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Ecological Risk Evaluation Of Heavy Metals In Cultivated Farmland Soils Of Fika Agrarian Communities, Yobe State, Nigeria

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ABSTRACT

This study evaluates the ecological risk of heavy metals in cultivated farmland soils of Fika agrarian communities. Soil samples were collected from cultivated farmlands of fourteen (14) agrarian communities across the local government area at a depth of 0 to 30 cm using soil auger and global positioning system (GPS) device was used to mark the sampling location and elevation above sea level and SPSS 23rd version was the statistical package employed for the statistical analysis in this research ED-XRF analytical technique was used for measurement of heavy metals concentrations in soil. The results revealed that the heavy metals concentration mean is in the order of Cd (1226) > Fe (15351) > Zn (70.00) > Pb (44.571) > Cu (37.19) > Cr (36.27) > Ni (18.13) > As (10.63) ppm respectively which were all below the permissible limits except Cd found to be above the permissible limit set by International organizations such WHO, USEPA among others which might be due to natural and anthropogenic means. The study area has low CF with respect to Zn, Cr, Ni & As, moderately contaminated with Pb & Cu but very high contaminated with Cd and Fe, The PER in the following order Cd > As > Pb > Cu > Cr > Zn were found while ERi was from 9.3066 to 368733, whereas the highest values calculated was around the areas of frequent application of chemicals as herbicides/pesticides which established extremely strong risk of ecological damage which classified the study area as low ecological risk with respect to Zn, Cr, Pb, Cu & As but has very high ecological risk in terms of Cd which revealed that Cd was the only heavy metal posing a potentially high ecological risk in the farmland while Zn, Cr, Pb, Cu & As has low ecological risk. It was concluded that the farmers can cultivate the areas with low heavy metals (Zn, Cr, Pb, Cu & As) concentration and recommended that they should abandon the areas with high concentration of Cd by applying the method of shifting cultivation.
Keywords: Heavy Metals, contamination Factor, Ecological Risk Evaluation, Soil, Farmlands, Fika,

INTRODUCTION

Soil is a composite system which consists of organic and inorganic matter that directly and indirectly supports plant and animal life and is a crucial component of our rural and urban environments (Emanuel, 2015). Soil is a main part of the terrestrial ecosystem which is a heterogeneous mixture of different organisms and minerals, organic, and organo-mineral substances present in three phases: solid, liquid and gas (Coskun et al., 2006). As such soil is feasibly the most endangered component of our environment which is open to potential contamination by a variety of different pollutants arising from majorly human activities such as nuclear, industrial, agriculture, among others (Hussaini and Kachallah, 2023). Heavy metals are highly toxic with confrontational implications on the plants, animals and human being (Negahban, & Mokarram, 2021), causing many complications such as high blood pressure, damages to the nervous system, bone diseases and several serious health disorders, such as diarrhea, stomatitis, tremor, ataxia, paralysis, convulsion, depression, and pneumonia (Matheus, *et al.*, 2020). The nature of the effects of these disorders can be toxic, neurotoxic, carcinogenic, mutagenic, or teratogenic (EU, 2002). Heavy metal pollution in the agricultural soils is one of the dangerous issues due to toxicity (Zhan et al., 2010, Varol and Sen, 2012). Heavy metals in agricultural soils originate from both natural and anthropogenic sources. Natural processes like atmospheric inputs, geological weathering of parent material and soil erosion (Emmanuel, 2014), anthropogenic sources are mainly from industrial processing, urban sewage, mining activity and agricultural run – off (Rezaei and Sayadi, 2015, Negahban, & Mokarram, 2021). However, plants/crops may accumulate heavy metals existing in soils which are not needed and the agricultural products might be contaminated and might cause serious health problems to the consumers. The main objective of this research is to evaluate the ecological risk of heavy metals (Cd, Cr, Fe, Pb As, Ni Cu, and Zn) in cultivated farmland soils of Fika agrarian community since agriculture continues to be the most major sector of Yobe State economy, as 70% of the population were involved in agriculture and related activities for their livelihood. So, the environmental risks of heavy metals in soil have been, and will continue to be, a significant issue of great concern (Krishna et al., 2009; Siyue & Quanfa, 2010; (Swarnalatha *et al.,* 2013). Energy Dispersive X-ray fluorescence is an analytical technique that is used to determine the chemical composition of all kinds of materials. It is one of the most common non-destructive methods for qualitative as well as quantitative determination of elemental composition of materials. It is suitable for solids, liquids as well as powders. This technique is fast, accurate and non-destructive, and will only require a minimum of sample preparation. Energy and wavelength are related in the fundamental equation which gives a very useful relationship for the conversion of wavelength to energy (Twyman, 2005).

$$E = \mathrm{h}v = \frac{hc}{\lambda}$$

(1)

Where E is the energy, λ is the wavelength of the radiation in meters, v is the frequency of the radiation, c is the velocity of light in vacuum, ($2.9979\text{x}10^{8}$ ms^{-1}) and h is Planck's constant $6.624\text{x}10^{-34}$ Js^{-1}.

Study area: The study area comprised the whole of Fika local government area of Yobe State, Nigeria. Fika is located between latitude 11°17'16" North and longitude 11°18'28" East (Maplandia, 2025). It has an area of 2208 km^{2} consisting of ten wards. It has a total population of 136,895 at the 2006 census with over 70% of the population involved in agricultural activities. The vegetation of Fika falls under Sudan savannah whose annual rainfall range from 500 mm to 1000 mm. Fika populace experience cool dry (harmattan) season from December to February with a minimum temperature of 22^{0}C; a hot dry season from March to May with a maximum temperature range of 39^{0}C to 42^{0}C; a warm wet season from June to September with average temperature of 40^{0}C and a less marked season after rainfall during the months of October to November with temperature of 28^{0}C (Meteorological Station Potiskum, 2025).

MATERIALS AND METHOD

Sample locations:

The study was carried out in 14 sample locations within the Fika agrarian community. The locations were sited using Global Positioning System (GPS) device and coded as in Table 1 and figure 1.

Table 1: Sampling points and location of soil sample

Sample Code	Sample Coordinates by GPS Latitude	Longitude	Agrarian Communities	Elevation in metre
FKA_1	Lat. 11.43877^0	Long. 011.18919^0	Gudi	399
FKA_2	Lat. 11.57554^0	Long. 011.19951^0	Dogo Abare	470
FKA_3	Lat. 11.12596^0	Long. 011.37274^0	Ngalda	284
FKA_4	Lat. 11.35297^0	Long. 011.28611^0	Moiduwa	450
FKA_5	Lat. 11.27931^0	Long. 011.41694^0	Zangaya	333
FKA_6	Lat. 11.31313^0	Long. 011.37569^0	Turmi	374
FKA_7	Lat. 11.26034^0	Long. 011.36388^0	Malda	323
FKA_8	Lat. 11.18351^0	Long. 011.34393^0	Gadana	296
FKA_9	Lat. 11.54636^0	Long. 011.07249^0	Siminti	485
FKA_{10}	Lat. 11.27842^0	Long. 011.30257^0	Fika	371
FKA_{11}	Lat. 11.31580^0	Long. 010.99308^0	Godowoli Gamari	414
FKA_{12}	Lat. 11.32176^0	Long. 011.05304^0	Balde	416
FKA_{13}	Lat. 11.28263^0	Long. 011.14703^0	Gadaka	446
FKA_{14}	Lat. 11.30619^0	Long. 011.23099^0		450

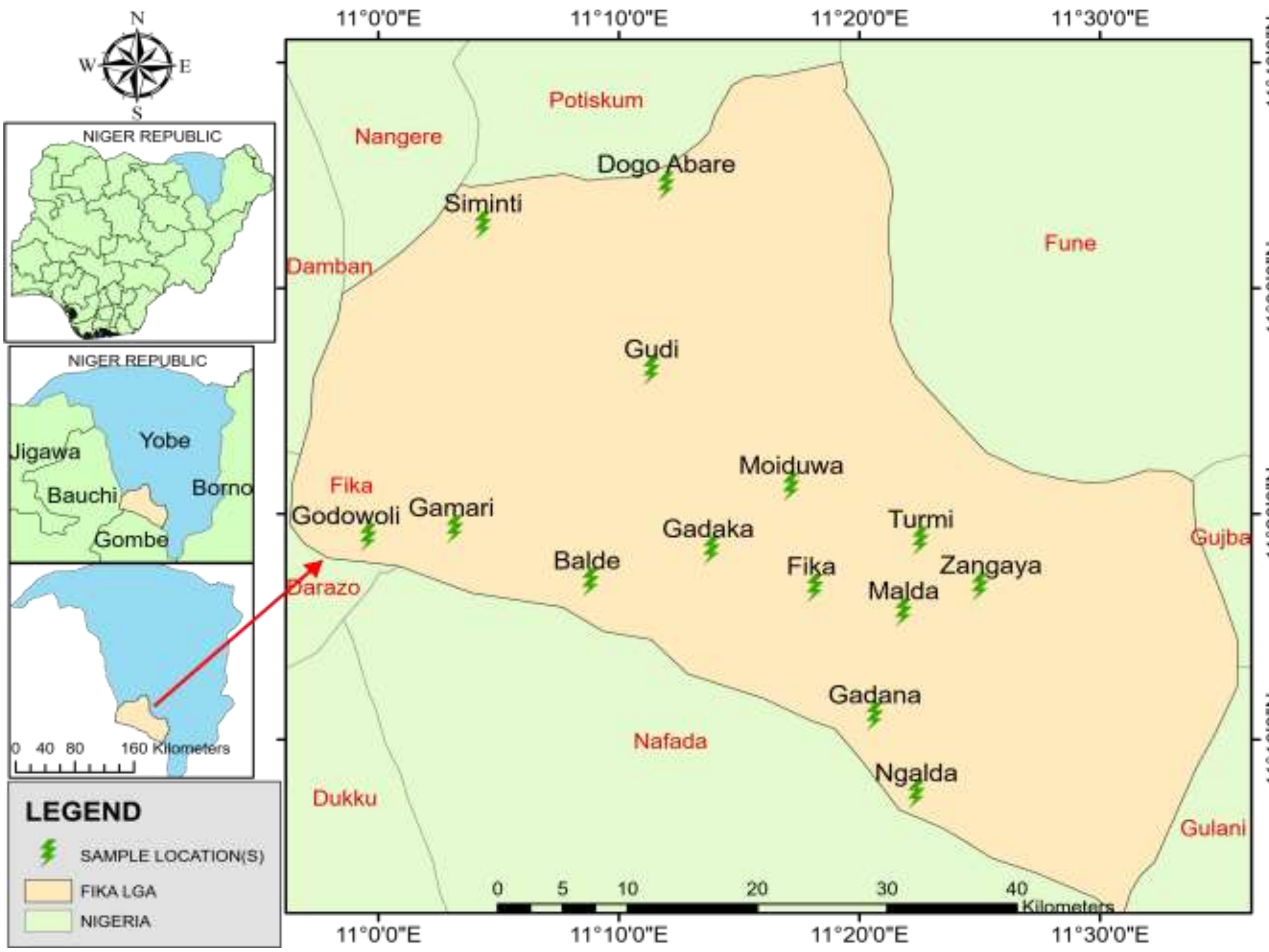

Fig. 1: Map of Fika Local Government Yobe State Showing locations of collected samples

Sample Collection, Preparation and Experimental Procedure

A total of 14 soil samples were collected from cultivated farmlands 14 agrarian communities across the study area at a depth of 0 to 30 cm using soil auger and GPS device was used to mark the coordinates and elevation above sea level. The samples were stored in polyethylene bag, labeled properly and taken to the laboratory for analysis. The soil samples were prepared for ED-XRF analysis by drying, grinding and sieving to produce homogeneous samples from loose powders. 5g of each sample were weighed into 32 mm sample cups with a polypropylene X-ray film of 4 μm thickness and were hydraulically pressed. 2 g of each of the samples was weighed into a sample holder and covered with cotton wool to prevent it from spraying, it was run in a vacuum for 10 minutes and inserted into the ED - XRF Spectrometer for the elemental analysis, the samples were run in the ED-XRF spectrometer for 10 minutes each after which the results for the heavy metals concentration in elemental form were obtained in percentage and then converted to ppm before data analysis (Jauharah, *et al.,* 2011). The following parameters were determined from the collected soil samples:

Contamination Factor (CF)

The contamination factor (CF) is a measure of the contamination level of heavy metals in the soil samples. This factor was calculated using the following formula employed by Harikumar *et al.,* (2009), Odat, (2015) and Ali *et al.,* (2016).

$$CF = \left(\frac{C_x}{C_r}\right)_{sample}$$

(2.0)

Where C_x is the mean concentration of elements from sampling sites in the study area and Cr is the concentration of the examined element in the reference environment. The CF values are classified in Table 2.

Table 2: Classification of Contamination Factor

S/N	Values	Classification
1	CF < 1	Low contamination factor
2	1≤ CF < 3	Moderate contamination factor
3	3 ≤ CF < 6	Considerable contamination factor
4	6 ≤ CF	Very high contamination factor

(Source: Rahman *et al.,* 2012; Ali *et al.,* 2016).

Potential Ecological Risk Factor (PER) and Ecological Risk Index (ERi)

Potential Ecological Risk Factor (PER) measure both risk factor and metals concentrations in soil. For an accurate assessment of heavy metal pollution in terms of ecological risks index (ERi), potential ecological risk factors (PER) were determined (Hakanson, 1980). PER represents the sensitivity of the biological risk caused by the toxic substance and illustrates the potential ecological risk caused by the overall contamination (Zhihao *et al.,* 2012). The PER values are determined using equation (4) and the risk factors are classified (Hakanson, 1980) as shown in Table 3.

The potential ecological risk factor was determined using equation 4

$$PER = CF \times TRF$$

(4.0)

Where PER is the potential ecological risk factor/index, TRF represents the toxic response factor for a given element with values for each element as Zn = 1, Cr = 2, Cu = 5, Pb = 5, As = 10, and Cd = 30 while CF represents contamination factor of a single heavy metals (Hakanson, 1980 & Swarnalatha *et al.,* 2013).

Table 3: Classification of Potential Ecological Risk Factor (PER) and Ecological Risk Index (ERi)

S/N	Potential Ecological Risk (PER)	Ecological Risk Index (ERi)	Classification
1	PER < 40	Ri < 150	Low Ecological Risk
2	40 ≤ PER < 80	150 < Ri < 300	Moderate Ecological Risk
3	80 ≤ PER ≤ 160	300 < RI <600	Considerable Ecological Risk
4	160 ≤ PER ≤ 320	-	High Ecological Risk
5	PER ≥ 320	RI > 600	Very high Ecological Risk

(Source: Hakanson, 1980).

The Ecological Risk index (ERi) was obtained as a summation of PER of six heavy metals of interest (i.e. As, Cd, Cr, Cu, Pb and Zn) using equation 5.0 below (Hakanson, 1980 & Swarnalatha *et al.*, 2013).

$$ERi = \sum PER$$

(5.0) **Statistical analysis**: SPSS 23rd version was employed for the statistical analysis in this research. Mean, range and standard deviation descriptive statistics as well as Pearson Product Moment Correlation (PPMC) inferential statistic were used to analyze the data.

RESULTS AND DISCUSSION

The ED-XRF analysis results obtained shows presence of Cd, Cr, Fe, Pb, As, Ni Cu, and Zn for all the samples at 0 to 30 cm soil depths with their concentrations in ppm as shown in Table 4. The values vary as follows: Fe (3716 – 41416), Cd (1221 – 1229), Zn (26.20 - 199.40), Cu (11.70 – 80.70), Cr (11.30 - 105.30), Pb (14.30 – 75.70), Ni (6.67 – 56.50) & As (3.00 – 20.00). From the result, only Zn, Pb, Fe and Cu were detected in all the samples while Cr Cd, As and Ni were below detection limit in some of the sample locations. Cd is the only element whose concentration in only three locations was found to be above the permissible limit set by (WHO, 1996; USEPA, 2017; Ibrahim *et al*, 2021). The high concentration of Cd might be due to anthropogenic activities such as sewage effluents and application of herbicides/pesticides by farmers (Yin. *et al.,* 2011).

Table 4: Elemental Concentration (EC) of heavy metals in soil samples in ppm.

Sample Codes	Zn	Fe	Cd	Cr	HEAVY Pb	METALS Cu	Ni	As
FKA_1	28.20	8065	BDL	BDL	53.30	26.40	8.00	BDL
FKA_2	39.70	14060	BDL	33.40	39.00	52.30	10.70	5.00
FKA_3	44.00	7203	BDL	15.70	33.00	31.70	10.70	17.00
FKA_4	28.80	7225	BDL	11.30	17.50	18.40	7.40	20.00
FKA_5	89.10	27663	1229	57.50	75.00	51.00	35.10	7.00
FKA_6	105.1	19897	BDL	34.10	59.60	30.70	18.90	BDL
FKA_7	146.5	41416	1227	105.3	62.20	76.70	56.50	BDL
FKA_8	143.2	38975	BDL	84.30	73.70	80.70	47.50	BDL
FKA_9	38.20	6331	BDL	16.70	24.10	16.60	10.50	BDL
FKA_{10}	199.4	20918	BDL	43.10	75.70	46.70	21.30	BDL
FKA_{11}	26.20	3716	1221	12.50	29.80	11.70	6.67	7.00
FKA_{12}	33.60	7471	BDL	24.70	43.30	31.20	11.60	3.00
FKA_{13}	29.40	3948	BDL	12.50	14.30	28.80	BDL	15.00
FKA_{14}	28.70	8035	BDL	20.40	23.50	17.80	9.00	11.00
MEAN	**70.00**	**15351**	**1226**	**36.27**	**44.571**	**37.19**	**18.13**	**10.63**

BDL – Below Detection Limit

Contamination Factor (CF)

Table 5 shows the CF of each heavy metal in soil samples. CF cannot be computed for Cd in (FKA_1, (FKA_2, FKA_3, FKA_4, FKA_6, FKA_8, FKA_9 , FKA_{10}, FKA_{11}, FKA_{12} and FKA_{13}), As in (FKA_1, FKA_6, FKA_1, FKA_8, FKA_9 and FKA_{10}), Ni in(FKA_1) and Cr in (FKA_1) because their elemental concentrations were below detection limit. The overall CF level of the study area can be classified as low contamination to moderately contamination to very high contamination as shown in Table 6. A very high CF might be due to waste discharge from gutters, and application of herbicides/pesticides in the farmlands (Arao *et al.*, 2010; Decena *et al.*, 2018 & Rashid *et al*, 2023). Table 7 shows the PPMC correlation coefficients of CF of heavy metals, Strong positive correlations were obtained between Zn – Cr, Cu – Zn, Zn – Fe and Cu – Pb at significant level of 0.01. Moderate negative correlation was found between and Pb – As, Ni – As and Zn – As. Weak negative correlation was found between Cr – As, Fe – As and Cu – As amongst others.

Table 5: Contamination Factor (CF) of heavy metals in soil samples in ppm.

Sample Codes	Zn	Fe	Cd	Cr	HEAVY Pb	METALS Cu	Ni	As
FKA_1	0.3810	2743.1	-	-	2.0500	1.1478	0.296	-
FKA_2	0.5364	4782.3	-	0.5475	1.5000	2.2739	0.396	0.384
FKA_3	0.5945	2450.0	-	0.2573	1.2692	1.3782	0.396	1.307
FKA_4	0.3891	2457.4	-	0.1852	0.6730	0.8000	0.274	1.538
FKA_5	1.2040	9409.1	12290	0.9426	2.8846	2.2173	1.300	0.538
FKA_6	1.4202	6767.6	-	0.5590	2.2923	1.3347	0.700	-
FKA_7	1.9797	14087	12270	1.7262	2.3923	3.3347	2.092	-
FKA_8	1.9351	13256	-	1.3819	2.8346	3.5086	1.759	-
FKA_9	0.5162	2153.4	-	0.2737	0.9269	0.7217	0.388	-
FKA_{10}	2.6945	7114.9	-	0.7065	2.9115	2.0304	0.788	-
FKA_{11}	0.3540	1263.9	12210	0.2049	1.1461	0.5086	0.247	0.538
FKA_{12}	0.4540	2541.1	-	0.4049	1.6653	1.3565	0.429	0.230
FKA_{13}	0.3972	1342.8	-	0.2049	0.5500	1.2521	-	1.158
FKA_{14}	0.2405	2732.9	-	0.3344	0.9038	0.7739	0.333	0.841

Table 6: Mean, CF Class and Remark of CF of heavy metals in soil samples.

Elements	N	Mean	CF class	Remark
Zn	14	0.93550	< 1	Low CF
Fe	10	5221.50	6 ≤ CF	Very High CF
Cd	3	12256.6	6 ≤ CF	Very High CF
Cr	13	0.55000	< 1	Low CF
Pb	14	1.7143	1 ≤ CF < 3	Moderate CF
Cu	14	1.6170	1 ≤ CF < 3	Moderate CF
Ni	13	0.6713	< 1	Low CF
As	8	0.81675	< 1	Low CF

Table 7: The PPMC coefficients of CF for Heavy Metals in the study area

Elements	Zn	Fe	Cd	Cr	Pb	Cu	Ni	As
Zn	1.000							
Fe	0.806**	1.000						
Cd	0.171	0.382*	1.000					
Cr	0.756**	0.967**	0.448	1.000				
Pb	0.822**	0.799**	0.275	0.686**	1.000			
Cu	0.725**	0.920**	0.234	0.913**	0.722**	1.000		
Ni	0.743**	0.977**	0.477*	0.971**	0.750**	0.879**	1.000	
As	-0.531	-0.495	0.108	-0.444	-0.667**	-0.419	-0.478	1.000

**Correlation is significant at the 0.01 level. *Correlation is significant at the 0.05 level.

Potential Ecological Risk (PER) and Ecological Risk Index (ERI)

To obtain a perfect assessment of heavy metal pollution in terms of ecological risks, potential ecological risk indices were determined (Hakanson, 1980). Potential Ecological Risk Index (PERI) represents the sensitivity of the biological risk caused by the toxic substance and illustrates the potential ecological risk caused by the overall contamination (Zhihao *et al.*, 2011). Table 8 shows the PER and ERi values of soil samples, the mean PER values decreased in the following order: Cd (367700) > Pb (8.5712) > As (8.1675) > Cu (8.0650) > Cr (1.100) > Zn (0.9355). Almost all the potential ecological risk factors of the heavy metals were < 40 which indicates low potential ecological risk factors except Cd in only 3 sample locations with potential ecological risk factors PER > 320, implying a very high risk factor in the area of study. The area can thus be classified to be of low to very high risk index since 11 sample locations have low ecological risk index (ERi < 150) with only 3 sample locations whose index (ERi) is > 600 (see Table 9). The foremost reason contributed to the very high ERi index in some of the sample locations is Cd with very high potential ecological risk values (PER > 320) in only 3 sample locations which posed a high ecological risk index to the studied area. The results obtained in this study is in line with those conducted by (Negahban, & Mokarram, 2021) which gives a PERI values > 500; ERI values of 250 – 350 (Krupadam *et al.*, 2006) and ERI value of 12.3 ((Zhihao *et al.*, 2012).

Table 8: Potential Ecological Risk Factor and Ecological Risk Index values of soil samples in ppm.

Sample Codes	Zn	As	Cd	Cr	HEAVY Cu	METALS Pb	ERi
FKA_1	0.3810	-	-	-	5.7390	10.250	**16.370**
FKA_2	0.5364	3.840	-	1.0950	11.369	7.5000	**24.340**
FKA_3	0.5945	13.07	-	0.5146	6.8910	6.3460	**27.416**
FKA_4	0.3891	15.38	-	0.3704	4.0000	3.3650	**23.504**
FKA_5	1.2040	5.380	368700	1.8852	11.086	14.423	**368733**
FKA_6	1.4202	-	-	1.1180	6.6735	11.461	**20.673**
FKA_7	1.9797	-	368100	3.4524	16.673	11.961	**368134**
FKA_8	1.9351	-	-	2.7638	17.543	14.173	**36.414**
FKA_9	0.5162	-	-	0.5474	3.6085	4.6345	**9.3066**
FKA_{10}	2.6945	-	-	1.4130	10.152	14.557	**28.817**
FKA_{11}	0.3540	5.380	366300	0.4098	2.5430	5.7305	**366314**
FKA_{12}	0.4540	2.300	-	0.8098	6.7825	8.3265	**18.672**
FKA_{13}	0.3972	11.58	-	0.4084	6.2605	2.7500	**21.396**
FKA_{14}	0.2405	8.410	-	0.6688	3.8695	4.5190	**17.707**

Table 9: Mean, Potential Ecological Risk (PER) of Heavy Metals in soil samples.

Elements	N	Mean	PER Class	Remark
Zn	14	0.9355	PER < 40	Low PER Low
As	8	8.1675	PER < 40	PER
Cd	3	367700	PER > 320	Very High PER
Cr	13	1.100	PER < 40	Low PER Low
Cu	14	8.0850	PER < 40	PER
Pb	14	8.5712	PER < 40	Low PER

Table 10: The PPMC coefficients of Potential Ecological Risk Factor (PER) of Heavy Metals in soil samples.

Elements	Zn	As	Cd	Cr	Cu	Pb
Zn	1.000					
As	-0.531	1.000				
Cd	-0.171	-0.108	1.000			
Cr	0.756**	-0.444	0.448	1.000	1.000	
Cu	0.725**	-0.419	0.234	0.913**	0.722**	1.000
Pb	0.822**	-0.667*	0.275	0.688**		

**Correlation is significant at the 0.05 level. *Correlation is significant at the 0.01 level.

CONCLUSION

The ED-XRF analysis results obtained for the soil samples shows presence of Cd, Cr, Fe, Pb As, Ni Cu, and Zn in the study area with their mean concentrations in ppm as follows: Fe (), Cd (), Zn (), Cu (), Cr (), Pb (), Ni () & As () which were all below the permissible limits except Cd found to be above the permissible limit set by International Organizations such WHO, USEPA among others, this might be due to natural and anthropogenic means. The study area has low CF with respect to Zn, Cr, Ni & As, moderately contaminated with Pb & Cu but very high contaminated with Cd and Fe, the study area is also classified as low PER/ERi with Zn, Cr, Pb, Cu & As with very high PER/ERi in terms of Cd, therefore the ecological risk assessment results revealed that Cd was the only heavy metal posing a potentially high risk to the environment while other heavy metals has low ecological risk. The highest PER and ERi caused by Cd concentration in soils samples were 368700 and 368733 respectively, corresponding to very high ecological risk. By comparison of heavy metals concentrations and correlation analysis, the heavy metals originated mainly by frequent application of chemicals going on by the farmers of study area. Therefore, the control of high ecological risk in Fika agrarian communities is vital for the mitigation of Cd contamination in the study area, especially the activities that release Cd to the environment such as contaminated irrigation water, use of municipal waste for fertilizer and frequent application of chemicals for herbicides/pesticides in the farmlands. Furthermore, a well-managed waste disposal system is essential for controlling the high ecological risk caused by potentially toxic metals like Cd. It was also concluded that the farmlands are still safe and good for agricultural activities to some extent but farmers and other relevant agency involved in planning regards to agricultural practices should be properly guided on the soil utilization and consumption of agricultural products cultivated in the study area may not constitute any health hazards to humans and animals at the time of this study.

Conflict of Interest: The authors declared no conflict of interest.

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