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Heavy Metals Levels and Contamination Status in Soils of Koudalwa, Tchad

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ABSTRACT

This study is aimed at determining the heavy metal levels in agricultural soils and around oil drilling pits in Koudalwa, Tchad and evaluating pollution levels. Soil sampling was done on three sites AA (AA1 & AA2), BB (BB1 & BB2), CC (CC1 & CC2) with two samples collected per site, giving a total of six samples. The subsamples with code one represent the 0-30 cm depth and code two represent the 30-60 cm depth. A control sample was taken far from sites having any oil activities. 2 mm sieved soil samples were digested in a mixture of HCl and HNO_3 in the ratio 1:3 and the concentrations of Cr, Cd, Pb, Hg, Cu, Mn, Fe and Ni in the digested solutions determined by atomic absorption spectroscopy. The contamination level of the heavy metals was assessed using the Geo-Accumulation Index (Igeo), Contamination factor, Pollution load index (PLI), Enrichment Factor (EF), and Potential Ecological Risk Assessment (PER) models. Results obtained shows that the abundance of heavy metals in the soils of Koudalwa is in the order; Cu ˃ Hg ˃ Cr ˃ Mn ˃ Fe ˃ Cd ˃ Ni ˃ Pb. The site AA shows the highest levels of all the determined heavy metals except Ni with highest amount of Cr (197.98 mg/kg), Cd (6.49 mg/kg), Hg (531.46 mg/kg), Ni (0.088 mg/kg) in the 30-60 cm soil depth, and Pb (0.021 mg/kg), Cu (815.24 mg/kg), Mn (166.55 mg/kg) and Fe (60.04 mg/kg) in the top soil, 0-30 cm depth. PLI analysis confirms that sites AA1 and AA2 present a decline of site quality as compared to other sites which are of perfect site quality. ER values for Cd, Cr, Cu, Hg showed severe enrichment due to contributions of anthropogenic sources with higher values in subsurface samples, thus indicating their high mobility in these soils. Results of this study shows that critical attention must be given to site AA as well as other activities in other sites that can contaminate the soils with special focus on remediation measures and sensitization of the population on the dangers of different activities on the soils.

Keywords: Ecological risk, Heavy metals, Koudalwa, Pollution, soil.

1. Introduction

Developing countries all have some common similarities such as increase in population density, increasing industrialization, increase urbanization and inadequate waste management strategies etc. These activities send toxic substances in to the environment either directly or indirectly, hence causing the degradation of the environmental quality (Saha et al., 2017). One group of these toxic substances which are of serious environmental concerns are heavy metals. This is because they are toxic but very abundant, very chronic in nature, resistance to decomposition, and bio-accumulate. In polluted soils, heavy metals can accumulate which may create health problems to humans and other animals, plants, and ecosystems (Pham et al., 2028; Alahabadi and Malvandi, 2018). The soil is considered as the support to all life because it is a source which is vital to both production of food, global energy balance and ecosystem functioning (Doran et al., 1996). When the heavy metal gets into the soil, their distributions are believed to be governed by reactions in soil such as: mineral precipitation and dissolution, ion exchange, adsorption and desorption, aqueous complexation, biological immobilization and mobilization and plant uptake (Levy et al., 1992). The soil can be contaminated by toxic substances found in effluent either due to long term disposition, industrial leaks or application of various compounds (such as sewage sludge manure, fertilizers, pesticides etc.) (Zhu et al., 2020).

In Chad, most estimates that 80 percent of Chad's population relies on agriculture, livestock, or fishing (**International Trade Administration**, 2020). Chad exported USD 33.8 million of sesame seeds and USD 21.5 million of gum Arabic in 2019, according to the International Trade Centre. Other potential export crops include peanuts, shea butter, hibiscus, cashews, dates, moringa, and spirulina. Chad is the second largest global producer of premium grade gum arabi. Secondly, Chad economy is very dependent on petrol as Chad is an oil-producing country since 2003, and has become very dependent on this resource while its economy was previously based on agriculture (Banque africaine de développement, 2023). Different specified activities of crude oil extraction process as well as the disposal of petrochemical waste can result in the contamination of soils with Cd, Cr, Cu, Ni, Pb, V, As, Hg, Cr (VI), Ni, Co, Cu, Mn, and Zn among other potentially toxic elements (Nadal et al., 2004; Radulescu et al., 20120). Equally due to use of different agro-chemicals, agricultural soils have been reported to be contaminated by the following heavy metals: Cd, Pb, Cr, As, Hg, Ni, Cu, Zn, Cu, Fe, Mn, Mo, Ni, Mg, and B, and having toxic effects at elevated levels on plants (Rashid et al., 2023; Biradar et al., 2023).

Despite the threats posed by heavy metals resulting from the use of agrochemicals and different activities of crude oil extraction process in Chad, very little attention is given to this area like in many developing countries due to complete lack of awareness on the risk of these activities, poor policy and regulatory systems and low level of law enforcement (Tsamo, 2014). However, in 2013, the Chadian government ordered a company to stop oil exploration drilling in Koudalwa area, 200 kilometers south of the capital, N'Djamena due to violation of environmental standards by the company. This originated from that fact that crude was spilled during exploitation but it was buried in pits on the ground, without any precautions, leading in particular to contamination of soil and groundwater. Also, drilling sludge, a highly toxic waste, was also placed in open pits, causing contamination of soil, ground and surface water. Furthermore, quarries of 3 to 4 meters deep (the required standard is 1.50 m) were also dug during exploitation without being secured, representing a permanent danger for the population and local fauna (Boris, 2013). The soil in Chad is sandy soil as it is a Sahelian zone. soil contamination from the use of agro-chemicals and petroleum extraction can easily spread due the nature of the soil. While SAMBA et al. (2021) (Prosper et al., 2021) have studied the impact of oil installations on groundwater resources in Bongor Basin, Republic of Chad and determined heavy metals in soils of Koudalwa around the oil installations, studies on heavy metals levels in agricultural soils in Koudalwa as well as risk assessment of heavy metals from these agricultural soils and around drilling pit is scarce in literature. This work is therefore aimed at determining the heavy metal levels in agricultural soils and around oil drilling pits in Koudalwa, Tchad and evaluating pollution levels through standard risk assessment models. This study will allow the government and other partners to properly plan remediation measures in case of excessive pollution and to educate the population on the safe use of agro-chemicals.

2. Experimental Methods

2.1. Study Area and Soil Sampling

Koudalwa (Fig.1.) is situated within the Bongor Basin (which is the capital of the region of East) which is located between longitude 15.15° and 17.50° E and between latitude 9° and 11.25° N covering approximately 105,767 km^2 (Prosper et al., 2021). This area has a transitional zone between Sahelian and Sudanese climates, with vegetation being mainly Sudanese shrub savanna supported by sandy textured soils (Prosper et al., 2021). Soils that predominate in this area are tropical ferruginous soils formed on silica sands or clay sands (Prosper et al., 2021).

Soil sampling was done on three sites with two samples collected per site, 0-30 cm depth and 30-60 cm depth giving a total of six samples. A control sample was taken far from sites having any oil activities. The samples points, their geographical coordinates and description of activity on each sample site is shown in Table 1. The corresponding map of the sampling points in the study area is shown in Fig. 2. The soil was collected using a hand shovel. For each sub sample, collected soil was properly mixed for homogenization, parceled in a polyethylene bag and labelled using a tape and marker.

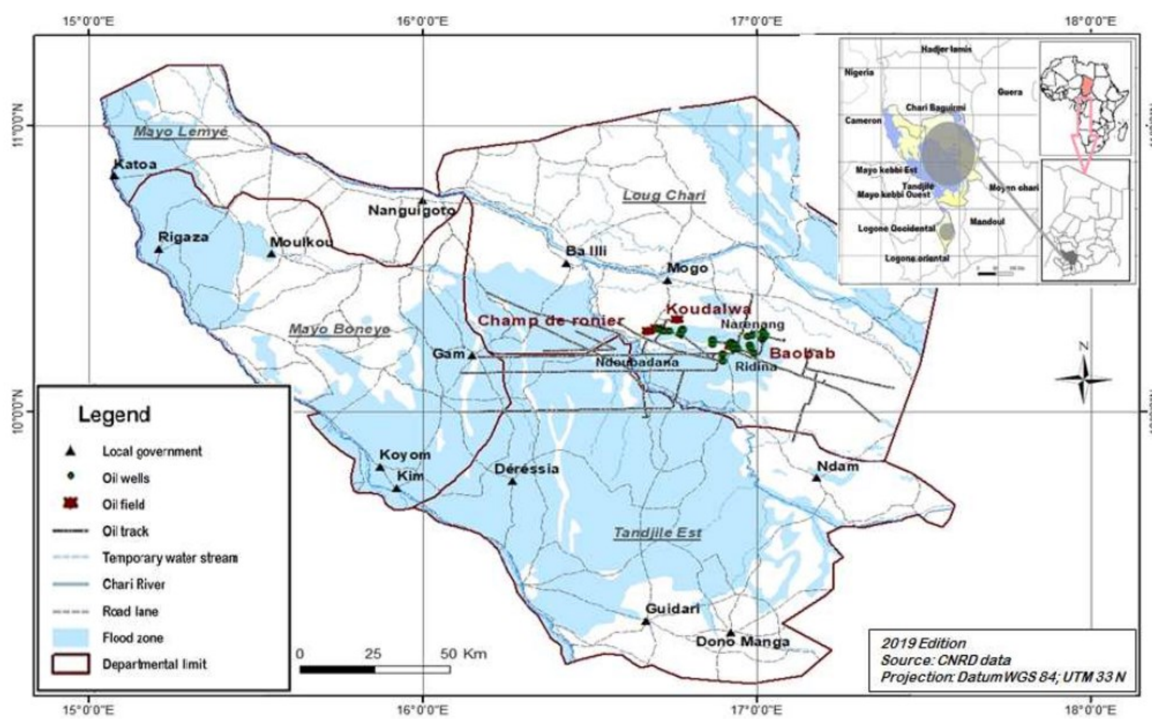

Fig.1 Map of Bongor Area showing Koudalwa, the study area (Prosper et al., 2021)

Table 1 Sampling Points

Site	Sub samples	Geographical Coordinates	Description
Control		9°59'2,34''N, 17°31'18,72''E	It is a point away from oil wells with little agriculture activities.
AA	AA1 0-30 cm	10°11'15,84''N,17°6'15,144''E	This is the end of the drilling where drilling holes underwent treatment using chemicals. This site is also characterized by oil fields which were left fallow. There is no agricultural activity on these sites
	AA2 30-60 cm	10°11'15,84''N,17°6'15,144''E	
BB	BB1 0-30 cm	9°59'2,226''N, 17°31'18,612''E	Sampling at these sites was carried out next to a well platform in the surrounding area. Pipelines (crude oil pipes) traverse these areas. There are agricultural farms around these wells from where samples were collected
	BB2 30-60 cm	9°59'2,226''N, 17°31'18,612''E	
CC	CC1 0-30 cm	10°1'22,134''N, 17°27'51,384''E	
	CC2 30-60 cm	10°1'22,134''N, 17°27'51,384''E	

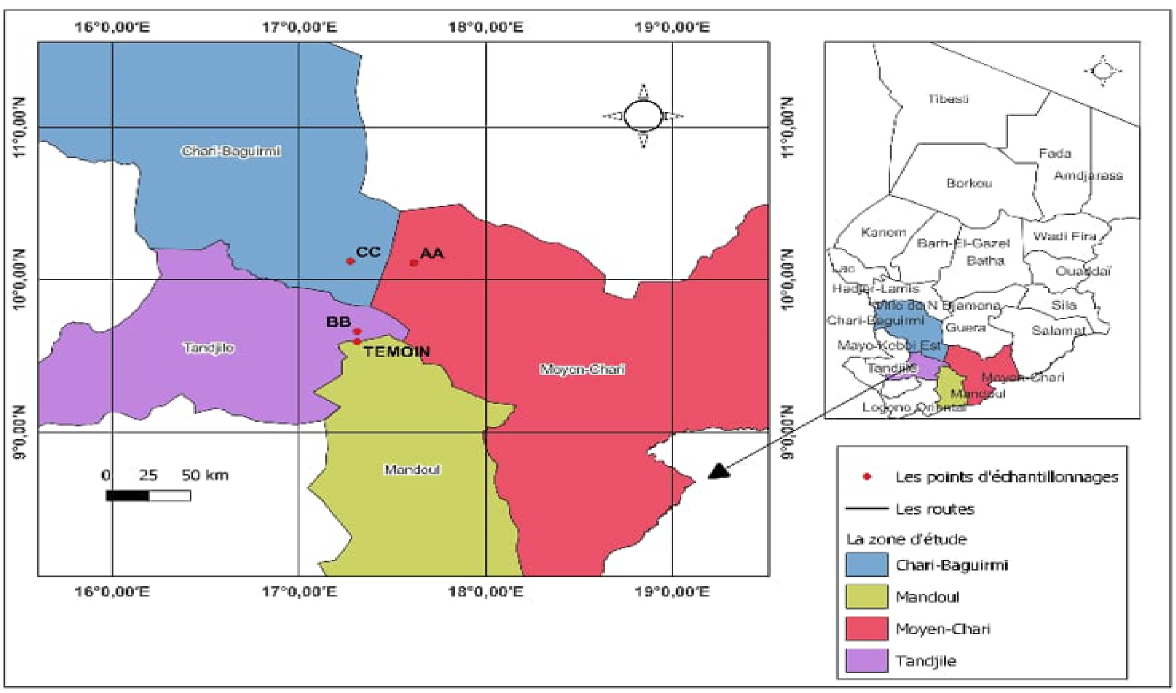

Fig.2 Map of sampling points in Koudalwa (AA, BB, CC and Temoin or control), the study area

2.2. Heavy Metals Analysis

Fresh soil samples from different sites were air dried in the laboratory, then ground in a porcelain mortar using a pestle and sieved through a 2 mm sieve. All chemicals used were of analytical grade. For heavy metals extraction from the soil, 2g of each 2 mm sieved soil samples were digested in a mixture of HCl and HNO_3 in the ratio 1:3. The concentrations of heavy metals (Cr, Cd, Pb, Hg, Cu, Mn, Fe and Ni) in the digested solution were determined by atomic absorption spectroscopy (Atomic Absorption Spectrophotometer (AAS) RAYLEIGH WFX-130B).

2.3. Method of Assessing Pollution

2.3.1. Geo-Accumulation Index (Igeo)

This index is applied to quantify the metal pollution in the soils and aquatic sediments (Rahman et al., 2022). It is calculated using the equation:

$$Igeo = \log 2 \frac{Cn}{1.5 * Bn}$$

where, Cn is concentration of metal measured in sediment samples in the study area, Bn is background value of the corresponding metal, and 1.5 is the background matrix correction due to lithological effects. According to Muller (Rahman et al., 2022) the geo-accumulation index can be classified according to the following seven grades or classes: i) Igeo > 5 = extremely polluted, (ii) Igeo = 4–5 = strongly to extremely polluted, (iii) Igeo = 3–4 = strongly polluted, (iv) Igeo = 2–3 = moderately to strongly polluted, (v) Igeo = 1–2 = moderately polluted, (vi) Igeo = 0–1 = unpolluted to moderately polluted, and (vii) Igeo < 0 = practically unpolluted.

2.3.2. Contamination Factor

The degree of contamination of each heavy metal element was also calculated. Contamination factor is deemed as a useful tool to monitor contamination in soils over time (Ahamad et al., 2020). It is the ratio of every metal in the present sample to the background values in the same metal (Ahamad et al., 2020).

$$CF = \frac{\text{Cheavy metal}}{Cbackground} \text{......................} (4)$$

The contamination degrees were categorized according to their values from 1 to 6 "if CF < 1, low pollution; 1 < CF < 3, moderate pollution; 3 < CF < 6, considerable pollution; CF > 6, very high pollution" Hakanson (1979) (Ahamad et al., 2020).

2.3.3. Pollution Load Index (PLI)

The PLI is calculated by obtaining the n-root from the n-CFs that were obtained for all the metals.

$$\text{PLI} = \sqrt[n]{Cf1 \ x \ Cf2 \ x \ Cf3 \ x \dots \dots . x \ Cfn}$$

where, Cf is the contamination factor and n is the quantity of metals in the study. The PLI gives unassuming yet sensible intends to evaluating a site quality (Rahman et al., 2022), where an estimation PLI < 1 mean perfection; PLI = 1 present that only baseline levels of contaminant are available; and PLI > 1 would show decline of site quality

2.3.4. Enrichment Factor (EF)

EF for every metal is used to estimate how much metals originate from anthropogenic activities in the soils. The EF index determined in the soil samples using the following equation (Luo et al., 2021):

$$EF = \frac{\left(\frac{Cn}{CFe}\right)Sample}{\left(\frac{Cn}{CFe}\right)Background}$$

where, Cn sample is concentration of the heavy metal in the sample soil studied; Cn background is the concentrations in a suitable baseline reference material. Cn background is the average heavy metal concentration in the upper continental crust according to Wedepohl (1995) in mg/kg (Mokhtarzadeh et al., 2020): Cr, 35; Cu, 14.3; Fe, 30890; Mn, 728; Ni, 18.6; Pb, 17; Ni, 18.6; Hg, 0.056; C_{Fe} is the Fe content in the upper continental crust (Wedepohl 1995). So, the reference metal used to normalize the measured heavy metal concentration was Fe because of the low variation coefficient (CV) in all the soil samples (Mokhtarzadeh et al., 2020). The significance of EF is as follows: EF < 1 indicates no enrichment, EF < 3 is minor enrichment, EF = 3–5 is moderate enrichment, EF = 5–10 is moderately severe enrichment, EF = 10–25 is severe enrichment, EF = 25–50 is very severe enrichment, and EF > 50 is extremely severe enrichment (Luo et al., 2021).

2.4. Potential Ecological Risk Assessment (PER)

The potential ecological risk index method evaluates heavy metal pollution in soils or sediments from the perspective of sedimentology according to the nature of heavy metals and environmental behavior characteristics (Ahamad et al., 2020; Luo et al., 2021). While considering the content of heavy metals in the soil, this method links the ecological and environmental effects of heavy metals with toxicology and can more accurately represent the impact of heavy metals on the ecological environment (Prosper et al., 2021; Rahman et al., 2022; Ahamad et al., 2020; Luo et al., 2021). The equations used are shown in the following equations:

$$C_f^i = \frac{C_s^i}{C_n^i}$$

$$E_r^i = T_r^i \text{ x } C_f^i$$

$$RI = \sum_{i=1}^{n} E_r^i$$

where C_f^i is the pollution coefficient of a heavy metal i; C_s^i is the measured value of soil heavy metal i concentration, mg/ kg; and C_n^i is the background value of soil elements, and the background value in this study uses the concentration value of the control. E_r^i is the potential ecological risk index of a single element; T_r^i is the toxic response parameter of heavy metal i. According to the standard established by Hakanson (Prosper et al., 2021; Rahman et al., 2022; Ahamad et al., 2020; Luo et al., 2021), the toxic response coefficient of heavy metals is Hg = 40, Cr =2, Cd =30, As =10, Pb = 5, Cu =5, Zn = 1, Mn = 1, Fe = 1, and Ni = 5. RI is the potential ecological risk index of a variety of heavy metals. E_r^i represents the "ecological risk," and RI denotes the overall "risk index" of metal. Different levels of risk index are presented in Table 2.

Table 2 Ecological risk and risk index (RI) classification (Prosper et al., 2021; Rahman et al., 2022; Ahamad et al., 2020; Luo et al., 2021)

ER Level	Value of ER	Risk	Value of RI	Risk
0	ER˂40	Low	RI ˂ 110	Low
1	ER = 40-80	Moderate	RI = 110-200	Moderate
2	ER = 80-160	Considerable	RI = 200-400	Considerable
3	ER = 10-320	High	RI ˃ 400	Very high
4	ER ˃ 320	Very high		

3. Results and Discussion

3.1. Heavy Metal Levels

The variations of the determined heavy metals in the soils of Koudalwa are presented in Table 3. The range of concentrations (mg/kg) obtained are 6.84-173.90, 1.75-6.49, 0.008-0.033, 33.72-526.02, 115.39-815.24, 7.45-60.04, 0.066-0.103 for Cr, Cd, Pb, Hg, Cu, Mn, Fe and Ni respectively. The abundance of heavy metals in the soils of Koudalwa is in the order; Cu ˃ Hg ˃ Cr ˃ Mn ˃ Fe ˃ Cd ˃ Ni ˃ Pb (Table 3). The site AA shows the highest levels of all the determined heavy metals except Ni. This site has highest amount of Cr (197.98 mg/kg), Cd (6.49 mg/kg), Hg (531.46 mg/kg), Ni (0.088 mg/kg) in the 30-60 cm soil depth (sub-sample AA2), and Pb (0.021 mg/kg), Cu (815.24 mg/kg), Mn (166.55 mg/kg) and Fe (60.04 mg/kg) in the top soil, 0-30 cm depth (sub sample AA1). This study is similar to other findings on heavy metals mobility in soils with a contradiction in the case of Ni and Hg. Asmoay et al. (2019) reported that Cd, and Cr have high mobility compared Pb, Ni, and Cu metals in the soil. Mehes-Smith, (2013) also reported that the total amount of Cu, Ni, Fe, Mg and Zn were significantly higher in the soil top horizon. However, Okoli et al. (2020) reported that the Ni mobility factor in the soils was high and was in the following order of abundance; Falsebedded sandstones > alluvium> Imo clay shale > coastal plain sands. Boszke et al. (2008) reported that the surface layer of soil (0–20cm) was characterized by higher mercury concentrations than that of the subsurface soil (60–80cm) contradicting results of this study where higher mercury concentrations were obtained in the 30-60 cm soil depth. According to Gilli et al. (2018), the mobility of Hg is influenced by the chemical forms of Hg, as different Hg species exhibit vastly different environmental behaviors and toxicities. From Table 1, site AA is the end of the drilling where drilling holes underwent treatment using chemicals. This site is also characterized by oil fields which were left fallow and has no agricultural activity on it. So, the high concentration values of heavy metals obtained on this site is likely due to the use of chemicals in the post treatment of the site. The control showed significant heavy metals concentration (mg/kg) 173.90, 3.55, 0.012, 324.75, 115.39, 79.69, 16.64, and 0.103 for Cr, Cd, Pb, Hg, Cu, Mn, Fe and Ni respectively. Though this site was far from other points as evident from geographical coordinates, it has been cultivated for many years before being abandoned. With the exception of site AA, all other sites involved agricultural activities and mainly farming. Depending on the type of fertilizer used, they all have the potentials of adding heavy metals to the soil as evident from Table 4. This may account for the concentration of heavy metals obtained in this study especially from sites with agricultural activities. Other sources of heavy metals in agricultural soils include: irrigation with municipal wastewater and Industrial waste water which introduces Zn, Cu, Ni, Pb, Cd, Cr, As, and Hg in the soil, as well as atmospheric deposition from mining metal smelting and refining, manufacturing processes, transport, and waste incineration: primarily Ni, Cd, Pb, Cu, Zn, Hg and Cr (Srivastava et al., 2017).

Comparing the results obtained in this study to standard values of heavy metals in agricultural soils (Table 5), it can be observed that only Cu and Hg exceed those standards. The standards are grouped under threshold and permissible limits. These limits are applied worldwide to measure the heavy metal contents in agricultural soils (Adagunodo et al., 2018). The threshold limit is used to checkmate the minimum toxicity in all soil's environment. The permissible limit is applicable to the agricultural soils. If the values of the heavy metals exceed the permissible limit, such soil is regarded as contaminated soils for agricultural activities (Adagunodo et al., 2018). It is either associated with health risk (hr) or ecological risk (er).
Equally comparing the concentrations of Heavy metals in Koudalwa, Tchad soils with other agricultural soils not closed to oil field activities and agricultural soils around oil fields activities reported in literature Table 6), it can be seen that results obtained in this study were similar to other studies with very low values for Pb and Ni.

Tabel 3 Variation of heavy metals levels in the soils of Koudalwa, Chad

	Metal concentration (mg/kg)							
Location	Cr	Cd	Pb	Hg	Cu	Mn	Fe	Ni
Control	173.90	3.55	0.012	324.75	115.39	79.69	16.64	0.103
AA1	162.66	4.28	0.021	526.02	815.24	166.55	60.04	0.081
AA2	197.98	6.49	0.017	531.46	526.54	162.32	53.52	0.088
BB1	20.08	5.01	0.033	84.81	220.77	5.24	15.63	0.081
BB2	20.48	1.80	0.021	58.06	293	49.91	15.08	0.095
CC1	13.11	1.75	0.012	39.34	180.62	6.71	7.45	0.081
CC2	6.84	4.73	0.008	33.72	344.51	11.42	10.89	0.066
Maximum	173.90	6.49	0.033	526.02	815.24	166.55	60.04	0.103
Minimum	6.84	1.75	0.008	33.72	115.39	5.24	7.45	0.066
Average	85.007	3.944	0.018	228.3	356.58	68.834	25.61	0.085

Table 4 Heavy metal concentrations (µg g-1) in agricultural amendments (Srivastava et al., 2017).

Metals	Agricultural Amendments						
	Pesticides	Lime	Nitrate fertilizers	Phosphate fertilizers	Farmyard Manure	compost	Sewage sludge
Cr	-	10-15	3.2-19	66-245	1.1-55	1.8-410	8.4-600
Ni	-	10-20	7-34	7-38	2.1-30	0.9-279	6-5300
Cu	-	2-125	-	1-300	2-172	13-3580	50-8000
Zn	-	10-450	1-42	50-1450	15-556	82-5894	91-49000
Cd	-	0.04-0.1	0.05-8.5	0.1-190	0.1-0.8	0.01-100	$^{<}$1-3410
Pb	11-26	20-125	2-120	4-1000	0.4-27	1.3-2240	2-7000

Table 5 Threshold and permissible limits for heavy metals in soils (Adagunodo et al., 2018)

Heavy metal	Threshold limit (mg/kg)	Permissible limit (mg/kg)	This study	
			Range	Mean
Cr	100.0	200.0 (er)	6.84-173.90	85.007
Cd	1.0	10.0 (er)	1.75-6.49	3.944
Pb	60.0	200 (hr)	0.008-0.033	0.018
Hg	0.5	2 (er)	33.72-526.02	228.3
Cu	100.0	150.0 (er)	115.39-815.24	356.58
Ni	50.0	100.0 (er)	0.066-0.103	0.085
Mn	-	-	5.24-166.55	68.834
Fe	-	-	7.45-60.04	25.61

Table 6 Comparing the concentrations of Heavy metals in Koudalwa, Tchad soils with other agricultural soils not closed to oil field activities and agricultural soils around oil fields activities reported in literature (mg/kg).

Soil milieu	Metal concentration (mg/kg)								
	Cr	Cd	Pb	Hg	Cu	Mn	Fe	Ni	Ref
1	6.84-173.90	1.75-6.49	0.008-0.033	33.72-526.02	115.39-815.24	5.24-166.55	7.45-60.04	0.066-0.103	This study
2	21.5-42.5	0.15-0.88	8.9-34.5	-	16.1-30.6	213-406	10,979-19,807	16.4-32.0	(Micó et al., 2006)
3	16.7 -204.4	0.094-0.873	10.7-1028.4	-	13.3-73.9	205-681	-	7.3-32.7	(Peris et al., 2006)
4	-	0.06-0.65	20.5-38.0	-	21.0-171.5	-	-	28.7-36.9	(Rashid et al., 2023)
5	22.77–170.83	0–0.09	9.79–41.08	132.7–5016.2	75.33–859.95	107–582	23016.4–38458	29–68.2	(Rahman et al., 2012)
6	3.00-65.87	Below detection limit	4.11-16.81	Below detection limit	4.12-33.79	-	-	2.52-34.14	(Mussa et al., 2020)
7	174.707-502.33	0.19-0.623	12.54-22.853	-	4.513-21.073	-	-	-	(Mwegoha, and Kiham

									pa ,2010)
8	27.8–422.7	0–7.3	0–3320	-	12.1–909	55.4–3282	1.5–47.3	9–283.7	(saah et al., 2006)
9		0.27-1.02	17-82	-	123-574		-	213-552	(Karbassi et al., 2015)
10	120-215	-	116 - 2154	-		13.25-15.25	-	10.12-14.10	(Qaiser et al., 2019)
11	101	0.3564	1.47-2.26	-	16.79-43.96	235.3-908.7	-	55.69	(Kareem, and Goran , 2023)

1= Koudalwa, Tchad; 2= agricultural soils, Alicante, Spain; 3= Agricultural Soils of the European Mediterranean Region; 4=greenhouse soil using inorganic fertilizers; 5= Agricultural Soil Dhaka Export Processing, Bangladesh; 6 = agricultural soils of Lake Chilwa, Malawi; 7- agricultural soils in Dar es Salaam city; 8= surface soils of, Douala; 9= soils around Ab-Teymour oil field (25 soil samples around wells and agricultural land); 10= soil affected by oil and gas-drilling waste discharge; 11= soil samples around oil refineries in Erbil-Gwer road, Iraq

3.2. Assessment of the Level of Pollution

3.2.1. Geo-Accumulation Index (Igeo)

The Igeo values of Cr and Ni were all negative for the different sites (Table 7). They were also negative for; Cd except site AA2, Pb except sites AA and BB AA1 & BB2), negative for Hg except site AA (AA1 & AA2), negative for Mn and Fe except site AA (AA1 & AA2). For Cu, the values were positive for all the sites. These results shows that all the sites were not contaminated as for Cr and Ni, site AA (AA2) was polluted by Cd with status of moderate pollution, site AA (AA1) was polluted by Pb with status of moderate pollution, site AA (AA1 & AA2) was polluted by Hg all with status of moderate pollution, site AA (AA1 & AA2) was equally contaminated by Mn and Fe with status of no to moderate pollution for Mn and moderate pollution for Fe. Pb was polluted. All the sites were contaminated by Cu with moderate to heavy pollution for site AA (AA1 &AA2) and no to moderate pollution for the other sites. The fact that site AA is highly enriched with nearly all the tested heavy metal except Cr and Ni is probably due to the use of chemicals in the post treatment of the site as this site is the end of the drilling where drilling holes underwent treatment using chemicals. And the site is also characterized by oil fields which were left fallow.

Table 7 Variation of Igeo values and significance for each heavy metal at different study sites

		Cr			Cd	
site	**Igeo**	**Class interval**	**Significance**	**Igeo**	**Class interval**	**Significance**
AA1	-0.681	Igeo≤0	No pollution	-0.315	Igeo≤0	No pollution
AA2	-0.398	Igeo≤0	No pollution	0.285	Igeo=0-1	No to moderate pollution
BB1	-3.699	Igeo≤0	No pollution	-0.088	Igeo≤0	No pollution
BB2	-3.671	Igeo≤0	No pollution	-1.565	Igeo≤0	No pollution
CC1	-4.314	Igeo≤0	No pollution	-1.605	Igeo≤0	No pollution
CC2	-5.253	Igeo≤0	No pollution	-0.171	Igeo≤0	No pollution
		Pb			**Hg**	
site	**Igeo**	**Class interval**	**Significance**	**Igeo**	**Class interval**	**Significance**
AA1	0.222	Igeo=0-1	No to moderate pollution	0.111	Igeo=0-1	No to moderate pollution
AA2	-0.082	Igeo≤0	No pollution	0.126	Igeo=0-1	No to moderate pollution
BB1	0.874	Igeo=0-1	No to moderate pollution	-2.522	Igeo≤0	No pollution
BB2	0.222	Igeo=0-1	No to moderate pollution	-3.069	Igeo≤0	No pollution
CC1	-0.585	Igeo≤0	No pollution	-3.630	Igeo≤0	No pollution
CC2	-1.170	Igeo≤0	No pollution	-3.853	Igeo≤0	No pollution
		Cu			**Mn**	
site	**Igeo**	**Class interval**	**Significance**	**Igeo**	**Class interval**	**Significance**
AA1	2.236	Igeo=2-3	Moderate to heavy pollution	0.479	Igeo≤0	No to moderate pollution
AA2	1.605	Igeo=1-2	moderate pollution	0.441	Igeo≤0	No to moderate pollution
BB1	0.351	Igeo=0-1	No to moderate pollution	-4.512	Igeo≤0	No pollution

BB2	0.759	Igeo=0-1	No to moderate pollution	-1.260	Igeo≤0	No pollution
CC1	0.061	Igeo=0-1	No to moderate pollution	-4.155	Igeo≤0	No pollution
CC2	0.993	Igeo=0-1	No to moderate pollution	-3.388	Igeo≤0	No pollution

		Fe			**Ni**	
site	**Igeo**	**Class interval**	**Significance**	**Igeo**	**Class interval**	**Significance**
AA1	1.266	Igeo=1-2	Moderate pollution	-0.932	Igeo≤0	No pollution
AA2	1.100	Igeo=1-2	Moderate pollution	-0.812	Igeo≤0	No pollution
BB1	-0.675	Igeo≤0	No pollution	-0.932	Igeo≤0	No pollution
BB2	-0.727	Igeo≤0	No pollution	-0.702	Igeo≤0	No pollution
CC1	-1.744	Igeo≤0	No pollution	-0.932	Igeo≤0	No pollution
CC2	-1.197	Igeo≤0	No pollution	-1.227	Igeo≤0	No pollution

3.2.2. Contamination Factor (CF)

Site BB (BB1 & BB2) and CC (CC1 & CC2) shows low to moderate contamination for all the studied heavy metals (Table 8), while site AA shows low pollution for Cr (AA1) and Ni (AA1 & AA2). Site AA (AA1 & AA2) showed moderate pollution for Cd, Pb, Hg, Mn but shows very high pollution for Cu (AA1), considerable pollution for Cu (AA2), and considerable pollution for Fe (AA1 & AA2). Sites BB and CC which are soils from agricultural farms shows low to moderate pollution indicating probably less use of agro-chemicals.

Table 8 Variation of CF values and significance for each heavy metal at different study sites

		Cr			Cd	
site	**CF**	**Class interval**	**Significance**	**CF**	**Class interval**	**Significance**
AA1	0.935	CF<1	low pollution	1.206	1<CF<3	moderate pollution
AA2	1.138	1<CF<3	moderate pollution	1.828	1<CF<3	moderate pollution
BB1	0.115	CF<1	low pollution	1.411	1<CF<3	moderate pollution
BB2	0.118	CF<1	low pollution	0.507	CF<1	low pollution
CC1	0.075	CF<1	low pollution	0.493	CF<1	low pollution
CC2	0.039	CF<1	low pollution	1.332	1<CF<3	moderate pollution

			Pb			Hg
site	**CF**	**Class interval**	**Significance**	**CF**	**Class interval**	**Significance**
AA1	1.75	1<CF<3	moderate pollution	1.62	1<CF<3	moderate pollution
AA2	1.417	1<CF<3	moderate pollution	1.637	1<CF<3	moderate pollution
BB1	2.75	1<CF<3	moderate pollution	0.261	CF<1	low pollution
BB2	1.75	1<CF<3	moderate pollution	0.179	CF<1	low pollution
CC1	1	1<CF<3	moderate pollution	0.121	CF<1	low pollution
CC2	0.667	CF<1	low pollution	0.104	CF<1	low pollution
			Cu			**Mn**
site	**CF**	**Class interval**	**Significance**	**CF**	**Class interval**	**Significance**
AA1	7.065	CF>6	very high pollution	2.09	1<CF<3	moderate pollution
AA2	4.563	3<CF<6	considerable pollution	2.037	1<CF<3	moderate pollution
BB1	1.913	1<CF<3	moderate pollution	0.066	CF<1	low pollution
BB2	2.539	1<CF<3	moderate pollution	0.626	CF<1	low pollution
CC1	1.565	1<CF<3	moderate pollution	0.084	CF<1	low pollution
CC2	2.986	1<CF<3	moderate pollution	0.143	CF<1	low pollution
			Fe			**Ni**
site	**CF**	**Class interval**	**Significance**	**CF**	**Class interval**	**Significance**
AA1	3.608	3<CF<6	considerable pollution	0.786	CF<1	low pollution
AA2	3.216	3<CF<6	considerable pollution	0.854	CF<1	low pollution
BB1	0.939	CF<1	low pollution	0.786	CF<1	low pollution
BB2	0.906	CF<1	low pollution	0.922	CF<1	low pollution
CC1	0.448	CF<1	low pollution	0.786	CF<1	low pollution
CC2	0.654	CF<1	low pollution	0.641	CF<1	low pollution

3.2.3. Pollution Load Index (PLI)

The PLI gives unassuming yet sensible intends to evaluating a site quality (Rahman et al., 2022). It is a powerful tool for processing, analyzing and conveying raw environmental information to decision makers, managers, technicians and the public (Sey and Belford, 2019). According to Angula (1996) (Sey and Belford, 2019), the PLI is able to give an estimate of the metal contamination status and the necessary action that should be taken. In this study PLI values of 1.844, 1.825, 0.568, 0.630, 0.347 and 0.400 were obtained for sites AA1, AA2, BB1, BB2, CC1, and CC2 respectively. PLI < 1 mean perfection; PLI = 1 present that only baseline levels of contaminant are available; and PLI > 1 would show decline of site quality. This show that sites AA1 and AA2 present a decline of site quality as compared other sites which are of perfect site quality. Thus, critical attention must be given must be given to site AA especially in terms of remediation.

3.2.4. Enrichment Factor (EF)

EF was used to estimate how much metals originated from anthropogenic activities in the soils. For Pb, Fe, Ni, and Mn, there is no enrichment for all the sites but Cr there is moderate enrichment for the control and AA1 (top soil) but no enrichment for the other sites (Table 9). This indicates that the principal source of these metals were mainly from crust material. Though the concentration of Cd ranged from 1.75 to 6.49 mg/kg in all the sites, EF values were very high for all the sites indicating very severe enrichment for the control, AA1, BB1, and CC2, very severe enrichment for BB2 and CC2 and extremely severe enrichment for AA2 (Table 9). Hg had extremely severe enrichment status for all the sites while Cu has severe enrichment for sites BB1, BB2 CC1, CC2; moderately severe enrichment for the control, minor enrichment for AA1 and very severe enrichment for AA2. In almost all the cases where there was enrichment (Cd, Cr, Cu, Hg), the values of subsurface samples were higher than those for surface samples (Table 9). This shows high mobility of these heavy metals in these soils as they are mainly sandy soil and they could be transported into adjacent soils as well as contaminate the underground water. The high EF values are due to contributions of anthropogenic sources mainly agricultural activities and use of chemicals in the post treatment of the sites with petroleum activities.

Table 9 Variation of EF values and significance for each heavy metal at different study sites

		Cr			Cd	
site	**EF**	**Interval**	**significance**	**EF**	**Interval**	**significance**
Control	4.969	$3^<EF^<5$	moderate enrichment	34.804	$25^<EF^<50$	very severe enrichment
AA1	4.647	$3^<EF^<5$	moderate enrichment	41.961	$25^<EF^<50$	very severe enrichment
AA2	5.657	$EF^<1$	no enrichment	63.627	EF > 50	extremely severe enrichment
BB1	0.574	$EF^<1$	no enrichment	49.118	$25^<EF^<50$	very severe enrichment
BB2	0.585	$EF^<1$	no enrichment	17.647	$10^<EF^<25$	severe enrichment
CC1	0.375	$EF^<1$	no enrichment	17.157	$10^<EF^<25$	severe enrichment
CC2	0.195	$EF^<1$	no enrichment	46.373	$25^<EF^<50$	very severe enrichment
		Pb			**Hg**	
Site	**EF**	**Interval**	**significance**	**EF**	**Interval**	**significance**
Control	0.0007	$EF^<1$	no enrichment	5799.107	EF > 50	extremely severe enrichment
AA1	0.0012	$EF^<1$	no enrichment	9393.214	EF > 50	extremely severe enrichment
AA2	0.0010	$EF^<1$	no enrichment	9490.357	EF > 50	extremely severe enrichment

BB1	0.0019	EF<1	no enrichment	1514.464	EF > 50	extremely severe enrichment
BB2	0.0012	EF<1	no enrichment	1036.786	EF > 50	extremely severe enrichment
CC1	0.0007	EF<1	no enrichment	702.500	EF > 50	extremely severe enrichment
CC2	0.0005	EF<1	no enrichment	602.143	EF > 50	extremely severe enrichment

		Cu			Mn	
Site	**EF**	**Interval**	**significance**	**EF**	**Interval**	**significance**
Control	8.069	5<EF<10	moderately severe enrichment	0.151	EF<1	no enrichment
AA1	57.010	EF > 50	minor enrichment	0.316	EF<1	no enrichment
AA2	36.821	25<EF<50	very severe enrichment	0.308	EF<1	no enrichment
BB1	15.438	10<EF<25	severe enrichment	0.010	EF<1	no enrichment
BB2	20.490	10<EF<25	severe enrichment	0.095	EF<1	no enrichment
CC1	12.631	10<EF<25	severe enrichment	0.013	EF<1	no enrichment
CC2	24.092	10<EF<25	severe enrichment	0.022	EF<1	no enrichment

		Fe			Ni	
Site	**EF**	**Interval**	**significance**	**EF**	**Interval**	**significance**
Control	0.0005	EF<1	no enrichment	0.006	EF<1	no enrichment
AA1	0.0019	EF<1	no enrichment	0.004	EF<1	no enrichment
AA2	0.0017	EF<1	no enrichment	0.005	EF<1	no enrichment
BB1	0.0005	EF<1	no enrichment	0.004	EF<1	no enrichment
BB2	0.0005	EF<1	no enrichment	0.005	EF<1	no enrichment
CC1	0.0002	EF<1	no enrichment	0.004	EF<1	no enrichment
CC2	0.0004	EF<1	no enrichment	0.004	EF<1	no enrichment

3.3. Potential Ecological Risk Assessment (PER)

All the studied heavy metals except Cd in sites AA2 and BB1 had low potential ecological risk factor in all the studied sites (Table 10). Hence, these heavy metals were not likely to pose harm or ecological risk to the environment. The cadmium in sites AA2 and BB1 have moderate potential ecological risk indicating Cd is likely to pose harm or ecological risk to the environment at these two sites and this is confirmed by the RI status of Cd which is considerable. RI denotes the overall “risk index” of metal. Though the ER status of Hg is low, the RI status is moderate indicating Hg can also cause some risk to the environment at the study sites.

Table 10 Variation of PER and RI values and significance for each heavy metal at different study sites

			Cr							Cd		
site	**ER**	**Value of ER**	**Risk**	**RI**	**value of RI**	**risk**	**ER**	**Value of ER**	**Risk**	**RI**	**value of RI**	**risk**
AA1	1.871	ER<40	Low	4.844	RI<110	Low	36.169	ER<40	Low	203.324	RI = 200-400	Considerable
AA2	2.277	ER<40	Low				54.845	ER=40-80	moderate			
BB1	0.231	ER<40	Low				42.338	ER=40-80	moderate			
BB2	0.236	ER<40	Low				15.211	ER<40	Low			
CC1	0.151	ER<40	Low				14.789	ER<40	Low			
CC2	0.079	ER<40	Low				39.972	ER<40	Low			

			Pb							Hg		
site	**ER**	**Value of ER**	**Risk**	**RI**	**value of RI**	**risk**	**ER**	**Value of ER**	**Risk**	**RI**	**value of RI**	**risk**
AA1	8.750	ER<40	Low	46.67	RI<110	Low	64.791	ER<40	Low	156.848	RI=110-200	moderate
AA2	7.083	ER<40	Low				65.461	ER<40	Low			
BB1	13.750	ER<40	Low				10.446	ER<40	Low			
BB2	8.750	ER<40	Low				7.151	ER<40	Low			
CC1	5.000	ER<40	Low				4.846	ER<40	Low			
CC2	3.333	ER<40	Low				4.153	ER<40	Low			

			Cu							Mn		
site	**ER**	**Value of ER**	**Risk**	**RI**	**value of RI**	**risk**	**ER**	**Value of ER**	**Risk**	**RI**	**value of RI**	**risk**
AA1	35.325	ER<40	Low	103.158	RI<110	Low	2.090	ER<40	Low	5.046	RI<110	Low
AA2	22.816	ER<40	Low				2.037	ER<40	Low			
BB1	9.566	ER<40	Low				0.066	ER<40	Low			
BB2	12.696	ER<40	Low				0.626	ER<40	Low			
CC1	7.827	ER<40	Low				0.084	ER<40	Low			
CC2	14.928	ER<40	Low				0.143	ER<40	Low			

			Fe							Ni		
site	**ER**	**Value of ER**	**Risk**	**RI**	**value of RI**	**risk**	**ER**	**Value of ER**	**Risk**	**RI**	**value of RI**	**risk**
AA1	3.608	ER<40	Low	9.772	RI<110	Low	3.932	ER<40	Low	23.883	RI<110	Low
AA2	3.216	ER<40	Low				4.272	ER<40	Low			
BB1	0.939	ER<40	Low				3.932	ER<40	Low			
BB2	0.906	ER<40	Low				4.612	ER<40	Low			

CC1	0.448	ER<40	Low	3.932	ER<40	Low
CC2	0.654	ER<40	Low	3.204	ER<40	Low

4. Conclusion

In this, we investigated the concentrations of Cr, Cd, Pb, Hg, Cu, Mn, Fe and Ni in agricultural soils and soils around oil drilling pits in Koudalwa, Tchad and evaluating pollution levels through standard risk assessment models. soil samples were digested in a mixture of HCl and HNO_3 in the ratio 1:3 to put the heavy metals in solution for analysis. The range of concentrations (mg/kg) obtained were 6.84-173.90, 1.75-6.49, 0.008-0.033, 33.72-526.02, 115.39-815.24, 7.45-60.04, 0.066-0.103 for Cr, Cd, Pb, Hg, Cu, Mn, Fe and Ni respectively. The abundance of heavy metals in the soils of Koudalwa is in the order; Cu > Hg > Cr > Mn > Fe > Cd > Ni > Pb. The site AA shows the highest levels of all the determined heavy metals except Ni. Cr, Cd, Hg, Ni were more present in the 30-60 cm soil depth (sub-sample AA2), while Pb, Cu, Mn and Fe were more present in the top soil, 0-30 cm depth (sub sample AA1). The concentration of heavy metals obtained in this study were within standards of heavy metals in agricultural soils around the world except for Cu and Hg which exceeded the standards. Results from Pollution load index (PLI) shows that sites AA1 and AA2 present a decline of site quality as compared other sites which are of perfect site quality. Thus, critical attention must be given must be given to site AA especially in terms of remediation. While Cd, Cr, Cu, and Hg Pb show high enrichment from anthropogenic sources, there is no enrichment for all the sites for Fe, Ni, and Mn. All the studied heavy metals except Cd in sites AA2 and BB1 had low potential ecological risk factor in all the studied sites, indicating these heavy metals are not likely to pose harm or ecological risk to the environment. Sites AA1 and AA2 present a decline of site quality as compared other sites which are of perfect site quality. Thus, critical attention must be given must be given to site AA especially in terms of remediation and increasing awareness campaign for the safety of the population.

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