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ASSESSMENT OF HEAVY METALS IN SOILS AND *ZEA MAYS* PLANT FROM FARMED DUMP SITES IN TUBAH SUBDIVISION-NORTHWEST CAMEROON

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ABSTRACT: *This study assessed the physicochemical and heavy metal properties of soil and the risks associated with Zea mays contamination by heavy metals in farmed dump sites in Tubah Sub-division, Northwest Cameroon. Three surface soil samples (0-20 cm) and Zea mays plant samples were collected from Bambili (S1), Baforkum (S2) and Bambui (S3) and analyzed following standard analytical procedures. Results of physicochemical analysis showed that all the soils had low pH values (5.45-6.12), moderate organic matter content (3.93% - 7.14%), and high available phosphorus (9.51-52.58 mg/kg). Total heavy metal concentrations for all soil samples ranged from 4.66-5.23 mg/kg, 65.32-98.12 mg/kg, 1555.12-2158.65 mg/kg, 94.64-115.34mg/kg, 0.87-1.01 mg/kg, 96.54-156.3 mg/kg, and 289.43-450.48 mg/kg for Cd, Pb, Mn, Cu, Hg, Cr and Zn respectively. Total heavy metal concentrations in Zea mays plant ranged from 2.66-4.33 mg/kg, 21.32-28.21 mg/kg, 55.12-230.34 mg/kg, 8.64-34.23 mg/kg, 0.47-0.81 mg/kg, 53.43-76.3 mg/kg, and 89.43-108.48 mg/kg for Cd, Pb, Mn, Cu, Hg, Cr and Zn respectively. This study thus revealed that the soils and Zea mays plants were contaminated to varying degrees by the heavy metals Cd, Mn, Cu, Hg, Cr and Zn, and consequently, there are potential health hazards associated with the consumption of Zea mays cultivated on these soils. Physical remediation (capping, washing of soil, excavation of soil), chemical remediation (immobilization, solidification, vitrification), and phytoremediation can be employed to recover heavy metals from such soils, meanwhile, lime-induced immobilization of heavy metals could assist to keep the metals in the soil in an insoluble state.*

KEYWORDS: Soil pH, Liming, Immobilization, Heavy metal, Health risk.

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INTRODUCTION

The yield and quality of farmed products depend largely on soil quality, and living organisms need quality food to complete their life cycle (Njoyim et al., 2016a). The composition of soil reflects the distribution and the intensity of physicochemical properties and trace elements within the soil. Soil physicochemical properties are important factors that determine agricultural yields (Mbene et al., 2017; Yerima et al., 2020). Soil nutrient content and other physicochemical properties such as soil pH are factors that qualify a soil to be good for farming (Mofor et al., 2017). However, the agricultural sector in the world today tends to face a lot of challenges associated with the quality of soil due to various forms of soil pollution.

Landfills have long been used as repositories for industries, municipal and commercial wastes (Amos-Tautua et al., 2014). Cameroon, a developing country with non-adequate waste disposal or recycling processes, is at risk of heavy metal contamination of its soils. Tubah is a non-industrialized area; the waste generated within the municipality comprises largely degradable materials from markets, offices, hospitals, and households. However, metallic materials from damaged vehicle parts, electronic computers and cans disposed in this area constitute sources of heavy metal contamination. The persistent increase in anthropogenic activities in the environment releases heavy metals that contaminate the soil and not only affect the growth and quality of crops, but also threaten the health of consumers (Tadesse & Kumie 2014; Zhou et al., 2015). Heavy metals have become the major chemical pollutants in agricultural soils, and a global challenge facing food production and the sustainability of life (Mofor et al., 2020). The two main sources of heavy metals in soils are natural pedo-geochemical background and anthropogenic contamination (Salem et al., 2020). Heavy metals are non-degradable, biologically, or thermally, and keep on accumulating in the environment to levels exceeding permissible limits that can lead to soil degradation (Rodrigo-Comino et al., 2018; Antonelli et al., 2018). The problems associated with farmlands contamination by heavy metals is a serious call for concern, especially for developing countries such as Cameroon (Njoyim et al., 2016b).

Heavy metals are chemical elements with specific weight of more than 5 g cm^{-3} (Witkowska et al., 2021). Due to their longer half-life and fairly immobile nature (some of them are mobile), heavy metals are very persistent in soil (Inoti et al., 2012). They enter plants through roots and leaves. The most common heavy metals in soils are Cd, As, Cr, Cu, Hg, Co, Pb, Ni, and Zn. Micronutrients like Zn, Cu, Mn, Ni and Co are necessary for plant growth, while others like Cd, Pb, As, and Hg lack the known biological functions and are toxic (Sarmistha et al., 2021). Heavy metals exist in the soil in a variety of forms such as the water soluble, exchangeable and bound to specific sites of organic and inorganic components, and in the structure of primary and secondary minerals (Violante et al., 2010). These forms of heavy metals affect their reactivity, mobility, and bioavailability (Cao et al., 2018).

The concentrations of heavy metals in soil increases with soil development, its mobility, and can be changed by environmental conditions such as type of soils, agricultural input, climate change and saturation capacity of the soil (Garcia-Carmona et al., 2019). Distribution of heavy metals in soil is controlled by reactions such as adsorption and desorption, mineral precipitation and dissolution, ion exchange, biological mobilization and immobilization, and plant uptake (Caporale & Violante, 2016). Due to hazards associated with heavy metal contamination, most countries brought a major shift of an international concern towards the prevention of heavy metal accumulation in soil, food and other ecosystem. The hazards associated with heavy metal contamination of the environment, plants and animals, necessitated a study of this nature. Such

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a study will no doubt accentuate the need for a more constant monitoring of heavy metals in the studied soils and also serve as a relevant input into the existing global record on soil pollution by heavy metals.

From the foregoing problem, this study generally was aimed to assess some physicochemical and heavy metal properties of surface soils (0-20 cm), and the risks associated with *Zea mays* contamination by heavy metals in farmed dump sites in Tubah. Specifically, this study was aimed to: (1) determine the physico-chemical properties of soils and *Zea mays* grown on farmed dump sites in Tubah, (2) determine the concentrations of heavy metals in selected soils and *Zea mays* grown in Tubah, and (3) finally, investigate possible pollution in the soils and crops grown in Tubah, thereby suggesting possible ways to mitigate the effects caused by heavy metal pollution in soils and crops.

MATERIALS AND METHODS

Sampling Site Descriptions

The sampling sites (Bambili, Bambui and Barfokum) are found in the grass field zone of Cameroon, specifically in Tubah subdivision, Mezam division of the North West Region of Cameroon. Tubah Subdivision is located on latitude N6^{0}2′18.42″, longitude E10^{0}17′26.84″, and at an elevation of 1350 m above sea level. It has a mountain topology with hills and vegetation. It covers a surface area of 450 km^2 with a population of about 65,250 persons, and population density of 145 persons/km^2. Its hydrology is characterized by the existence of a lake, small rivers, streams, springs, and swamps.

Sampling was done in early February 2022. Three representative sites were chosen for sampling: Bambili village (S_1), Baforkum (S_2) and Bambui (S_3). 1 kg surface soil (0-20 cm) and *Zea mays* plant samples were collected randomly from each of the sampling sites. Bambili sampling point is found along the Bambili village road, about 2 km away from the Bambili 3-corners. This site is located on latitude N6^{0}0′16.32″, longitude E10^{0}15′20.10″, and at an elevation of 1388.0 m above sea level. Baforkum sampling point is located about 300 m away from IRAD. The study site is located on latitude N6^{0}0′40.54″, longitude E10^{0}15′43.95″, and at an elevation of 1438.0 m above sea level. Bambui sampling point is located along the Bambui-Nforyah road, about 100 m away from Bambui 4-corners. The study site is located on latitude N6^{0}2′60″, longitude E10^{0}13′59.99″, and at an elevation of 1228.0 m above sea level.

Laboratory Analysis

Freshly collected soil samples were air dried (at room temperature) in the laboratory, ground in a porcelain mortar using a pestle and sieved through a 2-mm sieve. The collected *Zea mays* plant samples were washed using tap water and rinsed with distilled water to eliminate dusts, pesticides, fertilizers, and any airborne pollutant that could be present. The plant samples were dried at room temperature to remove moisture; thereafter, they were sliced using a stainless-steel knife, weighed and oven dried at 80℃ for 72 hours. The oven dried plant samples were then powdered and sieved through a 2 mm sieve. The prepared soil and maize samples were thereafter analyzed for various physicochemical properties using international standard methods (Dipak & Abhijit, 2005; Pauwels et al., 1992). All reagents used in this study were of analytical reagent grade.

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Physicochemical Analysis

The pH of the soil was determined electrochemically over a 1:2.5 soil—water solution ratio in a 1 N KCl (pH-KCl) and distilled water (pH-H_2O) using a glass electrode coupled pH meter. Organic carbon (OC) was determined by the oxidation of OC by potassium dichromate ($K_2Cr_2O_7$) in the presence of concentrated sulfuric acid followed by titration with hydrated iron (II) sulfate ($FeSO_4.7H_2O$) (Walkley & Black, 1934), and organic matter (OM) was calculated from the levels of organic carbon in the soil by multiplying by 1.72 as reported by Hazelton and Murphy (2007). Exchangeable bases were determined following the Schollenberger method using a 1 M ammonium acetate solution buffered at pH 7, and after which the amount of Na^+ and K^+ ions in the extract were determined by flame photometry. The amount of Ca^{2+} and Mg^{2+} ions were estimated by complexometric titration. Cation exchange capacity (CEC) was determined as a direct continuation of the Schollenberger method using a 1 N KCl solution for the displacement of ammonium ions, and the desorbed ammonium ions were determined by the Kjeldahl's distillation method using 0.02 N HCl and 0.02 N NaOH solutions. Total nitrogen (% N) was determined by completely mineralizing the total N in the soil with a mixture of concentrated H_2SO_4 solution and salicylic acid at 80°C in the presence of a catalyst (mixture of 100 g K_2SO_4 + 20 g $CuSO_4$ + 2 g selenium) (Juo, 1979). The mineralized extract was distilled with an excess 0.01 N NaOH and titrated with 0.01 N H_2SO_4 (Kjeldahl's distillation method). Available P was determined by Bray 2 method. Particle size distribution was determined by hydrometer method (Bouyoucos, 1962) using sodium hexametaphosphate as a dispersant. The soil textural class was determined using the 'textured triangular diagram.'

Heavy Metal Analysis

The remaining oven dried powdered plant samples above were then put in crucibles and kept in desiccators before placing them in a muffle furnace and ashed for 12 hours at 450°C. Soil samples were digested in Teflon beakers with *aqua regia* (a mixture of conc. HNO_3 and HCl in the volume ratio of 1:3). Similarly, ash powdered plant samples were digested with a mixture of concentrated $HClO_4$, HNO_3 and H_2SO_4. The digested samples were analyzed for heavy metals using Atomic Absorption Spectrometry (AAS) analysis.

Statistical Analyses

Student's test (t-test) was used to compare correlation matrix between some soil physicochemical properties, soil and plant physicochemical properties, and finally some heavy metals in soil and plants. Correlation analysis was done with the help of Statistical Package for Social Sciences (SPSS) version 20 software.

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RESULTS AND DISCUSSION

Physicochemical Properties

Results of physicochemical analysis for soils and *Zea mays* plant samples are presented in Table 1 and Table 2 respectively.

Table 1: Soil Physicochemical Properties

Sample	*pH- H_2O*	*pH-KCl*	*ΔpH*	*%N*	*%OC*	*%OM*	*C/N*	*CEC (cmol(+)/kg)*	*AP (mg/kg)*	*K(cmol(+)/kg)*
S_1	5.45	4.85	-0.60	0.12	2.28	3.93	19.00	48.88	13.59	0.74
S_2	6.12	5.88	-0.24	0.30	4.14	7.14	14.00	45.32	52.58	0.64
S_3	5.77	4.95	-0.82	0.15	3.99	6.88	27.00	41.72	9.51	0.67

Sample	*Na^+*(cmol(+)/kg)	*Ca^{2+}*(cmol(+)/kg)	*Mg^{2+}*(cmol(+)/kg)	*SB*	*TBS(%)*	*Sand (%)*	*Silt (%)*	*Clay (%)*	*Textural class*
S_1	0.29	5.64	4.01	10.64	22.00	36.00	34.00	30.00	CL
S_2	0.29	5.38	3.64	9.95	21.00	44.00	35.00	21.00	CL
S_3	0.28	4.94	3.24	9.13	22.00	48.00	27.00	25.00	SL

ΔpH = net charge (pH KCl – pH H_2O), OC = Organic carbon, N = Total nitrogen, OM = Organic Matter, C/N = Mineralization factor, CEC = Cation Exchange capacity, AP = Available phosphorus, SB = Sum of Bases, TBS = Total Base Saturation, CL = clay loam, SL = sandy loam.

Table 2: *Zea mays* Plant Physicochemical Properties

	Bambili (S1)	Baforkum (S2)	Bambui (S3)
%N	6.20	12.80	11.60
%OC	43.28	45.90	44.51
%OM	74.61	70.13	76.74
C/N	6.98	3.59	3.84
TP(mg/kg)	146.90	1530.15	1112.15
K (cmol(+)/kg)	38.80	14.90	22.60
%DWK	1.70	0.75	0.87
Na (cmol(+)/kg)	1.99	1.09	1.36
%DWNa	0.08	0.06	0.05
Ca (cmol(+)/kg)	56.80	68.80	31.80
%DWCa	1.11	1.44	0.68
Mg (cmol(+)/kg)	13.20	12.20	9.25
%DWMg	0.34	0.23	0.19

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N = total nitrogen, OC = Organic carbon, OM = organic matter, C/N = mineralization factor, TP = total phosphorus, DWK = dry weight of potassium, DWNa = dry weight of sodium, DWCa = dry weight of calcium, DWMg = dry weight of magnesium.

The results of soil physicochemical properties from Bambili village, Bambiu, and Baforkum showed that pH values in the soils were 5.45, 5.77 and 6.12 respectively. Thus, the soils were classified as strongly acidic (Bambili village), moderately acidic (Bambui) and slightly acidic (Baforkum) (Hazelton & Murphy, 2007). The acidic nature of the soils could have resulted from their high organic matter content, as organic waste is continuously dumped on the farmlands. The decomposition of organic matter releases H^+ and CO_2. The H^+ is a direct source of soil acidity while the CO_2 released reacts with water to produce weak carbonic acid that reduces soil pH (Okeke, 2014).

Organic matter + $O_{2(g)} \longrightarrow CO_{2(g)} + H^+_{(aq)}$ (source of acidity (1)

$CO_2(g) + H_2O_{(l)} \longrightarrow H_2CO_{3(aq)}$ (source of acidity) (2)

The charge status of the soil, ΔpH, which relates to the sign and magnitude of soil surface charge, were negative for the soils, signifying that these soils were above their point of zero charges. Thus, the soils had net negatively charged surfaces, and hence a net CEC at field pH. Many crops grow well when the soil pH is between 6.0 and 8.2. The soils of Bambili village and Bambiu were thus not within the pH suitable for plant growth. Lime pellet legume seed and use of Molybdenum (Glendinning, 1986) could be implemented to reduce acidity and induce the immobilization of the components responsible for the adsorption of soil essential nutrients, thereby releasing inorganic plant nutrients such as N, S and P to soil solution (Yerima & Van Ranst, 2005).

The soil organic matter (%M) levels were 3.9, 6.8 and 7.14% in Bambili, Bambui and Baforkum respectively. SOM levels were thus very high for Bambui and Baforkum, while the soil of Bambui had medium SOM level (Spargo et al., 2013). Soil buffering capacity increases with high organic matter content. These soils thus will have a high buffering capacity and can resist changes in pH (Hazelton & Murphy, 2007). The very high SOM contents of Baforkum and Bambui probably resulted from organic waste materials continuously being directly dumped on the surface of these farmed sites. Very high OM implies that soils have good structural condition, high structural stability and soils are probably water repellent (Hazelton & murphy, 2007). SOM positively influences the concentrations of certain parameters such as organic carbon, total nitrogen, and available phosphorus (Okeke, 2014; Mabagala & Mng'ong'o, 2022).

The organic matter content for all the three maize plant samples was found to be high, with values ranging from 70.13-76.74%. These values were by far greater than the values obtained for the soils organic matter content at a depth of 20 cm.

Total nitrogen (N) contents in all soil samples were very low, with values ranging from 0.12 to 0.3%. Nitrogen is considered a limiting nutrient because much of it is held in the organic matter in the soil (Hazelton & Murphy, 2007). Carbon/nitrogen (C/N) ratios were high (ranging from 14 to 27), indicating that the SOM was poorly mineralized and decomposition may proceed at the maximum rate possible under environmental conditions (Beernaert & Bitondo, 1992). The

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poor mineralization of the OM% could be explained by the prevalence of low pH values and low water content in the soils. Low soil N content and high C/N values could have resulted from immobilization and denitrification processes by soil bacteria (Mofor et al., 2022).

The total nitrogen content in all maize plant samples ranged from 6.20-12.80% which is far much greater than the values obtained for the soil's nitrogen content at a depth of 20 cm. This high content obtained in plants could be due to the high availability of nitrate or ammonium based fertilizers in the soil for plant uptake.

Available phosphorus for all the three soil samples ranged between 9.51-52.58 mg/kg. Available P in the soil samples from Bambui, Bambili village, and Baforkum were classified as low (9.51 mg/kg), moderate (13.59 mg/kg) and very high (52.58 mg/kg) respectively (Hazelton & Murphy, 2007). The trend of the available P in the soils were perfectly in conformity with the variations in the soil pH. The soil from Baforkum thus had the highest concentration of phosphorus (52.58 mg/kg), indicative of the moderate pH for which the availability of soil nutrients is high. Low P concentrations in soil from Bambui may be associated with the acidic nature of the soil. At low pH values, oxides and hydroxides of Al, Fe, and Mn are highly soluble and will react with phosphate ions ($H_2PO_4^-$) to form hydroxyl phosphates, which are insoluble and unavailable for plants (Mofor et al., 2022).

Total phosphorus in all maize plant samples were very high ranging from 146.90-1530.15 mg/kg. These values were higher than the soil available P. Higher P content in plants could have resulted from the high organic matter content in plants which also influences certain parameters like the available phosphorus (Okeke, 2014). Also, high P content in the plants could be due to the high availability of phosphate based fertilizers (NPK fertilizers) in the soil for plant uptake.

Exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, and Na^+) in all soil samples showed the following trend: $Ca^{2+} > Mg^{2+} > K^+ > Na^+$. Quantitatively, the concentrations of these basic ions varied as follows: Ca^{2+} (between 4.94 and 5.64 cmol(+)/kg), Mg^{2+} (between 3.24 and 4.01 cmol(+)/kg), K^+ (between 0.64 and 0.74 cmol(+)/kg), and Na^+ (between 028 and 0.29 cmol(+)/kg). Based on the ratings established by Horneck et al. (2011), these concentrations were quite low especially for K^+, Na^+, and Mg^{2+} and varied from low to medium for Ca^{2+}. These low concentrations could be due to the porous nature of the soils that are prone to base leaching. These low concentrations could also be explained by the prevalence of pH values of less than 6.5, where these cations are deficient (Mofor et al., 2022).

The basic cations (Na^+, K^+, Mg^{2+} and Ca^{2+}) in maize plants were high, ranging from 14.9-38.8 cmol(+)/kg for K^+, 1.09-1.99 cmol(+)/kg for Na^+, 31.8-68.8 cmol(+)/kg for Ca^{2+} and 9.25-13.2 cmol(+)/kg for Mg^{2+}. These values were higher than the values obtained for basic ions in the soils. This could be due to less availability of heavy metals toxicity in the plants which resulted to a proper uptake of basic cations by plants (Fonge et al., 2019).

Cation exchange capacity (CEC) for all soil samples were high, with values ranging from 41.72 to 48.88 cmol(+)/kg. The high CEC could be associated with the high SOM as organic matter is a source of negative charge (phenolic and carboxylic groups) in soil. Cation Exchange Capacity can range from below 5 cmol(+)/kg in sandy low organic matter soils to over 15 cmol(+)/kg in finer textured soils and those high in organic matter. High CEC soils are less susceptible to cation nutrient loss through leaching (Spargo et al., 2013).

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The sum of exchangeable bases was high for all the soils, ranging from 9.13-10.64 cmol (+)/kg. Base saturation for the three soil samples was low (Hazleton & Murphy, 2007), ranging from 21% for Baforkum to 22% for Bambili village and Bambui. Total base saturation, which is the percentage of the CEC of soil that is occupied by the calcium, magnesium, potassium and sodium ions at the current soil pH value, was less than 50% for all the soils. The base saturation thus may be regarded as not satisfactory for pastures. Therefore, the application of lime to the surface soil is of great importance to increase the base saturation within the range 60-80%, with a tolerance value of ±10%.

The textural class of soils of Bambili village was clay loam, which is a fine soil texture with a high water and nutrient holding capacity. Soils of Baforkum and Bambui were of soil type sandy loam, which is a soil texture with a low water and nutrient holding capacity. Soil texture is important because it influences water and nutrient holding capacity, drainage, aeration, susceptibility to compaction, irrigation and planting practices, and erodibility (Mofor et al., 2017).

Results of Total Metal Heavy Metal Analysis

The results of total metal heavy metal analysis in soil and *Zea mays* plant of Bambili village, Bambui and Baforkum are presented in Table 3 and Table 4 respectively. These results are discussed with respect to ratings (maximum allowable concentrations) published by Kabata-Pendia (2011) and FAO/WHO (2011).

Table 3: Results of Heavy Metal Analysis for the Soils

Site (sample)	Cd (mg/kg)	Pb (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Hg (mg/kg)	Cr (mg/kg)	Zn (mg/kg)
Bambili (S1)	5.23	75.65	1555.12	94.64	0.99	123.53	289.43
Baforkum(S2)	10.33	98.12	2158.65	103.45	1.01	156.3	450.48
Bambui (S3)	4.66	65.32	1650.34	115.34	0.87	96.54	305.67
MAC	**5**	**100**	**2000**	**100**	**1.8**	**100**	**300**

Table 4: Results of Heavy Metal Analysis for the *Zea mays* Plant Samples

Site (sample)	Cd (mg/kg)	Pb (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Hg (mg/kg)	Cr (mg/kg)	Zn (mg/kg)
Bambili (P1)	3.23	25.65	55.12	8.64	0.81	53.43	89.43
Baforkum(P2)	4.33	28.12	258.65	18.45	0.89	76.3	108.48
Bambui (P3)	2.66	21.32	230.34	34.23	0.47	66.54	105.67
MAC	**3**	**30**	**500**	**73**	**1**	**75**	**100**

MAC = Maximum Allowable Concentration

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Cadmium (Cd): The total concentration values of Cd in the soil samples of Bambili, Baforkum and Bambui were 5.23, 10.33 and 4.66 mg/kg respectively. The concentrations of Cd in the soils of Bambili and Baforkum were above the maximum allowable limits (5 mg/kg). Apparently, this value of Cd in the soils, higher than background contents reflected the anthropogenic impact such as the use of fertilizers, pesticides and effluent from the wastes dumped on the soils. However, this elevated levels of Cd in the soil could also be of lithogenic (geogenic) origin (Curlik & Forgac, 1996). Cd has no known essential function but causes toxicity above certain tolerance levels. Soil contamination with Cd is believed to be the most serious health risk; chronic exposure to cadmium can result in kidney, bone and lung diseases (Sarmistha et al., 2021). The continuous use of fertilizers or pesticides and greywater might be the high source of Cd in these soils**.** Kitagishi and Yamane (1981) reported that the best and most reliable results in reducing Cd availability is achieved by layering of unpolluted soil over polluted soil to a depth of 30 cm. In recent years, phytoremediation technique with the use of *Zea mays, Salix viminalis, Helianthus annuus,* and *Viola baoshanensis*, has been applied to remediate Cd from contaminated soils (Dickinson & Pulford, 2005).

The total concentration of cadmium in the *Zea mays* plant samples of Bambili, Baforkum and Bambui were 3.23, 4.33 and 2.66 mg/kg respectively. The samples from Bambili and Baforkum had Cd levels above the maximum allowable limit of 3 mg/kg, while the sample from Bambui was within this limit. The primary source of Cadmium in the plants could be linked to its direct uptake from the contaminated soils (Shaari et al., 2021). Elevated concentration of Cd in maize grown on these farm dump sites is a serious problem on human health, and so remediation techniques can be applied to alleviate Cd in soils (Chavez et al., 2016).

Lead (Pb): The total concentration values of Pb in the soil samples were 75.65, 98.12 and 65.32 mg/kg for Bambili, Baforkum and Bambui respectively. These concentrations of Pb in the soils were below the maximum allowable limit (100.0 mg/kg), hence not enough to cause acute toxicity in living things. Pb accumulation near the soil surface mainly is due to its sorption by SOM. Studies conducted by Sipos et al. (2005) suggested that SOM plays a decisive role in the Pb adsorption, but the fixation by clay minerals is much stronger. High levels of lead in the soil causes adverse health effects. Pb can enter the human body through food consumption (65%), water (20%) and air (15%) (Ruqia et al., 2015). The present study revealed that, over time, Pb concentration in the soils could exceed the safe limit because the amount of Pb in the wastes dump on the soils was growing over time.

The total concentration of Pb in the maize plant samples of Bambili, Baforkum and Bambui were 25.65, 28.12 and 21.32 mg/kg respectively. These values were lower than the maximum allowable limit of 30 mg/kg Pb in maize. The primary source of Pb in the maize plants could be linked to its direct uptake from the soils. Lead uptake by plants depends on several soils properties, such as SOM, granulometric composition, CEC, pH, as well as genetic plant factors, root surface area, and root exudates (Sillanpää, 1982).

Manganese (Mn): The total concentration values of manganese in the soil samples of Bambili, Baforkum and Bambui were 1555.12, 2158.65 and 1650.34 mg/kg respectively. The presence of Mn in the soil is the key to the entire soil redox. All Mn compounds are very important soil constituents because this element is essential in plant nutrition and controls the behavior of several other micronutrients. The soil of Baforkum had Mn level higher than the maximum limit of 2000 mg/kg (Kabata-Pendias, 2011), recommended for agricultural soils. The Mn in all the soils probably resulted from the soil parent materials (basalt, trachytes and rhyolite)

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which are natural sources of Mn in the soil. Elevated Mn level in the soil of Baforkum was the result of anthropogenic sources such as municipal wastewaters, sewage sludge, and metal smelting processes. Since the soils were acidic, Mn solubility was highly favoured leading to high available concentrations (Mofor et al., 2017). When Mn has accumulated in topsoil due to the Mn application over a long period of time, toxic effects such as retarded growth in some plants might be observed (Sparrow & Uren, 2014).

The total concentrations of Mn were 55.12, 258.65 and 230.34 mg/kg for the maize plant samples from Bambili, Baforkum and Bambui respectively. Mn concentration in all plant samples were within the recommended limit (500 mg/kg). Adequate level of available Mn in plants is necessary for plant growth. Mn is known to be a specific component of two plant enzymes; arginase and phosphotransferase, but this metal can also substitute for Mg in other enzymes. The correction of Mn deficiency in crops may be done by both soil and foliar application (Kabata-Pendias, 2011).

Copper (Cu): The total concentration values of Cu in the soil samples from Bambili, Baforkum and Bambui were 94.64, 103.45 and 115.66 mg/kg respectively. The soil sample from Bambili had Cu concentration within the maximum allowable limit (100 mg/kg) while those from Baforkum and Bambui had their Cu levels above this limit. Elevated Cu concentrations in surface soils of Baforkum and Bambui reflect its bioaccumulation as well as its anthropogenic sources such as fertilizers, sprays, and agricultural or municipal wastes (Ruqia et al., 2015).

The total concentration of Cu in the maize plant samples of Bambili, Baforkum and Bambui were 8.64, 18.45 and 34.23 mg/kg respectively. All maize plant samples were within the FAO/WHO recommended limit of 73 mg/kg. The appropriate content of Cu in plants is essential both for the health of the plant and for nutrient supply to man and animals. The concentration of Cu in plant tissues seems to be a function of its level in the nutrient solution or in soils; therefore, the primary source of Cu in the maize plants could be linked to its direct uptake from the contaminated soils (Shaari et al., 2021).

Mercury (Hg): The total concentration values of Hg in the soil samples from Bambili, Baforkum, and Bambui were 0.99, 1.01, and 0.87 mg/kg respectively. These concentrations were within the tolerable limit of 1 mg/kg Hg in soil, for the soils from Bambili and Bambui. The soil of Baforkum had Hg level higher than the maximum allowable limit. There are several exogenic sources of Hg, and most of them are from the atmosphere, and are emitted from (1) combustion of coal and oil, (2) cement production, (3) production of nonferrous metals and steel, (4) gold production, (5) waste incineration, and (6) Hg production. Furthermore, fungicides and seed dressings, as well as sewage sludge used for soil amendment, are serious Hg sources (Kabata-Pendias, 2011). Hg is the most abundant and toxic heavy metal pollutant in the environment, but Hg has no known essential biological function and its emission from industrial sources is of great environmental concern (Balali-Mood et al., 2021). The toxicity of Hg in the soil can be remediated through the application of physical, chemical and biological techniques.

The total concentration of Hg in the plant samples from Bambili, Baforkum and Bambui were 0.81, 0.89 and 0.47 mg/kg respectively. These Hg levels in all maize plant samples were below the maximum allowable limit of 1 mg/kg. Plants take up Hg easily from solution cultures. Soil Hg however is not only directly absorbed by plants, but also indirectly absorbed from Hg vapor gradually released in soils (Manomita & Sudhir, 2022).

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Chromium (Cr): The total concentration values of Cr in the soil samples from Bambili, Baforkum and Bambui were 123.53, 156.3 and 96.54 mg/kg respectively. The soil of Bambili and Baforkum had Cr level above the recommended limit of 100 mg/kg . The Cr content of the surface soils is known to have increased due to pollution from various sources, of which the main ones are COPR, pigments and tannery wastes, leather-manufacturing wastes, and municipal wastes. Forms and transformation of Cr in soils have great environmental and health implications. Cr in its normal dose helps in the proper functioning of the brain, but intake of Cr above 100 mg/kg for a long period of time can lead to skin irritation, nausea, headache, dizziness and mood change (Achmad et al., 2017). Activities of soil microbial enzymes decrease under increased Cr-levels in soils; dehydrogenase activity and nitrification processes are especially sensitive (Kabata-Pendias, 2011). A positive relationship between Cr and the fine granulometric fraction in soils of Bambili resulted in a higher Cr content in clay loamy soils than in sandy loamy soil of Bambui (Kabata-Pendias, 2011). Some of the remediation treatment methods of Cr include: (1) immobilization of Cr using materials of high sorption capacity, for example, smectite clays, coal, bone charcoal (or other sorbents), (2) removal of Cr by electrokinetic techniques, (3) reduction of Cr^{6+} by ferrous sulfate and/or sulfate-reducing bacterial biofilms, and (4) phytoremediation.

Contents of Cr in plants have recently received much attention not only due to the knowledge of its importance as an essential micronutrient in human metabolic processes, but also because of its carcinogenic effects (Kabata-Pendias, 2011). FAO and WHO recommend a maximum allowable limit of 75 mg/kg Cr in maize plants. The total concentration values of Cr in the plant samples from Bambili, Baforkum and Bambui were 53.43, 76.3 and 66.54 mg/kg respectively. The Cr content in the maize plant from Baforkum was thus above the allowable limit. The high accumulation of Cr in maize plant might be due to the sequestration of Cr in the vacuoles of root cells as protective mechanism (Mangabeira et al., 2011). Contents of Cr in plants are controlled mainly by the soluble Cr contents of the soils. The most available form of Cr to plants is Cr^{6+}, which is the very unstable form under normal soil conditions, and its availability depends on soils properties such as soil texture and pH (Asfaw et al., 2017).

Zinc (Zn): Zn is an indispensable macronutrient at low concentration but toxic at high concentration in the soil. The total concentration values of Zn in the soil samples from Bambili, Baforkum and Bambui were 289.43, 450.48 and 305.67 mg/kg respectively. The soil samples from Baforkum and Bambui had Zn concentrations above the maximum allowable limit of 300 mg/kg. Elevated levels of Zn in the soils might have resulted from the improper disposal of Zn containing wastes from garage dealing with metal transformations and electric utilities. According to Olivier et al. (2009), the Zn speciation in contaminated soils is highly controlled by pH and Zn content. The concentration of Zn in soils can be reduced by excessive watering of the soil since excessively wet soil inhibits the uptake of zinc (Nielse, 2012).

The total concentration values of Zn in the maize plant samples from Bambili, Baforkum and Bambui were 89.43, 108.48 and 105.67 mg/kg respectively. Maize plants from Baforkum and Bambui had Zn levels of higher magnitudes than the maximum allowable limit of 100 mg/kg. Zinc toxicity in plants reduce yields and inhibit the growth of both roots and shoots (Cabot et al., 2019).

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RESULTS OF STATISTICAL ANALYSIS

Pearson correlation coefficient (r) between some relevant soil physicochemical properties, soil and plant physicochemical properties, and between soil and plant heavy metals are presented in Table 5, Table 6 and Table 7 respectively.

Table 5: Pearson Correlation Coefficient between Some Soil Physicochemical Properties

	pHKCL	OM	C/M	TotN	AP	Mg	CEC	SB	Clay
pHKCL	1								
OM	0.632	1							
C/M	-0.736	0.059	1						
Tot N	0.971	0.684	-0.688	1					
AP	0.985	0.489	-0.482	0.971	1				
Mg	-0.66	-0.814	-0.628	-0.133	0.108	1			
CEC	-0.085	-0.825	-0.613	-0.152	0.089	**1.000***	1		
SB	-0.038	-0.798	-0.649	-0.I06	0.135	**1,000***	**0.999***	1	
Clay	-0.878	-0.926	0.321	-0.908	-0.782	0.536	0.551	0.512	1

*****Correlation is significant at the 0.05 level (2 tailed)

Table 6: Pearson Correlation Coefficient Matrix between Soil and Plant Physicochemical Properties

	Soil Tot N	Soil OM	Soil K	Plant N	Plant K	Plant TP	Plant Na
Soil N	1						
Soil OM	0.684	1					
Soil K	-0.828	-0.975	1				
Plant N	0.752	0.995*	0.992*	1			
Plant K	-0.842	-0.969	**1.000***	0.989	1		
Plant TP	0.830	0.975	**-1.000****	0.992*	**-1.000***	1	
Plant Na	-0.828	-0.975	**1.000***	-0.992*	**1.000***	**-1.000****	1

*****correlation is significant at the 0.05 level (2 tailed)

******correlation is significant at the 0.01 level (2 tailed)

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Table 7: Pearson Correlation Coefficient Matrix for Total Metal Concentrations in the Soils and Plants

	Soil Cd	Soil Pb	Soil Cu	Soil Hg	Plant Cd	Plant Pb	Plant Cu	Plant Hg	Plant Zn	Plant Mn
Soil Cd	1									
Soil Pb	0.976	1								
Soil Cu	-0.176	-0.388	1							
Soil Hg	0.680	0.824	-0.842	1						
Plant Cd	0.969	**1.000***	-0.415	0.842	1					
Plant Pb	0.832	0.933	-0.693	0.973	0.943	1				
Plant Cu	-0.223	-0.432	**0.999***	-0.867	-0.458	-0.727	1			
Plant Hg	0.714	0.851	-0.815	**0.999***	0.866	0.983	0.205	1		
Plant Zn	0.539	0.341	0.734	-0.251	0.313	0.020	0.701	-0.205	1	
Plant Mn	0.532	0.333	0.740	0.259	0.305	-0.028	0.707	-0.213	**1.000****	1

***** correlation is significant at the 0.05 level (2 tailed)

****** correlation is significant at the 0.01 level (2 tailed)

Correlation study between soil physicochemical properties showed that significant positive correlations existed between CEC and SB ($r = 0.999; p < 0.05$) and between Magnesium and CEC ($r = 1.000; p < 0.05$). This may be due to the fact that Mg being a divalent cation (Mg^{2+}), when adsorbed on the negative charged sites of the soil clay minerals or organic matter, can help neutralize the negative charges thereby increasing the soil CEC. A significant positive correlation also existed between SB and Magnesium ($r = 1.000; p < 0.05$). This may be attributed to the fact that Mn being one of the major exchangeable cations in the soil, along with calcium, potassium and sodium, will normally cause an increase in SB for any increase in Mn. A significant positive correlation between CEC and SB indicated that since CEC of a soil represents its ability to adsorb and hold positively charged cations, such as Ca^{2+}, Mg^{2+}, K^+ and Na^+, any increases in CEC, the soil's capacity to absorb and retain these basic cations also increases, leading to a higher sum of bases. Negative correlations were observed between organic matter and clay ($r = -0.926; p < 0.05$). This may be attributed to the fact that clay-rich soils have a higher mineral content which occupies a larger volume in the soil, reducing the relative proportion of soil organic matter.

Correlation analysis between soil heavy metals and plant heavy metals revealed significant positive correlations between soil Lead and plant Cadmium ($r = 1; p < 0.05$), soil Copper and plant Copper ($r = 0.999; p < 0.05$), soil Zinc and plant Manganese ($r = 1; p < 0.01$). Significant positive correlations between soil-plant metal pairs indicate the interdependence of these metal pairs. This suggests that the metals in the maize plants originated from the soil (Wang et al., 2012; Ma et., 2016).

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CONCLUSION

The main objective of this research work was to assess some soils and maize (*Zea mays)* plants physicochemical properties and the risks associated with the soil and crops contaminated by heavy metals in farmed dump sites in Tubah-Subdivision, North West Cameroon. Surface soils (0-20 cm) and maize plant samples were collected and analyzed for physicochemical and heavy metals (Cd, Pb, Mn, Cu, Hg, Cr, Zn) properties using standard procedures. The results of physicochemical analysis showed that all the soils were acidic with pH values ranging from 5.45-6.12. Organic matter levels in the soils ranged from 3.93-7.14%. The organic matter content for all the three maize plant samples were found to be high, with values ranging from 70.13-76.74%. Total phosphorus values in all maize plant samples were very high, ranging from 146.90-1530.15 mg/kg. Textural classes of the soils were dominated by Clay Loam for Bambili and Baforkum, and Sandy Loam for Bambui. The results of heavy metal analysis showed that the soils and plants were contaminated to different levels by heavy metals (above MAC). The soils and maize plants were contaminated to varying degrees by the heavy metals Cd, Mn, Cu, Hg, Cr and Zn. Therefore, there are potential health hazards associated with the consumption of crops cultivated from the soils. Natural origins, fertilizer application and intensive domestic waste disposal were identified as the major sources of heavy metals in the soils. To reduce health risks in soils with elevated heavy metal content, food crops should be thoroughly washed to remove as much soil as possible. Roots and greener leaves of plants can be cut off before consumption, because Pb and Hg accumulate in the vacuoles of roots to serve as protective mechanism. Heavy metal concentration in soil can be reduced, recover or recycled by remediation techniques such as physical remediation (capping, washing of soil, excavation of soil), chemical remediation (immobilization, solidification, vitrification), electro-kinetic remediation, bioremediation, phytoremediation and microbial remediation.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this article.

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