ECOLOGICAL RISK ASSESSMENT OF SOME HEAVY METALS IN FARMLAND SOILS OF FUNTUA AREA, KATSINA STATE, NIGERIA

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Abstract

The problem of reasonable amount of heavy metals concentrations in agricultural soils creates a global environmental issue due to the importance of food production. This study was carried out to investigate ecological risk and contamination status of heavy metals in agricultural soils of Funtua area Katsina state. For this purpose, twelve soil samples were collected from farmlands. The soil samples were analyzed for Pb, Cr, Cd, Mn, Zn and Fe using atomic absorption spectrophotometry to determine the concentrations of selected heavy elements. Descriptive statistics were employed to summarize the obtained data and Pearson's correlation analysis were also performed. The mean concentration of Pb (0.098), Cr (0.292), Cd (0.233), Mn (0.233), Zn (0.171) and Fe (0.185) were found below the CCME limits in agricultural soils. Result of I-geo revealed moderately polluted by Cd at Maska 3 (1.125) and unpolluted in all samples, the soil was found to be moderately contaminated with Cd and considerably and very high CF for Cd at Maska 3, Maigamji 1, Goya 2 and Goya 3. CD showed five sites having low degree of contamination and the rest having considerable degree of contamination, PLI revealed unpolluted in all samples. High and very high ecological risk for Cd was observed in all samples. Correlation analysis revealed positive correlation between Cr and Mn, Cd and Mn, Cd and Fe, Mn and Zn, Zn and Fe. It is concluded that the area has highly ecological risk contaminated. Monitoring of cadmium concentration in the area is highly recommended.

Keywords: Pollution status, Ecological risk, Heavy metals, Farmland soil, Funtua area

Introduction

Funtua is one of the agricultural areas in the past as well as present in Katsina state. The area is in Katsina state one of the most important agricultural belt. Since sensitive farming activities were conducted over several years, anthropogenic metal pollution may affects the soils quality in the agricultural areas. Soil is a vital natural resource for sustaining human needs of quality food supply and quality environment. Soil is a critical environmental medium, which is subjected to a number of pollutants due to different human activities (Santuraki *et al.,* 2018). Naturally occurring heavy metal content in ecosystem have been largely varied. In modern times, anthropogenic sources of heavy metals, i.e. pollutions from the activities of humans, have introduced some of these heavy metals into the ecosystem. The concentrations of heavy metals in the environment is of great ecological significance due to their toxicity at certain limits, translocation through food chains and non-biodegradability which is responsible for their accumulation in the biosphere (Abdulkadir *et al.,* 2021). Increasing level of heavy metal in soil are associated with biological and geochemical cycles which reduces the quality of the soil, plants, water and eventually increase human exposure to the metals, which can threaten food safety and also pose potential health risks (Appiah *et al.,* 2018). Huge quantity of metals concentration in soil results in serious environmental degradation and threatens all forms of life because its toxicity. (Abdulkadir *et al.,* 2021).

Heavy metal contamination in agricultural lands is a major issue which poses long-term risks for ecosystem health all over the world (Sungur *et al.,* 2016; Gurel, 2018). Heavy metal concentrations are present in trace amounts as a natural result of geochemical processes. There may be increases in the concentrations of heavy metals in the soil by mineralization processes such as hydrothermal alteration and/or weathering processes (Kelepertzis *et al.,* 2015; Sungur *et al.,* 2020) and anthropogenic activities resulting from agricultural practices. There may also be increases in heavy metals concentration in the soil by agrochemicals application (Muktar *et al.,* 2021). The metal uptake by plants is determined by the kinetics of metals mobilized in the soil solution in rhizosphere. In this manner, bioavailability of metals in soils may be defined in terms of a capacity factor, which describes how much is available and a rate factor, which relates the amount of metal to be absorbed by plants (Nwajei *et al.,* 2012; Abdulkadir *et al.,* 2021). Distribution of heavy metals within the soil profile could provide information about their origin (Sołek-Podwika *et al.,* 2016). The study of the concentration, source identification, and ecological risk assessment of heavy metals in agricultural soils is very important in order to identify the areas of pollution and assess the potential sources of pollutants (Esmaeilzadeh *et al.,* 2019; Keshavarzi and Kumar, 2020). Several researchers worldwide have applied numerous environmental pollution indices to assess level of contamination by heavy metals and to describe the quality of soil in the environment (Muller, 1969; Hakanson, 1980; Kowalska *et al.,* 2018; Kumar *et al.,* 2019a). Despite a number of efforts made by previous researchers in Katsina state, Nigeria e.g. Yaradua *et al.,* (2020), numerous research is needed on the pollution status and ecological risks of heavy metals in soils particularly agricultural soils of Funtua area to assess their proper pollution level, because farming activities in this area provides high quantity of both rain-fed and irrigational crops for the people of the area and environs. Therefore the determination of the level of heavy metals in farmlands soils is of great significance since these metals are

taken up by plants and thereby enter into the food chain and may cause serious implication to human health.
Therefore this study aim at assessing contamination status and ecological risk of some heavy metals in farmland soils of Funtua local government area Katsina state. This knowledge will enable farmers to understand the condition of the soils and determine the types of crops to be cultivated in the area and decision makers to have information about the pollution condition contributed by heavy metals in the study area.

Materials and Methods

Site Description

Funtua is among the oldest local government area of Katsina state. It lies between latitudes 11°19'59''N and 11°42'58''N, and longitudes 7°14'42''E and 7°29'15''E, (Figure 1). It is situated on the southern edge of the state. It has a total land mass of approximately 448km^2. Climatically, the area falls within tropical continental belt of wet and dry, with two main seasons; a rainy season, which is irregular, and runs from May to October, characterized by short intense rains, and a prolonged dry season that stretches from September to April. The annual rainfall ranges between 900 mm to 1,200 mm. The area experiences a maximum temperature of 36°C-38°C in the month of March and April, and a minimum of 14°C-19°C in the month of December and January with the mean monthly temperature of 24°C to 31°C (Abaje *et al.,* 2016).

The soil type of the area is tropical ferruginous brown and reddish–brown soils derived from basement complex rock. The Aeolian drift materials are mostly derived from the Cretaceous sandstones lying in the area, and the parent material underlying the study area are composed of unconsolidated sands (Maiwada and Hassan, 2018). Relief of the area is composed of undulating plain (part of the high plains of Hausa-land) which generally rises up to about 600 – 700 m above sea level (Hazo *et al.,* 2019). The area lies in the Sudan savanna vegetation zone, with trees such as shea tree (*Vitellaria paradoxa),* tamarind (*Tamarindus indica),* Neem (*Azadirachta Indica*) e.t.c. Shrubs such as young dum palm (*Hyphaene thebaica*) and grasses such as *Digitaria debilis*; *D. velutina*, scent-leaf (*Ocimum basilicum),* spiderwort (*Commehna nudiflora*) e.t.c. Land uses include residential, agricultural and grassland. Major crops cultivated were maize, rice, corn, soyabeans and beans.

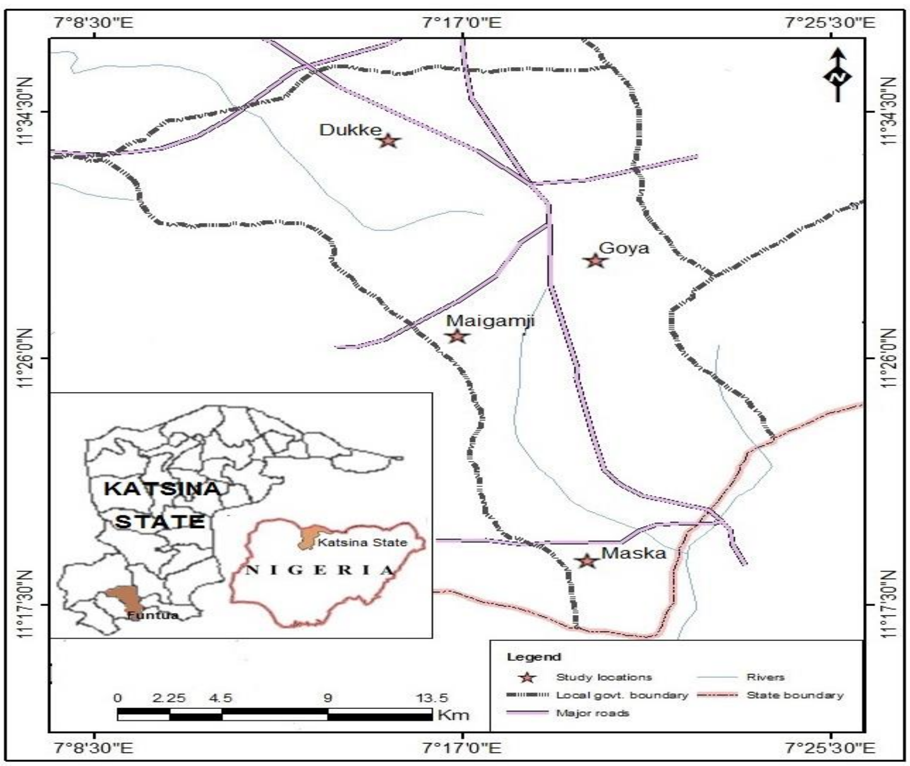

Figure 1: Study area of Funtua local government

Soil Sample Collection and Processing

Soil samples were collected from top soil (0 – 15cm) with the aid of cylindrical plastic auger at twelve randomly selected points. These sampling points were selected for the considerable engagement in rain-fed farming activity and on the basis of spatial locations of the areas. A total of twelve samples were collected, stored in polyethylene bags and taken to soil and water laboratory at Bayero University Kano. All samples were stored at room temperature for further analyses.

Sample Preparation and Digestion

Samples were air-dried at room temperature for a period of four days and later oven-dried at 100°C for three hours to obtain a constant weight. They were then ground using agate mortar and pestle and sieved using 2mm mesh standard sieve. The resulting powders were then digested with concentrated 4MHN0$_3$ on a hot plate for 3 hours, then evaporated and diluted with 50 mL of distilled water to determine the concentration of Pb, Cd, Mn, Zn, Cr and Fe, with atomic absorption spectrophotometer (AAS BRANDMODEL VGP 210).

Soil Contamination and Ecological Risk Assessment

Geo-accumulation Index (I_{geo})

Geo-accumulation index (I_{geo}) is widely used to estimate the potential risk of metals derived from anthropogenic activities. It was first proposed by Muller (1969). I_{geo} is calculated using following equation:

$$\text{Igeo} = log_2 \left[\frac{Cn}{1.5Bn}\right] \quad (1)$$

Where:

Cn = presents concentration of the element in the enriched samples (mg/kg)

Bn = denotes background value of heavy metals (mg/kg)

The factor 1.5 is introduced to minimize the effect of possible variations in the background values which may be attributed to lithologic variations in the soils (Stoffers *et al.*, 1986; Ahmed, *et al*, 2016). The index of geo-accumulation (Igeo) is characterized as follows: Igeo is ≤ 0 (unpolluted), class 0; if Igeo is 0 – 1 (unpolluted to moderately polluted), class 1; if Igeo is 1 – 2 (moderately polluted), class 2; if Igeo is 2 – 3 (moderately to strongly polluted), class 3; if Igeo is 3 – 4 (strongly polluted), class 4; if Igeo is 4 – 5 (strongly-extremely polluted), class 5; if Igeo is >6 (extremely polluted), class 6 (Muller, 1969).

Contamination Factor

Contamination Factor (CF) was used to determine the contamination status of the agricultural soil samples. CF was calculated according to the equation described below (Kumar *et al*., 2019a):

$$C = M_c/B_c \quad (2)$$

Where M_c Measured concentration of the metal and B_c is the background concentration of the same metal. Four contamination categories are documented on the basis of the contamination factor (Hakanson, 1980). CF<1 low contamination; 1≤CF<3 moderate contamination; 3≤CF<6 considerable contamination; CF>6 very high contamination.

Degree of contamination

This is the sum of all the contamination factors in the sample. It is calculated as:

$$CD = \sum M_c/B_c \quad (3)$$

Where Mc = measured concentration in soil; Bc = local background concentration (value) of metal, Four categories have been defined for the degree of contamination which includes: <8 = low degree of contamination; 8-16 = considerable degree of contamination; >32 = very high degree of contamination (Hakanson, 1980)

Pollution load index.

The pollution load index (PLI) was used to characterize the degree of soil contamination for each metal. It is express as:

$$PLI = (Cf_1 \times Cf_2 \times Cf_3 \ldots\ldots Cf_n)1/n \quad (4)$$

Where Cf = contamination factor, n = number of studied metals. The PLI gives an estimate of the metal concentration status. The ranks of values of PLI < 1 denote perfection: PLI = 1 present that only baseline levels of the pollutants are present and PLI > 1 would indicate deterioration of site quality (Hakanson, 1980).

Ecological risk index

The ecological risk index (Er^i) is employed to express the potential ecological risk of a given contaminant, and it is determined through the following equation (Hakanson, 1980).

$$(Er^i) = Tr^i * Cf_1 \quad (5)$$

Where 'Tr^i' is the toxic-response factor for a given substance and the values for each elements are Pb = 5, Cd = 30, Cr = 2, Mn = 1, Zn = 1 and Fe = 1. Cf_1' is the contamination factor of individual metal. The terminologies used to express the degrees of ecological risk index are given as $Er^i < 40$ is low potential ecological risk, $40 \leq Er^i < 80$ is moderate potential ecological risk, $80 \leq Er^i < 160$ is considerable potential ecological risk, $160 \leq Er^i < 320$ is high potential ecological risk, and $Er^i \geq 320$ is considered very high ecological risk

Data analysis

Data were statistically analyzed using descriptive statistics with the aid of Statistical Package for Social Sciences (SPSS) 20.0 version. Pearson's correlation analysis was conducted to find the relationship among different heavy metals using Graphad Instant software 3.0.

Results and Discussion

The descriptive analysis of heavy metals is shown in Table 1. Pb has the lowest concentration ranges from 0.043 to 0.217 mg/kg with the mean content of 0.098 mg/kg, while Cr having the highest concentration ranges from 0.125 to 0.500 mg/kg with the average value of 0.292 mg/kg. Cd content varied from 0.10 to 0.60 mg/kg with the mean value of 0.233 mg/kg, Mn ranges from 0.10 to 0.40 mg/kg with mean value of 0.233 mg/kg, Zn ranging from 0.111 to 0.278 mg/kg with the mean value of 0.171 mg/kg. Low concentration of Zn is associated with less OC. Fe ranging from 0.074 to 0.333 mg/kg with the mean value of 0.185 mg/kg. The low content of Fe could be due loam-sandy texture of the soil in the area. Generally, Fe concentration was recorded more in clayey soil as compared to sandy soil (McGovern 1987). The high concentration of Cr could be attributed to the increase inputs from anthropogenic emissions. All studied parameters were found to be low in comparison with the Canadian soil quality guidelines for the protection of environment and human health, (2007) and European Union regulatory standard (2001). The concentration values for the heavy metals evaluated is in the decreasing order Pb > Zn > Fe > Cd > Mn > Cr. Pb, Mn, Zn and Fe concentration in this study is lower than that reported by Yaradua *et al.*, (2020) in agricultural soils of Katsina state. Cr concentration in this study is slightly similar with that reported by Ahaneku and Sadiq, (2014) for agricultural soils in Bosso, Chanchaga, Gidan Kwano, Lafia metropolis, Maiduguri metropolis and the city of Owerri all in Nigeria. Mn and Cr content reported in this study is much lower than that described for agricultural and background soils of Isfahan, Iran (Esmaeili *et al.*, 2014). Similarly Opaluwa *et al*. (2012) reported Cd content several times higher than that reported in this study.

The skewness values of Pb, Cr, Mn, Zn, Fe and kurtosis values of Pb, Cr, Cd, Zn and Fe in agricultural soil samples were found less than one indicating their normal distribution.

Low standard deviation was observed in all samples but high standard deviation is associated with the lack of evenness in heavy metals dispersal in the soils (Heidari *et al.*, 2019).

Table 1: Statistical summary of heavy metals samples from agricultural soils (mg/kg)

	Min	Max	Mean	S.E	S.D	Skewness	Kurtosis	CCME[a]	EU[b]
Pb	0.043	0.217	0.098	0.017	0.060	0.765	-0.380	70	84
Cr	0.125	0.500	0.292	0.028	0.097	0.668	0.924	64	180
Cd	0.10	0.60	0.233	0.047	0.161	1.216	0.891	1.4	3.0
Mn	0.10	0.40	0.233	0.022	0.075	0.686	1.656	-	200
Zn	0.111	0.278	0.171	0.015	0.051	0.636	0.113	200	70
Fe	0.074	0.333	0.185	0.025	0.086	0.051	-0.856	-	1500

[a] Canadian soil quality guidelines for the protection of environment and human health, 2007.
[b] European union regulatory standard 2001.

Contamination assessment of agricultural soils

The contamination level in agricultural soil was determined by employing geo-accumulation index (I-geo), contamination factor (CF), degree of contamination (CD) and pollution load index (PLI). Table 2, 3, 4 and 5 presented the result.

Table 2: Heavy metals geo- accumulation index of agricultural soils sample

Sample site	Geo-accumulation Index (I-geo)					
	Pb	Cr	Cd	Mn	Zn	Fe
Maska 1	-0.589	0.036	0.347	-0.290	-0.798	-2.268
Maska 2	-0.492	-0.140	0.648	-0.466	-1.002	-2.097
Maska 3	-0.890	-0.140	1.125	-0.765	-0.701	-2.276
Maiganji 1	-1.191	0.036	0.949	-0.290	-0.856	-2.149
Maiganji 2	-0.714	-0.140	0.347	-0.466	-0.923	-2.775
Maiganji 3	-1.201	-0.140	0.347	-0.466	-0.923	-2.745
Goya 1	-1.191	-0.140	0.397	-0.767	-1.099	-2.568
Goya 2	-0.890	-0.441	0.824	-0.466	-1.099	-2.744
Goya 3	-1.191	0.036	0.624	-0.369	-1.099	-2.276
Dikke 1	-0.714	-0.061	0.678	-0.466	-0.923	-2.257
Dikke 2	-.1.191	-0.140	0.347	-0.466	-0.798	-2.276
Dikke 3	-0.681	-0.140	0.648	0.369	-1.099	-2.357

Table 2 revealed that nearly all the I-geo values for Pb, Cr, Cd, Mn, Zn and Fe in agricultural soils of the 12 sites are lower than 0 except for Maska 3. This indicates the negligible contamination in agricultural soils by the six heavy metals. The Igeo values for Cd in agricultural soils in the Maska 3 is higher than 1. This suggests that the agricultural soils in the Maska 3 is moderately contaminated by Cd. This results were in agreement with that reported in previous studies by Wei and Yang (2010) because they have also observed slightly higher Cd geo-accumulation in agricultural soils of some cities China.

Table 3: Heavy metals contamination factor of agricultural soils sample

Sample site	Contamination Factor (CF)					
	Pb	Cr	Cd	Mn	Zn	Fe
Maska 1	0.387	1.630	3.333	0.769	0.238	0.008
Maska 2	0.483	1.086	6.667	0.513	0.149	0.012
Maska 3	0.017	0.087	20.000	0.026	0.298	0.008
Maiganji 1	0.096	1.630	13.333	0.769	0.219	0.010
Maiganji 2	0.290	0.011	3.333	0.512	0.179	0.026
Maiganji 3	0.097	1.087	3.333	0.512	0.427	0.002
Goya 1	0.098	0.087	3.333	0.256	0.119	0.046
Goya 2	0.192	0.544	10.000	0.512	0.119	0.026
Goya 3	0.097	1.630	13.333	0.589	0.119	0.008
Dikke 1	0.290	2.000	6.667	0.512	0.179	0.066
Dikke 2	0.097	1.087	3.333	0.512	0.238	0.008
Dikke 3	0.290	1.087	6.667	0.641	0.119	0.006

From the results of heavy metals contamination factor obtained (Table 3), it shows that, the relative distributions of the contamination factor among the samples were described as Cd > Cr > Mn > Zn > Pb > Fe. The contamination factor indicated a considerable and high contamination of Cd in agricultural soils of the study area as considerable CF for Cd 3 < CF < 6 were observed at Maska 1, Maigamji 2, Maigamji 3, Goya 1 and Dikke 2. There is a very high contamination of Cd at the rest of the sample sites in the study area. Cr contamination values ranges from 0.011-2.000 mg/kg, indicating that the agricultural soil samples were also low and moderately contaminated. The remaining heavy metals (Pb, Mn, Zn and Fe) were found less than one, indicating minimum contamination in the agricultural soils. The result of our study is in support with the findings of Kumar *et al.*, (2019a) with the similar trend of Cd in agricultural soils.

Table 4: Heavy metals degree of contamination and pollution load index of agricultural soils sample

Sample sites	Degree of Contamination	Pollution Load Index
Maska 1	6.3664	0.3355
Maska 2	8.9107	0.3403
Maska 3	20.4366	0.0080
Maigamji 1	16.0542	0.3670
Maiganji 2	4.3531	0.0309
Maiganji 3	5.4597	0.0879
Goya 1	3.9337	0.0379
Goya 2	11.3957	0.2483
Goya 3	15.7777	0.2066
Dikke 1	9.7154	0.9249
Dikke 2	5.2765	0.1111
Dikke 3	8.8105	0.1970

Based on the result of degree of contamination (Table 4), Maska 1, Maiganji 2, Maiganji 3, Goya 1, and Dikke 2 were found negligible degree of contamination. Maska 2, Maigamji 1, Goya 2, Goya 3 Dikke 1 and 3 having considerable degree of contamination. Maska 3, has high degree of contamination in agricultural soils. The considerable and high degree of contamination may be attributed to the influence of anthropogenic influence of waste, pesticides and other chemical fertilizers into the soils. This study disagreed with the findings of Yaradua *et al.,* (2020).

The extent of pollution in the area is also determined through pollution load index (PLI) as shown in Table 4. PLI values obtained across all the study area revealed that all the sampled areas were unpolluted (PLI < 1) by heavy metals. This result is not in conformity with studies carried out by Nafiu *et al.* (2019) in Bomo and Galma irrigation farmlands in Zaria which showed that most of the soil samples were found PLI > 1 indicating deterioration of the soil by heavy metals.

Table 5: Heavy metals ecological risk index of agricultural soils sample

Sample site	Ecological Risk Index (Er^i)					
	Pb	Cr	Cd	Mn	Zn	Fe
Maska 1	1.935	3.26	99.999	0.769	0.238	0.008
Maska 2	2.415	2.172	200.01	0.513	0.149	0.012
Maska 3	0.085	0.174	600.000	0.026	0.298	0.008
Maiganji 1	0.485	3.26	390.99	0.769	0.219	0.010
Maiganji 2	1.45	0.022	99.99	0.512	0.179	0.026
Maiganji 3	0.485	2.174	99.99	0.512	0.427	0.002
Goya 1	0.49	0.174	99.99	0.256	0.119	0.046
Goya 2	0.96	1.088	300.000	0.512	0.119	0.026
Goya 3	0.485	3.26	399.99	0.589	0.119	0.008
Dikke 1	1.45	4.000	200.01	0.512	0.179	0.066
Dikke 2	0.485	2.174	99.99	0.512	0.238	0.008
Dikke 3	1.45	2.174	200.01	0.641	0.119	0.006

Table 5 present ecological risk assessment. It revealed Er values for Pb, Cr, Mn, Zn and Fe were found less than 40 in all samples, demonstrating low ecological risk in the agricultural soils. Cd demonstrated considerable ecological risk at Maska 1, Maiganji 2, Maiganji 3, Goya 1 and Dikke 3. High ecological risk was observed at Maska 2, Goya 2, Dikke 1 and Dikke 3 and very high ecological risk at Maska 3, Goya 3. The Er^i values for all heavy metals was 2835.828, indicating very high ecological risk in the agricultural soils of the study area. This is in conformity with the findings of Kumar *et al.,* (2019a).

Table 6: Pearson's correlation matrix between different heavy metals.

	Pb	Cr	Cd	Mn	Zn	Fe
Pb	1.000					
Cr	-0.0017	1.000				
Cd	-0.2903	-0.2411	1.000			
Mn	0.0899	0.1817	0.6518	1.000		
Zn	0.0542	0.0210	0.4054	0.8090	1.000	
Fe	0.0577	-0.1358	0.7010	0.7010	0.6521	1.000

Correlation coefficients of six heavy metals were shown in Table 6. A very significant positive correlation was observed between Cr and Mn, Cd and Mn, Cd and Fe, Mn and Zn, Zn and Fe. Pb did not display obvious correlation with any other trace metals. This may be due to the fact that major source of Pb in the area was from other anthropogenic activities. Significant correlated coefficients that exists in soils between metal elements suggest that these metal elements existed like contamination sources (Liang *et al.,* 2017). For instance, Cd was noted to be highly correlated with Fe, Mn was also strongly positive correlated with Zn and Fe indicating they are likely from the same source viz., excessive use of fertilizer and pesticides which sinks in soils of the study area. Similarly strong negative correlations are observed between Pb with Cr, Cd, Cr with Cd, Cr with Fe. This study find support from Kumar *et al.,* (2019b) in their work on soils from catchment area of Ravi and Beas rivers and found that Fe showed positive correlation with Zn, Mn. A similar findings by Liang *et al.* (2017) in their study on surface soils of China observed positive correlation of Fe with Mn which is in confirmation with our results.

Conclusion

The results of the study found that the average content of studied heavy metals were below the limit set by Canadian soil quality guidelines for the protection of environment and human health, (2007) and European Union regulatory standard (2001). It was observed that the I-geo values of Pb, Cr, Mn, Zn and Fe was lower than 0 indicating uncontaminated except at Maska 3 that is moderately contaminated by Cd at since the I-geo value obtained is more than 1. There was moderate and considerable contamination factor of Cd in nearly all samples in the area. Result of degree of contamination showed considerable and high class. PLI were observed perfectly. High and very high ecological risk index for Cd was observed at all locations of the study area. There is need to minimize the emission of cadmium in the area since it is responsible for contamination so as to safeguard the ecosystems. Further agricultural soil monitoring is required. Policy makers should develop a strategies in mitigating of high cadmium concentration from agricultural soils because it may pose serious human health risk.

Conflict of Interest

Authors have declared that there is no conflict of interest reported in this work.

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