 mg/kg [25].

From the principal component analysis biplot (correlation matrix) in Figure 3, the first component which is a size variable accounts for 67.1 % of the total metal load in the range soil.

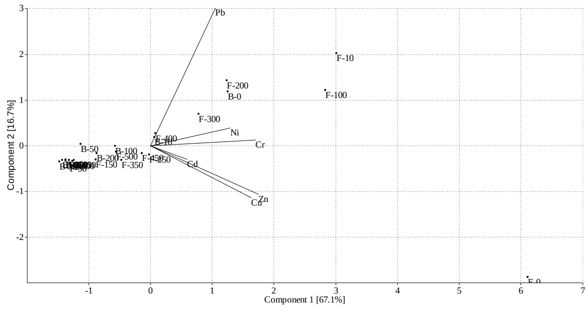

Figure 3. Principal component analysis biplot (correlation matrix) of soil metal data

These points which lie to the right hand side of the vector: F-0 m, F-10 m, F-100 m, F-200 m, F-300 m, F-400 m, B-0 m and B-10 m have very high metals contamination. Points to the left of the metal vector are clustered together accounting for only 16.7 % (component 2) of the total metal load indicating that they tend to have very low metal levels. These points which are in component 2 are mostly found behind the impact berm and between firing lines of the range.

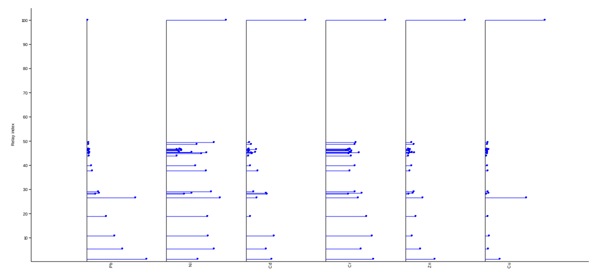

Figure 4. Correspondence analysis relay plot of metal data set

The correspondence analysis relay plot (Figure 4) shows pollution order of Pb > Ni > Cd > Cr > Zn > Cu, similar to the trend produce by the PCA biplot.

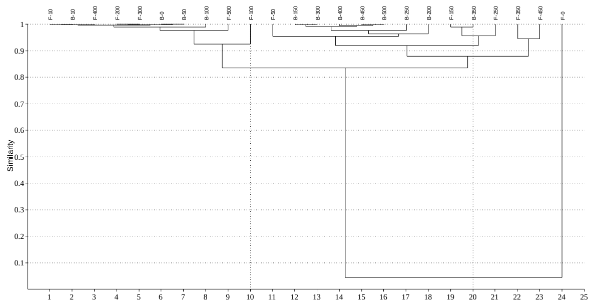

Figure 5. Hierarchical cluster analysis (correlation) of soil metal data

Hierarchical cluster analysis (Figure 5) shows three distinct groups of similar metal load. *Group One*: F-0 m, *Group Two*: F-10 m, F-100 m, F-200 m, F-300 m, F-400 m, F-500 m, B-0 m, B-10 m, B-50 m, B-100 m and *Group Three*: F-50 m, F-150 m, F-250 m, F-350 m, F-450 m, B-150 m, B-200 m, B-250 m, B-300 m, B-350 m, B-400 m, B-450 m, B-500 m. The first group (front of impact berm) has very high metal level and is distinct from other two groups, followed by the second group which is mostly few meters from the berm and firing lines showing rather same metal levels. This two cluster groups have highest similarity to the PCA metal distribution patterns in the range soil. The third group comprising of back of berm and in-between firing lines have very low metal levels comparatively to others. These multivariate analysis confirms soil contamination especially around the impact area, i.e. impact berm and firing lines, and non-impact area, i.e. B-0 m, B-10 m B-50 m and B-100 m.

4. Conclusions

From the present study, soil-Pb contamination was extensive majorly at the shooting range impact berm both in front (impact area) and behind (non-impact area). Contamination was observed to decrease with increasing distance from the berm on both side. The prevailing acidic soil condition occasion by high rainfall of the tropical region may provide favorable environment for transformation and mobility of bioavailable Pb (66.9 %) in soil. Soil-Pb contamination varied by a factor of five-fold over a period of about twenty years at the impact berm of the range. This demonstrate the impact of shooting activities within the range with significant difference in Pb, Cr, Ni and Zn concentration between impact and non-impact areas. Environmental consequence of high soil-Pb levels within the range especially at the non-impact areas utilized for farming activities will leave much to desire. Therefore, the current status of soil-Pb contamination within the range calls for extensive and continuous monitoring. However, remediation through appropriate soil washing technique could reduce the Pb levels and improve soil condition regardless of age. Further studies to establish possible soil-plant relationship in terms of Pb uptake need be conducted.

Conflict of interest

The authors declare no conflict of interest.

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